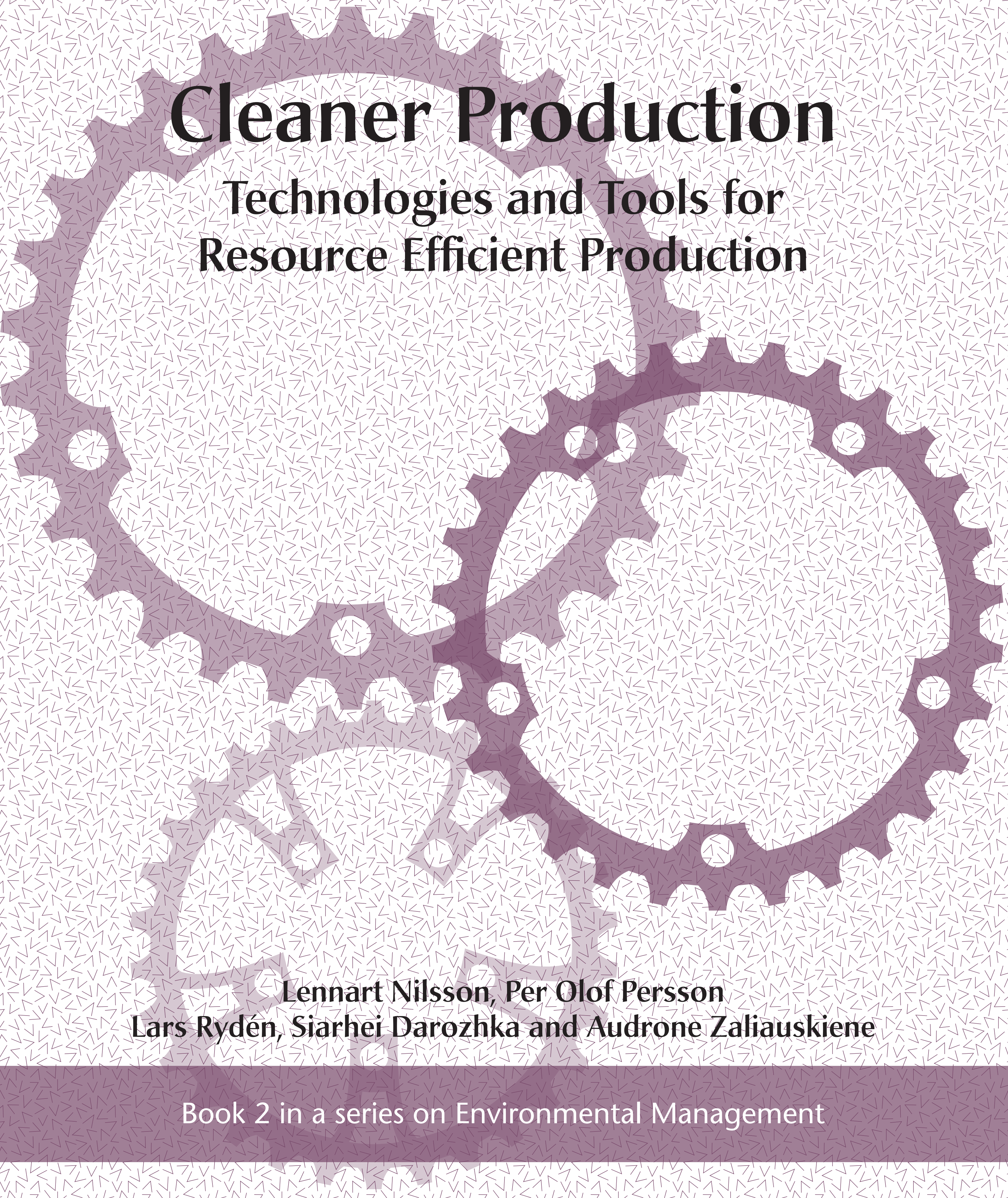

Cleaner Production

Technologies and Tools for Resource Efficient Production

Lennart Nilsson, Per Olof Persson
Lars Rydén, Siarhei Darozhka and Audrone Zaliauskiene

Book 2 in a series on Environmental Management

The Baltic University

Environmental Management

book series

1. Environmental Policy – Legal and Economic Instruments
2. Cleaner Production – Technologies and Tools for Resource Efficient Production
3. Product Design and Life Cycle Assessment
4. Environmental Management Systems and Certification

Cleaner Production

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Preface

The efforts to minimise the environmental impacts of production processes, products and services during the last decades has clearly been supported by an increased commitment of governments and industry to environmental protection. The underlying agenda is the development of strategies for sustainable development in business and in society at large.

There are a number of broadly synonymous concepts that describe this drive towards sustainability. UNEP has coined the term *Cleaner Production (CP)* to describe the concept, US-EPA calls it *Pollution Prevention (P^2)*, the World Business Council for Sustainable Development (WBCSD) uses the term *Eco-efficiency* and other institutions use terms such as *waste minimisation* and *green productivity* to describe more or less the same concept.

A more recent concept is that of *Zero Emission*, adopted as a vision and a target by industrial sectors such as the Pulp and Paper Industry, as well as by the research community in e.g. the Global ZERI Network (Zero Emissions Research & Initiatives). It is meant to go beyond Cleaner Production, by being more comprehensive and making all resources useful. A Technology Platform for Zero Emission Fossil Fuel Power Plants is developed within the EU Seventh Framework Programme. The concept of *Industrial symbiosis*, or *Industrial ecology* is even more comprehensive, in that it optimises the industrial system as a whole or a considerable set of industries. (Both concepts are treated in the book.)

Cleaner Production describes a preventative approach to environmental management. It is neither a legal nor a scientific definition to be dissected, analysed or subjected to theoretical disputes. It rather refers to a mentality of how goods and services are produced with minimum environmental impact under current technological and economic limitations.

Cleaner Production does not deny growth; it merely implies that growth should be ecologically sustainable. It should not be considered only as an environmental strategy, because it also relates to economic considerations in determining the optimal way of producing a product or a service. In this context, waste may be considered as a "product" with negative economic value. Each action to reduce consumption of raw materials and energy, and prevent or reduce generation of waste, can increase productivity and bring financial benefits to an enterprise.

Cleaner Production is a "win-win" or even "win-win-win" strategy. It protects the environment, the consumer and the worker while improving industrial efficiency, profitability, and competitiveness.

The definition of Cleaner Production that has been adopted by UNEP is the following:

Cleaner Production is the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society.

For production processes, Cleaner Production results from one or a combination of a number of measures as conserving raw materials, water and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process.

For products, Cleaner Production aims to reduce the environmental, health and safety impacts of products over their entire life cycles, from raw materials extraction, through manufacturing and use, to the "ultimate" disposal of the product.

For services, Cleaner Production implies incorporating environmental concerns into designing and delivering services.

The main purpose of the book is to be a course text on master's level in engineering and management. The book deals with both management and technical aspects of cleaner production. The book fits together with the other books in the series; *Environmental Policy – Legal and Economic Instruments, Product Design and Life Cycle Assessment,* and *Environmental Management Systems and Certification* to give a comprehensive picture of the application of Environmental Management in enterprises with a particular focus on the Baltic Sea region. Some parts in this book dealing with environmental management systems and ecodesign have deliberately been kept rather short in order not to overlap too much with the other books in the series.

A number of people have helped in writing this book. In particular I want to thank Prof. Lars Rydén and the staff at the Baltic University Programme Secretariat in Uppsala for making this project possible.

Co-authors of the book, contributing important parts of the text, have been Professor Lars Rydén, at the Baltic University Programme, my colleague at the division of Industrial Ecology at KTH, Per Olof Persson, Professor Siarhei Darozhka from the Belarusian National Technical University in Minsk and Audrone Zaliauskiene from Kaunas University of Technology, Lithuania. Important contributions and comments have also bee given by Prof. Linas Kliucininkas from Kaunas University of Technology and Natalia Golovko from the Belarusian National Technical University.

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We would like to improve and update the book for future editions. All comments, large or small will be much appreciated and incorporated in future changes. Please send your comments to: lennart@ket.kth.se

Stockholm, February 21, 2007
Lennart Nilson

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The diagrams in Chapters 2, 6, 7, 8 and 9, except those where a different source is given, were originally produced for a compendium in Industrial Ecology (*Kompendium i Miljöskydd, part 2 – Miljöskyddsteknik*, in Swedish) by Lennart Nilson and Per Olof Persson published by the Royal Institute of Technology in 1998. The diagrams have been improved, updated and translated into English for this book.

We are indebted to Roine Morin, Environmental Manager of SCA Graphic Sundsvall AB, for providing material on pulp and paper production (Case Study 5); to Assa Abloy AB for providing material for surface treatment processes (Case Study 6) and assisting in making the film on surface treatment on the accompanying CD; to Dr Mickael Planasch, Faculty of Chemistry, Institute for Resource Efficient and Sustainable Systems, Graz University of Technology, Austria for providing material on zero emission and environmental management accounting for the Introduction and Chapter 10.

We have relied on several open sources for some of the material. The section on Cleaner Production Practices was extracted from the *BREF (Best available techniques reference documents)* of the European Union DG Environment and the Information Exchange Forum (IEF), the *Best Management Practices for Pollution Prevention* published by the US-EPA Office of Research and Development, and the UNEPs *Industry Sector Guides for Cleaner Production Assessment*.

Chapter 4 (Cleaner Production Assessment) followed the UNEP/UNIDO *Cleaner Production assessment methodology*, Chapter 5 (Tracking Environmental Performance), followed mainly *A Guidebook to Environmental Indicators* published by CSIRO (Commonwealth Scientific and Industrial Research Organisation) Australia, while Chapter 13 (Promoting Cleaner Production) is partly based on the UNEP/IE document *Government Strategies and Policies for Cleaner Production*.

INTRODUCTION
Cleaner Production

Industrial Environmental Management through Cleaner Production

Throughout the second half of the 20th century a growing worldwide movement has attempted to change the way industry interacts with the environment. Governments and industry alike have contributed to this movement. The focus has been to reduce environmental impacts from industry through changes in industrial behaviour and technology.

The background is a common recognition that human activities have contributed to the deterioration of the environment and the loss of natural resources. Many significant steps have been taken towards restoring the natural environment. Still pollution of air, water and soil remains one of the largest environmental challenges facing today's world.

Over the period Industrial Environmental Management (IEM) practices have developed gradually by the evolution of strategies for mitigating the environmental problems. Practising IEM could be understood as walking in a staircase. The concepts and strategies for pollution abatement make up the steps. Concepts higher up the staircase include the concepts below, and add additional elements of scope and complexity. The art and science of management expands as one moves up the staircase.

Below some of these steps – concepts and strategies – will be introduced. All of them are relevant. Some are however in themselves insufficient to solve the environmental problems of an industrial activity. For many of the more efficient strategies the problem is rather that they have not been fully used and implemented.

The Staircase of Industrial Environmental Management

A number of terms have been used to describe both the movement and the approaches used. The concepts on the staircase (Figure 1) are, from lowest to the highest:

- Waste Disposal
- Pollution Control
- Recycling
- Waste Minimisation
- Pollution Prevention
- Cleaner Production
- Industrial Ecology
- Sustainable Development

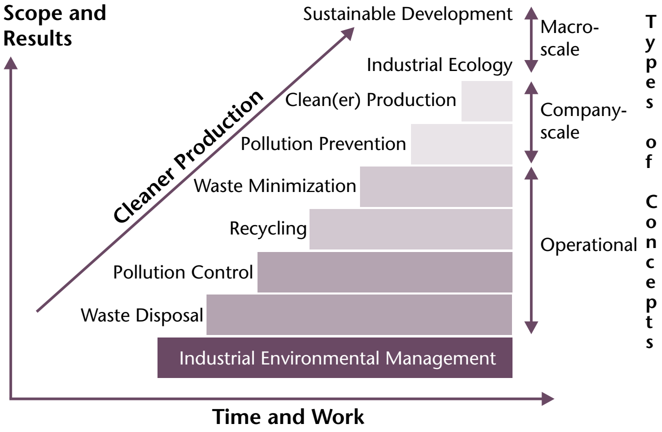

Figure 1 *Staircase of Concepts of Industrial Environmental Management [Adapted from Hamner, 1996].*

The relationship between these terms is one of subsets and supersets. The lower terms are part of the higher terms. The highest term, sustainable development, also includes other "staircases" of concepts such as social responsibility, natural resource management, and economic development, as well as the staircase of industrial environmental management.

There are three types of concepts on the staircase. The *macro-scale* concepts of sustainable development and industrial ecology extend far beyond the firm and include relationships between companies, social institutions, the public and the environment in all its facets. The *company-wide* concepts of environmental management systems and cleaner production address all aspects of the firm's operations in a life cycle approach, from the use of natural resources via suppliers, production, marketing and product use to product disposal. The *operational* concepts address specific activities, aspects, of the company, aimed to reduce its environmental impacts.

Pollution Control

In the past, *pollution control* was seen as the key to a cleaner environment. Pollution control refers to the measures taken to manage pollution after it has been generated.

One example is the extensive investment in the building of sewage or wastewater treatment plants, both in industries and in municipalities. This took place in Western Europe typically during 1960s and 70s, while in Central and Eastern Europe it was not until after the systems change around 1990 that WWTPs were built on a significant scale. Another example is the installation of flue gas cleaning equipment, for instance different types of filters for separation of dust and particles from industrial flue gases produced by incineration of oil and solvent wastes. Also here equipment for gas cleaning was being installed in Western Europe long before it was in Central and Eastern Europe.

Figure 2 Pollution control. *During the 1960s and 1970s wastewater treatment plants were built at all urban centres in Western Europe to save the recipients - rivers, lakes, and coasts. (Photo: iStockphoto)*

The operational concepts also include the strategies of *waste minimisation* and *recycling*. Waste minimisation includes both *waste avoidance* and *waste utilisation*. Waste avoidance refers to the actions taken by producers to avoid generating hazardous waste, while waste utilisation includes a variety of actions which make waste a useful input into the production processes.

The overall concept of recycling can also be broken down into a number of subsets, with terms as *reuse*, *recycling*, and *recovery*. Reuse, or closed loop recycling, refers to the repeated use of a "waste" material in the production process. Recycling occurs when one producer is able to utilise the waste from another production process. Recovery refers to the extraction of certain components of a "waste" material for use in a production process.

Pollution Prevention and Cleaner Production

In recent decades we have witnessed a paradigm shift from pollution control to *pollution prevention* (sometimes referred to as P^2). Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that diminish the use of hazardous materials, energy, water, or other resources, and practices that protect natural resources through conservation or more efficient use.

Most recently, the concept of *cleaner production* (CP) has entered the global environmental arena. CP fits within P^2's broader commitment towards the prevention, rather than the control, of pollution.

Cleaner production refers to the continuous application of an integrated preventive environmental strategy to processes and products to reduce risks to humans and the environment. For *production processes*, cleaner production includes 1) conserving raw materials and energy, 2) eliminating toxic raw materials, and 3) reducing the quantity and toxicity of all emissions and wastes before they leave a process. For *products*, the strategy focuses on reducing impacts along the entire life cycle of the product, from raw material extraction to the ultimate disposal of the product. Cleaner production is achieved by applying know-how, by improving technology, and by changing attitudes.

P^2 is an approach which can be adopted within all sectors, whether it is a small service operation or a large industrial complex. CP, on the other hand, directs activities toward production aspects. Unlike in the past, when pollution was simply controlled, P^2 and CP programmes attempt to reduce and/or eliminate air, water, and land pollution. Therefore, the P² and CP approaches benefit both the environment and society.

Economically, P² and CP can actually reduce costs and in some cases, generate profit. Both approaches are practical and feasible, and can consequently contribute to a sustainable future.

Eco-efficiency

The concept of eco-efficiency was introduced by the World Business Council for Sustainable Development, WBCSD, in 1992 and since then has been widely adopted. Many businesses in all continents have been pursuing ways of reducing their impact on the environment while continuing to grow and develop.

According to the definition given by the WBCSD Eco-efficiency is a management philosophy that encourages business to search for environmental improvements that yield parallel economic benefits. This concept describes a vision for the production of economically valuable goods and services while reducing the ecological impacts of production. The reduction in ecological impacts translates into an increase in resource productivity, which in turn can create competitive advantage. In other words eco-efficiency means producing more with less.

However, the concepts of Eco-efficiency and Cleaner Production are almost synonymous. The slight difference between them is that Eco-efficiency starts from issues of economic efficiency which have positive environmental benefits, while Cleaner Production starts from issues of environmental efficiency which have positive economic benefits.

Sustainable Development

Cleaner production, pollution prevention, etc. are all subsets of the concept of *sustainable development*, which states the basic problem that the other concepts attempt to address: There are

Figure 3 Changing technology. *The chlor-alkali factory outside Skoghall in west Sweden once used the mercury electrode method to produce chlorine. In 1987 the new membrane-based technology was introduced, replacing all use of mercury. There has been a 100% change to this new technology in Japan, a partial change in Western Europe and USA, but no change has yet taken place in eastern and central Europe. (Photo: Courtesy of Akzo Nobel Industries)*

Box 1 The Concept of Cleaner Production

Why Cleaner Production
Cleaner Production (CP) begins with the insight that even if environmental technologies has lead to a significant reduction of emissions (at least per product) they are expensive and need further input of materials, energy and manpower. Environmental technologies therefore offer no economic incentives for industry. On the opposite they generally lead to higher production costs, and they include a regulatory approach. Industry may avoid environmental technologies by investing in countries with less strict regulations.

Cleaner Production, on the contrary, aims to reduce both the negative effects to the environment and the operating costs. Cleaner Production works with process integrated – preventive – methods instead of End-of-Pipe solutions. Cleaner Production is the conceptual and procedural approach to production that demands that all phases of the life cycle of a product or of a process should be addressed with the objective of prevention or minimisation of short and long-term risks to humans and to the environment.

There are some basic methods/techniques to implement CP in companies, but every single company has a different problem. You do not have the same solution twice! Every solution is unique, due to the specific features of every company.

Five Basic Principles of Cleaner Production
Cleaner Production requires that resources be managed efficiently. This consists both of careful use of resources, the closing of material streams, and resource substitution. It is possible to outline five general principles of Cleaner Production:

1. *Input-Substitution*
   - Use of less hazardous raw-, auxiliary- or operating materials.
   - Use of operating materials with a longer lifetime.
2. *Good Housekeeping*
   - Increase the Material and Energy efficiency of actions in the process. Try to fetch the "low hanging fruits" first, e.g. reduce losses due to leakage. It is important to train employees.

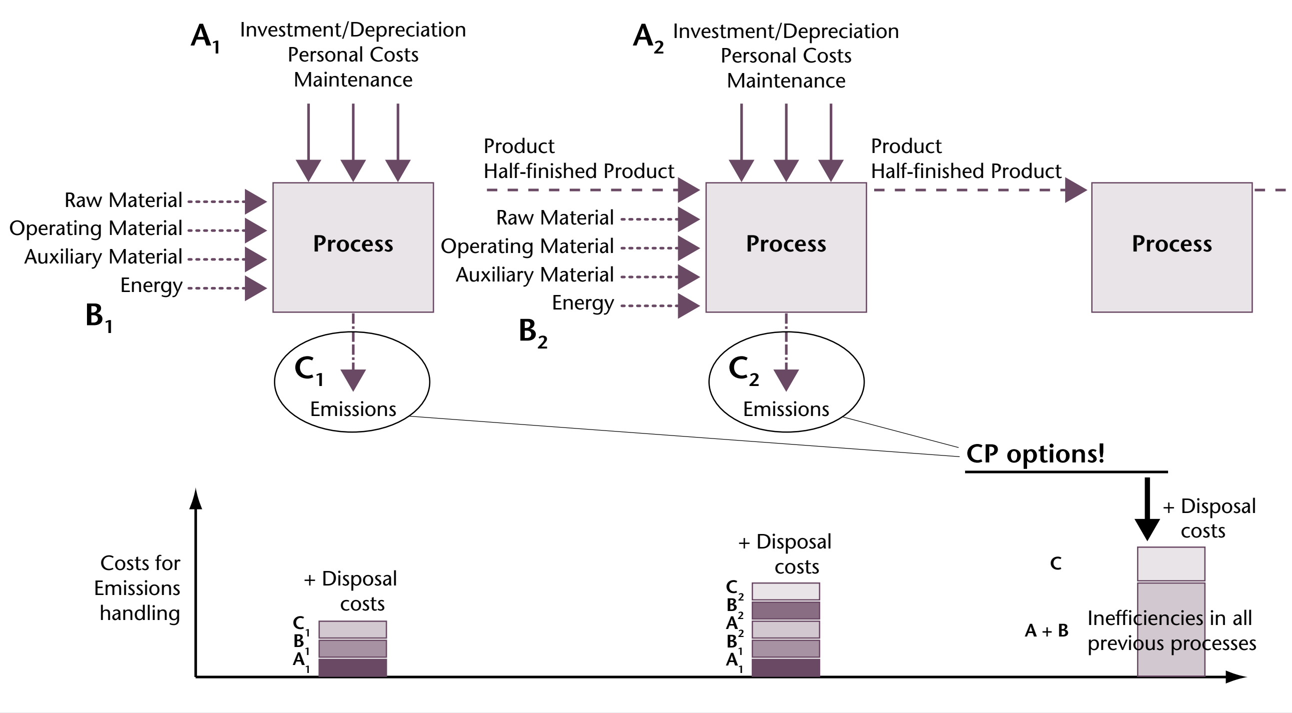

Figure 4 Cleaner Production opportunities. *An industrial production can be seen as consisting of a series of processes, each with its investments (A) inputs of raw material, energy etc (B) and outputs of product/half-finished product and process emissions (C). Costs for emission handling of each partial process originate in inefficiencies in raw material use etc (A), investments (B), or process emissions (C). To that should be added the cost for disposal of the product after use. Cleaner Production may be directed to all these inefficiencies [Based on a diagram from Planasch, 2006].*

3. *Internal Recycling*
    - Close Material and Energy Loops for water, solvents, etc.
    - Cascading of Material and Energy streams.
4. *Technological Optimisation/Change*
    - Implementation of new technologies.
    - Improved process control.
    - Redesign of processes.
    - Change in or substitution of hazardous processes.
5. *Optimisation of the Product*
    - Increasing the lifetime.
    - Easier repair.
    - Easier de-manufacturing, recycling or deposition.
    - Use of non-hazardous materials.

Recycling

Setting up well functioning cyclic material flows is crucial for good resource management. Internal recycling refers to actions within a process (closed loop), while external recycling refers to actions after production (open loop) where the material may be fed into different and multiple processes. Internal recycling reduces the amount of materials purchased. External recycling has no influence on the amounts of materials purchased. Finally the use of wastes/emissions in another process, even if at the same industrial site, is not considered as recycling.

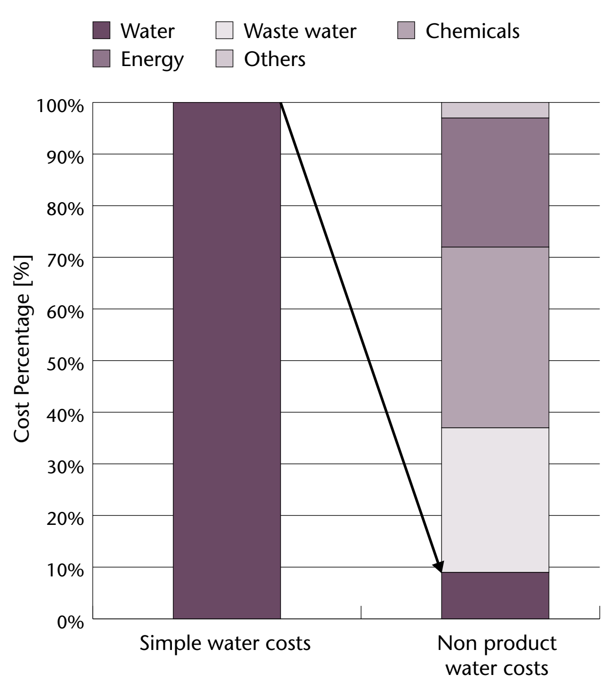

Figure 5 Total industrial water costs. *The costs for handling resources and emissions in a company are often underestimated. In this case, from a textile company in Austria in 2005, the costs of water (left) is only about 20 % of the total costs for handling the water (right). This consists of the water costs, the costs for wastewater treatment, for chemicals used, energy needed and some other costs. Taking components such as depreciation, maintenance and personnel costs into account thus adds a factor 4-5!! [Based on a diagram from Planasch, 2006].*

Internal recycling includes:
- Re-utilisation of materials, such as solvents, for the same purpose.
- Reuse of materials for different purpose (paper, solvents for inferior use i.e. pre-cleaning etc.
- Closing of loops (water).
- Multi-way systems (packaging materials).
- Reclaiming of materials with high value.

How to implement CP actions in companies

Start by getting to know the process. Important tasks are:
- Define the processes units, e.g. in electro-plating; degreasing, etching, bondering, rinsing.
- Understand the process with its chemical and physical connections.
- Draw a flow sheet with all (!) Input and Output-streams and all interrelationships (quantitative).
- Take a closer look at the most important material streams (qualitatively and economically, m^3/a, EUR/a).
- Look at existing cross-media effects.

Identify the weak points of the process: it is easier to convince companies to take actions if the economic benefits are clear at the start, so identify the low-hanging fruits, and define process optimisations.

In the longer term Cleaner Production will shift from being a process of continuous improvements to a process of redesign of production. The goal is to reach zero emission, that is a process in which all input material is turned into products, either to be sold or used in another process.

Based on a presentation by Planasch, 2006.
planasch@tugraz.at

limits to what the environment can tolerate, and society needs to ensure that development today does not cause environmental degradation that prevents development tomorrow. There are many issues here but the role of industry and industrial pollution is obvious. Industrial systems and individual companies will need to make changes in order to prevent future generations from being unable to meet their own needs. Sustainable development is thus the long-term goal of individual companies rather than a business practice.

As expressed by the Brundtland Commission in 1987:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

It contains within it two key concepts:

1. The concept of "needs", in particular the essential needs of the world's poor, to which overriding priority should be given.
2. The idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs.

Thus the goals of economic and social development must be defined in terms of sustainability in all countries, developed or developing, market-oriented or centrally planned. Interpretations will vary, but must share certain general features and must flow from a consensus on the basic concept of sustainable development and on a broad strategic framework for achieving it.

Whatever interpretation is chosen it remains clear that sustainable development is a goal, not a thing. The real problem with the Brundtland Commission definition is that it does not include or imply real actions in any particular dimension, so no one knows what to really do about it.

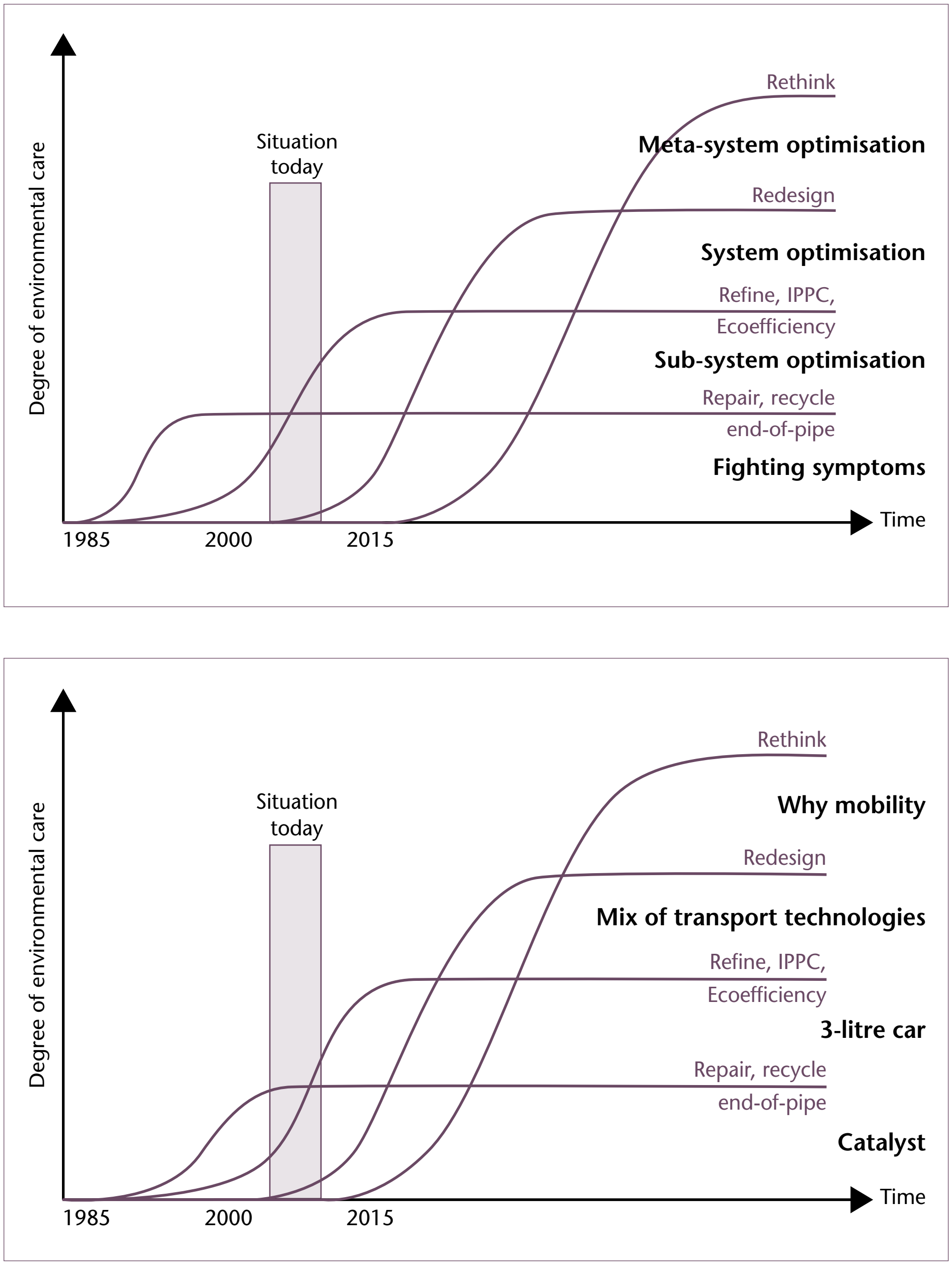

Figure 6. A. The paradigm shift in environmental protection. *The paradigm shift is here seen as four stages (Compare Figure 1). Fighting symptoms of environmental impact led to the first stage of "repair, recycle, end-of-pipe" in the 1990s. Today we are concerned with refine, IPPC and eco-efficiency. To fully implement Cleaner Production we need to address systems optimisation by redesign, or even the higher level, meta-system optimisation.* **B. The paradigm shift illustrated by the case of car driving.** *First stage, fighting pollution, led to the catalytic converter, while later stages refer to the eco-efficient car, other ways of transport or reconsidering mobility itself. [Planasch, 2006].*

Industrial Ecology

Industrial ecology can be considered the "production" component of sustainable development. The most important aspect of industrial ecology is the idea of industry as a system in which there is no waste at any step because all "waste" is a resource for another part of the industry network. Individual firms participate in industrial ecology by considering how their activities fit into the larger industrial system. For example, they have to consider what other industries can use the company's wastes as inputs, and how they can work with them. This concept is thus one of relationships and dynamics between companies. To make industrial ecology work, of course, requires conscious application of the lower level concepts on the staircase as well as a motivation to support sustainable development.

Using the same definition approach as that of the Brundtland Commission industrial ecology may be defined as follows:

"Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a system view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to product, to waste product, and to ultimate disposal. Factors to be optimised include resources, energy and capital." [Graedel and Allenby, 1995].

In this definition, the emphasis on *deliberate* and *rational* differentiates the industrial-ecology path from unplanned, precipitous, and perhaps quite costly and disruptive alternatives. By the same token, *desirable* indicates the goal that industrial ecology practices will support a sustainable world with a high quality of life for all, as opposed to, for example, an alternative where population levels are controlled by famine. Industrial ecology is therefore a more realizable macro-scale goal for industrial enterprises. Eco-efficiency and industrial ecology approaches can be used as examples of wise management of raw materials-products-waste streams.

The concepts below industrial ecology on the IEM staircase are all fundamental to making industrial ecology successful.

Cleaner Production as Long-term Vision

Throughout this book the practices of the several concepts and strategies introduced here will be detailed and exemplified, on both a managerial and a technological level. The managerial level is concerned with motivating, planning, following up and evaluating a technology. The technological level is concerned with the practice and functioning of the techniques used. In all cases it will hopefully be clear that the techniques, with a focus on cleaner production, are realistic, highly profitable, and sometimes required, to follow legal requirements and permits.

It seems incredible that so far and over its entire history industrialism mostly has relied on methods and techniques that are wasteful, imprecise and polluting. We have to learn from nature where the living cell is typically resourceful, precise and non-polluting. In some cases, such as in sustainable chemistry, this is approached, but much is left to be developed in the future. We have to create a society that uses renewable resources, is efficient and non-polluting, and recycles all material. Developing and using cleaner production methods is the first step towards creating such a society.

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Lennart Nilson is researching, teaching and applying cleaner production at the university and in industries, e.g. pulp and paper production and metal processing, and is also coordinating the Environmental Management and Cleaner Production masters programme in Baltech, Baltic Technical Universities Consortium.

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Internet Resources

United Nations Environmental Programme (UNEP)
Cleaner Production activities

http://www.uneptie.org/pc/cp/

United Nations Industrial Development Organisation (UNIDO)
Cleaner Production (CP) programme

http://www.unido.org/doc/4460

Zero Emissions Research & Initiatives (ZERI)
(exploring the concept of Cleaner Production on a meta level)

http://www.zeri.org/

1

Industrial Impacts on the Environment

1.1 Industrial Use of Natural Resources

1.1.1 Resource Availability and Use

The production of industrial materials and products begins with the extraction of natural resources from the environment. The availability of these resources is vital for the sustained functioning of both industrialised and developing societies. But increased resource use per capita in industrial countries and global population growth has led to increasing pressure on worldwide natural resources including air and water, arable land, and raw materials. Over the 20th century industrial production has thus increased by a factor of 40, energy use by a factor of 16, ocean fishing by a factor of 35, and global population from 1.5 to 6 billion people [McNeill, 2000]. Material flows in industrialised countries amount today to about 60 tonnes of material per capita and year. This corresponds to an ecological footprint of about 2.2 ha/capita, which is far above the productive area available on the planet, about 1.8 ha/cap [Loh, 2004]. It is obvious that resource use has to be reduced in the years to come.

Renewable resources have the capacity to be replenished, while non-renewable resources are only available in finite quantities. It is necessary to realise that, while as individuals we might not be able to think in longer terms than centuries, as a society we must. The half-life of plutonium is 24,000 years; the replacement of the water in the deep oceans takes 1,000 years. Non-renewable resources once removed from the geosphere will never be replenished. Renewable resources cannot be extracted at a rate higher than their rate of renewal, the so-called carrying capacity.

Even if the basic limitations for resource use have to do with their availability, the extraction of resources and their use in industry give rise to a series of environmental impacts. This

In this Chapter

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    - Energy.
    - Water.
2. Environmental Impacts – The Atmosphere.
    - Global Warming.
    - Policies to Reduce Emissions of Greenhouse Gases.
    - Stratospheric Ozone Depletion.
    - Ozone-destroying Substances.
    - Reduction of Ozone-depleting Substances and the Montreal Protocol.
3. Industrial Air Pollution.
    - Air Pollution.
    - Acidification.
    - Sulphur Oxides.
    - Nitrogen Oxides.
    - Convention on Reduction of Air Born Long-Range Transboundary Pollution, LRTP.
    - Tropospheric Ozone.
    - Particulate Pollutants.
    - Radioactivity.
4. Industrial Water Pollution.
    - Organic Pollution.
    - Nutrients.
    - Salts.
5. Pollution by Toxic Substances.
    - Pollution by Heavy Metals.
    - The Heavy Metals.
    - Persistent Organic Pollutants.
    - Pesticides.
    - Industrial Chemicals and By-products.
    - Measures to Control the Use of Chemicals.

chapter will give a general overview of these impacts and basic explanations on the mechanisms behind, as well as some information on how emissions from industry are controlled by legal and financial means.

1.1.2 Bulk Material, Minerals and Biotic Resources

There are different types of resources. All have their specific properties from the point of view of the environment. *Bulk material* is material extracted from the uppermost layer of the ground. This corresponds to the largest material flows. Bulk material is used e.g. in building and construction industry. The problem connected with its use is disturbed or destroyed areas of extraction, transportation costs etc.

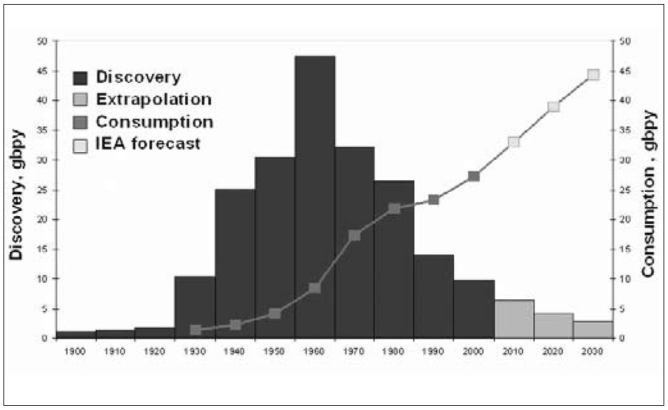


Figure 1.1 Oil rate of production versus rate of extraction. *Global oil discoveries peaked in the 1960s and are rapidly declining as oil becomes harder to find. Today there is a growing gap between new oil discoveries and production [ASPO Ireland, https://aspo-ireland.org/ see also Aleklett, 2006].*

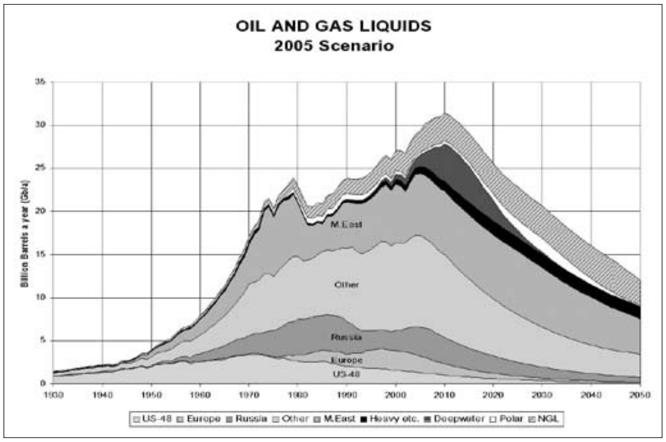


Figure 1.2 The oil depletion curve. *Oil availability over time is shown for a number of regions in the world. It is seen that e.g. the American oil is practically used up and the North Sea resources is declining. Oil is a finite resource. Peak oil refers to the time when global oil production is at its maximum. It is presently expected to occur 2008-2010. The production is then predicted to come to a very low level at about 2040. Natural gas production and consumption is seen to follow a similar pattern, with some ten years delay [ASPO Ireland, https://aspo-ireland.org/newsletter/Newsletter71.pdf]*

Macronutrients, nitrogen, phosphorus and calcium, are used in large quantities in agriculture but also in a long series of chemical compounds, such as phosphorus in detergents, and nitrogen in various plastics, that is, in chemical industry. Nitrogen compounds are mostly produced by reduction of atmospheric nitrogen into ammonia, a process that requires large amounts of energy, for which fossil fuels are used. Phosphorus is mined and as such is a non-renewable resource. The present layers are large, however, and will last more than 200 years, at the present rate of extraction.

Minerals are compounds mined from the bedrock used to produce metals. Metals are very varied. Iron, the most heavily used metal, is in a class by itself. Metals used mainly as alloys with iron, called ferro-alloy metals, include chromium, nickel, titanium, vanadium and magnesium. The traditional non-ferrous metals are aluminium, copper, lead, zinc, tin and mercury. Metals are of course by definition non-renewable. Iron and aluminium, however, which are very abundant in the surface of the planet, will not be depleted by present levels of use. All other metals are being mined at a rate of about one order of magnitude larger than the natural weathering. Some rare earth metals are already almost depleted.

Environmental problems, connected with the mining of ore and production of metals, are numerous. Mining often causes large-scale water pollution; especially strip mining is very destructive to large areas of the landscape, and it is resource consuming. The production of metal from the ore is usually dependent on reduction with oxygen in a smelter or furnace. It produces large amounts of solid waste, slag, and air pollutants, such as SO_x and NO_x and uses huge amounts of energy. Several of the metals are toxic and as such pollute the environment when they are emitted to air and water.

Biotic resources are biomass to provide food and fibre for our livelihood, and a long series of other products, such as pharmaceutical substances, as well as the landscape. These resources are *renewable*, but, of course, limited. The production rate of the biotic resources is referred to as the *carrying capacity* of the area considered. Biotic resources are used in several industrial sectors, such as the food processing industry, timber in e.g. the building industry, and wood in paper and pulp production. Agriculture and forestry is today conducted in an industrial fashion and several environmental concerns are shared with the manufacturing industry. This sector is also connected to a series of environmental impacts.

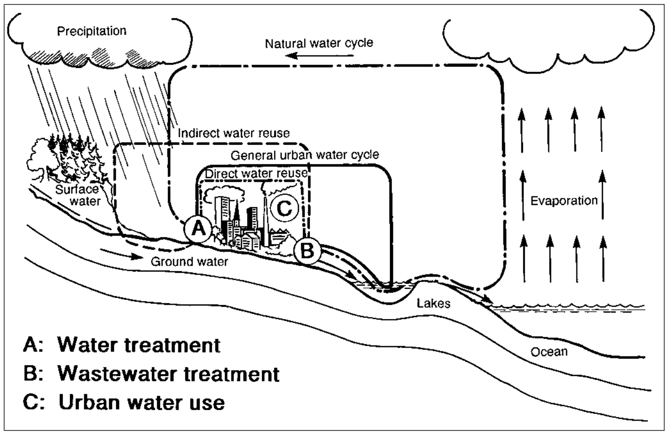


Figure 1.3 Water cycled. *The natural water cycle refers to the way water takes from precipitation, surface water runoff to the oceans and evaporation. A society may short cut this cycle by setting up so-called consumption cycles. These may be using surface water to which wastewater was discharged, as if often the case in urban water cycles, or even direct reuse of wastewater after treatment [Hultman et al., 2003].*

1.1.3 Energy

The availability of adequate energy resources is necessary for most economic activity and makes possible the high standard of living that developed societies enjoy. Although energy resources are widely available, some, such as oil and coal, are non-renewable; others, such as solar, although inexhaustible, are not currently cost effective for most applications. An understanding of global energy-usage patterns, energy conservation, and the environmental impacts associated with the production and use of energy is therefore very important.

Fossil energy resources include lignite, black coal, oil and gas. Coal, oil and gas, which were formed hundreds of millions of years ago, are fossil. The fossil fuels are *non-renewable*. They are presently used at a rate that is millions of times higher than their eventual renewal. Peat is formed on a time scale of thousands of years. Some consider peat fossil since it does not at all reform at the rate we might use it, while others do not include peat in the group of fossil fuels. Fossil fuel extraction and use constitute today the second largest resource flow on the planet.

Fossil fuel is limited, and the point in time at which oil will be depleted is today estimated as 2040. So-called peak oil, the year when half of the existing resources has been used up, is estimated to be about 2008-2010. Increased demand and increased scarcity of oil will lead to dramatic price increases. The spectacular development of Asia, with accelerated demand for energy, is presently pushing this scenario even closer in time.

Many environmental effects are associated with fossil energy consumption. Fossil fuel combustion releases large quantities of carbon dioxide into the atmosphere. During its long residence time in the atmosphere, CO_2 readily absorbs infrared radiation, contributing to global warming. Further, combustion processes release oxides of sulphur and nitrogen into the atmosphere where photochemical and/or chemical reactions can convert them into ground level ozone and acid rain. This will be further discussed below.

Flowing energy resources refer to resources which depend on the sun. They include solar heat, solar electricity and photosynthesis. *Streaming* energy resources includes waves, wind or flowing water. These are used in wave energy (which is technically difficult), wind energy and hydro power. These too have their environmental dilemmas. Hydro power requires large scale water reservoirs and changes natural water streams, while wind power influences the landscape in ways that are not always acceptable, a kind of visual pollution.

1.1.4 Water

The availability of freshwater in sufficient quantity and purity is vitally important in meeting human domestic and industrial needs. Though 70% of the earth's surface is covered with water, the largest share exists in oceans and is too saline to meet the needs of domestic, agricultural, or other users. Of the total 1.36 billion cubic kilometres of water on earth, 97% is ocean water, 2% is locked in glaciers, 0.31% is stored in deep ground water reserves, and 0.32% is readily accessible freshwater (4.2 million cubic kilometres). Freshwater is continually replenished by the action of the hydrologic cycle.

The earth's water supply remains constant, but man is capable of altering the cycle of that fixed supply. Population increases, rising standards of living, and industrial and economic growth have placed greater demands on our natural environment. Our activities can create an imbalance in the hydrologic equation and can affect the quantity and quality of natural water resources available to current and future generations.

In many countries water use by households, industries, and farms has increased. People demand clean water at reasonable costs, yet the amount of fresh water is limited and the easily accessible sources have been developed. In developing countries availability of clean water remains one of the main concerns.

In the Baltic Sea region, in contrast to the global pattern, water use has effectively diminished over several years both in industry and households. Thus in many areas the per capita water use amounts to about 100 – 200 litres/day. Some 10 – 20 years ago this figure was closer to 400 litres/day. More efficient appliances in the households, water saving due to the increased price of water, and better water infrastructure are some of the explanations. Industrial water use has decreased as a result of better efficiency. Irrigation in agriculture does not constitute a large share of water use in the Baltic Sea region.

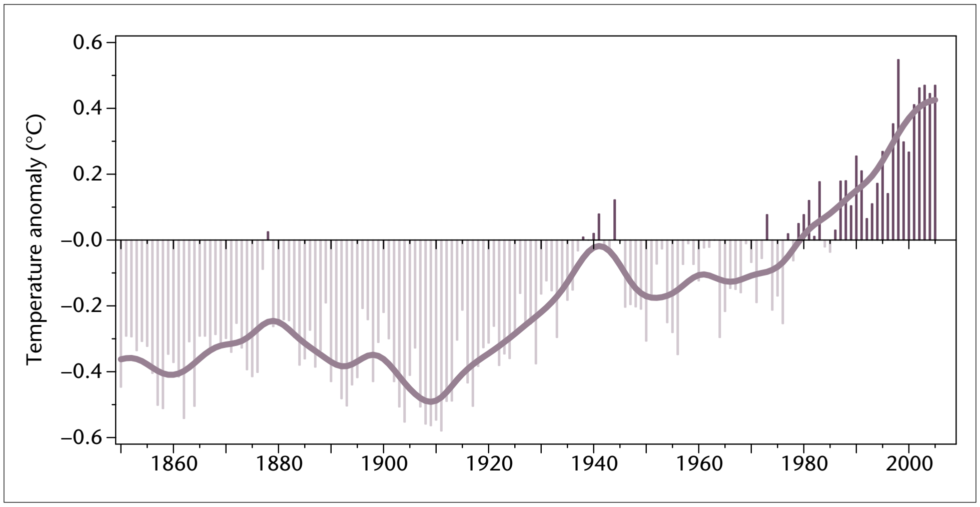


Figure 1.4 Average global temperature 1850-2005. *The temperature increase over the last 100 years is 0.6°C. The increase is however different for different regions. It was most dramatic during the 1990s [Brohan et al., 2006]. http://www.cru.uea.ac.uk/cru/info/warming/*

The withdrawal of water in the region varies from about 4% of the annual run off in Scandinavia to close to 18% in Poland. With the higher figure the water reuse in society becomes a reality, that is, wastewater discharged at some point will be used at another point.

The problem connected with water use in the Baltic Sea region is rather one of discharges of wastewater and runoff to recipients that are not able to handle the stream of pollutants. Fertilisers and other pollutants often overload water supplies with hazardous chemicals. Eutrophied and polluted surface water is a serious problem in most Baltic Sea countries.

1.2 Environmental Impacts – The Atmosphere

1.2.1 Global Warming

The atmosphere allows solar radiation from the sun to pass through without significant absorption of energy. Some of the solar radiation that reaches the surface of the earth, is absorbed, heating the land and water. Infrared radiation is emitted from the earth's surface, but certain gases in the atmosphere, so-called greenhouse gases (GHG), absorb this infrared radiation and re-direct a portion of it back to the surface, thus warming the planet and making life, as we know it, possible. This process is often referred to as the *greenhouse effect*. The surface temperature of the earth will rise until a radiative equilibrium is achieved between the rate of solar radiation absorption and the rate of infrared radiation emission.

The greenhouse effect contributes to a temperature increase on Earth of about 35°C. Water vapour is the most important greenhouse gas. Other greenhouse gases include carbon dioxide and methane.

Fossil fuel combustion, traffic, deforestation, agriculture and large-scale chemical production, have measurably altered the composition of gases in the atmosphere, and in particular increased the concentrations of carbon dioxide from the beginning of industrialisation and dramatically so the last several decades. This has resulted in an *enhancement* of the greenhouse effect. Table 1.1 is a list of the most important greenhouse gases along with their anthropogenic sources, emission rates, concentrations, residence times in the atmosphere, relative radiative forcing efficiencies, and estimated contribution to global warming [IPPC, 2001]. Since the 1990s a dramatic increase in global average temperature is ongoing. The observed temperature increase is in fair agreement with the calculated consequences of actual accumulation of anthropogenic carbon dioxide in global climate models. The possibility that the observed accelerated increase in global temperature is due to other, so called natural, causes is today not likely and a large majority of scientists agree that increased atmospheric concentration of GHG, the enhanced greenhouse effect, is a major cause of climate change.

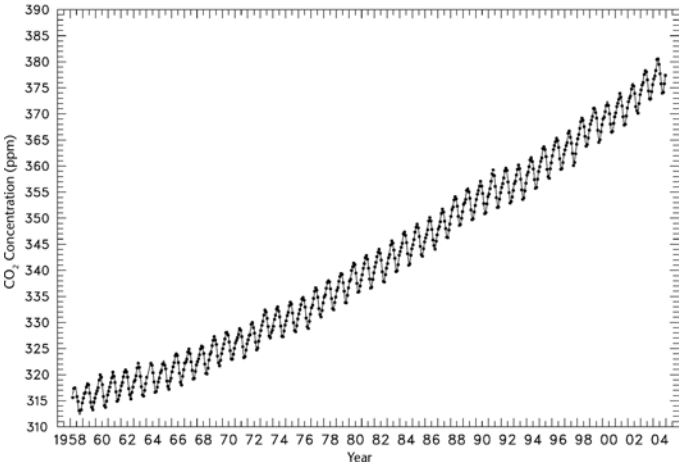


Figure 1.5 CO_2 concentrations in the atmosphere 1956-2004. *Data from Manua Loa mountain observatory on Hawaii where carbon dioxide concentrations in the atmosphere have been carefully monitored since 1956. The variation in the curve corresponds to the yearly breathing of the entire Earth ecosystem [Keeling and Whorf, 2005]. http://cdiac.esd.ornl.gov/trends/co2/graphics/mlo145e_thrudc04.pdf*

Climate change is today seen as the perhaps most serious threat to our environment and societal infrastructure worldwide. Climate change will affect the water cycle and water availability, the conditions for agriculture and forestry, lead to habitat change and biodiversity reduction. It will lead to an increase in sea water level, and therefore extinction of extensive low-lying land areas, especially in the Pacific area. It may at some point stop the so-called thermo-haline water circulation, and thereby the Gulf Stream, and thus make parts of Northern Europe and the Baltic Sea Region, dramatically colder.

1.2.2 Policies to Reduce Emissions of Greenhouse Gases

Fossil fuels are today dominating the world's energy flows and are a base for much industrial production. At the same time as the reduction of fossil fuel use seems remote, the environmental consequences of it are serious. The world leaders have reacted by efforts to reduce the emission of carbon dioxide. This is for all practical purposes identical to reduction of fossil fuel use. A major step was the elaboration of the Kyoto Protocol of the Climate Convention in 1997. This requires an average reduction of CO_2 emissions by 8% by 2008-2012 using 1990 as a base year. The Kyoto protocol finally went into force in February 2005 after the Russian Federation had signed and ratified as the latest of some 120 states. The largest fossil fuel dependent nation, United States, has, however, not yet done so.

Policy tools to achieve reduction of carbon dioxide emissions include taxes on emitted CO_2, already quite high in some countries, as well as subsidies for changes to other sources of energy. Substantial reductions of fossil fuel use is seen e.g. in Denmark (coal substituted mainly by wind power) Sweden (oil substituted mainly by nuclear power and biomass) and Germany (coal substituted in several ways, wind power and improved efficiency included). In addition for many years a large scale exchange of coal to gas has been on-going, which will reduce carbon dioxide emissions per energy unit. Finally, increased efficiency of energy use is a main strategy where much remains to be done, a strategy which is becoming increasingly interesting to industry as energy prices increase.

Table 1.1 Greenhouse gases and Global Warming contributions. *Data are based on IPCC, 2001, but updated for atmospheric concentrations and contribution to enhanced global warming for CO_2 and all other gases (2004) through the Carbon Dioxide Information Analysis Center (CDIAC) (see http://cdiac.ornl.gov/pns/current_ghg.html). The concentration given for CO_2 in January 2007 was not used in the calculations of the contribution to enhanced global warming.*

Gas	Source	Estimated Anthropogenic Emission Rate	Preindustrial Global Conc.	Approx. Current Conc.	Estimated Residence Time in the Atmosphere	Radiative Forcing Efficiency (CO_2=1)	Estimated Contribution to Enhanced Global Warming
Carbon Dioxide (CO_2)	Fossil fuel combustion deforestation	6 000 Mt/yr	280 ppm	377 ppm, 383 ppm (2007)	50-200 yrs	1	55%
Methane (CH_4)	Anaerobic decay, cattle, natural gas, coal mining, biomass burning	300-400 Mt/yr	0.7 ppm	1.85 ppm	10 yrs	58	17%
Nitrous oxide (N_2O)	Deforestation, agricultural practices, land clearing, low-temperature fuel combustion	4-6 Mt/yr	0.27 ppm	0.31 ppm	140-190 yrs	206	5%
CFC's	Refrigerants, air conditioners, foam-blowing agents, aerosol propellants, solvents	1 Mt/yr	0	0.0004-0.001 ppm	6-110 yrs	4 860	11%
Tropospheric ozone (O_3)	Photochemical reactions involving VOCs and NO_X	No direct emission	NA	0.022 ppm	Hours-days	2 000	12%

The Kyoto protocol includes trading of emission rights. This is now becoming an important economic incentive to reduce fossil fuel use in industry, as it was introduced in the European Union in 2004. Units such as power plants in less developed countries, for which it is less costly to reduce emissions, will sell emission rights to units where fossil fuel substitution or efficiency increase is already far advanced. This may accelerate the march away from fossil fuel dependency.

Some technical solutions to the problems, such as sequestration of carbon dioxide in the underground, e.g. in emptied oil wells, are at hand but these probably will play only a minor role in the near future. Thus we should expect that the efforts to implement strategies of substitution of fossil fuel with flowing energy resources will soon be intensive.

1.2.3 Stratospheric Ozone Depletion

The solar radiation reaching the earth's surface is sharply cut out at wavelengths below about 290 nm, although the radiation entering the top of the atmosphere includes considerable amounts of radiation at shorter wavelengths. The reason is that small quantities of ozone (O_3), chiefly in the layers between 15 and 40 km above ground level, effectively filter out the missing radiation and use it to produce the warm conditions of the upper stratosphere (Figure 1.6).

The energy-rich ultraviolet radiation with wavelengths shorter than 240 nm is absorbed in the stratosphere by oxygen molecules splitting them into two free oxygen radicals. The free oxygen radicals combine with other oxygen molecules (O_2) forming ozone (O_3). The creation of O_3 is continuous as long as the sun shines, yet the amount of O_3 remains small and is largely confined to the stratosphere. This is because ozone is attacked by other gases diffusing upward from the earth's surface. The most important of these in nature is nitrous oxide (N_2O), emanating from the soil and from certain industrial processes. In the stratosphere it is quickly oxidised to NO, and this attacks O_3:

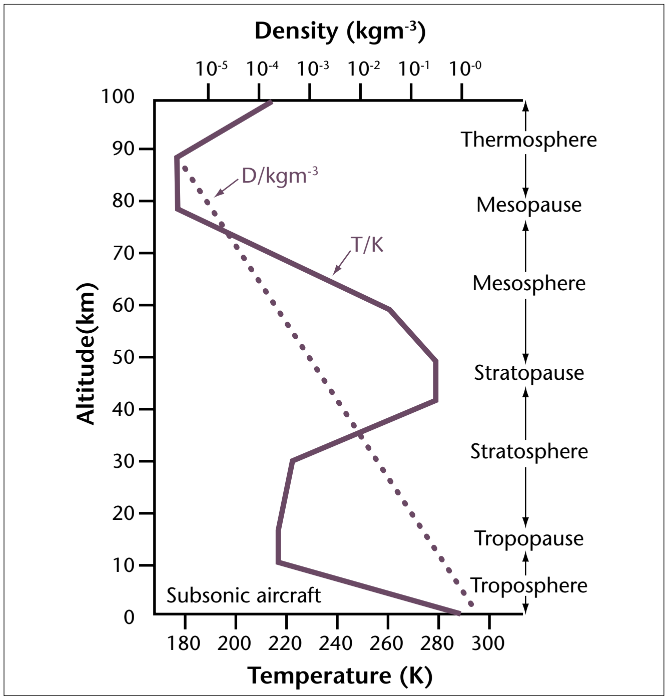


Figure 1.6 *Structure as density (dotted line) and temperature profile (solid line) of the atmosphere [IChemE, 1993].*

$$N_2O + O_3 \longrightarrow 2NO + O_2$$

$$NO + O_3 \longrightarrow NO_2 + O_2$$

This and other processes create a natural equilibrium: ultraviolet radiation creates ozone, and other natural processes lead to its decay. The ozone is formed in the stratosphere. Of the total amount of ozone in the atmosphere, 90% is found in the stratosphere, where it constitutes the so-called *ozone layer*.

Ultraviolet radiation has shorter wavelengths than visible light and is commonly divided in three types:

UV-A 320-400 nm, passes the atmosphere and will in the main reach the Earth's surface.

UV-B 280-320 nm, is over 99% absorbed by the ozone layer in the stratosphere.

UV-C <280 nm, is completely absorbed by the atmosphere.

On penetrating the atmosphere and being absorbed by biological tissues, UV radiation damages protein and DNA molecules on the surfaces of all living things. If the full amount of ultraviolet radiation falling on the stratosphere reached Earth's surface, it is doubtful that any life could survive. We are spared more damaging effects from ultraviolet rays because most UV-B radiation (over 99%) is absorbed by ozone in the stratosphere. For that reason, stratospheric ozone is commonly referred to as the *ozone shield*.

In 1985 British scientists discovered that the ozone concentration over the Antarctic had decreased dramatically, about 50%, during the Antarctic spring in October-November. They later proved that this had been ongoing since the late 1970s. The uniquely large loss of stratospheric ozone over the South Pole was called the *Antarctic Ozone Hole*. This phenomenon has been growing since then, with about 5% yearly loss of ozone. Since the 1990s a reduction of ozone concentrations has also been recorded over the Arctic. Here it appears in the late Nordic winter and early spring. It so far amounts to about a 25% reduction.

The environmental consequences of the increased UV radiation caused by this loss of stratospheric ozone include reduced photosynthesis and increased cancer incidence.

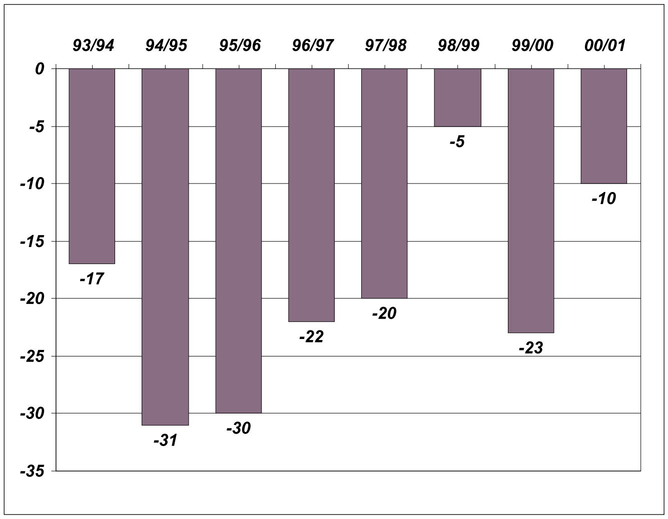


Figure 1.7 Ozone losses over the Arctic. *Figures show losses in % over winter months. The variation depends a lot on air currents. When a stable low pressure area over the Arctic isolates the cold air for longer periods the ozone content may sink by more than 30% [Murtagh, 2003].*

1.2.4 Ozone-destroying Substances

In 1974 two American researchers, Rowland and Molina, showed that atomic chlorine catalysed the breakdown of ozone. Some chlorine is present naturally in the atmosphere, mostly originating from salt in the sea, but they suspected that some halogenated substances emitted from society might be a threat to stratospheric ozone. Later *freons*, or CFCs, were identified as the major culprit behind the stratospheric ozone destruction.

Chlorofluorocarbons (CFCs) are a kind of halogenated hydrocarbons. They are non-reactive, non-flammable, non-toxic organic molecules in which both chlorine and fluorine atoms replace all or several of the hydrogen atoms. Their thermodynamic properties are the primary reason for their use as 1) heat-transfer fluids in refrigerators, air conditioners and heat pumps; 2) foaming agents in production of plastic foams; 3) solvents for use in the electronic industry for cleaning parts that must be meticulously purified; and 4) pressurising agents for aerosol cans.

All of these uses led to the release of CFCs into the atmosphere, where they mixed with the normal atmospheric gases and eventually, because of their stability and extremely long residence time in the atmosphere, reached the stratosphere. Here they are subjected to the intensive UV radiation, inducing photochemical reactions that break the molecules up.

There are a large number of different reactions involved in this reaction chain. The most important ones are:

$$CF_2Cl_2 + \text{UV–C} \longrightarrow CF_2Cl + Cl^{\bullet} \qquad (1)$$

The second chlorine atom is also freed in a similar reaction yielding one more chlorine radical. The chlorine radicals then act as catalysts as described by:

$$Cl^{\bullet} + O_3 \longrightarrow ClO + O_2 \qquad (2)$$

$$ClO + ClO \longrightarrow 2Cl^{\bullet} + O_2 \qquad (3)$$

Table 1.2 *Serious air pollution incidents [IChemE, 1993].*

Year	Incident	Pollutant	Number of excess fatalities	Number of cases of illness
852	London, England	Complaints of foul air due to burning of sea-coal		
1873	London	SO_2, particulates	"excess deaths"	
1880	London	SO_2, particulates	27% increase	
1892	London	SO_2, particulates	1484	
1930	Meuse Valley, Belgium	Fluorides, SO_2, particulates	63	6000
1948	Dondora, Penn., USA	SO_2, particulates	17	6000
1948	London	SO_2, particulates	700 – 800	
1953	London	SO_2, particulates	4000	
1956	London	SO_2, particulates	1000	
1960	Osaka, Japan	SO_2, particulates		
1962	London	SO_2, particulates	700	
1976	Seveso, Italy	Complex mixture + dioxins		28
1984	Bhopal, India	Methyl isocyanate gas	2000	
1986	Chernobyl, USSR	Radioactive gases		

Reactions 2 and 3 are called the *chlorine cycle*, because chlorine is continuously regenerated as it reacts with ozone. Thus each free chlorine radical released in the stratosphere will be able to catalyse the break-down of tens of thousands of ozone molecules before other reactions removes the chlorine from the chlorine cycle.

1.2.5 Reduction of Ozone-depleting Substances and the Montreal Protocol

The global production of CFCs reached its peak in 1986 with about 1,300,000 tonnes yearly. In the EU countries alone production was 700,000 tonnes. Efforts to reduce production started in the 1970s with voluntary actions. In 1979 CFCs were outlawed as propellants in spray cans in many western countries. Production increased, however, as they found new uses. After the 1985 discovery of the ozone hole the pressure to reduce freon production and use increased. Finally a 1987 agreement in Montreal to totally eliminate the use of ozone-depleting substances was signed by many nations. The Montreal protocol has led to significant reductions in CFC production and use. In 1995 the production was 10-20% of the peak value, and in 2003 it was almost eliminated.

The ozone concentration in the stratosphere is predicted to have reached its lowest values at about 2003-4 and then increase. The inter-annual variations are, however, large and final confirmation will have to await a longer time series.

1.3 Industrial Air Pollution

1.3.1 Air Pollution

Air pollution is certainly not a new phenomenon. Indeed, early references to it date to the Middle Ages, when smoke from burning coal was already considered such a serious problem that in 1307, King Edward I banned its use in lime kilns in London. In more recent times, though still decades ago, several serious episodes focused attention on the need to control the quality of the air we breathe. The worst of these occurred in London, in 1952. A week of intense fog and smoke (smog) resulted in over 4,000 excess deaths that were directly attributed to the pollution. Table 1.2 shows a number of other serious air pollution incidents.

All these episodes have had significant health effects. In addition, there have been incidents of severe crop, forest, and materials damage, and the costs have been substantial.

The early air pollution episodes were clearly detectable by the senses without special aids or instrumentation. Particles in urban atmospheres reduced visibility and were aesthetically dirty. Sulphur dioxide smelled, caused silvered surfaces to turn black, caused plant damage, and in extreme situations, made breathing difficult. Ozone caused rubber and synthetic materials to deteriorate very quickly, and photochemical smog containing high concentrations of ozone caused eye irritation. Nitrogen oxides, NO and NO_2, and hydrocarbons, of which there are several thousand different species, were found to be precursors of photochemically formed ozone and Peroxy Acetyl Nitrate (PAN) in a shallow layer of the atmosphere at the earth's surface. It was also well recognised that carbon monoxide represented a severe health hazard at extremely low concentrations.

Figure 1.8. Forest dying after acid rain in Izierskie, the Sudety Mountains, in 1995. *The area, in the so-called black triangle bordering Poland, Czech Republic, and Eastern Germany, was especially badly hit by acid rain in the period up to the mid 1990s. (Photo: iStockphoto)*

1.3.2 Acidification

One of the most serious air pollution problems has been that of acid rain. The water of unpolluted rain, snow, hail, mist and fog is not pure H_2O. It contains small but significant concentrations of dust, dissolved solids and gases. Of particular importance is the presence of dissolved carbon dioxide as this maintains the pH of clean rainwater at about 5.6. This is due to its equilibrium with the 380 ppm of carbon dioxide in the atmosphere. The epithet acid rain is therefore reserved for precipitation (rain, snow, fog, etc.) that has a pH appreciably lower than expected in the absence of pollution. Usually all precipitation with a pH of 5 or lower is referred to as acid rain.

Acid rain is produced when sulphur dioxide (SO_2) and/or the oxides of nitrogen (NO_X) and their oxidation products are present in moisture in the atmosphere.

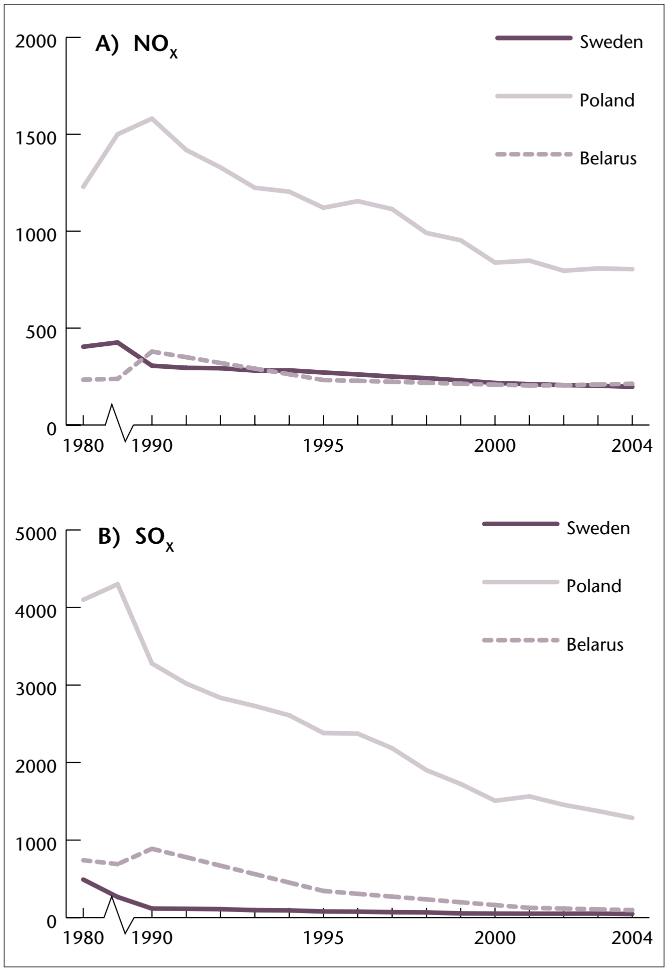


Figure 1.9 Changes in anthropogenic emissions of nitrogen oxides (A) and sulphur oxides (B) from 1980. *The NO_2 and SO_2 emissions (1,000 tonnes per year) in Belarus, Poland and Sweden are given as examples of the trends in Europe [EMEP, Expert Emissions. http://webdab.emep.int/]*

Both acid rain and acid mine drainage contribute significantly to the acidification of natural waters. The environmental consequences are serious and far reaching. Tens of thousands of lakes in Norway and Sweden, and to some extent Finland, where the buffering capacity of the soil is limited, have pH values low enough, below 4.5, to kill all higher life, caused by acid rain. This is due both to the pH itself and to the leaching of aluminium from sediment at lower pH. The aluminium thus brought into solution is toxic, especially to fish. Also other metals, e.g. mercury, become more mobile as a result of the lower pH. Acids and/or alkalis discharged by chemical and other industrial plants make a stream unsuitable not only for recreational use but also for propagation of fish and other aquatic life.

Other effects of acidifying substances in air include health effects, especially on children. It also leads to the destruction of materials, e.g. cultural monuments in limestone or sandstone, and it has corrosive effects on e.g. metals. It further has an effect on reducing harvest in agriculture and in forestry. Forests killed by acid rain in Central Europe were one of the first serious concerns caused by acid rain. The value of damage caused by acid rain in Europe was estimated in 1997 to about 91 billion euros yearly. It is much more than the costs of measures needed to stop this pollution.

1.3.3 Sulphur Oxides

The major cause of acid rain is the emission of *sulphur dioxide* (SO_2). SO_2 has an unpleasant odour that is detectable at concentrations greater than about 1 ppm. Its concentrations in the atmosphere range from less than 1 ppb in locations very remote from industrial activity to 2 ppm in highly polluted areas. However, concentrations of 0.1 to 0.5 ppm are more typical of urban locations in industrialised countries, while levels of around 30 ppb are normal for rural areas in the northern hemisphere. Sulphur dioxide is oxidised in the atmosphere to the highly damaging secondary pollutants sulphuric acid (H_2SO_4) and/or its acid anhydride, sulphur trioxide (SO_3). SO_X refers to both di- and trioxides of sulphur in any proportion.

Sulphur dioxide is produced mainly as the result of the burning of sulphur-containing fossil fuels, particularly coal and oil, during electricity generation. Other industrial processes, notably metal sulphide ore roasting, for example of nickel (NiS), lead (PbS) and copper (Cu_2S), in order to recover the metal, make a sizeable contribution. The principal natural sources of sulphur dioxide are volcanic and biological activity. The latter is mainly an indirect source, providing reduced sulphur compounds (particularly H_2S and $(CH_3)_2S$) which are rapidly oxidised in the air to sulphur dioxide.

There are two principal sink mechanisms for atmospheric sulphur dioxide. These are direct deposition from the gas phase onto wet or dry surfaces (a process known as *dry deposition*) and oxidation to sulphur trioxide and/or sulphuric acid, which subsequently are efficiently removed from the air during precipitation (*wet deposition*), contributing to the phenomenon of acid rain.

1.3.4 Nitrogen Oxides

Oxides of nitrogen usually originate from power stations and from vehicle emissions. As a rule, they contribute less than SO_x to the problem of acid rain. Three of the oxides of nitrogen are significant primary pollutants. These are nitrous oxide (dinitrogen oxide, N_2O), nitric oxide (NO) and nitrogen dioxide (NO_2).

Nitrous oxide (N_2O) is an un-reactive gas found at a level of about 0.3 ppm. Nitrous oxide is a greenhouse gas and therefore contributes to global warming. In addition, its unreactiveness and therefore very long residence time in the atmosphere (20-100 years) allows it to enter the stratosphere, where it by photochemical reactions produces nitric oxide (NO) and thus contributes to the depletion of stratospheric ozone. The main source of atmospheric nitrous oxide is probably microbial reduction (denitrification) of nitrate (NO_3-) that occurs in soils and waters with low oxygen contents. This is a natural process as well as a process used in the denitrification of wastewaters. The production of N_2O is a side reaction to the main reaction that converts nitrate to molecular nitrogen gas (N_2).

Nitric oxide (NO) and *nitrogen dioxide* (NO_2) are collectively referred to as NO_x. They are both highly reactive gases and therefore have extremely short residence times in the atmosphere. Levels of nitrogen dioxide vary from less than 1 ppb in remote areas to 0.5 ppm during severe periods of pollution in urban areas. While NO_x compounds are pollutants in their own right, contributing both to acidification and eutrophication, the main problems they cause are associated with the secondary pollutants that they produce (See 1.3.6 *Tropospheric Ozone*).

Almost all NO_x emissions are in the form of NO, which is a colourless gas that has no known adverse health effects at concentrations found in the atmosphere. However, NO is easily oxidised to NO_2, by oxygen, ozone or radicals. NO_2 can irritate the lungs, cause bronchitis and pneumonia, and lower resistance to respiratory infections. Nitrogen dioxide reacts with the hydroxyl radical ($OH^\bullet$) in the atmosphere to form nitric acid (HNO_3), which corrodes metal surfaces and contributes to the acid rain problem. It also can cause damage to terrestrial plants and is a significant contributor to eutrophication, especially in nitrogen-limited estuaries.

The main natural sources of NO_x are biomass burning (forest fires), electrical storms, in situ ammonia oxidation, and, in the case of nitric oxide, anaerobic soil processes. Estimates of the total flux generated vary, but are typically in the range 30 to 40 million tons NO_x/year globally. This is roughly comparable with the anthropogenic flux, which is estimated to be 60 to 70 million tons NO_x/year. The clearly dominating source is transportation, including work machines and shipping, burning of fossil fuels and biomass and industrial processes. Another substantial source for nitrogen emissions comes from agriculture in the form of diffuse ammonia emissions from animal farming and fluid fertilising.

There are two principal routes that NO_x is formed in combustion processes. *Thermal* NO_x is created when nitrogen and oxygen in the combustion air are heated to a high enough temperature (above 1000ºC) to oxidise the nitrogen. *Fuel* NO_x results from the oxidation of nitrogen compounds that are chemically bound in the fuel molecules themselves.

1.3.5 Convention on Reduction of Air Born Long-Range Transboundary Pollution, LRTP

Claims that acidification of lakes and rivers was caused by industrial emissions of SO_x and NO_x have been advanced by Sweden and Norway since the early 1970s. In 1979 thirty nations signed the Convention on reduction of air born Long-Range Transboundary Pollution (LRTP), a convention within the UN-ECE, the United Nations Economic Commission for Europe. The convention came into force in 1983. In 1985 the sulphur protocol with solid commitments of reduction of SO_x emissions was signed. As a result emissions were generally cut by 30% up to 1993, and in some cases by up to 80%. It has since continued to decrease. A protocol on nitrogen oxides was signed in 1988. However this has been less successful, as some of the signatory nations were not able to reduce emissions at all.

Reduction of sulphur emissions is technically fairly easy and cost-efficient. It has thus been rather successful. European emissions of sulphur dioxide were highest around 1980 when they amounted to about 56 million tonnes. By 2006 they had decreased to about 12 million tonnes.

European emissions of NO_x peaked around 1990, when they amounted to an estimated 28 million tonnes. By 2004 this figure had decreased to about 16 million tonnes.

1.3.6 Tropospheric Ozone

When oxides of nitrogen, volatile organic compounds (VOCs), and sunlight come together, they can initiate a complex set of reactions that produce a number of secondary pollutants known as *photochemical oxidants*.

Volatile Organic Compounds include un-burnt hydrocarbons emitted from exhaust pipes and smoke stacks when fossil fuels are not completely combusted along with gaseous hydrocarbons that enter the atmosphere when solvents, fuels, and other organic compounds evaporate. The transportation sector is responsible for about one-third of anthropogenic VOC emissions.

Photochemical oxidants are the most significant agents in formation of *photochemical smog*. Ozone (O_3) is the most abundant of the photochemical oxidants. Other components of photochemical smog are formaldehyde (HCHO), Peroxy Benzoyl Nitrate (PBzN), Peroxy Acetyl Nitrate (PAN), and acrolein (CH_2CHCOH).

Tropospheric ozone is formed when sunlight makes nitrogen dioxide split into NO and a free oxygen radical:

$$NO_2 + hv \longrightarrow NO + O^\bullet$$

$$NO + O_2 \longrightarrow NO_2 + O^\bullet$$

$$O^\bullet + O_2 + M \longrightarrow O_3 + M$$

M represents a molecule whose presence is necessary to absorb excess energy from the reaction. Without M, the ozone would have too much energy to be stable, and it would dissociate back to $O^\bullet$ and O_2. Atomic oxygen radicals in turn will react with water to form $OH^\bullet$, the *hydroxyl radical*, a key substance in atmospheric organic chemistry. The hydroxyl radical will initiate the reaction sequence involving VOCs such as ethane (C_2H_6), propane (C_3H_8) etc. to form aldehydes. The removal of NO by these reactions slows the rate at which O_3 is removed, while the addition of NO_2 increases the rate at which it is produced, which allows higher levels of O_3 to accumulate in the air.

The tropospheric ozone contributes to the global warming but has above all direct effects on vegetation and human health. Ozone will penetrate into the leaf tissues of plants and trees where it damages cell membranes and enzymes. It also disturbs the cell's ability to photosynthesise. Ozone leads to a less efficient water utilisation in the plants and makes them more sensitive to drought. Ozone has been shown to seriously reduce yields of major agricultural crops, such as corn, wheat, soy beans, and peanuts. Ozone alone is thought to be responsible for about 90% of all of the damage that air pollutants cause agriculture.

Ozone and other components of photochemical smog are known to cause many annoying respiratory effects, such as coughing, shortness of breath, airway constriction, headache, chest tightness, and eye, nose, and throat irritation. These symptoms can be especially severe for asthmatics and others with impaired respiration, but also healthy individuals who engage in strenuous activities for relatively modest periods of time, e.g. jogging, experience these symptoms at levels near the ambient air quality standard.

Figure 1.10 *Car exhaust is one of the worst environmental health problems. (Photo: Inga-May Lehman Nådin)*

1.3.7 Particulate Pollutants

Atmospheric particulate matter consists of any dispersed matter, solid or liquid, in which the individual aggregates range from molecular clusters of 0.005 µm diameter to coarse particles up to about 100 µm. As a category of pollutants, particulate matter is extremely diverse and complex. Size and chemical composition, as well as concentration, are important characteristics.

A number of terms are used to categorise particulates, depending on their size and phase (liquid or solid). The most general term is *aerosol*, which applies to any tiny particles, liquid or solid, dispersed in the atmosphere. Solid particles are called *dusts* (1 to 1000 µm) if they are caused by grinding or crushing operations and *fumes* (0.03 to 0.3 µm) if they are formed when vapours condense. Liquid particles may be called *mist* (0.07 to 10 µm). Mists are concentrated to *fog*. *Sprays* (10 to 1000 µm) are particles formed from the atomisation of liquids. *Smoke* (0.5 to 1 µm), and *soot* are terms used to describe particles composed primarily of carbon that result from incomplete combustion of carbon containing compounds. *Fly ash* (1 to 1000 µm) is non-combustible particles connected with combustion gases in the burning of coal.

Smog is a term that was derived from smoke and fog. There are two types of smog. *Gray or industrial smog* is an irritating, greyish mixture of soot, sulphurous compounds, and water vapour (a combination of smoke and fog). This kind of smog is mostly found in industrial areas and where coal is the primary energy source. *Brown or photochemical smog* is produced when several pollutants from automobile exhausts, nitrogen oxides and volatile organic hydrocarbons are undergoing photochemical reactions induced by sunlight. Typically this smog appears during the morning rush traffic and only begins to disappear by the end of the evening commuter traffic.

The particles of largest interest have aerodynamic diameters in the range 0.1 μm to 10 μm (roughly the size of bacteria). Large particles that enter the respiratory system can be trapped by the hairs and lining of the nose. Once captured, they can also be driven out by a cough or sneeze. Smaller particles, however, are often able to traverse the many turns and bends in the upper respiratory system, they tend to follow the air stream into the lungs, where they are adsorbed or go back out again.

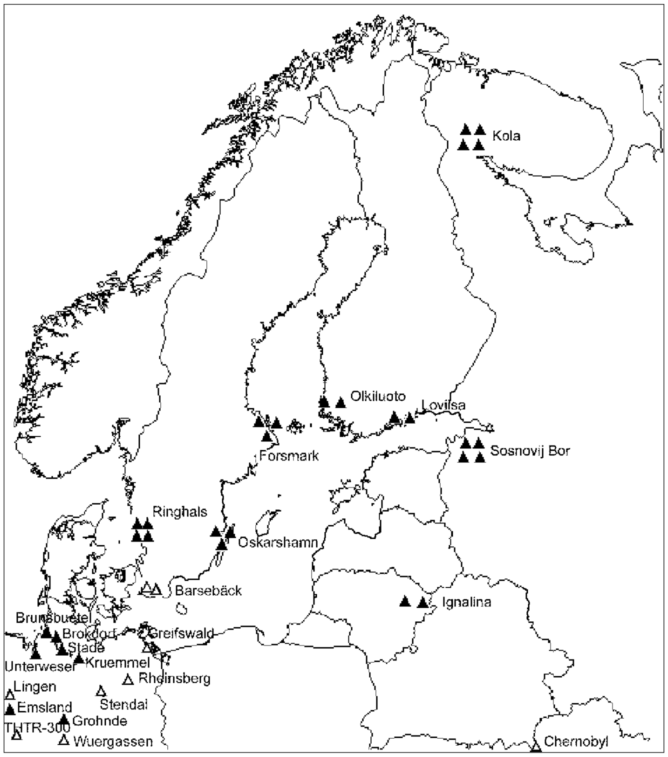


Figure 1.11 Nuclear power plants in the Baltic Sea region. *Each triangle is a reactor, and each group of reactors is a power plant. White triangles denote reactors that have been shutdown or cancelled. The two reactors at Greifswald were closed 1990, the Chernobyl ones 2001 and the two of Barsebäck at 2005. Ignalina will close at 2009 as part of the EU accession agreement. Several new reactors are planned notably in Finland, Russia and Ukraine. [Based on information from INSC at Argonne National Laboratory, http://www.insc.anl.gov/pwrmaps/]*

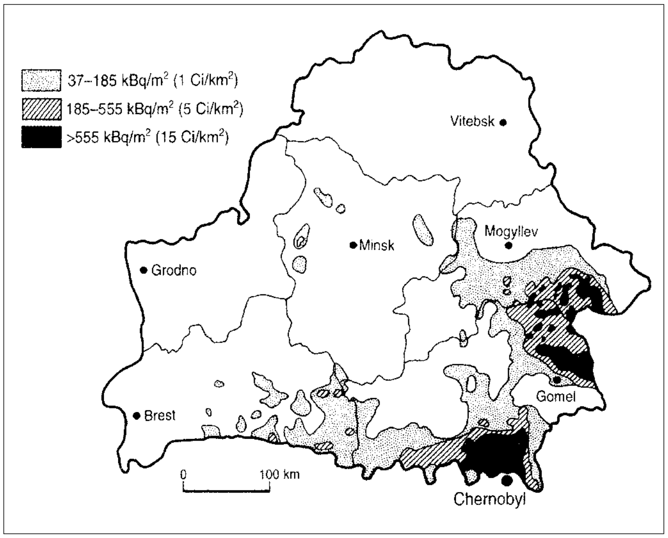


Figure 1.12 *Radiation fallout in Belarus after the Chernobyl accident [Redrawn from Walker et. al., 2001].*

The chemical and physical nature of particles is extremely important when assessing the effects of the emissions. Metallic oxides from spray painting and the coating industries; catalyst dusts from refineries; asbestos fibres from the insulation, cloth, and pipe industries; and special chemical releases such as barium, beryllium, boron, and arsenic from the metals processing or manufacturing industries and cadmium, lead, and mercury from batteries are designated as hazardous particles because they are highly toxic or carcinogenic and are in the respirable size range (< 2.5 μm). The largest industrial particle emissions are ash from combustion of coal, oil and solid wastes; carbon particles from the combustion and processing of fossil fuels; and particles from quarrying and mining and their associated industries.

Iron and steel plants emit large quantities of small particles to the atmosphere. Most of the particles are oxides of iron, carbonate fluxing materials, or oxides of metals used to produce special alloys. Most of these are smaller than 2.5 μm. The shift to basic oxygen furnaces has resulted in a shift of particle emissions to even smaller sizes and in greater quantities.

Coarse particle inhalation frequently causes or exacerbates upper respiratory diseases, including asthma. Fine particle inhalation can decrease lung functions and cause chronic bronchitis. Inhalation of specific toxic substances such as asbestos, coal mine dust, or textile fibres are now known to cause specific associated cancers (asbestosis, black lung cancer, and brown lung cancer, respectively). Asbestos is especially hazardous in this respect since asbestos fibres effectively adsorb other carcinogenic substances, such as benzo(a)pyrene, and are suspected to subsequently act as transport media for these substances into the cells of the lung tissue.

1.3.8 Radioactivity

Severe environmental contamination by radioactive pollution emitted into the air, has occurred on a number of occasions. These include the aftermath of the dropping of nuclear bombs on Hiroshima and Nagasaki in Japan at the end of the Second World War, but also fall-out from the atmospheric testing of nuclear weapons before 1962. Fall-out from tests in the North by the Soviet army is still serious in the Northern Baltic Sea region.

Perhaps the most pressing public concern with regard to nuclear energy production is the possibility of a serious accident and the following radioactive pollution. Such accidents have occurred, notably at Three Mile Island in Pennsylvania in 1979, and at Chernobyl in Ukraine in 1986, one of the most severe environmental disasters in the Baltic Sea region. The emissions from a melt-down in a nuclear power plant has a mixture of radioactive nuclides, most of them very short lived but some staying radioactive for many years. In practice the first days and weeks of a nuclear fall-out is dominated by iodine nuclides, and later by radioactive caesium 137. The latter isotope with a half-life of 27 years is what today and for many years to come will be the main concern after the Chernobyl disaster.

Figure 1.13 Excessive amounts of nutrients, entrophication, leeds to growth of algae. *In small bays, algal growth may cause both a terrible sight and smell. (Photo: www.nps.gov)*

Table 1.3 *Total dissolved solids levels for different types of waters [Tchobanoelous and Schroeder, 1985].*

Water type	TDS value
Freshwater	< 1 500 mg/L
Brackish water	1 500 – 5 000 mg/L
Saline water	> 5 000 mg/L
Sea water	30 000 – 34 000 mg/L

The so-called nuclear fuel cycle consists of mining of uranium, enrichment processing, its fission in the nuclear reactor, and finally disposal and storage of nuclear waste. All of these stages give rise to risk of radioactive pollution and exposure to humans. Mining and mineral processing of uranium ore may lead to high exposure for miners. Also, mine tailings may contain residual radioactivity, and in some cases these tailings have not been disposed of in the proper manner.

Radioactive, also called nuclear, waste is generated by a number of different industries and services, from both the civilian and military sectors. Sources include nuclear power generation and nuclear weapons production. To a lesser extent medical and scientific research applications involve radio nuclides. The main public attention is focused on the major producer of non-military radioactive waste, the nuclear power industry, and, in particular, the nature and safe disposal of the wastes generated by the final stages of the nuclear fuel cycle.

1.4 Industrial Water Pollution

1.4.1 Organic Pollution

Water pollution occurs when the discharge of wastes impairs water quality or disturbs the natural ecological balance. By far the greatest volume of pollution is caused by the discharges of organic material into freshwater systems. Municipal sewage, industrial wastewater and agricultural wastewaters are waste streams rich in organic matter.

The organic waste provides a rich substrate for bacteria. As the organic pollutants are decomposed by biological activity in the water, oxygen dissolved in the water is consumed, thereby lowering the oxygen levels in the water. The decomposition processes also liberate nutrient components such as nitrates and phosphates. The concentration of organic pollutants in water is measured in terms of its *biological oxygen demand* (BOD), which is the amount of oxygen required by microorganisms to degrade the wastes biologically. Another way of determining the level of organic contamination is the *chemical oxygen demand*, or COD, the amount of oxygen needed to oxidise the wastes chemically. While BOD gives a measure of the concentration of easily biological degradable components, COD measures the total content of biologically degradable organic matter as well as the content of oxidisable inorganic components.

Wastewater with a high content of organics is generated in e.g. the food processing industry, and the pulp and paper industry.

1.4.2 Nutrients

Eutrophication is the enrichment of waters by inorganic plant nutrients. Nutrients are chemicals, such as nitrogen, phosphorus, carbon, sulphur, calcium, potassium, iron, manganese, boron, and cobalt that are essential to the growth of living organisms.

In terms of water quality, nutrients can be considered as pollutants when their concentrations are sufficient to allow excessive growth of aquatic plants, particularly algae. These form algal blooms, usually dominated by blue-green algae, also called cyanobacteria. Sunlight is prevented from reaching the aquatic plants underneath and these will eventually die. Large quantities of dead organic matter from the submerged vegetation and the algal blooms themselves become available for decomposition, stimulating the growth of bacteria, and causes problems of oxygen depletion. It finally leads to levels of dissolved oxygen insufficient to sustain higher life forms. Algae and decaying organic matter cause discolouring, turbidity, odours, and objectionable tastes of water that is difficult to remove and greatly reduce its usefulness as a domestic water source. In oxygen depleted environments anaerobic decomposition of organic matter will lead to the formation of methane and hydrogen sulphide gas.

Aquatic species require a long list of nutrients for growth and reproduction, but from a water quality perspective, the three most important ones are carbon, nitrogen, and phosphorus. Plants require relatively large amounts of each of these three nutrients, and unless all three are available, growth will be limited. The nutrient that is least available relative to the plants' needs is called the *limiting nutrient*. In general, sea water is most often limited by nitrogen, while freshwater lakes are most often limited by phosphorus. The eutrophication of the Baltic Sea is dependent on either phosphorus or nitrogen, depending on the situation and the place.

Major sources of nitrogen include municipal wastewater discharges, run-off from animal husbandry, chemical fertilisers, and nitrogen deposition from the atmosphere, mostly originating from combustion processes. In addition, certain bacteria and blue-green algae can obtain their up-take of nitrogen directly from the atmosphere. While there are usually enough natural sources of nitrogen to allow algae and aquatic weeds to grow, there is not much phosphorus available from nature, so it tends to become the controlling nutrient in rivers and lakes.

Case Study 1.1
Mercury Pollution: The Minamata Disaster

In the early 1950s, the Minamata disaster in Japan sparked off widespread public concern about the pollution of the environment by mercury and other toxic metals. A local factory used mercuric oxide as a catalyst in the production of acetaldehyde and vinyl chloride. Effluent contaminated with mercury was discharged from the factory into Minamata Bay, where it by bacterial action was converted to the highly toxic methyl form:

$$Hg^{2+} \longrightarrow CH_3Hg^{+} \longrightarrow (CH_3)_2Hg$$

The first indication of mercury poisoning was the development of nervous disease in many local cats and dogs, with a number of fatalities. Later, local residents started to show a variety of symptoms including numbness of limbs, deafness and mental derangement. By 1958 there were over 50 reported cases of "Minamata disease", 21 of which proved fatal. The consumption of seafood contaminated with mercury was pinpointed as the cause and the sale of fish from Minamata Bay was banned. It was found that nearly all of the victims ate fish from the bay three times a day.

However the connection between the high levels of mercury in local fish and shellfish and the effluent from the local factory was not apparently made. The factory continued to discharge mercury for another decade until economic pressure forced its closure. By 1975 the disease had claimed over 100 lives, out of a 800 confirmed cases of Minamate disease.

Source: Kutsuna, 1968 (see also Hylander & Meili, 2005 and Hylander & Goodsite, 2006).

Figure 1.14 A hospital in Minamata Japan in 2001. *The 40-year old man in the wheelchair was born paralysed. He is one of the victims from the 1962 mercury poisoning disasters that killed over 100 in the village and harmed many more. The Minamata disaster was a turning point in the history of concern for the environment. (Photo: Lars Hylander)*

Human activities, however, often provide enough phosphorus to allow excessive growth of aquatic weeds and algae. Major anthropogenic sources of phosphorus are agricultural run-off from heavily fertilised areas and domestic wastewaters.

1.4.3 Salts

Water naturally accumulates a variety of dissolved solids as it passes through soils and rocks on its way to the sea. These salts typically include such cations as sodium, calcium, magnesium, and potassium, and anions such as chloride, sulphate, and bicarbonate. The commonly used measure of salinity is the concentration of *total dissolved solids* (TDS). Table 1.3 shows the approximate values of TDS for different types of waters.

The concentration of dissolved solids is an important indicator of the usefulness of water for various applications. Drinking water, for example, has a recommended maximum TDS concentration of 500 mg/L. Animals can tolerate higher concentrations. Of greater importance, however, is the salt tolerance of crops. At concentrations above 2100 mg/L, water is generally unsuitable for irrigation except for the most salt tolerant of crops, but already with salt concentrations within the range of freshwater (500-1500) it becomes increasingly important with careful water management to maintain crop yields.

Large amounts of salts are discharged from mining activities.

1.5 Pollution by Toxic Substances

1.5.1 Pollution by Heavy Metals

Most metals are toxic. *Heavy metals* is often used as a term to refer to some toxic metals with high specific gravity. In terms of their environmental impacts, the most important heavy metals are mercury (Hg), lead (Pb), and cadmium (Cd). Also arsenic (As), although not a metal, is often included in the group. Here we will also include asbestos, being an inorganic mineral.

Metals differ from other toxic substances in that they are totally non-degradable in the environment. Most heavy metals are distributed in the environment dissolved in water. Several of them may however also be emitted as air pollutants. This is in particular the case for arsenic, asbestos, cadmium, lead and mercury.

Metals may be inhaled, and they may be ingested. How well they are absorbed in the body depends somewhat on the particular metal in question and the particular form that it exists in. Metals bound to organic compounds are most easily taken up in the body and accumulated. The heavy metals are neurotoxic, carcinogenic or toxic to the kidneys.

Metals are produced in many different industries and also typically released in the flue gases during incineration of fossil fuels. Metallurgic industries are obviously important but also e.g. tanning of leather that usually uses chromium, some compounds of which are very toxic. Another source are the dental services which until recently discharged considerable amounts of toxic mercury.

Figure 1.15 Pike in blacklisted lakes. *Pike is one of the fish which accumulates mercury in blacklisted lakes, to the despair of the young fisherman in the photo. In Sweden in the 1960s, large pikes had 5-8 mg Hg/kg w.w. (a few even more than 10 mg/kg in the 1950s). (Photo: www.duiops.net/seresvivos/)*

1.5.2 The Heavy Metals

Inorganic liquid *mercury* is not very toxic, while mercury vapour is highly toxic, as are mercury compounds, such as methyl mercury. As such it enters the lungs, where it diffuses into the bloodstream. Mercury causes serious damage to the central nervous system, and is associated with a series of symptoms.

Most often mercury is released to the environment in its metallic, liquid or vapour, forms. As vapour it is emitted to the atmosphere from industrial or combustion sources. Historically pulp and paper industry released large amounts of mercury to water. Mercury is also emitted as an air pollutant, from the chlor-alkali industry for production of chlorine and sodium hydroxide, waste incineration and coal fired power plants. A large portion of the mercury emitted to the environment over the years can be found deposited in the ground and in the sediment in rivers and lakes, from where it is slowly leaking as methyl mercury into the water bodies. There it is transported through the food chains to the top consumers such as pike and perch, and then to humans and predatory birds and animals living on the fish. This bioaccumulation and biomagnification of mercury puts the top consumers at risk.

In contrast to mercury, *lead* does not pose much of a threat as a vapour. It is most dangerous when it is dissolved into its ionic form, Pb^{2+}. Lead dissolved in blood is transferred to vital organs, including the kidneys and brain. Children and foetuses are most at risk since their brains are growing rapidly and exposure to lead may lead to severe and permanent brain damage. Lead may be present in the food and water we consume and in the air we breathe. Until the introduction of unleaded fuel the combustion of leaded gasoline, containing organically bound lead, was the largest source of lead pollution in the atmosphere. Lead accumulates slowly in the body. Initial symptoms of lead poisoning include decreased haemoglobin synthesis, while later on, the central nervous system is damaged.

Cadmium, a metal toxic to most species, is released into the environment from industries (electroplaters, battery producers, etc.) in sufficient quantities to warrant its classification as a pollutant. Though mostly considered a water borne toxic it also is emitted as cadmium fumes, and as such suspected to be carcinogenic. Cadmium, together with lead and mercury, accumulates in the kidneys, where it is also toxic.

Arsenic is a by-product of copper and lead smelting and the roasting of gold, silver, and cobalt ores. It is primarily an airborne pollutant, but it can contaminate bodies of water and accumulate in fish. It is also a component of some agricultural insecticides and fungicides. Arsenic is also a serious natural contaminant of ground waters in particular in India and Bangladesh. Arsenic is a carcinogen contributing to occupationally related lung cancer.

In the form of fibres, *asbestos* is an airborne pollutant, and inhalation of these fibres over an extended period can result in asbestos pneumoconiosis, or asbestosis. Asbestos is a carcinogen. Lung cancer among people exposed to asbestos "dust" occurs with a frequency more than twice that of the general population. Asbestos has been used for the production of asbestos-cement floor tiles, brake linings, and gaskets and the manufacture of fireproof linings and textile, but has in many countries been phased out and replaced with other materials.

Figure 1.17 White-tailed eagle (Haliaeëtus albicilla). *This magnificent bird of prey, the largest in the Baltic Sea region, was until recently threatened by extinction due to the contamination of DDT and PCB. The white-tailed eagle was saved by a long-term programme where non-polluted carcasses were made available as food. From 1999 the white-tailed eagle population has been increasing in the Baltic Sea region. (Photo: Hannu Ekblom, Finland)*

1.5.3 Persistent Organic Pollutants

Persistent organic pollutants (POPs) include an array of chemicals from mainly three sources: Pesticides based on organochlorine or organo-phosphorus compounds; various compounds used in industry, such as PCB, flame retardants, plastic components etc, and several by-products from chemical processes, such as dioxins. Persistent organic pollutants are characterised by their extremely slow decomposition. Many of them also directly affect an organism's health, and these are called *toxic pollutants*.

Toxic organic substances mostly act on the cellular level. The biological activity in a cell depends critically on the function of the cell membranes. Different substances are passively or actively transported across the membranes. Water soluble substances are separated outside the cells and excreted via the kidneys. A toxic substance which is soluble in fat, on the other hand, can pass through the cell membranes into the cells, where the substances can be accumulated and eventually disturb the function of the cell and cause damage.

Figure 1.16 Pesticides. *Spraying with pesticides. (Photo: iStockphoto)*

Most persistent organic pollutants are hydrocarbons containing chlorine or other halogen atoms, especially bromine. These organo-halogen compounds are very stable – persistent – and are readily soluble in fats and oils. They therefore easily penetrate cell membranes, and finally are accumulated in fatty tissue. This fact, called *bioaccumulation*, means that the substance eventually reaches concentrations where it becomes toxic. The toxins are also typically accumulated in the food chains, a phenomenon called *biomagnification*. Animals at successively higher trophic levels in a food chain are consuming food that has successively higher concentrations. At the top of the food chain body concentrations of these pollutants are the highest, and it is here that organo-chlorine toxicity has been most recognisable.

The main sources of emissions of toxic organic pollutants are: use of pesticides, industrial processes, incineration plants,

Case Study 1.2 The Bhopal Disaster

The world's worst industrial disaster, in terms of fatalities, occurred in Bhopal, India, in 1984. In the early hours of the morning of 3rd of December, an extremely toxic gas, methylisocyanate (MIC), escaped from a local pesticide plant. Denser than air, it lingered in the vicinity of the factory, a densely populated shanty-town area. People were killed as they slept or fled from the choking gas. Within two hours, the highly poisonous gas had spread to cover an area of 60 km^2. The initial death toll exceeded 2500, with hundreds of thousands injured.

The pesticide plant at Bhopal was owned by Union Carbide, India Ltd (UCIL), a subsidiary of the multinational chemical company Union Carbide Corporation (UCC). UCC owns 50.9% of the stock of UCIL.

The Bhopal plant was used for the production of carbamate pesticides, mainly carbaryl (brand name Sevin), together with small amounts of butylphenyl methylcarbamate and aldicarb (brand name Temik), all destined for the Indian market. The first two of these pesticides are classed as 'moderately hazardous' by the World Health Organisation whilst aldicarb is classed as 'extremely hazardous'. The extremely toxic substance methylisocyanate (MIC) is used as an intermediary in the production of these pesticides.

Methylisocyanate has the chemical formula $CH_3–N=C=O$. It is a highly volatile liquid, with a boiling point of 39°C. It is very unstable and in the presence of certain external substances, including water, polymerises rapidly. This exothermic reaction releases large quantities of heat which in turn accelerates the polymerisation reaction. At UCIL in Bhopal, large quantities of MIC were stored underground in three stainless steel tanks. At the time of the accident 62 tons of MIC were stored at the plant, although only 5 tonnes were needed each day. Refrigeration was installed to keep the stored MIC in liquid form and help prevent a runaway polymerisation reaction from occurring.

Just after midnight on 2 December 1984, the pressure inside one of the three methylisocyanate storage tanks was observed to rise rapidly. The tank was equipped with a safety valve designed to rupture at 40 psi and release gas into a vent. When this burst, the safety valve within the vent itself popped, allowing methylisocyanate to escape into the atmosphere through the 33 m high vent tube.

The plant was fitted with two safety devices designed to deal with a gas escape. One of these, the vent gas scrubber, was turned on. This device consists of a packed tower through which a solution of caustic soda is poured in order to destroy the escaping gas. Although there is evidence to show that this system worked, it was not adequate to deal effectively with the escaping gas. The vent gas scrubber was designed to destroy only 88 kg/h of MIC, whilst the gas escape was in the region of 20,000 kg/h. A second safety device, a flare tower designed to burn off escaping gas, was shut for maintenance at the time of the accident. As a result, 40-45 tonnes of highly toxic methylisocyanate gas poured into the air during the next 40 minutes before the safety valve was re-sealed.

Investigations into the accident at Bhopal revealed that, as suspected, a runaway polymerisation reaction had occurred in one of the methylisocyanate storage tanks. This was evident from damage in the tank that the internal temperature had exceeded 300°C. The runaway reaction had been initiated by the accidental introduction of water during the cleaning of the MIC pipes, a task undertaken without proper precautions.

An estimated 200,000 people were affected by the gas, many thousands of whom descended on the local hospital. Tragically, there was very little knowledge of how to treat the gas victims and many more subsequently died. Those who did survive suffered from a variety of ailments including blindness, blackouts and nausea. Little was known at the time about the long-term effects of exposure to methylisocyanate. This made effective treatment of the survivors problematic.

The Bhopal disaster is described in several places, see e.g.:
http://www.bhopal.org/whathappened.html
http://en.wikipedia.org/wiki/Bhopal_Disaster

wastewater treatment plants, combustion processes and power plants.

1.5.4 Pesticides

Many toxic compounds are used as *pesticides*. The term pesticide is used to cover a range of chemicals that kill organisms that society considers undesirable. Pesticides can be delineated as insecticides, herbicides, rodenticides, and fungicides. There are three main groups of synthetic organic insecticides: chlorinated hydrocarbons, organo-phosphates, and carbamates.

The most widely known organo-chlorine pesticide is DichloroDiphenylTrichloroethane (DDT) which has been widely used to control insects that carry diseases such as malaria, typhus, and plague over many years. Predatory birds, for example, are at the top of the food chain, and it was the adverse effect of DDT on their reproductive success that focused attention on this particular pesticide. DDT, and its metabolite, DDE interferes with the enzyme that regulates the distribution of calcium in birds, resulting in eggs with shells that are too thin to support the weight of the nesting parent. DDT is since the 1970s forbidden to use in the countries in the Baltic Sea region, but it is still used in e.g. Africa, from where it may travel as air pollutant and be deposited in the colder climate further north.

Other widely used organo-chlorines included methoxychlor, chlordane, heptachlor, aldrin, dieldrin, endrin, endosulfan, and Kepone®. Animal studies have shown that dieldrin, heptachlor, and chlordane produce liver cancers, and aldrin, dieldrin, and endrin have been shown to cause birth defects in mice and hamsters.

Organo-phosphorus biocides include parathion, malathion, diazinon, TEPP (tetraethyl pyrophosphate), dimethoate, Parathion and Dipterex. Like DDT, they are nerve poisons used to control insect pests on crops. They are much more acutely toxic to humans than the organo-chlorines that they have replaced. Insecticides, carbamates, are derived from carbamic acid, H_2NCOOH, are short-lived in the environment and do not bioaccumulate in food chains, but they also share the disadvantage of high human toxicity.

1.5.5 Industrial Chemicals and By-products

Polychlorinated biphenyls (PCBs) belong to the same family of substances as DDT, the *chlorinated hydrocarbons*. Unlike DDT, which is a single compound, PCBs are a chemical family of 209 congeners. PCBs lack flammability, which makes them very suitable for use as dielectric fluids in power transformers and capacitors. PCBs were also used as plasticizers and as deinking fluids in the recycling of newspapers. PCBs are very persistent and lipophilic (fat-soluble) and therefore subject to the processes of bioaccumulation and biomagnification. PCBs are volatile and can escape into the atmosphere, although the main escape route is as water pollutants from sewage water, toxic dumps and landfills, but they are also suspected of playing a significant role in the formation of dioxins in waste incineration and landfill fires. PCB is outlawed as of the 1970s in most countries in the Baltic Sea region, but it is still leaking from technical infrastructure, buildings etc.

More recently organic compounds containing bromine atoms have been used as flame retardants in everything from textiles to computers. Some of these substances have been observed to bioaccumulate and are found in the Baltic Sea fauna.

Chlorinated hydrocarbons are also used as herbicides. The chlorophenoxy compounds, 2,4,5-T and 2,4-D, are among the best known.

Figure 1.18 Landfill fire. *PCBs are suspected of playing a significant role in the formation of dioxins in waste incineration and landfill fires. (Photo: http://www.btfire.org/)*

2,4,5-T has been banned in part because the manufacturing process also produces a highly toxic side-product, dioxin. Dioxin is also formed in combustion processes from e.g. polyaromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB).

Dioxins represent a family of chemicals referred to as polychlorinated dibenzo-para-dioxins (PCDD) or polychlorinated dibenzofurans (PCDF). The most toxic of these compounds is 2,3,7,8-tetrachlor-dibenzo-p-dioxin (TCDD). This chemical occurs as an impurity in the manufacture of many chemicals and pesticides having a trichlorophenol base. When plastics or PCBs are burned, small amounts are released to the atmosphere, as from pulp and paper mills, pesticide plants, vehicles, forest and landfill fires and cigarette smoke. Dioxins are formed optimally in the temperature range 180 to 400ºC in low temperature fires. Dioxins, especially TCDD, are extremely toxic in concentrated form, causing damage to the kidney, liver and the nervous system. They are powerful teratogens (damaging to the growing foetus) and also possibly carcinogenic.

More recently many of the persistent pollutants have been shown to act as hormones, causing e.g. a different sex differentiation in fish and amphibians. There are some indications that they may cause reduced fertility in men and breast cancer in women.

1.5.6 Measures to Control the Use of Chemicals

A number of legal actions have been taken to reduce and control the use of toxic chemicals in society. The first steps to ban the use of some of the worst pollutants were taken as early as the 1970s when e.g. DDT and PCB were outlawed in Western Europe. Several EU directives control the use of chemicals and pesticides and prescribe how risk assessment and registration of such chemicals should be done.

In 2001 the signing of the so-called Stockholm Convention resulted in a black list of the worst pollutants with the aim to ban them entirely and globally. In 2006 the European Council agreed on the implementation of the REACH Directive, accepted as a proposal to the Commission in October 2003. REACH – Registration, Evaluation and Authorisation of CHemicals – will make industry responsible for management of all chemicals and implement a proper system for registration, risk evaluation and use. It is a long-term programme which aims to achieve full control of the close to 100,000 chemicals presently used in the European Union, most of them with poorly or not-at-all evaluated environmental and medical effects.

Study Questions

1. List the five important categories of environmental impacts of industry.
2. Which categories of resources are used for industrial production? List these according to amounts, and make some estimate of the amounts.
3. Discuss the concepts of non-renewable and renewable resources and the carrying capacity.
4. Climate change is today a major environmental threat. Describe how and the main causes.
5. List the main sources of air pollution. What global environmental problems have been caused by air pollution? Name international agreements on reduction of emissions into the atmosphere, and mark the main directions of the policy in this sphere.
6. Describe some historic disastrous events caused by air pollution. List where and when they occurred, the approximate number of individuals affected, and the causes.
7. Discuss the history of stratospheric ozone depletion, and which measures were made to stop it, and if these were successful.
8. List the main sources of air pollution. What global environmental problems have been caused by air pollution? Name international agreements on reduction of emissions into the atmosphere, and mark the main directions of the policy in this sphere.
9. Eutrophication is one of the most difficult problems in the Baltic Sea. Explain what it is, its causes, and how one may deal with it.
10. Both mercury and lead pollution is more severe when these metals are present in organic compounds. Describe when this happens and give examples of serious pollution events caused by such compounds.
11. PCB is one of the worst organic pollutants, previously a much used industrial chemical, now outlawed. Describe what PCB is, how it was used, and if it is still a problem.
12. Use the Internet to find out more about the REACH Directive, and how it will be implemented in your country.
13. List the main sources and components of discharges into water, and the impacts these pollutions may lead to.

Abbreviations

DDT	DichloroDiphenylTrichloroethane.
PAH	PolyAromatic Hydrocarbons.
PAN	Peroxy Acetyl Nitrate.
PCB	PolyChlorinated Biphenyls.
ppb	parts per billion.
ppm	parts per million.
TDS	Total Dissolved Solids.
VOC	Volatile Organic Compounds.

Internet Resources

CRU, Climatic Research Unit
– Information sheet no. 1: Global Temperature Record
http://www.cru.uea.ac.uk/cru/info/warming/

CDIAC, Carbon Dioxide Information Analysis Center
– Atmospheric carbon dioxide record from Mauna Loa
http://cdiac.esd.ornl.gov/trends/co2/sio-mlo.htm

EMEP, Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
http://www.emep.int/

WebDab 2006, EMEP activity data and emission database
– Expert Emissions used in EMEP models
http://webdab.emep.int/

INSC, International Nuclear Safety Centre
– Maps of Nuclear Power Reactors
http://www.insc.anl.gov/pwrmaps/

ASPO Ireland,
Association for the Study of Peak Oil & gas, Ireland
https://aspo-ireland.org/

The Bhopal Disaster
http://www.bhopal.org/whathappened.html

Environmental Science of Baltic University
http://www.balticuniv.uu.se/environmentalscience/

IPCC – Climate Change 2001: Synthesis Report
http://www.ipcc.ch/pub/syreng.htm

IPCC – Graph on Global Temperatue Change
http://www.ipcc.ch/present/graphics/2001syr/large/05.16.jpg

2

Development of Pollution Abatement Methods

2.1 Searching for Solutions to the Pollution Problem

2.1.1 Introduction

The urgency to find solutions to the different environmental problems we are facing today is increasing, just as it is to avoid new environmental problems tomorrow. The media every day tell us about different environmental problems in forests, fields, lakes and rivers. The scale is today global – both the oceans and the atmosphere are affected by the discharges of pollutants. You may yourself have noticed disturbing changes in the environment we all are so dependent on.

What possibilities are there to avoid, or at least reduce, the discharges of different pollutants to the air, water and soil from, for example, industrial processes? There are many different technical solutions to diminish the stress on our environment. The traditional methods are the technical waste stream treatment approaches, the so-called end-of-pipe solutions. But today strategies to address environmental problems using a process integrated approach, cleaner production, are coming to the forefront. Which alternative or alternatives one should choose depends on, of course, the nature of the problem, but also on a number of other factors, for instance economy, space limits in a factory, indirect effects on the environment etc.

Figure 2.1 illustrates an industrial process, the manufacturing of a product, in general. The plant could be, for instance, a paper mill, a steel mill or a power plant for energy production based on fossil fuels. The various raw materials, as well as, mostly, air and water are transported to the process. Coming from the process are the products – paper, stainless steel or electrical energy in these cases – and by-products, if any. But, in most cases, we will also get polluted air, polluted water and different kinds of solid or liquid wastes.

The discharges of pollutants through wastewater, gas emissions, or as solid wastes, and the environmental problems these cause, can be approached in different ways. We will review in this chapter the different alternatives and briefly discuss them, as well as give some examples.

In this Chapter

2.1.2 Remediation Measures – Can We Clean Up the Environment?

Is it possible to solve the problem of pollution simply by remediation, that is, cleaning up the site which was contaminated? It is and was practised when polluters were legally forced by those who had suffered from the emission. But it is highly inadequate. Remediation is not really a solution to the environmental problem. As long as the discharges are going on, the remediation measure has to continue. Step one is to stop the pollution.

When regarding, for instance, the liming of acidified lakes, comprehensive action on all damaged lakes would be very expensive, and does not lead to permanent improvement, as long as the acid rain keeps falling. Furthermore, other damage caused by the pollution would still be there, for instance the damage to the forests. Remediation may also itself cause new environmental problems. For instance, the liming of a lake may hurt organisms sensitive to high pH.

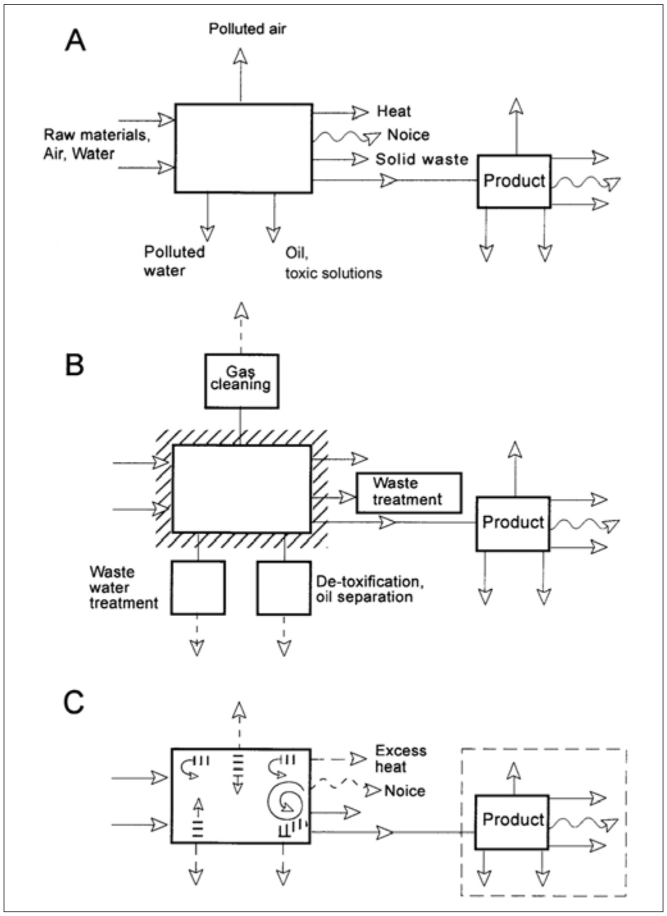


Figure 2.1 Industry generated pollution. *An industrial process (A) causes different kinds of pollution problems. These can be solved by external measures (B), or internal measures (C). (B) and (C) can also be combined.*

Case Study 2.1 Restoration of Lake Järnsjön

Lake Järnsjön in south Sweden is situated in the upper part of River Emån basin. River Emån has a high biological value, including e.g. otter and salmon, but the biodiversity was diminishing. Lake Järnsjön was found to be leaking PCB from deposits from a copy paper factory not any longer in operation, as well as heavy metals from a closed battery factory. Restoration, considered necessary to save the ecology of the river basin, was initiated in 1970s.

Restoration started when waste deposits with lead, cadmium etc were removed from near the water. In a major project a large part of the bottom sediment was moved to a sealed landfill. In this way 300 kg of PCB was removed and leakage to the river system was brought to safe levels.

The Swedish Environmental Protection Agency (SEPA), made this a major project to develop the methods needed. The total cost was 50 Mln SEK.

Internet sites:
http://www.hultsfred.se/miljo/pcbsv.htm (Swedish)
http://www.hultsfred.se/miljo/Sjoar/Jarnsj1.htm (Swedish)
http://www.ambio.kva.se/1998/Nr5_98/aug98_1.html

In spite of these shortcomings remediation or restoration is done today to clean up after pollution and to manage damaged sites. Both water and soil are treated: Lakes and streams which were damaged by acidification, by pollution by POPs , PCBs, creosote, and heavy metals; lakes eutrophied by excess nutrients, and finally lakes polluted by radioactive caesium from Chernobyl. All have been restored in different ways.

As a case we can briefly summarise the work with restoration of the many lakes in Sweden seriously damaged by acid rain. More than 17 000 Swedish lakes are acidified. Acidified lakes become devoid of higher life forms at about pH 4, but can be partly restored by adding lime. In Sweden treating lakes with lime started in the mid 1980s. The objective was to increase pH to above 6, and the buffering capacity to above 0.05 meqv/l in limed waters. Some 7 000 lakes are limed in Sweden today, corresponding to about 90% of the acidified lake area. Only 10%, or 10 000 km, of acidified streams are limed at 2 012 sites. During 2004 liming costs were 185 MSEK/yr and are expected to increase in the future. Still, liming does not always solve the problem. Acid spring pulses, occurring when the melting snow drains to the lake from acidified surrounding soils, may be disastrous. Only hours or a day with a much lower pH may be enough to kill many species. The whole environment has to return to an increased pH. This has been shown in several experiments to be a very slow process. It will take many decades before the environment has been healed.

2.1.3 The Long-term Perspective

We can outline the long-term perspective as follows.

- In the 1960s the problems of environmental pollution were recognised.
- In late 1960s the first environmental legislation was introduced.
- In the 1970s and 80s technologies to stop the emissions, especially end-of-pipe technologies were introduced.
- In the 1990s integrated technologies were introduced to address the problems of pollution abatement at the source.
- In the 2000s remediation of contaminated soil, sediment and ground water is on the agenda.

We should be prepared that in the near future the remediation of the environment, which we have damaged over many years, will be the major cost in the environmental budgets. Wetlands which have been drained are being restored for large sums of money. Rivers which were canalised are getting back their original course. Eutrophied and acidified waters are treated. Species which have been lost are reintroduced. All these measures have proven to be very costly. It is now that we are paying back our environmental debt.

The most severe problem are those sites, land and water, which have a high concentration of pollutants which do not degrade, POPs and heavy metals. Many thousands of such sites have been identified in all countries in the Baltic Sea region and all over the world. They are mostly abandoned in-

Case Study 2.2 Teckomatorp

In 1965 BT Kemi AB started the production of pesticides in an old sugar refinery in Teckomatorp in Skåne, close to Landskrona. For 10 years, until the company went bankrupt in 1975, hundreds of drums with hazardous waste were buried on the grounds of the factory and some of the waste was flushed directly into the adjacent stream, Braån. In 1977 the company was declared bankrupt after a government decision to stop the production.

In 1978 a first attempt was made to restore the contaminated site. Contaminated soil was deposited on one side of the factory grounds, a drainage system and wells for collection of ground water were installed. The collected water was stored in an intermediate pond before being transferred to the wastewater treatment facility in the city of Landskrona, for final treatment.

Although the concentrations of hazardous substances in the drainage water has decreased substantially, it is estimated that there still remain about three tons of hazardous substances in the contaminated soil.

It has been decided that the site will be remediated in such a way that the area after treatment will not pose any risk for the environment and will be fit for use as a recreational area and for small business localisation. The cost for the remediation is estimated at between 70 and 130 Million SEK.

Internet sites:
http://www.svalov.se/BTKemi/historik.htm (Swedish)
http://www.renaremark.se/filarkiv/hm2003/englov_bevmo_foredrag.pdf (Swedish)

Figure 2.2 Remediation of soil. *Old filling stations are sites where the soil is routinely monitored for chemicals before new uses. Here the soil under a previous gas station is being removed for a new residential house. (Photo: Lars Rydén)*

dustrial sites, gas works, land fills, gas stations etc., so-called brown fields, but also waters and very often waterfronts. In many countries also former military bases are badly polluted. These sites leak hazardous substances to ground water, air and biota. Remediation is possible but costly. Polluted soil, sediments etc. may be moved to a safe site with leakage control. Sometimes the soil/sediments can be treated by e.g. extraction or evaporation. Restoration of polluted sites is a major task for environmental engineering for many years. The proposed cost in the Swedish national budget for the five coming years is 2.5 billion SEK (260 Mln euro). Only a few hundred sites are treated every year.

Remediation is often the only way to give the polluted sites back their former function. In cities, new residential areas built on brown fields are required to be non-toxic. Fishing and angling requires that streams are restored. A rich biological life requires remediation of the environment.

2.2 Avoiding the Problem – Let Nature Handle it

2.2.1 The Philosophy of Dilution

The original solution to the pollution problem was to ensure that the industrial waste was discharged in a recipient where it would be diluted enough to "disappear". Actually, only a generation ago, a red flag was shown every Saturday in a small river in Sweden. This was the signal for the women busy with their laundry downstream to stop the washing and take away their clothes from the water. The industry then dumped about 2 m^3 of "pickling liquor" into the water that flowed down the river as a brown plug, down to the nearest lake. After a while the washing was resumed again.

The solution to the pollution problem was thus to build a chimney high enough or an industry next to a big river with enough flow to ensure a good dilution. This dilution method shows somehow the view one used to have on industrial pollution problems. The industrial wastes gave disturbing effects for the waters and the organisms living there, but from a human point of view it wasn't considered so bad. The sewerage from toilets with its hygienic risks was of more urgent concern. But also here there is a history of neglect. For a long time the toilet waste was just emptied into the nearest water stream.

This way of handling waste relies on natural processes to clean it. Nutrients, such as toilet waste, are certainly taken care of by bacteria and the like. But if there is too much of it the natural processes are inadequate. This happens especially in cities and towns where many people are living together. Industrialism greatly increased the flows of waste and in early industrialised England the waste heaps gave rise to unbearable smells and was also the source of serious infections. Chimneys, to send the pollution far away, as mentioned, became the solution.

2.2.2 Site Selection

In the early stages of industrialism factories were located close to or in cities since that is where the workers lived. Industrial cities grew immensely as production increased. Classical examples are provided by e.g. Lodz in Poland or Manchester in England. When the pollution became too severe, in spite of high chimneys, an alternative was the selection of a site for the factory not too close to a city but where discharges could be handled. One of several reasons why there are many industries along coastlines is that the recipient (the receiver of sewerage) – in this case the sea – provides very much better dilution and therefore handles the emission better, compared to a small in-

Figure 2.3 Distribution of pollutants in the environment. *Pollutants emitted to the air are often distributed over continental-scale distances and may even damage the global atmosphere. Most, however, are precipitated close to the point of emission. (Photo: Morguefile/Kenn Kiser)*

land river. By placing a combustion plant outside a city, as well as off the wind direction, the pollution situation can be considerably improved in the cities. Naturally, it is not common that production can be moved. Very often the plant is situated in a place chosen long before the environment became an issue.

A "proper" site selection, however, does not decrease the emissions but only redirects it and saves the neighbourhood. In this way it is just the same as the dilution method. But sometimes the choice of a proper location can work. One example can illustrate this. A chemical industry handling a smelly chemical with a very low smell detection limit was situated in the wind direction to a high density urban area. When filling the chemical to storage tanks from trucks, small leakages were inevitable, and the inhabitants in the area were affected. The very simple solution was to fill the tanks at times when the wind came from other directions.

For plants in need of huge amounts of cooling water, a proper location is essential. Thus all nuclear power plants are situated close to the coast or on a river. About 75% of the effect generated is recovered as heat, and removed by cooling. Also for security reasons they are seldom found close to a population centre. As a result the heat is wasted rather than used in district heating. Pulp and paper industries were also built close to coasts due to their extensive use of water, as well as because of their discharges. This industry has however greatly improved its environmental performance since the 1990s and the location is no longer so essential.

2.2.3 Chimneys are Not Enough

The shortcomings of the method of dilution become obvious when we regard the rules for dimensioning and building a chimney for a combustion plant for heat production. The rules specify how high the chimney should be in order to maintain a low enough level of pollutants nearby the polluting source, so that people living and working in the area should not be affected.

By using a high chimney one solves the problems with too high a concentration in the neighbourhood. But the total amount of pollutants emitted to the environment of course remains the same. The strategy relies on the environment to handle it. But we have numerous examples showing that the sea and the air space isn't large enough for the waste generated. For instance all nutrients discharged into the Baltic Sea have made the whole water body eutrophic, as can be seen from the ever larger algal blooms. A similar situation is found in many coastal areas in e.g. Southeast Asia and North America. The acid emissions from smoke stacks in England, Germany and Poland (and to some extent in Sweden) over many years have killed ten of thousands of lakes in Norway, Sweden and Finland. The amounts of carbon dioxide emitted from industries all over the world are so large that not even the entire global atmosphere can manage with it. The natural cycle, where carbon dioxide is dissolved in the oceans, is much too slow compared with the rate of emission. Dilution is obviously no solution.

Figure 2.4 Himmerfjärden wastewater treatment plant. *This plant located in the southwestern part of Stockholm region receives wastewater from nearly 250,000 people. It is today highly automated. (Photo: Józef Trela)*

Today it is possible to estimate the land or water needed to recycle a certain amount of a specific pollutant. It is part of the ecological footprint of that activity. Thus the footprints of the largest cities in the Baltic Sea region have been estimated. The footprint of a city is roughly 200-1000 times the area of the city itself. As a rule about 80% of the footprint consists of the area needed for absorption of waste emitted. Only 20% is there for food production, forestry etc. Thus the area needed for waste absorption is about 160 times larger than the area in the city in which it was produced. Again it points to the fact that dilution is no solution.

2.3 The End-of-pipe Approach

2.3.1 External Cleaning

Yet another possibility to handle the pollution problem in an industrial plant is to take care of the waste in specially designed waste treatment facilities. Since this is done outside the actual manufacturing process it is referred to as an external measure. There are a number of examples of this strategy in environmental technology. One is wastewater or sewerage treatment plants (WWTPs). During the 1960s and 70s extensive investments in the building of such plants, both for industrial and municipal wastewater, were made in Western Europe. The same investments were typically not made in Central and Eastern Europe until the 1990s. Industrial wastewater is often sent to the municipal treatment plants sometimes far away.

Some industries with discharges requiring special methods of treatment, however, have their own designated plants nearby.

Facilities for management of hazardous waste are also generally located outside the origin of the waste. They mostly incinerate the waste at very high temperatures. Such incineration plants may also use waste oil and solvent wastes from industries as fuel.

Landfills and composts may also be seen as places for waste treatment externally to the site of production.

2.3.2 The Filter Strategy

The strategy of separating pollutants from a water flow with a therefore designed cleaning facility constitutes a so-called filter strategy or "end-of-pipe" solution. Sometimes a particular component in a waste stream is separated by e.g. an ion exchanger or a membrane. The substance then has to be washed out regularly and is received as a concentrate. Flue gases are cleaned by end-of-pipe technologies. These include scrubbers to remove sulphur oxides by the addition of lime, electrostatic precipitators to remove particulates, and incinerators to remove hazardous organic pollutants at high temperature. Special measures are used to e.g. remove mercury from flue gases, or chromate from discharges from the tanning industry.

With the end-of-pipe technologies the pollutant is not dispersed in the environment. It is still there but now as a concentrate, for instance a filter cake or mud. The most typical might be the sludge produced in a wastewater treatment plant. Other examples are the filter cakes from a flue gas cleaning equipment, and the residual ash received after incineration.

This concentrate is then often taken care of externally, and very often new problems arise. The question about how to handle the sludge from wastewater treatment can be used as an example for the discussion. The sludge is rich in water, and dewatering is the first problem to deal with. Secondly it may also be polluted with e.g. heavy metals, which makes it unsuitable as compost for agricultural use. Thus even if it may be useful, it is often sent to the landfill.

The result from the external cleaning technology does not always constitute a concentration of pollutants. Sometimes the pollutants may be transformed in the external cleaning step into less harmful products that subsequently can be handled by nature itself. One example of this is the destruction of cyanides in wastewater through oxidation to carbon dioxide and nitrogen gas.

2.3.3 Waste as a Resource

Concentrated waste may also be useful. The sludge that arises in a wastewater treatment plant was originally used directly as fertiliser on farmland. This is still possible if the contamination of e.g. metals and organic micro-pollutants is low enough, which is often the case today.

The capture of sulphur oxides in a desulphurisation scrubber also produces a useful residue. The sulphur is oxidised to sulphate which together with the lime forms gypsum, which can be used as building material. The success story of reduced acid rain from the power industry thus goes hand in hand with the invention of a new product, gypsum boards for the building industry.

Other residue from wastewater treatment or flue gas cleaning may be more difficult to turn into useful products. Ashes from combustion still mostly end up on landfill although it is also possible to mix them with asphalt to be used in road construction. Hazardous organic waste may be used as fuel in cement furnaces. But some pollutants filtered away cannot be used, the most typical being heavy metal residue, such as mercury. This has to be stored in safe places forever.

Figure 2.5 Growing in sludge. *Sludge that arises in a wastewater treatment plant can be used directly as fertiliser and to improve soil on farmland. (Photo: Morguefile/Kevin Connors)*

2.4 Process Integrated Solutions

2.4.1 A Promising Case – the Pulp and Paper Industry

The third possibility of tackling the problem of pollution is to change the process itself and/or purify/exchange the raw material used in the process. This is the concept of process integrated measures.

By changing the process itself it is possible to reduce the formation and emissions of pollutants and the production of solid waste from the process. We may achieve this by changing the equipment used, the process conditions (temperature, pressure, chemical environment, etc.), or by installing a separation equipment inside the process itself. These are some of several different possibilities.

The pulp and paper industry is one industrial branch where many examples of integrated process solutions are found. This particular industrial branch started comparatively early with the integration of environmental protection solutions in their processes. One important reason for this was that the branch was rather homogeneous. This made it possible to find common solutions for many different plants. The costs for development could thus be shared between several companies.

A classic and illustrative example is the following. A major environmental problem was the huge discharges of fibres in the surrounding waters. A dramatic decrease in fibre discharges was achieved by installing strategically placed sieves to collect the fibres. The fibres, which used to go to waste, could now be recycled into production. As a result the yield of raw materials in the process increased considerably. The measure was very simple and at the same time very profitable.

Another example is the change of technology for bleaching pulp. A main environmental impact was due to the discharges of large amounts of chlorinated hydrocarbons, shown to be toxic to fish and waster ecosystems. It was caused by the use of chlorine to bleach the paper. By changing bleaching technology, e.g. using hydrogen peroxide instead of chlorine, these emissions virtually disappeared.

The most important step may however be the transition from sulphite to sulphate pulp technology. The sulphate process, also called the Kraft pulp process, is a recovery process, where the chemicals used in the cooking of the pulp are, generally, recycled. In addition so-called black liquor produced in the process may be incinerated and as such provide the industry with all energy needed.

Within the industry an extensive structural rationalisation has therefore taken place. A number of the smaller sulphite pulp and paper plants, causing rather big discharging problem, were closed down and instead investments were made in bigger sulphate units. Due to this the discharges of oxygen consuming compounds and sulphur etc., have been drastically decreased, in spite of a substantial increase in production. At the same time the industry is virtually self-sufficient in energy. The result is overwhelming. The whole industry of paper production after 20 years of restructuring has turned from one of the worst environmental culprits to a clean, modern, efficient and very profitable industry.

2.4.2 Changed Technology

Another industry which has undergone a major change of process technology is the chlor-alkali industry. Here chlorine and sodium hydroxide are produced. Although pulp and paper industry was the major customer needing both chlorine and sodium hydroxide for the bleaching of pulp, these products are used in many different types of technologies. Now that bleaching with molecular chlorine (Cl_2) has been replaced with other methods, sodium hydroxide is still a major raw material in the pulping process.

The chlor-alkali production relied on the so-called mercury cell method. A solution of salt, sodium chloride in water, was electrolysed using a mercury electrode. Sodium was captured as sodium amalgam and chlorine gas left. In the second step the amalgam was processed into sodium hydroxide and mercury.

A typical chlor-alkali plant used 200 tonnes of mercury. In Europe as a whole there are today (data from 2002) 60 factories with this technology. About 100 tonnes of mercury are used every year to replace mercury emitted to the environment from these factories.

The chlor-alkali industry is thus a major source of mercury pollution. This is decreasing now when the technology is changing to membrane or diaphragm methods, which are mercury free. The new methods are in addition more energy efficient (but produce less concentrated sodium hydroxide). A transition to the new technologies is completed in Japan and will be enforced in Europe before 2010 through a decision from the European Commission.

The replacement of old "poor" process technology, with new is a phenomenon we have seen in many industries. The reasons have often been economic, but also environmental, which translates into economic and legal reasons as permits and charges are implemented. The described industries of pulp and paper and chlor-alkali are only two. Other examples include the textile industry, which has halved its emissions to water with respect to non-biodegradable compounds, basically due to closing down of inadequate plants. In the steel industry there has been a significant decrease of emissions of dust. This is basically due to the replacement of older martin furnaces with modern electro-steel furnaces, equipped with efficient dust separator systems.

2.4.3 The Substitution of Raw Materials

The substitution of raw materials in a process is an important process integrated measure. The raw materials and the process are closely connected. The process has to be designed with respect to the raw materials utilised. Exchange of process and raw materials often amounts to the same thing.

Raw materials may be exchanged because of legal constraints, made by authorities for environmental reasons. A well-known case is the drastic decrease of emissions of sulphur oxides, due to restriction on the allowed amount of sulphur in fuels. Other cases include taxes on emissions, e.g. sulphur oxides and nitrogen oxides, taxes on energy or emissions of carbon dioxides, and outlawing certain chemicals, e.g. freons or CFCs.

A strategy for the review of raw materials and support chemicals used includes the following steps:

- Identify the substances causing problems in the effluent.
- Localise this substance in the flow of raw materials or support chemicals.
- Replace the substance with a better one, from an environmental point of view.
- If an exchange is not possible, separate the substance causing problems with some suitable separation technology.

The current discussion concerns not only the raw materials used, but also environmentally damaging by-products in the process, or by-products that can give rise to problematic conversion products in the environment. In these cases a solution to the problem may be a radical change of process or process conditions. One current example is the discharges of dioxins from waste incineration plants. By using a more accurate process control (which can guarantee a high enough temperature in the incineration) and a decreased amount of PVC in the waste, the emissions of dioxins could be decreased. Another example, mentioned above, is the chlorine bleaching of pulp. In this case the use of chlorine has decreased due to changes in the cooking and bleaching processes.

The strategy of replacing the raw materials by more environmental friendly ones has been very efficient and important in industrial environmental work, and there are many applications to illustrate this. To achieve this, many compounds have been banned by the authorities. The first legal measures were taken in the 1970s, concerned with POPs, e.g. certain biocides. Since the 1980s limitations on the use of CFC compounds have been introduced and it has today virtually ended. Several national and international institutions, chemical inspectorates, as well as individual industries have produced lists with compounds or groups of compounds which eventually will be banned. In 2001 the Stockholm Convention on hazardous chemicals was signed. In the near future we will see restrictions on the use of among others the metals lead, mercury, and cadmium as well as the solvents trichloroethylene, methylene-chloride and tetrachloroethylene. The implementation of the REACH Directive of the European Commission will take chemicals control into a new phase where the responsibility of industry will increase. The list of banned chemicals will, most certainly, be longer during the coming years of environmental work.

2.4.4 Integration and Environmental Audits

To change the process and/or substitute the raw materials in the process is a rather drastic measure. A much simpler approach is to improve the existing process. Satisfying results, that is, a decrease in emissions, can often be achieved by bearing in mind that there are human beings involved in production, and they may make errors. It is very likely that one can prevent completely unnecessary discharges to the environment by regularly performing so-called environmental audits. This consists of proper inspection of all the different procedures in the activity, improvement of the process supervision and control, improvement in the maintenance of the equipment etc. and education of the staff. Every single separate discharge may be almost negligible when looking at the complete emission profile of an industry, but all various discharges taken together may add up to be very significant.

Yet another factor not to be forgotten is the manufactured product itself. By simple changes in the product it might be possible to eliminate those process steps that are doubtful from an environmental point of view.

The majority of the different measures, in this case taken together under the name integrated measures, means striving to eliminate the production of pollutants and wastes at the source. The applied strategy is to question whether pollutants and wastes should be produced, i.e. to focus on eliminating the formation of pollutants and wastes. The concepts used in this area are cleaner production, low- and non- waste technology, preventive environmental protection and environmentally adapted technology. The underlying philosophy is that an industry should use all the incoming resources to produce products to the customers, not pollutants to the environment.

2.5 Recycling

2.5.1 Levels of Recycling

Recycling has sometimes been regarded as *"the solution"* to many of our environmental problems. By a substantial increase in recycling we would get away from our environmental problems. The reality is, of course, never so simple. Naturally, it is important to get an increased degree of recycling, but we must also remember that there are limits for how far recycling can be taken. Recycling often needs substantial resources of different kinds. These include personnel, economic, energy as well as environmental resources.

Below we will differentiate between three levels of recycling. These are 1) recycling of a "consumed" product; 2) recycling carried out in, or in connection with, a manufacturing process, so-called internal recycling; and finally 3) recycling as an external recycling process carried out as a separate industrial activity.

Recycling of a "consumed" product can be subdivided, based on how far back in the production chain one looks. We have at least three different kinds:

- Reusing or regaining a *product* means that the product is reused after, for instance cleaning and check-up. A well-known example is the reuse of recycled glass bottles.
- Material recovery means that the *material* is utilised in a new life cycle after, for instance re-melting or some other treatment. An example is the recovery of recycled paper, glass or solvents.
- Recovery of the *energy* in the waste means incineration of the material for recovery of the energy content. The incineration of oil and domestic waste is an example.

Figure 2.6 Bleaching towers in a Kraft Mill System. *The sulphate process, also called the Kraft pulp process, is a recovery process, where the chemicals used in the cooking of the pulp are, generally, recycled. In addition so-called black liquor produced in the process may be incinerated and as such provide the industry with all energy needed. (Photo: © Andritz AG)*

Recycling carried out in, or in connection with, a manufacturing process, basically implies the establishment of feed back loops in a process, for instance, the separation and recovery of a valuable component within a process. The above-mentioned recovery of fibres in the pulp and paper industry is an example of this. Another one is the use of so-called counter current rinsing in the metal plating industry. A third example is solvent recovery by means of adsorption, in connection to a de-greasing step in the manufacturing industry. The feedback of material in a process yields a higher degree of raw material utilisation and less solid waste. Also large volumes can be treated and fed back into the process after the removal of contaminants. One example is the complexation of manganese cations in process water in pulp and paper peroxide bleaching. It leads to dramatically decreased discharges and water use.

Recycling can also be external to the original process. An example of external recovery is when an industry has a separate plant for solvent distillation. Solvent mixtures are transported from different process steps to the special plant for recovery. By distilling, the solvent mixture can be separated and most of the solvents recycled. There are several companies specialised in solvent recovery, as well as recovery of other types of wastes.

2.5.2 Organising Production to Decrease Emissions

Recycling and actions to increase recycling, although important for a better environment, are not regarded as preventive environmental protection measures. They are rather ways to organise production in such a way that environmental protection measures are less necessary. We may subdivide and, at the same time, give priority to different measures for decreasing the production of pollutants and wastes in the following way:

1. Measures which completely eliminate the pollutants and waste, for example substitution of raw materials, changes of a production process etc.
2. Measures which reduce the quantity of pollutants and wastes, and other environmentally problematic exhausts, for example by external treatment (oxidation of cyanides), or turning sulphur oxides into gypsum in a scrubber.
3. Measures which increase the amount of pollutants and wastes which are treated e.g. sent to wastewater treatment

plant, or undergo internal recycling or recovery external to the factory.

4. Measures which facilitate external recovery or recycling of pollutants and wastes, e.g. securing that sludge is devoid of heavy metals and can be reused as fertiliser, and various legal and economic incentives to stimulate recycling.

The best thing is to avoid the concept of waste all together. This is the concept of *zero waste*. An important part of the zero waste strategy is to see the so-called waste as a resource to be used somewhere else in the production or in a different production. Comparing with nature always gives insight. In nature there is little waste. Most is used by some other ecosystem. Nature only supports cyclic flows, even if some of them are on a geological rather than biological time scale. Waste on the other hand is by definition perceived as the end point of a linear flow. This is what we have to avoid.

Figure 2.7 Housing. *Insulation of a house as here may decrease energy demands considerably. Additional possibilities for reducing energy costs are installation of a heat pump, and use of solar panels. (Photo: Morguefile/Kenn Kiser)*

2.5.3 Legal Measures

The European Commission has long sought legal measures to improve recycling in our societies. The most far reaching is the IPP initiative. Integrated Product Policy (IPP), seeks to go to the heart of supply side factors by encouraging the production sectors to undertake a fundamental review of the way their products are engineered, put together and marketed. IPP achieves this by the simple mechanism of obliging manufacturers of consumer capital goods to incorporate end-of-life collection, dismantling and environmental neutralisation as another element of production costs.

Another approach is the waste management directives. Sending material to a landfill will always be associated with a cost in the future. For the material where there is a clear alternative treatment, such as composting organic waste, the fee for land filling will be high, and is already high in the old EU-15 countries.

The economic incentives to reduce emissions are also increasing. Taxation of emission of sulphur, nitrogen and carbon dioxide has been mentioned as examples. Industry is in general protesting when it comes to new regulations. The REACH directive for chemicals management is under heavy attack from European industry and so is the IPP Directive. These Directives are, however, implemented in 2007. As this chapter has shown many times the changes that industry is pushed to carry out is often advantageous not only to the environment and the society but also to the industry itself. The incentives to find new ways to manage solid "waste" and avoid emission to water and air will be increased.

2.6 The Long-term Solution – Reorganise Society

2.6.1 Products or Functions

Several of the above described environmental undertakings can be regarded as corrections or cleaning-up measures in order to reduce the problems caused by the technical and industrial development. In a shorter perspective this might constitute the only possible kinds of environmental protection. In a longer perspective the possibility of enforcing environmental considerations must be examined when developing new technologies.

Let us study the car as an example. From a product-oriented point of view the car is the fixed point of departure, and the discussion is focused on how this product can emit less exhausts, pollution, and noise and consume less energy and so on. From a functional point of view, however, the function of the car is the interesting and important issue. In this case the main point is to facilitate the transport of people and/or merchandise between different places. The product, i.e. the car, is then no longer a fixed condition. The discussion in this case concerns which alternative solutions there are to fulfil the transportation function, and the problems connected to these different solutions.

Public transport could in many cases constitute a more environmentally sound and resource saving solution. This is true in particular for track-bound traffic, railways. The merchandise should, from this point of view be transported not by trucks but by railway. Trains use only a fraction of the energy of the car per kilometre and amount of transported goods (ton-kilometre) and have almost no emissions.

2.6.2 Changing Production or Consumption?

Another example concerns our need for energy. Today a number of different methods are utilised to supply us with energy, mainly combustion of fossil fuels. When burning a fuel, the remains are generally various gases and a solid waste. Which the produced gases are and the amount of each depends on the fuel used, as well as the conditions during combustion. The emissions from a combustion plant may thus be diminished by the choice of a different fuel and improved conditions under which combustion takes place, i.e. process integrated measures. Another possibility is of course to use external cleaning technology. But we may also look at the function of the power station – to provide heat and electricity. Can it be done differently?

One measure which has proven to give large environmental gains in urban areas is to replace all small household heating systems, with a large power plant, that is, to turn to district heating. By building a central power plant with an improved process control, as well as cleaning equipment, and with an energy distribution net instead of a number of small household heaters, the amount of air pollutants drastically decreases.

2.6.3 Eco-development rather than Environmental Protection

There are also a number of other ways to economise produced energy, such as controlling the temperature in our flats and houses, using more energy efficient electrical equipment, etc. In many urban areas the local electricity companies can inform and encourage the inhabitants to buy and use more energy-saving products (lamps etc.), in order to lower the consumption of electricity.

Improved public planning of our societies may be seen as the highest level in the hierarchy of changes to protect the environment better. According to this radical perspective, the environmental and resource problem as well as a number of other difficult problems in society today are caused by the present developing pattern in our society. This development is basically characterised by increased consumption, considerable centralisation and specialisation etc. which, in this perspective, leads to more difficult problems.

The concept of *eco-development* has sometimes been used to describe a development in the opposite direction, i.e. towards a society which saves resources, works on a small scale and is decentralised, with a lower degree of consumption and a lesser need for transportation. Many of the severe environmental and resource problems we are facing today would decrease with such a development. It must also be said that, new problems could arise. In western industrialised societies the material standard would most probably not be as high as today. On the other hand, eco-development would most probably significantly decrease the risk of ecological and technical breakdowns. And it may lead to a better life in other ways than through increased consumption of material goods.

Study Questions

1. What kind of environmental problems can be caused by an industrial process? List possible measures to reduce these impacts.
2. In what way have the strategies of environmental protection changed during the last 50 years?
3. What is the main strategy of environmental protection nowadays? Explain why. How is this strategy used to change industrial processes and substitute raw materials?
4. Compare the costs of remediation of polluted soil and water compared to the costs of pollution abatement. Give concrete examples.
5. Discuss the limitations of the dilution approach, and in particular the capacities nature has to absorb pollution; compare with e.g. eutrophication and acidification.
6. Give examples of how end-of-pipe technologies give rise to a concentrate of pollutant and what can be done with it.
7. How is it possible to decrease the production of pollutants and wastes? Explain the concept of "zero waste". What international and national agreements support this initiative?
8. How should the production and consumption in society, in your opinion, be changed, in your point of view, to meet the demand for sustainable development and environmental protection?
9. Explain how pulp and paper production has turned from being a culprit to a "best in class" industry.
10. Give examples of how a change of technology or raw material in an industrial process may give rise to reduced pollution.
11. Name three kinds of recycling, give typical examples.
12. Give examples of how a change from selling a product to a service, so-called servicizing, gives rise to less pollution.

Abbreviations

CFC	Chloro Fluoro Carbons.
IPP	Integrated Product Policy.
PCB	Poly Chlorinated Biphenyls.
POP	Persistent Organic Chemicals.
PVC	Poly Vinyl Chloride.
SEPA	Swedish Environmental Protection Agency,
WWTP	Waste Water Treatment Plant.

Internet Resources

PCB-remediation of Lake Järnsjön

http://www.hultsfred.se/miljo/pcbsv.htm (Swedish)
http://www.hultsfred.se/miljo/Sjoar/Jarnsj1.htm (Swedish)
http://www.ambio.kva.se/1998/Nr5_98/aug98_1.html

Remediation of BT Kemi Teckomatorp

http://www.svalov.se/BTKemi/historik.htm (Swedish)
http://www.renaremark.se/filarkiv/hm2003/englov_bevmo_foredrag.pdf (Swedish)

The Baltic University Programme – Environmental Science

http://www.balticuniv.uu.se/environmentalscience/

European Environment Agency

http://www.eea.eu.int

INEM (International Network for Environmental Management)

http://www.inem.org

3

Industry in the Baltic Sea Region

3.1 Baltic Sea Region Industrial History

3.1.1 Natural Resources and Early Industrialisation

The distribution of natural raw materials was the determining factor in the development of industry in the Baltic Sea Region. Forests and fields, as well as metal and coal deposits, led to a considerable early proto-industrial economy in many of the countries in the region. This included iron production in Sweden as early as medieval times. Coal was produced in Germany and Silesia in Poland also very early, as were many of the metals used such as copper, tin, lead, zinc and cadmium as well as gold and silver.

Already here it should be pointed out that the proto-industrial activities were connected to serious environmental problems. Thus silver mining in lower Saxony in the early 1700s used so much timber that a forests crisis occurred, a crisis which led to the first attempt to develop sustainable forestry and in fact the first mention of the concept of sustainability. A similar situation happened in mid Sweden later in the same century, as in several other European countries. The crisis was again caused by the enormous demand for timber in iron mining. It was used to heat the mountain enough to produce cracks to recover the iron ore. Wood was also needed to produce the necessary charcoal. To reduce the consumption of wood for heating, the newly formed Swedish Academy of Sciences had a commission to design a stove (so-called tiled stove) to heat houses which was much more efficient than the old way with open fire.

Proto-industrialisation not only caused over-consumption of natural resources but also pollution. The copper mine in Falun in mid Sweden (the richest copper find in the world at the time, decisive for the national economy) according to Carl Linnaeus caused death among all vegetation in the vicinity (due to sulphur oxides). A similar situation was likely occurring in Silesia.

3.1.2 Industrialisation Gains Momentum – late 1800s and early 1900s

Industrialisation gained speed in the region from the late 19th century. This was a time when more than 80% of the work force was still found in agriculture. Industries were established where they could rely on boat transport to receive raw materials and export their products. A very considerable production of sawed timber was established on the Finnish and Swedish coasts. Saw mills were built at the mouths of the large northern

In this Chapter

rivers, on which logs were floated to the coasts, long before roads were built.

Further south the large mills were built to produce flour from the farmer's crops. Southern Sweden, Northern Germany, Denmark, parts of Poland and East Prussia were important agricultural areas with considerable crop and meat production.

Coal mining in Germany, Southern Poland (Katowice region in Poland) and Ostrava region in Czechia, Ukraine, and Russia was the base for increased iron production. Iron production as well as lead and zinc mining paved the way for an important metallurgic industry. A considerable part of this production consisted of arms to fuel the two world wars. The defence industry was large.

The Sovietisation of Tsarist Russia with the three Baltic States led to brutal industrial development in traditional farmland. As a result, industrial cities expanded as the farmers' children went there to find jobs. The industries caused terrible smells. Life expectancy in the cities was much lower than in the poor countryside. Still, cities expanded as immigration compensated for the losses.

Hydropower in Sweden and Finland, metal and coal deposits in Russia and Poland, and oil shale in Estonia led to a diversified industrial structure in the region. Pulp and paper industry and metal industry became the most important branches in the northern part of the Baltic Sea Region. The copper smelter in Rönnskär, the titanium dioxide production plant in Pori, and the metal smelter in Harjavalta were the biggest plants in North. Germany developed a highly diversified industrial structure.

Again it should be pointed out that industrialisation led to very obvious environmental damage. Emissions from the ever burning coal left the tall chimneys and polluted large parts of the Baltic Sea region. Sulphur and nitrogen oxides, heavy metals, particles and various toxic substances were emitted over nature and society. Table 3.1 lists the industrial branches in the Baltic Sea Region which traditionally have constituted challenges for environmental management, and partly continue to do so. These include both branches with large consumption of resources as well as those with serious emissions or both.

3.1.3 Changes in the late 20th Century

The industrial production in the Central and Eastern Europe, CEE, countries in the transition between the centrally-planned and market economies, underwent significant restructuring after the systems change in 1989-91. Many large plants were shut down due to financial problems, often owing to falling demand or problems with the supply of raw materials. Many of them were using outdated technology and did not work well. The products often became outdated as western industrial products became available.

Table 3.1 *Overview of traditionally environmentally problematic industrial branches in Baltic Sea Region.*

Branch	Main products	Main environmental problems	Country
Mining	Brown coal, hard coal, metal ores, minerals, salt	GHG emissions, air pollution, resource consumption	Belarus, Czech, Finland Germany, Norway Poland, Sweden, Ukraine
Energy	Electricity, steam	Coal power plants, as above; hydropower caused large changes in the landscape	Belarus, Estonia, Lithuania, Norway, Sweden
Pulp & paper	Pulp, paper, board	Exhausts to water of fibre, chlorinated toxic pollutants	Belarus, Finland, Poland, Russia, Sweden
Metallurgy	Cast iron, steel, aluminium, chromium, nickel	Heavy metal emissions, large waste	Czech, Norway, Poland, Sweden, Ukraine
Metal	Various metals processing	Heavy metal emissions	Belarus, Estonia, Germany, Norway, Poland, Russia, Sweden
Chemical	Basic chemical, fertilisers, oil products, petrochemicals, Plastic and rubber, pharmaceuticals, specialty chemicals, synthetic fiber, textiles	GHG emissions, emissions of POP, nutrient exhausts	Belarus, Czech, Denmark, Germany Lithuania, Norway Russia, Sweden, Ukraine
Food	Food products, sugar	Nutrient discharges	Belarus, Denmark, Estonia Latvia, Lithuania, Poland, Sweden
Machine	Machinery, vehicles	Heavy metal emissions, air pollution	Belarus, Czech, Denmark, Estonia, Finland, Latvia, Poland, Sweden, Ukraine

After years of disruption industry started to recover and in 1997 real industrial output compared to its level in 1990 was estimated at 90.5% in CEE sub-region. However after the mid 1990s the development has been impressive. Annual growth rates based on GDP in the three Baltic States and Poland in the order of 7% also has touched industry and industrial production has increased more than 50%, in Poland almost 90%, as compared to the EU15 value of 16%. The financial crisis in Russia in 1998 impacted the surrounding countries negatively. Russia after having passed this crisis has had an annual growth rate of close to 11% the last few years.

During the same period industrial infrastructure in Western countries of the Baltic Sea Region was affected by world economy globalisation. Rapid advances in information technologies and networks, and improvements in capacity of international transportation systems made companies less sensitive to where to place production. Heavily polluting industries faced increasing demands for environmental protection and some of them were shut down. Case Study 3.1 illustrates this with an example of changes in the metallurgy industry.

Figure 3.1 A renovated traditional industrial environment in the small town of Gimo in Uppland about 100 km north of Stockholm. *For a hundred years iron production was the almost exclusive industry in Gimo. The owners lived in the mansion and all workers lived in these houses along a central street, called "bygatan." Gimo is still a lively town. Industry there has been transformed several times and is now producing high quality steel products for special purposes. The old houses for workers have been renovated and are again popular, although many of their inhabitants commute to the city of Uppsala. (Photo: Lars Rydén)*

3.2 The Major Branches of Industry

3.2.1 The Classification of Industrial Economy

All major branches of industrial economy are present in the Baltic Sea region. Table 3.2 gives an overview of how industry is classified in the international system, the so-called NACE, which is used for classification of economic activities in the European Community. The main branches of industrial production are briefly reviewed in this section, with some examples from several of the countries in the region.

3.2.2 Agriculture, Forestry and Fishing

The Baltic Sea region has a very large agricultural production in the south, especially Denmark. The food industry provides meat and a series of other agricultural products, dairy products, beer and beverages. A large production of meat and cereals are also typical of e.g. Estonia and Poland. However pre WWII large producers such as Eastern Prussia, today the Kaliningrad region and Ukraine are not as important today. Large slaughterhouses, dairies, mills, bakeries and factories for food are today part of the industrial structure of the region.

Forestry is of increasing importance in the region. Sweden, Finland and Russia in particular are large exporters of timber and sawed timber, and other products such as boards. Also biomass production for energy is important with e.g. wood chips and pellets.

Fishing in the Baltic Sea was at its peak in the early and mid 1980s with total catches of close to one million tonnes yearly. Over fishing and eutrophication have been disastrous for the Baltic fishing industry, and today restrictions are severe in an effort to save the most damaged populations, especially cod. The traditional fishing is minimal and most fish are caught in large boats, industrial fishing. This is one of the reasons for over fishing.

All these sectors are today in the west industrialised and very few individuals are working, up to 3% of the work force. Big machinery is used, and a single person can manage also a rather large farm or forest property. In the Baltic States and Poland, many small farms still exist, but the future will certainly see a dramatic structural change and depopulation of the countryside.

3.2.3 Coal, Petrol, Oil shale and Gas

The Baltic Sea region has large fossil energy resources as coal, lignite, oil and gas. Coal has been mined since medieval times. Since the 1980s and 1990s coal mining has decreased, mostly for economic reasons – they cost more that the income they provide. Closing down coal mines has been going on from the 1960s from West to East with England followed by Germany and later Poland, where about 50% of the mines had closed as of 2004. The production data for Germany can illustrate this. In 1990 the country produced and used close to 400 million tonnes of coal. In 2002 just over half, about 210 million tonnes, was produced.

Working coal mines are situated in three areas in Germany: Ruhr, Saar and Ibbenbüren (21 pits). Germany produced 225 million tonnes of coal in 2000, dominated by lignite (184 million tonnes). Most of the lignite is produced in five areas: between Cologne and Aachen (Rhine coalfield), near Helmstedt, in the Halle-Leipzig area and the Lausitz (13 sites), where a new pit mining of lignite now opens in the near future. The large coal mines in Poland are situated in Silesia, while the largest lignite field is in Belchatow, not too far from Lodz. The power plant in Belchatow produces a large share of Polish electricity.

In Czech Republic several hard coal mine fields (Kladno, Trutnov, Ostrava-Karvina, Oslavany) are still in operation. Lignite is mined in Northern Bohemia. Uranium is still mined with some of the deepest shafts in Europe (1838 m). Four coke plants and a steel mill are situated in Ostrava region.

The Norwegian oil fields in the North Sea have been very important for Norwegian economy over a long period. Today oil production has decreased, though gas production is important.

Russia is by far the largest producer of oil and gas. It is providing much of the energy resources for e.g. Poland, and Belarus. The transport of oil and gas through the region is large and increasing.

Oil shale provides over 75% of Estonia's total energy supply, making Estonia the only country in the world where oil shale is the primary source of energy. Oil shale is produced by majority state-owned Eesti Polevkivi (Estonian Oil Shale) near Kohtla-Järve. After 2006, Eesti Polevki is forecasting its production target will shift downward, to 10.5 million tons per year, as Estonia tries to curb pollution from the oil shale industry in an effort to meet EU environmental regulations. Eesti Polevkivi has indicated that it expects the oil shale industry to continue for another 40 years, but no new mines are scheduled to be built.

On the whole, hard coal is becoming less important and gas increasingly so as an energy source. Large gas pipe lines are planned to connect the Russian and Norwegian gas fields to Germany and Central Europe. Oil transport on tankers over the Baltic Sea, from Russian harbours in particular, is also increasing. The environmental consequences of a possible accident in the Baltic Sea are alarming. As competition for fossil fuels is increasing and resources decreasing prices will soar.

Case Study 3.1
Production of Cadmium in HELCOM area

Production of cadmium has declined slightly during the last decade in the HELCOM area. For environmental reasons, the use of cadmium has been increasingly restricted or banned, and the main demand for cadmium now arises from its use in rechargeable Nickel-Cadmium batteries.

Commercial cadmium is obtained mainly as an impurity in zinc ores: approximately 3 g of cadmium are produced for every ton of primary zinc produced, and cadmium production is more closely related to the demand for zinc than to the demand for cadmium itself. Some cadmium is also produced from the recycling of scrap metals, industrial wastes, dusts and fly ash etc. containing cadmium impurities. Primary cadmium production has slightly decreased since 1990, while secondary production has increased.

OSPAR (2001) has compiled data on European cadmium production as listed in the table below.

Cadmium production in different years in some of Baltic Region countries (in tons).

Country	1985	1990	1993	1998
Finland	564	591-568	785	550
Germany	1095	973	1069	1150
Norway	164	286	213	270

In the period 1996 – 2000 of the HELCOM Contracting Parties, only Sweden reported production of cadmium ore, and only Finland reports production of cadmium metal in the Baltic Sea catchment area. Germany produced 1150 tons of refined cadmium in 1998, presumably outside the HELCOM catchment area. Poland's production of refined cadmium, averaging around 600 t/a in the 1980's, has declined after 1990 and has now ceased.

Source: HELCOM, 2002.

3.2.4 Iron and Metal Mining

The metals industry mainly consists of a few large companies. Norway, Sweden, Finland and Poland are important mining countries. Most of the metals companies are a part of large groups, such as Norsk Hydro, Elkem and Fesil. Aluminium production makes up the largest part of the Norwegian metals industry. Norway produces the largest amount of primary aluminium in Western Europe, and 80-90% of its output is exported.

Poland is one of Europe's top coal and copper producers. Poland's mining industry has suffered declining production and consequently several mining sectors have reported job losses and closures. However, there have been signs of recovery, with the country's silver, zinc and copper production showing an increase over previous years. All of Poland's

Figure 3.2 *Belchatow is one of the largest lignite fuel power plants in the World and the main electricity producer in Poland.*

copper production comes from KGHM Polska Miedz (Polish Copper) SA which produces approximately 520,000 t of refined copper and 1,100 t of silver each year. Poland has several lead, zinc and silver mines.

Sweden has a large mining industry which contributes 0.3% to Sweden's GDP. Sweden has substantial base metal, gold and iron ore deposits, which are being actively exploited and developed. Iron, copper, silver, gold, lead are the main products in metal mining in 12 active mining areas in Sweden (Kiruna, Garpenberg, Zinkgruvan, Garpenberg in Boliden, Bergslagen and Åmmeberg districts). Eight metal mining operations were closed (one of the latest closed – Laisvall in 2001).

Five active metal mining operations for copper, zinc, nickel, gold, chromium (Kemi, Hitura) are situated in Finland.

The several important steel mills in the region, include Nowa Huta in Krakow, Katowice, and Chestochowa in south Poland rely on local coke production and local or imported iron ore. The Swedish steel mills are found in central Sweden, including Borlänge and Sandviken. Several of the smaller Swedish steel mills produce special steel alloys and have a tradition for several hundred years. Several others have been forced to close in the last 10-20 years. There is one steel mill in production in Raahe in Finland.

3.2.5 Stone, Mineral and Cement

Production of natural stone, stone chips, sand and gravel is important part for e.g. the building industry and infrastructure development. It is fairly easy in the north of the region since the glacier has created many eskers which mostly consist of gravel.

A stretch of chalk mines across the Baltic Sea from the Estonian North coast, all the way to Bornholm, forms the base for a cement industry. Large plants are found in Kunda on the Estonian north coast, Slite on the east coast of Gotland and Degerhamn on the west coast of Öland.

The Norwegian mining industry is now undergoing a considerable restructuring process, with a strong increase in the production of industrial minerals, moderate growth in the production of natural stone, stone chips, sand and gravel, and a sharp reduction in the extraction of ore. Norway produces olivine, an industrial mineral, from olivine mines, and is one of the world's three largest producers of nepheline syenite, another industrial mineral.

Two underground mines at Glanshammar near Örebro in Sweden are producing dolomite.

3.2.6 Textile Clothing; Leather

Textile and clothing industry had an important role in the early phases of industrialisation in the 19th century. For the English cotton industry Manchester became a legendary city. In the Baltic Sea region Lodz in Poland has a most extraordinary position in this industrial history, as the city grew tremendously from late 19th century up to 1939, to become Poland's second largest city and a European centre for textile production. After the Second World War although in a state of decline this production continued up to the mid 1990s. Other centres were found in west Denmark and west Sweden.

In the 20th century and especially after the 1970s, this industry has gradually declined due to competition from low-wage countries, first to southern Europe, e.g. Portugal and Spain, and later to Asia. Today, in the early 21st Century, several west European textile and clothing firms have outsourced their sewing operations to transition countries, such as the Baltic States and Poland. This is typically organised in the way that e.g. a Danish firm still buys woven cloth, organises the dying and cutting operations in Denmark, then ships the pieces to e.g. Poland where they are sewn, and then is transported back to Denmark where they are quality controlled, finished, and marketed. Some production remains in the west, e.g. in the industrial district of Herning-Ikast, in Western Jutland. The sector is still successful.

Much of the leather industry, producing e.g. shoes, has also been moved from the west to east over the last half of the 20th century.

3.2.7 Pulp and Paper

Finland, Sweden and Russia together have a majority of the global pulp and paper production. The Swedish and Finnish industry is located on the shores of the Baltic Sea, while the Russian Karelian Republic has its important pulp and paper factories on the shores of lakes Onega and Ladoga.

Table 3.2 Branches of industry or production sectors. *Only main categories are included. The complete list contains several thousand items, as most of the categories have subcategories. The list gives an impression of which industrial branches should be looked at when assessing the complete picture of industrially caused environmental impacts. [The list is a based on the EU system NACE, which is part of ISIC (see Internet Resources)].*

A	**Agriculture, hunting and forestry**
B	**Fishing**
C	**Mining and quarrying**
CA 10	Mining of coal and lignite; extraction of peat
CA 11	Extraction of crude petroleum and natural gas;
CA 12	Mining of uranium and thorium ores
CB 13	Mining of metal ores; iron, other metals
CB 14	Other mining and quarrying
D	**Manufacturing**
DA	Manufacture of food products; beverages and tobacco
DB	Manufacture of textiles and textile products
DC	Manufacture of leather and leather products
DD	Manufacture of wood and wood products
DE	Manufacture of pulp, paper and paper products; publishing and printing
DF	Manufacture of coke, refined petroleum products and nuclear fuel
DG	Manufacture of chemicals, chemical products and man-made fibres
DH	Manufacture of rubber and plastic products
DI	Manufacture of other non-metallic mineral products
DJ	Manufacture of basic metals and fabricated metal products
DK	Manufacture of machinery and equipment n.e.c.
DL	Manufacture of electrical and optical equipment
DM	Manufacture of transport equipment
DN	Manufacturing of e.g. furniture;
E	Electricity, gas and water supply
F	Construction
	Service
G	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
H	Hotels and restaurants
I	Transport, storage and communication
J	Financial intermediation
K	Real estate, renting and business activities
L	Public administration and defence; compulsory social security
M	Education
N	Health and social work
O	Other community, social and personal service activities
P	Activities of households
Q	Extra-territorial organisations and bodies

Sweden is the world's third largest exporter of pulp and paper, with 80% of exports marketed in the EU countries. The Swedish pulp and paper industry has undergone numerous mergers. The two top companies, Stora and SCA, are among Sweden's biggest industrial groups. Other leading groups are MoDo, the previously state-owned Assi Domän (privatised in 1994), Södra Skogsägarna, Korsnäs and NCB.

In recent years Swedish forest product companies have made major acquisitions in the EU. Recently the Swedish and Finnish forest companies Södra and Metsäliitto and the Latvian Republic have agreed on building a 600,000-tonne per annum kraft pulp mill in Ozolsala, near the town of Jekabpils in eastern Latvia on the shores of the river Daugavpils.

3.2.8 The Chemical Industry

An important chemical industry exists in most of the countries in the region, although Germany has by far the longest tradition and the largest chemical sector. Much of this industry is based on petrochemistry and refineries. Refineries have been established in Norway, on the Swedish west coast, in Poland in Gdansk and close to Plock on River Wisla north of Warsaw, and in Lithuania with the Mazeikiai Crude Oil Refinery. All of them produce a complex series of oil products. For example Mazeikiai Crude Oil Refinery started operating in 1980 and was one of the most modern refineries of the former Soviet Union. Today Mazeikiu nafta is the only crude oil refinery in the Baltic States operating as a typical complex refinery. It has a design capacity of 15 Mt per annum. The modern products of the refinery are different grades of high octane unleaded gasoline, new gasoline VENTUS with multifunctional additives, summer and winter diesel, jet fuel, heating oil, construction, roofing and road bitumen, LPG, sulphur, MTBE.

Another branch of the chemical industry produces fertilisers and nitrogen products, again present in several of the countries in the region. For example in Lithuania there are two fertiliser factories. Following several reconstructions and further upgrading, JSC (joint stock company) and Achema (formerly the Azotas Fertiliser Plant) currently produce ammonia, carbamide, ammonium nitrate, nitric acid, carbonic acid, and various composite fertilisers for gardeners. JSC Lifosa (formerly the Kedainiai

Figure 3.3 *Industrial mass production of chemicals in is one of the large environmental dilemmas of modern society. Pollution from the site of production was originally the largest problem. Today, pollution during consumption and waste, the rest of a product's life-cycle, is often much more problematic. (Photo: Lars Rydén)*

Chemical Fertiliser Plant) currently produces sulphuric acid, phosphoric acid, single and granulated superphosphate, di-ammonium phosphate and aluminium fluoride. Other large plants exist in Novgorod in Russia and Köping in Sweden. These factories use considerable quantities of fossil fuel for the reduction of atmospheric nitrogen.

Pharmaceutical industry originated in Germany in the 19th century, and several of the largest companies are still active, although the largest facilities are found in Southern Germany or even in Switzerland. The Swedish companies Astra and Pharmacia, now merged with American General Electrics, count among the largest pharmaceutical companies in the World. Astra is now operating under the name of AstraZeneca and Pharmacia belongs to Pfizer. This branch is very research intensive.

A series of other chemical branches could be added to the list. These include e.g. the chlor-alkali industry, producing chlorine gas and sodium hydroxide. As they traditionally use the mercury electrode technology they are (were) environmentally problematic. The coal fired power plants produce sulphuric acid as a base chemical, from the sulphur in the coal. The plastics industry uses a series of petrochemicals in the production.

3.2.9 Manufacturing of Machinery, Electrical and Optical Equipment, Car Industry

Metallurgic industry, including the fabrication of all kinds of equipment and car industry is a large and economically dominant branch in several of the countries in the region. Germany was and is the most important country in this respect. Siemens originally produced electrical equipment, motors, generators, etc. Sweden has had a large production of refrigerators, stoves, vacuum cleaners etc with Electrolux Company since 100 years back. ABB, Asea Brown Bovery, originally with Asea as a Swedish company which produced equipment for power transfer and equipment for hydropower plants, later nuclear power plants, etc. The company also produced trains and engines for trains. Before the systems change this sector was also important in the Baltic States. Thus all train wagons for the USSR were produced in Riga, while e.g. Jelgava had a large factory for microbuses.

The car industry has a long tradition in Germany and Sweden. For example Volkswagen, Audi, Volvo, Saab and Scania are well known car producers. The car industry accounts for a very large part of the industrial economy, as a number of producers and maintenance companies are included.

The defence industry is also part of this sector. Before the systems change the defence industry was an important sector in the whole region, and particularly in Russia. Nobel industries, best know for guns, have been and still are important. They had large factories in St Petersburg up to the revolution. The German defence industry, e.g. guns, tanks, air fighters, was large up to the end of the Second World War but is still important. Fighter planes have been produced in Sweden since the Second World War.

Ship building was up to recently very large in some countries. Classical yards were found in Gdansk (Lenin yard) and Gdynia in Poland; Bremen, and Hamburg in Germany; and in Malmö and Uddevalla in Sweden.

3.2.10 The Power Industry

Some of the largest power companies in Europe are found in the region. These include Fortum in Finland, and Vattenfall in Sweden. The power companies run power plants – including hydropower, nuclear power and coal and gas fired power plants – as well as power distribution infrastructure. (Producers of oil, gas and coal are not included here, and have already been mentioned.)

The power companies are typically state-owned but operate as independent companies. Nationally important power companies are found in all countries. In Estonia state-owned Eesti Polevkivi (Estonian Oil Shale) near Kohtla-Järve, in Latvia Latenergo in Riga using imported gas, and several companies in Poland, the largest being Belchatow near Lodz using lignite. A great number of local power companies also exist, very often municipally owned.

Since the deregulation of the power market a number of fusions of companies have occurred. Many companies are today international.

The development in the power sector is much discussed since the political incentives to reduce fossils to curb the carbon dioxide emissions are increasing. In Finland a decision was recently taken to build one more nuclear power plant, while Sweden has recently closed one plant (Barsebäck). Ignalina in Lithuania, one of the largest nuclear power plants, will be closed in 2009 as part of the EU accession agreements. Waste incineration is increasing, and district heating is built in many cities. Wind power is becoming important in many countries, and is already so in Denmark and Northern Germany.

Figure 3.4 *Hydropower provides 50% of the electricity in Sweden. Porjus hydropower station is the largest in Sweden. The environmental costs of hydropower are mainly related to the large infrastructure requirements, especially upstream reservoirs. (Photo: Hans Blomberg, courtesy of Vattenfall AB)*

Figure 3.5 Iron and metal mining. *Heavy equipment digs and hauls ore inside an enormus open pit mine. (Photo:iStockphoto)*

3.2.11 Construction

The building industry is today in a state of rapid expansion. Building is extensive in many of the major cities in Central and Eastern Europe. The largest construction companies, e.g. Skanska and NCC, are active in many countries in the region, both in housing and in infrastructure expansion, e.g. roads, railroads, bridges, tunnels etc. This sector will continue to develop for many years in the CEE countries too improve the often very poor quality of both housing and road infrastructure.

3.3 Industrial Structure and Restructuring

3.3.1 Industry Restructuring

As many other sectors in the economy, industry is continually being restructured. This is a consequence of developing technology, globalisation and changing markets. Examples are many. Computers substituted for the older typewriters; clothing became cheaper to produce elsewhere; defence contracts were discontinued.

Restructuring may lead to the closure of whole factories and even a whole city, town or area losing the basis of its livelihood. This is painful for the workers and all who depend on them. For one work place in the basic sector of the economy, such as an industry, there are many more, often 6-8, other working places, e.g. hairdressers, shop assistants, nurses, fire brigadiers, school teachers and so on. In addition there are the up to 50% of the population that are not in the labour market. The closure of a basic industry thus may mean either that a town or neighbourhood disappears as inhabitants are moving out, or to a complete restructuring. This often leads to considerable responsibilities of the both local and national governments to develop new opportunities to support oneself and a new labour market in areas which were heavily dependent on a declining industry.

In the west a number of industrial branches have undergone such changes over many years. This includes ship building, which practically disappeared starting from the 1970s, as ships were less expensive to build in e.g. North Korea and Eastern Europe. Textile manufacturing was greatly reduced as cheaper production took over first in Southern Europe and later in Asia, India and China in particular. The closing of mines, especially coal mines, is another sector where structural change has been accompanied by dramatic political protests, not least because they were typically state-owned. More recent structural changes include the defence industry, where orders (for some!) are decreasing as a consequence of the end of the Cold War.

The system change in Central and Eastern Europe became an all encompassing structural change in all industry and the whole economy. So much technological development was forced onto the sectors at once, markets were lost as a consequence of the break down of the Soviet Union and Comencom.

Restructuring is a natural development in all economic sectors and in the end should be beneficial for the countries, even if painful if too sudden. The introduction of new technologies as they become available has led to increasing labour efficiency of about 2-4% yearly. Thus today a worker produces 100-200 times more value per working hour as compared to early industrialisation 150 years ago. Many hard and dangerous jobs have disappeared and taken over by machinery and will not be missed by anybody. Monotonous jobs have been taken over by robots or computers, more exact and enduring than humans, who will unavoidably make mistakes. The introduction of cleaner technologies is one such development of production that is beneficial, but may lead to fewer jobs.

3.3.2 Economy versus Environment

The different sectors in an economy have very different environmental impacts. This is reported in the so-called national environmental accounts or green budgets of a country. The environmental data are added to the traditional economic data, without changing them, and are therefore called satellite accounts. An international standard to be used, called SEEA,

Case Study 3.2 Kiruna Iron Ore Mine, Sweden

With an ore body 4km long, 80m thick and reaching a depth of 2km, LKAB's Kiruna is the world's largest, most modern underground iron ore mine. Since mining began here over 100 years ago, LKAB has produced over 950Mt of ore, yet only one-third of the original ore body has been extracted. Since mid-1999, Kiruna's haulage level at a depth of 775m has been replaced by the next level down at 1,045m, which will support production until 2018. The operation employs 1,800 people, of whom 400 work in the mine. In 2000, Kiruna produced 13.7Mt of iron ore products (10.9Mt of pellets, 2.6Mt of sinter fines and 200,000t of high-phosphorus ore) with an average grade of 66% Fe. This represented two thirds of LKAB's total Swedish production.

The ore contains a very pure magnetite-apatite mix, containing more than 60% iron and an average of 0.9% phosphorus. The original reserve at Kiruna was some 1,800Mt. The KUJ2000 project has integrated the move down from the 775m level haulage to 1,045m with the upgrading of all of the mine's ore handling systems, which can now handle 26Mt/y. Components include the new automated rail transport system on the 1,045m level, uprating the hoists and crushers, and increasing the ventilation system capacity. Seven 500t-capacity shuttle trains, controlled from the 775m level, collect ore from ten groups of ore passes, and deliver it to one of four crushing stations. 100 mm ore is then skip hoisted in two stages to the 775m level and then to surface. The mine is divided into eight production areas, each containing its own group of ore passes and ventilation systems.

Ore is mined using sublevel caving, with sublevels spaced at 28.5m vertically. With a burden of 3.0-3.5m per ring, this yields around 8,500t for each blast. Electric-powered, remote-controlled drilling and ore handling equipment is widely used. After blasting, load-haul-dump machines carry the run-of-mine ore to the nearest ore pass, from which it is loaded automatically on to one of the trains operating on the 1,045m level. After primary crushing, sampling using a Morgårdshammar automatic sampler to obtain the apatite and magnetite contents, and hoisting to surface, the ore is processed in Kiruna's complex of one sorting plant, two concentrators and two pellet plants to give pellet and sinter fines products.

THE LAKE ORE PROJECT LKAB is investing some $50 million to dewater part of Lake Luossajärvi in order to access 100Mt of ore beneath it. Draining is scheduled for completion in 2001.

Source: The website for mining industries – Kiruna: http://www.mining-technology.com/projects/kiruna/

System of Environmental and Economic Accounts, has been developed within the UN system.

Case Study 3.3 gives one example of such accounts from a report from the Swedish Institute for Economic Research. Twelve sectors in the economy are reported with data on traditional statistics (production value, processing value, and employment), energy statistics (fuel used, electricity and district heating) and emissions (carbon dioxide, sulphur oxides and nitrogen oxides). The data are from 1998. It is clear that the environmental impact per value in the economy is very different. The pulp and paper, power and metallurgic industries stand out as bad performers from the environmental point of view. The service sectors as well as building and construction are producing much value and jobs for each unit of environmental impact.

The data in the green budget of a country does not mean that some sectors in the economy should be closed, but it points to where environmental policy should be focused, and production developed. It is interesting to note that the worst sector, pulp and paper, is now undergoing the largest reforms through the introduction of cleaner technologies.

Industry has, as mentioned above, increased the value per working hour labour productivity, dramatically over its entire history. To improve its environmental profile it needs to also improve its energy and resource productivities as well. Increased resource productivity means that more value is produced with a given amount of resources. This is an important mission of cleaner production. Resource productivity is increasing as internal and external recycling is increasing, with more efficient use of energy and other resources such as water.

Case Study 3.3 Green Budgets – Environmental and Economic Profiles

The green budget, or environmental accounts, of a country includes data on environment together with the traditional data. In a report from the Swedish Institute for Economic Research, the traditional statistics (1-3) are given together with data on energy (4-6) and emissions (7-9) for 12 sectors in the economy.

The data reported are the following:

- Traditional statistics (production value, processing value and employment).
- Energy (all fuel to be incinerated (i.e. not uranium), biomass and electricity and district heating).
- Emissions (carbon dioxide, CO_2, sulphur oxides, SO_x and nitrogen oxides, NO_x).
-

The sectors are very different in terms of economic value per environmental impact. Manufacturing, such as pulp and paper, and the transport sector, is quite polluting while the service sectors are low in this respect.

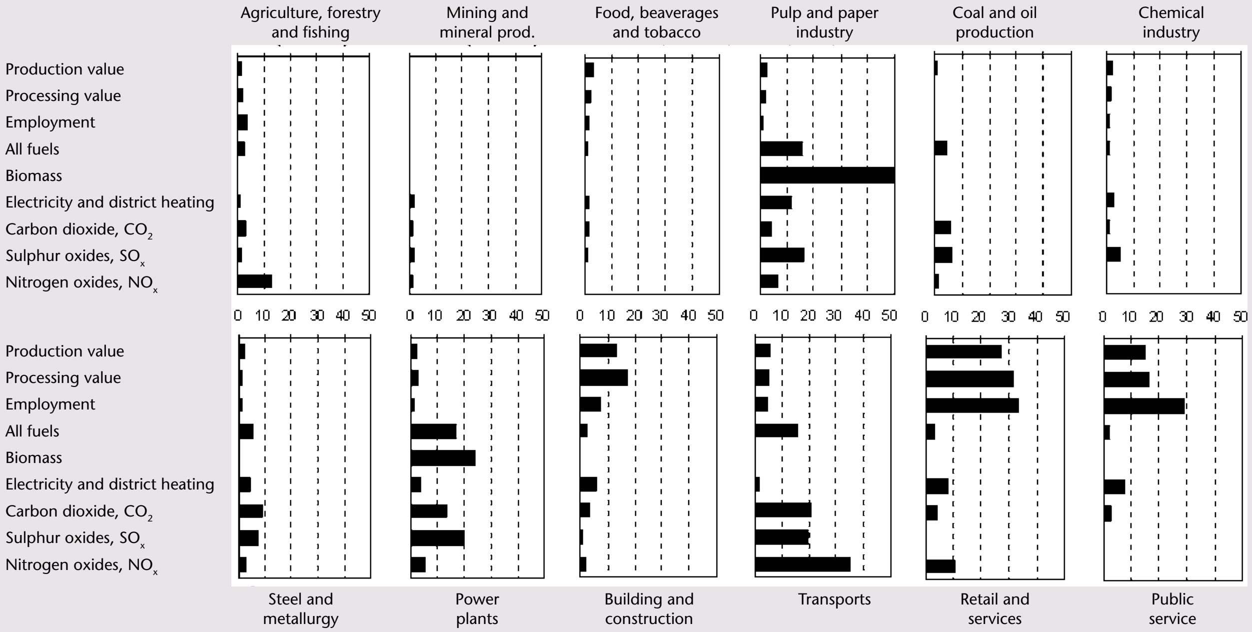


Figure 3.6 Environmental and economic profiles for 12 industrial sectors in Sweden, share of total in 1998. *Figures are given in percent of total for Sweden. Since not all sectors are included the sum of the reported values are less than 100% [SCB, 2001].*

Changes in product design and use also contribute to improved resource productivity. Thus productivity is increasing with dematerialisation and with longevity of the manufactured products. It is increasing with the more efficient use of products, which includes both multi-functionality and increased number of users, for example through leasing or pooling. As labour costs have been much larger than resource costs, labour productivity has developed much further than resource productivity. But we are now in a situation where it is cost-efficient to improve resource productivity, and there is much to be done.

Increased productivity amounts to a so-called decoupling of resource use from production value. This has to be much larger than today in a sustainable society. The decoupling can be seen e.g. the decreased use of energy in western European industry. This is however offset by a larger increase of total resource use, the so-called rebound effect. Sustainability will require an absolute decrease in resource use of about a factor of five according to more recent estimates.

3.3.3 The Change to a Post-industrial Society

Industry can be seen from the point of view of production, employment, economic turnover or resource use. Industrial production has been increasing more or less linearly over almost the entire 20th century and is still doing so. However employment was at its peak between the 1950s and 1970s in the west. In the east it probably occurred just before the system change, that is, 1990. The term industrial society refers normally to the fact that the largest share of the work force is occupied in industry. It was in Sweden about 70% at the peak. But as labour productivity has increased regularly first about 3% and later 4% per year, due to machinery, automation, computerisation etc, the work force has decreased dramatically. In 2005 less than 18% of the work force was found in the industrial sector in the country. In the future very few individuals will manufacture all goods the society needs, just as very few are producing all food we eat. We are on our way into the post-industrial or service society.

Services cannot be undergoing a similar development of labour productivity as in manufacturing industry. There will never be fewer than four people to play a quartet, and a piece of music will always take so many minutes to play, you cannot do it in half the time. We should expect that service sector will remain large in the future. The challenge will be to organise the economy of the society so that we can afford the services we all want, such as health care, as well as child and elderly care.

Also, some services have a very considerable environmental impact. This includes the dramatically increasing tourism industry, with all its travelling. Transport has very different environmental impacts and long distance air transport is problematic from this point of view. Also the destinations of tourism needs to be protected, be they natural or cultural sites.

Study Questions

1. What was the basis of early industrialisation of the Baltic region?
2. What is the main difference between the industry of the Nordic countries and the Baltic CEE countries?
3. What are the main energy resources in the Baltic Sea region?
4. How is industry in the Baltic area being restructured? What is the difference between Nordic and CEE countries?
5. Describe the history of industrial development in the Baltic Sea region.
6. Name the major industrial branches and their environmental problems in the Baltic Sea region. What are the problems in your country?
7. How are the economics of different countries connected to the environment?

Abbreviations

CEE	Central and Eastern Europe.
CIS	Commonwealth of Independent States.
GDP	Gross Domestic Product.
HELCOM	Helsinki Commission (Baltic Marine Environment Protection Commission).
ISIC	International Standard Industrial Classification of all Economic Activities.
JSC	Joint Stock Company.
LPG	Liquid Propane (and Butane) Gas.
MTBE	Methyl Tertiary-Butyl Ether (added to gasoline to increase its oxygen content).
NACE	Classification of Economic Activities in the European Community.
OSPAR	Commission for the Protection of the Marine Environment of the North-East Atlantic.

Internet Resources

NACE – Classification of Economic Activities
in the European Community

http://www.fifoost.org/database/nace/nace-en_2002AB.php

ISIC – International Standard Industrial
Classification of all Economic Activities

http://forum.europa.eu.int/irc/dsis/coded/info/data/coded/en/gl006814.htm

The Website for Mining Industries
– Kiruna Iron Ore Mine, Sweden

http://www.mining-technology.com/projects/kiruna/

The Website for Mining Industries
– Kemi Chromite and Ferrochrome Mine, Finland

http://www.mining-technology.com/projects/kemi/

NDH, Ministry of Trade and Industry in Norway
– Handbooks and brochures

http://odin.dep.no/nhd/engelsk/publ/brochures/index-b-n-a.html

Environmental Conditions in the Baltic Sea Region

http://www.baltic.vtt.fi/demo/balframe.html

4

Cleaner Production Assessment

4.1 Cleaner Production Assessment Methodologies

4.1.1 UNEP/UNIDO Methodology

Cleaner Production *assessment* is one of the specific Cleaner Production diagnostic tools. This is a systematic procedure for the identification and evaluation of Cleaner Production options for the companies that are launching a Cleaner Production project. The methodology allows us to identify areas of inefficient use of resources and poor management of wastes in production.

Many organisations have produced manuals describing Cleaner Production assessment methodologies with the same underlying strategies. Table 4.1 lists some of the documents described in the more common methodologies. This chapter will follow the UNEP/UNIDO Cleaner Production assessment methodology [UNEP, 1996a]. The five phases in this methodology correspond to sections 2-6 in the chapter. An overview of the methodology, is therefore found in the box of the chapter content on this page.

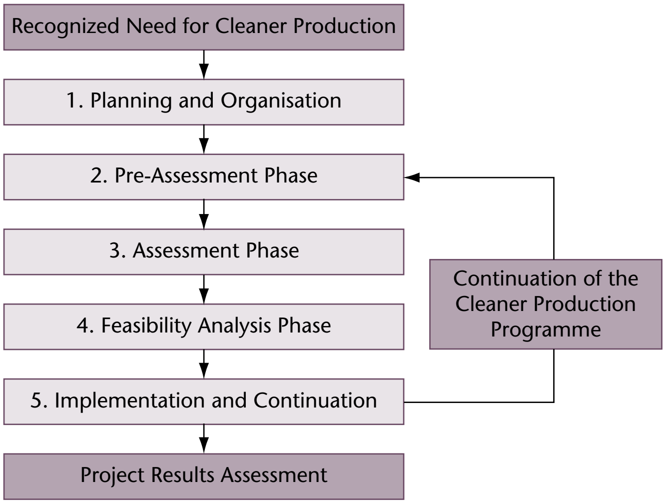


Figure 4.1 *Overview of the Cleaner Production assessment methodology [UNEP, 1996a].*

In this Chapter

1. Cleaner Production Assessment Methodologies.
    UNEP/UNIDO Methodology.
2. Planning and Organising Cleaner Production.
    Obtain Management Commitment.
    Establish a Project Team.
    Develop Environmental Policy, Objectives and Targets.
    Plan the Cleaner Production Assessment.
3. Pre-assessment.
    Company Description and Flow Chart.
    Walk-through Inspection.
    Establish a Focus.
4. Assessment.
    Collection of Quantitative Data.
    Material Balance.
    Identify Cleaner Production Opportunities.
    Record and Sort Options.
5. Evaluation and Feasibility Study.
    Preliminary Evaluation.
    Technical Evaluation.
    Economic Evaluation.
    Environmental Evaluation.
    Select Viable Options.
6. Implementation and Continuation.
    Prepare an Implementation Plan.
    Implement Selected Options.
    Monitor Performance.
    Sustain Cleaner Production Activities.

A Cleaner Production Assessment and an Environmental Management System (EMS), are comparable. While Cleaner Production projects have a technical orientation, an environmental management system focuses on setting a management framework. It will be obvious from this chapter that a CP assessment needs a solid management structure, just as it is clear that an EMS needs a technical component when it is implemented.

4.2 Planning and Organising Cleaner Production

The objective of this phase is to obtain commitment to the project, allocate resources and plan the details of the work to come.

4.2.1 Obtain Management Commitment

Experiences from many companies show that Cleaner Production initiatives results in both environmental improvements and better economic performance. However, this should be recognised by the management of the company. One of the most effective ways for the management to see the benefits of implementation of Cleaner Production is by example of similar companies which already implemented CP programmes. Several sources for study cases around the world are found in the Internet addresses for this chapter.

4.2.2 Establish a Project Team

The CP project team undertakes the following tasks:

- Analysis and review of present practices.
- Development and evaluation of proposed Cleaner Production initiatives.
- Implementation and maintenance of agreed changes.

The project team should consist of people responsible for the business functions of the major facilities in the company, research & development staff as well as expert consultants in order to facilitate team activities. Members from outside the company would give an independent point of view to Cleaner Production activities.

4.2.3 Develop Environmental Policy, Objectives and Targets

The environmental policy outlines the guiding principles for the assessment. The policy contains the company's mission and vision for continuous environmental improvement and compliance with legislation. The objectives describe how the company will do this. For example, the objectives could include reducing the consumption of materials and minimising the generation of waste. Targets are used to monitor if the company is proceeding as planned. An example of a target might be a 20% reduction in electricity consumption within 2 years. In general, objectives and targets should be:

- Acceptable to those who work to achieve them.
- Flexible and adaptable to changing requirements.
- Measurable over time.
- Motivational.
- In line with the overall policy statement.

4.2.4 Plan the Cleaner Production Assessment

The project team should draw up a detailed work plan and a time schedule for activities within the Cleaner Production assessment. Responsibilities should be allocated for each task so that staff involved in the project understands clearly what they have to do.

Table 4.1 *Methodologies for undertaking a Cleaner Production assessment [CECP, 2001].*

Organisation	Document	Methodology
UNEP, 1996	Guidance Materials for the UNEP/UNIDO National Cleaner Production Centres	1. Planning and organisation 2. Pre-assessment 3. Assessment 4. Evaluation and feasibility study 5. Implementation and continuation
UNEP, 1991	Audit and Reduction Manual for Industrial Emissions and Wastes. Technical Report Series No. 7	1. Pre-assessment 2. Material balance 3. Synthesis
Dutch Ministry of Economic Affairs, 1991	PREPARE Manual for the Prevention of Waste and Emissions	1. Planning and organisation 2. Assessment 3. Feasibility 4. Implementation
US EPA, 1992	Facility Pollution Prevention Guide	1. Development of pollution prevention programme 2. Preliminary assessment

4.3 Pre-assessment

The objective of the pre-assessment is to obtain an overview of the production and environmental aspects of a company. Production processes are best represented by a flow chart showing inputs, outputs and environmental problem areas.

4.3.1 Company Description and Flow Chart

A description of the company's processes should answer the following questions:

- What does the company produce?
- What is the history of the company?
- How is the company organised?
- What are the main processes?
- What are the most important inputs and outputs?

When looking for the answers to the questions the assessment team should first try to find already existing operational data such as production reports, audit reports and site plans. A checklist (Box 4.1) would make this step more comprehensive.

Where information is not available the project team should set up a plan how to obtain the missing data.

The production line to be studied can best be represented using a detailed process flow chart. Producing a flow chart is a key step in the assessment. It will be the basis for material and energy balances which occur later in the assessment. In a process flow chart for a CP assessment, the team should pay particular attention to several activities which are often neglected in traditional process flow charts. These are:

- Cleaning.
- Materials storage and handling.
- Ancillary operations (cooling, steam and compressed air production).
- Equipment maintenance and repair.
- Materials that are not easily recognisable in output streams (catalysts, lubricants etc.).
- By-products released to the environment as fugitive emissions.

The process flow chart is meant to provide an overview and should thus be accompanied by individual input/output sheets for each unit operation or department in the company. Figure 4.2 provides an example of an input/output worksheet.

4.3.2 Walk-through Inspection

Much of the information needed to fill out the input/output sheets, described above, may be obtained during a walk-through inspection of the company. The walk-through inspection should follow the process from start to finish, focusing on areas where products, wastes and emissions are generated.

Case Study 4.1 Management Commitment in ABC Foods AB, Simrishamn

ABC Foods AB is located near Simrishamn, in the south of Sweden, and produces a range of jams and conserves. The plant employs approximately 50 people and supplies wholesalers, for ultimate retail through supermarkets. The plant has a manufacturing capacity of 750,000 kg of jam per year. Apart from the normal range of jams, special recipes are also produced for large users such as bakers, jam tart and pie makers such as the Best Pies Company.

Management Commitment

Over the past few years, the Plant Engineer had implemented a number of process and operations improvement programmes, including upgrading some of the equipment. The Plant Engineer then wanted to formalise an overall assessment of operations to identify opportunities for savings through waste minimisation and process optimisation.

Because such an assessment would involve all departments of ABC Foods, he approached the Managing Director to seek approval to proceed with the idea. The Managing Director complemented the Plant Engineer on his initiative, and was enthusiastic about the concept of a Cleaner Production Programme.

They discussed the basic approach and agreed on the following:

- All departments would be involved in the project and a Cleaner Production Team would be formed, coordinated by the Plant Engineer. The Team would identify, investigate and evaluate cleaner production options. There should be regular reports to the Managing Director to keep him in touch with progress.
- All cost-effective proposals (with less than two-year pay back) would be budgeted for in the following financial year.

The Managing Director wrote a Memo to all staff expressing his commitment to the project, and asked all departments to provide the Plant Engineer with support and assistance. He also called a meeting of all department heads, to explain the project and to seek their commitment. The Plant Engineer made a presentation at this meeting.

Source: NSW-DSRD/NSW-EPA, 2000.

Box 4.2 provides examples of the types of questions which the team may ask operators to facilitate the investigation. During the walk-through all obtained information should be listed, and if there are obvious solutions to the existing problems, they should be noted. Special attention should be paid to no-cost and low-cost solutions. These should be implemented immediately, without waiting for a detailed feasibility analysis.

4.3.3 Establish a Focus

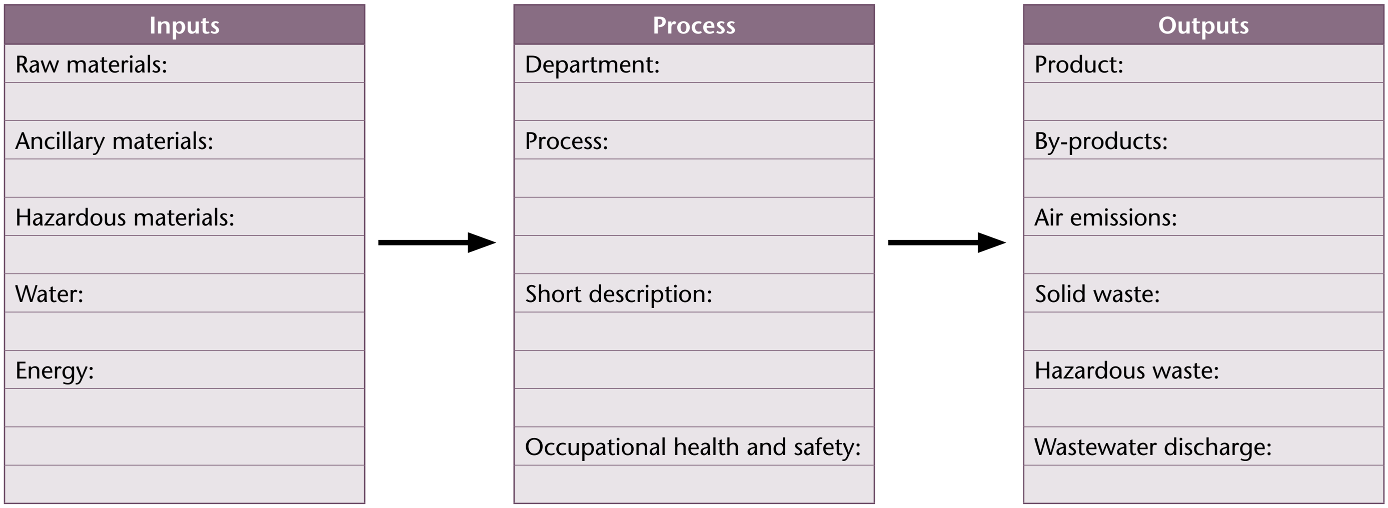
The last step of the pre-assessment phase is to establish a focus for further work. In an ideal case all processes and unit operations should be assessed. However time and resource constraints may make it necessary to select the most important aspects or process areas. It is common for Cleaner Production assessments to focus on those processes that:

Box 4.1 Checklist for Background Information

Type of information	Available	Not available	Requires updating	Not applicable
Process Information				
Process flow diagram				
Material balance data				
Energy balance data				
Site plans				
Drainage diagrams				
Operating procedures*				
Equipment list & specifications				
Regulatory Information				
Waste license(s)				
Trade waste agreement(s)				
Environmental monitoring records				
EPA license(s)				
Environmental audit reports				
Raw Material/Production Information				
Material safety data sheets				
Product & raw material inventories				
Production schedules				
Product composition & batch sheets				
Accounting Information				
Waste handling, treatment & disposal costs				
Water & sewer costs				
Product, energy & raw material costs				
Operating & maintenance costs				
Insurance costs				
Benchmarking data				

** Note whether the plant is ISO 9001 or ISO 14001 certified.*

Source: NSW-DSRD/NSW-EPA, 2000.



Inputs	Process	Outputs
Raw materials:	Department:	Product:
Ancillary materials:	Process:	By-products:
Hazardous materials:		Air emissions:
Water:	Short description:	Solid waste:
Energy:		Hazardous waste:
	Occupational health and safety:	Wastewater discharge:

Figure 4.2 *Example of an input/output worksheet [NSW-DSRD/NSW-EPA, 2000].*

- Generate a large quantity of waste and emissions.
- Use or produce hazardous chemicals and materials.
- Entail a high financial loss.
- Have numerous obvious Cleaner Production benefits.
- Are considered to be a problem by everyone involved.

For example, in order to meet new effluent regulations for chromium discharge, a tannery has to upgrade several aspects of its operation. In this case the assessment should focus on the chromium effluent problem.

All information collected during the pre-assessment phase should be well organised so that it is easily accessed and updated.

4.4 Assessment

The aim of the assessment phase is to collect data and evaluate the environmental performance and production efficiency of the company. Data collected about management activities can be used to monitor and control overall process efficiency, set targets and calculate monthly or yearly indicators. Data collected about operational activities can be used to evaluate the performance of a specific process.

4.4.1 Collection of Quantitative Data

It is important to collect data on the quantities of resources consumed and wastes and emissions generated. Data should be represented based on the scale of production. Collection and evaluation of data will most likely reveal losses. For instance, high electricity consumption outside production time may indicate leaking compressors or malfunctioning cooling systems. Input/output worksheets are useful documents in determining what data to collect. Most data will already be available within the company's recording systems, e.g. stock records, accounts, purchase receipts, waste disposal receipts and production data.

Box 4.2 Walk-through Inspection

Questions to be answered during a walk-through inspection:

- Are there signs of poor housekeeping?
- Are there noticeable spills or leaks? Is there any evidence of past spills, such as discolouration or corrosion on walls, work surfaces, ceilings and walls or pipes?
- Are water taps dripping or left running?
- Are there any signs of smoke, dirt or fumes to indicate material losses?
- Are there any strange odours or emissions that cause irritation to eyes, nose or throat?
- Is the noise level high?
- Are there open containers, stacked drums, or other indicators of poor storage procedures?
- Are all containers labelled with their contents and hazards?
- Have you noticed any waste and emissions being generated from process equipment (dripping water, steam, evaporation)?
- Do employees have any comments about the sources of waste and emissions in the company?
- Is emergency equipment (fire extinguishers etc.) available and visible to ensure rapid response to a fire, spill or other incident?

Source: NSW-DSRD/NSW-EPA, 2000.

Where information is not available, estimates or direct measurements will be required.

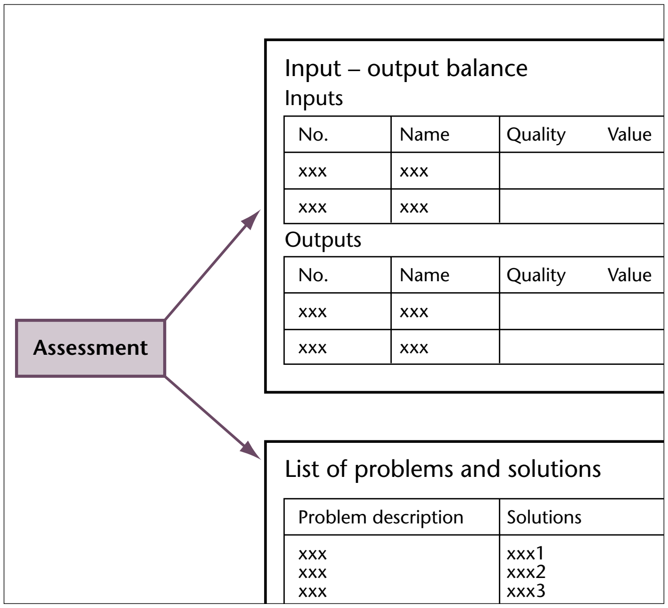
4.4.2 Material Balance

The purpose of undertaking a material balance is to account for the consumption of raw materials and services that are consumed by the process, and the losses, wastes and emissions resulting from the process. A material balance is based on the principle of "what comes into a plant or process must equal what comes out". Ideally inputs should equal outputs, but in practice this is rarely the case, and some judgment is required to determine what level of accuracy is acceptable.

Simply expressed, material or mass balance calculations are based on the following equation:

Total material in = material out (product)
+ material out (wastes)
+ material out (emissions)
+ material accumulated

A material balance makes it possible to identify and quantify previously unknown losses, wastes or emissions, and provide an indication of their sources and causes. Material balances are easier, more meaningful and more accurate when they are undertaken for individual unit operations. An overall company-wide material balance may then be constructed using these partial balances. The material balance sheets can also be used to identify the costs associated with inputs, outputs and identified losses. Presenting these costs to the management of the company often result in a speedy implementation of Cleaner Production options.



Input – output balance

Inputs

No.	Name	Quality	Value
xxx	xxx		
xxx	xxx		

Outputs

No.	Name	Quality	Value
xxx	xxx		
xxx	xxx		

List of problems and solutions

Problem description	Solutions
xxx xxx xxx	xxx1 xxx2 xxx3

Figure 4.3 *Assessment [UNEP, 1996a].*

Box 4.3
Sources of Material Balance Information

1. Samples, analyses, and flow measurements of feed stocks, products, and waste streams.
2. Raw material purchase records.
3. Material inventories.
4. Emission inventories.
5. Equipment cleaning and validation procedures.
6. Batch make-up records.
7. Product specifications.
8. Design material balance.
9. Production records.
10. Operating logs.
11. Standard operating procedures and operating manuals.
12. Waste manifests.

Source: UNEP, 1996a.

Box 4.3 lists the potential sources of material balance information.

While it is complicated to present a complete methodology for establishing a material balance, the following guidelines may be useful:

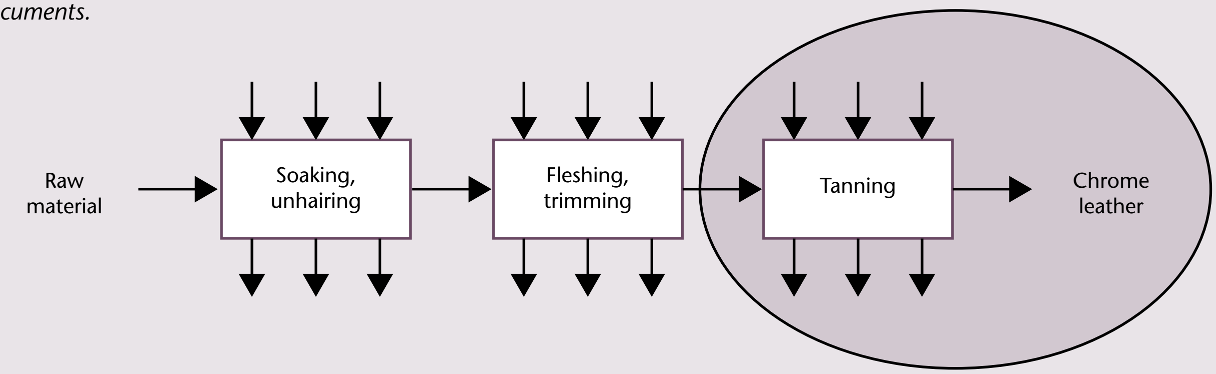
- Prepare a process flow chart for the entire process, showing as many inputs and outputs as possible.
- Sub-divide the total process into unit operations. Sub-division of unit operations should occur in such a way that there is the smallest possible number of streams entering and leaving the process.
- Do not spend a lot of time and resources trying to achieve a perfect material balance; even a preliminary material balance may reveal plenty of Cleaner Production opportunities.

Environmental performance indicators for the process can be developed from the material balance data. This is achieved by dividing the quantity of a material input or waste stream by the production over the same period. Performance indicators may be used to identify over consumption of resources or excessive waste generation by comparing them with those of other companies or figures quoted in the literature. They also help the company track its performance towards its environmental targets.

It is important to determine the true source of the waste stream. Impurities from an upstream process, poor process control, and

Case Study 4.2 Material Balance for Tanning in Leather Treatment

This example focuses on the constructing of material balance for the tanning process in leather treatment technology. *Please note that the figures used in this exercise do not represent a real situation. They are ball park figures drawn from various documents.*



Process inputs

Inputs and water usage:

Hides processed	40 tonnes/day
Process water (tannage)	30 m³/day
Rinse water (tannage)	140 m³/day
Total plant water	1800 m³/day
Tanolin (16% Cr)	2076 kg/day (322 kg Cr/day) (8 kg Cr/tonne of hides)

Waste reuse/recycling:

There is no recycling of waters or solids.

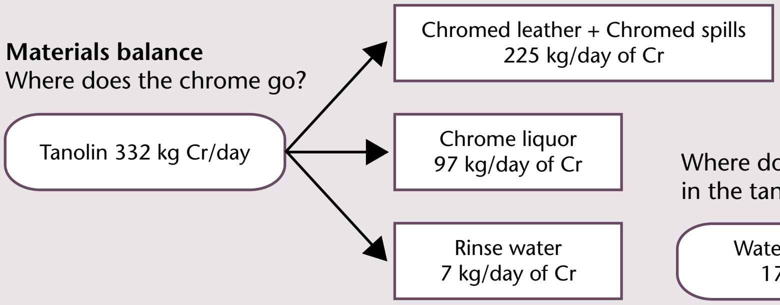
Expected absorption rate of Tanolin is 70% (i.e. 30% is wasted).

Process outputs

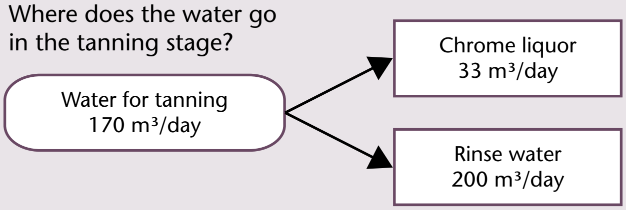
Chrome leather	7 tonnes/day
Trimmings and shavings	7 tonnes/day
(Containing together	*225 kg Cr/day)*
Tanning liquors	33 m³/day 90 kg Cr/day
Tanning rinse waters	200 m³/day 7 kg Cr/day
Total plant wastewater	1800 m³/day

Materials balance

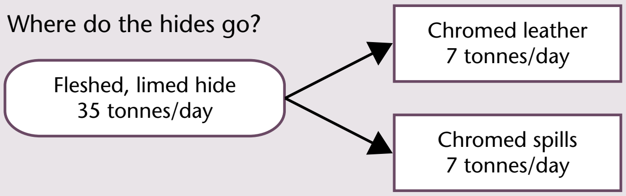
Where does the chrome go?



Where does the water go in the tanning stage?



Where do the hides go?



Source: UNEP, 1996b.

other factors may combine to contribute to waste. Unless these sources are identified and their relative importance established, the generation of Cleaner Production options is too limited. It may focus on a piece of equipment that emits the waste stream but produces only a small part of the waste.

In the example shown in Figure 4.4 the waste stream has four sources. Two of these sources are responsible for about 97% of the waste. However, because these sources were not identified beforehand, roughly equal numbers of options address all four sources. Fortunately, the causes of the waste stream were understood before the assessment was complete. But knowing the major sources of the waste beforehand would have saved time by allowing members to concentrate on them.

Depending on the findings in the initial assessment, the team may see the need to know more about specific details of wastes or energy use. This is done by conducting a detailed audit.

4.4.3 Identify Cleaner Production Opportunities

The Cleaner Production assessment phase starts with making a "diagnosis" of the process to identify shortcomings and their causes, as well as to find options for how to improve it (Figure 4.5). The assessment team uses all means possible to identify Cleaner Production options. Ideas may come from:

- Literature.
- Personal knowledge.
- Discussions with suppliers.
- Examples in other companies.
- Specialised databases.
- Further research and development.

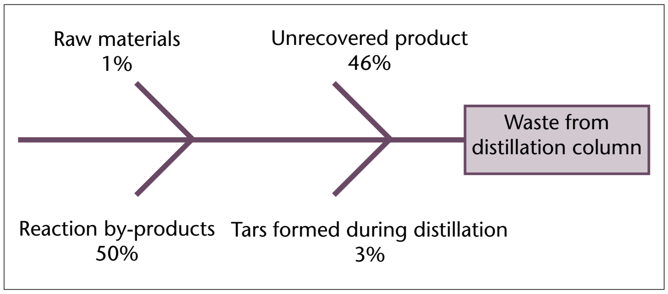


Figure 4.4 *Fishbone analysis of waste sources [UNEP, 1996a].*

It should be noted that during the assessment process, a number of obvious possibilities for immediate improvements may already have been identified. For example one of the simplest and obvious measures is reduction in water use or energy use.

One way to produce ideas for Cleaner Production opportunities is to run a brainstorming session. Brainstorming sessions have proved to be most effective when managers, engineers, process operators and other employees as well as some outside consultants, work together without hierarchical constraints.

Many Cleaner Production solutions are arrived at by carefully analysing the cause of a problem. Often the temptation is to jump from identifying where wastes and emissions are

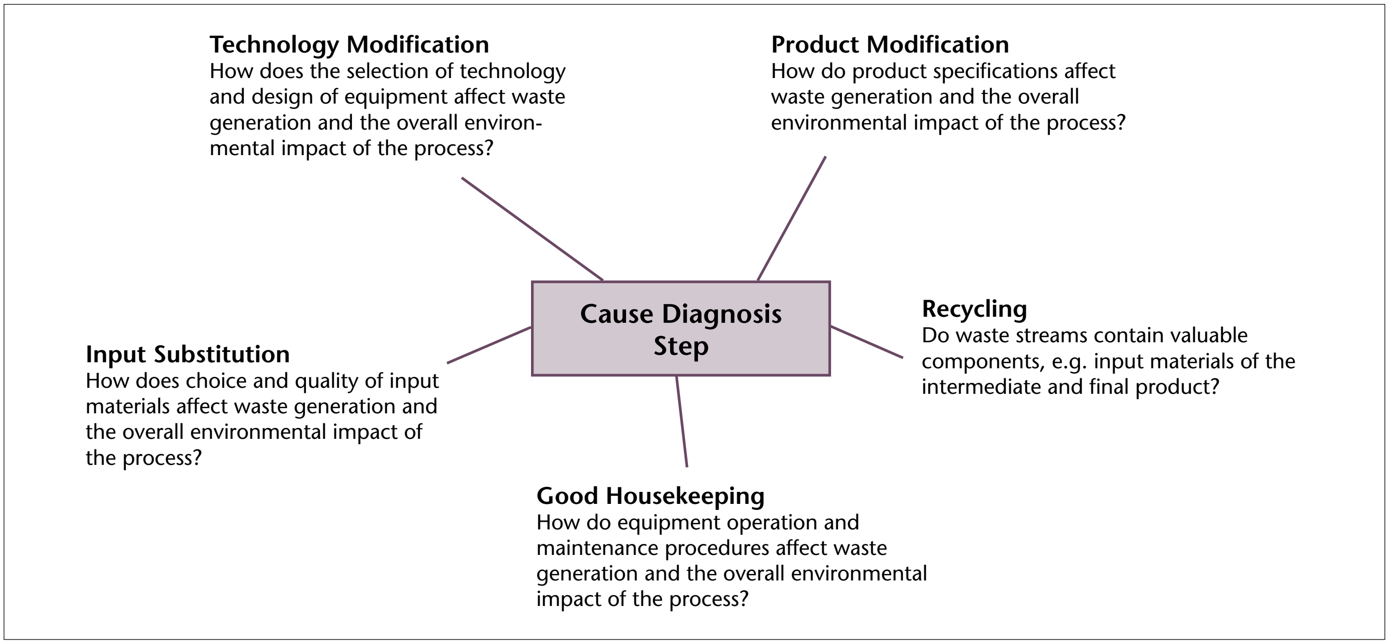


Figure 4.5 *Cause diagnosis [UNEP/DEPA, 2000].*

being generated directly to coming up with solutions how to prevent them. However, adding a middle diagnostic step is often a good idea. It provides additional information, which complements the Cleaner Production options. Five key areas of diagnosis of the causes are described in Figure 4.5.

Secondly the team focuses on Cleaner Production prevention practices. Here it is important to keep in mind that there are five features which influence the process, and which can serve as focus points for generating options:

1. Input materials.
2. Technology.
3. Execution of the process.
4. Product.
5. Waste and emissions.

Based on these five features that influence the environmental performance of a process, the corresponding points of action can be used to improve the environmental performance of the process (Figure 4.6). These are:

1. Input material changes or input substitution.
2. Technology changes or technology modifications.
3. Good housekeeping or good operating practices.
4. Product changes or product modifications.
5. Recycling.

We will briefly comment on each one of these in the following.

Input material changes may contribute to Cleaner Production by reducing or eliminating hazardous materials that enter the production process. Also, changes in input materials can be made to avoid the generation of hazardous wastes within the production processes. Input material changes are either material purification or material substitution.

Technology changes are oriented toward process and equipment modifications to reduce waste, primarily in a production setting. Technology changes range from minor alterations that are possible to implement in a matter of days at low costs, to the replacement of processes involving large capital costs. These may be changes in the production process; introducing new equipment, layout, or piping changes; introducing the use of automation; and implementing changes in process conditions such as flow rates, temperatures, pressures and residence times.

Good housekeeping implies procedural, administrative, or institutional measures that a company can use to minimise waste. Many of these measures are used in larger industries as efficiency improvements and good management practices. Good housekeeping practices can often be implemented in all areas of the plant, including production, maintenance operations, and raw material and product storage. Good housekeeping or operating practices include the following:

- Cleaner Production programmes, as described in this chapter.
- Management and personnel practices, including employees training, incentives and bonuses, and other

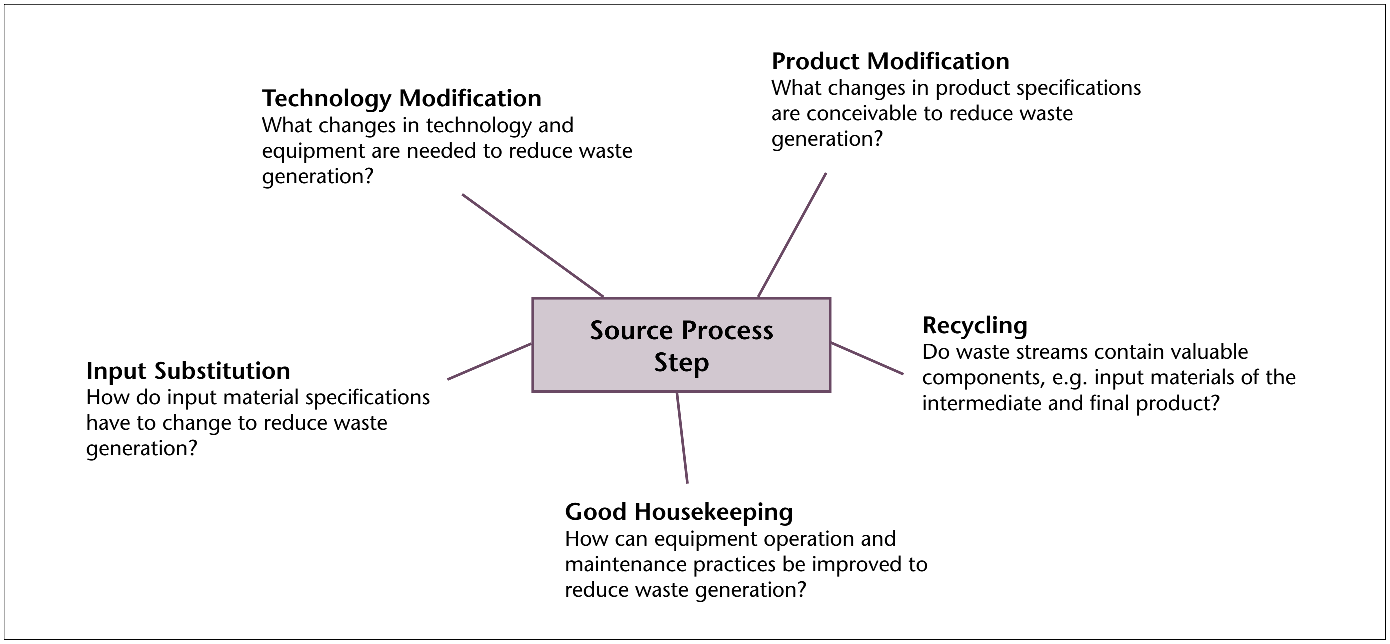


Figure 4.6 *Cleaner Production prevention practices [UNEP/DEPA, 2000].*

programmes that encourage employees to conscientiously work to reduce waste.

- Material handling and inventory practices, including programmes to reduce loss of input materials due to mishandling, expired shelf life of time-sensitive materials, and proper storage conditions.
- Loss prevention, minimising wastes by avoiding leaks from equipment and spills.
- Waste segregation, reducing the volume of hazardous wastes by preventing the mixing of hazardous and non-hazardous wastes.
- Cost accounting practices, including programmes to allocate waste treatment and disposal costs directly to the department or groups that generate waste, rather than charging these costs to general company overhead accounts. In doing so, the departments or groups that generate the waste become more aware of the effects of their treatment and disposal practices, and have a financial motivation to minimise their waste.
- Production scheduling, and scheduling batch production runs. This way the frequency of equipment cleaning and the resulting waste can be reduced. It is at this stage also that the energy efficiency of the process, and of the general plant operations, can be considered.

Product changes are performed by the manufacturer of a product with the intent of reducing waste resulting from a product's use. Product changes include:

- Product substitution.
- Product conservation.
- Changes in product composition.

Product modification is about changing the characteristics of a product such as its shape and material composition. Eight groups of strategies have been identified for the reduction of environmental impacts in products, and summarised in the so-called *ecodesign strategy wheel* (Figure 4.7). By working through the categories and mapping them on this ecodesign strategy wheel, a product's environmental improvement options soon become more clear (See Book 3 in this series).

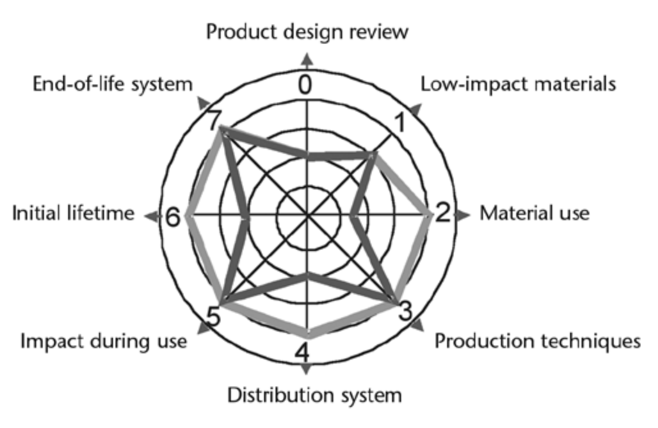


Figure 4.7 *Ecodesign strategy wheel [Hemel and Brezet, 1997 & Van Hemel, 1995].*

Recycling via use and/or reuse involves the return of a waste material either to the originating process as a substitute for an input material, or to another process as an input material.

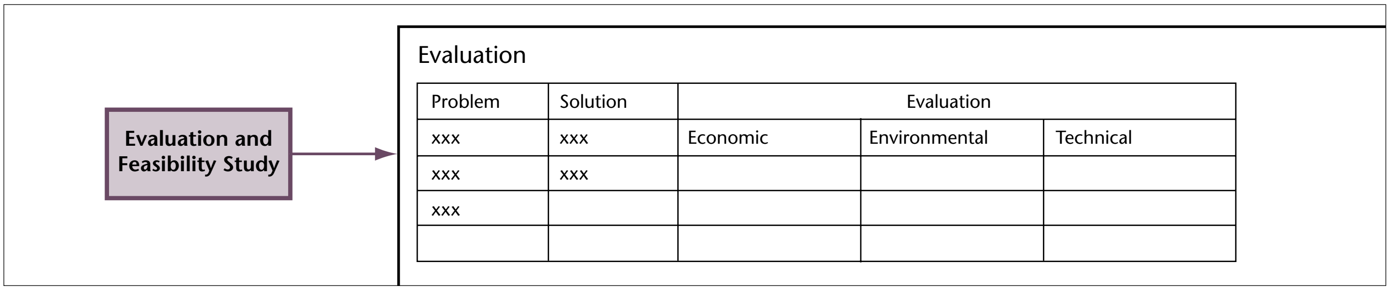
4.4.4 Record and Sort Options

Once a number of Cleaner Production opportunities have been suggested and recorded, they should be sorted into those that can be implemented directly and those that require further investigation. It is helpful to follow the steps:

- Organise the options according to unit operations or process areas, or according to inputs/outputs categories (e.g. problems that cause high water consumption).
- Identify any mutually interfering options, since implementation of one option may affect the other.
- Opportunities that are cost free or low cost, that do not require an extensive feasibility study, or that are relatively easy to implement should be implemented immediately.
- Opportunities that are obviously infeasible, or cannot be implemented should be eliminated from the list of options for further study.

Table 4.2 *Example of information recorded for identified options [UNEP, 1996a].*

Problem type	Problem description	Cleaner Production Options
- resource consumption - energy consumption - air pollution - solid waste - wastewater - hazardous waste - occupational health and safety	- name of process and department - short background of problem - amount of materials lost or concentration of pollutants - money lost due to lost resources	- how the problem can be solved - short-term solution - long-term solution - estimated reductions in resource consumption and waste generation



Problem	Solution	Evaluation		
xxx	xxx	Economic	Environmental	Technical
xxx	xxx			
xxx				

Figure 4.8 *Evaluation and feasibility study phase [UNEP, 1996a].*

4.5 Evaluation and Feasibility Study

The objective of the evaluation and feasibility study phase is to evaluate the proposed Cleaner Production opportunities and to select those suitable for implementation. The opportunities selected during the assessment phase should all be evaluated according to their technical, economic and environmental merits. However, the depth of the study depends on the type of project. Complex projects naturally require more thought than simple projects.

4.5.1 Preliminary Evaluation

The quickest and easiest method of evaluating the different options is to form a group, consisting of the project team and management personnel, and discuss the possible solutions one by one. This process should give a good indication of which projects are feasible and what further information is required.

4.5.2 Technical Evaluation

The potential impacts on products, production processes and safety concerns of the proposed changes need to be evaluated before complex and costly projects can be decided upon. In addition, laboratory testing or trial runs may be required when options significantly change existing practices. A technical evaluation will determine whether the opportunity requires staff changes or additional training or maintenance. An example is described in Case Study 4.3.

4.5.3 Economic Evaluation

The objective of this step is to evaluate the cost effectiveness of the Cleaner Production opportunities. Economic viability is often the key parameter that determines whether or not an opportunity will be implemented.

Case Study 4.3 An Example of Technical Evaluation

An insulation manufacturer came up with an option to replace the main raw material for its primary product with another material. The following table shows a before and after comparison, forming part of the technical evaluation.

Consumption rates	Before implementation	After implementation
Main raw material in solid waste	120 tonnes/year	0 tonnes/year
Resin fumes	5 m^3/year (estimated)	0/year
Energy		>50% reduction (no extraction equipment used to remove fumes, no heating of raw material required)
Reject products (in solid waste)	7.5% of product	1% of product
Transport		Reduced for main raw material as it is lighter and less bulky
Storage		Reduced for main raw material as it is lighter and less bulky
Productivity		>200% improvement, ie takes less than half the time to process new raw material
Product cost		Reduced due to lower cost of main raw material

Source: CECP, 2001.

Case Study 4.4 Calculation of the Net Present Value (NPV) for a CP Investment in a Tannery

A tannery considers spending USD 351,120 for the installation of four special drums in order to use Cleaner Production process for un-hairing hides.

Yearly savings will be USD 87,780 in reduced chemical costs. The pay back period is therefore 4 years.

The tannery will need to borrow money in order to fund this project. The interest rate for the loan is 8.5%. The loan will be for the full USD 351,120 investment and will be for a four-year term. The NPV is then USD 63,557.

As the NPV is positive, the project is financially viable. If the drums have a longer life time than 4 years the NPV will increase by USD 87,780 each additional year.

Source: UNEP, 1996b.

$$\text{NPV} = -351120 + \frac{87780}{(1+0.085)^1} + \frac{87780}{(1+0.085)^2} + \frac{87780}{(1+0.085)^3} + \frac{87780}{(1+0.085)^4} = 63557$$

Box 4.4
Aspects to be Considered in the CP Evaluation

Preliminary evaluation

- Is the Cleaner Production option available?
- Can a supplier be found to provide the necessary equipment or input material?
- Are consultants available to help develop an alternative?
- Has this Cleaner Production opportunity been applied elsewhere? If so, what have been the results and experience?
- Does the option fit in with the way the company is run?

Technical evaluation

- Will the option compromise the company's product?
- What are the consequences for internal logistics, processing time and production planning?
- Will adjustments need to be made in other parts of the company?
- Does the change require additional training of staff and employees?

Economic evaluation

- What are the expected costs and benefits?
- Can an estimate of required capital investment be made?
- Can an estimate of the financial savings be made, such as reductions in environmental costs, waste treatment costs, material costs or improvements to the quality of the product?

Environmental evaluation

- What is the expected environmental effect of the option?
- How significant is the estimated reduction in wastes or emissions?
- Will the option affect public or operator health (positive or negative)? If so, what is the magnitude of these effects in terms of toxicity and exposure?

Source: CECP, 2001.

When performing the economic evaluation, costs of the change are weighed against the savings that may result. Costs can be broken into capital investments and operating costs.

Investment capital estimates can be broadly classified in three types according to the accuracy and purpose of the estimate.

1. *Preliminary feasibility estimates* are used for initial feasibility studies and to make rough choices between design alternatives. The accuracy of theses estimates is in the order of ± 30%. *Feasibility estimates* are often made on capital cost information for a complete process taken from previously built plants. The cost information is adjusted using scaling factors for capacity and for inflation to obtain the estimated capital cost.

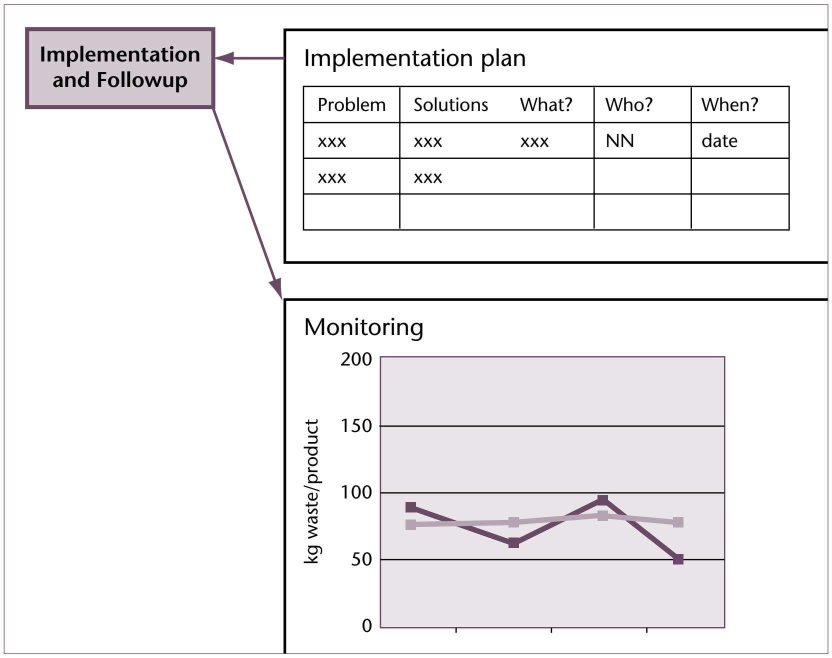
$C_2 = C_1 (S_2/S_1)n$

where
C_1 = capital cost of the project with capacity S_1.
C_2 = capital cost of the project with capacity S_2.
n = cost factor. The empirical value for process plants, for individual units of equipment the value varies from ca 0.3 to 0.8.

Major equipment estimates provide more accurate (± 30%) capital estimates. In this method all major process equipment is roughly sized and the approximate purchased equipment cost is calculated. The total cost of the equipment is then factored for installation, piping, instrumentation, electrical installations, utilities, buildings, foundations etc. to give the total estimated process cost. The so called Lang factor for a mixed fluids-solids processing plant indicates that the total capital investment is 3.6 times the cost of the major process equipment.

2. *Budget (or Authorisation) estimates*, with accuracy of ± 10-15%, are used for authorisation of funds to proceed with the design to the point where a more accurate estimate can be

Figure 4.9 *Implementation and continuation phase [CECP, 2001].*



made. This type of estimate requires preliminary specifications of all the equipment, utilities, instrumentation, electrical and off-site installations of the process.

3. Detailed (Quotation) estimates, accuracy ± 5-10%, are used for project cost control and for contractor negotiations. This type requires complete, detailed process design, firm quotations for equipment and detailed breakdown and estimation of construction cost.

Operating costs include *direct manufacturing costs* such as raw materials, waste treatment, utilities, labour costs, maintenance and repairs, *fixed manufacturing costs* which include capital costs (interest), depreciation of the installed equipment, taxes, insurance and plant overhead costs. The operating costs also include *general costs* shared with other parts of the company such as administration, distribution and sales costs and costs for research and development.

Standard parameters used to evaluate the economic feasibility of a project are pay back period, net present value (NPV), or internal rate of return (IRR).

As an example we can take a tannery, which will have to spend USD 351,120 for the installation of four special drums in order to use a Cleaner Production process for un-hairing hides, rather than using a chemical method. The annual savings is estimated to be USD 87,780 in reduced chemical costs. The pay back period is therefore 4 years.

A more accurate evaluation of the financial viability of a project is obtained by calculating its net present value (Case Study 4.4). The NPV is calculated using the formula.

$$\text{NPV} = \text{CF}_0 + \frac{\text{CF}_1}{(1+r)^1} + \frac{\text{CF}_2}{(1+r)^2} + \frac{\text{CF}_3}{(1+r)^3} + \dots + \frac{\text{CF}_n}{(1+r)^n}$$

CF_x =cash flow in period x, n=the number of periods (normally the expected lifetime of the project).
r=the discount rate.
CF_0 =investment cost, which will be negative as it is money paid out.

Choosing the correct discount rate is a very important part of any NPV calculation. As it is essentially an interest rate, there are two basic ways of selecting which rate to use.

- If you are going to borrow capital to implement the project you can simply use the interest rate you will be charged on the loan.
- If you will not take a loan to fund the project, use the interest rate you would receive if you were to invest the money.

Most companies will add a small risk margin of 2-5% to the discount rate, for example, in case interest rates go up. If you are taking a loan, you may also want to take into account the effect on the discount rate of the tax deductions allowable on interest payments for business loans.

The IRR method is evaluating projects in the opposite way to the NPV method. It enables you to calculate the interest rate equivalent to the return expected from the project over its lifetime. When this rate is known, it can be compared to the rates you would receive if you invested the money elsewhere. Generally, if the IRR is higher than cost for a loan, then the project is financially viable.

Calculation of IRR is based on the same equation as NPV, but now the equation is solved for r.

$$0 = \text{CF}_0 + \frac{\text{CF}_1}{(1+r)^1} + \frac{\text{CF}_2}{(1+r)^2} + \frac{\text{CF}_3}{(1+r)^3} + \dots + \frac{\text{CF}_n}{(1+r)^n}$$

The capital investment is the sum of the fixed capital costs of design, equipment purchase, installation and commissioning, costs of working capital, licenses, training, and financing. Operating costs, if different from existing conditions, will need to be calculated. It may be that operating costs are reduced as a result of the change. In this case it should be accounted for in the evaluation as an ongoing savings.

4.5.4 Environmental Evaluation

The objective of the environmental evaluation is to determine the positive and negative environmental impacts of the proposed Cleaner Production option. In many cases the environmental advantages are obvious: a net reduction in toxicity and/or quantity of wastes or emissions. In other cases it may be necessary to evaluate whether an increase in electricity consumption, for instance, would outweigh the environmental advantages of reducing the consumption of materials.

For a good environmental evaluation, the following information is needed:

- Changes in amount and toxicity of wastes or emissions.
- Changes in energy consumption.
- Changes in material consumption.
- Changes in degradability of the wastes or emissions.
- Changes in the extent to which renewable raw materials are used.
- Changes in the reusability of waste streams and emissions.
- Changes in the environmental impacts of the product.

In many cases it will be impossible to collect all the data necessary for a good environmental evaluation. In such cases a qualified assessment will have to be made on the basis of the existing information. Given the wide range of environmental issues, it will probably be necessary to prioritise those issues of greatest concern. In line with the national environmental policy of the country or the company, some issues may have a higher priority than others.

4.5.5 Select Viable Options

The most promising options must be selected in close collaboration with the management of the company.

A comparative ranking analysis may be used to prioritise opportunities for implementation. The concept of such a method is shown below in Table 4.3. An option can be assigned scores, say from 1 to 10, based on its performance against a set of evaluation criteria. By multiplying each score by a relative weight assigned to each criterion, a final score can be arrived at. The options with the highest scores will probably be best suited for implementation. However, the results of this analysis should not be blindly accepted. Instead, they should form a starting point for a discussion. All simple, cost-free and low-cost opportunities should of course be implemented as soon as possible.

4.6 Implementation and Continuation

The objective of the last phase of the assessment is to ensure that the selected options are implemented, and that the resulting reductions in resource consumption and waste generation are monitored continuously.

4.6.1 Prepare an Implementation Plan

To ensure implementation of the selected options, an action plan should be developed, detailing:

Table 4.3 *Example of a weighted sum method for evaluating alternative options [CECP, 2001].*

Evaluation criterion	Weight	Score*					
		Option A		Option B		Option C	
		score	weighed score	score	weighed score	score	weighed score
Reduced hazardous waste treatment	3	+3	9	+2	6	+3	9
Reduced wastewater treatment costs	3	+1	3	0	0	+2	6
Reduced amount of solid waste	3	+3	9	+2	6	+3	9
Reduced exposure to chemicals	2	+3	6	0	0	-1	-2
Reduced amount of water consumption	1	+1	1	0	0	+2	2
Reduced odours problems	1	0	0	-1	-1	0	0
Reduced noise problems	1	-2	-2	0	0	0	0
Easy to install and maintain	3	-1	-3	-1	-3	+1	3
Weighted sum			23		8		27

-3 = lowest rank, 0 = no change, +3 = highest rank (preferred)

- Activities to be carried out.
- The way in which the activities are to carried out.
- Resource requirements (finance and manpower).
- The persons responsible for undertaking those activities.
- A time frame for completion with intermediate milestones.

4.6.2 Implement Selected Options

As for other investment projects, the implementation of Cleaner Production options involves modifications to operating procedures and/or processes and may require new equipment. The company should, therefore, follow the same procedures as it uses for implementation of any other company projects. However, special attention should be paid to the need for training of the staff. The project could be a failure if it is not backed up by adequately trained employees. Training needs should have been identified during the technical evaluation.

4.6.3 Monitor Performance

It is very important to evaluate the effectiveness of the implemented Cleaner Production options. Typical indicators for improved performance are:

- Reductions in wastes and emissions per unit of production.
- Reductions in resource consumption (including energy) per unit of production.
- Improved profitability.

There should be periodic monitoring to determine whether positive changes are occurring and whether the company is progressing toward its targets. Examples of the types of aspects that could be checked to evaluate improvements are shown in Table 4.4.

The most important steps in establishing or upgrading an environmental monitoring system are to agree on the objectives of the system and design the system to address these objectives. Monitoring methodologies for the different pollutants of concern, and monitoring planning are described elsewhere. Case Study 4.5 describes a monitoring and reporting case from an iron and steel manufacturing industry, which is implementing a World Bank pollution-related project.

4.6.4 Sustain Cleaner Production Activities

Sustained Cleaner Production is best achieved when it becomes part of the management through a formal company environ-

Table 4.4 *Evaluation checklist [UNEP, 1996a].*

	YES	NO
Overall Cleaner Production assessment check - Are the opportunities implemented according to the action plan? - Are new procedures being followed correctly by the employees? - Where do problems occur and why? - Do licenses or permits require amendments? Which ones? - Has compliance with legislation been maintained as a result of the changes?		
Environmental performance check - Are the opportunities cost effective? Is the cost effectiveness as expected? - Has the number of waste and emission sources decreased? By how many? - Has the total amount of waste and emissions decreased? By how much? - Has the toxicity of the waste and emissions decreased? By how much? - Has the energy consumption decreased? By how much? - Have the Cleaner Production goals been achieved? Which have and which have not? - Have there been any technical ramifications? What are they and why?		
Documentation check (The following items should be included in the files.) - Statements of the company's objectives and targets and the environmental policy - Company description and flow diagram with input and outputs - Worksheets completed during the Cleaner Production assessment - Material balances - List of Cleaner Production opportunities generated during brainstorming sessions - Lists of opportunities that are technically, economically and environmentally feasible - Implementation action plan - Monitoring data - 'Before-and-after' comparisons - Post-implementation evaluation reports		

Case Study 4.5 Environmental Monitoring in an Iron and Steal Manufacturing Plant Implemented as Part of a World Bank Project

Air emissions should be monitored continuously after the air pollution control device for particulate matter (or alternatively an opacity level of less than 10%) and annually for sulphur oxides, nitrogen oxides (with regular monitoring of sulphur in the ores) and fluoride. Wastewater discharges should be monitored daily for the listed parameters, except for metals, which should be monitored at least on a quarterly basis. Frequent sampling may be required during start-up and upset conditions.

Source: The World Bank Group, 1999.

mental management system or a total environmental quality management approach. An environmental management system provides a decision-making structure and action plan to support continuous environmental improvements, such as the implementation of Cleaner Production. If a company has already established an environmental management system, the Cleaner Production assessment can be an effective tool for focusing attention on specific environmental problems. If, on the other hand, the company establishes a Cleaner Production assessment first, this can provide the foundations of an environmental management system.

Abbreviations

DEPA	Danish Environmental Protection Authority.
EMS	Environmental Management System.
EPA	Environmental Protection Authority.
IRR	Internal Rate of Return.
NPV	Net Present Value.
NSW	New South Wales.
PPAH	Pollution Prevention and Abatement Handbook, The World Bank Group.
UNEP	United Nations Environment Programme.
UNIDO	United Nations Industrial Development Organisation.

Study Questions

1. Describe the Cleaner Production assessment methodology of UNEP/UNIDO.
2. How may the implementation of Cleaner Production assessment methodologies in companies give environmental and economic benefits?
3. Which company specialists should be included in a project team for the analysis and review of present practices and development of Cleaner Production initiatives? Which questions should first be considered? Determine the sources of information.
4. What does the material balance mean?
5. How is it possible to accomplish a Cleaner Production programme in a company? Give some examples of good housekeeping in companies, product changes and so on.
6. In which way may the environmental, economic and technical effectiveness of a project be evaluated? Write the formula for calculating the NPV and other methods of evaluation.
7. What should be included in an action plan for Cleaner Production implementation?

Internet Resources

Centre of Excellence in Cleaner Production (CEPE)
http://cleanerproduction.curtin.edu.au

The University of Queensland, Australia, School of Geography, Planning, Architecture – Cleaner Production Programme
http://www.gpa.uq.edu.au/CleanProd/

New South Wales Department of State and Regional Development – Cleaner Production in Small Businesses
http://www.smallbiz.nsw.gov.au/smallbusiness/Technology+in+Business/Cleaner+Production/

United Nations Industrial Development Organisation (UNIDO)
http://www.unido.org/

The International Institute for Industrial Environmental Economics at Lund University
http://www.iiiee.lu.se/

United Nations Environment Programme Division of Technology, Industry, and Economics (UNEP DTIE) – CP Assessment in Industries
http://www.uneptie.org/PC/cp/understanding_cp/cp_industries.htm

5

Tracking Environmental Performance

5.1 Environmental Performance Evaluation

5.1.1 Environmental Performance is Difficult to Assess

Environmental Performance Evaluation (EPE), is the evaluation of the environmental performance of an organisation or company in relation to its environmental goals. To conduct such an evaluation may be quite a large and complex job. It requires that you define criteria, select indicators, measure and analyse them, and finally assesses and report the results. Environmental issues are complex and often difficult to quantify. Relating the environmental impact of a company with its different economic activities is problematic, but essential. Without performance evaluation the environmental policy of a company loses much of its value.

Decision-making and management of complex issues requires a method for representing these issues by simple units of measure, i.e. indicators. It is obvious that the information required for decision-making varies with the type of decision to be made, the context of the decision-making and the stakeholders involved [Viegas, 2005].

What is needed for an effective control is an information management that is concise and possible to validate. This is a reason why indicators have long been used in business management to summarise abundant data and to support managers in their decision-making (See further, Internet Resources: *How and Why of Environmental Indicators*).

5.1.2 Environmental Performance Evaluation, EPE

Environmental performance evaluation (EPE) is the ongoing evaluation of the environmental performance of an organisation. It is a method to measure the results of its management of the environmental aspects of activities, products, or services. EPE is based on the saying "what gets measured gets managed" [Kuhre, 1998].

In this Chapter

The information generated by EPE can assist an organisation to [Olsthorn et al., 2000]:

- Determine if its environmental objectives and targets are being met.
- Identify significant environmental aspects.
- Identify opportunities for better management of its environmental aspects (e.g. cleaner production and pollution prevention).
- Provide a basis for benchmarking of the management, operational and environmental performance.
- Identify trends in its environmental performance.
- Increase the organisation's efficiency and effectiveness.
- Demonstrate compliance with regulations.
- Determine proper allocation of resources.
- Increase the awareness of employees.
- Improve community and customer relations.
- Identify strategic opportunities.

The scope of environmental performance evaluation is very broad and is usually conducted by larger organisations on a continuous basis. Before the term EPE received its current meaning there have been several approaches to how to evaluate the environmental performance of an organisation using some kind of agreed criteria. The basic principles of Environmental Indicator Systems are outlined in Box 5.1. EPE is defined by the International Organisation for Standardisation in standard ISO 14031:1999. Below we will in principle follow this standard.

5.1.3 The EPE Process

EPE, as outlined in ISO 14031, follows the Deming cycle management model, "Plan-Do-Check-Act". ISO 14031:1999 recommends that the overall EPE process includes seven major steps. They are the following:

1. Planning.
2. Collection of data.
3. Analysis.
4. Conversion into indicators.
5. Evaluation of information.
6. Comparison against criteria.
7. Reporting.

Many of these steps have subcomponents. For example, the planning step should be composed of management considerations and the selection of appropriate indicators. The overall process should be reviewed and continually improved. Therefore, the main goal of environmental indicators is to summarise extensive environmental data into significant and comparable key information.

In the description below of environmental performance indicators we will mainly follow D. Heinemann et al. *A Guidebook to Environmental Indicators* published by CSIRO (Commonwealth Scientific and Industrial Research Organisation) Australia in 1998-1999.

5.2 Environmental Performance Indicators

5.2.1 What is an Environmental Performance Indicator?

Using indicators is the recommended way for an organisation to follow and communicate its environmental performance. Indicators are quantitative measures, which reflect the status of significant environmental aspects associated with the

Box 5.1 Basic Principles of Environmental Indicator Systems

Comparability
The indicators must allow comparisons to be made and must reflect changes of environmental impact.

Target orientation
The selected indicators should pursue improvement goals that can be influenced by the company.

Balance
The indicators must represent the environmental performance as accurately as possible and provide a balanced illustration of environmental problem areas as well as improvement potential.

Continuity
In order to compare indicators, it is essential that they are established with the same data collection criteria in every period, that they refer to comparable intervals, and that they are measured in comparable units.

Time lines
The indicators should be determined in short enough intervals (e.g. monthly, quarterly, annually) in order to have the opportunity of actively pursuing and influencing the achievement of target figures, and to avoid providing outdated information.

Clarity
The indicators must be clear and comprehensive for the user and correspond to the user's information requirements. The system should therefore be coherent and concentrated on essential data.

Source: BMU/UBA, 2003.

organisation. The emphasis should be on indicators that the organisation can control or influence in a positive and measurable way.

Environmental indicators can be established for the three core evaluation areas or systems of a company. These are:

- Management.
- Operation.
- Environmental evaluation.

An indicator may apply to one or all three of these areas. Many of the indicators and evaluation areas are interrelated. For organisations that have implemented an environmental management system the indicators should relate to its environmental policy, goals, and targets as well as its normal business functions.

EMS and tools for environmental analysis come with an abundance of concepts and terms. Sometimes different meanings are used for the same expression and several words are used for a concept. In order to minimise the confusion in terminology ISO has developed a special standard, ISO 14050:2002 *Environmental Management Vocabulary*. The ISO 14050 definitions and terms are used throughout this chapter.

5.2.2 Core Principles of Environmental Performance Indicators

There have been various attempts to identify what constitutes a good Environmental Performance Indicator (EPI). Some important features of EPIs are the following [Ammenberg et al., 2001]:

- Show today's performance and targets, not last week's.
- Provide a means of communication.
- Point out the evolution of the environmental results.
- Connect company actions and environmental results.
- Be simple and understandable; complex statistics are not helpful.
- Be appropriate for the users.
- Be measurable against objectives.
- Show progress.
- Be challenging yet attainable.
- Be easily measurable and transparent.
- Be owned by the staff who use them.
- Be documented.
- Use existing data.

5.2.3 Selecting Environmental Performance Indicators

When choosing indicators it is important to be selective, and not create indicators for their own sake. Indicators are tools for judging the success or failure of environmental actions. Distortion of the purpose and value of indicators will be avoided if a realistic view is maintained of their uses and limitations and of the need to develop practical, soundly-based methodologies for their development and use. The advices below are from *A Guidebook to Environmental Indicators* [Heinemann et al., 1998-1999].

Environmental indicators should serve management processes, which, to an increasing degree, focus on *integrating all aspects of sustainability* in its considerations. Therefore robust management solutions require attention to environmental as well as social and economic factors.

Indicators *need to deliver information of use to managers*. The science behind an indicator may be complicated, but the interpretation and use of an indicator must be simple and straightforward. Complex or obscure indicators will do more harm than good.

Timeliness is another consideration; indicator data must be available when decisions are being made.

A good indicator provides *information of the links between a human activity and its consequences*. Where causal links between activities and effects are well understood, it may be possible to use indicators as early warning signals. Stratospheric ozone depletion is a good illustration of this.

While some human activities harm the environment, *others are beneficial*. It is important to avoid the mindset that all human activities are negative.

The *nature of the activities and impacts* should be assessed as part of choosing indicators. Indicators depend on whether human impacts are acute or chronic, local or regional, and limited or cumulative in effect. Activities such as fishing, agriculture, and driving cars, have a continued effect on the environment. Others may fluctuate strongly, such as accidents, but may affect the environment seriously.

A range of scales in space and time apply to environmental management. Careful account must be taken of this when selecting indicators. The scale associated with the indicator will depend on the objective of the management.

5.2.4 Approaches to Data Collection

Both existing and new data can be used. Raw data are often expensive to collect, so it is important for indicators to make use, where possible, of all available data, even if collected for other purposes. On the same grounds, indicators that can be used for several purposes or by more than one group should be preferred to those with a single application. However, where new information is critical to the management goal, it must be collected.

A monitoring program is often needed for indicators to establish the facts and the trends. A trade-off may be necessary between the cost of monitoring and the quality of the information acquired. The most cost-effective indicators should be chosen, and the cheapest options are not necessarily the most effective. A monitoring program of repeated measurements of the indicator, in various places and times and in a defined way, will give the basis for detecting environmental change, through comparison with a benchmark set or condition.

The indicator must also reflect the aspect of the system that is the objective of the monitoring. It may be a key species which provides information about the system and other species dependent on it or a key process, which reflects changes in ecosystem, landscape or river basin scale processes.

An assessment should be made of risks associated with the choice of indicators. This will be based on how critical it is to monitor a particular system and whether the indicator will provide sufficient information about the changes in the system to manage them better. Where it is too expensive to provide a desirable level of accuracy, it may be necessary to trade-off maximum benefits and use a less accurate indicator (a surrogate): the fact that a compromise has been made should be made clear.

Finally, the indicator's effectiveness and efficiency in representing the state of the system must be addressed. Is measurement of the indicator feasible in technological and logistic terms? Are measurements repeatable? Will the data give a statistically representative sample from the system? Is aggregation of the data within larger regions feasible? Can the indicator be combined with similar indicators collected in other regions?

5.3 Types of Environmental Indicators

5.3.1 Absolute and Relative Environmental Indicators

A distinction must be made between the absolute and relative environmental indicators [INEM, 1999].

From an ecological view-point, the absolute indicators are the primary focus, since they represent the organisation's consumption of resources and emission of polluting substances (e.g. energy consumption in kilowatt hours or amount of waste in tonnes).

Absolute indicators can be recorded for time periods of several months or years in a time series analysis, and supply the basis for deriving environmental objectives and targets. In comparing efficiency aspects, however, these absolute indicators must be expressed in relation to valid reference figures (e.g. annual output volume, number of staff members, or machine operation time).

Examples could be the energy consumption per manufactured product, the amount of waste per ton of manufactured products, or the consumption of copying paper per staff member. The relative indicators therefore demonstrate a organisation's environmental performance relative to its size or production capacity.

While absolute indicators describe the extent of environmental pollution, relative indicators demonstrate whether environmental measures produce efficiency improvements. Absolute and relative indicators therefore represent two ways of looking at the same issue. For a comprehensive evaluation, both the absolute and the relative indicators must be taken into consideration. The implication of a relative indicator can hardly be evaluated without the absolute basic data (e.g. for an increase in production or a decline in production) and vice versa.

5.3.2 Corporate, Site and Process Related Environmental Indicators

Environmental indicators can refer to different departments of the same company and can therefore be derived from data of the entire company, of individual plants or sites, and of specific production processes or departments. They can therefore be divided into corporate, site and process indicators [BMU/UBA, 2003].

Indicators determined at the lowest organisational level (production process) are well suited as planning, controlling and monitoring instruments for the department concerned. In order to detect weak points and initiate corrective measures early, it is advisable to determine them in shorter intervals (e.g. quarterly, monthly, or weekly).

Determining process indicators is especially important for the main source of consumption of resources and the main cause of emissions.

Site and corporate indicators, on the other hand, serve as a general performance information tool for environmental management over a longer period of time as well as internal information (e.g. in the annual executive report). Site indicators can additionally be used for illustrating environmental impacts in environmental statements.

5.3.3 Quantity and Cost-related Environmental Indicators

Environmental indicators are usually quantity-related, i.e. in physical measurements such as kilograms, tonnes, items, etc. Due to the increasing relevance of cost aspects in environmental protection, cost-related indicators can be developed at the same time (environmental cost indicators).

During the initiation phase of establishing indicators, it is sometimes not possible to obtain quantity-related data, while the accounting department can supply the necessary data on related expenditures. For example, if the exact composition of the disposed amount of waste is not available, the waste disposal costs can be used to determine waste indicators: the quantity-related indicator "amount of waste in kilograms per output in tonnes" is then substituted by the indicator "waste disposal costs per production costs".

Another advantage of cost-related environmental indicators is the fact that environmental issues are translated into costs and revenues i.e. the management's language. An executive manager may not be able to imagine what effect 450 cubic meters of hazardous waste has on revenues, and whether it is worthwhile to have a waste avoidance study conducted. However, if the same amount is represented by waste disposal costs, it will usually be given a different priority. By adding indirect waste disposal costs (storage, transportation, personnel and purchasing expenditures of the materials for disposal) to the pure waste disposal fees, good reasoning for cost effective environmental protection measures can be provided. The basis of such environmental cost evaluations is always the absolute figures of the purchased or disposed quantities, to which the relevant internal costs are then allocated (e.g. the amount of waste determines the proportionate waste disposal costs, the energy consumption determines the energy costs).

5.4 Classification of Indicators

5.4.1 Performance and Condition Indicators

ISO 14031 describes two general categories of indicators for environmental performance evaluation:

- Environmental performance indicators (EPIs).
- Environmental condition indicators (ECIs).

EPIs provide information about the environmental performance of an organisation, while ECIs provide information about the condition of the environment. This information can help an organisation to better understand the actual impact or potential impact of its environmental aspects, and thus assist in the planning and implementation of EPE.

There are two types of EPIs:

- Management performance indicators (MPIs) are a type of indicators that provide information about the management efforts to influence the environmental performance of the organisation's operations.
- Operational performance indicators (OPIs) are a type of indicators that provide information about the environmental performance of the organisation's operations.

5.4.2 Environmental Performance Indicators

Environmental performance indicators can be used for presentation of qualitative or quantitative information about an organisation's environmental performance in an understandable and useful form. EPIs are primarily used for planning, controlling and monitoring the environmental impact. Typical examples are absolute energy consumption, amount of waste per unit of output, number of environmentally relevant installations, or total volume of transportation. Environmental performance indicators are also a significant tool for communicating environmental data through environmental reports or environmental statements. By integrating cost aspects into them, they can also represent the basis of environmental cost management.

5.4.3 Management Performance Indicators

Management performance indicators present the organisation's capability and efforts in managing matters such as training, legal requirements, resource allocation and efficient use of resources, environmental cost management, purchasing, product development, documentation, or corrective action. Examples could be the number and results of environmental audits conducted, staff member training, or supplier assessments.

The figures serve as internal control and information measurements, but do not provide valid information on the actual environmental performance of the organisation's. Due to the fact that they do not specifically reflect the environmental impact, environmental management indicators cannot be exclusively used for environmental performance evaluation.

Management performance indicators demonstrate the performance of the management of an organisation and can be in its turn split into two categories: system indicators and functional area indicators.

System indicators:
- System implementation.
- Legal matters and complaints.
- Environmental costs.

Functional Area indicators:
- Training, staff.
- Health/safety.
- Purchasing.
- External communication.

5.4.4 Operational Performance Indicators

Operational performance indicators (OPIs) should provide information on the environmental performance of the organisation's operations. The OPIs of an organisation may be based on:

1. Inputs
    - Materials (e.g. processed, recycled, reused or raw materials; natural resources), energy and services.
    - Supply of inputs to the operations.
    - Design, installation, operation (including emergency events and non-routine operation), and maintenance of the physical facilities and equipment.

2. Outputs
   - Products (e.g., main products, by-products, recycled and reused materials), services, wastes, and emissions.
   - Delivery of the outputs from the operations.

Box 5.2 illustrates this approach.

5.4.5 Environmental Conditions Indicators

Environmental condition indicators (ECIs) provide information about the quality of the environment surrounding the organisation, for example, the water quality of a nearby lake, or the regional air quality. Since the condition of environmental media (air, water, land) and the environmental problems arising (e.g. ozone depletion, land contamination, greenhouse effect) depend on a variety of influences (e.g. emissions from other companies, private households, or traffic), such environmental data are usually measured and recorded by governmental institutions. These data are used to derive specific environmental indicator systems for the main environmental problems.

In connection with environmental policy goals, public environmental indicators can be used by companies as an orientation for setting priorities in determining their indicators and objectives. Determining condition indicators is usually a major effort and only worthwhile if the company is the main contributor to an environmental problem in its area (e.g. noise pollution from an airport, water pollution from a large direct discharging company). Otherwise, companies can often use information and data from regional authorities to verify their direct effects on a regional level and to demonstrate changes and improvements.

Box 5.2 The Operations of an Organisation

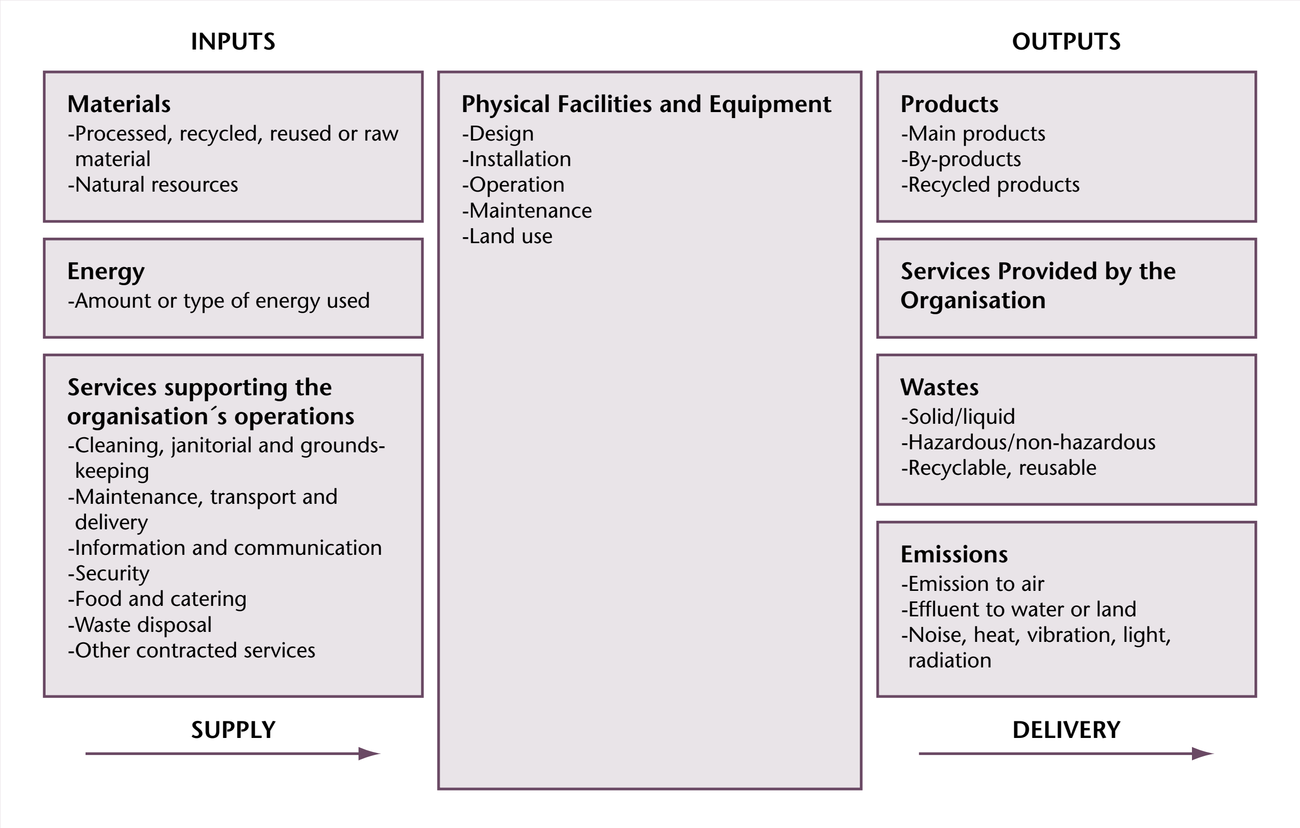


Figure 5.1 Overview of the operations of an organisation. *Operational performance indicators (OPIs) are based on the operations of a company or organisation. These include the inputs, that is the use of resources, such as materials, energy and services (left); the performance of the physical facilities and equipment (middle); and the outputs, such as products, services, wastes, and emissions (right). [ISO 14031].*

5.5 Establishing Environmental Performance Indicators

5.5.1 Selecting Indicators for EPE

When selecting indicators for environmental performance evaluation, one should take a number of considerations into account. In order to fill their function the chosen indicators must be appropriate for comparing the actual environmental performance with the performance criteria that have been set. They should of course also be relevant, adequate and understandable for those who will use the information provided by the indicator. Furthermore it should be responsive and sensitive to changes over time. The best use of indicators is when they are explicitly built into management processes. Vice versa, management processes will often be better if they make explicit and deliberate use of indicators in connection with agreed objectives.

There are a number of special concerns that should be taken into account when choosing indicators. The most important ones are listed below.

Indicators may be developed to address the fundamental or underlying cause of a significant environmental aspect, *a cause-and-effect approach* can be used.

Indicators may be selected *based on the risks* associated with particular activities, products or services. Different risk-based approaches may be applied. A probabilistic risk-based approach identifies specific activities which are the most likely to cause a major accident or release of pollutants to the environment. A human health risk-based approach identifies materials having a major risk of posing a significant health-threat. A financial risk-based approach can be used to identify aspects that are related to the most significant environmental costs. A sustainability risk approach refers to environmental aspects that may threaten the environment or the competitiveness of the company.

A *life-cycle approach* considers inputs and outputs associated with a particular product and the significant aspects and impacts at a specific stage of a product's life-cycle.

A *regulatory or voluntary initiative* approach assesses the performance of the company in relation to identified regulatory or voluntary performance requirements. Some indicators may have thresholds above which environmental action is recommended or required. For example, where the concentrations of pollutants such as ozone or carbon monoxide exceed levels that endanger health, it is necessary to take steps to reduce them.

5.5.2 Starting the Process

Working with environmental indicators is a process in which environmental data is summarised as valid key information and makes them comparable from year to year. The indicators can be used as effective management tools only by periodically updating and developing them. The CSIRO *A Guidebook to Environmental Indicators* emphasises the following points.

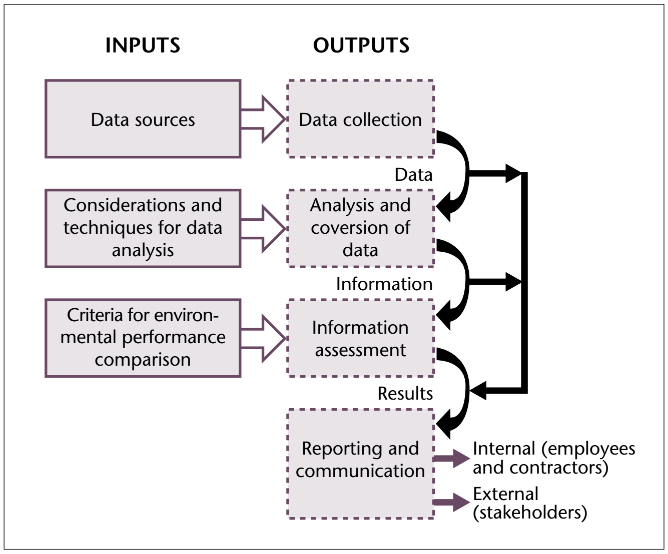


Figure 5.2 *Establishing environmental performance indicators [ISO 14031].*

The company should begin by taking inventory of the surrounding environmental problems: where is the environment affected the most and what effects are caused? Based on this information, select the first environmental indicators. Integrate the indicators into a system, where internal and external considerations are taken into account and weighed against one another. The selected environmental indicators should comply with environmental policy priorities:

- How does the company affect the local or regional environmental situation (condition of the environment)?
- What environmental problems dominate the current political discussions?
- What external requirements affect the company?

Indicator development and use must be "plugged-in" to the environmental management cycle. It begins by addressing a question posed at some stage in the cycle and ends by delivering answers back to the cycle. Questions from different stages of the cycle will justify different types of indicators or ones that operate at different scales in time and space.

Indicator use can relate to any stage but typically begins by identification of tools and resources, and re-enters the cycle near the action and evaluation stages. Before beginning indicator design, it is essential to be sure about the questions being addressed, the stage of the management cycle to which the indicators link, and relevant local factors.

5.5.3 Collecting Data

Data for updating the selected EPE indicators should be collected on a regular basis. The procedures for data collection should be formulated so that data reliability is ensured. Factors to considered are availability, adequacy, scientific and statistical validity and verifiability. Appropriate quality control and quality assurance practices should be applied. Since the EPE indicators must be comparable over time the data used for calculation of the indicators need to be transparent and retrievable. Records for the indicator data must therefore be designed with appropriate identification, filing, storage, retrieval and disposition of data and information.

Often, indicator data will require sophisticated interpretation, such as through extensive statistical analyses, computer modelling, or expert assessment. Evaluation of potential management actions typically involves a variety of inputs, of which indicators are just one.

Data used for calculating EPE indicators can be either be collected for sources within the organisation or from external sources, for example:

- Monitoring and measurements.
- Interviews and observations.
- Regulatory reports.
- Inventory and production records.
- Financial and accounting records.
- Purchasing records.
- Environmental audit and assessment reports.
- Environmental training records.
- Scientific reports and studies.
- Government agencies, academic institutions and NGOs.
- Suppliers and subcontractors.
- Customers, consumers and stakeholders.

Different indicators may be needed for managers operating at different levels. They may often be based on the same data, and finding reliable ways to aggregate, or disaggregate, data across space scales is a continuing and difficult challenge. The challenge is even greater when linking both space and time considerations. EPE data can be converted into indicators using calculations, best estimates, statistical methods and/or graphical techniques or by indexing, aggregating or weighting.

The effectiveness of management and indicator processes is greatly enhanced when processes, products and outcomes are evaluated, and those evaluations are used to modify the cycles. Environmental conditions change, human values alter, policies evolve, and understanding of systems improves – all of which demand that all aspects of management systems, including the indicators used to evaluate the system, be flexible, dynamic and adaptive.

5.6 How to Use Environmental Indicators

5.6.1 The Roles of Indicators

The main strengths of environmental indicators are that they quantify important developments in corporate environmental protection and make them comparable from year to year. If they are determined periodically, environmental indicators enable the early detection of non-conformance trends and can also therefore be used as an early warning system. Comparing

Box 5.3 How to Calculate some Key Environmental Indicators

Water use ratio:

$$\frac{\textit{Total water use (litres)}}{\textit{Production volume (ton, kg, litres)}}$$

Water cost ratio:

$$\frac{\textit{Water cost (USD or €)}}{\textit{Production volume (ton, kg, or litre)}}$$

Solid waste generation ratio:

$$\frac{\textit{Total solid waste generated (kg) x (1,000)}}{\textit{Production volume (ton, kg, litres)}}$$

Solid waste % recovered or recycled:

$$\frac{\textit{Solid waste recovered or recycled (kg)}}{\textit{Total solid waste (kg)}}$$

Energy use ratio:

$$\frac{\textit{Sum of all individual energy sources (MJ)}}{\textit{Production volume (ton, kg, litres)}}$$

Energy cost ratio:

$$\frac{\textit{Sum of all energy costs (USD or €)}}{\textit{Production volume (ton, kg, litres)}}$$

Electricity use ratio:

$$\frac{\textit{Electricity (kWh)}}{\textit{Production volume (ton, kg, or litres)}}$$

Liquid fuel ratio:

$$\frac{\textit{Sum of fuel oils plus kerosene (MJ)}}{\textit{Production volume (ton, kg, litres)}}$$

Gaseous fuel ratio:

$$\frac{\textit{Sum of propane plus natural gas (MJ)}}{\textit{Production volume (ton, kg, litres)}}$$

Solid fuel ratio:

$$\frac{\textit{Coal (MJ)}}{\textit{Production volume (ton, kg, litres)}}$$

environmental indicators from different companies or company departments can demonstrate weak points and optimisation capacities, which can be used to derive specific improvement goals.

Environmental indicators therefore support four essential environmental management responsibilities in a company:

- Identifying weak points and optimisation of potential.
- Determining quantifiable environmental objectives and targets.
- Documenting continuous improvement.
- Communicating environmental performance.

Each of these will be commented on below.

5.6.2 Identifying Weak Points and Potential for Improvements

One of the most important functions of environmental indicators is the internal identification of weak points and optimisation of potential. Comparisons can reveal environmental improvement potential. These are often economically profitable. They can be used as inventory data, for the regular control of material and energy flows, as well as other environmental performance measures.

Indicators are used for comparisons between and within organisations, preferably as time series. Time series analyses allow the detection of weak points, e.g. as unexpected upward or downward trends. Indicators of comparable sites, production processes, machinery, or departments within an organisation can be compared. Such internal comparisons can be used to derive preliminary weak points and strengths of corporate environmental protection.

When comparing organisations, one should normally use relative environmental indicators, showing performance-related differences. Reference figures for comparison can be number of workdays, machine operating hours, personnel, production volume, manufactured quantity, revenues, etc. Comparing indicators between organisations may disclose weak points, e.g. inefficient use of raw material, as well as "success recipes" of departments with good figures.

5.6.3 Determining Quantifiable Environmental Objectives and Targets

Environmentally and economically optimal management can most effectively be achieved if relevant goals exist. Precisely defined corporate objectives should be combined with quantified target figures. Environmental indicators support the process of defining such effective environmental objectives and pursuing them over a long period of time. They can especially provide small businesses that have a minimally developed environmental information system with a simple yet effective control of target figures.

In practice, it is often difficult to derive and quantify objectives. Experiences with environmental indicators can be helpful. Internal time series and company comparisons can reveal optimisation potential, which allow the setting of realistic objectives. These may either be in absolute terms and, i.e. without relating to output levels, or in relative terms, that is, dependent on the actual output. The more demanding definition of absolute objectives is best when specific materials, e.g. a certain solvent for cleaning or one-way packaging, are to be completely eliminated or changed to environmentally safer versions (e.g. environmentally safer cleaning agents).

Relative target figures are convenient when a specific consumption or emission cannot be completely avoided, but, in proportion to the volume of production output, can be employed more efficiently or used less. A typical example is energy consumption: it is possible to reduce consumption per unit produced by using energy saving methods; complete elimination of energy consumption is not possible for manufacturing, however.

5.6.4 Documenting Continuous Improvement

A periodic target performance comparison based on environmental indicators is used:

- To monitor whether the set objectives and targets were attained.
- For documenting continuous improvement of environmental performance.

At the same time, it ensures the timely implementation of corrective measures in case of deviances from the target performance. With the help of environmental indicators parts of environmental audits could be supported. For example in providing data for periodic and systematic site monitoring to evaluate whether the environmental activities, in connection with the environmental objectives and the environmental programme, promote continuous improvement of the corporate environmental performance.

5.6.5 Communicating Environmental Performance

Environmental performance evaluation provides useful information describing the environmental performance of an organisation. This information may be used for reporting and communicating the environmental performance to stakeholders within as well as outside the organisation.

Management should ensure that appropriate and necessary information describing the environmental performance is communicated throughout the organisation in a structured and regular way. This will assist employees, contractors and others related to the company to fulfil their responsibilities, and the organisation to meet its environmental performance targets.

Such internal information may include:

- Trends in the environmental performance.
- Legislative and regulatory compliance.
- Conformance with the environmental policy of the organisation, objectives and targets.
- Cost savings and financial results.
- Opportunities or recommendations to improve the environmental performance of the company.

Organisations may choose to or be required to issue environmental statements or other communications providing information about their environmental performance to external stakeholders. EPE provides information that an organisation may wish to include in environmental reports or other communications to external audiences [Hopkinson et al., 1999].

Information describing the performance of the organisation should be reliable, substantive and presented in a manner that recognises the level of technical knowledge of the intended audience.

The ability to utilise corporate environmental reports to benchmark environmental performance requires the development and inclusion of standardised environmental performance indicators. Most systems for benchmarking corporate environmental reports are measures of environmental activities rather than performance. A most often used format for environmental reporting, and in fact sustainability reporting today, is the GRI, Global Reporting Initiative. An extensive manual for this reporting is available on Internet. In 2004, it was used by companies, especially in the USA and Japan but also in Europe. As of 2005 a manual for sustainability reporting for public authorities, such as cities, is also available.

Abbreviations

CSIRO	Cmmonwealth Scientific and Industrial Research Organisation.
ECI	Environmental Condition Indicators.
EPE	Environmental Performance Evaluation.
EPI	Environmental Performance Indicator.
INEM	International Network of Environmental Management.
MPI	Management Performance Indicators.
OPI	Operational Performance Indicators.

Study Questions

1. What does Environmental Performance Evaluation (EPE) mean?
2. For what purposes can Environmental Performance Evaluation be used for a company or organisation?
3. What basic requirements should be applied when developing an Environmental Indicator System?
4. What are the main roles/objectives of Environmental Indicators?
5. Explain the differences between the four main categories and types of Environmental Indicators.
6. Describe the process of EPE.
7. What indicators of EPE can you mention? List the core principles on which the EP-indicators are based.
8. Explain the difference between two general categories of indicators (EPIs and ECIs). In what international standard are they described?
9. Explain the role of Environmental Indicators.

Internet Resources

How and Why of Environmental Indicators

http://igpa.ema.org.tw/newsletter/2002no03/2002no030501.htm

ISO 14031:1999

http://www.iso.org

INEM – EMAS Toolkit for Small Organisations:
Monitoring and Measurement.

http://www.inem.org/new_toolkit/comm/environment/emas/toolkit/toolkit_16_3_2.htm

Impulsprogramm Nachhaltig Wirtschaften
(Forschungs- und Technologieprogramm des
Bundesministeriums für Verkehr, Innovation und Technologie)

http://nachhaltigwirtschaften.test.eva.ac.at/nw_pdf/

Measuring Environmental Performance of Industry (MEPI)
– Science and Technology Policy Research (SPRU) at the
University of Sussex, UK

http://www.casa.susx.ac.uk/Units/spru/mepi

Global Reporting Initiative – GRI & G3 Guidelines

http://www.grig3.org/grig3.html

6

Energy Conservation

6.1 Energy – the Basis of Life and Society

6.1.1 World Energy Development

Over the last 100 years global energy use has increased 16 times, and the global economy 14 times, almost proportional. Energy has been seen as a key resource for development. This increase is still going on more or less linearly. The Energy Information Administration (EIA) of the US Department of Energy (DOE) has studied the energy development for the first 20 years in the new century. Their predictions are as follows:

Between 1999 and 2020, total world energy use is projected to grow from 403 EJ (ExaJ =10^{18} J) to 645 EJ (Figures 6.1a-c), a 60% increase. Developing countries as a whole are expected to account for 60% of the increment in total energy use over this 20 years period, the western industrialised countries 30%, and Central and Eastern Europe and the former Soviet Union (EE/FSU) 10%.

Fossil fuels today account for 80% of energy provision at large, and are expected to continue to be the major source of energy. Oil is expected to remain the dominant energy fuel, with 40% of the whole, as it has for decades. In the industrialised world, oil use increase is due to a growing transportation sector. In the developing world, oil consumption is projected to increase for all end uses. Natural gas is believed to be the fastest growing primary energy source worldwide, maintaining a growth of 3.2% annually. Gas is increasingly seen as the desired option for electric power, given the efficiency of combined-cycle gas turbines relative to coal- or oil-fired generation. The fact that it burns more cleanly than either coal or oil, makes it a more attractive choice, also for reducing greenhouse gas emissions.

Coal use worldwide is projected to increase at a rate of 1.7% per year between 1999 and 2020. Substantial declines in coal use are projected for Western Europe and the CEE/FSU coun-

In this Chapter

1. Energy – the Basis of Life and Society.
    - World Energy Development.
    - The Development in the EU and the Baltic Sea Region.
    - Environmental Issues and World Energy Use.
    - Implementing the Kyoto Protocol.
2. Improving Energy Use in Society.
    - Energy for Transport – Alternatives.
    - Electric Energy – More Efficient Lighting, Motors and Processes.
    - Heating Energy – Saving, Upscaling and Downscaling.
    - Integrated Solutions.
3. Power Generation.
    - Kinds of Energy Sources.
    - Power Plants.
    - Cogeneration.
    - Trigeneration.
4. Saving Electric Energy.
    - Strategic Choices.
    - Power Factor Improvement.
    - Load Factor Improvements.
5. Saving Thermal Energy – Heating Systems.
    - Boilers.
    - Heat Recovery Systems.
    - Pinch Technology.
    - Heat Pumps.
    - Insulation.
6. Saving Thermal Energy – Cooling Systems.
    - Choosing the Right Source of Cold Temperature.
    - Cooling Towers.
    - Absorption Refrigeration.
    - Mechanical Refrigeration.
    - District Cooling.
    - Insulation.

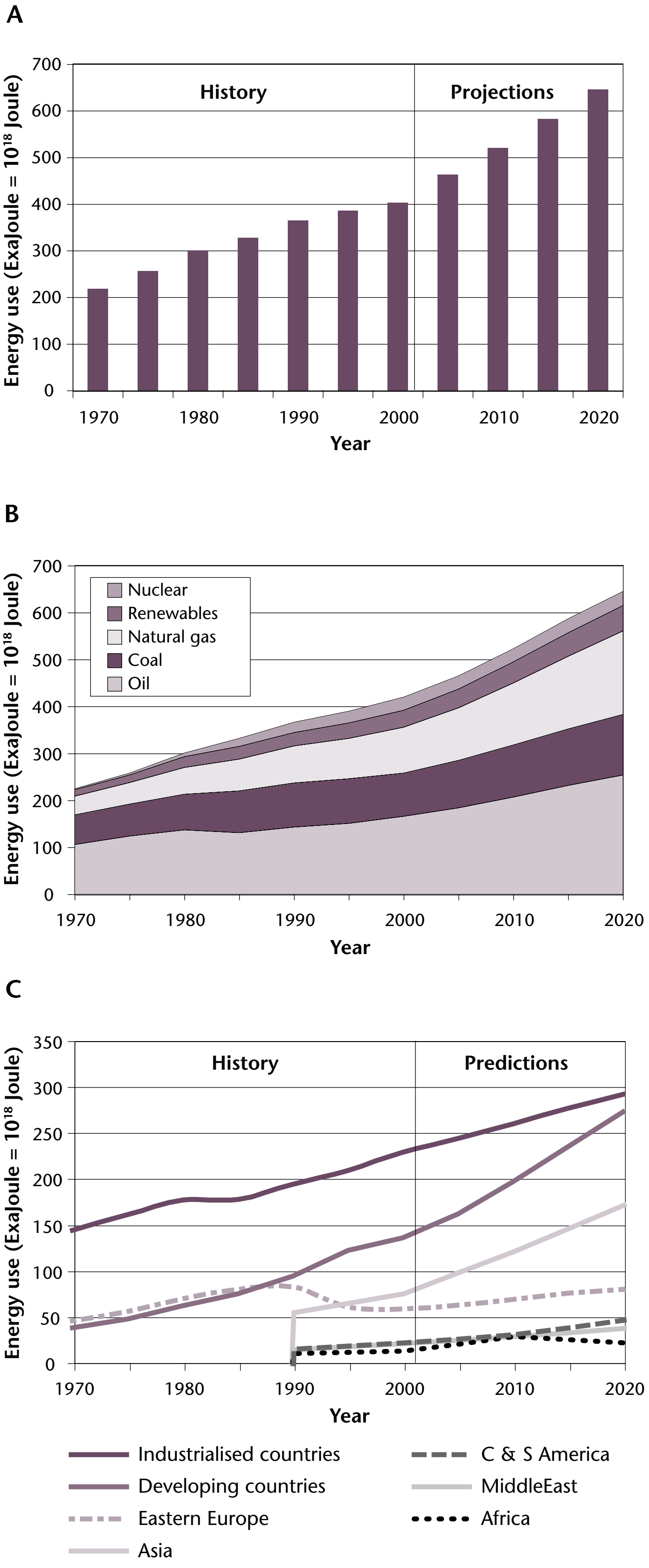


Figure 6.1 World energy consumption. The world energy consumption 1970-2002 as well as predictions by the Energy Information Administration (EIA) of the US Department of Energy (DOE) for the period 2003-2020. *A. World energy consumption 1970-2020. B. World energy consumption per fuel type 1970-2020. C. World energy consumption per region 1970-2020. The data are based on extrapolation of existing trends. A very different view based on the prediction of the Association for the Study of Peak Oil is shown in Chapter 2 of Book 3 in this series [Zibcinski et al, 2006]. [Sources. History: EIA, 2001 and EIA Office of Energy Markets and End Use, International Statistics Database. Projections: EIA, 2002].*

tries, where natural gas is increasingly being used to fuel new growth in electric power generation, and for the industrial and building sectors. In the developing world, however, coal use increases. 85% of the rise is projected for China and India.

Electricity generated from nuclear power is expected to increase by 11.3% in the period with the highest growth, 4.7% per year, in the developing world. Electricity from hydropower and other renewable energy sources is projected to grow by 2.1% annually. The renewable share of total energy use is expected to decline from 9% in 1999 to 8% in 2020. In the developing world large-scale hydroelectric power plants is expected to account for the largest share of growth, while wind, biomass and geothermal power will dominate in the industrialised world.

6.1.2 The Development in the EU and the Baltic Sea Region

The projection of the United States DOE is basically a projection of existing trends. This way to see the development is not shared by all.

First of all, independent researchers doubt that the oil reserves, which DOE assumes for its forecast, exist at all. They are not proven; it is just an assumption. Secondly, the limited oil supply and competition for the existing fossil fuel resources is believed to give a very substantial price increase. Peak Oil, the point in time when half of the existing resources have been used and production is declining, is projected to occur at 2008-2010. This is confronted with dramatically increased demand from China and other Asian countries. A new cost level for oil and gas will force western economies to look more seriously into energy saving measures and new sources of energy.

The increase in *total energy use* is obvious on a global scale but not on a national or regional. It is obvious that at some point in time energy use based on fuels have to stop increasing. In the more mature economies this is approaching. In the EU15 energy growth is declining. In Sweden the total energy use has been almost constant since the 1980s, if the surplus heat generated by nuclear power plants is not included.

For some time already, in fact since about the 1970s, economic value per used energy unit has been increasing. This is called *decoupling*. In the European Union the decoupling of the economy from energy has amounted to about 4% yearly. Increasing production without using more energy becomes more interesting as energy prices increase. A decoupling of economy from energy is very noticeable in housing, service and industry. It is still not obvious in the transport sector, but is expected to be so as oil prices soar.

The alternatives to fossils are also developing and become more interesting as oil prices mount. This is a question of *decarbonising* the energy flows, or, differently said, decoupling energy from carbon flows. This trend is visible in the industrialised world starting in the 1970s. In the EU the relationship of TWh/tonnes carbon has decreased 25% over the period. In Sweden, where a very clear policy to reduce oil dependency has been pursued since the oil price crisis in 1973, the share of fossils in the energy budget has decreased to less than half. The substitution includes nuclear power, hydropower and increased efficiency. In 2005 about 40% of the energy was based on oil.

6.1.3 Environmental Issues and World Energy Use

In the coming decades, environmental concerns could significantly affect patterns of energy use around the world. Global climate change is a wide-reaching environmental issue that is receiving increased attention in recent years. Carbon dioxide, the most prevalent greenhouse gas in the atmosphere, has two major anthropogenic (human-caused) sources: the combustion of fossil fuels and changes in land use. Net releases of carbon dioxide from these two sources are believed to be contributing to the rapid rise in atmospheric concentrations since pre-industrial times. Because estimates indicate that approximately 80% all anthropogenic carbon dioxide emissions currently come from fossil fuel combustion, world energy use has emerged at the centre of the climate change debate.

Based on expectations of regional economic growth and dependence on fossil energy, particularly in developing countries, the DOE study expects global carbon dioxide emissions to grow more rapidly over the period 1999-2020 than they did during the 1990s. Factors such as population growth, rising standards of living, and further industrialisation are expected to have a much greater influence on levels of energy consumption in developing countries than in industrialised nations. Energy-related emissions are projected to grow most rapidly in China, the country expected to have the highest rate of growth in per capita income and fossil fuel use over the coming period.

The DOE study expects carbon intensity – the amount of carbon dioxide emitted per dollar of gross domestic product, GDP (the inverse of decoupling) – to improve (decrease) throughout the world over the next two decades. The steepest rates of improvement are, for the most part, expected to occur among the transitional economies of Central and Eastern Europe and the former Soviet Union (CEE/FSU).

6.1.4 Implementing the Kyoto Protocol

The world community's effort to address global climate change has taken place largely under the auspices of the Climate Convention. It was adopted at the UN Conference on Environment and Development in Rio in May 1992 and entered into force in March 1994. The ultimate objective of the convention is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The details of implementation of this goal were finally agreed on in Tokyo in 1997 (the Kyoto Protocol). The terms of the Kyoto Protocol call for the participating countries to reduce their overall greenhouse gas emissions by at least 5% (EU 8%) below 1990 levels to 2008 to 2012. The Kyoto protocol entered into force in March 2005, when the Russian Federation ratified it.

In addition to any domestic emission reduction measures that countries may choose to implement, the Kyoto Protocol allows the use of four "flexibility mechanisms" (sometimes called "Kyoto mechanisms"):

International emissions trading (Article 17) allow participating countries to transfer some of their allowable emissions to other participating countries, beginning in 2008, for the cost of emission credits. For example, a participating country that reduces its 2010 greenhouse gas emissions level by 10 million metric tons carbon equivalent more than needed to meet its target level can sell the "surplus" emission reductions to other participating countries. This trade would lower the seller's allowable emissions level by 10 million metric tons of carbon equivalent and raise the buyers' allowances by the same amount in total. In the Baltic Sea region the CEE countries, especially Russia, where industrial production had decreased since 1990, will be able to sell emission rights.

Joint fulfilment of commitments (Article 4) allows participating countries that are members of an established regional grouping to achieve their reduction targets jointly, provided that their aggregate emissions do not exceed the sum of their combined Kyoto commitments. For example, EU countries have adopted a burden-sharing agreement that reallocates the aggregate Kyoto emission reduction commitment for the EU among the member countries.

The Clean Development Mechanism (CDM), (Article 12) allows participating countries, either through the government or a legal entity, to invest in emission reduction or sink enhancement projects in non-participating countries, gain credit for those “foreign” emissions reductions, and then apply the credits toward their own national emissions reduction commitments. The CDM, in principle, redistributes emission reductions from developing country parties to participating parties.

Joint implementation (JI), (Article 6) is similar to the clean development mechanism except that the investment in emission reduction projects must occur within the participating countries.

The Kyoto targets refer to overall greenhouse gas emission levels, which encompass emissions of carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Hence, a country may opt for relatively greater reductions of other greenhouse gases emissions and smaller reductions of carbon dioxide, or vice versa, in order to meet its entire Kyoto obligation. Currently, carbon dioxide emissions account for the majority of greenhouse gas emissions in most participating countries, followed by methane and nitrous oxide.

The governments will have to implement various incentives, such as carbon dioxide taxes or energy taxes, to reduce emissions in their countries. Some of these will be of significance to industry.

6.2 Improving Energy Use in Society

6.2.1 Energy for Transport – Alternatives

Transport is today using about 40% of the energy budget of industrial societies, a share that is increasing. In a car engine the heat released when combusting the fuel (gasoline or diesel) is used to generate the mechanical work needed to drive the car forward. This is a quite inefficient process. Up to 18% of the energy content in the fuel becomes kinetic energy. The yield is slightly higher in a Diesel motor in which the combustion temperature is higher.

Efforts to reduce energy use in transport have priority, but are the least successful today. A few measures are the following: Car motors can be made much more efficient and the mileage of a car can be improved by up to 50%. Alternative renewable fuels include ethanol and biogas. Today petrol in the European Union has 5% ethanol content. This may increase. Cars which can take either ethanol or petrol (flexi fuel cars) are increasing in popularity, and a conventional motor may easily be converted into one that runs on ethanol. So-called environmentally friendly cars have a number of advantages, no tax on ethanol, no parking fees in some cities etc. which will make them less expensive to drive. Electric cars, and hybrid vehicles (with both an electric and a combustion motor), are increasingly used. Electric energy can be transformed to movement (and vice versa when braking) with high efficiency. Drawbacks include the lack of efficient batteries, and high cost.

Transport on rail is at least one order of magnitude more energy efficient than road transport in traditional cars.

More efficient use of cars should be mentioned as a separate measure. This includes car pooling, but also that transport in industry not is dependent on owned cars, but rather that the service is bought from the car provider. A complete reorganisation of transport in society is the most far-reaching measure. A society in which the need for transport is decreasing, and the remaining transport is using mainly rail, would decrease energy use in this sector dramatically.

6.2.2 Electric Energy – More Efficient Lighting, Motors and Processes

Electricity accounts for close to 50% of national energy budgets. Electric energy is used for *lighting*, *movements* in electrical motors and a number of *industrial processes* such as electrolysis in which the final energy form is electricity. Industry spends more money on electric energy than on any other energy source. Big total savings can be realised through small savings in electricity consumption practices, thus increasing the ratio between production volume to energy costs.

In a house, electricity is used to heat the kitchen stove as well as in many cases for direct or indirect heating of the house. In industry many energy intensive processes rely on heat from direct firing of fossil fuels, but electricity is used in induction ovens where it is converted to heat.

But electricity is a higher form of energy. This becomes clear with the concept of *exergy*. Exergy expresses the capacity of energy to do work. Electricity has 100% capacity to do work and thus its exergy is 1. For heat the capacity to do work is dependent on temperature. Low temperature heat, which may be excellent to heat a building, has very little capacity to do work and has little exergy. It is clear that electric energy has to be carefully used and only exceptionally used for heating.

The equipment using electricity in industry as well as in households has developed to become more efficient. This is a considerable source of energy saving. In cities the local electricity companies may inform and encourage the inhabitants to buy and use more energy-saving products in order to lower the consumption of electricity.

The use of low energy *lamps* may reduce energy costs considerably. It is also important to turn off lamps when they are not needed. *Electric motors* – that is, movement – are often used less carefully in that they are either on or off. If the work output from the engine is regulated by rotation speed control, considerable savings are possible. Electricity using *processes* is more difficult to change.

6.2.3 Heating Energy – Saving, Upscaling and Downscaling

In many cases the final use of energy is in the form of *heat*. It is thus crucial that the use of heating in society is optimally organised. The largest share is the heating of housing, about 30% of total energy use in society. Traditionally heating was done independently for each house or even household, by an individual boiler using wood, coal, coke, etc. These burners were seldom efficient (temperature too low) and often gave rise to considerable pollutants in the flue gases, especially particles.

One measure which has proven to give large environmental gains in urban areas is district heating, that is to replace all small household heating systems with a large power plant, that is *upscaling*. By building a central power plant with improved process control, as well as cleaning equipment, and with an energy distribution net instead of a number of small household heaters, the amount of air pollutants drastically decrease. Central power plants may also use a fuel, which is difficult to use for a household, such as household waste or peat.

There are also a number of other ways to *save* energy, economise with the produced energy, as for instance controlling the temperature in our flats and houses. These measures are dependent on incentives, for example increased cost of heating. With proper insulation it is today possible to build houses which use very little or even no heating at all, so called passive energy houses (< 15 kWh/m²/year) or low energy houses (< 40 kWh/m²/year). Energy use in residential areas has been decreasing for several years.

It is also possible to save by finding proper local solutions, that is, *downscaling*. These include solar panels and heat pumps. Solar panels, producing hot water, in many cases are enough to provide a household with warm water. Solar panels are usually added to roofs and then do not require extra space. Of course these measures also apply to the heating of industrial buildings. Heat pumps use electricity to extract heat from the surrounding. The possible savings, compared to electric heating, are up to 2.5 times or a reduction of 60%. Here it is important that the electricity does not come from combustion. Then there is no systems gain. Alternatives include e.g. hydropower. Heat pumps may be very profitable if the heat is extracted from e.g. wastewater or surface water. Alternatives are so-called rock heat (from great depths) or even from the air.

6.2.4 Integrated Solutions

Energy together with materials, waste, and water make up the flows of a society, its metabolism. Considerable gains can be made by coordinating these flows. E.g. wastewater always carries some heat, which may be extracted by a heat pump. The sludge from a wastewater treatment plant may be fermented to produce biogas, which is an excellent source of energy, for example for buses or cars. Solid waste may be incinerated to produce district heating and cogenerated electricity.

Integrated solutions include the coordination of several facilities, sometimes referred to as industrial symbiosis. The steam produced in one factory may be sold to another factory, instead of just emitted. Several factories use extra heat for the district heating system in the city where they are located. Many times the waste in one production can be used in the next production. Slaughter house organic waste may be fermented to produce biogas.

Special solutions are also possible. In cities in the north of Sweden snow, collected when cleaning the streets in wintertime, is deposited in one place to be used for local cooling e.g. in a hospital during the rest of the year.

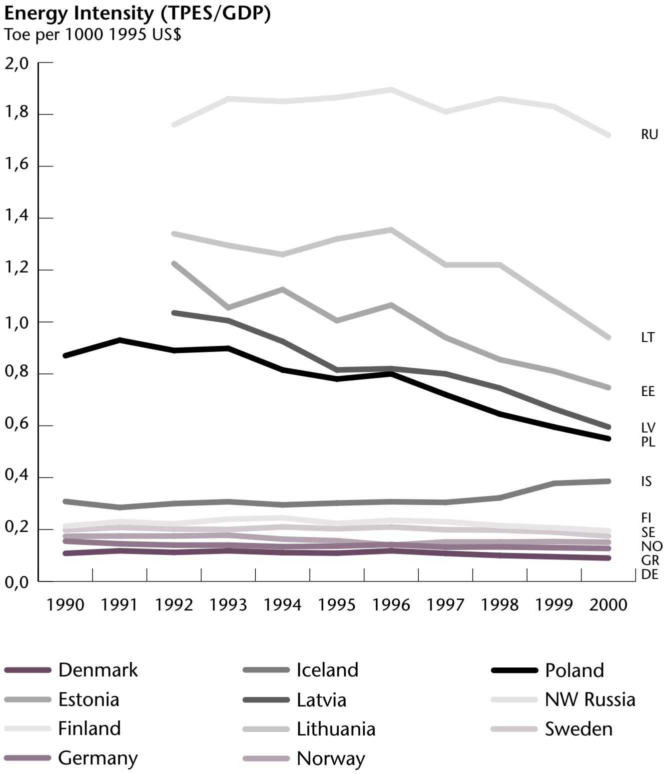


Figure 6.2 The development of energy intensities in Northern Europe, 1990-2000. *The development shows a general decline in the eastern european countries while the western countries exhibit a more stable situation. (TPES=Total Primary Energy Supply.) [Adapted from Baltic 21, 2003].*

6.3 Power Generation

6.3.1 Kinds of Energy Sources

There will always be a demand for primary energy. To meet the need for primary energy there are basically three classes of energy sources:

1. Fossil fuels – Coal, Oil, and Natural gas.
2. Nuclear power.
3. Renewable energy sources, i.e. energy from the sun. These are:
   - Hydropower, Biomass.
   - Wind, Solar energy, Wave and tidal energy, Geothermal energy.

It is useful to distinguish between *dispatchable* and *intermittent* sources of energy. Dispatchable sources can be stored – to be used later – and to some extent transported to the place where the energy is converted to heat or electricity. Power plants that convert solar radiation, wind or wave power directly into electricity cannot be dispatched since the flowing energy will be lost unless it is utilised when it is available. Solar radiation, wind, wave and tidal power sources are therefore considered as intermittent sources. To some extent the energy generated by an intermittent source can be stored however. Thus hot water can be stored as such, and electricity can be stored in a battery or used e.g. to pump water to a high level reservoir.

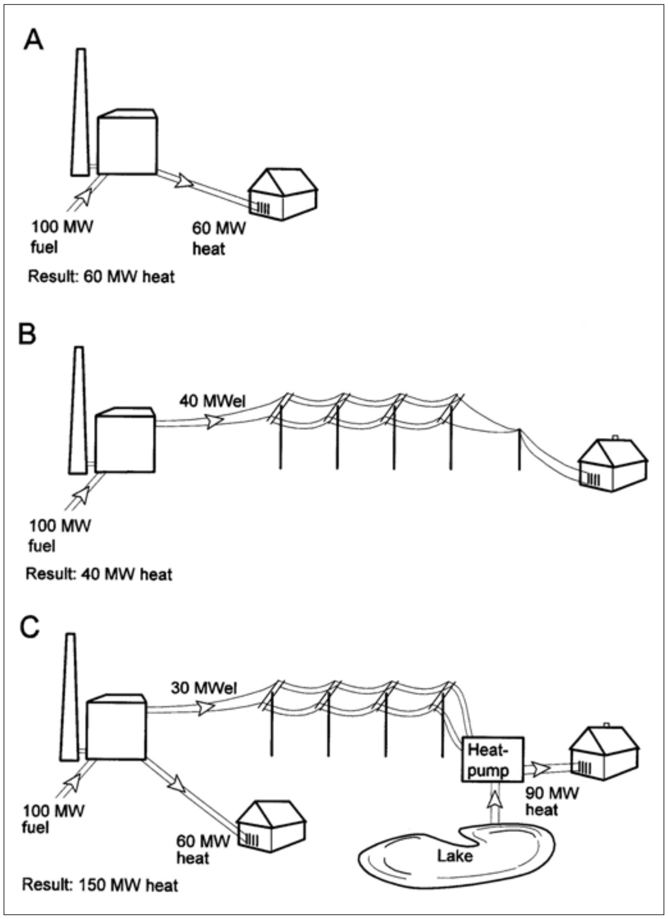


Figure 6.3 Comparison between three different alternatives for production of heating energy for households. *A "bad" energy plant (A). An energy plant where all produced electricity is used for heating purposes (B), and an energy plant where the produced electricity is used to run a heat pump (C). (Illustration: Gunnar Svedberg, Royal Institute of Technology)*

Fossil- and biomass-fuelled power plants – as well as other energy converters such as vehicle engines – are dispatchable since the energy is stored in the fuel. The use of biomass, especially in the form of wood chips and biopellets, has increased much recently. Biomass is produced in forestry, where the residual is taken care of, from energy forests and recently also from oat.

Hydropower stations are mostly dispatchable since they often have dam-capacity to allow storage of water so that the production of electricity can be regulated according to the demand. It is not likely that there will be any additional large hydropower plants in the Baltic Sea region. The capacity was taken into use in the early part of the 20th century. Proposals for new large hydropower plants have been developed for River Daugava close to Daugavpils in Latvia, and in River Wisla in Poland, but protests against these plans have been voiced, as they would destroy much of the natural beauties of these rivers. In northern Norway, Sweden and Finland expansion of hydropower also meets protests. In Sweden the four remaining large rivers are protected against exploitation by a parliamentary decision. The technology of small scale hydropower, to provide e.g. a neighbourhood with electricity, has developed recently in an interesting way.

Wind power stations and wind farms are increasing since the 1990s. Wind power will provide some 10-25% of electricity in many parts in the region, e.g. Denmark and north Germany. Wind energy is more efficient on a water surface and many wind farms are located outside the coasts. Wind power electricity is fed into the general net of the country and in this way can be stored, as hydropower is resting. As with hydropower, wind farms disturb the landscape.

Wave power technology is now developing in an interesting way and may have the capacity to be just as important as wind power in the future. Tidal power is of very limited significance generally and not at all possible in the Baltic Sea region. In regions with high tidal differences it is however a feasible technology. The Rance Valley Tidal Power Station close to St Malo in Normandy, France has an installed capacity of 240 MW, distributed on 24 turbines. The amplitude of the tide here is in the order of 13,5 m.

Solar panels have been mostly known as solutions for individual buildings, but solar panel fields also exist and are a growing energy sector. The largest today seem to be the one at Aeroe in southern Denmark. It provides all district heating needed for the town of Aeroe from March to November. Large solar panel fields are also working in Kungsbacka and Uppsala in mid Sweden. The technology for solar panels develops. Today they are quite efficient also in winter as long as the sun is shining. Heat may be stored as warm water in large spaces in the rock. In this sense they are semi-dispatchable. It provides much more heat per surface area, up to 50 times, than growing of biomass which then is incinerated. Geothermal energy, where it is available, is similar. Large geothermal power plants are found outside Szczecin in Poland and in Denmark.

Figure 6.4 Wind power is now rapidly expanding in the Baltic Sea region. *It is expanding in Denmark, northern Germany, and southern Sweden, where this wind power park is found. The environmental costs of wind power are mainly related to landscape intrusion. If fully exploited, wind power could not, it is projected, provide more than up to 7% of Sweden's electricity requirements.*

Photovoltaic cells convert sunlight to electricity. Recently the cost of the electricity, measured as euro per kWh, has decreased and is more competitive. Still photovoltaic is expected to be used mostly is special circumstances, for example in distant areas to which distribution of electricity is not practical.

6.3.2 Power Plants

Power plants are mostly based on burning of fuels. These are fossils, biomass (wood or peat), or waste. In general fossil fuels totally dominate the picture in most countries in the region.

When burning a fuel, the remains are generally various gases and a solid waste. What gases are produced and the amount of each depends on the fuel used, as well as the conditions during the combustion. The emissions from a combustion plant are thus influenced by the choice of fuel and conditions under which combustion takes place, i.e. process integrated measures. Another possibility is, of course, to use external cleaning technology.

The aim of a power plant is to supply us with energy in the form of heat and electricity. We can also use some other source of energy instead of the fossil fuel, for instance nuclear power. We must then realise that we have other environmental problems to consider.

Figure 6.3 shows some alternatives which gives very different results regarding the consumption of raw materials and, consequently, emissions of pollutants. From an environmental point of view the above mentioned outlook on the problem of supplying us with energy is considerably more important, compared to the discussion of how to increase the efficiency in an exhaust cleaning process by some percents.

6.3.3 Cogeneration

Cogeneration, also known as combined heat and power (generation) or CHP, is an efficient, clean, and reliable approach to generating (electric) power and thermal energy from a single fuel source. Cogeneration uses heat that is otherwise discarded from conventional power generation to produce thermal energy. This energy is used to provide cooling or heating for industrial facilities, district energy systems, and commercial buildings. By utilising this waste heat, cogeneration systems achieve typical effective energy efficiencies of 50% to 70%, a dramatic improvement over the average 33% efficiency of conventional fossil-fuelled power plants.

Cogeneration's higher efficiencies reduce air emissions of nitrous oxides, sulphur dioxide, mercury, particulate matter, and carbon dioxide, the leading greenhouse gas associated with climate change.

Case Study 6.1 Co- and Trigeneration

A factory requires 1 MW of electricity and 500 refrigeration tons* (RT) of heat/cooling. The gas turbine generates electricity required for the on-site energy processes as well as the conventional vapour compression chiller.

Assuming an electricity demand of 0.65 kW/RT, the compression chiller needs 325 kW of electricity to obtain 500 RT of cooling. Therefore, a total of 1325 kW of electricity must be provided to this factory. If the gas turbine efficiency has an efficiency of 30%, primary energy consumption would be 4417 kW.

A cogeneration system with an absorption chiller (thereby making this a ”trigeneration” plant) can provide the same energy service (power and cooling) by consuming only 3,333 kW of primary energy, thereby saving nearly 25% in primary energy usage.

** Note: A refrigeration ton (RT) is defined as the transfer of heat at the rate of 3.52 kW, which is roughly the rate of cooling obtained by melting ice at the rate of one ton per day.*

Another example of a cogeneration process would be the automobile in which the primary fuel (gasoline) is burned in an internal combustion engine. This produces both mechanical and electrical energy (cogeneration). These combined energies, derived from the combustion process of the car’s engine, operate the various systems of the automobile, including the drive-train or transmission (mechanical power), lights (electrical power), air conditioning (mechanical and electrical power), and heating of the car’s interior when heat is required to keep the car’s occupants warm. This heat, which is manufactured by the engine during the combustion process, was “captured” from the engine and then re-directed to the passenger compartment.

6.3.4 Trigeneration

Trigeneration is the simultaneous production of cooling, heating and power, in one process. Trigeneration, when compared to (combined-cycle) cogeneration, may be up to 50% more efficient than cogeneration. When found in a hospital, university, office-campus, military base, downtown or group of office buildings, a trigeneration plant has also been referred to as a *district energy system* or *integrated energy system* and as previously mentioned, can be dramatically more efficient and environmentally friendly than *cogeneration.*

The trigeneration energy process produces four different forms of energy from the primary energy source, namely, hot water, steam, cooling (chilled water) and power generation (electrical energy).

Trigeneration allows greater operational flexibility at sites with demand for energy in the form of heating as well as cooling. This is particularly relevant in tropical countries where buildings need to be air-conditioned and many industries require process cooling.

When a trigeneration energy and power system is installed *on-site*, that is, where the electrical and thermal energy is needed by the customer, so that the electrical energy does not have to be transported over long distances, and the thermal energy is utilised on-site, system efficiencies can reach and surpass 90%.

6.4 Saving Electric Energy

6.4.1 Strategic Choices

In the power industry, energy efficiency involves getting the most usable energy out of the fuels. At its best, energy efficiency improvements in the power industry can lead to postponing – or altogether avoiding – the construction of new power plants.

The efficient generation of power is only one way a power plant can pursue energy efficiency. New technologies, applied to the storage of energy and the transmission of energy, contribute to energy efficiency. For instance, the copper wires used in typical transmission lines lose a percentage of the electric energy passing through them because of resistance, which causes

Figure 6.5 Cogeneration. *Combustion for heat production may be coupled to electricity generation in turbines, as in this turbine hall. When the hot steam is pressed through the turbines electricity is generated. The steam is cooled to temperatures appropriate for the district heating system. With this combined system efficiency is close to the theoretical maximum. (Photo: Kjell-Arne Larsson)*

some of the electric energy to turn into heat. But "superconducting" materials have no resistance, and if they are used to transmit electricity in the future, very little of the electric energy will be lost.

Energy storage can also make an electric utility system operate more efficiently. The most familiar way to store electricity is using batteries, but many other technologies have been developed, ranging from pumping water uphill to trapping electrical current in superconducting wire loops.

Unlike other energy sources like natural gas, fuel oil, or gasoline, which are held in large storage tanks until they are needed, most of the electricity is generated at the moment it is needed. To meet changing electrical demands, some power plants must be kept idling in case they are needed. These plants are known as *spinning reserves*, and they waste energy. During times of high electrical demand, inefficient power plants may be brought on-line to provide extra power, and the transmission system may be stretched to near its limit, which also increases transmission energy losses.

On the other hand, the inability to store excess electricity during periods of low demand can force utilities to operate power plants at less than full power, which is usually less efficient. Energy storage allows excess electricity to be stored during slack times and used during periods of high demand. Energy storage can also help electric utilities to make the best use of intermittent energy sources, like wind and solar power.

Another way for utilities to meet these changing energy demands is to locate smaller power sources close to the customers that need the power. This concept, called *distributed generation*, helps take the load off of transmission lines and, because the electricity travels only short distance before it is used, there is little or no energy lost in the transmission of the electricity.

6.4.2 Power Factor Improvement

Power factor quantifies the reaction of alternating current (AC) electricity to various types of electrical loads. Inductive loads, as found in motors, drives and fluorescent lamp ballasts, cause the voltage and current to shift out of phase. Electrical utilities must then supply additional power, measured in kilovolt amps (kVA), to compensate for phase shifting.

The total power requirement constituents can be broken down into the resistive, also known as the real component, and reactive component. Useful work performance comes from the resistive component, measured in kilowatts (kW) by a wattmeter. The reactive component, measured in reactive kilovolt amps (kVAR), represents current needed to produce the magnetic field for the operation of a motor, drive or other inductive device but performs no useful work, and does not register on measurement equipment such as the watt meter. The reactive components significantly contribute to the undesirable heating of electrical generation and transmission equipment formulating real power losses to the utility.

Power factor derives from the ratio of real, usable power (kW), to apparent power (kVAR). Mathematically, power factor is expressed as:

$$\mathrm{PF} = \frac{\mathrm{kW}}{\mathrm{kVAR}}$$

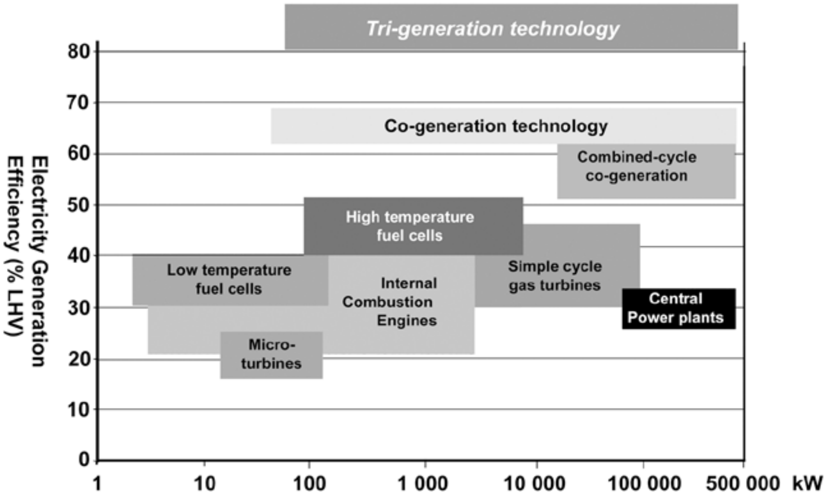


Figure 6.6 *Comparison of the over-all energy efficiency between different electricity generation technologies [Adapted from brochure: Trigeneration, EPA Combined Heat and Power Partnership, 1999.].*

Example: Consider a 480 volt 3-phase system with an assumed load and instrument readings as follows: the ammeter indicates 200 amps and wattmeter reads 120 kW. The power factor of the load can be expressed as follows:

The apparent power for a 3-phase circuit is given by the expression:

$$\text{kVA} = \frac{\text{E x I x } \sqrt{3}}{1000} = \frac{\text{480volts x 200amps x 1,73}}{1000} = \text{166,08kVA}$$

Therefore:

$$\text{PF} = \frac{\text{kW}}{\text{kVA}} = \frac{120}{166{,}08} = 0{,}7224 = 72{,}25\%$$

From the above example it is apparent that by the decreasing power drawn from the line (kVA) the power factor can be increased.

Preventive measures involve selecting high-power-factor equipment. For example, when considering lighting, only high-power factor ballasts should be used for fluorescent and high intensity discharge (HID) lighting. Power factor of so-called normal-power factor ballasts is notoriously low, on the order of 40 to 55%.

When induction motors are being selected, the manufacturer's motor data should be investigated to determine the motor power factor at full load. In the past few years, some motor manufacturers have introduced premium lines of high-efficiency, high-power-factor motors. In some cases, the savings on power factor alone can justify the premium prices charged for such motors. Motors should also be sized to operate as closely as possible to full load, because the power factor of an induction motor suffers severely at light loads. Power factor decreases because the inductive component of current that provides the magnetising force, necessary for motor operation, remains virtually constant from no load to full load, but the in-phase current component that actually delivers work varies almost directly with motor loading.

6.4.3 Load Factor Improvements

Load factor is defined as the ratio of the average kilowatt load over a billing period to the peak demand. For example, if a facility consumed 800,000 kWh during a 30-day billing period and had a peak demand of 2,000 kW, the load factor is:

$$\text{Load Factor} = (\text{800,000kWh}/\text{720hrs})/\text{2,000kW} = 0.55 \text{ or } 55\%$$

The user will obtain the lowest electric cost by operating as close to a constant load as possible (load factor 100%). The closer a plant can approach this ideal situation, the lower the monthly demand charge will be. The key to a high-load factor and corresponding lower demand charge is to even out the peaks and valleys of energy consumption.

In order to level out peaks in the demand profile, it is necessary to reduce loads at peak times. Consequently it is necessary to identify the various loads that could be reduced during periods of high demand. Approaches that could be considered are:

Stagger Start-Up Loads – If a high-peak load is determined to result from the simultaneous start-up of several loads, such as might occur at the beginning of a shift, consideration can be given to staggering start-up of equipment to span two or more demand intervals.

Reschedule Loads – Peak demands are usually established at particular times during the day shift. A review of the operating schedule may show individual loads can be rescheduled to other times or shifts to even out demand. This technique can provide significant gains at little or no cost. For example, operation of an electric oven might be rescheduled to the evening shift if the oven is not needed full-time. Another example is conducting routine testing of the fire pump during periods when peak demands are not likely to occur.

Increase Local Plant Generation – When some electricity is generated by the plant, plant generation can be temporarily increased to limit demand. In some cases, any venting of excess low-pressure steam from the turbo-generator for short periods may represent a lesser penalty than the increased demand charge.

Install Automatic Demand Control – The power demand controller automatically regulates or limits operation in order to prevent set maximum demands from being exceeded. The type of controller best suited for a plant operation is that which will predetermine the demand limit and the demand interval. The overall usage of power is constantly monitored from the power company meter, the power usage of all the controlled loads is also monitored. By having this information the controller can calculate when an overrun of the desired demand limit will occur. The controller will delay any demand threatening to exceed the demand limit to allow time for loads to "level out".

6.5 Saving Thermal Energy – Heating Systems

6.5.1 Boilers

Thermal energy services in an industry consist of the supply of heating and cooling to an industrial process. A boiler is a device where energy extracted from some type of fuel is converted into heat that is distributed to needed places (to do useful work). In the process, the carrying media (circulating water or steam) gives up the heat and is cyclically reheated again and again.

An ideal model of a boiler operation is based on the Carnot cycle. The Carnot cycle is defined as two reversible isothermal and two reversible adiabatic processes. Heat is added to the cycle during the isothermal process at high temperature, T_H. Then follows an adiabatic process producing work as the working fluid is expanded to a lower pressure. During the next isothermal stage, heat is rejected to the low temperature reservoir at T_L. During the last phase the working fluid is adiabatically compressed to finish the cycle. The Carnot cycle is the most efficient cycle for the given low and high temperatures. Its efficiency is given by:

$$\eta = 1 - ({}^{T_L}/{}_{T_H})$$

The efficiency of a real boiler is always lower than this ideal Carnot efficiency. The boiler efficiency can be improved and maintained through proper maintenance and monitoring of operation.

Some performance improvements are easily achieved. They are all dependent on proper maintenance or operation procedures.

Adjustment of air-to-fuel ratio. For each fuel type, there is an optimum value for the air/fuel ratio. The air/fuel ratio is the ratio of combustion air to fuel supplied to the burner. For natural gas boilers, this is 10% excess air, which corresponds to 2.2% oxygen in the flue gas. For coal-fired boilers, the values are 20% excess air and 4% oxygen.

Elimination of Steam Leaks. Significant savings can be realised by locating and repairing leaks in live steam lines and in condensate return lines. Leaks in the steam lines make steam to be wasted, resulting in higher steam production requirements from the boiler to meet the system needs. Condensate return lines that are leaky return less condensate to the boiler, increasing the quantity of required make-up water.

Maintenance of Steam Traps. A steam trap holds steam in the steam coil until the steam gives up its latent heat and condenses. In a flash tank system without a steam trap (or a malfunctioning trap), the steam in the process heating coil would have a shorter residence time and does not condense completely. The uncondensed high-quality steam would then be lost from the steam discharge pipe to the flash tank.

High Pressure Condensate Return Systems. As steam loses its heat content it is condensed into hot water, called condensate. A sudden reduction in the pressure of a pressurised condensate will cause the condensate to change phase into steam, more commonly called flashing. Flash tanks are often designed into a pressurised return system to allow flashing and to remove non-condensable gases from the steam. The resulting low-pressure steam in the flash tank can often be used as a low-temperature heat source. A more efficient alternative is to return the pressurised condensate directly to the boiler through a high-pressure condensate return system.

Figure 6.7 Boilers. *Boilers, mostly for providing hot water, are basic in most energy systems. In smaller or medium sized industries, residential areas or large buildings, boilers in the size of 100-1000 m³ with output energy of 10-500 MW are common. The proper maintenance and use of boilers is important for energy efficiency. Further improvement is possible by using a cogeneration equipment in the scale proper – also small equipments are available – to produce both heat and power (electricity). (Photo: iStockphoto)*

Conversion of boilers. An important means to improve energy management is to change boilers using oil to other fuels, such as gas or biofuels. This conversion reduces GHG emissions per output energy. By replacing the burners and changing the burner configuration the efficiency of the boiler can be greatly improved. Thus a more complete combustion of the fuel with right temperature, and a better distribution of the flue gases in the boiler can be achieved. The better distribution of gases will increase the overall heat transfer as well as prevent “hot spots” in the neighbourhood of the burner orifice that causes extensive formation of nitrogen oxides.

Fluidised bed combustion (FBC) has emerged as a viable alternative boiler design that has significant advantages over conventional firing system and offers multiple benefits. FBC boilers can burn fuel with a combustion efficiency of over 95% irrespective of ash content, and an overall efficiency of 84% (plus or minus 2%). High heat transfer rate over a small heat transfer area immersed in the bed result in overall size reduction of the boiler. FBC boilers can be operated efficiently with a variety of fuels. Air emissions can be reduced as SO_2 formation is minimised by the addition of limestone or dolomite for high sulphur coals or oil, while a low combustion temperature

Figure 6.8 Using heat pumps. *This large industrial heat pump is taking its heat from the flue gases from waste combustion at Vattenfall, Uppsala Energy. In the process the gas condenses and the heat extracted is transferred to the district heating system. In other large-scale applications heat is extracted from sewage water or surface water. The chilled water may be used for district cooling. Most heat pumps are smaller and used for individual homes. (Photo: Kjell-Arne Larsson)*

eliminates NO_X formation. Finally by operating the fluidised bed at elevated pressure, it can be used to generate hot pressurised gases to power a gas turbine. This can be combined with a conventional steam turbine to improve the efficiency of electricity generation and give a potential fuel savings of at least 4%.

6.5.2 Heat Recovery Systems

Heat recovery systems are installed to make use of some of the energy which otherwise would be lost to the surroundings. The systems use a hot media leaving the process to preheat other, or sometimes the same, media entering the process. Thus energy otherwise lost does useful work.

Ventilation, process exhaust and combustion equipment exhaust are the major sources of recoverable energy. Regardless of the amount or temperature of the energy discharged, recovery is impractical unless the heat can be effectively used somewhere else. Also, the recovered heat must be available when it is needed.

Heat recovery uses heat exchangers. Heat exchangers have been improved considerably in recent years, both for exchanges in gas and liquid phase. Heat exchangers are used in a great many processes.

Heat extracted from indoor air ventilated to the outdoors is used to heat the incoming air. This is a very important part of heat recovery. In modern buildings the air is exchanged once every hour and some 25% of the heat used to heat buildings is lost in ventilation. Heat exchangers are also used to recover heat from exhausts flue gases.

6.5.3 Pinch Technology

The design of a new process, or the optimisation of an existing process, is a complex task, due to interactions between the unit operations that make up the process. These interactions force the designer not to consider each unit operation individually, but the whole process system as a whole. This is especially important for analysis and optimisation of heat recovery systems.

Pinch technology presents a simple methodology for systematic analysis of processes and the surrounding utility systems with the help of the first and second laws of thermodynamics. The first law of thermodynamics provides the energy equation for calculating the enthalpy changes (ΔH) in the process streams passing through a heat exchanger. The second law stipulates that heat energy only may flow in the direction of warm to cold, whereby the direction of the flow of heat is determined. This prohibits "temperature crossovers" of the warm and cold stream profiles through the exchanger. The warm stream can only be cooled to, and the cold stream heated to a temperature defined by the "temperature approach" of the heat exchanger. This temperature approach is the minimum allowable temperature difference (ΔT_{min}) in the stream temperature profiles. The temperature level at which ΔT_{min} is observed in a process is referred to as the *"pinch point"*.

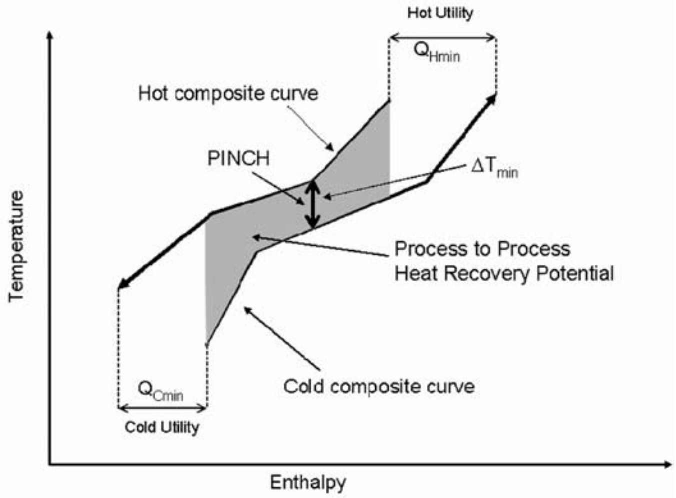


Figure 6.9 *Pinch Analysis Composite Curve diagram [Adapted from Cheresources, 2004]. http://www.cheresources.com/pinchtech1.shtml*

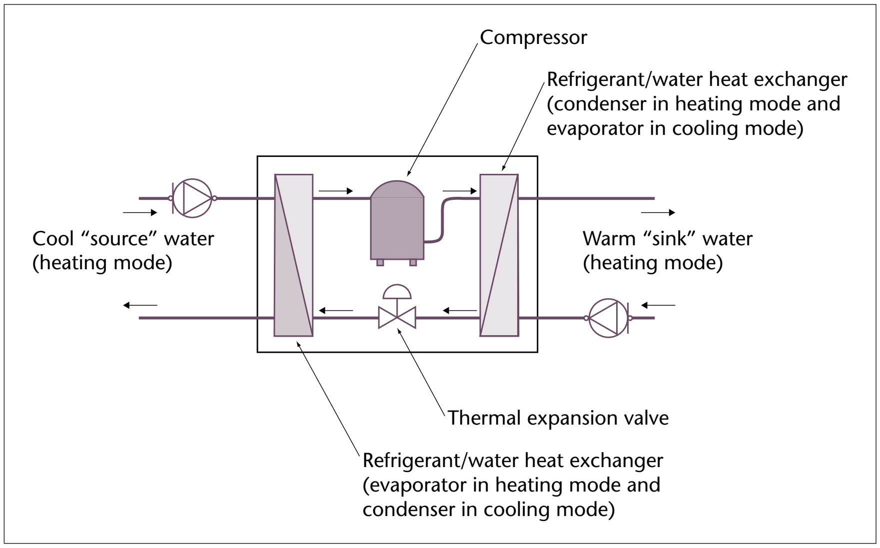


Figure 6.10 *Geothermal heat pump [adapted from U.S. DOE, 2003].*

The steps of a pinch analysis are:

1. Identification of hot, cold and utility streams in the process.
   - Hot streams are those that must be cooled or are available to be cooled.
   - Cold streams are those that must be heated.
   - Utility streams are used to heat or cool process streams.
     - A hot utility may be steam, hot water, flue gases etc.
     - A cold utility may be cooling water, air, refrigerant etc.
2. Thermal data calculation.
   - From the supply temperature (T_SºC), the target temperature (T_TºC) and the heat capacity flow rate (CP kW/ºC) of each stream the potential enthalpy change (ΔH) of the streams are calculated.
3. Selection of the initial ΔT_{min} value.
   - A minimum heat transfer driving force must always be allowed for a feasible heat transfer design. In mathematic terms, at any point in an exchanger $T_H - T_C \geq \Delta T_{min}$, where T_H is the hot stream temperature and T_C the cold stream temperature.
4. Construction of composite curves.

Composite curves consist of temperature-enthalpy profiles of heat availability in the process (the hot composite curve) and heat demands (the cold composite curve). We can then build the curves of hypothetical heat exchangers overlapping these hot and cold composite curves so that they are separated by a minimum temperature difference. The final horizontal overlapping of the composite curves is the maximum amount of energy that can be recovered and the enthalpy intervals not overlapping represent the enthalpy requirements that cannot be fulfilled with process streams and thus are the minimum required cooling and heating utilities for the process.

By applying the pinch analysis methodology to a complex process system the task of optimising the heat flows in the process system is greatly facilitated. In order to maximise energy recovery and minimise the energy (both heating and cooling) requirement an appropriate heat exchanger network is required. With the use of pinch analysis the design of the heat exchanger network becomes very systematic and methodical.

6.5.4 Heat Pumps

Heat pumps function by moving (or pumping) heat from one place to another. A heat pump takes heat from a heat source outside and pump it inside. Heat pumps use electricity to operate pumps that alternately evaporate and condense a refrigerant fluid to move that heat. In the heating mode, heat pumps are far more "efficient" at converting electricity into usable heat because the electricity is used to move heat, not to generate it.

The most common type of heat pump – an air-source heat pump – uses outside air as the heat source during the heating season and the heat sink during the air-conditioning season. Water-to-water heat pumps work the same way, except that the heat source/sink is the ground, ground water (geothermal heat pumps), or a body of surface water, such as a lake (surface water heat pumps). For large installations geothermal or surface water based heat pumps are the most common.

The efficiency or coefficient of performance (COP) (a ratio calculated by dividing the total heating capacity provided by the heat pump by the total electrical input) of water-to-water heat pumps is significantly higher than that of air-source heat pumps because the heat source is warmer during the heating season and the heat sink is cooler during the cooling season. Ground-source heat pumps are also known as geothermal heat pumps.

Ground-source heat pumps are environmentally attractive because they deliver so much heat or cooling energy per unit of electricity consumed. Water-to-water heat pumps connected to geothermal sources and low temperature, below 100ºC, loads typically have COPs in the range of 2.5 to 3.2. The best ground-source heat pumps are more efficient than high-efficiency gas combustion, even when the source efficiency of the electricity is taken into account.

6.5.5 Insulation

Although not generally viewed as a part of the mechanical design system, insulation is an important part of every piece of equipment or building where any transfer of fluids or gases takes place and that their temperature is required to be different then that of ambient air. Properly insulated pipes, tanks and other equipment can save substantial amounts of energy.

There are several opportunities in the industrial sector to realise energy savings by installing insulation in manufacturing facilities. Good insulation design and installation are very important in terms of performance and energy efficiency. It is essential to determine the most appropriate type and thickness of insulation for specific applications. The most cost-effective approaches involve insulating pipes and tanks.

Other obvious measures include covering surfaces of hot liquids – also water – and dimensioning the equipment correctly. Large pipes and tanks leak more heat to the surroundings than smaller, as diffusion is proportional to the surface area.

6.6 Saving Thermal Energy – Cooling Systems

6.6.1 Choosing the Right Source of Cold Temperature

For process cooling it is always best from the standpoint of energy conservation to use the lowest form of energy first. That is, for a piece of equipment or a process that is air cooled, first use outside air (an economizer) if the outside air temperature is low enough. The next step, in appropriate climates, would be to use direct evaporative cooling. This is a process in which air passing through water droplets (a swamp cooler) is cooled, as energy from the air is released through evaporation of the water. Evaporative cooling is somewhat more energy intensive than the economizer but still provides some relatively inexpensive cooling. The increase in energy use is due to the need to pump water.

Indirect evaporative cooling is the next step up in energy use. Air in a heat exchanger is cooled by a second stream of air or water that has been evaporatively cooled, such as by a cooling tower and coil. Indirect evaporative cooling may be effective if the wet-bulb temperature is fairly low. The wet-bulb temperature is the temperature indicated by a thermometer for which the bulb is covered by a film of water. As the film of water evaporates, the bulb is cooled. High wet-bulb temperatures correspond to higher air saturation conditions. For example, dry air has the ability to absorb more moisture than humid air, resulting in a lower, wet-bulb temperature.

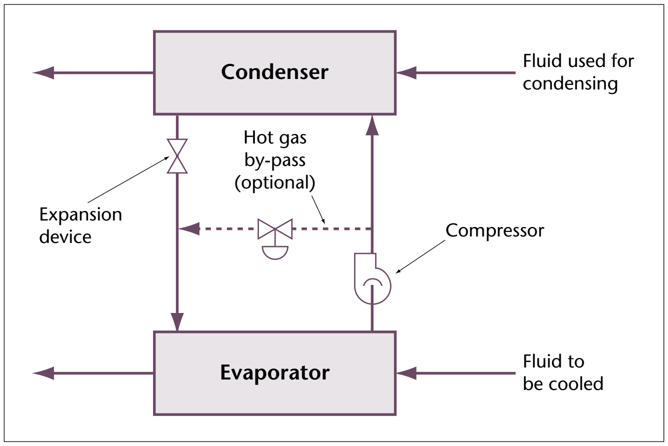


Figure 6.11 *Vapour-compression refrigeration system [Perry and Green, 1984].*

Indirect evaporative cooling involves both a cooling tower and swamp cooler, so more energy will be used than for the economizer and evaporative cooling systems because of the pumps and fans associated with the cooling tower. However, indirect cooling systems are still less energy intensive than systems that use a chiller. The final step would be to bring a chiller on line. Many plants have chillers that provide cooling for various plant processes. Chillers consist of a compressor, an evaporator, an expansion valve, and a condenser.

6.6.2 Cooling Towers

Cooling towers dissipate heat by evaporation of water that is trickling from different levels of the tower. Usually the water is sprayed into the air, so the evaporation is easier. Cooling towers conserve water, prevent discharge of heated water into natural streams and also avoid treating large amount of make-up water.

There are three types of cooling towers widely used today: mechanical forced-draft towers, induced draft towers and hyperbolic towers. Mechanical forced-draft is designed to provide an air supply at ground level and at amounts that are easily controlled by fans. In case of induced-draft towers the fan is mounted on the top of the tower. This arrangement improves air distribution and less make-up water is needed. The hyperbolic tower is based on the chimney effect. The effect of the chimney eliminates the need for fans that are necessary for both induced-draft and mechanical forced-draft cooling towers.

6.6.3 Absorption Refrigeration

Packed absorption liquid chillers are used to produce chilled liquid for air-conditioning and industrial refrigeration processes. The chillers are usually powered by low-pressure steam or hot water, which can be supplied by the plant boiler or by waste heat from a process.

In the absorption cycle, two distinct chemicals are used and the cycle is driven by heat. The most common absorption system fluids are water as the volatile fluid and lithium bromide brine as the absorber fluid.

6.6.4 Mechanical Refrigeration

Refrigeration machines provide chilled water or other fluid for both process and air conditioning needs. Of the three basic types of refrigeration systems (mechanical compression, absorption, and steam jet), mechanical compression is the type generally used. The other two have application only in special situations.

The mechanical compression refrigeration system consists of four basic parts; compressor, condenser, expansion device, and evaporator. A refrigerant, with suitable characteristics, is circulated within the system. Low-pressure liquid refrigerant is evaporated in the evaporator (cooler), thereby removing heat from the warmer fluid being cooled. The low-pressure refrigerant vapour is compressed to a higher pressure and a correspondingly higher saturation temperature. This higher pressure and temperature vapour is condensed in the condenser by a cooling medium such as cooling tower water, river water, city water, or outdoor air. The higher pressure and temperature refrigerant liquid is then reduced in pressure by an expansion device for delivery to the evaporator.

Figure 6.12 *Energy efficiency requires that pipelines are well-insulated. See also Case Study 4. (Photo: Waska Williams Jr. – North Slope Borough)*

6.6.5 District Cooling

By connecting to a trigeneration power plant delivering district cooling, an industry may cover its need for process or facility cooling in an energy and environmentally efficient manner. This is becoming increasingly used in e.g. restaurants and other services where cold rooms are used. It is obvious that just as with district heating, environmentally it is advantageous with a central facility that can be run with optimal efficiency, be well regulated, and equipped with proper environmental protection.

6.6.6 Insulation

Just as with heating systems, cooling systems need to be properly insulated. Insulation is an important part of every piece of equipment or building where any transfer of fluids or gases takes place and that their temperature is required to be different then that of ambient air. Properly insulated pipes, tanks and other equipment can save substantial amounts of energy. Good insulation design and installation are very important in terms of performance and energy efficiency. It is essential to determine the most appropriate type and thickness of insulation for specific applications.

Study Questions

1. Describe the world energy development and the development of the Baltic Sea region. How do regional peculiarities influence these processes?
2. List different kinds of energy sources.
3. What are the general terms of the agreement in the Kyoto Protocol? What role do the Baltic Sea countries play in this process?
4. Explain the concept of exergy.
5. What is the distinction between dispatchable and intermittent energy sources? Is this distinction absolute or are there ways of circumventing the problem of intermittent energy sources?
6. Explain the difference between cogeneration and trigeneration.
7. How can the energy efficiency of a boiler be improved?
8. What are the principles of pinch technology for analysis and optimisation of energy systems?
9. Describe different ways of saving electricity, heating and thermal energy.

Abbreviations

AC	Alternating Current.
CDM	Clean Development Mechanism.
CHP	Combined Heat and Power (cogeneration).
COP	Coefficient of Performance (efficiency).
DOE	US Department of Energy.
EIA	Energy Information Administration (of DOE).
EJ	ExaJoule (10E18 Joule).
GDP	Gross Domestic Product.
HID	High Intensity Discharge lighting.
JI	Joint Implementation.
kVAR	kiloVolt Amps Reactive (apparent power).
RT	Refrigeration Ton.
UNCED	UN Conference on Environment and Development.

Internet Resources

International Energy Agency (IEA),
an autonomous agency linked to the OECD
http://www.iea.org/

ASPO – The Association for the Study of Peak Oil and Gas
http://www.peakoil.net/

Energy Information Administration of the
US Dept. of Energy, DOE
http://www.eia.doe.gov/

U.S. Geological Survey World Petroleum Assessment 2000
http://pubs.usgs.gov/dds/dds-060/

European Commission Green Paper on Energy Efficiency
(Doing More With Less)
http://ec.europa.eu/energy/efficiency/index_en.htm

End Use Energy Efficiency; The Renewable Energy Unit of
Institute for Environment & Sustainability of the European
Commission Joint Research Centre (JRC)
http://energyefficiency.jrc.cec.eu.int/

Energy Saving Trust of UK
http://www.est.org.uk/

World Energy Efficiency Association
http://www.weea.org/

The Office of Energy Efficiency (OEE)
of the Natural Resources Canada – A centre of excellence for
energy efficiency and alternative fuels information
http://oee.nrcan.gc.ca/english/

Energy Information Administration (EIA) of the US
Government – A portal for energy savings with many links
http://www.eia.doe.gov/emeu/efficiency/energy_savings.htm

Save Energy Now is the US Department of Energy programme
on Energy Efficiency and Renewable Energy
http://www1.eere.energy.gov/industry/saveenergynow/

American Council for an Energy-efficient economy
– Emerging Energy-Efficient Industrial Technologies
http://www.aceee.org/pubs/ie003.htm

Combined Heat and Power Association
http://www.chpa.co.uk/

Trigeneration Technologies
(Cogeneration Technologies, Texas USA)
http://www.cogeneration.net/Trigeneration_Technologies.htm

Pinch Analysis for the Efficient Use of Energy,
Water and Hydrogen – Natural Resources Canada
http://cetc-varennes.nrcan.gc.ca/fichier.php/codectec/En/2003-140/2003-140e.pdf

L'Usine Marémotrice de la Rance (French)
http://membres.lycos.fr/chezalex/projets/rance/sommaire_rance.htm

7

Water Conservation

7.1 Water Management in Society

7.1.1 A Global Water Perspective

Water dominates our planet and is basic to man's living conditions. Still it is a limited resource and also a threatened resource world wide. To improve and limit water management is one of the main priorities for this century. Water is very unevenly distributed over the world. While e.g. in Africa, the Middle East, China and other arid and semi-arid areas a water access crisis is already a reality, in northern Europe, the situation is different. Here water quantity is not a large problem. The challenge is instead to improve water quality in rivers, lakes and the Baltic Sea itself.

Availability of water depends on the yearly run off, i.e. the amount of precipitation. In the Baltic Sea region this is very large in the north about 22,000 m^3 per person and year, while in the south, in Germany and Poland, it is about 20-fold lower. Here water is sometimes limiting for agriculture. Water use in society is in the north, e.g. in Sweden and Finland, is about 3-4% of the run off, or available resources, while in Poland it is about 18%. This is the level at which problems start to be visible due to the fact that water is re-circulated: wastewater emitted at some point is soon after recovered to be used for a new purpose. It is then often still too polluted. This is the water consumption cycle.

Water use is very different in different parts of the world. On the global level irrigation and agriculture account for the largest share, about 65%, followed by industry, 24%, municipal needs, 7%, and reservoirs 4%. In the Baltic Sea region irrigation is a much smaller part of water consumption.

7.1.2 Water Consumption in Industry

Water consumption in society has decreased significantly over a period of some 15 years. A general trend in Europe is a decline of withdrawal of water especially for industry but also for households. Many water saving strategies have been introduced with the purpose to save freshwater resources, decrease discharges of wastewater and facilitate the recovery of chemicals and energy. We will illustrate this with data from Sweden.

In total, industry is the largest water user in the region. For example, in Sweden industry accounted for close to 70% of all water use, households another 20% and agriculture 5% (data for year 2000, Figure 7.1). Three industrial branches dominate water use. Pulp and paper industry accounts for almost half (0.9 billion m^3). Together with chemical industry (0.5 billion m^3) and metals work (0.4 billion m^3) these three branches use 85% of all industrial water.

In this Chapter

Industrial water use in Sweden increased dramatically from the 1940s up to a peak in 1965. Thereafter a strong decrease took place up to about 1975, and less so up the 1990s. In the period 1990-95 there was a slow decrease (just under 1% yearly) even though, at the same time, industrial production increased by about 25%. Since then (preliminary data for 2003) water use has been quite constant at around 2,200 Mm³ yearly, while the total water consumption in Sweden was 3,240 Mm³. The distribution of water consumption between different consumer groups is shown in Figure 7.1.

The withdrawal for production of *potable water* in the region was, around 1980, about 500-800 m³/person and year. In the early 21st century this figure has decreased to almost half. Households dominate with more than half of this consumption (57% in Sweden during the 1990s) while industry use no more than some 10%. Leakage in the network is considerable and amounts to close to 25% of the total in all countries.

An important reason for decreased water consumption is the price for water. Water companies, most of them municipally owned, charge for the provision of potable water and treatment of sewage. Costs are mostly related to investments, and not strongly so to the volumes. Still prices are related to consumption, which helps reduce consumption.

Measures to save water in households are mostly trivial. This includes fixing leakage in toilets – a running toilet uses much water over 24 hours – and kitchen and bathrooms; the introduction of water efficient washing machines and dish washers, and water reduction taps for e.g. showers. The reduction of water use is coupled to reduction of warm water use. Lower water costs thus lead to lower energy costs.

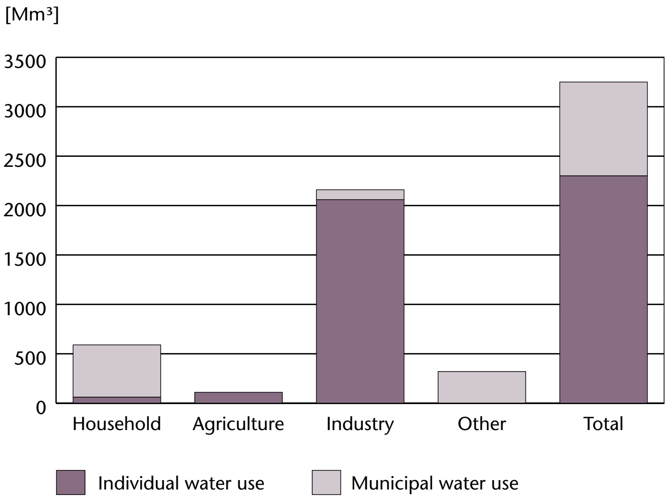


Figure 7.1 *Water consumption in Sweden 2000 [SCB (Statistics Sweden), http://www.scb.se/templates/tableOrChart____27297.asp]*

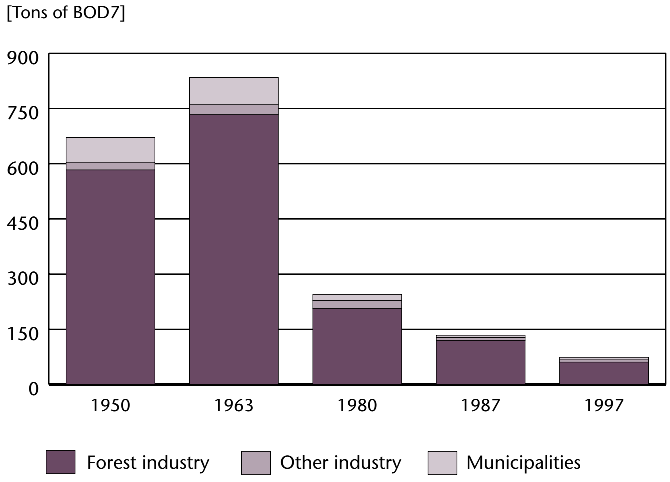


Figure 7.2 *Emissions of biodegradable compounds from Swedish sources (BOD$_7$) 1950-1987 [Persson and Nilson, 1998, compiled from the Swedish Environmental Protection Agency].*

Measures to reduce water consumption in industry are partly of the same character. But more importantly a radical new way to treat process water and other kinds of water typical for industry are more important. These measures will be the topic of this chapter.

7.1.3 Integration of Industrial and Municipal Water Management

Industrial water handling, as well as solid waste treatment, has several connections to municipal water and solid waste treatment, basically because the industry often utilises the municipal wastewater treatment plants. If not, the same processes as in the municipal plants are often used. Naturally, industrial activities most often give rise to residual-product flows, entirely different from municipal waste flows, which has to be treated with its own technology.

The industry has the opportunity, already at the manufacturing stage to influence the amount and properties of the residual-flows. This possibility to process integrated solutions has, to a large extent, been used in industry. To combine internal and external measures in order to reduce emissions, at a low cost, is a very common feature of current industrial environmental protection technology. The large reduction of BOD-emissions (oxygen demanding) from the pulp and paper industry during the 70s and 80s and the very large reduction in organic chlorine compounds during later years are some illustrative examples (Figure 7.2).

7.1.4 Provision of Water to Industry

Figure 7.3 shows the details of water use in Swedish industry in year 2000 as an example. It is clear that volume-wise cooling water dominates followed by process water. Almost all of the water is withdrawn from surface water (lakes and rivers) and in a few cases as sea water. Ground water resources are thus not exploited for industrial purposes.

Industries with very large water demand have their own sources of water. However, smaller industries normally rely on municipal water. Their sources of water are thus the same as for municipal water, a mixture of ground and surface water, and artificially infiltrated water.

The volume of cooling water varies from industry to industry, depending on the amount of heat to be cooled away from the process. Industries with large demand of cooling water are situated along the coast or along rivers.

To use cleaned water from the municipal or industrial wastewater treatment plant as raw-water is one alternative that can be useful for areas with a restricted supply of water. To use reused wastewater can, however, present problems, practical as well as aesthetic. Due to variations in the inflow to the wastewater treatment plant it could become difficult to guarantee a certain quality of the cleaned water. The wastewater treatment plant could be subject to disruptions which might mean longer or shorter production stops. An industry demanding continuous supply of raw water might therefore need an alternative raw-water source as a reserve from which, when necessary, water could be drawn.

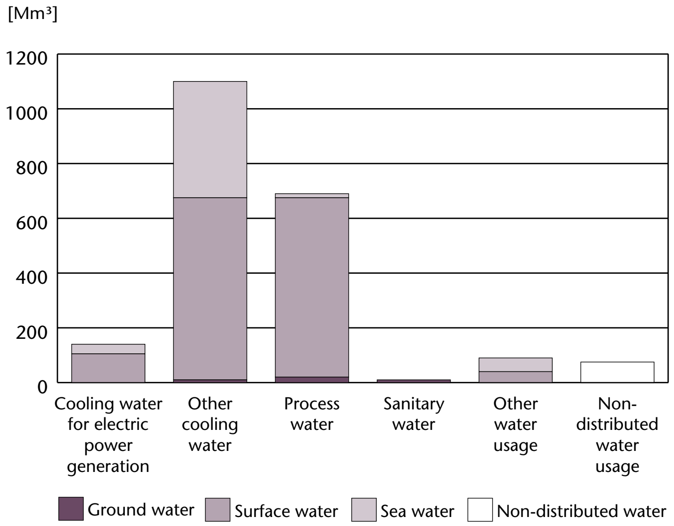


Figure 7.3 *Industrial water use in Sweden in 2000 [SCB (Statistics Sweden), http://www.scb.se/templates/tableOrChart____39386.asp].*

7.2 Measures to Reduce Water Consumption

7.2.1 Strategic Choices

Water is an expensive raw material today. In earlier days water was a cheap resource that could be utilised in almost unlimited quantities, but today the costs for water supply and the treatment of wastewater have become considerable. It has thus become necessary, for economic reasons, to reduce water consumption.

Yet another reason for lowering water consumption is that emissions of pollutants from an industry depend on the wastewater production. One important step to reduce the effects of industrial emissions on the recipient and the external wastewater treatment plants is, therefore, to reduce the volume of the emissions. This can be achieved through:

- Separate handling of different kinds of wastewater.
- Process changes in order to reduce the volume of wastewater.
- Reuse of industrial wastewater as input water.
- Elimination of the intermittent emissions of process wastewater.

7.2.2 Separation of Different Kinds of Wastewater

The kinds of water in an industry may be drastically different. Treatment of these streams separately is an important strategy. This refers to water provision, where e.g. cooling water may be withdrawn from a nearby river or lake, while process water may depend on municipal potable water. But even more so, it is important to separate the wastewater streams.

While the most polluted water should be subject to a thorough cleaning, the less polluted water may achieve a less thorough treatment or maybe even no treatment at all. This will in practice reduce the volume of wastewater significantly.

Wastewater can be divided into four classes:

1. *Process water* is part of the chemical or physical production processes. Process water may contain very specific components, pollutants, which require specific treatments. In some industries process water may be very large volumes.
2. *Cooling water* is water used to remove heat produced in the processes, e.g. in power plants. Large volumes of cooling water are used in some industries, e.g. nuclear power plants and cement industries. It is most often little, or not at all, polluted.
3. *Sanitary wastewater* is water from kitchens, toilets etc, the same as in households and residential areas. It is normally sent to the municipal sewage network.

4. *Storm water* is run-off from the industrial area, roofs and hard made surfaces. The character of storm water is dependent on the surface, and may be either similar to storm water from streets in the city or much more polluted.

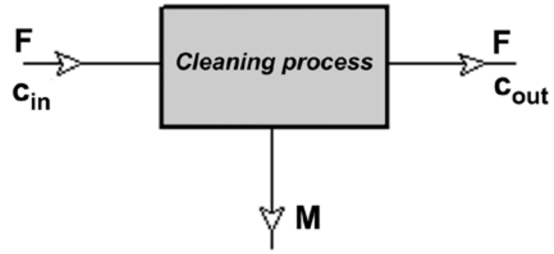
Each of these streams will be discussed below.

7.2.3 Process Water

Process water is the most important class of wastewater. The task is not only to reduce the cost for the used volume of water, but also to reduce the amount of pollutants in the water. In a wastewater treatment plant it is usually possible, independent of the incoming concentration, to reach a specific residual concentration in the cleaned water. It is usually rather difficult to lower the concentration under this level even if the incoming concentration is low. Since the emissions from an industry usually are calculated in kg or tonnes per day and not per litre wastewater, it is desirable to lower the amount of water to be cleaned as much as possible, even if it means that the concentration becomes higher (Figure 7.4).

From an economic point of view, it is more profitable having an as small as possible water flow, since that usually means a lower investment requirement, even if the amount of pollutants to be separated is the same.

Yet another, but equally important, point of view is to separate the pollutants from the wastewater as close to the source as possible and not to mix different wastewaters. It is always simpler and cheaper to separate one component from a solution if it is the only component present, compared to separating one component from a complex mixture.



$$F \cdot c_{in} = F \cdot c_{out} + M$$

F = volume flow of waste water [m^3/d] (in and outflow)

c_{in} = incoming concentration pollutants [kg/m^3]

c_{out} = rest concentration pollutants [kg/m^3] (~ constant)

M = amount separated pollutants [kg/d]

Figure 7.4 *A simple equation expresses how the amount of separated pollutants depends on wastewater flow. A low flow and higher concentration will improve the cleaning process.*

The amount of water consumed to produce a certain amount of product is, as mentioned earlier, subject to continued reduction, among other things due to purposeful technological development towards less water consuming processes. Each unit operation in the industry demands generally as much water as earlier, but by recirculating the water within the process or reusing it after cleaning, the volumes of needed freshwater has been reduced step by step.

7.2.4 Cooling Water

The volume of cooling water varies from industry to industry, depending on the amount of heat to be cooled away from the process. A large refinery, for instance, will use 500,000 m^3 per day, of which only 15,000 m^3 is process wastewater, the rest is cooling water with very small amounts of pollutants.

One possible solution for reducing the amount of cooling water is to use a closed cooling water circuit. By circulating the cooling water through a cooling tower the heat energy can be transferred from the water to air by evaporating a small part of the water. Another option is to use a heat pump to extract the heat energy from the cooling water at a higher, more useful temperature.

7.2.5 Sanitary Wastewater

The volume of sanitary wastewater is normally between 75 and 150 litres per employee and day. The total amount produced depends on several factors, besides from the number of employees, for instance how much is flushed through floor drains during clean-up and what degree of personal hygiene is demanded from the personnel. Sanitary wastewater is normally sent to the municipal sewer network and treated like other wastewater. It is important that this water stream is not contaminated by industrial wastewater with pollutants not normally treated in the municipal wastewater treatment plant.

7.2.6 Storm Water

Storm water is connected to the precipitation and varies therefore strongly with time. The amount of pollutants in the water depends on how much the ground in the draining area is polluted, which also decides the degree of cleaning needed. Storm water might sometimes go straight to a recipient or to a municipal wastewater treatment plant without or after only simple pre-treatment (sedimentation) in storm water wells. In other cases the water must be treated in a separate wastewater treatment plant. The sludge from the storm water wells is treated and deposited as industrial sludge.

7.2.7 Elimination of Intermittent Emissions

In batch manufacturing processes the emissions of wastewater also come as batches. This could lead to problems with intermittent loads on the treatment plant and recipient, with respect to concentration of pollutants as well as amount of wastewater. There are at least two ways of reducing this effect:

1. Change the production so that the frequency of the emissions is increased, thereby decreasing (hopefully) the emitted amount at each emission.
2. Collect the wastewater in a tank and, from there, release it at a mean speed to the wastewater treatment plant.

7.3 Process Changes

7.3.1 Process Changes to Reduce Water Consumption

Just as the demand for water for human consumption can vary within certain limits the water demand for production of a certain product can vary. If there is a local shortage of water, or if its price entails large costs for a user, the user will try to save water or find substitutes. The savings are then twofold: the water costs as well as the cleaning costs are reduced.

The generally most efficient way to decrease the amount of outgoing wastewater is process integration. First of all a substantial recirculation of process water is an alternative to decrease the amount of freshwater required. The prime problem is to avoid the build-up concentration of pollutants and by-products in the process water to unacceptable levels. This may be avoided by cleaning the process water after each cycle. An example is the water in a paper mill which passes the paper when it is formed. However, many changes to reduce the amount of wastewater are expensive, and the gain from the reduction has to be weighed against the costs. An alternative is a limited bleed flow, which goes to wastewater treatment.

Also important are measures which do not necessarily depend on investments, but result in a decrease in the water consumption just by "good housekeeping". Some examples are:

- Use the countercurrent principle in all washing, flushing and leaching processes.
- Re-circulate polluted water, if required after treatment.
- Use water for purposes with lower quality demands – down-classing of water.
- Flush-wash instead of dip-wash.
- Use closed cooling-water system.
- Check the actual demand for water, for instance by installing water meters to monitor consumption.
- Install magnetic valves which close off the water during production disruptions.
- Avoid leakage of water, flush over etc.

Useful examples of recirculation of water are found in the food industry, where water can be used several times starting from the "clean side" of production to the first washing step. Sometimes an additional cleaning (intermediate cleaning) can take place, usually by sedimentation.

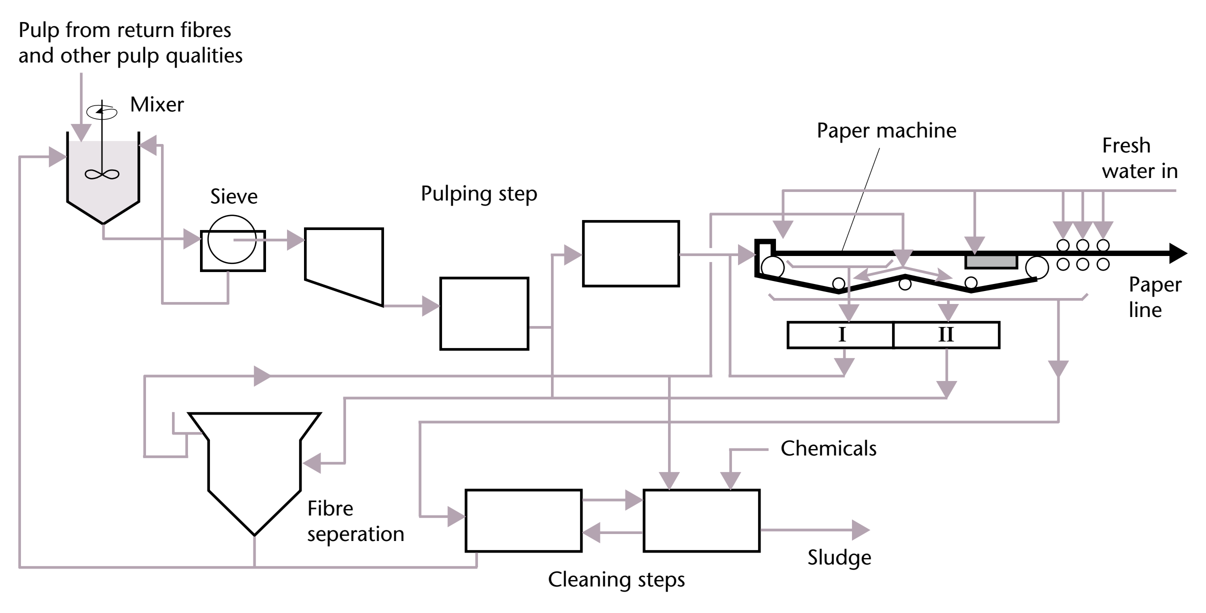


Figure 7.5 *Water cycle in a mill for recycled paper.*

7.3.2 Cases of Water Conservation

Figure 7.5 shows the water cycle in a mill for recycled paper, where the evaporation losses are compensated for by re-circulating the wash water. Clean water is added only in the last washing step.

In order to achieve a recirculation of process water, substantial additional measures are required. These include desalination of the water. Evaporation would otherwise lead to a substantial increase in the salt concentration of the process water. Sludge also builds up, and measures are required to reduce it. Otherwise microorganisms would contaminate the process water.

An example of substitution of water with steam can be found in potato handling. Earlier, industrially peeled potatoes required an amount of 6 m^3 of soda per tonne potatoes. Today the potatoes are peeled with steam. Water savings amounts to 60-70%. Another advantage of this new technique is that the peeling waste (about 150 kg/tonne potatoes) can be used as fodder. The amount of wastewater can be decreased by about 20% when soda, soil, and potato peels can be kept away from the wastewater.

There are many examples on production processes where water consumption has been decreased and, as a result, the amount of wastewater as well.

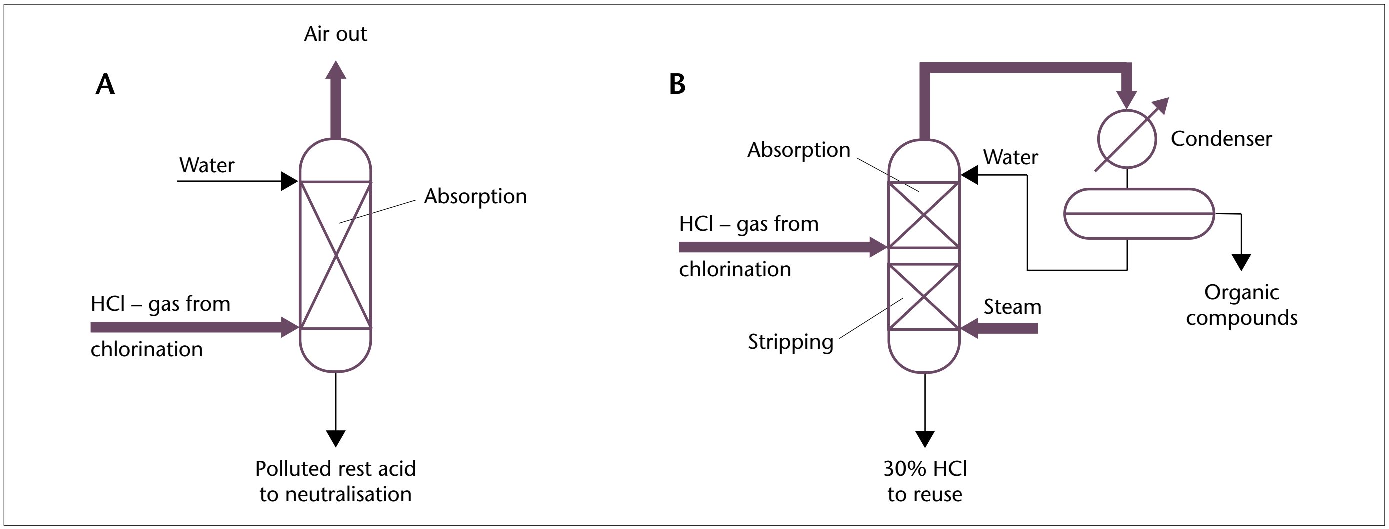


Figure 7.6 Processes for chlorinating of hydrocarbons; *conventional absorption of HCl with water (A), and a new process – adiabatic absorption with evaporation (B), respectively.*

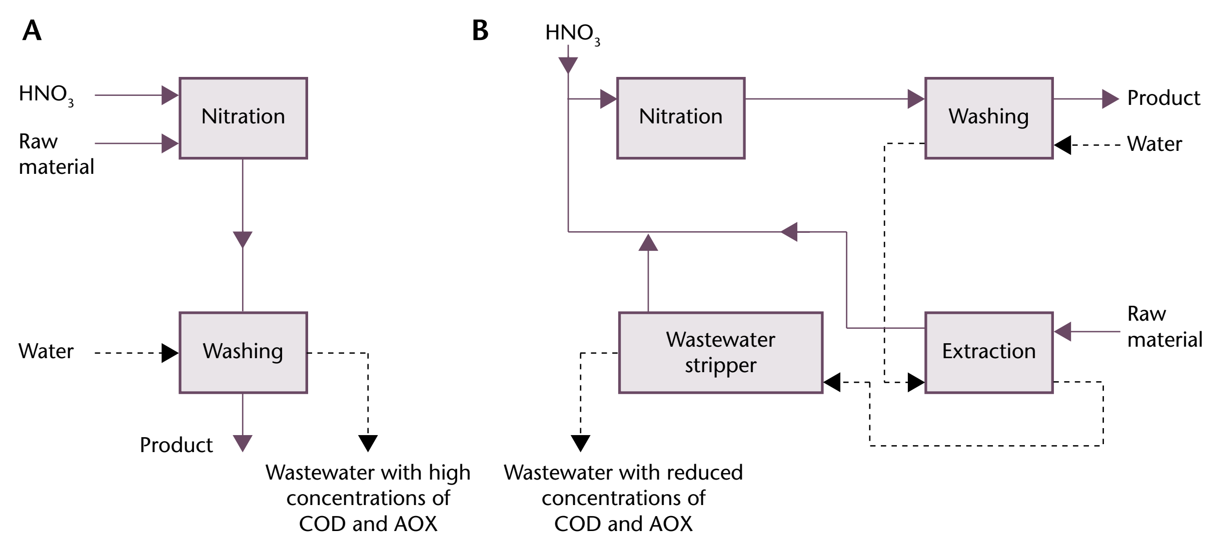


Figure 7.7 Nitration of hydrocarbons, *an earlier process (A) and a developed process (B) which through reuse and recirculation of "rest"-products and unreacted raw material leads to a decreased environmental hazard potential in the wastewater.*

In the classic chlorination of organic products, half of the added chlorine added to the reactor was unused and absorbed in water as dilute hydrochloric acid (HCl). It was then included in the waste acid, which had to be neutralised. In a new chlorination process the absorption product is stripped with steam in order to evaporate the organic components, and yields a concentrated acid as by-product, to be used for other purposes. The process has become completely free from wastewater as the separated organic compounds are recycled to the chlorination step. (Figure 7.6).

Another example is shown in Figure 7.7. An earlier process for nitration of hydrocarbons (chlorine aromatics, amines, etc.) has been improved. In the new process the organic compounds in the wash-water from the process is extracted with the incoming organic raw material in a countercurrent extraction column. The remaining hydrocarbons are evaporated and re-circulated. In addition to saving water, the environmental hazard potential of the wastewater has been decreased.

Study Questions

1. What are the four most common ways of reducing the volume of wastewater from an industrial process?
2. Explain why a reduction of the volume of process water in a process also reduces the amount of pollutants in the final wastewater stream.
3. List and comment six different ways of reducing the water consumption in a process by process integrated measures.
4. Give some examples of how the energy in the discharged cooling water stream can be utilised.
5. Explain why recirculation of process water can be a problem and give some examples of how such problems can be solved.
6. Describe the world water resources and compare them with the Baltic Sea region water resources.
7. On what principles is industrial water consumption based? Which branches of industry in the Baltic Sea region use the largest amount of water?
8. Describe the influence of the municipal wastewaters on the general water degradation.
9. State the classification of wastewaters.
10. How can water consumption be reduced?

Abbreviations

BOD	Biological Oxygen Demand.

Internet Resources

Waste Reduction Resource Center of N.C. Division of Pollution Prevention and Environmental Assistance and USEPA – Collection of links on water efficiency

http://wrrc.p2pays.org/indsectinfo.asp?INDSECT=27#Websites

North Carolina Division of Pollution Prevention and Environmental Assistance – Water conservation

http://www.p2pays.org/water/

US Environmental Protection Agency – Clean Water Through Conservation (Chapter 3)

http://www.epa.gov/water/you/chap3.html

GreenBiz.com – Water Conservation

http://www.greenbiz.com/toolbox/essentials_third.cfm?LinkAdvID=4089

Ministry for the Environment Ontario Canada – Water conservation tips for industry

http://www.ene.gov.on.ca/cons/3781-e.pdf

New Mexico Office of the State Engineer – A Water Conservation Guide for Commercial, Institutional and Industrial Users

http://www.ose.state.nm.us/water-info/conservation/pdf-manuals/cii-users-guide.pdf

Statistics Sweden

http://www.scb.se

8

Water Pollution Reduction

In this Chapter

8.1 Measures to Decrease Pollutants in Water Streams

8.1.1 A Range of Strategies

Reduction of pollutants in water streams is a key issue in cleaner production. It is required to decrease environmental impact, but it is also a key issue for making recirculation of water, especially process water, possible, to reduce by-products and to save input resources. The long-term goal is to eliminate or reduce the production of pollutants as much as possible. All efforts to lower the amount of produced pollutants will add to the savings. There will be less costs for resource material, water volumes and need of treatment.

One of the best strategies is to reduce water flows. A reduction of water consumption almost always leads to a decrease in emitted pollutants. This issue was discussed in Chapter 7.

The amounts of pollutants in the waste streams can be reduced in several ways:

- Exchange the raw material and support chemicals (material substitution).
- Modify the process.
- Modify the equipment.
- Improve process control, reliability of operation.
- Improve work methods, routines, "the human factor".
- Level out the wastewater flow.
- Improve separation and extraction of by-products.
- Make a revision of products and product design.

Each of these will be discussed below.

8.1.2 Exchange of Raw Material and Support Chemicals

Many of the materials regarded as pollutants in the wastewater from processes do not originate in the process itself but enter the process as components in the raw materials or in the help (support) chemicals. By systematically tracing the polluting components in the wastewaters, the origins of such pollutants can be found. The next step is to reduce or even eliminate them in the raw materials. This can be done by exchanging the contributing raw materials or finding one of higher quality. One needs to be aware, however, that the pollutants thereby are moved to another location/recipient.

A classic example of raw material substitution is when acid rain was reduced by requiring that low sulphur oil be used for heating. A higher quality raw material was used. Another example of raw-material substitution is found in the chlorine-based bleaching process in the pulp and paper industry. Here large amounts of eco-toxic chlorinated hydrocarbons were discharged with wastewater streams to the recipients. As chlorine was replaced with other bleaching chemicals, such as oxygen, chlorine-dioxide, ozone or hydrogen peroxide (generally there is a combination of different bleaching chemicals) this problem was essentially solved. Here a different raw material was used, and in fact the process chemistry itself changed.

8.1.3 Modifying the Process

The amounts of pollutants from a production process can be reduced by changing the process itself. Sometimes this can be achieved simply by optimising the process, that is, finding the best temperature, time and concentrations of reactants. A second standard approach is to install equipment for process control, e.g. through on-line measurement of the components in the process, and proper feed-back mechanisms.

In general, a number of different measures exist for modifying a production process. These include:

- Alter the reaction time, temperature, pressure and/or chemical environment in the process.
- Increase the yield by, for instance, improved technology for measurement and control.
- Install internal cleaning steps, for instance, for separation of pollutants from the process.
- Recover input chemicals and re-circulate them back to the process.
- Reuse input chemicals for purposes with lower quality demands.
- Improve the handling of raw materials (storage, transport, etc.).
- Change the process to an entirely new way of manufacturing the product.

Many industries have resolved waste problems through process changes. The following two examples of progressive management are from the textile and mining industries.

Textile-finishing mills were faced with the disposal of highly polluting wastes from sizing, kiering, desizing, and dyeing processes. Starch had been traditionally used as a sizing agent before weaving and this starch, after hydrolysis and removal from the finished cloth, was the source of 30 to 50% of the mill's total emissions of oxygen-demanding matter. The industry began to express an interest in cellulose-based sizing agents, which would exhibit little or no BOD or toxic effects in the recipients. Several highly substituted cellulose compounds, such as Carboxy Methyl Cellulose (CMC), were developed and used. The resulting waste reduction was almost in direct relation to the amount of cellulose-based sizing compounds used.

A coal mining company used the public water supply to wash the raw coal. At the same time a second waste stream was the acid mine wastewater. The company modified its process and washed raw coal with acid mine wastewater. In this way the use of public water supply decreased, and the mine drainage was neutralised while the coal was washed free from impurities. In one analysis, the initial mine water had a pH of 3 and an iron content of 551 ppm; the wastewater finally discharged from the process had a pH of 6.7 to 7.1 and an iron content of less than 1 ppm.

8.1.4 Modifying the Equipment

By optimising and modernising the equipment it is possible, in many cases, to reduce the amount of pollutants produced and emitted from a process. Often quite small changes in existing equipment may be sufficient to reduce the amount of waste. These include the addition of filters, and other mechanical devices to separate waste from a stream.

Illustrative examples are found in the food industry. In a pickle factory fragments of the cucumbers were part of and added to the strength and density of the waste stream. When screens were placed over the drain lines in the cucumber tanks they prevented the escape of seeds and pieces of cucumber. This solid waste was then dealt with separately.

In a poultry plant pieces of feathers and fat were found in the wastewater. Traps on the discharge pipeline removed these from the wastewater, and made it possible to treat them separately.

The removal of fibres from the wastewater streams in pulp and paper factories by simply adding filters is another example. In this case the fibres go back to the process.

8.1.5 Improved Process Control, Reliability of Operation

As the continuous emissions are mastered, the intermittent emissions, due to process disruption, will increase in importance. Many of the modern cleaning processes installed in connection with different processes work at a very high rate of efficiency. The emissions during breakdown or serious short time process disruptions are then important. The emissions during the production breakdowns sometimes exceed the total annual amount of emissions during normal conditions. The most urgent improvement in these situations is to reduce the risk of production disruptions.

Within the metal surface treatment industry breakdowns and process disruptions counts for about 80% of the total amount of pollutants emitted. Today, therefore, a technology with high stability and accessibility is more desirable than technology with a high cleaning effect.

8.1.6 Avoiding Accidental Spills

Accidental discharges of polluting process solvents or solutions represent one of the most severe pollution hazards. Many accidental discharges are usually small in volume and go unobserved. One therefore needs to pay special attention to them. Even if it is almost impossible to prevent every potential accident from occurring, there are some measures that can be taken to reduce the likelihood of accidents and severity when and if they occur. Some suggestions for general use include the following:

- Make certain that all pipelines and valves in the plant are clearly marked for identification.
- Allow only certain designated and knowledgeable persons to operate these valves.
- Install indicators and warning systems for leaks and spills.
- Provide for detention of spilled wastewater in holding basins or lagoons until proper waste treatment can be accomplished.
- Monitor all effluents – quantity and quality – to provide a positive public record, if necessary.
- Establish a regular maintenance programme of all pollution abatement equipment and all production equipment which may result in a liquid discharge to the sewer network.

In environmental work one must not forget that not only process equipment works with varying degrees of efficiency in a production plant, but there are also human beings who can make mistakes. Emissions may be caused by personnel using wrong routines, making mistakes due to fatigue, etc. By a systematic inspection of all routines used in a plant, education of personnel, etc., the emissions caused by the human factor may be substantially reduced.

8.1.7 Separation and Extraction of By-products

Keeping different kinds of wastewater in a plant separated often results in considerable savings in complexity and costs for wastewater treatment. By treating different process waters separately also considerable gains are possible. It may be possible to use relatively simple separation and concentration methods for extraction of components which in the wastewater are regarded as pollutants. In a separated and concentrated form they may be either re-circulated in the process or be extracted as by-products.

There are many examples of positive results from adapting waste treatment procedures to be able to recover by-products. One example is from the metallurgy industry (Figure 8.1). Metal-plating industries use ion exchangers to recover phosphoric acid, copper, nickel and chromium from plating solutions. The de-ionised water from the ion exchangers, without

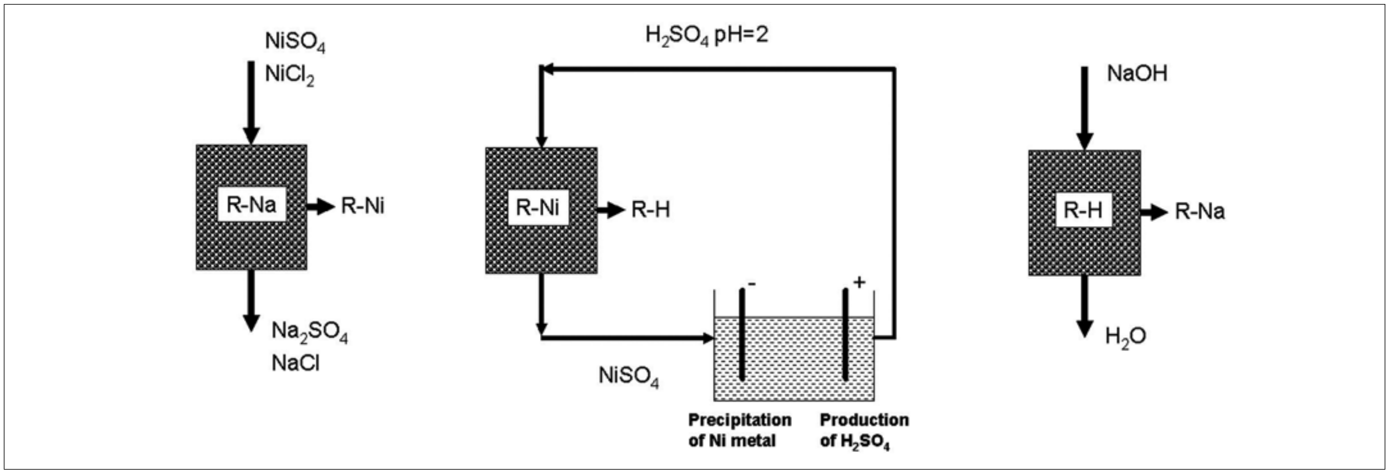


Figure 8.1 Recovery of metallic nickel from waste nickel plating solutions using ion exchange and electrolysis. *Left: Ni*$^+$ *in the wastewater stream is adsorbed to an ion exchanger resin (R). Middle: Ni*$^+$ *is desorbed from the resin with low pH solution and precipitated as metallic nickel on the cathode of an electrolytic bath. Right: The ion exchanger is regenerated using NaOH solution.*

any further treatment, is ideal for boiler-feed requirements. The solutions received from the regeneration of the ion exchanger resins, now with high content of metal ions, can either be recycled in the metal-plating process or used for recovery of valuable metallic chromium, copper and nickel.

8.1.8 Equalisation of Wastewater Flow

Industries with several products from different processes often prefer to level out their wastewater flows. This means that the wastewater is collected in a surge tank during a certain period of time, depending on the turnaround time for the different processes in the factory. If, for instance, a product is produced in a number of steps taking in total eight hours, the surge tank must have a residence time of at least eight hours. The wastewater flow from this tank will have a more even composition and characteristics compared to the inflow to the tank (Figure 8.2).

The goal with levelling out the wastewater is to achieve a stabilisation of, among other things, pH and BOD in the water. At the same time the tank also serves as a sedimentation tank for separation of particles. Stabilised wastewater can be treated more readily and efficiently in industrial and municipal cleaning plants than if composition and other properties vary. In some cases levelling out of wastewater will make other treatments unnecessary. This is the case, for instance, if pH varies heavily with time.

8.1.9 Choice of Products and Product Design

The emissions from a process are, of course, dependent on the produced product. If a certain product requires a production process that gives rise to large waste streams, one may reconsider the product itself. To use environmental concerns as a single reason not to produce a product seems rather drastic. This may seldom be needed. Even only smaller changes in the product can result in considerable reductions of emissions.

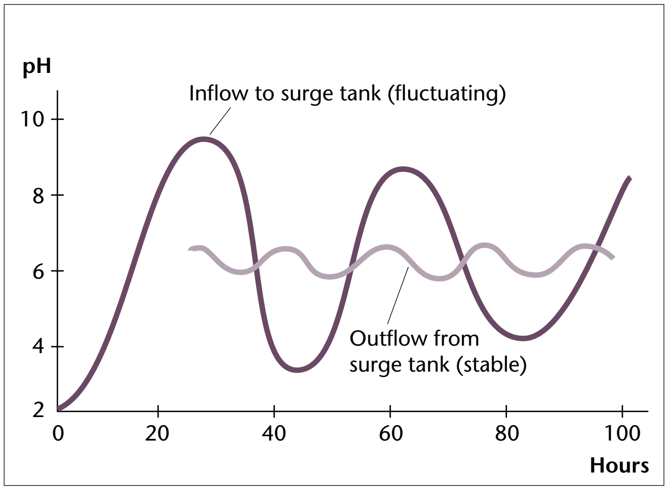


Figure 8.2 Equalisation of effluent from a process using a surge tank. *The inflow waste stream to the tank has large variation of pH due to the cyclic nature of the process, while the outflow has less variation as pH is equalised in the tank. The volume of the tank should correspond to at least one cycle [Nemerow and Dasgupta, 1991].*

Products are often treated to protect the surface and make it have a certain look or colour. Some of these treatments have been environmentally problematic. In these cases different coverings – lacquer or paint – have been one solution. For example cadmium containing paints were outlawed at some point, and were replaced by other paints. Some coverings are connected to specific solvents which may be environmentally hazardous. They may be simply exchanged. The materials in some products could also be reconsidered. The production of some plastics is environmentally problematic, and some added chemicals in plastics, such as softeners, may be problematic. In these cases a different material could be considered.

In cases when it seems difficult to modify the product as it is, a different approach may be needed. An analysis of the function of the product can sometimes suggest that there are other ways to fulfil the function, which may also lead to substantial environmental improvements.

8.2 Separation Unit Operations for Cleaner Production

A production process consists of a series of steps called unit operations. These perform different tasks such as reaction, separation, washing etc. The unit operations described here all separate the components in a flow from each other.

8.2.1 A Range of Methods

Cleaner production measures often imply process changes, change of raw materials or support chemicals, i.e. pure process technology. Many processes require that one includes some kind of unit operation for separation of certain components from a process flow. These components can then be recycled back into the process or extracted as by-products instead of generating a waste stream. Another application is to separate certain components from a process stream in order to prolong the usage time of a process solution. This is called a *kidney function*. Below a number of physical unit operations that are widely used in cleaner production applications are described.

Each separation process exploits the differences in a property of the components to be separated. In distillation, it is volatility. In absorption, it is solubility. In extraction, it is a distribution coefficient. Separation by adsorption depends on one component being more readily adsorbed than another. The selection of a suitable process may also depend on the ease with which the separated components can be recovered.

8.2.2 Adsorption

Adsorption has been used as a physical-chemical process for many years, but it is only over the last four decades that the process has developed to a stage where it is now a major industrial separation technique. In adsorption, molecules distribute themselves between two phases, one of which is a solid while the other may be a liquid or a gas.

In adsorption a component of a liquid solution or a gas mixture is separated from the main bulk of the fluid by being associated to a solid surface – *the adsorbent*. Adsorption occurs when molecules diffusing in a fluid are attached to a surface by weak intermolecular forces developing between the molecule and the surface as the molecule approaches the surface. The surface represents a gross discontinuity in the structure of the solid, and atoms at the surface have a residue of molecular forces which are not satisfied by surrounding atoms such as those in the body of the structure. Some of these, the weak so-called van der Waals forces, are common to all surfaces. The adsorption resulting from van der Waals forces is essentially *physical* in nature. In some systems, the absorbed molecules are also bound by chemical bonds to the solid surface. These are *chemical* in nature involving the exchange or sharing of electrons, or possibly molecules forming atoms or radicals. In such cases the term *chemisorption* is used to describe the phenomenon. Here much stronger forces are involved, and it is less easily reversed than physical adsorption; regeneration may be a problem. The most valuable adsorbents in a process are those with high specificity. It is often possible to find specificity in today's very large variety of adsorbents.

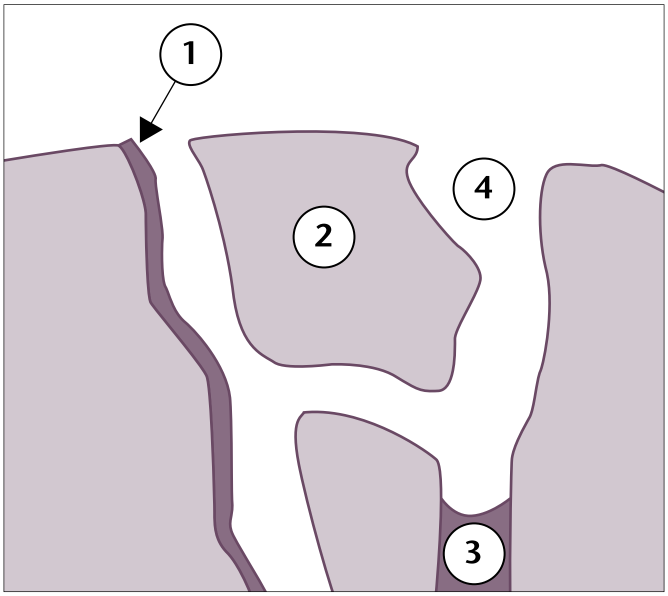


Figure 8.3 *Adsorption mechanisms in a porous adsorbent. (1) The adsorbed substance forms a monomolecular layer on the surface of the pores. (2) A small molecule penetrates into the solid phase. (3) The adsorbed substance forms a liquid plug. (4) The adsorbate is dissolved in the fluid inside the pore structure.*

The characteristic feature of an adsorbent is its high porosity creating an extremely large internal surface area. The most commonly used adsorbent, activated carbon, has a specific area of 500-1500 m^2/g, compared to an ordinary solid particle of e.g. iron oxide with a radius of 5 µm which has an external surface area of 10-15 m^2/g.

When molecules move from a bulk fluid to an adsorbed phase, they lose degrees of freedom and their free energy is reduced. Therefore adsorption always is accompanied by the release of heat; it is an *exothermal* process. In physical adsorption the forces holding the molecules to the surface are of the same order of magnitude as those holding molecules together in a liquid. Adsorption may therefore be compared to the process of condensing a vapour into a liquid. The heats of adsorption are therefore of the same magnitude as the *heat of condensation*. For chemisorption it is greater and of the order of magnitude normally associated with a chemical bond. If the heat of adsorption cannot be dispersed by cooling, the capacity of the adsorbent will be reduced as its temperature increases.

The reverse process by which the adsorbed molecules are removed from the surface to the bulk fluid phase is called *desorption*. Energy must be supplied to the adsorbed phase for the *endothermic* desorption process. The energy required for desorption is about the same as that released at the adsorption.

Figure 8.3 shows how the *adsorbate* molecules (the substance being adsorbed) can be associated to the pore surfaces. At ① the adsorbate has formed a monomolecular layer on the surface of the pores. If large amounts of adsorbate enter the pore structure condensable substances can form liquid plugs filling the entire pore as shown at ③ in the figure. Very small molecules may even penetrate and diffuse into the solid phase ②. A non-negligible amount of adsorbate will also be retained in the fluid inside the pore structure ④.

8.2.3 Ion Exchange

Ion exchange is a unit operation in its own right, sharing theory with adsorption or chromatography, although it has its own special areas of application. The oldest and most enduring application of ion exchange is in water treatment. Here it is used to soften (remove calcium) or demineralise water before industrial use, and to recover components from an aqueous effluent before it is discharged or recycled.

In ion exchange the substances in ionic form in the liquid phase are captured onto the ion exchanger by forming ionic (electrostatic) bonds. Ions initially present in the ion exchange resin are being exchanged for the substances in the liquid phase. Most often positively charged metal ions are exchanged with sodium (Na) or hydrogen ions and negatively charged ions as sulphate, phosphate or, for that matter, arsenate ions are exchanged with hydroxide ions. If the exchanging ions are positively charged, the ion exchanger is termed *cationic*, and if they are negatively charged it is called *anionic*. The rate at which ions diffuse between an exchanger and the liquid is determined, not only by the concentration differences in the two phases, but also by the necessity to maintain electro-neutrality in both phases.

An ion exchanger consists of a *resin* onto which charged groups have been added. Most base ion exchange resin consists of a styrene-divinylbenzene polymer. When the styrene-DVB polymer is sulphonated, it becomes the *cation exchanger* polystyrene sulphonic acid (-SO_3H), with exchangeable hydrogen ions. Other – much weaker – cationic groups are carbonic acid (-COOH) or phenolic (-OH). *Anion exchangers* are also manufactured from polystyrene by substituting amines (-R_3-N). A more selective type of ion exchange resins are the so called chelate ion exchange resins. In these, multifunctional groups are used to selectively separate multiple charged metallic ions by binding them in a ring structure.

Ion exchange can be applied for general or selective separation of cations and anions. It functions well for diluted solutions (< 4000 mg/l). The capacity of an ion exchange resin depends on the total number of exchangeable ionic groups per unit mass of resin, commonly expressed in milli-equivalents/gram (meq/g). The base unit of a polystyrene-sulphonic acid resin has a molecular weight of 184 kg/kmol. Each unit has one exchangeable hydrogen ion, so its maximum capacity is 1000/184 or 5.43 milli-equivalents/gram.

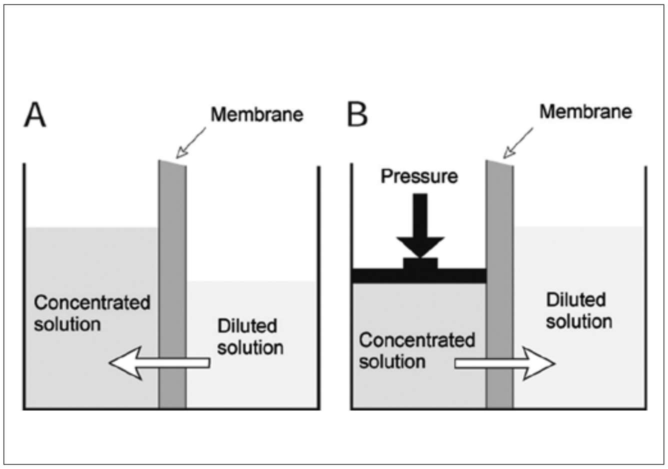


Figure 8.4 *In ordinary osmosis (A) the solvent flows form a higher to a lower concentration. In reverse osmosis (B) an external pressure forces the solvent in the opposite direction to form a more concentrated solution.*

Zeolites are also being used as ion exchangers. The loosely-bound nature of extra-framework metal ions (such as in zeolite NaA) often make them readily exchanged for other types of metal when in aqueous solution. This is exploited in a major way in water softening, where alkali metals such as sodium or potassium prefer to exchange out of the zeolite, being replaced by the "hard" calcium and magnesium ions from the water. Many commercial washing powders thus contain substantial amounts of zeolite. Commercial wastewater containing heavy metals, and nuclear effluents containing radioactive isotopes can also be cleaned up using such zeolites.

The capacity of styrene-based anion exchangers are not so easily calculated because there may not be an anionic group on every styrene group. Values of 2.5-4.0 meq/g are typical for strong anionic resins.

8.2.4 Membrane Separation

The technology of using synthetic membranes for process separations has developed rapidly since the 1960s. Such membrane separations have been widely applied to a range of conventionally difficult separations. They potentially offer the advantages of ambient temperature operation, relatively low capital and running costs, and modular construction.

The principle of membrane separation is that of selective passage of molecules across the membrane, largely depending on molecular size. When a solution with a certain concentration of a component is in contact with another solution with a different concentration across a semi-permeable membrane the concentration difference between the two sides is equalised as the solvent, e.g. water, diffuses across the membrane. Solvent molecules diffuse from the side with the higher solvent concentration to the side with the lower solvent concentration, which is consequently diluted, in the process of *osmosis*. This process will continue until the osmotic pressure between the two sides of the membrane is equal. At the same time the dissolved molecules also try to diffuse through the membrane towards the side where the concentration is lower for these components. If, as is normally the case, the membrane only allows small solvent molecules to pass, then larger, dissolved molecules are prevented from penetrating the membrane.

If a pressure higher than the osmotic pressure difference is applied to the concentrated side the process will reverse and water will diffuse from the concentrated side to the diluted, so called *reverse osmosis*. In this way saline water may be de-salinated and the concentrations of dissolved substances in the saline solution will increase.

8.2.5 Extraction

The separation of the components of a liquid mixture by treatment with a solvent in which one or more of the desired components is preferentially soluble is known as liquid-liquid extraction. This is an operation which is used, for example, in the processing of coal tar liquids and in the production of fuels in the nuclear industry. It has also been applied extensively to the separation of hydrocarbons in the petroleum industry. In this operation, it is essential that the liquid-mixture feed and solvent are at least partially if not completely immiscible and, in essence, three stages are involved:

1. Bringing the feed mixture and the solvent into intimate contact.
2. Separation of the resulting two phases.
3. Removal and recovery of the solvent from each phase.

It is possible to combine stages (1) and (2) into a single piece of equipment such as a column, which is then operated continuously. Such an operation is known as differential contacting. Liquid-liquid extraction is also carried out in stage-wise equipment, the prime example being a mixer-settler unit in which the main features are the mixing of the two liquid phases by agitation, followed by settling in a separate vessel by gravity.

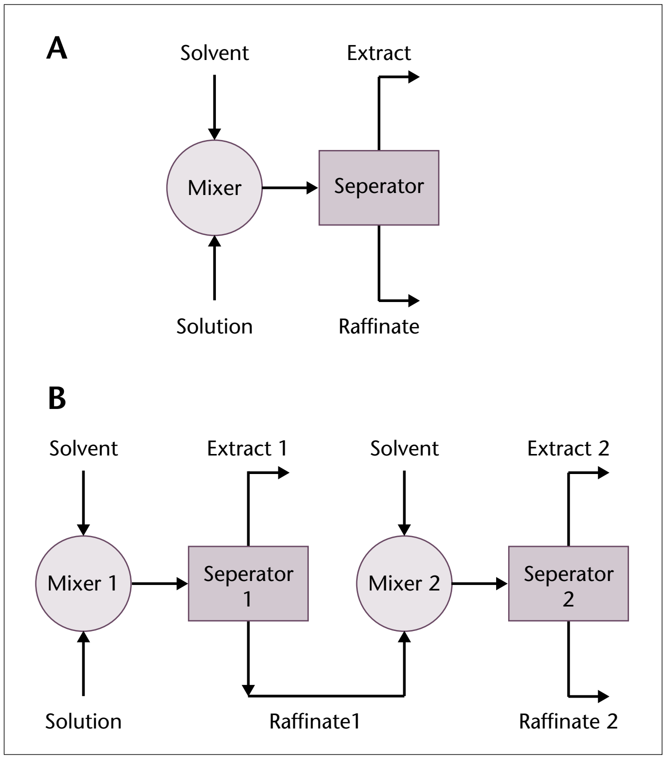


Figure 8.5 *Single-stage batch extraction (A) the solvent and solution is mixed and later separated to allow the purified raffinate to continue, while the pollutant is found in the extract. In a two (B) or multi-stage extraction the procedure is repeated to achieve a more efficient purification.*

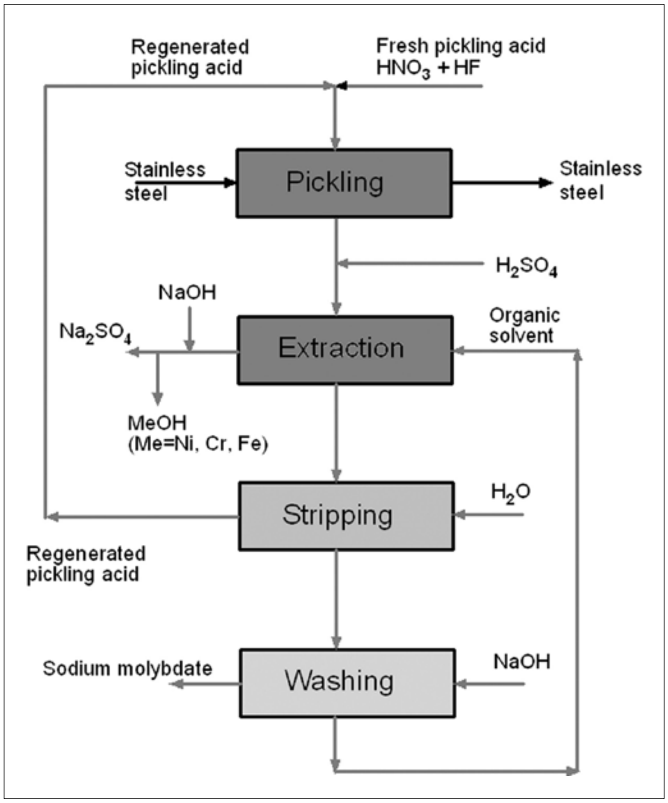


Figure 8.6 *Recovery of steel mill pickling acid by extraction.*

In all extraction processes, the important feature is the selective nature of the solvent in that the separation of compounds is based on differences in solubilities.

In the single-stage batch process illustrated in Figure 8.5a, the solvent and solution are mixed together and then allowed to separate into the two phases – the extract E containing the required solute in the added solvent and the raffinate R, the weaker solution with some associated solvent. With this simple arrangement mixing and separation occur in the same vessel.

A continuous two-stage operation is shown in Figure 8.5b, where the mixers and separators are shown as separate vessels. There are three main forms of equipment. First there is the mixer-settler as shown in Figure 8.5a, secondly, there is the column type of design with trays or packing and, thirdly, there are a variety of units incorporating rotating extractors. In all cases, the extraction units are followed by distillation or a similar operation in order to recover the solvent and the solute.

For cleaner production applications extraction is for example be used in the steel industry for recovery of pickling acids. The pickling acid (a mixture of nitric and hydrofluoric acids) is after the pickling stage treated with sulphuric acid, in order to convert the dissolved metals to sulphates. In the extraction stage nitrate and fluoride are extracted into an organic solvent in which an amine is dissolved, adding an ion exchange function to the solvent. The aqueous phase is treated with sodium hydroxide to precipitate the metals (Cr, Ni, Fe) dissolved in the pickling stage. Molybdenum (Mo) in the stainless steel is dissolved as an anion (molybdate) and is therefore extracted into the organic phase. In the next stage the organic phase is stripped with water yielding a regenerated pickling acid that is recycled to the process and to regenerate the amine. Finally the solvent is washed with sodium hydroxide to remove the molybdenum as sodium molybdate.

Extraction has also been used for recovery of zinc in rayon production. In this process a complex is formed with zinc and an organo-phosphorus compound. This metal-organo complex is soluble in an organic solvent and is extracted from the waste stream. Then the complex is broken by changing the pH of the organic phase. This makes the zinc water soluble and re-extracted with water forming a zinc-solution with much higher concentration. The zinc is then precipitated as a salt and recovered.

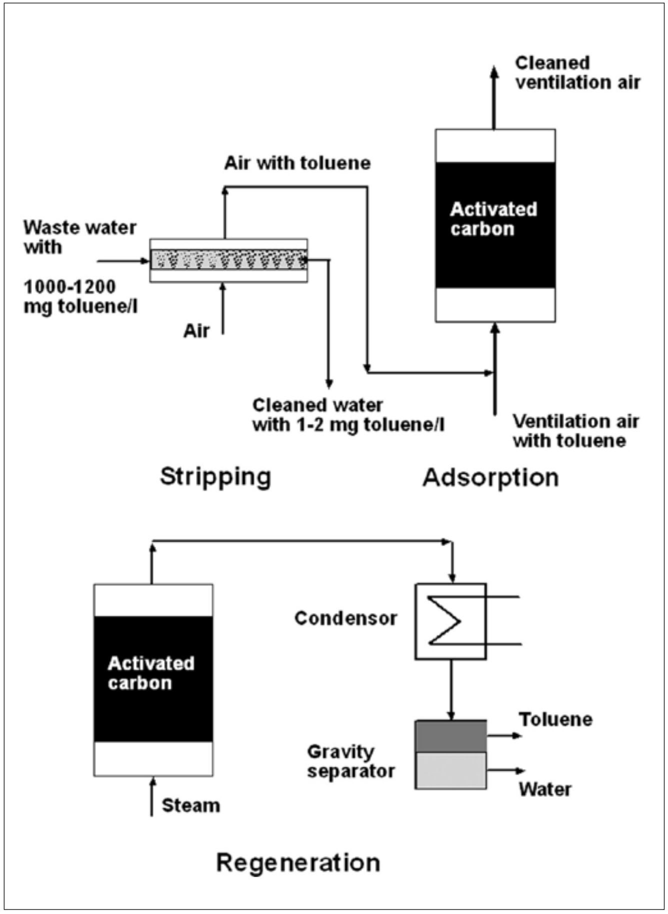


Figure 8.7 *Recovery of toluene from printing wastewater.*

8.2.6 Stripping

Desorption or stripping of substances from a water solution with steam or air followed by a combustion of the gas phase is an interesting option for separation of organic substances from a water solution.

An often used application is the stripping of toluene from wastewater from printing operations. The stripped toluene-air mixture is combined with the ventilation air and passed through the purification system, normally an activated carbon adsorption column where the toluene is adsorbed. When the activated carbon is saturated with toluene, it is regenerated with steam, and the toluene is condensed and recovered and recirculated to the printing process (Figure 8.7).

Stripping is also used for regenerating the solvent in an extraction process (Figure 8.6). Also in this case the equilibrium conditions are changed, e.g. by changing the pH allowing the transfer of the dissolved components from the extract to the raffinate phase.

8.3 Adsorbents

8.3.1 Types of Adsorbents

Adsorbents have large specific surface areas (500-1500 m^2/g), varying pore structures, and surface properties (polar and non-polar) that are responsible for selective adsorption of specific components of a fluid mixture. These include activated carbons, zeolites (molecular sieves), aluminas, silica gels, polymeric adsorbents, and ion-exchange resins. Adsorbents may be energetically homogeneous, containing adsorption sites of identical adsorption energy, or heterogeneous, containing a distribution of sites of varying adsorption energies.

Adsorbents are available as irregular granules, extruded pellets and formed spheres. The size reflects the need to pack as much surface area as possible into a given volume of bed and at the same time minimise pressure drop for flow through the bed. Particle sizes of up to about 6 μm are common. The external surface of a particle with a radius of 5 mm is only in the order of 12 m^2/g. The residual van der Waals forces are common to all surfaces and the only reason why certain solids are designated "adsorbents" is that they can be manufactured in a highly porous form, giving rise to a large internal surface. In comparison the external surface makes only a modest contribution to the total surface area, even when the solid is finely divided.

To be attractive commercially, an adsorbent should embody a number of features:

- It should have a large internal surface area.
- The area should be accessible through pores big enough to admit the molecules to be adsorbed. It is a bonus if the pores are also small enough to exclude molecules which it is desired not to adsorb.
- The adsorbent should be capable of being easily regenerated.
- The adsorbent should not age rapidly, that is, lose its adsorptive capacity through continual recycling.
- The adsorbent should be mechanically strong enough to withstand the bulk handling and vibration that is a feature of any industrial unit.

8.3.2 Activated Carbon

Activated carbon has a typical surface area of 1000 m^2/g, mostly associated with a set of pores of about 2 nm in diameter. Common raw materials for activated carbon are naturally occurring carbonaceous materials such as coal, wood, coconut shells or bones that are carbonised in an inert atmosphere at about 525°C. The carbonised material is then activated by a partial oxidation in an atmosphere of steam or carbon dioxide at about 725°C, generating the porous structure in the carbon that is a requirement for it to function as an adsorbent.

In water activated carbon preferentially adsorbs compounds with low solubility in water, high molecular weight and low polarity. The reason for these properties is that the adsorption is best for compounds with similar molecular structure and electron distribution as the adsorbent material. The adsorption capacity of activated carbon is commonly 100-200 g adsorbate/kg carbon.

In water applications activated carbon is being rarely used for recovery processes since the amount of energy needed for regeneration often makes the process too expensive. The nature of the substances adsorbed, (large organic molecules), requires high regeneration temperatures that often will decompose the activated carbon itself.

After use the activated carbon is therefore often discarded with the adsorbed substances. It may be used for energy recovery, i.e. for waste incineration.

8.3.3 Polymer Adsorbents

Polymer adsorbents are a relatively recent type of adsorbents. They are based on a cross-linked styrene or acrylate polymer structure in which different active groups are introduced. It is to these active groups that the adsorbate molecules are associated on adsorption. Polymer adsorbents can in principle be tailor-made to selectively adsorb organic compounds with varying polarity and water solubility. Thus it is a complement to activated carbons for adsorption applications. The specific surface area of a polymer adsorbent is lower than that of activated carbon, 100-700 m^2/g and the adsorptive capacity is also lower. The polymer adsorbent is on the other hand considerably easier to regenerate.

One clear advantage of polymer adsorbents is that their pore structure and internal surface area can be controlled by varying the polymerization conditions when they are produced. Uniform physical properties lead to adsorption homogeneity and often allow regeneration under milder conditions. The feasible applications of polymeric adsorbents are to remove hydrophobic components from dilute solutions and air streams. Moreover, one of the advantages of polymeric adsorbents is that the adsorption often is weaker than with the other adsorbents such as activated carbons. Therefore the adsorbent can more easily be regenerated by using solvents or even by using a simple pressure-swing operation without the addition of thermal energy for regeneration.

8.3.4 Molecular Sieves

By using naturally occurring *zeolites* and, later, synthesised members of that family of minerals, it has been possible to manufacture a range of adsorbents known collectively as *molecular sieves*. These have lattice structures composed of tetrahedra of silica and alumina arranged in various ways. The net effect is the formation of a cage-like structure with windows which admit only molecules less than a certain size. By using different source materials and different conditions of manufacture, it is possible to produce a range of molecular sieves with access dimensions of 0.3 nm-1 nm. The dimensions are precise for a particular sieve because they derive from the crystal structure of that sieve.

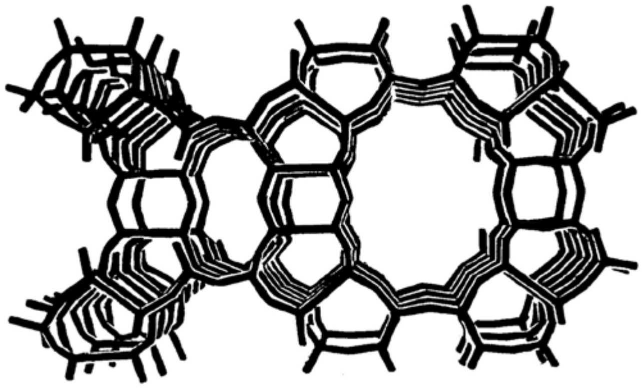


Figure 8.8 *Crystal structure of a zeolite (Gmelinite, pore size ~0.49 nm) [International Zeolite Association, http://www.iza-online.org/].*

Molecular sieves have relatively large specific areas, 500-1000 m^2/g. Natural zeolites contain aluminium atoms and are hydrophilic in character. As such they can be used as drying materials, preferably adsorbing polar compounds such as water. By successively removing the aluminium atoms from the crystal lattice the zeolite becomes more and more hydrophobic, and when all the aluminium is removed the crystal is all silicon dioxide, which is non-polar. This means that a zeolite can be tailored to selectively adsorb a specific type of substance depending on its degree of polarity.

The shape-selective properties of zeolites form the basis for their use in molecular adsorption. The ability to preferentially adsorb certain molecules, while excluding others, has opened up a wide range of molecular sieving applications. Sometimes it is simply a matter of the size and shape of pores controlling access into the zeolite. In other cases different types of molecules enter the zeolite, but some diffuse through the channels more quickly, leaving others stuck behind, as in the purification of *para*-xylene by silicate.

Cation-containing zeolites are extensively used as desiccants due to their high affinity for water, and also find application in gas separation, where molecules are separated on the basis of their electrostatic interactions with the metal ions. Conversely, hydrophobic silica zeolites preferentially absorb organic solvents. Zeolites can thus separate molecules based on differences in size, shape and polarity.

8.3.5 Silica Gel

When a silicate solution such as sodium silicate is acidified, a gel of polymeric colloidal silicic acid is formed as an agglomerate of micro-particles. When the gel is heated, water is expelled leaving a hard, glassy structure with voids between the micro-particles equivalent to a mean pore diameter of about 3 nm and specific surface area of about 500 m^2/g. This is silica gel. It is used as a powder.

Silica gel is probably the adsorbent which is best known. Unlike the activated carbons, the surface of silica gel is hydrophilic, and it is commonly used for drying gases and also finds applications where there is a requirement to recover unsaturated hydrocarbons.

8.3.6 Activated Alumina

When an adsorbent is required which is resistant to attrition and which retains more of its adsorptive capacity at elevated temperatures than does silica gel, *activated alumina* may be used. This is made by the controlled heating of hydrated alumina. Water molecules are expelled and the crystal lattice ruptures along planes of structural weakness. A well-defined pore structure results, with a mean pore diameter of about 4 nm and a surface area of some 350 m^2/g.

Activated alumina has a high affinity for water in particular, and for hydroxyl groups in general. It cannot compete in terms of capacity or selectivity with molecular sieves although its superior mechanical strength is important in many applications.

8.4 Membrane Processes

8.4.1 A Range of Membrane Processes

Membrane processes constitute a well-established branch of separation techniques (Table 8.1). They work on continuous flows, are easily automated, and can be adapted to work on several physical parameters. These include:

- Molecular size.
- Ionic character of compounds.
- Polarity.
- Hydrophilic or hydrophobic character of components.

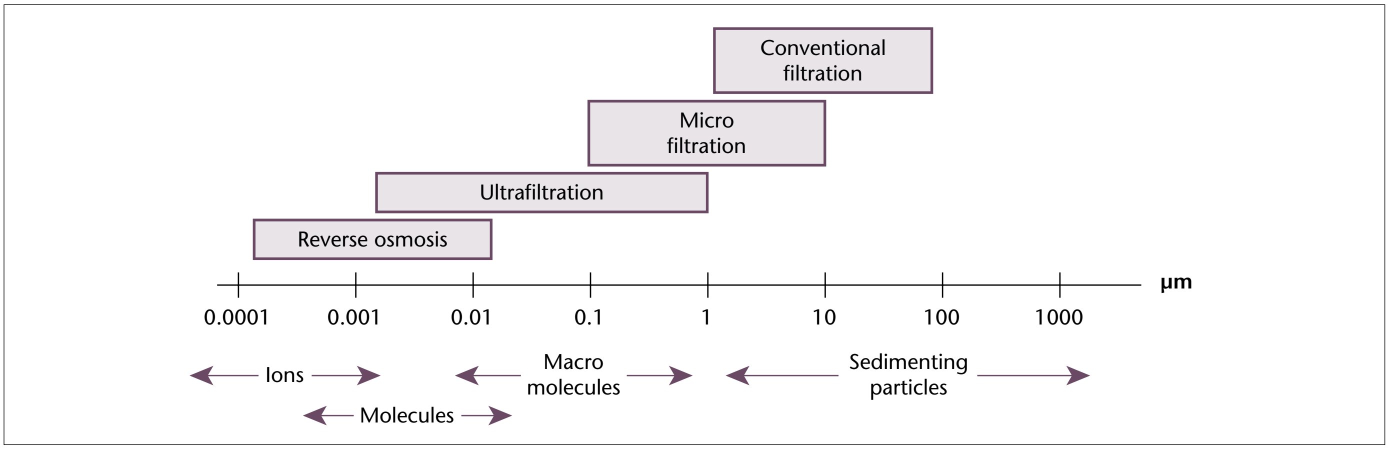


Figure 8.9 *Classification of membrane separation processes for liquid systems according to separation ranges, here from 0.001 µm. The measurements are approximate.*

Microfiltration, ultrafiltration, and reverse osmosis differ mainly in the size of the particles that the membrane can separate. They can be defined as follows:

- *Microfiltration* uses membranes with pore diameters of 0.1 to 10 µm for filtering suspended particles, bacteria, or large colloids from solutions.
- *Ultrafiltration* uses membranes with pore diameters in the range of 0.005 to 1 µm for filtering dissolved macromolecules, such as proteins from solutions.
- *Reverse osmosis* membranes have pores so small that they are in the range of the thermal motion of polymer chains, e.g., 5 to 200 Å.
- *Electrodialysis* membranes separate ions from an aqueous solution under the driving force of an electrostatic potential difference.

Membrane separation is also used in *pervaporation* or *membrane distillation* that permits the fractionation of liquid mixtures by partial vaporization through a membrane. The partial pressure of the separated components on the permeate side of the membrane is reduced by condensation or flushing by a gas stream, thereby generating the required driving force.

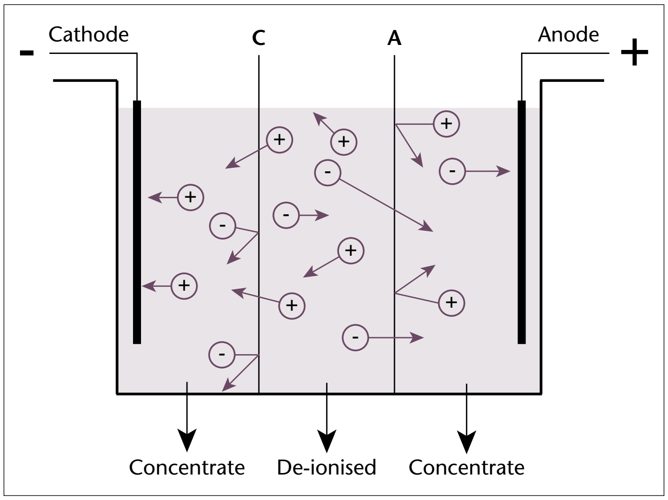


Figure 8.10 Principle for electrodialysis. *A and C are ion-selective membranes. In this equipment the negative ions are concentrated in the anode and the positive ions at the cathode, where they undergo electrode reactions.*

Table 8.1 Main membrane separation processes. *The table shows the operating principles and application of the eight processes, MPa=Mega Pascal [Orioli et al., 1989].*

Separation principle	Membrane type	Driving force	Method of separation	Range of application
Microfiltration	Symmetric micro porous membrane, 0.1 to 10 µm pore radius	Hydrostatic pressure difference, 0.1 to 0.5 MPa	Sieving mechanism due to pore radius and adsorption	Sterile filtration, clarification
Ultrafiltration	Asymmetric micro porous membrane, 1 to 10 µm pore radius	Hydrostatic pressure difference, 0.1 to 0.7 MPa	Sieving mechanism	Separation of macromolecular solutions
Reverse osmosis	Asymmetric skin-type membrane	Hydrostatic pressure, 2 to 10 MPa	Solution– diffusion mechanism	Separation of salt and microsolutes from solutions
Dialysis	Symmetric micro-porous membrane, 0.1 to 10 µm pore size	Concentration gradient	Diffusion in convection-free layer	Separation of salts and microsolutes from macromolecular solutions
Electrodialysis	Cation and anion exchange membranes	Electrical potential gradient	Electrical charge of particle and size	Desalting of ionic solution
Gas separation	Homogeneous or porous polymer	Hydrostatic pressure concentration gradient	Solubility, diffusion	Separation from gas mixture
Supported liquid membranes	Symmetric micro porous membrane with adsorbed organic liquid	Chemical gradient	Solution diffusion via carrier	Separation
Membrane distillation, pervaporation	Micro porous membrane	Vapour- pressure	Vapour transport into hydrophobic membrane	Ultra pure water, concentration of solutions

8.4.2 Membrane Technologies

Membrane technologies are gaining a wider application area as new and more resistant membranes are developed. This is particularly true for ultrafiltration that has found environmental applications such as recovery of water-based paints from rinsing water in electro-dip coating, purification of alkaline de-greasing baths and breaking oil emulsions. Reverse osmosis is used in surface treatment industry for concentrating rinsing baths in chromation in order to recover chromic acid. In pulp and paper industry ultrafiltration is used for concentrating waste streams instead of using evaporation. Ultrafiltration has also with excellent result been used for separation of chlorophenols from bleaching wastewaters.

Electrodialysis is another membrane technique that has become economically competitive with e.g. evaporation. The process utilises cation or anion active membranes that allow negative ions to penetrate the membrane but prevent the penetration of positive ions and vice versa. If a DC voltage is applied across a number of cells separated with alternating anion and cation active membranes, salt solutions will be concentrated respectively de-salinated in every other cell (Figure 8.10). The process has been used for recovery of nickel from surface treatment rinsing waters and for de-salination of process streams containing a mixture of organic and inorganic components e.g. in the food industry.

8.5 Choosing Separation Processes

8.5.1 Separate Treatments for Different Wastewater Streams

In practical work the large wastewater streams go to treatment plants. Wastewater streams may be treated separately if components, which ordinary wastewater treatment cannot handle, should be removed. For examples some heavy metal ions are removed in precipitation processes and organic components treated chemically for example by oxidation. More sophisticated adsorption methods are used for process water where the volumes may not be so large, and the value of recycling the water solution is high, because of components used in the process. This is especially true in biotechnical processes.

8.5.2 Which Method is Right

Finding the right separation method for a production process is often a matter of trial and error. The rules of thumbs rely on the property of the substance to be removed. This substance may be charged or non-charged, hydrophobic or hydrophilic, small or large and present in low or high concentrations. This is relevant for:

- Adsorption with activated carbon may be used as a polishing step, excellent for separation of organic compounds at low concentrations.
- Adsorption with polymer adsorbent is used for recovery of organic compounds at higher concentrations. Less suitable as polishing step at low concentrations.
- Ion exchange is used for recovery and as polishing step for ionic substances at low concentrations.
- Extraction is used for recovery and separation of hydrophobic organic substances at high concentrations.
- Stripping is used for separation of volatile often non-degradable substances at low to high concentrations.
- For comparatively large molecules, membrane separation is often selected for low to medium high concentrations. Also an alternative to evaporation for destruction processes.
- A special case is the use of electrodialysis for separation of ionic substances from complex water solutions at low to medium high concentrations.

It is even more efficient if some unique chemical property can be used for adsorption, such as complexation to a liganded metal by metal affinity chromatography. The possibility of immobilising a special ligand which forms a complex with the substance to be removed is opening a vast number of possibilities for chromatographic separation. These so-called affinity methods can probably not be used in large scale but rather for the kidney functions, that is removal of some special component in a process water stream. The basic chemistry is offering a large range of approaches and very many processes should in principle be possible to improve.

8.5.3 Column or Batch-wise Separation

Industrial scale unit operations can either be continuous or batch-wise processes. Continuous operations are designed to be operated 24 hours a day, 7 days a week, throughout the year. Some down-time will be allowed for maintenance and, for some processes, catalyst regeneration. The availability of a continuous plant is usually in the order of 90 to 95%. Batch processes are designed to operate intermittently, some, or all; units in a process will frequently be shut down and started up.

Continuous processes will usually be more economical for large scale operations. Batch processes are used where some flexibility in production or product specification is wanted.

An adsorbent is mixed with the water stream to be purified, stirred and finally the adsorbent is settling while the liquid phase is removed. After washing the adsorbed compounds are recovered from the adsorbent, eluted, by another solution, such as one with a different pH for an ion exchanger, which is followed by a re-equilibration of the adsorbent for a new cycle. While this is happening another batch is in parallel used for the process stream. Several parallel sets of equipment are thus necessary.

An adsorbent may also be packed in a fixed bed column. In this process the water stream is fed into the top of the column and the substance to be removed stays in the adsorbent bed, while the purified solution is recovered at the bottom. After the adsorbent is saturated the adsorbed substance is removed by elution with a different solvent. The bed is finally washed and returned to its original state and ready for a new cycle. Several columns work in parallel. An illustration of adsorption in fixed bed columns is shown in Chapter 9, Figure 9.3.

Study Questions

1. In what ways can the amount of pollutants in a waste stream be reduced? List the most important strategies.
2. Give an example of how the substitution of raw materials in a process can reduce the amount of pollutants being emitted from that process.
3. List and discuss briefly different measures for modifying a production process.
4. In what way can improved process control reduce the emissions of pollutants?
5. In what way can the equalisation of wastewater flow reduce the emissions of pollutants?
6. Describe the principle of the unit operation *adsorption* and which types of separations can be done with adsorption.
7. Describe the principle of the unit operation *ion exchange* and which types of separations can be done with ion exchange.
8. Describe the principle of the unit operation *membrane separation* and the different types of membrane separations.
9. Describe the principle of the unit operation *extraction* and which types of separations can be done with extraction.

Abbreviations

BOD	Biological Oxygen Demand.
CMC	CarboxyMethyl Cellulose.
DC	Direct Current.
DVB	DiVinylBenzene.

Internet Resources

International Zeolite Association – Database

http://www.iza-structure.org/databases/

Electrosynthesis Company Inc.
– What is Electrodialysis?

http://www.electrosynthesis.com/ess/weid.html

ZENON Membrane Solution
– Membrane Technology Overview

http://www.zenon.com/resources/introduction_to_membranes/

Activated carbon review from Virginia Tech

http://ewr.cee.vt.edu/environmental/teach/gwprimer/group23/webpage.htm

US Environmental Protection Agency
– Industrial Water Pollution Controls

http://www.epa.gov/waterscience/guide/index.html

Chapter on pollution prevention (P2) approaches

http://www.epa.gov/waterscience/guide/p2/ch5.htm

9

Air Pollution Reduction

9.1 Character and Origins of Air Pollutants

9.1.1 Strategies for Reducing Air Pollution

Air pollution, just like pollution of water streams, is a cost for the environment and the companies, and should be minimised. Air pollution includes all states of aggregation, that is, emissions of solid particles as dust, as droplets of liquid and as gases. Just as with water, the best strategies to address this problem is firstly to reduce the volumes of the (polluted) air streams, secondly to change the process causing the pollution and thirdly to treat the outgoing gases.

The processes causing the emissions are addressed with process integrated measures. Process integrated measures includes changes in the actual process causing the air pollution, for instance changes in pressure, temperature and chemical environment (employed by the process), as well as changes in the process equipment, raw materials and help chemicals. Process integrated measures to solve emission problems to air are thus comparable to those dealing with water.

Which measure, or combination of measures, to use in order to achieve the best result is related to the activity at hand, where and in what amounts pollution is generated and if the task is to build a new plant with new clean technology or if there is an existing problem to be solved. The strategies and technologies described in this chapter are general and can be used one by one or in combinations, as well as in combination with external measures, all depending on the application.

9.1.2 Decreasing Dust

During almost the whole industrial era dust problems have been considerable. It was not until after the 2nd World War that measures dealing with the dust problem began to be introduced, basically due to work hygiene requirements.

As a result, most of the measures are made within the process itself as well as in the handling of raw materials. However, initially there were doubts (at least in Sweden) if filtering the air and to re-circulate it in the work environment was a good idea. As a result process integrated measures developed. These also improved the outer environment.

Generally, there are four different types of measures:

In this Chapter

1. Character and Origins of Air Pollutants.
    - Strategies for Reducing Air Pollution.
    - Decreasing Dust.
    - Removing Liquid Mists and Aerosols.
    - Limiting Polluting Gases and Vapours.
2. Cleaner Production Strategies for Reducing Air Pollutants.
    - Changes in Raw Materials.
    - Changes in Process Technology.
    - Changing the System.
3. Unit Operations for Separating Gaseous Air Pollutants.
    - Condensation.
    - Adsorption.
    - Absorption.
    - Membrane Separation.
    - Biological Methods.
4. Unit Operations for Separating Particulate Air Pollutants.
    - Removal of Suspended Particles.
    - Dynamic Separation.
    - Scrubbers.
    - Electrostatic Precipitators and Filters.

1. Casing all dust creating activities.
2. Moistening of powder.
3. Granulating and making pills of the powder. Dust-binding agents.
4. Centralised preparation of raw material, Master-batch.

By *casing all dust creating activities*, dust generated in a process can effectively be controlled and separated e.g. where the equipment is vented. Today, machines as mills, sieves, mixers, saws and grinding-machines are in most industries well cased. In addition they are equipped with dust extractors, filters and air vents, taking care of the dust. Sensitive activities as sack openings can also be cased.

Moistening of powder in order to bind the dust is an old method to prevent dust from spreading. The method is used for conveyer belts, for instance. If water constitutes a problem, other liquids can be used.

Farmers and workers in fertiliser factories in Sweden were used to work in clouds of dust. Today these materials hardly create any dust problem in this environment. The reason for this positive development is largely due to *granulating and the making of pills* of the fertilisers. Furthermore, dust-binding agents are added to the products. A similar development has taken place in other areas and there are certainly more improvements to be done.

The dust problems at many smaller manufacturers have been solved by having one supplier take care of a specific part of the *preparation of raw material* (mixing), the *Master-batch* operation. In this larger mixing operation the supplier has a better opportunity to control the dust formation than the small manufacturers. This development has been most noticeable in the plastics manufacturing area, where, earlier, each single manufacturer bought a number of components, in the form of powders (colour pigments, etc.) and mixed them according to prescribed recipes. By using Master batches, manufacturers can buy pre-prepared mixtures, thereby avoiding the problem with the dusty handling of solid materials. (In addition, they can concentrate on their central business – to manufacture and sell the plastic products.)

9.1.3 Removing Liquid Mists and Aerosols

The formation of liquid mists has long been a partly overlooked problem, perhaps more from a work environmental point of view than from an outer environmental one. Liquid mists and aerosols are formed in many unit operations and the fine "particles" (droplets) can both penetrate material and be spread with air.

Today the potential dangers and risks with this kind of air pollutants are rather well known and, for both work environmental and for outer environmental reasons, many of them are heavily restricted. In this connection, it should be mentioned that the cleaning technologies regarding liquid mists and aerosols are rather expensive. Therefore authorities tend to accept some emissions. This might be part of the reason for the lack of process development in this area. Another, more substantial, explanation originates from the fact that liquid mists most often occurs as a direct consequence of different unit operations aiming at creating aerosols, for instance condensing of gas flows and the generation of well developed contacting surfaces between gas and liquid. In the latter case small liquid droplets are generated in order to increase the contacting surface between gas and liquids.

The most commonly used method to separate mist and aerosol droplets from air is by installing a coalesher unit, e.g. a KnitMesh separator in which the droplets are made to collide and aggregate to larger drops that can be separated in a gravitational separator. This can be used for both cleaner production and end-of-pipe purposes.

Examples of situations where aerosols and liquid mists occur are at the drying of chlorine gas with sulphuric acid, the absorption of SO_3 in sulphuric acid manufacturing, the mechanical machining with oils/emulsions and in drying ovens with components boiling at high temperatures (softeners, bitumen etc.).

9.1.4 Limiting Polluting Gases and Vapours

Gaseous air pollutants, generated in connection with the production and material handling, can usually be successfully reduced by using different kinds of process integrated solutions.

The handling of solvents and other organic liquids are often carried out in a traditional way. Therefore, by thoroughly examining products and processes, possible measures may be identified, leading to an elimination or at least a reduction of the solvent problem. The alterations might include anything from simple technical measures, as enclosures, to product changes, which also will affect the market and how customers will handle the product.

Inorganic gases as SO_X, NO_X, H_2S etc. are mostly formed in incineration processes or as by-products in different process steps. In order to substantially reduce the emissions of these gases, process integrated measures can be used, for instance changing the raw material or the process technology.

In combustion processes, process integrated measures are very commonly used. It is e.g. possible to reduce emissions by changing the fuel used. Thus, sulphur emissions can be reduced by changing to a low-sulphur fuel, and the contribution to the greenhouse effect can be avoided by changing from a fossil fuel to a biofuel.

9.2 Cleaner Production Strategies for Reducing Air Pollutants

9.2.1 Changes in Raw Materials

"Clean" raw materials. A general rule is to use raw materials with as low concentrations as possible of polluting or pollution generating components.

Specifically for solvents and other organic liquids, one should aim for the following three strategies.

Using smaller amounts of solvents. The amounts of solvent can often be reduced, at least in processes that are rather old, both in connection with processes and cleaning agents. A reduced amount of solvent generally also means a physical change in the product or the process; changes in viscosity,

Table 9.1 Ranking solvents as air pollutants. *In the ranking, the environmental impact of the solvents is considered more important than their hygienic impacts on humans. The Occupational Exposure Limits Values (OELV) or Occupational Exposure Standards (OES), are of three kinds: Time Weighted Average (TWA), Short Term Exposure Limits (STEL) – 15 min – and Maximum Exposure Limit (MOL). The values given are standard or time weighted values from the Swedish Work Environment Authority report AFS 2005:17. The corresponding EU values are still only in the making; see Internet Resources European Commission Directive 2000/39/EC [based on OSHA, 2000]. (NA = Not Available)*

Group of solvents	Comments (for the group)	Occupational exposure limit (mg/m^3)
I Ethanol	Decomposition OK. Low toxicity, regarding all factors (Methanol toxic for humans); "Approved as food." Part of "lifecycles".	1000
(Methanol)		250
i-Propanol		350
n-Paraffines		NA
Acetic esters from higher alcohol's		NA
Propylene glycol		NA
II Acetone	Decomposition OK. Low Toxicity (Ethyleneglycole toxic for humans). Part of some life processes.	600
Methyl Ethyl Ketone (MEK)		150
Esters from fatty acids		NA
Propyleneglucolethers		190
Etylacetate		500
III i-Buthanol		150
Methylpyrrolidon		200
Cyclohexanon		41
Triethanolamine		5
IV n-Butanol		45
n-Hexane		90
Etyleneglycolmonoethylether		19
V t-Butanol		150
De-aromatised solvents, D-100		NA
De-aromatised solvents, D-70		NA
Cyclohexanol		200
Naphtas		NA
i-Paraffines		NA
Methylisobutylketones, MIBK		100
Heptane		800
Decane		350
VI Ethanolamines	Slow Decomposition. Toxic.	8
Octanes		900
Terphenes		150
Butylacetate		500
VII Chlorinated hydrocarbons	Slow decomposition in liquids. Can give long-term effects and atmospheric effects.	NA
2-Ethylhexanol		NA
Toluene		200
Ethylenediamine		25
Higher Aromatics		NA

changes in flows etc. These changes have to be considered, but the exchange of a pump etc, can usually be done at a rather low cost.

Using solvents with lower volatility. In many applications there are alternative analogue solvents, with similar properties, but with higher boiling point and/or lower vapour pressure. A change to an analogue solvent will then result in a smaller amount of air pollutants. As in the case above it is important to look out for secondary effects on the production, etc.

Using a less hazardous solvent. The most common solvents can be classified both according to their effect on the work environment as well as on the outer environment. In Nordic countries and the EU an increased number of registers of criteria are being developed in order to rank chemicals. In Table 9.1 such a list is shown. In developing this list, the focus was basically on examining of products and is based on a mixture of evaluations of the effects on work environment and outer environment. However, it must be remembered that these registers have to be checked and maybe re-evaluated from time to time. Both knowledge and values develop and change with time.

When working with "not so hazardous solvents" a more thorough evaluation has to be done than merely studying Table 9.1, which is only an example of ranking and valuation. In the table, the least environmentally sensitive solvents are in group I, while the more environmentally "difficult" are in the higher groups. Please notice that "pure water" could have been placed in a group 0 by itself, but that is not the same as the water used as substitute for solvents, which commonly is a mixture of "water + surfactants, preservatives and/or fungicides" which, in turn, should be placed approximately in group III.

When substituting one solvent for another, it is important to remember that the solvent often is part of a larger system. The substitution can thus require a substantial development work. It has been experienced that substituting the solvent base in a production process will be rather costly. Attempting to substitute the solvent in the recipe of an active pharmaceutical substance will result in the revocation of the drug permit and the company will have to go through the whole, several years long, process of getting a new approval of its medicine.

Let others take care of the problems with solvents. In many cases is it simpler if the raw material supplier takes care of the processing step in which solvents are handled. One example is the use of pre-lacquered steel sheets, instead of painting it yourself.

9.2.2 Changes in Process Technology

Encapsulation of the process equipment. A large amount of the solvent emissions originates from open vessels etc. Experiences have shown that more than half of the emissions can be kept in the vessel by just sealing and re-lidding it. The costs for this are rather low.

Using cooling techniques. Vessels that cannot be covered can be supplied with a reflux cooler, which can be cooled down to -20 degrees, for a rather low investment cost. Such a cooler costs about 1 000-3 000 euros, depending on capacity.

Using modern fluid mechanics. By using modern fluid technology – for instance jets – airflow's can be guided without requiring large amounts of air. This has been shown in other contexts and will, in this context, primarily result in a lower flow of emissions.

Utilising indirect warming and drying. Conventional direct fired ovens for drying give rise to large contaminated gas flows, since the combustion gas both serves as heat source and transporting gas. By carrying out the process indirectly, the two functions are no longer coupled, resulting in a smaller flow to the gas cleaning. An alternative is to use electricity for drying etc. This can be done with IR-heaters or electrical heating coils. However, the electricity must be generated somewhere, which means environmental consequences there.

Utilising surface technology instead of solvents. In a number of modern processes a system of tensides is used to manage hydrophobic (oil soluble) components. Although this method decreases the amount of emissions to air, it could mean increased emissions to water.

Encapsulating a complete process. Airflow containing large volumes of solvents are sometimes conditioned by limitations set by the risks for an explosion of the mixture solvent/air. This problem can be solved by encapsulating the whole process and by working entirely in an atmosphere of nitrogen. The technology has been applied in some cases where the installation of a "nitrogen lock" is rather simple. Usually, a number of objects are to be treated with solvent-containing products, thus the moving of the objects to and from the treatment has to be isolated from air. Both the installation and the operation of such a plant are rather expensive, therefore this method usually is only considered when building a new plant.

9.2.3 Changing the System

To change the system is a measure which includes more than just a change in the actual process.

When filling tanks – re-circulate the exhaust gas. When filling of new liquid to a storage tank a saturated vapour is forced out of the tank. Although this might be small amounts it still can cause disturbances. The gas can, by simple measures, be brought back to the tank from which the liquid came. A precondition is that the gas can be brought back to the system without being emitted somewhere else.

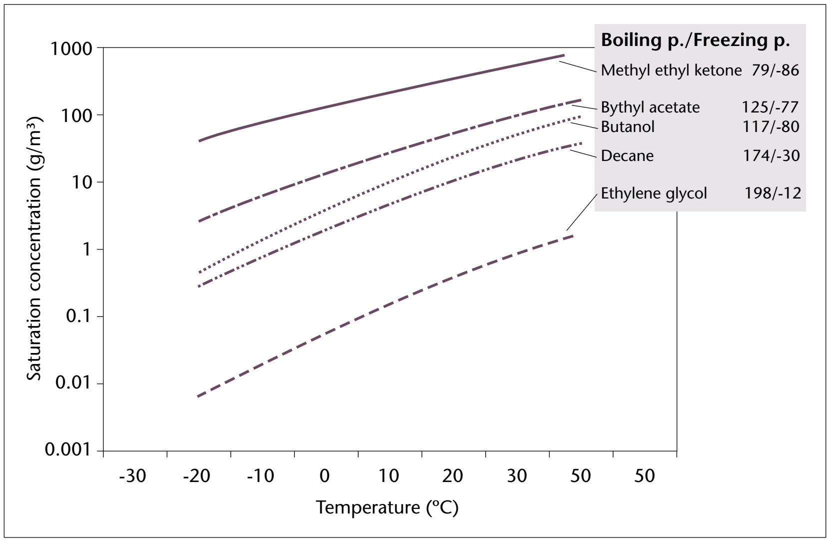


Figure 9.1 *Saturation vapour pressure for different solvents expressed as g/m³ at different temperatures.*

Incineration with heat generation for drying ovens, etc. As a gas cleaning technology, combustion processes can become (too) expensive if additional fuel is needed. However, if the combustion gas is used in a drying oven the cost of the additional fuel can be charged to the drying oven.

The latter is now carried out in the car industry's lacquering ovens. Outgoing gas is introduced to the combustion unit (gas cleaning) where it is "cleaned" at the same time as hot gases are produced and circulated to the dryer. The development of this process has earlier been hindered by fears that a formation of particles will take place when the gas-flows are re-circulated. These fears have been shown to be greatly overrated.

Reduced ventilation. Today, process air and general ventilation air are mixed in a common exhaust system. Sometimes process ventilation also serves as general ventilation, for instance in spray boxes. This is largely a relict from older days, when solvent emissions weren't regarded as a problem. To achieve a maximally effective gas cleaning it is important to plan the ventilation, and to get as small flows as possible to the cleaning equipment. A small concentrated flow is easier, and more economical to clean efficiently than a large diluted flow (Compare with Section 7.2.3).

Planning of the whole activity. Air pollution is not always clearly defined. Sometimes it is only a disturbing smell, without any indicated risks for man and environment. Nevertheless it is a form of air pollution.

Depending on the characteristics of the disturbance – distressing smell or toxic emissions – the feasible measures will differ. A chimney to dilute the disturbance could be enough in one case, in another a thorough cleaning is needed. There are indeed examples where information and an established relation between those causing the emission and those being subject to it is enough to eliminate the problem. The conclusion is that air emissions, as well as all other activities, do require a complete and thorough planning. Consequently, the planning becomes a question for the users as well. If we buy wooden boats and wooden floors instead of plastic boats and plastic floors, we have to use a solvent based varnish. If we buy clothes that cannot be washed in water, we become dependent on solvents.

9.3 Unit Operations for Separating Gaseous Air Pollutants

9.3.1 Condensation

Each component in a gas mixture takes up a part of the total volume of the gas corresponding to its concentration. In the same way the partial pressure of the component corresponds to its share of the total pressure. For each gas component there is a saturation value of the partial pressure and this value, called the vapour pressure, depends on the total pressure and the tem-

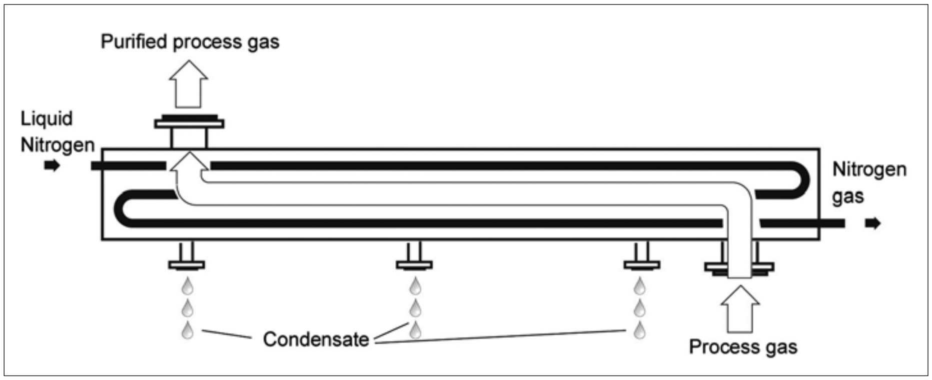


Figure 9.2 Condensation at low temperature. *The polluted process gas is cooled to -180°C temperature with liquefied nitrogen, which condenses in the heat exchanger tubes and escapes as nitrogen gas. This method is used to condense solvent vapours in process emissions/off-gases [based on material from Swedish Gas Company AGA].*

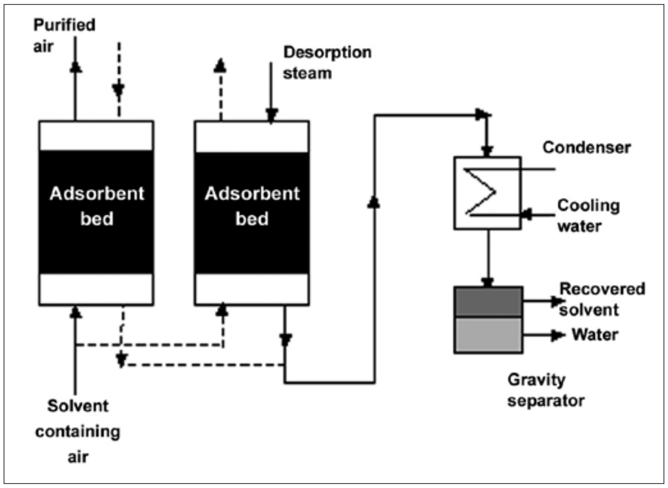


Figure 9.3 *Adsorption of a polluting solvent in exhaust air (left) in fixed bed columns. The adsorbent, typically activated carbon, is packed in columns (adsorbent beds). In a second step (right) the solvent is desorbed from the saturated column with steam and condensed to liquid phase and separated from water by settling (far right). While one column is used for adsorption the second is washed (dotted lines) and vice versa which makes continuous operation possible.*

perature. This may be used to achieve a separation between components in the gas mixture.

When a gas mixture is cooled to a sufficiently low temperature the partial pressure of a polluting component will at some point exceed its vapour pressure. The component will then start to condense until its partial pressure will be equal to its vapour pressure at the current temperature. With a very considerable cooling of a gas mixture its content of e.g. a solvent will be reduced. Figure 9.1 shows temperature dependence of the vapour pressure as the saturation concentration in g/m^3(N) for some common solvents.

As may be seen from these data you have to cool many of the solvents to a very low temperature to achieve a concentration range of about 10 g/m^3(N) which often is the current regulation limit.

Simple cooling machines have the capacity to cool to about -20°C. With advanced machines you can reach about -40°C. With cooling demands down towards -70 to -80°C cooling machines that are very advanced or several machines in series are required.

An alternative to cooling machines is to use solid CO_2 or liquefied nitrogen (LIN). This allows a flexible cooling (Figure 9.2). The costs of solid CO_2 and LIN cooling are very high, however. Despite this, it may be advantageous to use as a gas separation technique. In addition to being flexible this technique has few risks and produces a pure solvent.

An important factor that must always be considered is that solvents are flammable, which means that you always have to make sure to have ample margin to the lower as well as the upper explosion limits of the solvent.

9.3.2 Adsorption

Typically, adsorption is used for removing trace components from gas mixtures. In processes using volatile solvents, recovery may be performed by passing the air through a packed bed of adsorbent material.

The unit operation adsorption is described in Section 8.2.2.

Adsorption is normally performed in columns, (Figure 9.3) and often with several columns connected in series.

When the adsorbent has been saturated with adsorbed substance it has to be regenerated. This is achieved by treating the material with steam or with a chemical, an acid, alkali or organic solvent, that reverses the adsorption process by breaking the van der Waals bonds between the adsorbed molecules and the adsorbent surface.

However, in cases where activated carbon is used as the adsorbent and it is saturated with high molecular weight molecules, which are bound very hard to the surface, a thermal, reactivation type of regeneration has to be undertaken. Therefore this material is mostly used for recovery of low-molecular organic solvents from ventilation air, for example, toluene from printing operations.

9.3.3 Absorption

The removal of one or more selected components from a mixture of gases by absorption into a suitable liquid is the second major operation of chemical engineering that is based on interphase mass transfer controlled largely by rates of diffusion. Thus, acetone can be recovered from an acetone-air mixture by passing the gas stream into water in which the acetone dissolves while the air passes out. Similarly, ammonia may be removed from an ammonia-air mixture by absorption in water. In each of these examples the process of absorption of the gas in the liquid may be treated as a physical process, the chemical reaction having no appreciable effect. When oxides of nitrogen are absorbed in water to give nitric acid, however, or when carbon dioxide is absorbed in a solution of sodium hydroxide, a chemical reaction occurs, and this reaction determines the actual rate of absorption. Absorption processes are therefore conveniently divided into two groups, those in which the process is solely physical and those where a chemical reaction is the most important. In considering the design of equipment to achieve gas absorption, the main requirement is that the gas should be brought into intimate contact with the liquid, and the effectiveness of the equipment will largely be determined

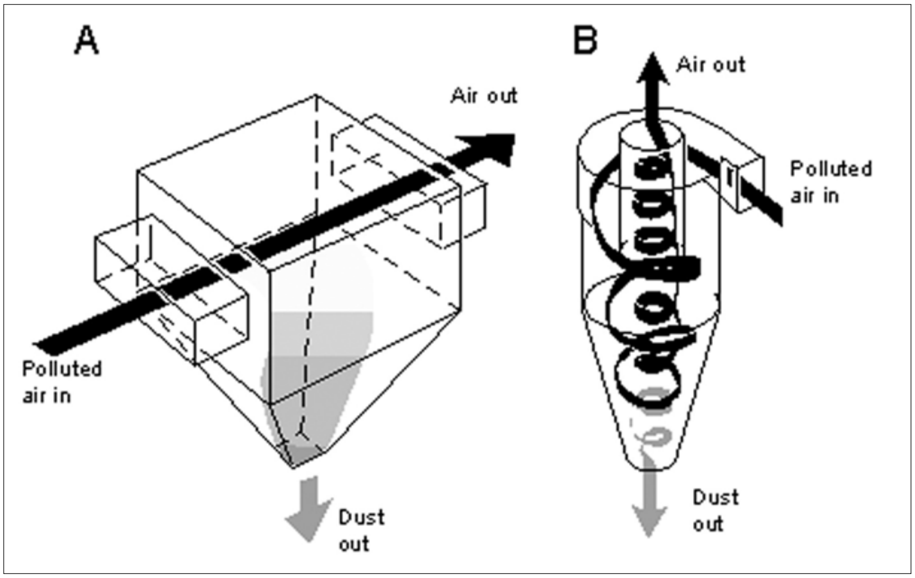


Figure 9.4 Dynamic separators. *The separation of dust particles from a gas stream is made either in a settling chamber (A) or a more efficient cyclone (B) in which a centrifugal movement forces larger particles to the wall of the vessel where they fall to the bottom of the chamber.*

by the success with which it promotes contact between the two phases.

When two phases are brought into contact, they eventually reach equilibrium. Thus, water in contact with air evaporates until the air is saturated with water vapour, and the air is absorbed by the water until it becomes saturated with the individual gases. In any mixture of gases, the degree to which each gas is absorbed is determined by its partial pressure. Three types of gases may be considered in this respect: a very soluble one, such as ammonia, a moderately soluble one, such as sulphur dioxide, and a slightly soluble one, such as oxygen.

The values in Table 9.2 show the concentrations in kilograms per m^3 of water that are required to develop a partial pressure of 1.3, 6.7, 13.3, 26.7 and 66.7 kN/m^2 at 303 K (= 25°C). It may be seen that a slightly soluble gas requires a much higher partial pressure of the gas in contact with the liquid to give a solution of a given concentration. Conversely, with a very soluble gas, a given concentration in the liquid phase is obtained with a lower partial pressure in the vapour phase. The most concentrated solution that can be obtained is that in which the partial pressure of the solute gas is equal to its partial pressure in the gas phase. These equilibrium conditions fix the limits of operation of an absorption unit.

Table 9.2 *Partial pressures and concentrations of aqueous solutions of gases at 303 K [Perry and Green, 1994].*

	Concentration of solute in water (kg/m^3 water)		
Partial pressure of solute in gas phase (kN/m^2)	**Ammonia**	**Sulphur dioxide**	**Oxygen**
1.3	11	1.9	-
6.7	50	6.8	-
13.3	93	12	0.008
26.7	160	24.4	0.013
66.7	315	56	0.033

While the solubility of a gas is not substantially affected by the total pressure in the system for pressures up to about 500 kN/m^2, it is important to note that the solubility falls with a rise of temperature. Thus, for a concentration of 25% by mass of ammonia in water, the equilibrium partial pressure of the ammonia is 30.3 kN/m^2 at 293 K (= 15°C) and 46.9 kN/m^2 at 303 K (= 25°C).

In many instances the absorption is accompanied by the evolution of heat, and it is therefore necessary to fit coolers to the equipment to keep the temperature sufficiently low for an adequate degree of absorption to be obtained.

For dilute concentrations of most gases, and over a wide range for some gases, the equilibrium relationship is given by Henry's law. This law can be written as:

$$P_A = K_H C_A$$

where: P_A is the partial pressure of the component A in the gas phase, C_A is the concentration of the component in the liquid, and K_H is Henry's constant.

9.3.4 Membrane Separation

Membrane separation may also be used for separation of gas mixtures. The principle for this is the same as in membrane separation for liquid solutions (Sections 8.2.4 and 8.4).

9.3.5 Biological Methods

Biological processes utilise the ability of microorganisms to oxidise organic material. This technology is commonly used for biological treatment of wastewater. It can also be used for cleaning air streams contaminated with biologically degradable organic compounds.

Biological oxidation is carried out in at least three different cleaning techniques; bioscrubbers, composting filters and biofilters. All cases require that the pollutant compounds in a first stage are separated from the air by a conventional method (absorption or adsorption). The biological oxidation is then carried out in a water solution or on the adsorbing surface.

9.4 Unit Operations for Separating Particulate Air Pollutants

9.4.1 Removal of Suspended Particles

The need to remove suspended particles, as dust or mist, from a gas stream not only arises in the treatment of effluent gases from a process before they are released into the atmosphere. In many processes solid or liquid particles are carried over into a gaseous process stream. There are a number of reasons for removing these particles before the polluted gas stream goes to the next process step.

Table 9.3 *Summary of dust separator performance [Richardson and Harker, 2002].*

Type of equipment	Field of application
Settling chambers	Removal of coarse particles, larger than about 100-150 µm
Cyclones	Removal of average dusts in the range 10-100 µm
Wet scrubbers	Removal of fine dusts down to about 5 µm
Textile filters	Removal of fine dusts and fumes down to about 1 µm or less
Electrostatic precipitators	Removal of fine dusts and fumes down to about 1 µm or less

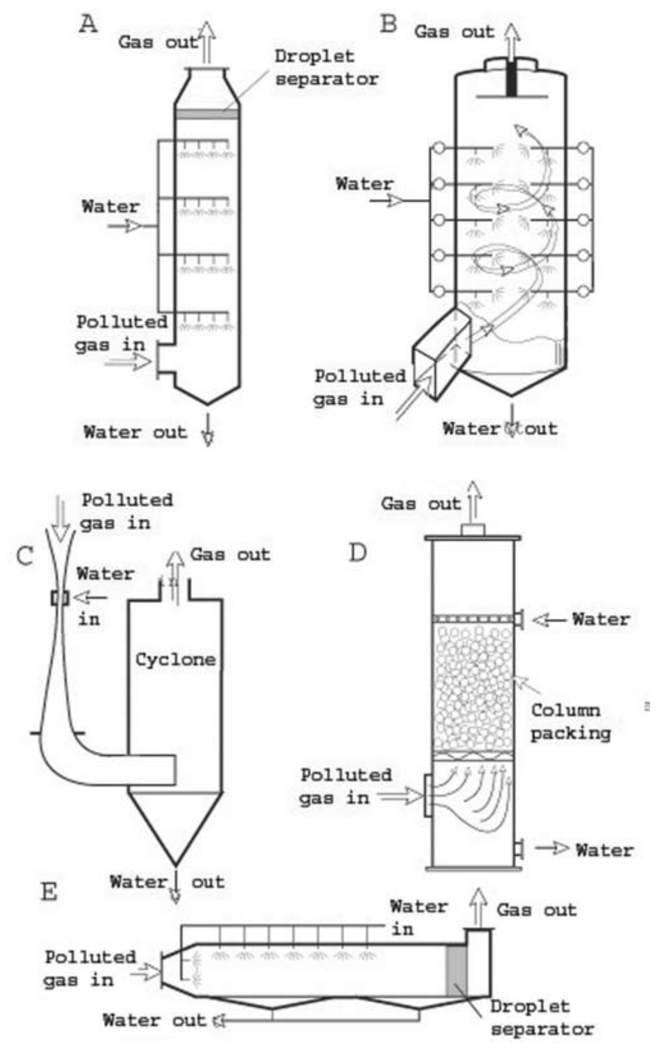


Figure 9.5 Wet scrubbers. *Spray scrubber (A), Cyclone scrubber (B), Venturi scrubber with cyclone (C), Packed bed scrubber (D) and Cross flow spray scrubber (E).*

- The polluting particles may interfere with the subsequent process.
- The particles represent loss of valuable material that can be recovered and re-circulated in the process.
- If the particulate material is a by-product from a reaction it may be recovered as a potential additional product.

For separation of particulate material, both solid and liquid, from a gas stream four principally different methods may be applied:

1. Dynamic separation.
2. Wet scrubbing.
3. Electrostatic separation.
4. Fabric or ceramic filtering.

9.4.2 Dynamic Separation

In *dynamic separation* the fact that the density of particles is higher than the fluid in which it is suspended is utilised. The simplest type of dynamic separation is gravitational separation in a so called *settling chamber* (Figure 9.4 A). It functions in exactly the same way as a sedimentation tank. The flow velocity of the fluid is reduced as it enters the chamber and gravitation will cause the particles to settle on the bottom of the chamber.

In a settling chamber only coarse particles (>50µm) can be separated. In order to remove small particles by dynamic means, *cyclones* are the most common type of separators (Figure 9.4 B). In a cyclone the dust containing gas flow enters

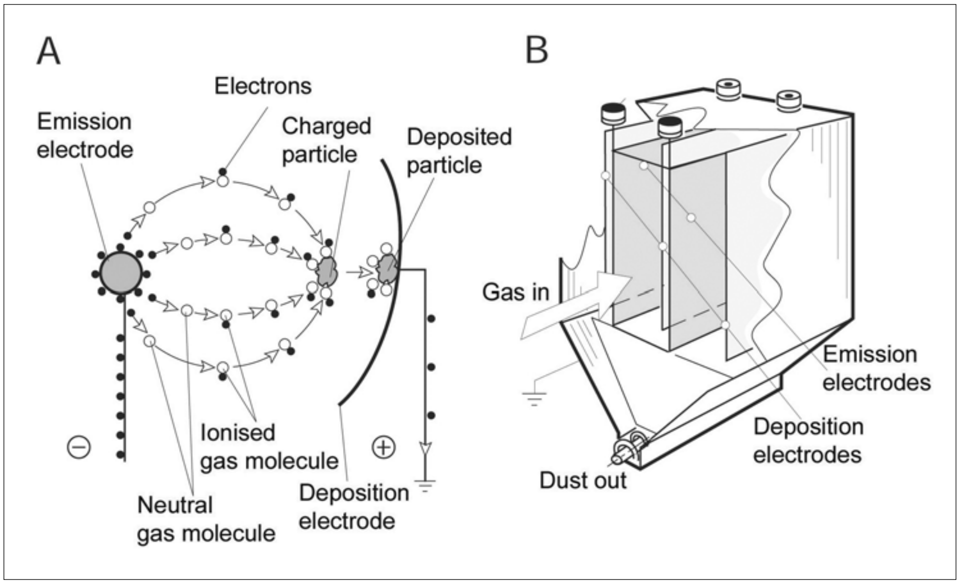


Figure 9.6 Electrostatic precipitation principle. *(A) Electrons emitted from the cathode (left) attach to dust particles and charge them negatively, making them stick to the anode (right). In an electrostatic precipitator (B) the adsorbed particles finally fall to the bottom and become separated from the gas stream.*

tangentially at the top of a cylindrical vessel at a velocity of about 30 m/s. The solids are thrown outwards towards the wall of the vessel by the centrifugal force caused by the rotational movement of the gas. When the particles hit the wall they loose their momentum and will slide downwards along the wall and are collected in the conical base of the cyclone. The cleaned gas leaves the cyclone upwards via a pipe fitted centrally in the cylindrical part. The abrupt change of flow direction when the gas enters the exhaust pipe will separate even smaller particles, which were not separated by the centrifugal force. The momentum of these particles will prevent them from following the gas flow as it enters the exhaust pipe. Instead they continue their movement downwards and are separated towards the lower part of the cyclone. A cyclone separates dust particles between 10 and 100 μm with high efficiency.

Figure 9.7 Multi-stage packed chemical scrubbers. *These scrubbers are designed to remove hydrogen sulphide (H_2S) based on neutralisation of the H_2S into a caustic solution. Recirculation increases the concentration of the gas in solution and decreases the quantity of scrubbing solution required. (Photo: www.bayprod.com)*

9.4.3 Scrubbers

In a *wet scrubber* the gas is contacted with a liquid, usually water, that will wash the particles out of the gas stream. In this operation it is essential to obtain an intimate contact between the liquid and the particles. Depending of the nature and concentration of the particles the scrubbing can be done in a number of different types of equipment, including spray, centrifugal, venturi or packed bed scrubbers (Figure 9.5). A wet scrubber may separate fine particles, >5 μm, at high efficiencies.

9.4.4 Electrostatic Precipitators and Filters

Electrostatic precipitators are capable of separating very fine particles, <1 μm, at very high efficiencies, above 99.8%. In an electrostatic precipitator (ESP) the gas passes between two electrodes charged to an electrical potential difference of 10-60 kV. The electric discharge between the electrodes will emit electrons and ions from the negative electrode. These will be drawn towards the positive electrode plate. On their way they will attach to and charge particles passing between the electrodes drawing also them to the positive electrode, thereby separating the particles from the gas stream.

Fabric or ceramic filters include all types of filters in which the filter medium is either in the form of a woven or felted textile fabric or a porous ceramic filter. Filters like this will capture particles of sizes down to 1 μm.

Study Questions

1. Describe four different measures for decreasing dust emission from solid materials handling by process integration.
2. What are the major process integration measures for reducing emissions of solvents and other organic liquids?
3. Give short descriptions of condensation, adsorption, absorption, membrane separation and biological methods for controlling air pollutants.
4. What differences are there between the unit operations adsorption and absorption for separating pollutants from a gas stream?
5. List the four major principles used for separating particulate pollutants from a gas stream?
6. How does an electrostatic precipitator work?
7. Describe the function of a cyclone for separation of particulate pollutants from a gas stream.
8. Why is water as an industrial solvent normally not considered the ultimate “clean” solvent?
9. How does the Cleaner Production strategy influence the qualitative and quantitative pollutants profile of an industrial plant?

Abbreviations

ESP	Electrostatic Precipitator
LIN	Liquefied Nitrogen.

Internet Resources

Swedish Work Environment Authority Hygienic Occupational Exposure Standards (OES) Hygieniska gränsvärden och åtgärder mot luftföroreningar 2005:17 (in Swedish)

http://www.av.se/dokument/afs/afs2005_17.pdf

European Commission Directive 2000/39/EC A first list of Indicative Occupational Exposure Limit Values (IOELV)

http://www.hse.gov.uk/consult/condocs/cd166.pdf

Wikipedia – Air Pollution

http://en.wikipedia.org/wiki/Air_pollution

Wikipedia – Scrubber for Air Pollution Control

http://en.wikipedia.org/wiki/Scrubber

Institute of Clean Air Companies (ICAC)
– Brief Descriptions of Air Pollution Control Technologies

http://www.icac.com/i4a/pages/index.cfm?pageid=3316

10

Waste Reduction

10.1 The Waste Concept

10.1.1 The Waste Concept

Waste is spontaneously perceived as anything *useless* resulting from a process, or other activity, may be for a long time. When things are worn-out or destroyed to the extent they can no longer be used they are wasted. Even if we are familiar with this way to see waste, it is not so old. It is connected to industrial society, and even more so to mass-consumerism. In the older agricultural society almost everything was used over again, repaired, or – if not possible to use in the original way – used for something else or in the last resort used as a material. Material flows were more expensive, slower, and more cyclic. Our present environmental dilemma is due to large-scale linear flows. We need to find our way back to a new, or perhaps rather original, way to deal with waste.

Pollution may be seen as a form of waste. Pollution is waste, which threatens to escape into the environment and needs to be controlled and collected. It is sometimes called molecular waste. Thus pollution discussed in Chapters 8 and 9 – that is waste in liquid and gas streams – is also waste. The strategies, and to an extent technologies, dealt with in Chapters 8 and 9 are relevant also here. The waste discussed in this chapter will, however, be solid waste.

Just as pollution may be seen as a "lost money and resources", solid waste is the same. It is a lost resource which costs to deal with or get rid of. It is a sign of inefficiencies in the production process or shortcoming of a product, which has to be wasted.

It is obvious that we will never be able to completely get rid of waste, but it is also clear that we need to reduce it dramatically to become sustainable. This chapter is about that. A further discussion on waste is found in Book 3 of this series.

10.1.2 How to Produce Less Waste

A main route to a less wasteful society is *efficiency*. By being more careful we will be able to use our input resources more carefully. This is at the heart of the cleaner production approach, and is developed later.

However a production process, which will only produce products, is seldom a realistic goal. Some waste will always result. A second main approach is therefore to see waste as a *resource*. Waste is sometimes called "a useful resource but in the wrong place". So what to do with waste to turn it into a resource? There are many stories on ingenious ways to use waste: Some are well known, such as when the SO_x extracted

In this Chapter

Box 10.1 Waste Definitions – Dispose of and Discard

While the EU definition intends to be absolute, the Basel Convention definition is relative to national law and opens the debate between the meanings of the terms *discard* versus *dispose*. The lack of common understanding of the term discard is a major issue in debate about the waste definition.

Because of the ambiguity of the waste legislation, the European Court of Justice has been called upon to resolve a number of disputes, to interpret the waste definition. The Court has developed a number of key criteria for assisting in determining the existence of waste in practice and confirmed that the definition should not be interpreted restrictively, given that the EC Treaty confirms that Community environment policy is to aim at a high level of protection and is to be based, in particular, on the precautionary principle and the principle that preventive action should be taken. In addition, the Court has expressly stated that it is immaterial to the legal definition of waste whether a substance or object may have a commercial value or is capable of economic re-utilisation.

The Court has also underlined that the term discard must be interpreted in light of the aim of the Waste Framework Directive, pointing out that in that regard, the third recital states that: "The essential objective of all provisions relating to waste disposal must be the protection of human health and the environment against harmful effects caused by the collection, transport, treatment, storage and tipping of waste."

In addition, the Court has also identified a number of other criteria for determining the presence of waste, discussed principally in the context of production residue. In particular, the European Court has also made it clear that where special precautions must be taken when a residue is used, owing to the environmentally hazardous nature of its composition, this may be regarded as evidence of discarding.

A number of consequences follow from the application of the waste definition. When a material is considered to be waste, it is subject not only to the requirements and controls contained in the basic framework legislation of the Community pertaining to waste, namely the Waste Framework Directive, the Hazardous Waste Directive as well as the Waste Shipment Regulation, which implements the Basel Convention in the EU, including its provisions outlawing the export of hazardous wastes to non-OECD countries. It is also subject to a number of specific Community legislative instruments addressing particular treatment operations and waste streams.

Table 10.1 *Categories of waste according to EU Directive 75/442/EEC, Annex I.*

Q1	Production or consumption residue not otherwise specified below
Q2	Off-specification products
Q3	Products whose date for appropriate use has expired
Q4	Materials spilled, lost or having undergone other mishap, including any materials, equipment, etc., contaminated as a result of the mishap
Q5	Materials contaminated or soiled as a result of planned actions (e.g. residue from cleaning operations, packing materials, containers, etc.)
Q6	Unusable parts (e.g. reject batteries, exhausted catalysts, etc.)
Q7	Substances, which no longer perform satisfactorily (e.g. contaminated acids, contaminated solvents, exhausted tempering salts, etc.)
Q8	Residue of industrial processes (e.g. slags, still bottoms, etc.)
Q9	Residue from pollution abatement processes (e.g. scrubber sludges, baghouse dusts, spent filters, etc.)
Q10	Machining/finishing residue (e.g. lathe turnings, mill scales, etc.)
Q11	Residue from raw materials extraction and processing (e.g. mining residue, oil field slops, etc.)
Q12	Adulterated materials (e.g. oils contaminated with PCBs, etc.)
Q13	Any materials, substances or products whose use has been banned by law
Q14	Products for which the holder has no further use (e.g. agricultural, household, office, commercial and shop discards, etc.)
Q15	Contaminated materials, substances or products resulting from remedial action with respect to land
Q16	Any materials, substances or products which are not contained in the above categories.

Source: EU Environmental Agency, 2003-03-09.

from a flue gas stream in a wet scrubber is transformed into gypsum. This is used for the production of gypsum boards for the construction industry. Other examples are less well known. Even if the construction/building industry most often produce large volumes of solid waste, it is not always so. A Japanese construction company at the site of house-building is sorting all "waste" into a total of some 60 fractions. All of this is used (Book 3, Chapter 10). A third case is the cement industry which uses waste and hazardous waste as fuel in the kilns. The Estonian Kunda Cement factory (Book 4, Case Study 1) even use the resulting alkaline ashes from the combustion to improve agricultural soil in Estonia, which is rather acid.

The more systematic use of waste as a resource relies on the so-called industrial symbiosis concept. (See further Chapter 11). Here all outputs from an industrial process are used in the next production process in a system of industrial plants. Fully developed examples of industrial symbiosis are not common. The best know case may be the Danish Kalundborg, but cases exits in many parts of the world. Most of them are in the agricultural sector where it seems to be easier to use waste, since it is organic material. This systems approach to production has been developed extensively by the Zero Emissions Research & Initiatives (ZERI). Here it is the careful use of all resources in a system that is in focus.

The long-term goal is to achieve the zero-waste plant. Here nothing is wasted. Everything is used for some purpose. The zero waste concept has been developed in practice e.g. by Zero Emissions Research at Graz University of Technology in Austria. Here the cleaner production approach has been in focus.

10.1.3 The Formal Definition of Wastes

In the formal definition of waste a more conventional view is taken. The definition of what is waste has been subject to intense debate in Europe. According to the EU Directive (75/442/EEC) as well as the international Basel Convention on control of "transboundary" movements of hazardous wastes from 1989 waste is defined as:

Substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law.

In the Council Directive 91/156/EEC, Art.1(a) this definition was amended:

Waste shall mean any substance or object in a waste category, which the holder discards or intends or is required to discard.

In the further discussion on the waste concept (Box 10.1) these notions of what is meant by discard and disposed of becomes central.

The waste categories referred to in the definition are listed in Table 10.1

10.1.4 Industrial Solid Waste

Industrial solid wastes is an important part of all waste produced in society. In most parts of Western Europe industrial waste is about 50% of all waste. In less rich societies, like the CEE countries, industrial waste is closer to 90%. In the list of solid waste categories (Table 10.1) industrial waste are found in categories Q6 to Q11. These will be further discussed below.

The largest amount of industrial waste is mining waste (Q11). The amount of waste as a percentage of the production of the resource extracted is very different for different mining processes and sources. Thus e.g. copper mining gives rise to a very large amount slag or over burden, typically more than 99% of the total, while in iron mining it is less. This waste is often landfilled at the site of extraction and forms large mounds. Sometimes this is rather harmless, as in the case of most iron mining waste. In other cases it is a serious environmental threat. Thus oil shale mining in Estonia has created mounds of waste, which leaks thousands of tonnes of wastewater containing resorcinol and other phenols, each year. The run-off thus has to be treated as toxic wastewater.

Residue from pollution abatement processes (Q9), such as calcium sulphate from desulphurisation of flue gases in a scrubber after combustion of sulphur-containing oil or coal may be large amounts, as well as ashes from incineration processes. Machining/finishing residue is most often the solid waste treated according to cleaner production strategies. It is also where the raw material utilisation may be improved.

10.2 Waste Management Strategies

10.2.1 The Waste Hierarchy

Waste management has a number of different concepts, which vary in their usage between countries or regions. The waste hierarchy classifies waste management strategies according to their desirability. The term *3 Rs*, or *Reduce-Reuse-Recycle*, has also been used for the same purpose. The waste hierarchy has taken many forms over the past decades, but the basic concept has remained the cornerstone of most waste minimisation strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.

Some waste management experts have recently incorporated a *fourth R*: *Re-think*, with the implied meaning that the present system may have fundamental flaws, and that a thoroughly effective system of waste management may need an entirely new way of looking at waste. Some *re-think* solutions may be counter-intuitive, such as a textile factory cutting fabric patterns with slightly more *waste material* left. The now larger scraps are then used for cutting small parts of the pattern, resulting in a decrease in net waste. This type of solution is by no means limited to the clothing industry.

Often the waste hierarchy is expanded to include a more complete series of alternative strategies for waste management. According to the sixth EU environmental action programme, 2001:

The EU approach to waste management is to prioritise waste prevention, followed by recycling, waste recovery and incineration, and finally, only as a last resort, land filling. The target is to reduce the quantity of waste going to final disposal by around 20% of 2000 levels by 2010 and in the order of 50% by 2050.

The waste hierarchy can be used most effectively as a guide to ensure that when developing a waste management policy or decision, an *integrated approach* is taken, where all options are considered.

10.2.2 Waste Minimisation or Source Reduction

This involves efforts to reduce hazardous waste and other waste materials by modifying industrial production. Source reduction methods involve changes in manufacturing technology, raw material inputs, and product formulation. As a consequence source reduction falls well within the concept of cleaner production and pollution prevention.

A practice that is being adopted in several countries either as voluntary measures or as legislation is the *Extended Producer Responsibility* (EPR) of holding the producer of a product responsible to some extent for the management of the waste products associated with that product. The producer is responsible to recover products that contain toxic and hazardous constituents which may present a threat to the safety of the community and which may place a burden on the end-of-life management of the product, for example motor vehicles, white goods, tyres, electronic equipment and mobile phones. This concept has developed in recent years as it is considered that an industry's responsibility for a product should not end with the sale of that product, but should extend to its reuse and/or disposal.

Figure 10.1 Abandoned TV-set. *An industry's responsibility for a product should not end with the sale of that product, but should extend to its reuse and/or disposal – Extended Producer Responsibility (EPR). (Photo: Morguefile/Pablo Gonzalez Vargas)*

10.2.3 Recycling

Recycling includes a number of recycling strategies, which may be described as;

Recovery as primary product or reuse, an example being the system of returnable beverage glass or PET bottles, in which every bottle is recovered and reused several times.

Material recycling is sometimes referred to as secondary recycling, where the waste is used to replace virgin raw material.

Recycled material can follow two major pathways: closed loop and open loop. In closed loop systems, recovered material and products are suitable substitutes for virgin material. In theory a closed loop model can operate for an extended period of time without virgin material. Of course, energy, and in some cases process material, is required for each recycling. Solvents and other industrial process ingredients are the most common materials recycled in a closed loop.

Open loop recycling occurs when the recovered material is recycled one or more times before its disposal. Many source separated industrial waste materials, as steel, aluminium, different plastic materials etc., are recycled in open loops. E.g. is scrap iron and steel sent to steel mills for re-processing. In many cases also post-consumer materials are recycled in open loops. The slight variations in unknown composition of such materials usually cause them to be downgraded to less demanding uses.

Some material also enters a cascade open loop model in which it is downgraded several times before the final disposal. For example, used white paper can be recycled into additional ledger or computer paper. If this product is then dyed and not de-inked, it can be recycled as mixed grade after use. In this form, it can be used for paper board or packing material. Ledger paper also enters an open loop system when it is recycled into tissue paper or other products that are directly discarded after use.

The popular meaning of recycling has primarily come to refer to the widespread collection and reuse of single-use beverage containers made of aluminium, glass, HDPE and PET after thorough cleaning. These types of containers may also be collected and sorted into common groups, so that the raw materials of the items can be recovered and used for production

Figure 10.2 Recycling bins. *Recycling is slowly making its way in all countries in the Baltic Sea region. In households a minimum of two fractions are required by law: organic waste and other. Today many households have on a voluntary basis six fractions; compostable, burnable, hard plastics for recycling, glass for recycling, paper for recycling, metal for recycling. (Photo: Morguefile/Kenn Kiser)*

of new containers or other products. Other common consumer items recycled in this way include steel food cans, and aerosol cans, glass jars, paper board cartons, newsprint, magazines and cardboard. Other types of plastic (PVC, LDPE, PP and PS) are also recyclable.

Recycling of material on molecular scale, also called tertiary recycling, is a more seldom applied principle, but in principle a possible way of utilising waste. One example that has been investigated is polymer recycling by processing polymers into the original monomers or other simple molecular compounds and then building new polymer molecules. One material that may be recycled this way is Poly-Ethylene-Tereftalate (PET), although it is still not economically feasible.

Resource utilisation or downgraded recycling. Instead of reusing the product or the waste material in a recycling material flow, the material is used for applications with less requirements regarding the purity and quality. An example of this is the use of recovered PET material for production of insulation material or for production of fleece fabric. Another example is the use of crushed glass as light-weight filling in road construction.

In principle also composting could be classed as downgraded recycling. By composting, organic material is converted into compost (humus or soil) that may be used for soil amendment and to replace commercial fertilisers in gardening and agriculture.

Energy recovery from waste is very common. Household waste as well as industrial waste consists to a large degree of combustible material as paper, wood and other organic material. This can be incinerated with energy recovery for heating and power production purposes. In Sweden 46% of all household waste is incinerated for district heating. The energy content of organic waste can also be recovered by digestion of the waste, whereby an energy rich biogas (a mixture of methane and carbon dioxide) is produced.

10.2.4 Waste Treatment

Waste treatment has as objective to convert waste to substances that either may be introduced into the natural material cycles or to be safely land filled. In order to be able to treat the waste it often has to be pre-treated. Pre-treatment primarily has the objective to prepare the waste for the final treatment. The more mixed or diluted a waste fraction is the more difficult it is to utilise or treat. Therefore a pre-treatment often involves a separation of the waste into fractions suited for a particular treatment method. The commonly used treatment methods can be subdivided into three groups.

Thermal treatment includes incineration and gasification or pyrolysis. In addition to energy recovery *incineration* reduces the waste volume by more than 90%. The ashes that are produced can be stabilised for safe land filling. In *gasification and pyrolysis* the waste is heated without access to air, contrary to the case of incineration. This means that the decomposition

Figure 10.3 Biological treatment of waste. *Anaerobic digestion of organic waste (anaerobic composting) produces methane, that can be recovered for energy purposes, and a soil residue often used in parks. (Photo: iStockphoto)*

Box 10.2 The Zero Emission Concept and Calculation of Total Environmental Costs

Emissions and costs

To be able to run a process (most often manufacturing, but in fact it could be any process) we need raw materials, operating materials, auxiliary materials, energy and labour force. These items normally represent constant streams.

During the process these different streams are treated mechanically, chemically or thermally. Due to different inefficiencies the amount of material that is part of the product in the end is less than what was fed into the process. These losses are called emissions. They can be defined in a very simple equation

Emissions = Input – Output

The output is the product. There are four different kinds of emissions: solid waste, fluidic waste, gaseous emissions, and energy losses (as heat, light etc).

These emissions correspond to a running cost. Thus reduced material and energy losses means a reduction of the running costs. If a reduction can be made it is not only a benefit for the environment but also a financial benefit for the company.

The meaning of zero emission

Zero emission refers to a production process that produces no waste at all. All resources are used for the product(s). That can be achieved in two different ways: either by the optimisation of the process itself, or by transforming the waste into a product that can be sold.

Zero can be defined in different ways:

- Absolute zero
- Analytical zero
- Zero impact

Absolute zero is the strictest definition of zero. For companies it means no emissions at all: no waste, no sewage water, no polluted air and no energy losses. It may be perfect for the future, but in our eyes it is presently neither necessary nor economically justifiable to try to achieve zero emission in the absolute sense. If an absolute zero emission is achievable or not depends on how the boundaries of the studied system is drawn. One could argue that unless the total entropy of the studied system is zero there will always be losses, mainly energy or exergy losses, in the environment outside the system boundaries (the 2nd law of thermodynamics).

Analytical zero means that the concentration of waste substances is below the point of detection by analytical methods. But analytical methods advance all the time and push the detection limits further down. Analytical zero is not well defined and not practical.

Zero impact is here understood as the concentrations of emissions are below the natural fluctuations in the environment. In this case one may assume that there is no impact. This is the definition of zero emission used here.

It should be noted that there is a similar notion on the input side. The use of renewable resources should be within the rates of their replenishment. For non-renewable resources one can take no more than what allows future generation to take the same amount.

Zero emissions and costs

Emissions mean lost input. The company has costs for buying resources and other inputs. To reduce the inputs means saving and costs reduction. By far the most common way to reduce costs is to reduce the number of employees. But to increase resource efficiency turns out to be a more interesting option. In Germany an average car manufacturing company has 67% of costs for materials, and 17% for personnel. These figures are similar for the manufacturing industry in general. Increasing personnel efficiency by some 3% yearly, which is typical for industry, thus only leads to some 0.5% improvements in the overall economy. Increasing resource efficiency by 3% would on the contrary be about 4 times better. The zero emissions concept is thus of interest to the company. It is also the solution for a sustainable company.

Using Environmental Management Accounting, EMA

EMA combines financial and physical data in a company and calculates its total environmental cost. The physical data includes material and energy input, material flows, products, waste and emissions. Financial data includes expenditures, costs, earnings, and savings related to the company activities.

The calculation of total environmental cost is not trivial. It is the combination of environmental protection costs, costs for wasted material, waste capital and wasted labour.

Environmental protection costs are defined as costs for prevention, disposal, planning, control, shifting actions and damage repair. Waste here has a double meaning. In addition to "normal" waste it also includes material that has been purchased and paid for but which was not turned into a marketable product. Waste therefore expresses production inefficiencies. The costs of waste materials, capital and labour have to be added up to arrive to a total corporate environmental cost and a sound basis for further calculations and decisions.

The total corporate environmental cost defined in this way should rather be described as the total direct environmental cost for the company. In order to get the overall environmental costs one would have to add the external environmental cost which e.g. consists of the environmental debt incurred due to the environmental damage caused by the emissions from the production of the company and the use of its products not paid for by the company or its customers either directly or via fiscal fees or taxes as well as the global loss of input resources not accounted for.

Waste in this context is used as a general term for solid waste, wastewater and air emissions and all other non-product outputs.

Environmental protection costs = costs for emissions treatment + costs for pollution prevention + costs for wasted material + costs of wasted capital + costs of wasted labour

How to arrive to environmental costs

For a company to calculate its total environmental costs its projects are compiled and described on the basis of existing data records, balance sheets, lists of accounts cost centre reports, list of assets etc. in the following way.

Step 1: List all environmentally relevant facilities in the company.

Step 2: Find the depreciation for these.

Continues on the next page >>

Table 10.2 *Worksheet for calculating total environmental costs.*

Environmental expenditure/costs and revenue/earnings									
Environmental media **Environmental cost/expenditure categories**	**Air/Climate**	**Wastewater**	**Waste**	**Soil/ground-water**	**Noise/ vibrations**	**Biodiversity/ Landscape**	**Radiation**	**Other**	**Total**
1. Waste and emission treatment									
1.1 Depreciation of related equipment									
1.2 Maintenance and operating materials and services									
1.3 Related personnel									
1.4 Fees, charges, taxes									
1.5 Fines and penalties									
1.6 Insurance for environmental liabilities									
1.7 Provision for clean up costs, remediation									
2. Prevention and environmental management									
2.1 External services for environmental management									
2.2 Personnel for general environmental management activities									
2.3 Research and development									
2.4 Extra expenditures for cleaner technologies									
2.5 Other environmental management costs									
3. Material purchase value of non-product output									
3.1 Raw materials									
3.2 Packaging									
3.3 Auxiliary materials									
3.4 Operating materials									
3.5 Energy									
3.6 Water									
4. Processing costs for non-product output									
Total environmental expenditures									
5. Environmental revenues									
5.1 Subsidies, awards									
5.2 Other earnings									
Total environmental revenues									

Box 10.2 Continues…

Step 3: Find number of hours of work and its costs at these facilities.
Step 4: Fill in all data in prepared excel sheets (Table 10.2).

In most cases the collection of all technical information takes much less time than the collection of financial data.

After this first round one should take a tour through the company to find environmentally relevant facilities forgotten in the first round. These data may be crucial for improvement through cleaner production approaches, but not for EMA accounting. As an example: total energy consumption of a plant is important for the EMA process, but temperature and pressure are not. However they may be crucial for finding cleaner production opportunities.

How to use the EMA results

The toolkit of EMA will allow the environmental managers to trace relevant costs in different records, to calculate total environmental costs, and to calculate the cost of an investment.

The whole procedure will identify the media or category of highest environmental costs but it will also show optimisation possibilities and cost saving potentials. The results should allow the company to:

- Estimate the total environmental costs.
- Verify the material balance equations.
- Discuss the existing information systems, weak points and potential improvements.

Most companies are not aware of their total environmental cost, what it is and what it comprises, labour, depreciation of facilities, etc. For example a company often believes that its wastewater costs equals the charges for wastewater discharges, which may be around 1 euro per m^3. However, depending on circumstances, the total costs for wastewater treatment may be 5-6 times higher.

A second result of the EMA process should be to identify where a company should start an optimisation process. For example it is not a good strategy to start energy saving if energy costs are just 10% of the total environmental costs and costs for solid waste is several times higher. In that case one should start to reduce solid waste.

Source: Mickael Planasch, Gernot Gwehenberger, Hans Schnitzer and Christoph Brunner, Graz University of Technology and Joanneum Research Institute for Sustainable Techniques and Systems, Graz, Austria, 2006.
[See e.g. Planasch et al., 2006.]

of the waste takes place in a reducing atmosphere producing an energy-rich gas mixture of carbon monoxide, carbon dioxide, water vapour, hydrogen and methane in addition to a solid residue of tar and coke.

Biological treatment. Composting is the microbiological decomposition and stabilisation of organic material under aerobic conditions. In *digestion* the microbiological decomposition is carried out anaerobically, producing an energy rich biogas consisting of methane and carbon dioxide.

Chemical treatment is usually used for liquid waste fractions such as inorganic solutions from surface treatment and other metal solutions. *Chemical oxidation* is generally applied to de-toxify cyanide solutions from surface treatment industries. *Chemical reduction*, may be exemplified by the reduction of Chromium (VI) solutions to the less hazardous Chromium (III) form. *Chemical precipitation.* Metals are commonly separated from water solutions by chemical precipitation. The solid residue produced can either be utilised as raw material or land filled after stabilisation.

10.2.5 Land Filling

The last stage in the waste management hierarchy is to deposit the waste on a landfill. This alternative is a last resort and should, as expressed in most environmental policies and targets on international, national and local levels in communities and enterprises, be phased out or reduced as much as possible.

10.3 Reducing Waste through Cleaner Production Methods

10.3.1 Mining Waste

A large or even the largest, category of solid waste, the mining waste, often cannot be avoided but may have uses and thus not discarded as waste. The largest use is in construction work. Thus overburden from strip mining may be used in road constructions, but generally it is used for restoring the mining area when the ore body has been exhausted.

Alternative ways of extraction of metals may produce much less waste. An example is copper mining using biotechnological methods, so called *bioleaching*. In this approach microorganisms are used to extract the metal from sulphidic ores by treating the water passing though a mining field. Bioleaching is commercially used to process ores of copper, nickel, cobalt, zinc and uranium. In the process the microorganisms catalyse the oxidation of iron sulphides to create ferric sulphate and sulphuric acid. The ferric sulphate then oxidises the copper sulphide minerals, and the copper is leached by the sulphuric acid formed. In the related case of uranium leaching, the ferric sulphate oxidises tetravalent uranium oxide, which is insoluble in acid, to soluble hexavalent uranium oxide, which is then leached by the sulphuric acid.

An associated process is *biooxidation*, which is the oxidation of sulphide minerals associated with, but not necessarily part of the mineral of interest to be extracted. It is used in gold processing and in coal desulphurisation. In gold processing bacteria are used to oxidise an iron sulphide matrix in which the gold particles are embedded. The formed ferric sulphate is soluble and can be removed to make the gold available for cyanide leaching.

10.3.2 Recycling Polluted Residue

A typical cleaner production strategy is to take care of polluted material to make it useful. Thus contaminated solvents may be recovered e.g. by membrane separation and redistilled to be used over again, a common practice e.g. in pharmaceuticals production.

Contaminated oils may be recovered from e.g. waste liquids from petrol stations and separated from the wastewater by flotation and ultrafiltration and then used for energy recovery in waste oil incinerators.

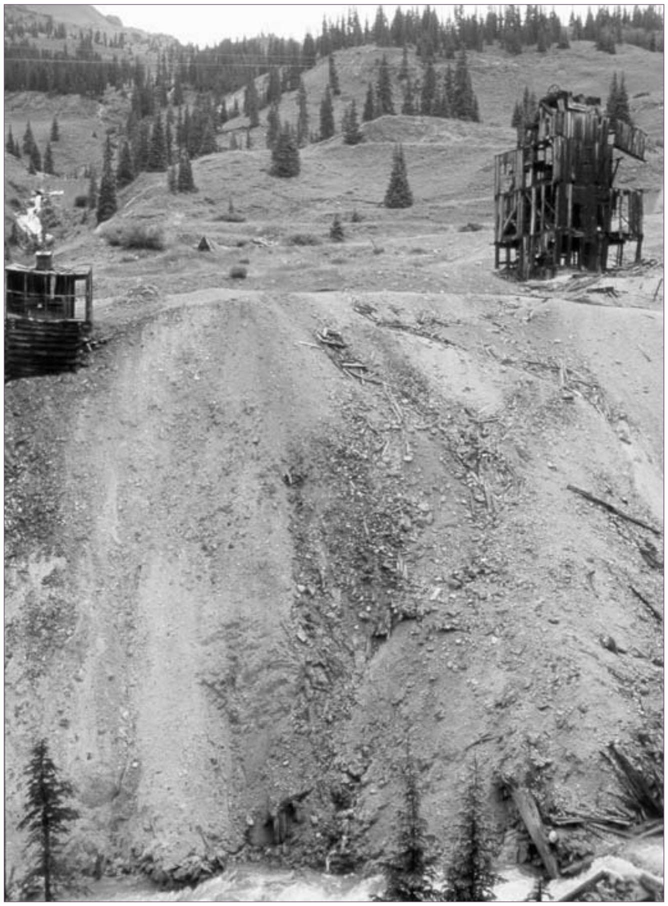


Figure 10.4 Mining waste. *Mining produces enormous amounts of waste, for example copper mining gives more than 99% waste. (Photo: U.S. Geological Survey)*

10.3.3 Efficient use of Materials

A process designed to use material in the most efficient manner reduces both material input and waste.

For example, a large American electronics company designed a flux-dispensing machine for use on printed circuit boards. This low solid flux (LSF) produces virtually no excess residue when it is applied, thus eliminating a cleaning step with CFCs and thereby simplifying operations. Performance of the boards produced with the new LSF was maintained, and the LSF helped this manufacturer reduce CFC emissions by 50%.

Material such as textile, paper or metal sheets used for cutting out pieces may be used more efficiently if the cutting process is optimised and carefully planned.

10.3.4 Resource Conservation

Resource conservation can reduce waste and directly lower environmental impact. A less material-intensive product may also be lighter, thus saving energy in distribution or use. For example, a fast-food franchise reduced material input and solid waste generation by decreasing the paper napkin weight by 21%. This did not lead to the use of more napkins.

10.4 Future Developments

During its first decade (1989-1999), the Basel Convention was principally devoted to setting up a framework for controlling the *transboundary* movements of hazardous wastes.

In 1999 the convention was revised and refocused. The result of this revision is that in the period 2000-2010 the Convention will focus its efforts on:

- Minimisation of hazardous waste generation.
- Active promotion and use of cleaner technologies and production methods;
- Further reduction of the movement of hazardous and other wastes;
- The prevention and monitoring of illegal traffic;
- Improvement of institutional and technical capabilities, especially for developing countries and countries with economies in transition;
- Further development of regional and sub-regional centres for training and technology transfer.

This means that the international priorities in waste management will be turned towards issues very central to Cleaner Production.

Study Questions

1. Describe why waste reduction is an important sustainability measure.
2. Discuss the two approaches of waste reduction, that is, efficiency and using waste as a resource.
3. Give the definitions of waste according to the EU Directives, and explain the concepts of dispose and discard waste.
4. Describe the waste hierarchy. Which measures are preferable and why?
5. What are the three Rs, and what is the fourth R, sometimes mentioned?
6. List the most important principles of waste reduction used in Cleaner Production work.
7. Explain the principles of recycling, including primary and secondary recycling, closed loop and open loop recycling, molecular scale recycling, and downgraded recycling.
8. Give three examples of successful waste reduction projects.
9. Describe briefly the zero emissions projects of ZERI and ZERIA.

Abbreviations

CFC	ChloroFluoroCarbon.
EPR	Extended Producer Responsibility.
HDPE	High Density PolyEthylene.
LDPE	Low Density PolyEthylene.
LSF	Low Solid Flux.
PET	PolyEthyleneTereftalate.
PP	PolyPropylene.
PS	PolyStyrene.
PVC	PolyVinylChloride.
UNEP	United Nations Environmental Programme.

Internet Resources

Secretariat of the Basel Convention, UNEP
http://www.basel.int

Council Directive 75/442/EEC on waste
http://eur-lex.europa.eu/en/index.htm

European Commission – Environmental Policies: Waste
http://ec.europa.eu/environment/waste/index.htm

Zero Emissions Research and Initiatives (ZERI)
http://www.zeri.org/

Graz University of Technology
– Zero emission research in Austria (ZERIA)
http://zeria.tugraz.at/index.php3?lang=en&sel=01ZERiA

European Commission
– Thematic Strategy on the Prevention and Recycling of Waste
http://europa.eu.int/comm/environment/waste/strategy.htm

International Solid Waste Association (ISWA)
http://www.iswa.org/

Resource Recovery Forum
http://www.resourcesnotwaste.org/

Chartered Institution of Wastes Management (CIWM)
http://www.ciwm.co.uk/pm/1

Air & Waste Management Association
http://www.awma.org/

Waste Management
http://www.wm.com/

U.S Environmental Protection Agency (EPA)
– Software for Environmental Awareness:
Household Waste Management
http://www.epa.gov/seahome/hwaste.html

EMARIC (Environmental Management Accounting Research and Information Centre)
http://www.emawebsite.org/about_ema.htm

11

Green Engineering

11.1 Green Engineering

11.1.1 Green Design

Most environmental impacts occur when materials accumulate in the biosphere. The materials may be naturally occurring and extracted from the earth, or they may be man-made. The management of the material flows is critical for efforts for materials conservation. One way to manage the material flows, aiming to avoid accumulation, is to close the material cycles of production and consumption systems.

The idea of closing the materials cycles is not new. It comes from the observation that in natural systems, waste as we see it, does not exist. Materials discarded by one organism generally are used by others to grow and survive. In contrast to the situation in nature, material and energy in our economy mainly flows in one direction only – from raw materials towards final disposal as industrial or municipal waste (part (a) in Figure 11.1.) Sustainable development requires a change in these flow patterns. We need to establish cyclic flows of material.

The different ways to achieve this are collected under Cleaner Production concepts such as Green Engineering, Green Design, or Sustainable Products Design and Production Design. The focus is on the efficient use of materials and energy, reduction of waste toxicity, and reuse and recycling of materials (part (b) in Figure 11.1).

Green engineering uses a series of different techniques. These include Ecodesign or Design for Environment (DfE). Ecodesign directs research and development (R&D) teams to develop products that are environmentally friendly. Toxics Use Reduction (TUR) considers the internal chemical risks and potential external pollution risks at the process and worker level. Life Cycle Assessment (LCA) defines the material usage and environmental impact over the life cycle of a product.

In this chapter the different strategies, approaches and techniques used in the area of green design will be reviewed. Some of these are covered in more detail in other books of the series, especially Book 3, *Product Design and Life Cycle Assessment*.

In this Chapter

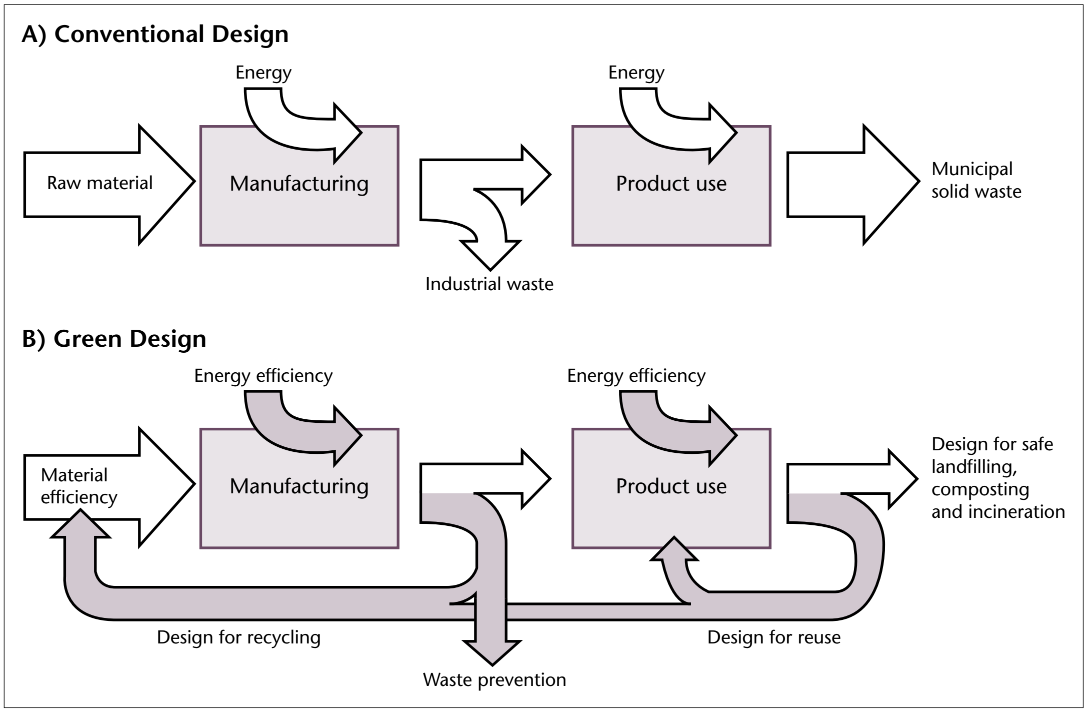


Figure 11.1 How product design affects material flows. *Making changes in a product's design reduces overall environmental impact. The green design emphasises the efficient use of material and energy, reduction of waste toxicity, and reuse and recycling of materials. [Reprinted from OTA, 1992].*

11.1.2 Corporate Strategies

Green Design may be seen as a comprehensive business strategy that maximises the economic and environmental returns on a variety of innovative pollution prevention techniques. Green Design or Sustainable Design of products and production seeks to meet consumer demands for products without compromising the resource and energy supply of future generations. It embeds corporate environmental responsibility into material selection, process and facility design, marketing, strategic planning, cost accounting, and waste disposal.

In the recent development of environmental strategies the focus has been on pollution from the point of view of industrial production. At the same time, advances in areas like materials and production technologies are creating openings for new developments.

An increasing number of companies with truly integrated global production systems direct their products to an increasingly homogeneous global market. The primary opportunities to reduce the adverse environmental impacts of economic activities continue to be technological. Conservation actions such as reducing waste or saving energy are important but among the simpler strategies one may adopt.

Efficiency improvements, such as modernising with more energy-efficient systems or re-engineering so that little or no waste is produced, or developing and deploying processes and systems that offer superior environmental quality, provide the greatest opportunity for improving environmental quality. These improvements are often driven by innovations in technology.

11.1.3 The Strategies of Green Engineering

Green engineering practice requires that concerns about environmental quality include not only production and product use but also useful materials or potential energy embedded in products. In this strategy, products are used in several systems or product cycles, either as parts, materials, or embedded energy. Product becomes input to several product cycles instead of merely ending up as waste ready for landfilling after one life cycle.

An important distinction is the lifetimes of products. Some are made to function for a decade or more; others have lives measured in months or weeks; still others are used only once. The designer must adopt different design approaches to these different types of products according to their durability, materials composition, and recyclability.

These approaches are implemented in a variety of business processes: product design, production design, materials management, supply chain management, order fulfilment, as well as service, maintenance, and asset recovery.

Below we will discuss sustainability strategies in production on several levels, all of them possible to improve by engineering.

On the *level of the industrial system*, the focus is on how one plant is coordinated with other production units in the same area. This is a close parallel to how an ecosystem works and is called industrial ecology or industrial symbiosis. This is a level where changes are slow to introduce since several companies are involved and each one has to agree on the profitability of the change. The essential of the strategy on this level is to organise the material and energy flows in such a way that what is coming out from one unit will be the input in another one.

On the *level of the product*, the focus is to make products such that they do not pollute and that their use does not require too much energy and other resources input. It is also important that products can be recycled or at least the material in the products can be recycled. They thus need to be designed in a way that makes this possible.

On the *level of materials management*, the focus is on material flows. We need to find materials which are renewable, we need to reduce the material flows, e.g. by dematerialisation of products, and we need to find materials which are not toxic.

On the *level of the production system*, the focus is on cleaner production methods. In addition, the up-stream factors are addressed by supply chain management and distribution and transport, and the down-stream factors on recycling as an important part of the end of life system of a product.

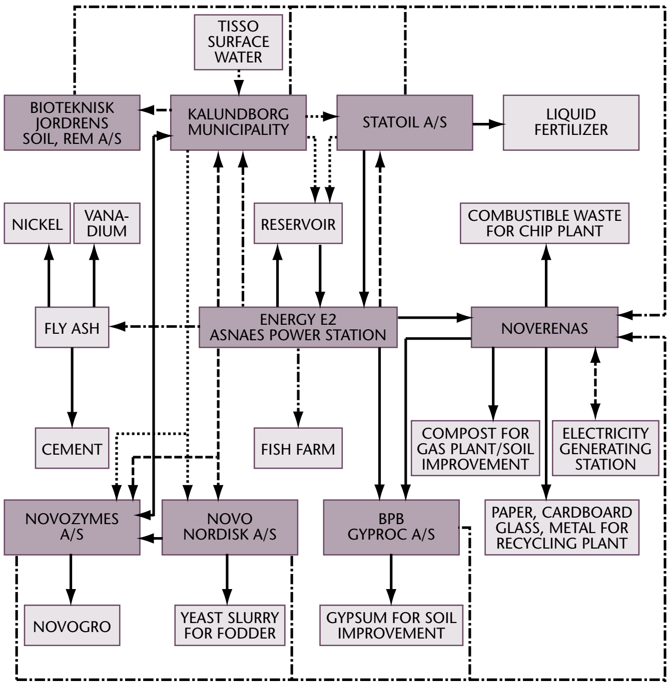


Figure 11.2 *Flow sheet of the Industrial Symbiosis of Kalundborg, Denmark. Dark colour indicates a company; lighter colour a product. [adapted from http://www.symbiosis.dk].*

11.2 Industrial Ecology

11.2.1 The Kalundborg Case

Industrial Symbiosis mimics the natural ecosystem by setting up a system of recirculation of residual materials from industrial processes or discarded products from consumer matter. Industrial Symbiosis attempts to optimise the industrial system as a whole, rather than a particular process or subsystem, to increase the efficient use of a material. In fact, a larger, more complex, more diverse system may offer greater opportunities for efficient use and reuse of materials.

Industrial Symbiosis typically is pursued in a limited area, in a municipality or industrial area in a municipality. Cases are not very common but are found in several countries, in the far East, in Canada in Europe in e.g. Denmark and Sweden. An example of optimisation, which may be reached also in a larger scale, is illustrated by the Industrial Symbiosis cooperation between a number of industries in Kalundborg, Denmark.

Kalundborg Municipality, together with a power plant, an oil refinery, a gypsum board manufacturing plant, a pharmaceuticals plant, a biotechnical plant for production of enzymes, a plant for remediation of polluted soil, a waste handling company and a fish farm and the surrounding farming community benefit from joint utilisation of material residue that otherwise would end up as waste.

The description below is divided between cycles of energy, nutrients, inorganic waste etc. One needs to remember however that truly integrated systems rely on these flows being coupled, as they are in the body metabolism. Water is a carrier of material and energy, waste is a carrier of energy, etc. Many municipalities have established their own symbiotic strategies. Examples include the use of energy in waste for incineration, nutrients in sludge to improve soil in parks, and the energy from wastewater streams by heat pumps.

11.2.2 Energy Cooperative Systems

Energy cooperation might be the most easy and typical case of symbiosis. In Sweden seven municipalities reported agreements with local industries on using residual heat for their district heating system. Some pulp and paper factories in the north are selling steam to other companies in the vicinity. Selling steam or hot water is a straightforward task and obviously should be profitable for all partners, as long as the needed infrastructure is available.

In Kalundborg, the Power Station produces heat for the city of Kalundborg and process steam for the oil refinery and for the enzymes factory. The combination of heat and power production results in a 30% improvement of fuel utilisation compared to a separate production of heat and power. Approximately 4,500 households in Kalundborg receive district heat from the Power Station. District heat has replaced approx. 3,500 small oil-fired units.

The oil refinery receives process steam and water from the Power Station. The steam covers about 15% of the refinery's total consumption of steam. The refinery uses the steam for heating oil tanks, pipelines etc. The enzymes and pharmaceuticals plants use steam from the Power Station for the heating and sterilisation of the processing plants.

11.2.3 Water Recycling in Kalundborg

The Kalundborg Region, as well as its industrial companies, is a large consumer of water. This is why the Symbiosis companies are seeking to recycle as much water as possible. The Power Station has, for example, reduced its total water consumption by 60% by recycling schemes. Previously the Power Station used ground water for its power and heat production only. The ground water has now been substituted by surface water from Lake Tissø and treated wastewater from the refinery. These efforts have enabled the Power Station to reduce its ground water consumption by 90%. Earlier, the enzymes company also used ground water exclusively for processes requiring drinking water quality. 1 million cubic metres of ground water have now been substituted by lake water from Tissø, whose water has been processed up to drinking water quality by Kalundborg Municipality.

As the water from Tissø is not an unlimited resource, the consumption of lake water has been reduced by 50% by recycling of the wastewater from the power plant.

The wastewater of the industrial park companies is led to a recycling reservoir together with the run-off from the surrounding fields and surplus water from Tissø in the winter period. The recycling reservoir has a capacity of 220,000 cubic metres of water, which are used in the power station processes.

The wastewater from the enzymes and pharmaceuticals plants is part of a genuinely symbiotic relationship: The enzymes company treats all wastewater up to a level corresponding to the wastewater of an ordinary household. The treated wastewater is pumped to the treatment plant of Kalundborg Municipality where a final treatment process takes place.

The wastewater from the enzymes plant is of a relatively high temperature, making it easier for the municipal treatment plant to treat its wastewater. In this collaboration process, the environment is also the winner as the overall discharge of nitrogen into Jammerland Bay is very limited. Wastewater is also discharged from the Power Station into the treatment plant of Kalundborg Municipality.

11.2.4 Gas and Inorganic Material Recycling

An "eternal" flare of surplus gas is part of the safety system in any refinery. But today the refinery flare in Kalundborg has been reduced to a mere night-light, because the refinery now exploits its own surplus gas internally. Formerly a large portion of the gas was transported by pipeline to the gypsum plant and the Power Station to be used in their production.

The desulphurisation plant of the Power Station removes sulphur dioxide (SO_2) from the flue gas, producing about 200,000 tonnes of gypsum on a yearly basis. Desulphurisation is a chemical process in which sulphur dioxide (SO_2) reacts with a lime slurry while forming the by-product gypsum. The gypsum is sold to the gypsum company that manufactures gypsum board products for the construction industry. The gypsum from the power station reduces the import of natural gypsum significantly. Being more uniform and pure than nat-

Figure 11.3 Oil refinery in Kalundborg, Denmark. *A collaboration – an industrial symbiosis – is pursued by the refinery with several other production companies in the Kalundborg area, which make commercial use of each other's spent coolant water and waste products. (Photo: TA Foto Scandex AS)*

ural gypsum, power station gypsum is therefore well suited for the gypsum board production.

Also gypsum stemming from the municipal recycling station of Kalundborg is delivered to the gypsum company, thereby contributing – on a smaller scale – to reducing imports of natural gypsum and the amounts of solid waste for landfilling.

The Power Station removes fly ash from the flue gases while producing about 30,000 tonnes of fly ash on a yearly basis. Ash deriving from orimulsion firing (orimulsion is a bitumen and water mixture mined in Venezuela) is recycled in a plant in Great Britain. Nickel and vanadium are reclaimed from this ash. The largest ash customer is a Portland Cement factory.

11.2.5 Biomass Recycling

The use of residual biological material is worldwide the most typical kind of industrial symbiosis. Of course a plant that has biological material as a residual product tries to sell it rather than pay for its destruction. Until recently a poultry farm on Gotland in the Baltic Sea shipped its dead chickens to Denmark for destruction. Since spring 2005 the dead chickens are instead incinerated in a power plant to produce heat. This is a win-win situation. In Uppsala in Sweden, the organic waste from the local slaughter house (a rather big one) is fermented by the municipality. The biogas formed is used by the local bus company to run 43 of the local buses. Typical cases of cooperation include the use of sludge from wastewater treatment in agriculture. The old view that waste is a resource, that nutrients is money, is expressed in a modern situation by industrial symbiosis.

In Kalundborg enzyme production is based on fermentation of raw materials such as potato flour and corn starch. The fermentation process generates about 150,000 cubic metres of solid biomass. At the same time, 90,000 cubic metres of liquid biomass is produced. After inactivation and hygienisation, this product is used by some 600 West Zealand farmers as fertiliser in the fields, thereby reducing their need for commercial fertilisers. The product contains the by-products nitrogen, phosphorus and lime.

The insulin production of the pharmaceutical company also provides feed for pigs. The insulin production builds on a fermentation process in which some of the main ingredients are sugar and salt, which are converted into insulin by adding yeast. After a heating process, the yeast, a residual product in this production, is converted into a much appreciated feed: yeast slurry. Sugar water and lactic acid bacteria are added to the yeast, making the product more attractive to pigs. The yeast slurry replaces approx. 20% of the soy proteins in traditional feed mixes. Over 800,000 pigs are fed on this product.

The refinery's desulphurisation plant reduces the sulphur contents of the refinery gas whereby SO_2 emissions are reduced significantly. The by-product is ammonium thio-sulphate, which is used in the production of approx. 20,000 tonnes of liquid fertiliser, roughly corresponding to the annual Danish consumption.

Sludge is a major residual product stemming from the municipal water treatment plant in Kalundborg. The sludge is utilised at the soil-remediation plant as a nutrient in the bioremediation process.

The waste handling company collects waste from all Symbiosis companies. Further, it produces electricity on the basis of landfill gas. This electricity is fed into the national power grid. In addition, a total of approx. 56,000 tonnes of combustible waste on a yearly basis is produced corresponding to the energy consumption of approx. 6,500 private households in terms of power and district heating.

11.3 Product Design

11.3.1 Ecodesign or Design for Environment (DfE)

A second main concern for green engineering is Ecodesign or Design for the Environment (DfE). Ecodesign aims to minimise environmental impacts of a product and achieve major reductions in resource and energy use throughout the life cycle of the product (including the manufacturing phase).

One of the methodologies developed for sustainable product design is the Ecodesign Strategy Wheel (Figure 11.3). It provides a basic framework to systematically review the entire life cycle of a product. It is a tool that can stimulate a creative design process and bring up opportunities for improvement.

The Strategy Wheel begins with the strategy called new product concepts, and then includes a series of strategies on materials selection, production, distribution, use, and end of a product's life, etc.

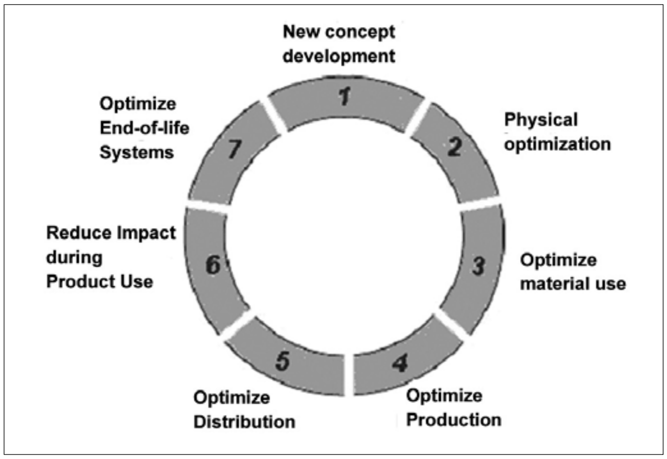


Figure 11.4 *The ecodesign strategy wheel [NRC, 2001]. (See also Figure 4.7)*

11.3.2 New Concept Development

In the strategy *New Concept Development* the function(s) of a product in terms of both development assumptions and the needs of the end-user are examined. The strategy focuses on basic assumptions regarding the function of a product. It determines the end-users' needs and how the specific product meet these needs.

The most radical form of New Concept Development is to replace the physical product with a *service*. One example is when a customer buys a transport service instead of a car. Then a company assumes responsibility for maintenance, repair, disposal, and/or recycling of the product – here the car – during its use and end-of-life phases. It is environmentally a better strategy for many reasons. It is in the interest of the company to make their cars long-lived, economical and maximally used.

Another road to decreased physical production is to increase *shared use*. When several people make joint use of a product without actually owning it, the product is used more efficiently. Good examples of products that can be shared include equipment such as photocopiers, laundry equipment, hardware, and construction tools. The products then have to be robust enough to stand heavy use.

Other examples are replacing a material product with an immaterial substitute, e.g., mail replaced by e-mail; and/or reducing the use of material or infrastructure-intensive systems, e.g., telecommuting vs. use of automobiles for work purposes.

11.3.3 Dematerialising Products and Services

An important part of ecodesign is to look for dematerialisation opportunities. Dematerialisation, of course, leads to less pressure on resources, less environmental impact, as well as smaller waste streams as the material stream as a whole is reduced. In addition, with dematerialisation less energy is used during production, transport and storage.

The most common form of dematerialisation is to make an existing product smaller or lighter. This may be possible due to technical developments, as illustrated by the dramatically reduced size of computers, phones, and other electronic equipment over the last decades. To design products so that they are of equally high quality but with less material may also be possible due to a change of material. Examples include the use of optical fibres instead of copper wire for electric transmissions or a strong alloy instead of iron for specific purposes. Sometimes dematerialisation is trivial. An American fast-food franchise reduced material input and solid waste generation by decreasing the paper napkin weight by 21%. Store tests revealed no change in the number of new napkins used compared to the old design.

A particular case is products which are deliberately designed to be heavy or large in order to project a quality image. However, a quality image can be achieved through other techniques, i.e., creating a lean but strong design. In many cases, a reduction in the weight or volume of materials is possible without affecting their technical life.

11.3.4 Extending the Life of a Product

Extending the life of a product is another objective in ecodesign. Making more long-lived products saves resources and generates less waste because fewer units are needed. If, however, new generations of products are environmentally better, which is sometimes the case, it may on the other hand be counter productive. Many cars illustrate this.

The reasons for products being wasted may be that the new generations are technically improved, that fashion asks for a new product, that they are worn out, either by normal wear or because of poor quality, because of degradation e.g. by environment or chemically, that they are damaged by accident or inappropriate use. Therefore, to make longer-lived products the designer needs to address *durability*, *adaptability* and *reliability*.

Durable products can withstand wear, stress, and environmental degradation over a long useful life. Designers should enhance durability as appropriate. For example, a company leases all the photocopiers it manufactures. The company designs drums and other key components of their photocopiers for maximum durability to reduce the need for replacement or repair. Because the company maintains control of the machines, they select materials to reduce the cost and impact of disposal.

Adaptable design requires that parts can be replaced as needed. For example, an adaptable strategy for a new razor blade design ensures that the new blade mounts on the old handle so that the handle does not become part of the waste stream.

Reliability refers to the ability of a product to serve its use for a certain period of time. Parts reduction and simplified design can increase both reliability and manufacturability. A simple design may also be easier to service. All these factors can reduce resource use and waste.

11.3.5 Making Products Recyclable

Recycling products in whole or in part is another key strategy in ecodesign. Recycling includes *reuse*, e.g. a bottle which can be refilled; *remanufacturing*, e.g. of a used car motor if most of it can be reused; *material recycling* e.g. in recycled glass, or at least *energy recycling* if the material can be used as fuel, as when paper is burned.

Remanufacturing restores worn products to a like-new condition. The used product is disassembled, its usable parts are cleaned and refurbished, and a new product is reassembled from both old and new parts. Designs must be easy to take apart if they are to be remanufactured. Adhesives, welding, and some fasteners can make this process impossible. Critical parts must survive normal wear, and extra material present in used parts allow re-finishing. Design continuity increases the number of interchangeable parts between different models in the same product line, as common parts make remanufacturing products easier. For example, a manufacturer remanufactured plastic moulders for one-third the cost of new machines. The remanufactured machines increased efficiency by 10 to 20% and decreased scrap output by 9% compared to the old equipment; performance was equal to the new moulder.

Reuse is the additional use of a product several times. Normally cleaning or maintenance is needed when going from one use to the next. Containers, bottles, are classical examples of reused products; other examples include reusable parts of machinery to filters in coffee machines.

Material *recycling* is the reprocessing of a recovered material. In *closed loop* systems, recovered material and products are suitable substitutes for virgin material. In theory a closed loop model can operate for an extended period of time without virgin material. Solvents and lead in batteries are common materials recycled in a closed loop. *Open loop* recycling (sometimes called down-cycling) occurs when the recovered material is recycled only once or a few times before disposal. The classical example is paper that may be used up to a maximum of six times. When the paper has been used for paper board or packing, it is not valuable enough to recover any more. Most consumer material is recycled in open loops.

In most projects, the *material selection* is not coordinated with environmental strategies. For instance, a passenger car currently uses 50 to 150 different materials. Separating this mixture from a used car to recycle them is impossible. Designers can, however, aid recycling by reducing the number of incompatible materials in a product, for example by using a single polymer for all plastic parts. The polymer has a moulded-in finish, eliminating the need for additional finishes, and moulded-in identification symbols. In addition, if parts snap together the use of metal pieces such as hinges and brackets can be avoided. Design features which facilitate recycling, include easy disassembly, elimination of costly plastic parts sorting, and easy identification of polymer composition.

11.3.6 Reducing Impact During Use

Many products consume considerable energy, water and/or other consumables during their life span. Resources consumed in maintenance and repair add to the environmental impact. An important product design strategy focuses on reducing environmental impact during product use. Energy-efficient products reduce energy consumption and greenhouse gas emissions.

Energy-efficient products use the lowest energy-consuming components available. If energy is required to move the product they should have light-weight materials. If energy is used for heating or cooling appropriate components are well insulated, and the temperatures used are as close to room temperature as possible. If batteries are needed passive solar heating and rechargeable batteries are good alternatives. Sometimes it is possible to use human-powered alternative designs. Electronic equipment should have a default power-down mode.

The use of *clean energy sources* for a product can greatly reduce harmful emissions at the energy-generation stage.

Ecodesigned products should also reduce the use of consumables such as water, oil, filters, cleaners/detergents and organic materials during a product's life span. The design may also foresee possible leaks from machines that use high volumes of consumables by, for example, by installing a leak detector. Some products may also re-cycle consumables, e.g., newer dishwashers re-circulate some wash water to reduce total water usage. Ecodesigned products should also reduce the handling of hazardous/dangerous materials, and prepare for reduced disposal costs of hazardous/dangerous materials. Implementing a collection/recycling/re-manufacturing system is a way to eliminate the disposal of filters, cartridges and dispensers in landfills or for incineration.

11.4 Materials Management

11.4.1 Choosing Material

Material selection is a fundamental part of design, and it offers many opportunities for reducing environmental impact. Materials management deals with the environmental impact caused by resource acquisition, processing, use, and wasting.

Substituting toxic materials and selecting the most environmentally appropriate materials, substances and surface treatments for product manufacture can be made for product as well as process materials, such as solvents and catalysts. For example, water-based solvents or coatings can sometimes be substituted for high-VOC alternatives during processing. Also, materials that do not require coating, such as some metals or polymers, can be substituted in the product.

For example, an American company replaced its five-layer finish on some products with a new three-layer substitute. The original finish contained nickel (first layer), cadmium, copper, nickel, and black organic paint (final layer). The new finish contains nickel, a zinc–nickel alloy, and black organic paint. This substitution eliminates cadmium, a toxic heavy metal, and the use of a cyanide bath solution for plating the cadmium.

The new finish is equally corrosion resistant. It is also cheaper to produce, saving the company 25% in operating costs.

Some materials or additives are best avoided because they cause hazardous emissions during production, when they are incinerated, or if they are landfilled. Reducing the use of toxic chemicals results in fewer regulatory concerns associated with handling and disposing hazardous material and less exposure to corporate liability and worker's health risks. For example, a water-based machining coolant can reduce the quantity of petroleum oils generated on-site and allow parts to be cleaned more effectively using a non-chlorinated or water-based solvent.

The use of *renewable materials* can represent a good environmental and societal choice for many reasons. They have reduced net emissions of CO_2 across their life cycle as compared to materials derived from fossil fuels. They result in biodegradable waste, and may be possible to grow and use locally, which promotes sustainability.

The energy assembled in a product during its production is called *embodied energy*. The number and type of processing steps for a material and its embodied energy are correlated. The fewer and simpler the extraction, processing and refining steps involved in a material's production, the lower its embodied energy. The embodied energy of a material is often reflected in its price. In some cases, the most technically appropriate material will lower energy costs over the life cycle of a product. For example, composite materials involving carbon fibres or ceramic compounds may have a relatively high embodied energy, but when they are used appropriately, they can save energy in a product's use-phase due to their advanced physical properties, e.g., strength, stiffness, heat or wear resistance.

11.4.2 Recycled Materials

The use of virgin material may be minimised by maximising the incorporation of *recycled material*. *Recyclable materials* are those that can be easily recycled, depending on the type of material and the available recycling infrastructure. Sources of recycled feedstock include in-house process scrap, waste material from another industry, or reclaimed post-consumer material. The quality of incoming material determines the amount of unusable feedstock and the amount of time required to prepare the material. Therefore, product design dimensions should closely match incoming feedstock dimensions to minimise machining, milling, and scrap generation. Reformulation is an appropriate strategy when a high degree of continuity must be maintained with the original product. Rather than replacing one material with another, the designer alters the percentages to achieve the same result. Some material may be added or deleted if the original product characteristics are preserved.

Recycling provides cost-benefits. Reducing the amount of waste a company sends to landfill can produce significant cost-savings. The waste materials could itself be a source of income. By implementing product take-back programmes, companies have a cost-effective source of materials and/or parts. Unique features of recycled materials such as variations in colour and texture can be advantageous when used appropriately in product production. This can include using recycled paper, steel, aluminium, other metals and plastics.

11.5 Production Design

11.5.1 Cleaner Production Strategies

Production optimisation focuses on practices for cleaner production. *Alternative production techniques* aim to process optimisation, quality control, energy conservation and preventive management. It can also lower energy and costs associated with raw materials, energy, labour, treatment and disposal, insurance and liability.

In optimisation of product production, techniques and processes should be undertaken with the objective of *reducing the number of production steps*. Means to do this include multiple production steps to be performed on a single part or component simultaneously; single production steps to be performed on multiple parts or components simultaneously; reducing the movement/transport distances of parts and components within the production facility; using materials that do not require additional surface treatment or finishing for performance or aesthetics.

Lower/Cleaner Energy production can be achieved by making production processes more energy efficient. Measures that may be explored include the use of cleaner energy sources; introducing cogeneration of heat and electricity; optimising the heating/ventilation/energy needs and set up systems and controls tailored to each specific process; more efficient compressed air systems; optimised use of space requirements.

Less Production Waste can be obtained by optimising production processes with respect to the output of waste and emissions. This optimisation increases the efficiency of material use and decreases the amount of material sent to a landfill by reducing or eliminating the "non-product output" per unit of production. Measures to promote this include elimination of processes such as sawing, turning, milling, pressing and punching in order to reduce waste, and secondly the recycling of production residue in-house.

Using *fewer/cleaner production consumables* is another strategy. The use of water, solvents, de-greasers, oil/lubricants, abrasives, solders and cutting tools can be correlated with per unit production and minimised. For example, identifying and using solvents, lubricants or de-greasers with low volatile organic compounds (VOCs) can reduce the use of ventilation systems and/or pollution prevention equipment.

Improved inventory control and materials handling reduces waste from oversupply, spills, or deterioration of old stock. Storage facilities are important elements of inventory and handling systems. If toxic chemicals are needed in a process less harmful precursors may be stored and reacted to form the toxic chemicals for immediate consumption. This system in addition avoids transporting toxic materials.

11.5.2 Distribution and Transport

Another way to reduce environmental impact is to use efficient ways of transport of products from the producer to the distributor, retailer and end-user. The factors involved in distribution optimisation include packaging, mode of transport, mode of storage/handling and logistics.

Packaging development should be considered separately from product development since packages have their own life cycles and associated environmental impacts. Also packaging can undergo ecodesign. The key is to reduce packaging. Packaging is a dominant part of waste streams in industrial countries. Less and smaller packaging result in less waste, less energy for transport, less emissions and less cost. Transport and bulk packaging, may rely on re-usable materials and a return system between producer and the retailer and, if possible, between the retailer and end-user. A package deposit/refund will encourage such a system. A returnable packaging should be durable to withstand several cycles and possible to fold to be easier to return.

Well-designed *transport* of the products may greatly contribute to a decreased environmental impact. Thus transport by rail is many times more energy saving than by car, and shorter distances are of course better than longer.

Logistics refer to the organisation of distribution and transport. Choosing a better provider of a material or product will reduce impact; a local provider if possible will avoid long distance transport. Coordination of transports may also greatly reduce the need for transport. Use of standardised pallets, boxes or bags to load products may also reduce impact. Efficient routing of transportation and distribution can significantly reduce the environmental impact. Efficient computer systems for distribution may also be part of improved logistics.

11.5.3 Supply Chain Management

Supply Chain Management (SCM) is, according to the Ryzex Group, "the oversight of materials, information, and finances as they move in a process from supplier to manufacturer to wholesaler to retailer to consumer. Supply chain management is the way a company finds the raw components it needs to make a product or service, manufacture that product or service and deliver it to customers. Supply chain management involves coordinating and integrating these flows both within and among companies."

Supply chain management flows can be divided into three main flows: The product flow, information flow and financial flow. The product flow includes the movement of goods from a supplier to a customer, as well as any customer returns or service needs. The information flow involves transmitting orders and updating the status of delivery. The financial flow consists of credit terms, payment schedules, and consignment and title ownership arrangements. The proper choice of supplier of raw material offers a very important possibility to reduce the environmental impact of a product. One needs to find a provider close by and with the product needed.

11.5.4 Optimising the End-of-life System

Optimising the end-of-life system is aimed at re-using valuable product parts/components and ensuring proper waste management at the end of a product's useful life. Optimised end-of-life systems can reduce environmental impacts through reinvestment of the original materials and energy used in manufacturing. Companies should consider various end-of-life scenarios to optimise the end of a product's life. Can the product/components/parts be reused? Can parts/components be remanufactured and then re-used? Can parts be used for material recycling? Can parts be safely incinerated? Should parts be disposed of in landfill?

Reuse of the product, either for the same application or a new one, is easier the more the product retains its original form, and the more environmental merit is achieved. The possibilities for re-use are dependent upon the product's technical, aesthetic and psychological life span, and the product being possible to clean, maintain and upgrade. Recycling depends on the existence of take-back programmes and the willingness of a secondary market to accept used products. It is easiest with recyclable materials for which a market already exists. Designing for disassembly should be considered. This type of design is also closely related to making a product more serviceable for users and aiding in maintenance and repair.

Factors such as the life span of parts/components, their standardisation, maintenance requirements, and instructions for servicing and re-assembly, play a major role in designing for disassembly. If the product can be easily disassembled the levels of recycling increases. If non-destructive disassembly is not possible, the different materials should be possible to easily separate into groups of mutually compatible materials.

This is important, for instance, in efficient metal recovery and recycling.

When product, component or material re-use and recycling are not possible, incineration is an end-of-life option. Design for safer incineration avoids the use of materials that can lead to toxic emissions if the product is incinerated without adequate environmental controls.

Study Questions

1. What is included in the concept of green engineering?
2. List the four levels of manufacturing at which green engineering strategies can be used.
3. Describe what is meant by *industrial symbiosis* and give two cases where it has been applied.
4. Explain how energy cooperative systems between different plants or activities can be designed. Give an example.
5. Explain how biomass cooperative systems between different plants or activities can be designed. Give an example.
6. Make a drawing of the ecodesign strategy wheel for *product* development, and give examples of each of the eight strategies.
7. Explain how recycling can be an important strategy in green engineering. Describe each of the levels of product, material and energy.
8. Describe green engineering strategies used in *production* design.
9. In what ways can supply chain management of *materials* contribute to cleaner production?
10. Make a personal assessment of the role of green engineering in cleaner production.

Abbreviations

DfE	Design for Environment.
LCA	Life Cycle Assessment.
OTA	Office of Technology Assessment, USA.
R&D	Research and Development.
SCM	Supply Chain Management.
TUR	Toxics Use Reduction.
VOCs	Volatile Organic Compounds.

Internet Resources

U.S. EPA – Green Engineering

http://www.epa.gov/oppt/greenengineering/

The Greenbusch Group – Green Engineering/LEED (Leadership in Energy and Environmental Design)

http://www.greenbusch.com/GreenEngineering.html

National Industrial Symbiosis Programme (NISP)

http://www.nisp.org.uk/

Industrial Symbiosis: Literature and Taxonomy, by Marian R. Chertow, in "Annual Review of Energy and Environment"

http://arjournals.annualreviews.org/doi/pdf/10.1146/annurev.energy.25.1.313

The Kalundborg Centre for Industrial Symbiosis

http://www.symbiosis.dk

CleanerProduction.com – Design for Cleaner Production

http://cleanerproduction.com/Directory/tools/design.htm

The Ryzex Group – Glossary of Terms for Bar Coding

http://www.ryzex.com/barcodeGlossary.cfm

The Centre for Sustainable Design,
Surrey Institute of Art & Design University College, UK

http://www.cfsd.org.uk/index.html

12

Green Chemistry

12.1 The Principles of Green Chemistry

12.1.1 What is Green Chemistry

Many chemical products can be manufactured using a wide variety of synthetic routes. The designer of a chemical process must choose from alternative raw materials, auxiliary materials such as solvents and catalysts, reaction pathways, and reaction conditions, and these design choices can have a significant impact on the overall environmental performance of a chemical process. *Green chemistry*, refers to the design of chemical products and processes that reduces or eliminates the use and generation of hazardous and polluting substances.

The identification of environmentally preferable chemical processes requires extensive chemical and process knowledge and creativity. Since the number of alternative process pathways is very large and the implications of the alternatives so complex, it is not feasible to develop a systematic, quantitative design tool covering all possible process alternatives of all conceivable products.

Ideal chemical reactions would have attributes such as:

- Simplicity.
- Safety.
- High yield and selectivity.
- Energy efficiency.
- Use of renewable and recyclable raw and auxiliary materials.
- Use of raw materials with no or low content of impurities.

In general, chemical reactions cannot achieve all of these goals simultaneously, and it is the task of chemists and chemical engineers to identify pathways that optimise the balance of desirable attributes.

If the agenda specifically includes the use of renewable and recyclable resources and energy generation without fossils, the term *sustainable chemistry* is often used. Often the concepts of green chemistry and sustainable chemistry are used interchangeably, although green chemistry is the more common expression. Below we will most often use "green chemistry" although we also include issues of renewable resources and avoidance of fossils in energy generation.

The concept of green chemistry is here presented in two basic parts – one qualitative and the other quantitative.

In this Chapter

12.1.2 The History of Green Chemistry

Green chemistry was first promoted by IUPAC, the International Union of Pure and Applied Chemistry, in the late 1980s. The focus was first on the avoidance of environmentally hazardous products. Later the agenda broadened and the chemical processes themselves grew more important. More recently the fact that both raw materials and energy in the chemical industry mostly relies on fossils, and that these should be avoided, have been added. This is a large source of both pollution and un-sustainability, as the energy source is non-renewable.

OECD, the Organisation for Economic Cooperation and Development, later rephrased the IUPAC principles for Green Chemistry to principles for Sustainable Chemistry as the following:

- Design, manufacture and use of efficient, effective and environmentally more benign chemical products and processes.
- Maximise resource efficiency, energy and non-renewable resource conservation.
- Risk minimisation, pollution prevention, waste minimisation.
- Reuse and recycling of products.

OECD continues by pointing to areas where Research and Development, R&D, in sustainable chemistry is needed:

- Use of alternative synthetic pathways.
- Use of alternative reaction conditions.
- Design of chemicals that are inherently safer than current materials.
- Use of renewable or recycled feedstock.
- Avoidance of persistent, toxic or bioaccumulative substances.
- Increased energy efficiency.
- Use of green analytical methods in processing.

It will be clear from this chapter that much remains to be done to strengthen the knowledge background for making chemistry sustainable. OECD says:

Chemical production is still far from being sustainable; substance and energy flow is too high, as are the emissions of hazardous substances both during production and from the products themselves. The whole design of chemical processes and chemicals is a challenge that needs to be met by a new chemicals policy. Issues that need to be considered include atom economy, less hazardous chemical synthesis, design of safer and degradable chemicals, and the need to avoid auxiliary substances and unwanted by-products. A paradigm shift is necessary.

Bernd Jastorff, Johannes Ranke, and Reinhold Störmann, who have written the first textbook on sustainable chemistry, say that we need to add three new dimensions to the classical triangle (synthesis, analysis, and reaction mechanisms) of Organic Chemistry education: First the principles of saving energy and resources, secondly the assessment of toxicological and eco-toxicological consequences of chemicals, and thirdly the understanding of the principles of sustainable development.

12.1.3 Green Chemistry Methodologies

A qualitative approach to chemical process design involves raw material selection, selection of auxiliary materials such as solvents, catalysts, and other materials and the selection of reaction pathways and conditions.

Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations. The *12 principles of green chemistry* [Anastas and Warner, 1998], provide a road map for implementing green chemistry. These principles have been adopted world wide.

1. *Prevent waste:* Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. *Design safer chemicals and products:* Design chemical products to be fully effective, yet have little or no toxicity.
3. *Design less hazardous chemical syntheses:* Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. *Use renewable feedstocks:* Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
5. *Use catalysts, not stoichiometric reagents:* Minimise waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
6. *Avoid chemical derivatives:* Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
7. *Maximise atom economy:* Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. *Use safer solvents and reaction conditions:* Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.

9. *Increase energy efficiency:* Run chemical reactions at ambient temperature and pressure whenever possible.
10. *Design chemicals and products to degrade after use:* Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. *Analyse in real time to prevent pollution:* Include in-process real-time monitoring and control during syntheses to minimise or eliminate the formation of by-products.
12. *Minimise the potential for accidents:* Design chemicals and their forms (solid, liquid, or gas) to minimise the potential for chemical accidents including explosions, fires, and releases to the environment.

The first step is thus to avoid pollution. This principle is well established and in a way inherited from the earlier concerns about environmental impacts. The methods are those developed in product design and cleaner technologies. A careful monitoring of this aspect requires the use Life Cycle Assessment or some of the simpler life cycle methods. A more careful toxicological or eco-toxicological assessment of the chemicals and products themselves will be requested as part of proper chemicals management, and will be required for all bulk chemicals in the new EU chemicals directive, REACH.

The second step is to use renewable resources. Several possibilities of replacing non-renewable oil products exist. These include cellulose, starch, vegetable oils, etc. From them it is possible to produce bulk chemicals such as methanol, ethanol, etc. Many standard chemicals are also made microbiologically, including acetic acid, citric acid etc. This is also called vegetable chemistry.

The third step is to use biological or biologically inspired conditions. Ordinary petrochemical reactions are usually far from that state, with their high temperature, organic solvents, and moderate yields. Biological reactions are normally conducted at body temperature, in water solution, and without toxic components such as heavy metals. The methods used to approach this are found in biotechnology or biotech-inspired chemistry.

12.2. Selecting Raw Materials

12.2.1 Criteria for Green Chemicals

The synthesis and manufacture of any chemical substance begins with the selection of raw materials from which the final product will be synthesised. In many cases, the selection of a raw material can be the most significant factor of the impact of a chemical manufacturing process on the environment. There are a number of criteria that can be used in evaluating the potential environmental impacts of materials. One set of criteria that may be important in evaluating the environmental performance of a material is that it should have low persistence in the environment, low or no bioaccumulation potential, and low or no eco-toxicity and human toxicity. The scarcity of the material, and whether it is a renewable or non-renewable resource, may also be considered. The environmental impacts associated with creating the raw material are also important factors.

In selecting the raw material for a chemical process a number of general principles can be applied.

Innocuous. The selection of raw material for a process should start with the evaluation of the material itself, in order to ensure that it does not possess any hazardous properties.

Generate Less Waste. An important consideration associated with the use of a particular raw material is whether it is responsible for the generation of more or less waste than other raw materials. The type of waste generated is also an important factor to be considered.

Selectivity. Utilising a raw material or reaction pathway that is more selective means that more of the raw materials will be converted into the desired product. High product selectivity does not, however, always translate into high product yield (and less waste generated). Both high selectivity and high conversion must be achieved for a synthesis to generate little or no waste.

Efficiency. Reaction efficiency, like product selectivity, will offer cleaner production benefits. If the overall yield of a reaction is increased, less material ends up in the waste streams and more is converted into product.

Renewability. If chemistry is to be sustainable the raw material needs to be renewable. Considering that the chemical industry today is dominated by petrochemicals, this is a big challenge.

12.2.2 Selecting Raw Materials

Raw materials below will refer to organic chemicals, metals, and biological materials, especially wood.

The chemical industry is today dominated by oil products, petrochemicals. About 10% of all petroleum products are used as raw materials in the chemical industry. Oil is used to produce everything from simple hydrocarbons, solvents, aromatics, up to complicated compounds. Part of this production is polluting, e.g. through emissions of by-products such as sulphuric compounds, SO_x, and heavy metals, especially mercury.

To replace this with materials from renewable resources is difficult and will take time. It is perhaps not entirely necessary if the use of oil products for energy purposes is drastically reduced. Biological sources include forest products and cultivated crops. Rape seed oil, corn, and sunflower oil are already used as alternative raw materials. Various crops (corn, sugar cane, wheat etc) are used for the production of ethanol through fermentation; organic waste is used for the production of methane, biogas, through fermentation; and wood can be used for the production of methanol. All these chemicals can be used for the production of more complicated compounds. A long series of raw materials can also be produced from recycled products. To some extent this is true of petrochemicals, as returned plastic products are processed into chemicals for new products.

Metals such as iron, aluminium, and copper are less controversial as raw materials as they are present in abundance and are non-toxic. However, the extraction of iron and aluminium is combined with environmental impacts. The alternative is to use recycled metals. Thus recycled iron, scrap iron, copper, and aluminium are common as raw materials in industry.

Wood as raw material is renewable. It can be used to the extent that its long-term production rate allows. Still one needs to know that it is not a threatened resource, such as tropical wood. This can be guaranteed if only certified sources are used.

Below we will give a few examples of how selection of raw material can improve the environmental profile of manufacturing.

12.2.3 Hydrogen and Fuel Cells vs Fossil Fuels and Combustion

Fossil oil products are totally dominant as fuel, that is, energy carrier, for many purposes, especially transports. Alternatives now on the market include ethanol and biogas. In the long term hydrogen appears to be an even more interesting alternative energy carrier, as it may be used in fuel cells. Hydrogen and fuel cell technology is in the starting blocks. Fuel cells are now a viable technology that can readily be put into production, and billions are being spent throughout the world on the further development of this technology. Proton exchange membrane fuel cells (PEM) and solid oxide fuel cells (SOFC) appear to be particularly promising areas of fuel cell development. An interesting new development are nano-biological fuel cells that are using the photo synthesis reaction for generating electrons for the electrical circuit.

The largely oil-based European Union transportation sector gives rise to about a third of the total CO_2 emissions. Once the mass production of fuel cells begins, this source of carbon dioxide would be reduced. It requires that automobiles propelled by fuel cells will become competitive in price with conventional cars. In the transportation sector, the first fuel cell driven cars, buses and light motorcycles have already been introduced on the market.

Like the transportation sector, the energy sector is heavily based on the use of fossil fuels. It is estimated that 85% of the world's commercial energy sales are based on fossil sources of energy. A renewable energy system based on hydrogen would preclude any pollution and contamination from the power stations, and the idea of building large entities would become obsolete. Fuel cells are efficient, even in small units, and they are very scaleable. Hence a single installation can easily be expanded to higher output by increasing the number of fuel cell units. Another advantage of fuel cells is that the efficiency is quite high even at a low load. This is particularly important in power production.

However these promising scenarios depend on that hydrogen can be produced in a renewable way. We will now look into this challenge for green chemistry.

12.2.4 Production of Hydrogen Based on Fossil Raw Materials

There are no barriers to the introduction of hydrogen and fuel cells either from a technological perspective or from the vantage point of safety. In fact hydrogen has been produced and utilised industrially for over a hundred years.

Hydrogen can be produced from a number of different sources using different techniques. If hydrogen is produced from coal, oil, or natural gas, the ensuing by-products will be harmful to the environment if they are not handled in an environmentally sound way.

The majority of hydrogen production processes based on fossil raw materials are based on heating up hydrocarbons, steam, and in some instances air or oxygen, in a reactor, producing a mixture of hydrogen, carbon monoxide, and carbon dioxide.

Steam reforming of natural gas is currently the cheapest way to produce hydrogen, and accounts for about half of the world's hydrogen production. Steam, at a temperature of 700-1000 ºC, is fed methane gas in a reactor with a catalyst, at 3-25 bar pressure. In addition to the natural gas being part of the reaction process, an extra 1/3 of natural gas is used as energy to power the reaction.

The formula for the chemical reaction is:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

and for the following "shift reaction":

$$CO + H_2O \rightarrow CO_2 + H_2$$

giving the overall reaction:

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

In this process 4 mol hydrogen is produced for each mol of methane. The percentage of hydrogen from water is 50%.

Autothermal reforming is a combination of partial oxidation and steam reforming. Burning hydrocarbons with reduced amounts of oxygen is called partial oxidation. The term autothermal reforming reflects the heat exchange between the endothermic steam reforming process and the exothermal partial oxidation. The hydrocarbons react with a mixture of oxygen and steam in a "thermo reactor" with a catalyst.

The processes described above produce gas with a high content of carbon monoxide – CO. It is therefore necessary to put the gas through the CO-shift process to increase the conversion to hydrogen. The shift reaction (see earlier) is a two-step process to achieve the most complete reaction between CO and steam. Initially steam is added in a high-temperature step (300-500 ºC), followed by a low-temperature step (200 ºC), with different catalysts in the two steps.

Each of the processes described above produces CO_2 in addition to H_2. In order to produce pure hydrogen gas, the CO_2 and H_2 must be separated. To separate hydrogen and CO_2, it is common to use amine-based absorption processes. This is conventional technology. Methods based on selective membranes or sorbents are under development.

12.2.5 Hydrogen Production Using Renewable Raw Materials

Over 70% of the earth is covered with water. The percent of hydrogen in water, measured by weight, is 11.2%. There is definitely an abundant supply. The advantage in using hydrogen as fuel is that, during combustion, it binds itself to the oxygen in the air, and creates water. Hydrogen is therefore totally renewable, and with this in mind, it could be said that we only "borrow" the hydrogen.

Breaking down water to hydrogen and oxygen is a process that requires energy. Heat, electricity, light, or chemical energy can be used for this purpose. If renewable energy is used, the resulting hydrogen will also be a clean and renewable energy carrier.

Water electrolysis is splitting water into hydrogen and oxygen. An electrolyser is a device for electrolysis. Water is subjected to electrical power and the result is hydrogen and oxygen.

$$2H_2O + \text{energy} \rightarrow 2H_2 + O_2$$

This is the opposite reaction of what happens in a fuel cell.

In the short term renewable electricity, green electricity, will have to come from hydro, wind, or wave power. In the longer term one may rely to some extent on electricity supplied by direct conversion of the solar radiation to electricity.

Case Study 12.1 Soldering of Integrated Circuit Boards – Lead vs Alternatives

Traditionally electronic components are connected on an Integrated Circuit Board by making an electrical and mechanical joint between the components connection pins and the copper connection network to make the electronic circuit, with *soft solder*. A solder is a low temperature melting metal or metal alloy. The most commonly used solder is an alloy of lead and tin.

The EU WEEE (Waste Electrical and Electronic Equipment) and RoHS (Restriction of Hazardous Substances) Directives require that by 2006 all (with a few exemptions) electronic applications have to comply with the elimination of lead in the manufacture. The reason is that lead is a toxic and cumulative poison that causes damage to the nervous system.

This has driven the electronics industry to develop alternative lead-free soldering materials. Most of the alternative soldering materials are alloys between tin and one or more other metals. The first major difference between tin lead (SnPb) and lead free soldering is the melting temperature. The majority of lead free solders require higher melting temperatures (Table 12.1); therefore, the soldering processes must have sufficient heating capacity to solder the assemblies without damaging the hardware.

The second major difference between tin-lead and lead-free soldering is wetting. Lead free solders do not wet as well as tin lead. To improve wetting, nitrogen or more active solder fluxing additives must be used.

Table 12.1 Melting temperatures of soldering materials.

Solder alloys	Melting temperature
SnPb	183 °C
SnBi	138 °C
SnAgCuBi	215 °C
SnAgCu	218 °C
SnAg	221 °C
SnAgCuSb	222 °C
SnCu	227 °C
SnSb	240 °C
AuSn	280 °C

Sources:
Kester, http://www.kester.com/en-us/leadfree/alloys.aspx
EFD, http://www.efdsolder.com/prod_alloys.htm

The sun's light energy can be converted directly into electricity in a single process using Photovoltaic (PV) cells, otherwise known as solar cells. A PV cell is a thin plate of light sensitive material made primarily of silicon, the second most abundant element in the earth's crust, and the same semiconductor material used for computers.

When the silicon is combined with one or more other materials, it exhibits unique electrical properties in the presence of sunlight. Electrons are excited by the light and move through the silicon. This is known as the photovoltaic effect and results in direct current (DC) electricity.

Many PV cells are linked together to create a standard PV module, which in turn are linked together into a PV array. PV modules have no moving parts, are virtually maintenance-free although they should be kept clean and clear of shading, and have a working life of 20-30 years.

12.2.6 Alternatives to Heavy Metals

In the classical chemical industry several heavy metals are important. As the toxic effects of heavy metals have become more obvious, alternatives to the use of heavy metals have developed. A well-known case is the replacement of organic *lead* (tetraethyl lead, $PbEt_4$) as anti-knocking agents in petrol with other compounds. This may be the single most significant step to reduce the toxic effects of heavy metals in our societies. Another case is the replacement of lead in soldering of metals (Case Study 12.1).

Another often cited large-scale alternative to heavy metal use is the replacement of *copper* wires with optical fibres in various electrical equipment.

Cadmium poisoning is increasing in the Baltic Sea region. One way to reduce cadmium use is to replace cadmium containing dies with alternatives. Cadmium may also be removed from phosphorus fertilisers.

The replacement of *mercury* in the process of production of chlorine gas and caustic soda is described below under "processes". Mercury has also been replaced in a series of other products. Thus amalgamates for repairing teeth can today be replaced with either plastics or ceramics. Ceramics, the most appealing alternative as it mimics the natural material hydroxyl-apatite, is still under development.

Below we will describe in some detail alternatives to the use of *chromium* in leather tanning. In this case it is the various toxic chromium compounds which are avoided by using alternative procedures.

12.3 Auxiliary Materials

12.3.1 Solvents

The most commonly used auxiliary materials in the chemical and the chemical-related industries are solvents. According to Toxic Release Inventory (TRI) data, 5 of the top 10 chemicals released or disposed of in the environment were solvents and include methanol, toluene, xylene, methyl-ethyl-ketone, and dichloromethane. With increasing regulatory pressure focusing on solvents, significant attention is being paid to the use of alternatives to traditional solvents. There are a number of general guiding principles in the selection of "solvents".

Use of less solvent. The amounts of solvents used can often be reduced. This is true both in processes as well as for cleaning applications, paints, etc. A reduced amount of solvent in a process as a rule results in physical changes in the product or for the process; viscosities of the process liquids are changed, process flows are reduced etc. This has to be taken into account by making equipment or process alterations, but normally these changes, e.g. replacing pumps, will not entail large costs.

Use of solvents with lower volatility. Often alternative solvents having similar properties, but with higher boiling temperature and/or lower vapour pressure, can be used. A replacement will result in lower emissions to the atmosphere. As in the former case one must be observant about secondary effects in the production process.

Use of less hazardous solvents. Solvents have been developed focusing on safety since they are used in such large volumes. The earliest and most obvious hazards that were addressed in the design of solvent molecules were their ability to explode or ignite. With the greater understanding of the health and environmental effects that could be caused by a large number of solvents, new solvents are being examined for other health hazards as well. Solvents are of particular concern because the likelihood of significant levels of exposure is high. Many solvents, by their nature, have high vapour pressures and, in combination with their use in large volumes, can result not only in the risk of explosions but also in significant exposures, with both acute and chronic health effects. Halogenated solvents such as carbon tetrachloride, perchloroethylene, and chloroform have been implicated as potential and/or suspect carcinogens while other classes of solvents have demonstrated neurotoxicological effects. Especially in these cases finding alternatives are important.

Use of solvents with less environmental impact. There are also a number of environmental implications of the use of large volumes of solvents. The use of solvents has caused both global and local environmental concerns. At the global level, the role of chlorofluorocarbons (CFCs) in stratospheric ozone depletion has led to a global phase-out of these substances from virtually all uses. Other solvents have been found to possess significant global warming potential and are thought to contribute to the overall greenhouse gas loading in the environment. At a more local level, the use of certain volatile organic compounds (VOCs) as solvents and in other applications has generated concern about their ability to contribute to the formation of secondary pollutants such as tropospheric ozone and other photochemical oxidants.

In investigating possible alternative solvents for an application, it is useful to refer to one of the ranking lists that have been developed. An example of such a list is given in Table 9.1 (Chapter 9). It is however important to realise that in replacing a solvent used in a process more factors than the potential hazard of the alternative must be considered.

12.4 Reaction Pathways

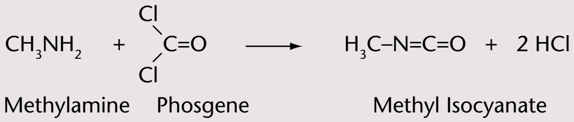
12.4.1 Finding Alternatives to Chemical Reactions

To identify chemical reaction pathways that may lead to better environmental performance of the production process of a product is complex and requires extensive chemical knowledge. But it is essential that a process engineer be able to identify classes of chemical reactions that have potential for environmental improvements.

Addition reactions (A + B → AB), substitution reactions (AB + C → AC + B), and elimination reactions (AB → A + B), for example, all have different degrees of impact on human health and the environment. Addition reactions incorporate the starting materials into the final product and, therefore, do not produce waste that needs to be treated, disposed of, or otherwise dealt with. Substitution reactions, on the other hand,

Case Study 12.2 How to avoid the Bhopal Disaster

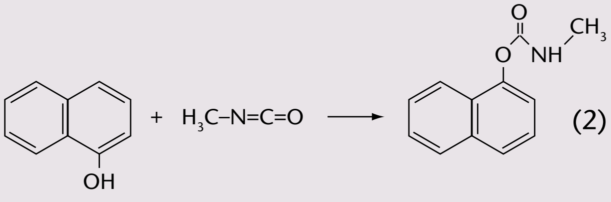
In the Bhopal disaster (Case Study 1.2 in Chapter 1) the pesticide produced was carbaryl or 1-naphthalenyl-methyl-carbamate from methyl amine, phosgene and 1-naphtol with methylisocyanate, MIC, as an intermediate product (Reactions 1 and 2). In the accident 40-45 tonnes of methylisocyanate was emitted due to a run-away polymerisation reaction in a MIC storage tank combined with inadequate safety precautions.



$$CH_3NH_2 + \overset{Cl}{\underset{Cl}{C}}{=}O \longrightarrow H_3C{-}N{=}C{=}O + 2\,HCl$$

(1)

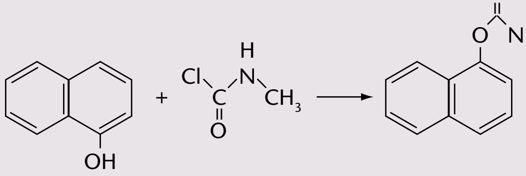
Methylamine Phosgene Methyl Isocyanate



1-Naphtol Carbaryl

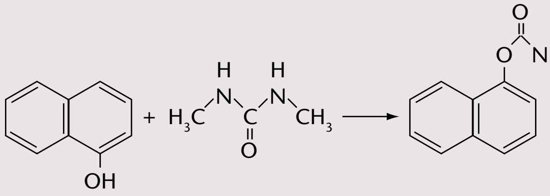
In this reaction sequence, two of the reactants are extremely toxic. Phosgene was used during the 1st World War as a chemical weapon and as such was responsible for the great majority of deaths due to chemical attacks. Methylisocyanate is the substance responsible for the toxic effects of the Bhopal accident.

There are a number of alternative reaction routes that will avoid the formation of MIC. In one such process 1-naphtol is reacted with methylcarbamoyl chloride to yield carbaryl and one mole of HCL (Reaction 3). However, the reactant methylcarbamoyl chloride is also toxic as well carcinogenic.



(3)

A recently proposed reaction uses dimethylurea in a catalytic reaction with 1-naphtol giving carbaryl directly and methylamine as a by-product (Reaction 4). Hereby the problem with toxicity of the raw material is solved.



(4)

However the product itself, being a pesticide, is of course a serious environmental problem. Pesticides can only be avoided by finding other methods to control crop damage.

necessarily generate equivalent quantities of substances as by-products and waste. Elimination reactions do not require input of materials during the course of the reaction other than the initial input of a starting material, but they do generate equivalent quantities of substances that are not part of the final target molecule.

Side reactions, which will generate by-products that need to be separated from the product mix, constitute another problem that needs to be dealt with. It is essential to minimise by-products both for efficiency and economic reasons, and if they are toxic or environmentally problematic, it is even more important. A semi-quantitative tool that a process engineer or chemist can use in evaluating reaction pathways is the concept of *atom and mass efficiencies*. The atom efficiency and mass efficiency characterise the fraction of starting materials that are incorporated into desired products.

Case Study 12.3 Alternative Ways for Chlor-alkali Production

The three dominating ways of producing chlorine and sodium hydroxide are the mercury, the diaphragm, and the membrane methods. In all three a solution of sodium chloride (NaCl) is electrolysed in electrolysis cells using a low-voltage direct electric current. All methods have the same gross formula:

$$NaCl + H_2O \rightarrow NaOH + ½Cl_2 + ½H_2 \qquad \Delta H = 218\ kJ$$

or

$$1.7\ \text{tons salt} + \text{water} + 3300 - 5000\ \text{kWh} \rightarrow 1.13\ \text{tons}\ NaOH + 1\ \text{ton}\ Cl_2 + 0.03\ \text{ton}\ H_2$$

The electrical energy for the electrolytic process has more the character of raw material than electricity. About half of the energy provided is found as chemically bound energy in the products, which can be seen in the reaction enthalpy, ΔH, being 218 kJ/mol or 1710 kWh/ton produced chlorine. It is the energy bound in the chlorine that gives it its remarkable reactivity. The requirements on the process are that the cell and process designs will give:

- Cl_2 and H_2 separate from each other
- Cl_2 free from O_2 and H_2
- NaOH free from NaCl
- Concentrated NaOH

The Mercury process

In the mercury process the anode for the electrolysis is made of carbon, and the cathode is liquid mercury. The reason for the choice of mercury as cathode material is that it enables the separation of the spaces where the chlorine is formed from where NaOH and hydrogen are. This will give a practically chloride-free NaOH and a hydrogen free chlorine. At the same time it effectively suppresses the mixing of hydrogen and chlorine which is a very explosive mixture. The electrolysis reactions are:

$$Na^+Cl^- \rightarrow Cl_2 + Na^+ + e^- \qquad (1)$$

$$Na^+ + nHg(liq) + e^- \rightarrow NaHg_n\ (Na - amalgam) \qquad (2)$$

$$NaHg_n + H_2O \rightarrow NaOH + ½H_2 + nHg\ (liq) \qquad (3)$$

Total:

$$NaCl + H_2O \rightarrow NaOH + ½H_2 + ½Cl_2$$

The reactions are carried out in two steps. The part where the salt solution is electrolysed is called the primary cell, and where the NaOH solution is formed is the secondary cell.

In the primary cell, sodium ions migrate towards the mercury cathode, where they are converted to sodium metal that reacts with the mercury to sodium-amalgam (reaction 2). The chloride ions migrate towards the anode where the chlorine gas is formed (reaction 1). The mercury with the sodium amalgam is circulated to the secondary cell.

In the secondary cell the amalgam is decomposed with water to sodium hydroxide, hydrogen, and liquid mercury (reaction 3). The mercury is pumped back to the primary cell (Figure 12.1a).

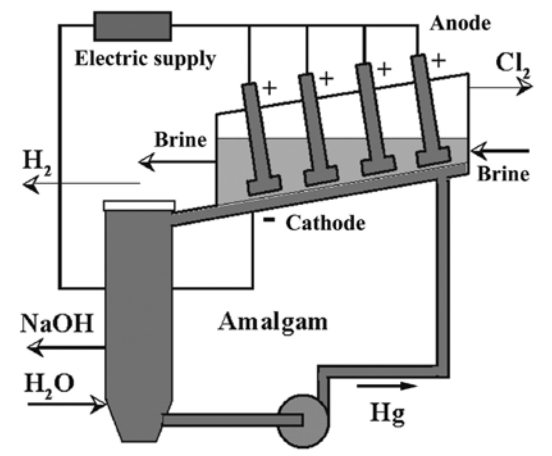


Figure 12.1a *The construction of an electrolysis cell for the mercury method used in the chlor-alkali process. See also the Cleaner Production Practice section.*

The Diaphragm process

In the diaphragm process a warm (70º) almost saturated solution of NaCl is fed to the anode compartment of the electrolysis cell where Cl_2 is formed. The solution flows through the diaphragm into the cathode compartment where H_2 and OH^- are formed. Continuous flow is

As an example of how it is possible to rethink a reaction pathway, the production of the pesticide carbaryl, 1-Naphthalenyl-methyl-carbamate, in an alternative way is described in Case Study 12.2. The classical way of synthesis involves very toxic compounds. It is this production that led to the disaster in Bhopal in India in 1984 (Case Study 1.2 in Chapter 1).

A recent example of how changing one reaction in a reaction sequence can cascade through the entire process pathway is the development of a new synthetic route for the production of ibuprofen. Ibuprofen is the active ingredient of a number of analgesic (pain reliever) drugs. The world production of ibuprofen exceeds 13,500 tons per year.

The traditional process for production of ibuprofen consists of a six-step synthesis with an atom efficiency of 40%, which means that only 40% of the raw materials for the process appear in the final product. The remaining 60% are undesired

achieved by hydrostatic pressure, different liquid levels in the two compartments. The diaphragm separating the anode and the cathode compartments allows ions to pass through the diaphragm but stops a mixing of hydrogen and chlorine gases. The flow direction from anode to cathode compartment was chosen to limit the migration of hydroxide ions into the anode compartment. The solution leaving the electrolysis cell contains ca 12% NaOH and 16% NaCl. The solution is evaporated in a crystalliser where NaCl is precipitated, yielding a final product with about 50% NaOH and 1% NaCl.

The Membrane process

In the membrane process the anode and the cathode compartments are separated by an ion-selective membrane that is impregnable by negatively charged ions like Cl^- and OH^-. The main reactions are:

Anode: $Cl^- \rightarrow ½Cl_2(g) + e^-$

Cathode: $H_2O + e^- \rightarrow OH^- + ½H_2(g)$

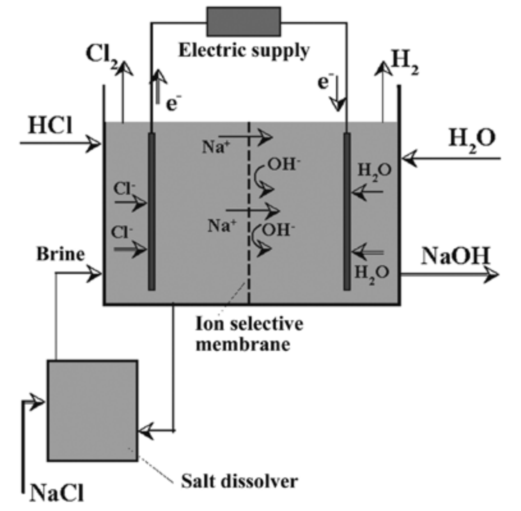


Figure 12.1b *The construction of a electrolysis cell for the membrane method used in the chlor-alkali process. See also the Cleaner Production Practice section.*

The main objective with the membrane is to hinder all side reactions. This enables the production of a practically chloride-free NaOH. The membrane technology also allows the cells to be made very compact. A plant with the membrane process takes up a floor space only a fraction of that required by a mercury process with the same production capacity (Figure 12.1b).

A comparison between the three processes

The Mercury process

This method yields a concentrated NaOH solution (ca 60%) that is chloride free. This entails major economic advantages. The hydrogen is free from other gases, but the chlorine can be contaminated with oxygen and hydrogen gas. But environmentally the mercury method is unacceptable since, despite large efforts towards process encapsulation and improved separation and recovery methods, there are still small but unacceptable emissions of Hg from the process.

The Diaphragm process

It is the technically least complicated method but requires extensive purification and concentration of the products. The diaphragms in the electrolysis cells are made of asbestos fibres which is a serious environmental and health risk. The process gives an almost hydrogen free chlorine gas but a contamination of oxygen is difficult to completely avoid. The NaOH produced is about 50% and the residual chloride concentration is about 1%.

The Membrane process

This is the latest development of the technology of chlor-alkali production. It has technical advantages over the mercury method and economic advantages compared to the diaphragm method. The major difficulty is finding a suitable membrane material. The most commonly used membrane is currently a thin ion-selective membrane based on a matrix similar to PFTE (Teflon). The gases produced have at least the same purity as in the diaphragm method. The NaOH is about 40% with a chloride concentration of no more than 50 ppm.

by-products and waste. The new process has only three catalytic steps and an approximately 80% atom utilisation, which easily can be increased to 99% if the recovered by-product, acetic acid, is utilised. In addition the new process saves 20-40% of the total energy required in the traditional process. All starting materials are either converted to products, recovered as by-products, or completely recycled in the process, virtually eliminating the production of waste.

12.4.2 Finding Alternatives to Chemical Processes

A number of industrial production processes may also be remade completely. There are several examples where new processes have been developed using e.g. new membrane technologies, heating with microwave radiation, separation using chromatography, etc. A creative approach is needed to find new alternatives, and no routine methods for this development seem to be available.

The conventional process for production of chlorine gas and sodium hydroxide, i.e. caustic soda, from sodium chloride, i.e. ordinary salt, is the mercury method. Here chlorine gas and caustic soda is produced by electrolysis of a concentrated solution of sodium chloride. The positive electrode (the anode) made of mercury dissolves metallic sodium produced in the process to form sodium amalgam. The amalgam is later transformed into (recycled) mercury and caustic soda. Even if the mercury is recovered, a significant amount of mercury leaks into the surroundings and is a major source of pollution. A chlorine alkali factory uses hundreds of tonnes of mercury.

Today alternative methods are used for production of chlorine and sodium hydroxides have found increased use. The most common are the diaphragm method and the membrane method, which are both mercury free. A disadvantage is that the caustic soda produced is less concentrated.

The description of the two technologies are found in Case Study 12.3 and in the Cleaner Production Practices section.

12.5 Biotechnology

12.5.1 The Promises of Biotechnology

Industrial production is too often characterised by use of organics solvents, high temperature, long reaction times, and not very good yields. This is very different from the way that the biological cell produces materials. Biological reactions occur mostly in a water environment, at room or body temperature, and with a very high yield. These reactions are typically catalysed by enzymes, which by themselves provide the hydrophobic environment that may be required for typical organic reactions to take place.

Biotechnological alternatives to traditional chemical processes are being developed and more and more introduced in large-scale production processes. Micro-organisms are being used in industrial production to produce many important chemicals, antibiotics, organic compounds, and pharmaceuticals. Using living organisms as chemical synthesis factories reduces many of the risks and complexities of industrial syntheses, allowing costly and polluting raw materials to be replaced, and

Figure 12.2 The mercury cell hall in the Skoghall chlor-alkali industry. *This hall houses 200 tonnes of metallic mercury. The production of chlorine from electrolysis of sodium chlorine solution was changed from using mercury cells to the so-called membrane method in 1987. Still there are two factories using the mercury cell method in Sweden and some 60 in Europe, many of them in Russia, 40 in Germany and 2 in Poland. These factories were the largest mercury polluters as metallic mercury was lost from the cells, which were yearly receiving large refills of the metal. Today the refills are reduced to 100 tonnes/year in western Europe, of which at least 10 tonnes are lost to air, water and products. In Sweden, mercury cells will be outlawed in 2010. (Photo: Courtesy of AkzoNobel Industries)*

the introduction of less expensive processes. The by-products of biosynthetic reactions are usually less toxic and hazardous than those of traditional industrial chemical reactions. The transition to cleaner industrial manufacturing does not necessarily require completely new and costly plant and equipment investments. Often, an introduction of biotechnological stages or a modification of an existing plant will achieve the desired result. However, we still await the introduction of biotechnology on a larger scale.

12.5.2 The Components of Biotechnology

Biotechnology usually refers to three distinct types of technologies.

Firstly, it refers to the *cultivation of biological cells* for technical purposes. Most common by far is the use of micro-organisms, bacteria and yeast cells. Classical biotechnological processes include the fermentation of sugar to produce alcohol, the oxidation or ethanol to produce acetic acid, and fermentation of organic material to produce methane. However a number of other processes rely on the use of biological cells. Chemicals produced on a large scale using bacterial processes include e.g. lactic acid, citric acid, and penicillin. The tanks used for the fermentations vary from hundreds of litres for special chemicals in the pharmaceutical industry to hundreds of cubic meters for bulk chemicals. Chemicals may also be produced in cultures of higher cells, both from animals and plants, e.g. in the pharmaceutical industry.

Secondly, biotechnology refers to the genetic change of cells, also called *genetic engineering*. With today's very highly developed DNA technologies, it is possible to make directed genetic changes in cells, and to introduce or block specific genes. Micro-organisms have been cultivated as special strains for very many years. More recently it has been possible to modify plant cells by genetic engineering; the resulting variants of plants are then referred to as Genetically Modified Organisms (GMOs). In animals the genetically changed individuals are often referred to as transgenic animals. Practically all micro-organisms used in biotechnology have been genetically fine-tuned for their purpose. Modified plant cells can be used for the production of several new components, which later have to be purified from the plant after harvest. Products from transgenic animals used for production, so-called genetic farming, include complicated bioproducts such as proteins, e.g. blood coagulation factors. Most of these are today either produced in cultivated animal cells or in micro-organisms.

A third very important part of biotechnology is the *use of isolated bio-molecules*, especially enzymes, for technical purposes. Enzymes are very sophisticated biocatalysts. Enzymes may be isolated from all sources mentioned above, especially from bacteria. Some of them are used in bulk without much purification, such as proteases for dissolving dirt in washing of clothes, or beta-galactosidase to reduce the lactose content in milk. Others are used as attached, immobilised, to a surface. The most common materials for this immobilisation are those used in chromatography. The resulting chromatographic column will then function as a bioreactor, conducting the process that the immobilised enzyme catalyses.

Enzymes are normally known as very delicate molecules, which cannot in any way be treated as the traditional chemicals used in the chemicals industry. However, more recently it has been possible to change them to survive the conditions typical of technical processes in two ways. One is that enzymes are isolated from bacteria found in hot springs. These are adapted to stand some 100°C heat and low pH, often close to 2. Another way is to genetically modify the enzymes to make them more resistant to tough conditions. This has been done e.g. for the proteases used in detergents.

Biotechnology is far from fully developed. The potential of biological methods to improve the performance of the chemical industry is huge, and systematic efforts to harvest this immense source of new environmentally friendly and non-toxic processes are just in their infancy. Ethical issues connected with this development exist, however, and should be considered carefully.

12.5.3 Textiles and Leather – Chromium vs Enzymatic Tanning

Leather tanning is the process of converting raw hides or skins into leather. The objective of the tanning process is to treat the hides and skins in such a way that the material is prevented from decaying, made resistant to wetting, and kept supple and durable.

During the tanning operation, collagen, the principal protein of the skin, will fix a tanning agent to its reactive sites, thus stopping the biological decaying of the material. The products which are capable of being fixed to skin to achieve tanning are many and varied.

Leather tanning is a general term for the numerous processing steps involved in converting animal hides or skins into finished leather. Figure 12.3 presents a general flow diagram for the leather tanning and finishing process. The first steps of the process, trimming, soaking, fleshing, and unhairing, are operations in which the skins are prepared for the actual tanning process.

The tanning process itself includes the process steps bating, pickling, tanning, wringing, and splitting. Finally the material go through finishing processes that include conditioning, staking, dry milling, buffing, spray finishing, and plating.

In traditional chrome tanning, the skins and hides are washed and re-moisturised, remaining meat and fat is cut out and the hair on the outside of the skin is removed by soaking in a lime and sulphide solution, which either loosens or dissolves the attached hair. In some operations, the hair is only loosened through the caustic action of the lime, with the hair removed mechanically, followed by washing and drying. However, the more common approach for hair removal is to completely dissolve the hair and discharge it to the wastewater stream.

Following the pre-tanning processes the actual tanning starts with de-liming and bating in which non-leather-forming proteins are removed in order to give the leather softness, stretch, and flexibility properties. This is done by soaking the skins and hides in a solution of an ammonium salt and proteolytic enzymes. In the subsequent pickling step the acidity of the hides are adjusted by treatment with a brine solution and sulphuric acid.

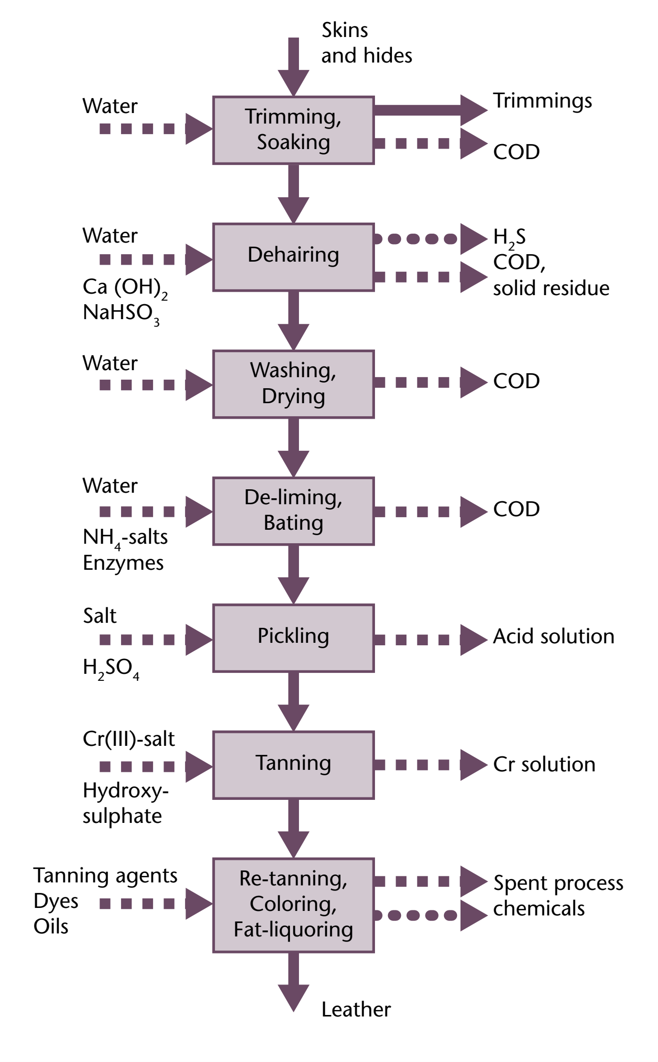


Figure 12.3 *Process flow diagram of leather tanning using chromium III as the tanning agent [UNEP, 1996].*

In the chromium tanning step chromium (III) hydroxysulphate reacts with the collagen in the hides, thereby preserving it from deterioration.

Another series of wet operations gives the leather the colour and other properties desired in the finished material. The tanned hides are placed into another drum for re-tanning, colouring, and fat-liquoring. Re-tanning is a second, shorter tanning operation normally using a tanning agent other than chromium, such as vegetable or synthetic tannins, formaldehyde or iron and zirconium salts. After the re-tanning, a pigment is added in order to dye the leather to the desired colour, after which the hides are taken out and wrung to remove excess moisture. Next a mixture of oils is added. This operation, called fat-liquoring, helps to produce the desired softness. Finally the leather is dried and physically conditioned.

12.5.4 Use of Enzymes for Leather Tanning

Several of the process steps in the traditional tanning process can be improved by replacing chemicals used with enzymes [Kamini, 2005]. In the tanning process the formation of hazardous pollutants is significantly greater in the pre-tanning stages than in the post-tanning ones. The chemicals mainly responsible for pollution in the pre-tanning are lime, sodium sulphide, and caustic soda as well as salt and de-greasing solvents. By introducing enzymatic treatment of the hides in the pre-tanning stages substantial reduction of hazardous pollutants is achieved. The type of enzymes used is proteolytic enzymes, proteases. By careful selection of specific strains of enzymes for the different pre-tanning stages, it is possible to produce non-polluting, easily biodegradable effluents. In the dehairing step the use of proteolytic enzymes instead of chemical treatment with lime and sodium sulphide will only digest the cells of the root section of the hairs, leaving the keratinised (hornified) parts unaffected, thereby enabling the recovery of hair with good quality and strength. Enzymatically dehaired skins also show better strength properties and greater surface area. The enzymatic action during dehairing, to some degree, also digests non-leather forming proteins as albumins, globulin and mucoids, and split collagen fibres. Because of this, separate bating and de-liming steps will be superfluous or at least greatly simplified.

Soft leathers such as glove and clothing leathers have to be de-greased. The traditionally used detergents and hazardous chlorinated organic solvents as perchloroethylene and trichloroethylene can be substituted with water-soluble enzyme lipases. The advantages of using enzymes for de-greasing are the elimination of solvents, reduction in surfactants, and possible recovery of valuable by-products.

In the tanning process, Chromium (III) is the most common tanning agent. In traditional chrome tanning the utilisation factor of Chromium is only about 66%. By introduction of high-exhaustion tanning and in-process chromium recycling the utilisation factor can be increased up to 98%. High-exhaustion tanning is achieved by increasing the reactivity of the collagen and increasing the penetration of chrome tannin's introduction of reactive groups into the chrome tannin complexes, so called masking, This is achieved by using additives or auxiliary preparations such as dicarboxylic acids, polycarboxylates, polyamids, oxazolidine, and others, together with optimisation of process parameters such as chrome concentration in the tanning liquid, temperature, pH, and reaction time.

The spent tanning liquid can be directly recycled in the process, either for pre-tanning or, after filtering, for preparation of fresh tanning liquid, thereby further reducing the amount of chromium emitted from the process.

Study Questions

1. Describe briefly the notion of green chemistry and list the original four IUPAC principles of green chemistry.
2. List and explain as many as possible of the 12 generally adopted principles of green chemistry.
3. How do you select raw materials in green chemistry? Give examples of "green" raw materials.
4. Explain why hydrogen is a particularly suitable energy carrier in green chemistry, and how it may be produced from non-fossil resources.
5. Compare the fuel cell and the combustion motor from an environmental perspective.
6. Give examples of how toxic heavy metals have been replaced by redesigning chemical processes.
7. Give some important principles used to find improved alternatives to chemical reactions.
8. Explain how mass efficiencies and atom efficiencies can be improved in a chemical process, and why it is important.
9. Give examples of how green chemistry based chemical reactions improve the economy, resource management, and environmental performance or of a reaction.
10. What is included in biotechnological processes? Describe and give examples of the three main technologies used.

Abbreviations

CFCs	ChloroFluoroCarbons.
DC	Direct Current electricity.
IUPAC	International Union of Pure and Applied Chemistry.
MIC	Methyl Iso Cyanate.
OECD	Organisation for Economic Cooperation and Development.
PEM	Proton Exchange Membrane fuel cells.
PFTE	Poly Tetra Fluoro Ethylene (common trade name Teflon).
PV	PhotoVoltaic cells.
R&D	Research and Development.
RoHS	Restriction of Hazardous Substances (EU directive).
SOFC	Solid Oxide Fuel Cells.
TRI	Toxic Release Inventory.
VOCs	Volatile Organic Compounds.
WEEE	Waste Electrical and Electronic Equipment (EU directive).

Internet Resources

Organisation for Economic Cooperation and Development (OECD) – Environment Directorate/Chemical Safety
http://www.oecd.org/ehs/

Green & Sustainable Chemistry Network
http://www.gscn.net/

U.S. Environmental Protection Agency (EPA)
– Green Chemistry
http://www.epa.gov/greenchemistry/

American Chemical Society (ACS)
http://www.chemistry.org/

The Royal Society of Chemistry (RSC)
– Green Chemistry Network
http://www.chemsoc.org/networks/gcn/

Interuniversity National Consortium
“Chemistry for Environment” (INCA)
http://venus.unive.it/inca/

International Union of Pure and Applied Chemistry (IUPAC)
http://www.iupac.org

First International IUPAC Conference on Green Chemistry, September 2006.
http://www.chemistry-conferences.com/2006/09/10%20-%2015%20IUPAC%20Conference%20on%20Green%20Chemistry%20(Dresden%20-%20DE).htm

Greenchem
– A research programme at Lund University, Sweden
http://www.greenchem.lu.se/

13

Promoting Cleaner Production

13.1 Supporting Cleaner Production

13.1.1 The Origin

The concept of Cleaner Production (CP) has its roots in the early 1970s. This is when international and national organisations started to realise the need not only to deal with already generated waste and emissions, but rather to prevent them at the source before they had been produced.

Nowadays cleaner production is a widely recognised and proven strategy for increasing the efficiency of natural resource use and minimising wastes. UNEP has defined cleaner production as:

A continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment.

Cleaner production can be applied to the processes used in any industry, to the products themselves and to various services provided in society.

Implementing cleaner production strategies has been described in earlier chapters in terms of measures in production, product design, and management. However there is another side to it as well, namely, the contexts in which CP is argued for or asked for. It consists of:

- Promotion and information.
- Capacity building, and development of institutions.
- Influences from market forces.
- Actions of authorities; legal measures and taxation.
- Economic support of authorities and others; subsidies.
- Cooperation with stakeholders.
- Education and training.

These different aspects of cleaner production will be dealt with in this final chapter.

In this Chapter

The description and structure of the chapter is mainly based on the UNEP document on Government Strategies and Policies for Cleaner Production [Ashford, 1994].

13.1.2 Capacity Building

Building infrastructure in industry, government, NGOs, academia and other cleaner production supporting institutions is essential for achieving advances in both the development and promotion of cleaner production. This capacity building for cleaner production should address the following needs:

- A common understanding of the cleaner production concept.
- Integration of the cleaner production concept in policies and operations of all enterprises.
- Education and training at all levels.
- Development of indicators to measure progress in cleaner production implementation.
- Incorporation of the cleaner production concept in the government policy framework.
- Providing information about both the technology involved and the environmental management tools needed.
- Integration of the environmental dimension in education (in schools, universities, and engineering and business management courses).
- Assisting key institutions in the development/delivery of the above.

13.1.3 Promotion

Promotion of cleaner production is an essential part of the work needed in a country to introduce CP strategies. Industrialists are most often sceptical to CP methods to start with. Thus good examples, description of economic advantages, and a host of information strategies are needed to get started.

Cleaner production promotion has to cover a range of related activities. Most important among these are:

- Awareness raising campaigns targeting industry, government, financing institutions, academia, and NGOs.
- Compilation and dissemination of up-to-date information on cleaner production practices and technologies in a user-friendly manner, addressing specific local/regional/national needs.
- Human resources development of personnel at various levels in the stakeholder groups.
- Demonstration projects in different sub-sectors and locations in the country especially in SMEs.

13.2 Promotion of Cleaner Production

13.2.1 UNEP's International Declaration on Cleaner Production

UNEP's International Declaration on Cleaner Production (IDCP) (Box 13.1) is a voluntary but public commitment to the strategy and practice of cleaner production. The declaration outlines a set of principles, which, when implemented, will lead to increased awareness, understanding and ultimately, greater demand for cleaner production. For cleaner production advocates, the declaration is a tool to encourage governments, companies and organisations to adopt and promote the strategy.

It was publicly introduced during the High-Level Cleaner Production Meeting CP5, in 1998 at Phoenix Park, South Korea, with 67 inaugural signatories. In December 2006 about 1,700 organisations were listed on UNEP's register of high-level signatories, including 89 on the government level.

UNEP's International Declaration on Cleaner Production is an important tool for securing commitment towards cleaner production capacity building.

Specific goals of the declaration are:

- To encourage support for the adoption of cleaner production activities as a prudent economic investment.
- To renew and intensify the commitment to cleaner production by industrial and governmental leaders to the extent that they acquire "ownership" and become the local promoters of this strategy.
- To promote further international cooperation and technology transfer that will maximise the results and synergies between cleaner production initiatives worldwide.
- To diversify and broaden the awareness beyond the typical users of cleaner production thereby increasing the overall demand.
- To disseminate the awareness of cleaner production as a preferred solution to the unsustainable production and consumption of goods and services, in a way that society and community leaders understand exactly how this strategy works and the relevant benefits it provides.

13.2.2 Networks and Partnerships for CP Promotion

Since CP is a cross-cutting, multi-sectorial issue a collaborative approach should be applied at all hierarchical levels (state, municipalities, etc.) to integrate preventive environmental strategies and efficient resource management in public policies.

The *Sustainability Web Ring* is a service of the Sustainable Development Communications Network (SDCN). This Internet tool allows users to navigate easily between web sites that deal with the principles, policies, and best practices for sustainable development.

EnviroLink is a major site with extensive listings and many support services for NGOs. It maintains the Sustainable Business Network, which is a good resource for finding potential partners on projects.

The Regional Environmental Centre (REC) for Central and Eastern Europe has links to many NGOs in that region as well as Western Europe. REC is located in the outskirts of Budapest.

Law and Environment Eurasia Partnership (LEEP) is a grassroots non-profit organisation, formed by NGOs in Central Asia. LEEP's goals are to improve existing environmental

Box 13.1 International Declaration on Cleaner Production

We recognise that achieving sustainable development is a collective responsibility. Action to protect the global environment must include the adoption of improved sustainable production and consumption practices.

We believe that cleaner production and other preventive strategies such as Eco-efficiency, Green Productivity and Pollution Prevention are preferred options. They require the development, support and implementation of appropriate measures.

We understand cleaner production to be the continuous application of an integrated, preventive strategy applied to processes, products and services in pursuit of economic, social, health, safety and environmental benefits.

To this end we are committed to:

Leadership	**Using our influence**
	to encourage the adoption of sustainable production and consumption practices through our relationships with stakeholders.
Awareness, education and training	**Building capacity**
	by developing and conducting awareness, education and training programmes within our organisation.
	by encouraging the inclusion of the concepts and principles into educational curricula at all levels.
Integration	**Encouraging the integration of preventive strategies**
	into all levels of our organisation.
	within environmental management systems.
	by using tools such as environmental performance evaluation, environmental accounting, and environmental impact, life cycle, and cleaner production assessments.
Research and development	**Creating innovative solutions**
	by promoting a shift of priority from end-of-pipe to preventive strategies in our research and development policies and activities.
	by supporting the development of products and services which are environmentally efficient and meet consumer needs.
Communication	**Sharing our experience**
	by fostering dialogue on the implementation of preventive strategies and informing external stakeholders about their benefits.
Implementation	**Taking action to adopt cleaner production**
	by setting challenging goals and regularly reporting progress through established management systems.
	by encouraging new and additional finance and investment in preventive technology options, and promoting environmentally-sound technology cooperation and transfer between countries.
	through cooperation with UNEP and other partners and stakeholders in supporting this declaration and reviewing the success of its implementation.

Source: The declaration is published on the net (http://www.uneptie.org/pc/cp/declaration/) where it is also possible to sign the declaration. In December 2006 the number of regional and national signatories totalled over 1,700!

legislation, policies, and enforcement in Central Asia, develop conservation projects, provide information to local NGOs, and encourage Western support for civil society in Central Asia.

Environmental Defence is a US-based national non-profit organisation engaged in many partnerships with different industry groups and communities with the objective to create innovative, equitable and cost-efficient solutions to environmental problems. Its website has extensive information.

Business Partners for Development is a World Bank website with many examples of successful partnerships between interest groups and industry. The NGO-Business Environmental Partnership programme provides examples of NGOs working in collaboration with the urban industrial business sector.

13.2.3 International Organisations

Many international organisations are involved in preventive policy development and actively participating in the programmes focusing on cleaner production and preventing pollution in Europe.

The *United Nations Environment Programme* (UNEP) through its Division of Technology Industry and Economics, located in Paris, is one of the main international players. Every two years, UNEP organises global High-Level Seminars on CP. UNEP is also the initiator of the International Declaration on CP. Furthermore, it has carried out work on CP financing, and has been coordinating the worldwide programme of National CP Centres, together with UNIDO.

The UNEP Industry and Environment Unit has promoted cleaner and safer industrial production and consumption patterns since 1975. Coordinating action with all UNEP units, UNEP-IE reaches out to its partners in business and industry, to the public sector, and to international and non-governmental organisations.

The Cleaner Production Programme has been a UNEP's main focus since its inception in 1989. Strongly endorsed by Agenda 21, cleaner production helps industry and governments develop their competitive economic and ecological edge. The programme strives to achieve its objectives by focusing its activities in two areas: information transfer and capacity building.

The *United Nations Industrial Development Organisation* (UNIDO) located in Vienna, initiated together with UNEP the worldwide National CP Centre Programme in 1994. UNIDO is responsible for overall administration, local liaison, and provision of industrial technical expertise, especially for sectorial industrial demonstrations. Both organisations are also providing expertise on training, information and policy analysis.

The Environment Division of the *Organisation for Economic Cooperation and Development* (OECD) in Paris has been involved in promoting sound environmental management practices in many member and non-member countries. The OECD coordinated the drafting of a Policy Statement on Environmental Management in Enterprises in Central and Eastern Europe and NIS. The Working Party on Pollution Prevention and Control has published a Guide on Strategic Waste Prevention.

The *World Business Council for Sustainable Development* (WBCSD) is the organisation that developed the concept of eco-efficiency. WBCSD has implemented various regional eco-efficiency initiatives, including many programmes in Europe. Headquartered in Switzerland, WBCSD is a coalition of some 150 international companies declaring commitment to, and involvement in work on environmental protection, social equity and economic growth. Member companies come from more than 30 countries and 20 major industrial sectors.

The *EU Institute for Prospective Technological Studies* in Sevilla, Spain, is one of the eight research institutes of the European Commission, which make up the Directorate General Joint Research Centre. In addition to its work on sustainable development strategies for Europe, the IPTS is home of the European IPPC Bureau which provides direct support to the implementation of the Directive on Integrated Pollution Prevention and Control. Sector-specific documents (called BREF's) present Best Available Techniques applicable in various industrial sectors, and provide guidance both to industry and to the regulators concerning state-of-the art environmental protection measures.

The *European Environment Agency* (EEA) in Copenhagen is the European Union's specialised environmental institution. The EEA seeks to provide timely, relevant and reliable environmental information to the policy makers and the public. The Agency's tasks also include disseminating best practice in environmental protection and technologies. Through its Enviro Windows platform, the EEA manages a web portal with information on cleaner production.

The *European Roundtable on Cleaner Production* is a non-profit organisation that provides a platform to stimulate, develop and disseminate new initiatives to foster implementation of cleaner production concepts, and approaches within local and regional sustainable development initiatives.

The *Factor 10 Institute* and the *Wuppertal Institute* are the driving forces behind the concept of reducing resource use without reducing the quality of life; they argue for a substantial dematerialisation, reducing global material flows, and the concept of industrial ecology.

The *International Institute for Industrial Environmental Economics* (IIIEE) at Lund University, Sweden, is one of Europe's leading academic institutes involved in pollution prevention. Since its foundation in 1994, the Institute has disseminated knowledge and practical experience on the application of preventive approaches in environmental and industrial policy. In addition to offering an MSc. programme in cleaner production, the staff of the Institute conducts CP-related projects in Europe and beyond.

Preventive Environmental Protection Approaches in Europe (PREPARE) is an informal, independent European network of experts in the field of cleaner production and sustainable development. The members come from research institutions, administration, governments, industry, and international organisations. The working groups include a group on cleaner production and EMS, and another one on good environmental practices.

An overview and contacts to numerous other national-level CP institutions and organisations in Europe and the former Soviet Union can be found in UNEP's Guide to Sources of Information on CP. There are also many other organisations worldwide which make up the global CP network.

13.2.4 National Cleaner Production Centres

UNIDO and UNEP have joined forces to help introduce cleaner production in developing countries and countries in transition. The UNIDO/UNEP Programme for National Cleaner Production Centres (NCPCs) is a unique programme of capacity development to help achieve adoption and further development of the cleaner production concept at the national level.

The Centre establishment depends upon the level of local support and commitment, largely from the organisation that volunteers to host the centre (host organisation). The host institution is selected so that the in-country institution has the ownership of the project.

Most Centres have been established with initial funding from donors supporting the UNIDO/UNEP programme. Few donors accept to continue funding a Centre for more than three years. Therefore, centres have a "window of opportunity" of three to five years in which to create a sufficient market for themselves in cleaner production to become financially sustainable after the initial funding finishes. Most of the first generation centres have successfully made the transition to financial sustainability, financing their activities from various sources such as:

Domestic funding – national or local government grants or contracts.

Operational income – cleaner production assessments, training programmes, consultancy fees, membership fees, publication sales, etc.

International funding – other multilateral/bilateral agencies – World Bank projects, bilateral assistance, etc.

Since late 1994, 31 National Cleaner Production Centres and Programmes have been established in 25 different countries.

The NCPC's primary beneficiaries are industry and governments. The Centres work with industry to show the economic and environmental benefits of cleaner production (the bottom up approach), while working with governments to set a policy framework to reward cleaner production (the top down approach).

The purpose of an NCPC is to promote the cleaner production strategy in enterprises and government policies, in har-

Box 13.2 The Mission of the National Cleaner Production Centre in Hungary

The Hungarian Cleaner Production Centre has the following objectives:

- To contribute to sustainable industrial development in Hungary.
- To improve the environmental performance and competitive advantage of industry through cleaner production.
- To increase nation-wide awareness of cleaner production in industry.
- To therefore reach an overall reduction of environmental pollution.

The Centre works on a non-profit basis and assists companies, consulting firms and policy-makers to understand the concept of cleaner production and to put it into practice.

The Centre intends to reach these objectives concentrating its activities on the following fields:

- Organisation and co-ordination of in-plant demonstration projects in cleaner production assessments, and the dissemination of the results among other companies. Special emphasis is given to solving environmental problems of small- and medium-size companies.
- Building up and developing information systems about cleaner production and environmentally benign technologies and new developments in this field. The Centre aims at disseminating this information throughout the country.
- Developing educational programmes, organising conferences, training and courses in preventive environmental protection.
- Giving policy advice and preparing environmental policy papers to help expand the use of preventive technologies.

Source: Hungarian Cleaner Production Centre, Report of Activities, 1998-2000.
http://hcpc.uni-corvinus.hu/exp_eng/index_exp.htm

mony with local conditions, and to develop local capacity to create and meet cleaner production demands throughout the country. The Centres (and the personnel trained by them) do not deliver ready-made solutions; rather they train and advise their clients on how to find the best solutions for their specific problems.

The objectives of one of the NCPC's, the Hungarian Cleaner Production Centre, is given in Box 13.2.

Basic services offered by National Cleaner Production Centres are: raising awareness of the benefits and advantages of cleaner production, e.g. through in-plant Cleaner Production Demonstration Projects; training local experts and building local capacity for cleaner production; Providing individual enterprises with technical assistance in cleaner production, e.g. cleaner production assessments, energy efficiency audits, establishment of environmental management systems, occupational safety and health assessments, life cycle assessment; Help in preparing project proposals for cleaner production investments; Disseminating technical information; providing policy advice to national and local governments.

13.3 Policy Instruments to Promote Cleaner Production

Environmental policy instruments are commonly classified in regulatory, market-based or information-based instruments.

13.3.1 Policy Frameworks

A supportive *policy framework* is of great importance to any new concept to become institutionalised and incorporated into routine business. UNEP writes the following:

"A cleaner production policy framework does not refer to simply making a few provisions (tax rebates, permitting provisions, etc.) in the existing system. Nor does it mean enacting a brand new, stand alone cleaner production Act. It requires interweaving the concept of preventive strategies in all facets of the governmental policy framework to make it uniformly supportive and favourable to the cleaner production concept.

It requires a change in thinking in how policies are formulated and implemented. In essence, it requires a paradigm shift – from the current reactive "cure" approach to a pro active "preventive" approach. Pollution and environmental management in the preventive approach get internalised and integrated into the developmental process. Cleaner production strategies would thereby be integrated in various policies such as environmental, industrial, resource pricing, trade, fiscal, educational and technology development policies."

There is a wide range of policy instruments that governments may use to stimulate the adoption of cleaner production. Environmental policy instruments are commonly classified in regulatory, market-based or information-based instruments. It is important that policy-makers select the right mix of these instruments given the circumstances within each country.

Success of cleaner production in the industrial sector generally is analysed and guided in the frame of implementation of the complete system consisting of four groups of factors as following [Randmer and Truusa, 2002]:

- Legal framework to set up regulations and standards to limit and restrict negative environmental impact.
- Economic instruments (both "positive" and "negative" incentives) guiding industries to achieving environmental objectives set in the regulations.
- Economic stability both on macro and micro levels to attract foreign and domestic investments and implementation of new technologies.
- Cultural and behaviour changes in the business community to introduce a pollution preventive (cleaner production) approach first rather then a re-act approach to treat pollution already generated. Everyone knows that to change thinking is difficult and takes time, and here positive motivation pay-off better than punishment.

13.3.2 Regulatory Instruments

Since the inception of environmental policy, the predominant strategy for pollution control has generally been through the use of regulatory instruments. Usually, a public authority sets standards, and then inspects, monitors and enforces compliance to these standards, punishing transgressions with formal legal sanction. These regulations may, for example, specify an environmental goal – such as the reduction of carbon dioxide emissions by a specified date – or they may mandate the use of a particular technology or process. Such an approach gives the authority maximum possibilities to control where and how resources will be allocated. It also allows the authority to predict how much the pollution levels will be reduced.

There are many situations where regulatory instruments are the most appropriate and effective to achieve a specified environmental result. This is especially true for the control of hazardous substances.

National and local governments may establish formal cleaner production strategies or programmes. These may be frameworks for the coordinated implementation of subsequent, more specific policy instruments. Through a material choice, or "substitution" principle, a ban or defined phase-out schedule may be imposed for a particular product or substance.

By making the manufacturer responsible for the product's life cycle by Extended Producer Responsibility environmental improvements may be achieved throughout the life cycle of a product. As part of their permits requirements, companies may be forced to undertake cleaner production audits of their plants. Companies may be required to implement an environmental management system and to publish information on their environmental performance. An effective means of promoting cleaner production practices is the establishment of waste minimisation clubs. Governments may finally stimulate cleaner production measures by providing grants, loans and favourable tax regimes, and/or by supplying targeted technical assistance to industrial companies.

13.3.3 Legislation

So far it is only China that has introduced legislation on CP. Since 2003 there is a Cleaner Production Promotion Law enforced in the People's Republic of China. The objectives of this law are to promote cleaner production, increase the efficiency of the utilisation rate of resources, reduce and avoid the generation of pollutants, protect and improve environments, ensure the health of human beings and promote the sustainable development of the economy and society.

According to this law any units or individuals engaged in activities relating to production or provision of services and their corresponding management agencies must organise and implement systems for cleaner production.

13.3.4 Specified and Negotiated Compliance

In industrialised countries, development of environmental quality has been built on regulation and authority control. Precise and specific demands have been imposed on industry or any activity, with little bargaining allowed and few exceptions made. This governmental control has been successful in improving environmental conditions. However, it has some significant drawbacks. The regulated activities tend to become in opposition to the rule-makers. The approach, in addition, has encouraged the use of end-of-pipe, media-specific technologies, and not integrated approaches.

More recently many authorities have adopted a negotiated compliance approach. This builds on a cooperation between the regulators and the regulated in setting and enforcing standards. This "shared responsibility" between government and industry promotes an open exchange of information between the parties, and flexibility regarding the means of meeting the standard. In the same spirit the authority may only define the targets while the means of achieving the targets are left in the hands of the industries (non-prescriptive regulations). This will increase the economic efficiency of the regulation, and may stimulate the adoption of innovative, preventative approaches. However, this more cooperative approach is not appropriate in all instances. It has to be supported by appropriate procedures to avoid undue "regulatory capture" by industry. The topic of voluntary means of regulations is discussed in some detail in Book 1 in this series.

13.3.5 Market-Based Instruments

Broadly speaking, market-based instruments seek to address the market failure of "environmental externalities" by incorporating the external cost of a firm's polluting activities into its private cost. This can be done either through taxation, or by creating property rights and establishing a proxy market, for example, of tradable pollution permits.

There is a large body of empirical evidence to demonstrate that market-based instruments are inherently more efficient than regulatory standards to achieve a given reduction in pollution. Market-based instruments act as incentives for the development of more cost-effective pollution control and prevention technologies. They provide greater flexibility in the choice of technology or prevention strategy. They are thus more cost-effective and may provide government with a source of revenue to support environmental and/or social initiatives for sustainable development.

Before introducing a new economic instrument, authorities should identify and evaluate any economic incentives that may already be used. These include for example subsidies to make local industries more competitive. Many of these policies lead to artificially low prices for resources, such as energy and water, and overuse, leading to both pollution and shortages.

Taxes, fees and charges may be used to promote cleaner production practices by raising the costs of unwanted outputs, or promote more efficient use of natural resources. In some instances the revenues may be used to support cleaner production activities and thus to further stimulate preventative approaches. However a drawback is that it is often not politically feasible to set taxes at a high enough level to achieve the desired environmental goals.

If environmental taxation is taken merely as a means of increasing government revenues there may be resistance. Then a solution may be to redistribute the collected charges in relation the each company's environmental improvement. Furthermore, the successful implementation of such instruments requires a system of monitoring, revenue collection, and enforcement, as well as measures to combat possible corruption.

Liability rules can exert a powerful direct economic incentive to move away from polluting technologies and unsafe products. Several countries have found that enforcing strict liability – where the companies are held responsible for all the environmental damage they cause, even if they have fulfilled their legal obligations. Then companies try to minimise their risks and take preventive measures. The success of liability systems depends on the nature of the enforcement and legal system of the country.

Financial subsidies, in the form for example of low-interest loans, direct grants, or preferential tax treatment, can be targeted to stimulate technological development. It is important that governments carefully examine the way that subsidies work to ensure that they don't create incentives for environmentally counter-productive behaviour.

Innovative financing schemes. Regular commercial sources should be the main channels of financing new and retrofit CP investments. But other means, such as revolving funds, energy efficiency windows, loan guarantee schemes for SMEs and innovative schemes have proven to be useful getting the process started. This is also a way to introduce the CP concept to banks and industries, particularly in developing countries and economies in transition.

13.3.6 Cleaner Production Investments

In many countries, the environmental sector is mainly subsidised by government funds, with resources coming from national budgets, donations, grants, fees and fines, environmental taxes and product charges as well as other resources determined in the legislation. Support can take the form of grants, soft loans, specialised credit lines, or financial or technical assistance for project preparation and implementation. In recent years, there has also been important support from international aid and bilateral technical cooperation programmes, aimed mainly at setting up and strengthening environmental institutions.

Most environmental expenditures in developing countries have been directed at national-level public programmes, such as water and wastewater infrastructure, sanitation, biodiversity and nature protection among others. Securing funding for environmental protection in industry tends to be left in the hands of the companies themselves. As a consequence, the availability of funds for environmental projects, especially CP, in private industry is limited.

The implementation of CP measures – beyond the low-cost, good housekeeping measures – calls for a customised approach to financing, as well as financial officers trained to evaluate the benefits of cleaner production programmes.

Even limited improvements in access to financing can lead to significant results in the introduction of cleaner production, provided the activities are successful and can serve as models and references for future projects.

13.3.7 Information-Based Strategies

Authorities may also stimulate the adoption of cleaner production practices through the use of information. Information may be used to provide the right incentive – for example by publishing the results of successful companies, that is the publication and dissemination of relevant case studies.

Examples of information-based strategies include:

- Promoting demonstration projects, to demonstrate the techniques and cost-saving opportunities associated with cleaner production.
- Encouraging education on preventive environmental management.
- Publication of information on environmental performance, for example, by establishing a pollutant release and transfer register and stimulating voluntary corporate reporting.
- Eco-labelling and environmental product declarations schemes.
- Promoting effective training initiatives.
- High profile awards for enterprises that have effectively implemented cleaner production.

13.4 Stakeholder Involvement

13.4.1 The Stakeholders

The UNEP strategies for cleaner production underlines the roles of different stakeholders. I says that good cleaner production strategies should include all groups of stakeholders, such as industry, government & local authorities, educational institutions, employees, suppliers and customers, financial organisations and NGOs. To motivate consumers towards more rational and sustainable consumption patters is an especially critical issue for an efficient CP programme.

Industry. CP originates from industry and it mainly targets industry. Successful companies will be those who are able to provide satisfied customers with less input of materials and energy. Companies easily introduce CP as a leading strategy for environmental management. The challenge is how to involve also non-pro active and smaller enterprises. Industrial associations or cooperation among particular enterprises provide a useful tool.

Governments provide conditions for economic development and environmental improvement. Governments therefore play a key role in the process of promoting CP. The last few decades we have witnessed several important shifts in environmental policies and strategies. CP should certainly play an important part in the further development of these shifts.

Local authorities are able to substantially contribute by promoting CP, and even take a lead as they have direct interests in the elimination of environmental risks, and supporting economic and social development in the region.

CP can be a tool to grasp the material flows within an area. CP also can be an alternative to the municipal end-of-pipe treatment, such as dumping sites and incinerators. Municipalities may also consider CP as means to improve environmental performance in its own operations.

The local projects co-ordinated by municipalities constitute an effective way to promote CP on a wide scale and reach small and medium size enterprises that are most in need of assistance from outside.

13.4.2 Educational Institutions

Cleaner production as a sustainability strategy requires new attitudes, new knowledge and skills for all professions, academic as well as non-academic.

The integration of CP into the curriculum is crucial for the long-term survival of CP programmes. It should provide a pool of domestic professionals and raise the level of awareness among all CP stakeholders. National CP policies would help in integrating CP into curricula from the university level to lower educational levels.

Training directed towards companies and their employees, public authorities, technological and academic institutions and NGO's is important i this respect. "Educate the educator" activities help educational planners and teachers to incorporate cleaner production in the curricula.

Universities bear profound responsibilities to increase the awareness, knowledge, technologies and tools to create an environmentally sustainable future. They must play a strong role in cleaner production education, research, policy development, information exchange and community out reach. Training of in-service personnel and applied research also should be addressed by the universities.

13.4.3 Production Chain Stakeholders

Employees are important stakeholders. They can influence the decision-making process of top management on implementing CP. The commitment of top management to CP remains the first condition for success of CP within the enterprise. However, success of CP also depends very much on the existing enterprise culture and on the acceptance and commitment of all employees.

Suppliers and customers. Application of CP to the whole product chain is another important direction. Each actor on the chain from supplier to consumer have a role and influence each other.

Financial organisations. Enterprises which practise CP are healthier both environmentally and economically. In this respect, it is surprising to see that financial organisations pay only limited attention to CP. One of the reasons may be that investments in CP generally need only relatively limited capital.

A financial analysis is required to make a decision on any type of investment to verify the technical, financial and legal aspects of the project.

The actual costs of waste and waste management are very often hidden in the management overhead accounts and do not find their way to the project cost analysis (See also Box 10.2). Environmental risks are also still often undervalued. It is here that the main challenge of mainstreaming cleaner production lies.

NGOs can play an important role in creating demand a for CP and in rising awareness in the public. NGOs and other public groups may also promote CP projects and see it as part of an environmental programme.

13.5 The Barriers to CP Implementation

13.5.1 Character of the Obstacles

Despite that Cleaner Production actions are economically and environmentally advantageous, the adoption of cleaner production still remains limited. Several studies have addressed the obstacles of adopting cleaner production at individual companies. The categories of obstacles in these studies are mainly the following:

1. *Financial*
    - High cost of external capital for investments in industry.
    - Lack of funding mechanisms for cleaner production investments.
    - Perception that investments in cleaner production present a high financial risk due to the innovative nature of cleaner production.
    - Cleaner production not properly valued by credit providers in their evaluation procedures for lending, equity participation etc.
2. *Economic*
    - Cleaner production investments are not sufficiently cost effective compared with other investment opportunities.
    - Immaturity of the company's internal cost calculation and cost allocation practices.
    - Immaturity of the company's internal capital budgeting and capital allocation procedures.
3. *Policies*
    - Insufficient focus on cleaner production in environmental, technology, trade and industrial development and strategies.
    - Immaturity of the environmental policy framework.

4. *Organisational*
    - Lack of leadership for environmental affairs.
    - Perceived management risk related to cleaner production.
    - Immaturity of the environmental management function in the company's operations.
    - Immaturity of the organisation structure of the company and its management and information systems.
    - Limited experience with employee involvement and project work.
5. *Technical*
    - Absence of a sound operational basis.
    - Complexity of cleaner production programme procedure.
    - Limited availability of equipment enabling cleaner production.
    - Limited accessibility of reliable technical information.
6. *Conceptual*
    - Indifference: not understanding one's own role in contributing to environmental improvement.
    - Narrow interpretation or misunderstanding of the cleaner production concept.
    - Resistance to change.

13.5.2 Leadership Commitment

The success of a cleaner production programme depends very much on leadership commitment as well as motivation, knowledge and innovative creativity of the work force. In addition cleaner production partnership development and a long-range view of the future is good.

Senior leaders have the task to create clear and visible values and a vision of a CP programme for the organisation with its strategies, systems and methods for achieving CP. The values and strategies should help to guide all activities and decisions throughout the organisation. CP requires strategies that set environmental performance goals that go beyond compliance with environment and health and safety regulations.

The role of senior leaders is to inspire and motivate the entire work force and encourage all employees to develop, learn, and motivate the pursuit of an organisation's vision of its CP programme. Their role is to:

- Provide adequate financial and human resources to assure implementation of action plans.
- Take a long-term view of the future regarding community environmental and economic sustainability through company and personal policies of good environmental stewardship.
- Sponsor community environmental activities, mentor other businesses, promote innovative regulatory approaches and create a "shared learning" environment.

13.5.3 Employees and Partners

A prevention-based environmental management system creates a framework for employee involvement in process analysis, problem solving, decision-making and implementation. Employee involvement ensures their participation in the continuous improvement process of the organisation's CP programme. The encouragement of employee learning, participation, innovation and creativity builds employee knowledge and support.

An organisation demonstrates employee value by creating and maintaining a safe and healthy work place. Prevention practices create a safer working environment and cleaner communities for employees and their families. Increased employee awareness of the state of the work place environment helps improve knowledge of risks and health and safety concerns in the work place. Greater understanding of risk and health and safety concerns will lead to improvements in these areas as

Table 13.1 *Possible organisational change problems [Ashford, 1994].*

Possible organisational change problems												
vision	+	skills	+	incentives	+	resources	+	terms of references	=	change
missing vision	+	skills	+	incentives	+	resources	+	terms of references	=	confusion
vision	+	missing skills	+	incentives	+	resources	+	terms of references	=	anxiety
vision	+	skills	+	missing incentives	+	resources	+	terms of references	=	apathy
vision	+	skills	+	incentives	+	missing resources	+	terms of references	=	frustration
vision	+	skills	+	incentives	+	resources	+	missing ToR	=	chaos

well as better conformance to environment, health and safety standards by employees.

Incentives should be created to reward good ideas, participation and the reporting of problems. Employee training needs should be identified and met to assure quality participation. The organisation can also benefit by communicating its environmental ethic to all employees and extend this ethic to their daily lives.

13.5.4 Partnership Development

Organisations need to build internal and external partnership to better accomplish their CP programmes. Internal partnerships might include labor-management cooperation, as well as employee high-performance work teams. For example, partnership between those responsible for waste management and those responsible for production process operations are essential for identifying the sources of waste and devising the appropriate pollution prevention measures to reduce that waste.

External partnership might be with customers and suppliers. For example, an organisation may develop a partnership with a major supplier to deliver goods with less packaging. Partnerships can also be effective mechanisms to communicate the organisation's environmental ethic, extending the idea of cleaner production to customers, employees, vendors, contractors and suppliers and communities. Partners should address the key requirements for success, means for regular communication, approaches to evaluating progress and means for adapting to changing conditions.

The development of internal partnership creates network that improve flexibility, responsiveness and knowledge sharing. External partnership with suppliers, vendors and customers and others, such as community representatives, can also provide valuable input into process improvements and product development, as well as bring a broader perspective to the programme.

Internal partnerships are essential to develop a fully integrated prevention-based environmental management system. Thus, partnership between administrative services such as procurement and the production areas can help employees understand the environmental impacts of purchasing decisions.

Customer feedback on product performance and level of "greenness" is another possible partnership which may support the customer's own environmental improvement efforts.

Partnership indirectly related to the organisation may also produce beneficial outcomes. For example, working with organisations such as schools, economic development agencies, or local governments can encourage broader environmental responsibility and organisational and community learning. This type of activity is especially relevant to sustainable development goals that will be met at the community level.

13.5.5 Education and Training for Employees

One of the most important elements of CP is to provide training for employees. Such education should best cover all levels of the company. The main task of it is to inform each employee about the facts of waste formation and to explain their and the whole company's impact on the environment, to show how it is possible to reduce waste and how to make production cleaner.

The information on the cleaner production programme can be included in the overall training programme for all new employees in the company, with the following themes:

- Concepts and activities of cleaner production.
- Activities for creation of cleaner production projects of simple processes.
- Review of opportunities for cleaner production.
- Process of implementation, possible obstacles and how to get it through.
- Opportunities for cleaner production projects of complex processes.

Box 13.3
Proven and Effective "New Idea killers"

1. Don't forget that we must also earn money!
2. You will never be able to sell this idea to the management.
3. Let's think more about that, LATER.
4. I know it's not possible.
5. We are too small/big for that.
6. We have already tried that (We haven't).
7. That will be too expensive!
8. NOW is not the right time for this discussion.
9. That will mean more work!
10. We have always done it this way/so why should we change now?
11. You don't quite understand the problem.
12. Let's take it up again/later/much later.
13. In our business/it's different.
14. Let somebody else try it first.
15. It doesn't fit into our long-term planning.
16. Talk to Lars, this is not my field.
17. We have already over-spent our budget for this year.
18. It won't work/and besides that/it's against our policy.
19. We have no time for that.
20. It sounds fine in theory/but how will it work in practice?
21. We don't have enough employees to implement that idea.
22. We are not ready for this idea yet.
23. It is too late to make changes now.

Source: Ashford, 1994.

- How to resist pressure of business, practical exercises.
- Communication between participants within the projects of cleaner production, practical exercises.
- Widening and deepening knowledge of opportunities for cleaner production.
- Team work skills.
- Priority list of opportunities for cleaner production, exercises.
- Value of contribution of all employees in the cleaner production programme.

13.6 Links between Cleaner Production and Other Tools

13.6.1 Integration of Cleaner Production and ISO 14001/EMS

In the early years of ISO 14001 and CP, the consulting communities most closely involved with each of the two concepts sometimes perceived each other – wrongly – as competitors. There is no reason to view CP and ISO 14001 as rival approaches, because in fact they are complementary. Several examples of the successful merging of the two concepts are now available, and experience shows that a CP programme can be an integral part of the work to introduce an environmental management system.

The rationale for the integration of the two concepts is that cleaner production focuses on the operational (plant floor) level, while an EMS system requires the development of a strong and formal management structure and procedures. CP can be used effectively to achieve the continued environmental improvement required under ISO 14001. CP is also likely to generate operational savings for a company, offsetting in part the cost of the EMS certification process. Conversely, a functioning EMS can help to keep a CP programme on track.

Box 13.4 Blocks to Creative Problem Solving

- Fear of making mistakes.
- Fear of being misunderstood.
- Fear of being criticised.
- Fear of being misused.
- Fear of being alone (a person with an idea is automatically a minority of one).
- Fear of making changes.
- Fear of losing security.
- Fear of losing the group's love.
- Fear of being an individual.

Source: Ashford, 1994.

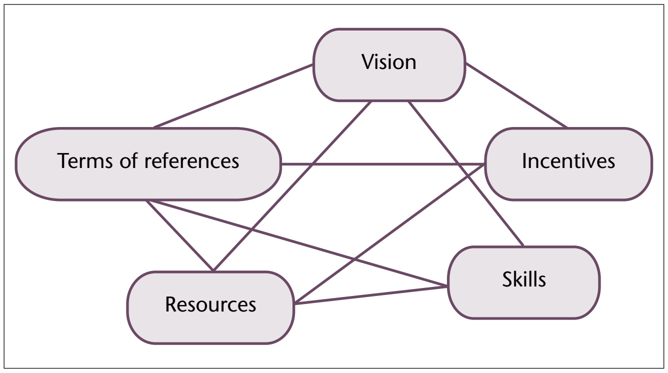


Figure 13.1 *Ingredients and their interrelationships for organisational change in cleaner production processes [Ashford, 1994].*

There are a number of examples where CP projects and EMS certification were combined in municipal operations.

13.6.2 Cleaner Production and Environmental Policies

Policy integration ensures that the CP policy harmonises with the objectives of various sectors of the economy, and that CP is promoted within sectorial policies, known as *mainstreaming*. This requires:

- Good analysis of existing sectorial policies.
- Inter-institutional and inter-sectorial effort.
- Strong leadership and broad support for CP.

Efforts should be taken to build the concept of cleaner production into the highest level environmental and other sector-specific policy documents, and included in the development of new sectorial policies. Prevention must be emphasised as the major principle of environmental protection. This is referred to as mainstreaming CP. Mainstreaming CP requires that the concept of preventive strategies are included in all aspects of the policy framework to make it uniformly supportive and favourable to cleaner production.

Similarly, policy integration is essential. It means ensuring that a CP policy is harmonised or consistent with the various other policies in force or under development. For instance, energy or water subsidies, the protection of certain industrial sectors from competition, or fragmented and piecemeal sectorial policies all have a negative effect on the implementation of CP. Insufficient data and information systems may also be an obstacle to the identification of priority regions or industrial sectors for CP action. Policy integration can occur both within the context of the price mechanism (market-based), or at the institutional level (government-based).

Policy integration asks for, cleaner production principles to be integrated into a range of policies, including:

- Industrial development policy.
- Foreign trade policy/customs policy.
- Investment promotion policy.
- Fiscal policy and tax regimes.
- Environmental policy.
- Energy and transport policy.
- Agricultural policy.
- Education and science and technology policy.
- Health policy.

The successful integration of CP into economic and environmental policies can bring multiple benefits by ensuring that policy goals are reached at the least cost, and that the burdens, which economic policies impose on the environment, are fully accounted for. So far, mainstreaming of CP has become a more common practice in only a handful of countries, but the Czech Republic, the Netherlands and the United States can provide useful examples in this context.

Box 13.5 Example of National CP Policy Approach in the Czech Republic

In the February 2000 Resolution on the National Cleaner Production Programme, the Government of the Czech Republic recommended that:

"... the Ministers of the Environment, Industry and Trade, Agriculture, Local Development, Defence, Transportation and Communications, the Interior and Education, Youth and Physical Education, the Vice-Chairman of the Government, the Minister of Finance, the 1st Vice-Chairman of the Government, the Minister of Labour and Social Affairs and Minister of Health consistently apply the principles of the National Cleaner Production Programme and introduce them into the activities of the sectors."

Abbreviations

BAT	Best Available Techniques.
BREF	Best available techniques REFerence document.
CEE	Central and Eastern Europe.
CFCs	ChloroFluoroCarbons.
CP	Cleaner Production.
DC	Direct Current electricity.
EEA	European Environment Agency.
EMS	Environmental Management System.
IDCP	International Declaration on Cleaner Production.
IIIEE	International Institute for Industrial Environmental Economics.
IPPC	Directive on Integrated Pollution Prevention and Control.
IPTS	European Union Institute for Prospective Technological Studies.
ISO	International Organisation for Standardisation.
IUPAC	International Union of Pure and Applied Chemistry.
LEEP	Law and Environment Eurasia Partnership.
MIC	Methyl Iso Cyanate.
NCPC	National Cleaner Production Centre.
NGO	Non Governmental Organisation.
OECD	Organisation for Economic Cooperation and Development.
PEM	Proton Exchange Membrane fuel cells.
PFTE	Poly Tetra Fluoro Ethylene (common trade name Teflon).
PREPARE	Preventive Environmental Protection Approaches in Europe.
PV	PhotoVoltaic cells.
R&D	Research and Development.
REC	Regional Environmental Centre for Central and Eastern Europe.
RoHS	Restriction of Hazardous Substances (EU directive).
SDCN	Sustainable Development Communications Network.
SMEs	Small and Medium-sized Enterprises.
SOFC	Solid Oxide Fuel Cells.
TRI	Toxic Release Inventory.
UNEP	United Nations Environment Programme.
UNEP-IE	UNEP's Industry and Environment Unit.
UNEPTIE	UNEP's Division of Technology, Industry, and Economics.
UNIDO	United Nations Industrial Development Organisation.
VOCs	Volatile Organic Compounds.
WBCSD	World Business Council for Sustainable Development.
WEEE	Waste Electrical and Electronic Equipment (EU directive).

Study Questions

1. List the main aims of the UNEP's International Declaration on Cleaner Production. What are the main parts of the UNEP's International Declaration on Cleaner Production?
2. List the most important organisations that promote Cleaner Production.
3. Describe the functions of the national Cleaner Production centres. Where is such a centre in your country?
4. What policy instruments may be used to implement the strategy of Cleaner Production? Which of them are, in your view, the most important?
5. Who are the most important stakeholders and their roles in a Cleaner Production programme? Describe in particular the roles of leadership/management, employee/personnel and external stakeholders.
6. What role does education play in the introduction of Cleaner Production?
7. Describe the main obstacles when introducing a Cleaner Production programme and how to deal with them.
8. Describe how Cleaner Production may be included in the environmental policy of an organisation, and why this is important.
9. Describe which role(s) a municipality may have in promoting cleaner production in its area.
10. What is the difference between Cleaner Production and ISO 14000 approaches, and how are they integrated in one single activity?

Internet Resources

UNEP DTIE – Cleaner Production (CP) Activities
http://www.uneptie.org/pc/cp/

UNEP DTIE – National Cleaner Production Centres
http://www.uneptie.org/pc/cp/ncpc/home.htm

SD Gateway – Sustainability Web Ring
http://www.sdgateway.net/webring/

Envirolink
http://www.envirolink.org/

Regional Environmental Centre for Central and Eastern Europe
http://www.rec.org/

Civil Society International –
Law and Environment Eurasia Partnership (LEEP)
http://www.civilsoc.org/usnisorg/law-hr/leep.htm

Business Partners for Development
http://www.bpdweb.com/

United Nations Industrial Development Organisation
http://www.unido.org/

World Business Council for Sustainable Development (WBCSD)
http://www.wbcsd.org/

EU Institute for Prospective Technological Studies
http://www.jrc.es/home/index.htm

European Environment Agency
http://www.eea.europa.eu/

Factor 10 Institute
http://www.factor10-institute.org/

Wuppertal Institute for Climate, Environment and Energy
http://www.wupperinst.org/en/home/index.html

International Institute for Industrial Environmental Economics (IIIEE) at Lund University
http://www.iiiee.lu.se/

Preventive Environmental Protection Approaches in Europe (PREPARE)
http://www.prepare-net.org/

Cleaner Production Promotion Law of China
http://www.chinacp.com/eng/cppolicystrategy/cp_law2002.html

The Sustainable Development Communications Network (SDCN)
http://www.sdcn.org/

Environmental Defence
http://www.environmentaldefense.org/

EnviroWindows – Environmental Information for Business and Local Authorities
http://www.ewindows.eu.org/Industry/Cleaner

Hungarian Cleaner Production Centre
http://hcpc.uni-corvinus.hu/exp_eng/index_exp.htm

References

Introduction

Graedel, T. E. and Allenby, B.R. *Industrial Ecology*, 2nd ed, Prentice Hall, 2003.

Hamner, W. B. A presentation at the 1st Asian Conference on *Cleaner Production in the Chemical Industry*, Taipei, Taiwan, December 9-10, 1996.

Planasch, M. *The Concept of Cleaner Production*. A presentation at the Baltic University Programme Teachers Conference on Environmental Management, Poland, June 30, 2006.

Chapter 1

Aleklett, K. *Energy Policy and Energy Supply – Part IV, in Realiziing a Common Vision for a Baltic Sea Eco-region*, Rydén, L. (ed.), The Baltic University Programme and Baltic 21, Sweden, 2006.
http://www.balticuniv.uu.se/pdf/kaliningrad.pdf

Brandt N. and Gröndahl F. *Kompendium i miljöskydd, part 4 – Miljöeffekter, Industrial Ecology*, KTH, Stockholm, 2000.

Brohan, P., Kennedy, J. J., Harris, I., Tett, S. F. B. and Jones P. D. Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850, in *Journal of Geophysical Research*, vol. 111, 2006.
http://www.cru.uea.ac.uk/cru/info/warming/

Cunningham, W. P., Cunningham, M. A. and Saigo, B. W. *Environmental Science: A Global Concern*, 8th ed, McGraw-Hill, 2005.

EMEP (Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe) *Expert Emissions used in EMEP models*.
http://webdab.emep.int

Freedman, B. *Environmental Ecology: The Ecological Effects of Pollution, Disturbance and Other Stresses*, 2nd ed, Academic Press, 1995.

Freedman, B. *Environmental Ecology: The Impacts of Pollution and Other Stresses on Ecosystem Structure and Function*. Academic Press, 1989.

Henry, J. G. and Heinke, G.W. *Environmental Science and Engineering*, 2nd ed, Prentice Hall, 1996.

Hultman, B., Levlin, E. and Plaza, E. Resource Management and the Technology of Clean Water, Chapter 17 in *Environmental Science*, Rydén, L., Migula, P. and Andersson, M. (eds). Baltic University Press, Sweden, 2003.

Hylander, L. D. and Goodsite, M. E. *Environmental Costs of Mercury Pollution, in Science of The Total Environment*, vol. 368, pp. 352-370, 2006.

Hylander, L. D. and Meili, M. The Rise and Fall of Mercury: Converting a Resource to Refuse After 500 Years of Mining and Pollution, in *Critical Reviews in Environmental Science and Technology*, vol. 35, no. 1, pp. 1-36, Jan/Feb 2005.

IChemE (Institution of Chemical Engineers). *Environmental Training for the Process Industries*. Rugby, UK, 1993.

INSC (International Nuclear Safety Centre) at Argonne National Laboratory. http://www.insc.anl.gov/pwrmaps/

IPCC (The Intergovernmental Panel on Climate Change). *Climate Change 2001: Synthesis Report*. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Integovernmental Panel on Climate Change. Watson, R.T. and the Core Writing Team (eds.). Cambridge University Press, 2001.
http://www.ipcc.ch/pub/syreng.htm

Jackson, A.R.W. and Jackson, J.M. *Environmental Science: The Natural Environment and Human Impact*, 2nd ed, Pearson Education, 2000.

Keeling, C. D. and Whorf, T. P. Atmospheric CO_2 records from sites in the SIO air sampling network, in *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, 2005.
http://cdiac.esd.ornl.gov/trends/co2/sio-mlo.htm

Kutsuna, M. (ed.). *Minamata Disease (Minamata Report)*, Kumamota University, Japan, 1968.

Liu, D.H.F. *Environmental Engineers' Handbook*, CRC Press LCC, 1999.

Loh, J. and Wackernagel, M. *Living Planet Report 2004*, WWF, 2004.

McNeill, J. R. *Something new under the sun*, W. W. Norton & Co, 2000.

Murtagh, D. *Ozone hole in Artic*, Chalmers University of Technology, 2003.

Tchobanoelous, G. and Schroeder, E. D. *Water Quality*, Addison-Wesley, 1985.

Walker C.H., Hopkin S.P., Sibly R.M. and Peakall D.B. *Principles of Ecotoxicology*, Taylor & Francis, 2001.

Wright, R.T. *Environmental Science: Toward a sustainable future*, 9th ed, Prentice Hall, 2004.

Chapter 2

Persson, P. O. and Nilson, L. *Kompendium i miljöskydd, part 2 – Miljöskyddsteknik*. Industrial Ecology, KTH, Stockholm, 1998.

Rydén, L., Migula, P. and Andersson, M. (eds). *Environmental Science*. Baltic University Press, Sweden, 2003.

Chapter 3

HELCOM. *Guidance Document on Cadmium and its Compounds*, presented by Denmark. Helsinki, Finland, 2002.

HELCOM. *The Baltic Sea Joint Comprehensive Environmental Action Programme*, Baltic Sea Environment Proceedings no. 48, Helsinki, Finland, 1993.

HELCOM. *The third Baltic Sea Pollution Load Compilation (PLC 3) Helsinki Commission*, Baltic Marine Environment Protection Commission, Baltic Sea Environment Proceedings no. 70, Helsinki, Finland, 1998.

Illeris, S. *Outsourcing of textile and clothing industry from Denmark to Baltic transition countries*, 5th Nordic-Baltic Conference in Regional Science, Pärnu, Estonia, October 1-4, 1998.

Rydén, L., Migula, P. and Andersson, M. (eds). *Environmental Science*. Baltic University Press, Sweden, 2003.

SCB (Statistiska centralbyrån, Statistics Sweden). *Miljöräkenskaper 1993-1998 (Environmental Accounting 1993-1998)*, MI 53 SM 0101. SCB, Sweden, 2001.

Chapter 4

CECP (Centre of Excellence in Cleaner Production). *Cleaner Production Manual for Small to Medium Sized Enterprises*, Module 1,2,3,4,5. Curtin University of Technology, Perth, Australia, 2001.
http://cleanerproduction.curtin.edu.au/cecp/cecptraininghome.htm

CECP (Centre of Excellence in Cleaner Production). *Cleaner Production Training for Local Government*, Module 1,2,3. Curtin University of Technology, Perth, Australia, 2003.
http://cleanerproduction.curtin.edu.au/cecp/cecplocalgovernmenthome.htm

Hemel, C. and Brezet, H. *Handleiding voor Ecodesign*. UNEP/TUDelft, The Netherlands, 1997.

NSW-DSRD/NSW-EPA (NSW Department of State and Regional Development/NSW Environment Protection Authority). *Profits from Cleaner Production – A Self-Help Tool for Small to Medium-Sized Businesses*, 2000.

Sinnott, R.K. *Chemical Engineering Design*, vol. 6, 4th ed. Elsevier Butterworth-Heinemann, 2005.

The World Bank Group. *Pollution Prevention and Abatement Handbook 1998: Toward Cleaner Production*, 1999.

UNEP (United Nations Environment Programme). *Cleaner Production – A Training Resource Package*, 1996a.

UNEP (United Nations Environment Programme). *Cleaner Production in Leather Tanning – A Workbook for Trainers*, 1996b.

UNEP/DEPA (United Nations Environment Programme/Danish Environmental Protection Agency). *Cleaner Production Assessment in Dairy Processing,* Industrial Sector Guides, 2000.

U.S. EPA (U.S. Environmental Protection Agency). *An organizational Guide to Pollution Prevention*, EPA/625/R-01/003, 2001.

Van Berkel, R. *Cleaner production for process industries.* Plenary lecture – CHEMECA, Perth, Australia, July 9-12, 2000.

Van Hemel, C.G. *Ecodesign empirically explored*. TUDelft, The Netherlands, 1995.

Chapter 5

Adams, R. The Accounting Profession, in *Green Reporting: Accountancy and the Challenge of the Nineties*, Owen, D. (ed). Chapman & Hall, 1992.

Ammenberg, J., Wik, G., Hjelm, O. Auditing External Environmental Auditors – Investigating how ISO 14001 is Interpreted and Applied in Reality, in Eco-Management and Auditing vol. 8, no. 4, pp. 183-192. Wiley Interscience, 2001.
http://www3.interscience.wiley.com/cgi-bin/jhome/5354

Bergout, F., Hertin, J., Carlens, J., Tyteca, D., Olsthoorn, X., Wagner, M., and Wehrmeyer, W. Environmental indicators in industry – the MEPI exprience. SPRU, Science and Technology Policy Research, University of Sussex, UK, 2000.
http://www.casa.susx.ac.uk/Units/spru/mepi/outputs/Berkhout.PDF

BMU/UBA (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety/Federal Environmental Agency). *A Guide to Corporate Environmental Cost Management,* Germany, 2003.
http://www.umweltdaten.de/publikationen/fpdf-l/2895.pdf

CEN (European Committee for Standardisation). *Environmental Management – Environmental Performance Evaluation – Guidelines*, EN ISO 14031:1999.

Heinemann D., Higgins, J., McAlpine, G., Raison, J. , Ryan, S. and Saunders, D. *A Guidebook to Environmental Indicators*, CSIRO (Commonwealth Scientific and Industrial Organisation), NSW, Australia, 1998-1999.
http://www.csiro.au/csiro/envind/code/pages/menu.htm

Hopkinson, P., Sammut, A. and Whitaker, M. The standardisation of environmental performance indicators and their relationship to corporate environmental reporting: What can we learn from the UK water industry?, in *Journal of Environmental Assessment Policy and Management,* vol. 1, no. 3, pp. 277-296. Imperial College Press, 1999.

IGPA (International Green Productivity Association). How and Why of Environmental Indicators, in *IGPA Newsletter*, vol. 4, no. 3, 2002.
http://igpa.ema.org.tw/newsletter/2002no03/2002no030501.htm

INEM (International Network of Environmental Management). *A tool-book for environmental indicators*, 1999.

ISO (International Standardisation Organisation). *Environmental Management – Examples of Environmental Performance Evaluation (EPE)*, ISO/TR 14031:1999.

Jasch, C. *Environmental Management Accounting Procedures and Principles,* United Nations Publications, 2001.
http://www.env.go.jp/policy/kaikei/sympo/04.pdf

Kuhre, W. L. *ISO 14031 Environmental Performance Evaluation (EPE),* Prentice Hall PTR, 1998.

Olsthoorn, X., Tyteca, D., Wehrmeyer, W. and Wagner, M. Environmental Indicators for Business: A Review of the Literature and Standardisation Methods, in *Journal of Cleaner Production*, vol. 9, no. 5, pp. 453-463, ScienceDirect, 2000.
http://www.casa.susx.ac.uk/Units/spru/mepi/outputs/Olsthoorn.PDF

Seifert, E. K. EPE According to ISO 14031: Concept, Experience, and Revision Issues, in *Information Systems for Sustainable Development,* Hilty, L. M., Seifert, E. K. and Treibert, R (eds). Idea Group Publishing, 2005.

Viegas, M. *Environmental Performance Evaluation – ISO 4031:1999 and the Future.* Plenary lecture at the ISO Technical Committee 207 meeting in Madrid, 14 Sep. 2005.

Chapter 6

Baltic 21. *Baltic 21 Report 2000-2002: Towards Sustainable Development in the Baltic Sea Region*, Baltic 21 Series no. 1/2003.

Cheresources (The Chemical Engineers' Resource Page). *Pinch technologies: Basics for Beginners*, 2004.
http://www.cheresources.com/pinchtech1.shtml

Coulson, J.M and Richardson, J.F. *Chemical Engineering,* vol. 2, 5th ed, Elsevier Butterworth-Heinemann, 2002.

EIA (Energy Information Administration). *International Energy Annual 1999*, DOE/EIA-0219(99), Washington DC, February 2001.

EIA (Energy Information Administration). *World Energy Projection System*, 2002.

Perry R.H. and Green, D.W. *Perry's Chemical Engineer's Handbook*, 6th ed, pp. 12-28, McGraw-Hill, 1984.

U.S. DOE (U.S. Department of Energy). *Central Heat Pump and Air Conditioner Installation*, DOE/GO102002-0781, 2003.

U.S. EPA (U.S. Environmental Protection Agency). *Guide to Industrial Assessments for Pollution Prevention and Energy Efficiency*. Washington, 2001.

USGS (U.S. Geological Survey) World Energy Assessment Team. *U.S. Geological Survey World Petroleum Assessment 2000 – Description and Results*, U.S. Geological Survey Digital Data Series – DDS-60, 2000.
http://pubs.usgs.gov/dds/dds-060

Chapter 7

Rydén, L., Migula, P. and Andersson, M. (eds). *Environmental Science*, Baltic University Press, Sweden, 2003.

SCB, Statistiska centralbyrån (Statistics Sweden).
http://www.scb.se/

Chapter 8

Coulson, J.M and Richardson, J.F. *Chemical Engineering,* vol. 2, 5th ed, Elsevier Butterworth-Heinemann, 2002.

Kiely, G. *Environmental Engineering*, McGraw-Hill, 1998.

Nemerow, N.L. and Dasgupta, A. *Industrial and Hazardous Waste Treatment*, van Nostrand Reinhold, 1991.

Orioli, E., Molinari, R., Calabrio, V. and Gasile, A.B. *Membrane technology for production – integrated pollution control systems*, Seminar on the Role of the Chemical Industry in Environmental Protection, CHEM/SEM. 18/R. 19, Geneva, 1989.

Perry R.H. and Green, D.W. *Perry's Chemical Engineer's Handbook*, 7th ed. McGraw-Hill, 1997.

Tchobanoglous, G., Burton, F.L. and Stensel, H.D. *Wastewater Engineering – Treatment and Reuse*, 4th ed., Metcalf & Eddy Inc., McGraw-Hill, 2003.

Chapter 9

Arbetsmiljöverket (Swedish Work Environment Authority). *Hygieniska gränsvärden och åtgärder mot luftföroreningar*, AFS 2005:17, Sweden, 2005.
http://www.av.se/dokument/afs/afs2005_17.pdf

Coulson, J.M and Richardson, J.F. *Chemical Engineering,* vol. 2, 5th ed. Elsevier Butterworth-Heinemann, 2002.

OSHA (Occupational Safety & Health Administration). *Health Guidelines*, U.S. Department of Labor, February 2000.
http://www.osha.gov/SLTC/healthguidelines/index.html

Perry R.H. and Green, D.W. *Perry's Chemical Engineer's Handbook*, 6th ed. McGraw-Hill, 1984.

Chapter 10

Nemerow, N.L. and Dasgupta, A. *Industrial and Hazardous Waste Treatment*, van Nostrand Reinhold, 1991.

Planasch, M., Gwehenberger, G., Schnitzer, H. and Brunner, C. From Cleaner Production to Zero Emissions, in *Sustainable Development in the Baltic and Beyond*, Leal Filho, W., Ubelis, A. and Berzina, D. Peter Lang (eds.), 2006.

Chapter 11

Boons, F. Eco-design and integrated chain management: dealing with networks of stakeholders, in *Journal of Sustainable Product Design*, April 1998.

NRC (National Research Council Canada). *Design for Environment Guide*, 2001. http://www.nrc-cnrc.gc.ca/

OTA (Office of Technology Assessment). *Green Products by Design: Choices for a Cleaner Environment*, OTA-E-541. Congress of the U.S., 1992.

Richards, D.J. *The Industrial Green Game: Implications for Environmental Design and Management*, National Academic Press, 1997.

Yarwood, J. M. and Eagan, P. D. *Design for Environment Toolkit*, Minnesota Office of Environmental Assistance and Minnesota Technical Assistance Program (MnTAP), 1998.
http://www.moea.state.mn.us/publications/dfetoolkit.pdf

Chapter 12

Allen, D.T. and Shonnard, D.R. *Green Engineering: Environmentally Conscious Design of Chemical Processes*, Prentice Hall, 2002.

Anastas, P. and Warner, J. *Green Chemistry: Theory and Practice*, Oxford University Press, 1998.

Kamini, N.R., Hemachander C., Geraldine Sandana Mala, J., Puvanakrishnan, R. Microbial enzyme technology as an alternative to conventional chemicals in leather industry, in *Current Science*, vol. 77, no. 1, 1999.

Ludvik, J. *Chrome Balance in Leather Processing,* UNIDO, US/RAS/92/120/11-51, 2000.

UNEP (United Nations Environment Programme). *Cleaner Production in Leather Tanning – A Workbook for Trainers*, 1996.

Chapter 13

Ashford, N. *Government Strategies and Policies for Cleaner Production*, UNEP/IE, 1994.

Hungarian Cleaner Production Centre. *Report of Activities*, 1998-2000.
http://hcpc.uni-corvinus.hu/exp_eng/index_exp.htm

Randmer, A. and Truusa, J. *Environmental top ten for industries: a simple motivation scheme to promote environmental management systems and cleaner production programmes,* 8th ERCP proceedings, 2002.

Cleaner Production Practices

A

Introduction

In this section you will find descriptions of cleaner production strategies in several industries. The intention is to give students the opportunity to look more in detail at how cleaner production concepts are, in reality, being used in a number of areas. Some of the strategies are, in addition, covered by a case study in the latter part of the book.

The sources are documents produced by authorities with responsibility for environmentally acceptable and improved industrial production. The European Integrated Pollution Prevention and Control Bureau (EIPPCB) of the EU, UNEP, and the US Environmental Protection Agency (EPA) are the most important agencies that have taken responsibility for this development.

The documents in this section have been shortened to a very abbreviated form. Only parts relevant for cleaner production strategies are included. In the original documents there is also extensive information about, for example, technology, environmental impacts, and relevant legal documents. The original documents all have extensive documentation of cases in industry, as well as details of monitoring, costs for investments needed for technology developments, and often references to relevant regulations.

The students studying one of these branches may wish to go to the original documents for a deeper study. Several of these are found on the accompanying CD.

The BREF Documents of the EU

The European Union DG Environment and the Information Exchange Forum (IEF) have published a number of documents to more precisely define what are Best Available Techniques (BAT) as referred to in the IPPC Directive. The documents are called BREF (best available techniques reference documents) and in their preliminary form DRAFT. The IEF consists of representatives from Member States industry and environmental non-governmental organisations. Each sector of work is addressed by a specific Technical Working Group (TWG) established for the duration of the work.

BREFs and DRAFTs are large documents. The adopted BREFs in English, together with translations of parts of them into all Member State languages, have been published on a CD by the Office for Official Publications of the European Communities. The CD is titled *Reference Documents on Best Available Techniques (Council Directive 96/61/EC): First edition (multilingual),* ISBN 92-894-3678-6, and can be ordered at: http://ec.europa.eu/environment/pubs/industry.htm

Or they can be downloaded as PDF-files at: http://www.epa.ie/Licensing/IPPCLicensing/BREFDocuments/

The following industries are included in the December 2006 BREF documents:

1. Chlor-Alkali Manufacturing industry.
2. Ferrous Metals Processing.
3. Intensive Rearing of Poultry and Pigs.
4. Large Volume Organic Chemical Industry.
5. Production of Iron and Steel.
6. General Principles of Monitoring.
7. Non Ferrous Metals Industries.
8. Pulp and Paper Industry.
9. Mineral Oil and Gas Refineries.
10. Tanning of Hides and Skins.
11. Textiles Industry.
12. Common Wastewater and Waste Gas Treatment/ Management Systems in the Chemical Sector.
13. Smitheries and foundries industry.
14. Surface Treatment using Organic Solvents.
15. Large Volume Inorganic Chemicals, Ammonia, Acids and Fertilisers Industries.
16. Emissions from Storage.
17. Food, Drink and Milk Industry.
18. Surface Treatment of Metals and Plastics.
19. Waste Treatments Industries.
20. Economics and Cross-Media Effects.
21. Manufacture of Organic Fine Chemicals.
22. Large Volume Inorganic Chemicals – Solid & Others Industry.
23. Ceramic Manufacturing Industry.
24. Production of Polymers.
25. Slaughterhouses and Animal By-Products Industries.
26. Production of Speciality Inorganic Chemicals.
27. Waste Incineration.
28. Cement and Lime Manufacturing Industries.
29. Industrial Cooling Systems.
30. Glass Manufacturing Industry.
31. Surface Treatment using Organic Solvents.
32. Waste Treatments Industries.

The Best Management Practices Documents of US EPA

The Best Management Practices for Pollution Prevention published by the US EPA Office of Research and Development is another source of documentation of cleaner production strategies. They can be downloaded as PDF-files at: http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/

The industries covered include the following branches:

1. Agricultural Chemical, Pesticide and Fertiliser Industry (2000).
2. Agricultural Crop Production Industry (2000).

3. Agricultural Livestock Production Industry (2000).
4. Aerospace Industry (1998).
5. Air Transportation Industry (1997).
6. Dry Cleaning Industry (1995).
7. Electronics and Computer Industry (1995).
8. Fossil Fuel Electric Power Generation Industry (1997).
9. Ground Transportation Industry (1997).
10. Health care Industry (2005).
11. Inorganic Chemical Industry (1995).
12. Iron and Steel Industry (1995).
13. Lumber and Wood Products Industry (1995).
14. Metal Casting Industry (1997).
15. Metal Fabrication Industry (1995).
16. Metal Mining Industry (1995).
17. Motor Vehicle Assembly Industry (1995).
18. Nonferrous Metals Industry (1995).
19. Non-Fuel, Non-Metal Mining Industry (1995).
20. Oil and Gas Extraction Industry (1999).
21. Organic Chemical Industry 2nd Edition (2002).
22. Petroleum Refining Industry (1995).
23. Pharmaceutical Industry (1997).
24. Plastic Resins and Man-made Fibres Industry (1997).
25. Printing Industry (1995).
26. Pulp and Paper Industry, 2nd Edition (2002).
27. Rubber and Plastics Industry, 2nd Edition (2005).
28. Shipbuilding and Repair Industry (1997).
29. Stone, Clay, Glass and Concrete Industry (1995).
30. Textiles Industry (1997).
31. Transportation Equipment Cleaning Industry (1995).
32. Water Transportation Industry (1997).
33. Wood Furniture and Fixtures Industry (1995).

The so-called Sector Notebook Project of the US EPA Office of Compliance adds to this series of documents, although it heavily relies on the first series.

UNEP Documents

UNEP has a series of documents, mostly referring to best practices in the agricultural sector, called Industry Sector Guides for Cleaner Production Assessment. At present they cover:

1. Dairy Processing.
2. Fish Processing.
3. Meat Processing.

The documents can be downloaded as PDF-files at:
http://www.agrifood-forum.net/publications/guide/

They are more concerned with introducing good practices in developing countries and contain many examples from such countries.

Descriptions

1. Dairy

The dairy industry processes milk and milk products at dairy processing plants. The life cycle of milk and milk products commences with the production of fresh cow's milk on dairy farms. The upstream process of fresh milk production on dairy farms and the downstream processes of distribution and post-consumer packaging management are not covered. The processing of milk to produce dairy products is, however, a significant contributor to the overall environmental load produced over the life cycle of milk production and consumption. Therefore the application of cleaner production in this phase of the life cycle is important. As in many food-processing industries, the key environmental issues associated with dairy processing (all covered in Section 1) are:

- High consumption of water.
- Generation of high-strength effluent streams.
- Consumption of energy.
- Generation of by-products.

2. Pulp and Paper

The pulp and paper industry converts wood or recycled fibre into pulp and primary forms of paper. *Pulp mills* separate the fibres of wood or from other materials, such as rags, linters, wastepaper, and straw in order to create pulp. *Paper mills* primarily are engaged in manufacturing paper from wood pulp and other fibre pulp, and may also manufacture converted paper products. The pulp and paper industry is an important component of the global manufacturing industry in both economic and environmental terms. In the northern Baltic Sea region, pulp and paper manufacture is responsible for a large part of regional economic activity.

Pulp and paper manufacturing can have potentially serious impacts on the environment and health of both human and wider ecosystems. Environmental problems include high consumption of water, high energy use, pollution of water streams by fibres and chlorinated organics from bleaching chemicals.

Many of the classical problems have been solved today in ways that well illustrate the power of cleaner production approaches. Emissions, however, continue to present toxicity problems. These facts emphasise the need to pursue closed loop strategies. Additionally, the effects of mill process changes on workers and local communities have rarely been factored into the mainstream debate on best routes forward. Decisions on how to make an ecologically responsible pulp mill must take these issues into account.

Pulp and paper is handled both in Section 2 and in Case Study 5.

3. Textile

The textile industry is comprised of a diverse, fragmented group of establishments that produce and/or process textile-related products (fibre, yarn, fabric) for further processing into apparel, home furnishings, and industrial goods. Textile establishments receive and prepare fibres; transform fibres into yarn, thread, or webbing; convert the yarn into fabric or related products; and dye and furnish these materials at various stages of production.

The process of converting raw fibres into furnished apparel and non-apparel textile products is complex; thus, most textile mills specialise. Little overlap occurs between hitting and weaving, or among production of man made, cotton, and wool fabrics.

The classic environmental issues in these sectors include high water consumption, chemical pollution of water streams from dyeing and other wet operations. The work environment issues have also been high on the agenda.

The processes used, cleaner production practices and opportunities in the textile industry are described in more detail in Section 3. Also, Case Study 1 describes a factory for yarn production.

4. Glass

The glass industry in the European Union is very diverse. Products range from intricate hand-made lead crystal goblets to huge volumes of float glass produced for the building and automotive industries. Manufacturing techniques vary from small electrically heated furnaces in the ceramic fibre sector to cross-fired regenerative furnaces in the flat glass sector, producing up to 700 tonnes per day. Container glass production is the largest sector representing around 60% of the total glass production.

Glass manufacturing occurs in glass furnaces with temperatures up to 1650°C or 2000°C in the flame. A main environmental aspect of glass manufacturing is thus energy use, especially fossil fuel use. Another is the air emissions of NO_X, arising from the oxidation of atmospheric nitrogen at temperatures above 1300°C. Several cleaner production programmes address the issue of reducing NO_X emissions. The use of recycled glass, so-called cullet, has become very important. Use of cullet requires less energy, causes fewer emissions to air, and reduces waste. Both internal cullet and external recycled glass are important today. Cullet use in container glass production varies from <20% to >90%, with an EU average of 48%.

Glass manufacturing and its cleaner production practices and opportunities are described in Section 4. Several of the points in this section are of general relevance, such as energy saving and reduction of NO_X emissions.

5. Chlor-Alkali

Elemental chlorine gas is produced in the chlor-alkali process, the electrolysis of sodium chloride solution. Chlorine in turn is used for the production of plastics, notably PVC (polyvinylchloride), and e.g. chlorinated organic solvents. The EU production of chlorine is more than 9 million tonnes per year. As chlorine and sodium hydroxide are produced in fixed proportions there is a corresponding production of NaOH.

Chlorine production is environmentally problematic. The main technology, the mercury cell process, has been a significant source of mercury pollution of air, water, and wastes. The alternative, the diaphragm electrolysis method, is also environmentally problematic since the asbestos from diaphragms pollutes both the surroundings and the work place. There has thus been a strong pressure to change the technology. In Japan, where the industry was pressed to find alternatives in the aftermath of the Minamata Bay disaster, membrane cell electrolysis was developed in the 1970s. Today all chlor-alkali plants in Japan have converted to membrane cell technology. The first European membrane plant opened in 1983 at Akzo in Rotterdam. Still 50 plants in Europe use the mercury cell method using an estimated total of 12,000 tonnes of metallic mercury. Most likely these plants will be forced to change technology by regulation as soon as practicable, and no later than 2010.

Section 5 on the chlor-alkali production describes how to make this technology shift, but also some other main difficulties in chlor-alkali processes, such as the huge demand for electricity and hazards in handling the chlorine gas and caustic soda produced. In all these areas Cleaner Production approaches have been essential. The technique is also treated in Chapter 12.

6. Cement

Cement and concrete (a mixture of cement, aggregates, sand and water) are basic materials for the building and construction industry. Cement production therefore tracks the overall economic situation closely.

Cement is produced from clinker, produced in a large rotating oven, called kiln, at high temperatures. The raw material used is calcium carbonate. The carbonate loses carbon dioxide to air in the calcination reaction at about 900°C to leave calcium oxide, lime, behind. This in turn reacts at high temperature (typically 1400-1500°C) with silica, alumina, and ferrous oxide to form the clinker. The clinker is then ground or milled together with gypsum and other additives to produce cement.

The cement industry is a main emitter of the greenhouse gas carbon dioxide, both because of its high energy use and the calcination reaction. The emission of CO_2 is estimated at 900 to 1,000 kg/tonne of clinker, related to a specific heat demand of approximately 3,500 to 5,000 MJ/tonne of clinker. Approximately 60% originates in the calcination process and the remaining 40% in fuel combustion. Mostly fossils are used as fuels. However, almost any organic compound can be used and clinker production has been fuelled by e.g. old tyres, and has been used for destruction of hazardous waste.

Cleaner production programmes in this sector described in Section 6 are not trivial. Emissions of CO_2 have been progressively reduced by about 30% in the last 25 years mainly by more fuel-efficient kiln processes. But how to reduce CO_2 emissions from calcinations? One way is to reduce the amount of clinker in cement. A case study on environmental management at Kunda Tsement in Estonia is described in Case Study 1, Book 4 in this series.

1 – Dairy Industry

1. Background

Milk Products and the Environment

The dairy industry is processing milk and milk products at dairy processing plants. The life cycle of milk and milk products commences with the production of fresh cow's milk on dairy farms. Milk is then processed to produce pasteurised and homogenised market milk, butter, cheese, yogurt, custard and dairy desserts etc. It may also be preserved for a longer shelf life in the form of long-life (UHT), condensed, evaporated or powdered milk products. The various products are packaged into consumer portions and distributed to retail outlets.

For fresh dairy products, refrigerated storage is required throughout the life of the products to maintain eating appeal and prevent microbiological spoilage. Following use by the consumer, packaging is either discarded or recycled.

Here the upstream process of fresh milk production on dairy farms and the downstream processes of distribution and post-consumer packaging management are not covered. But it is known that the processing of milk to produce dairy products is a significant contributor to the overall environmental load produced over the life cycle of milk production and consumption. Therefore the application of Cleaner Production in this phase of the life cycle is important.

As in many food processing industries, the key environmental issues associated with dairy processing are:

- High consumption of water.
- Generation of high-strength effluent streams.
- Consumption of energy.
- Generation of by-products.

For some sites, noise and odour may also be concerns.

Dairy Processing Industries

Dairy processing occurs world-wide; however the structure of the industry varies from country to country. In less developed countries, milk is generally sold directly to the public, but in major milk producing countries most milk is sold on a wholesale basis. In Ireland and Australia, for example, many of the large-scale processors are owned by the farmers as co-operatives, while in the United States individual contracts are agreed between farmers and processors.

Dairy processing industries in the major dairy producing countries have undergone rationalisation, with a trend towards fewer but larger plants operated by fewer people. In the United States, Europe, Australia and New Zealand most dairy processing plants are today quite large. Plants producing market milk and products with short shelf life, such as yogurts, creams and soft cheeses, tend to be located on the fringe of urban centres close to consumer markets. Plants manufacturing items with longer shelf life, such as butter, milk powders, cheese and whey powders, tend to be located in rural areas closer to the milk supply. The general tendency world-wide, is towards large processing plants specialising in a limited range of products.

In eastern Europe, due to the former supply-driven concept of the market, it is still very common for 'city' processing plants to be large multi-product plants producing a wide range of products.

The general trend towards large processing plants has provided companies with the opportunity to acquire bigger, more automated and more efficient equipment. This technological development has, however, tended to increase environmental loads in some areas due to the requirement for long-distance distribution. Basic dairy processes have changed little in the past decade. Specialised processes such as ultrafiltration (UF), and modern drying processes, have increased the opportunity for the recovery of milk solids that were formerly discharged. In addition, all processes have become much more energy efficient and the use of electronic control systems has allowed improved processing effectiveness and cost savings.

The Sources

This text is extracted from a document on Cleaner Production measures in the dairy industry included in a series of Industrial Sector Guides published by the United Nations Environment Programme UNEP Division of Technology, Industry and Economics (UNEP DTIE) and the Danish Environmental Protection Agency.

http://www.agrifood-forum.net/publications/guide/

2. Dairy Processing

Milk Production

The processes taking place at a typical milk plant include:

- Receipt and filtration/clarification of the raw milk.
- Separation of all or part of the milk fat (for standardisation of market milk, production of cream and butter and other fat-based products, and production of milk powders).
- Pasteurisation.
- Homogenisation (if required).
- Deodorisation (if required).
- Further product-specific processing.
- Packaging and storage, including cold storage for perishable products.
- Distribution of final products.

Figure 1.1 is a flow diagram outlining the basic steps in the production of whole milk, semi-skimmed milk and skimmed milk, cream, butter and buttermilk. In such plants, yogurts and other cultured products may also be produced from whole milk and skimmed milk.

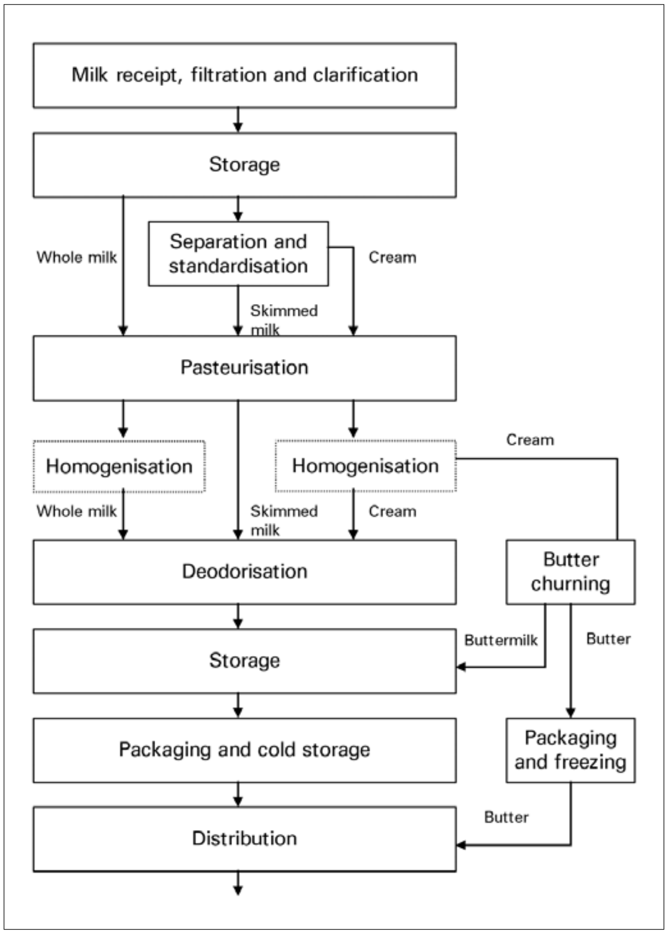


Figure 1.1 *Flow diagram for processes occurring at a typical milk plant.*

Butter Production

The butter-making process, whether by batch or continuous methods, consists of the following steps:

- Preparation of the cream.
- Destabilisation and breakdown of the fat and water emulsion.
- Aggregation and concentration of the fat particles.
- Formation of a stable emulsion.
- Packaging and storage.
- Distribution.

Figure 1.2 is a flow diagram outlining the basic processing system for a butter-making plant. The initial steps, (filtration/clarification, separation and pasteurisation of the milk) are the

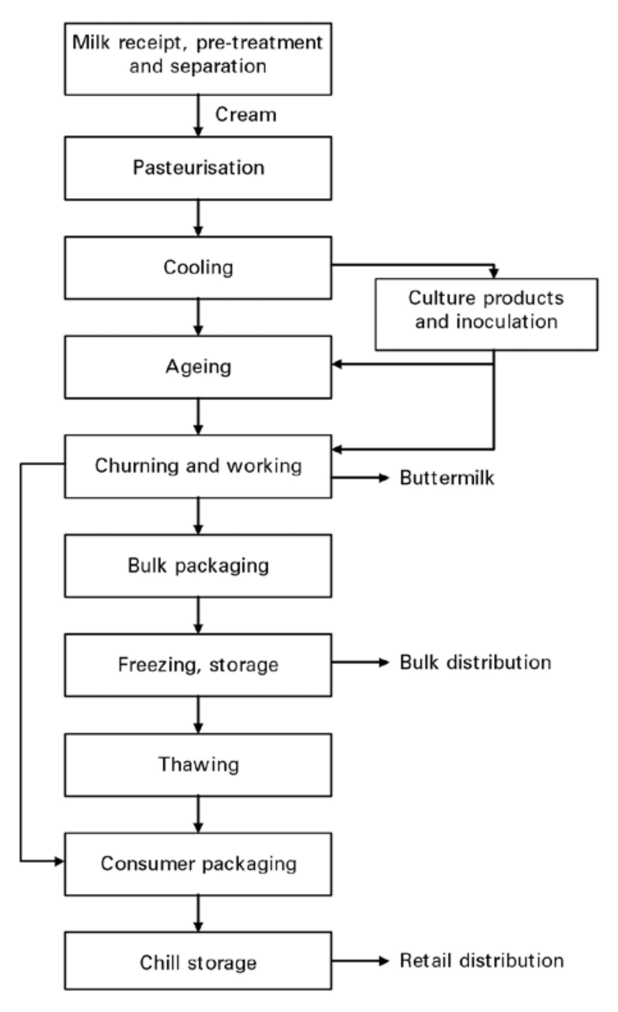


Figure 1.2 *Flow diagram for a typical butter-making plant.*

same as described in the previous section. Milk destined for butter making must not be homogenised, because the cream must remain in a separate phase.

After separation, cream to be used for butter making is heat-treated and cooled under conditions that facilitate good whipping and churning. It may then be ripened with a microbiological culture that increases the content of diacetyl, the compound responsible for the flavour of butter. Alternatively, culture inoculation may take place during churning.

Butter which is flavour-enhanced using this process is termed lactic, ripened or cultured butter. This process is very common in continental European countries. Although the product is claimed to have a superior flavour, the storage life is limited. Butter made without the addition of a culture is called sweet cream butter. Most butter made in the English-speaking world is of this nature.

Cheese Production

Virtually all cheese is made by coagulating milk protein (casein) in a manner that traps milk solids and milk fat into a curd matrix. This curd matrix is then consolidated to express the liquid fraction, cheese whey. Cheese whey contains those milk solids which are not held in the curd mass, in particular most of the milk sugar (lactose) and a number of soluble proteins.

Figure 1.3 outlines the basic processes in a cheese-making plant. All cheese-making processes involve some or all of these steps.

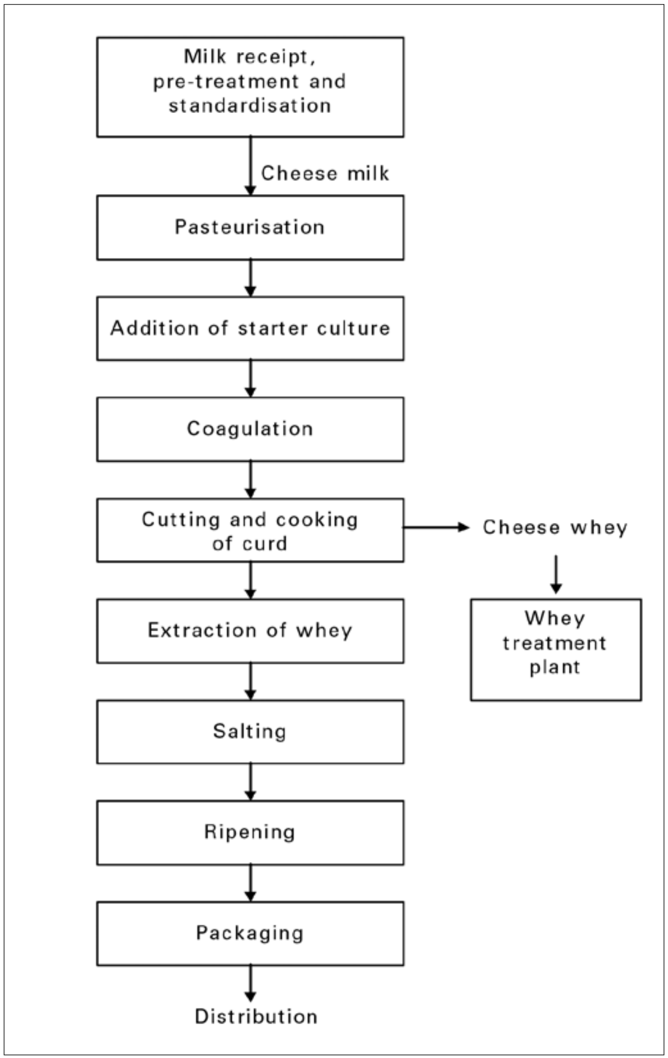


Figure 1.3 *Flow diagram for a typical cheese plant.*

3. Cleaner Production Opportunities

General

Dairy processing typically consumes large quantities of water and energy and discharges significant loads of organic matter in the effluent stream. For this reason, Cleaner Production opportunities focus on reducing the consumption of resources (water and energy), increasing production yields and reducing the volume and organic load of effluent discharges.

At the larger production scales, dairy processing has become an extremely automated process and resource efficiency relies, to a large extent, on the efficiency of plant and equipment, the control systems that are used to operate them and the technologies used to recover resources. As a result many Cleaner Production opportunities lie in the selection, design and efficient operation of process equipment. Operator practices also have an impact on plant performance, for example in the areas of milk delivery, plant maintenance and cleaning operations. Therefore there are also opportunities in the areas of housekeeping, work procedures, maintenance regimes and resource handling.

Good Housekeeping

Many food processors that undertake Cleaner Production projects find that significant environmental improvement and cost savings can be derived from simple modification to housekeeping procedures and maintenance programmes. They are generic ideas that apply to the dairy manufacturing process as a whole. A checklist of general housekeeping ideas is the following:

- Keep work areas tidy and uncluttered to avoid accidents.
- Maintain good inventory control to avoid waste of raw ingredients.
- Ensure that employees are aware of the environmental aspects of the company’s operations and their personal responsibilities.
- Train staff in good cleaning practices.

- Schedule regular maintenance activities to avoid breakdowns.
- Optimise and standardise equipment settings for each shift.
- Identify and mark all valves and equipment settings to reduce the risk that they will be set incorrectly by inexperienced staff.
- Improve start-up and shut-down procedures.
- Segregate waste for reuse and recycling.
- Install drip pans or trays to collect drips and spills.

Water

Water is used extensively in dairy processing, so water saving measures are very common Cleaner Production opportunities in this industry. The first step is to analyse water use patterns carefully, by installing water meters and regularly recording water consumption. Water consumption data should be collected during production hours, especially during periods of cleaning. Some data should also be collected outside normal working hours to identify leaks and other areas of unnecessary wastage.

The next step is to undertake a survey of all process area and ancillary operations to identify wasteful practices. Examples might be hoses left running when not in use, CIP cleaning processes using more water than necessary, etc. Installing automatic shut-off equipment and restricters could prevent such wasteful practices. Automatic control of water use is preferable to relying on operators to manually turn water off.

Once wasteful practices have been addressed, water use for essential process functions can be investigated. It can be difficult to establish the minimum consumption rate necessary to maintain process operations and food hygiene standards. The optimum rate can be determined only by investigating each process in detail and undertaking trials. Such investigations should be carried out collaboratively by production managers, food quality and safety representatives and operations staff.

Box 1.1 Reduction of Water Consumption for Cleaning at an Estonian Dairy Processing Plant

At an Estonian dairy processing plant, open-ended rubber hoses were used to clean delivery trucks. Operators used their fingers at the discharge end of the hose to produce a spray, resulting in ineffective use of water. Furthermore, the hoses were not equipped with any shut-off valve, and the water was often left running.

The operators found that they could reduce water consumption by installing high-pressure systems for cleaning the trucks, the production area and other equipment. Open-ended hoses were also equipped with trigger nozzles. The cost of this equipment was USD 6,450 and the saving in water charges was USD 10,400 per year; a pay back period of less than 8 months. Water consumption has been reduced by 30,000 m^3/year.

When an optimum usage rate been agreed upon, measures should be taken to set the supply at the specified rate and remove manual control. Once water use for essential operations has been optimised, water reuse can be considered. Wastewaters that are only slightly contaminated could be used in other areas. For example, final rinse waters could be used as the initial rinses for subsequent cleaning activities, or evaporator condensate could be reused as cooling water or as boiler feed water. Wastewater reuse should not compromise product quality and hygiene, and reuse systems should be carefully installed so that reused wastewater lines cannot be mistaken for fresh water lines, and each case should be approved by the food safety officer.

A checklist of water saving ideas follows:

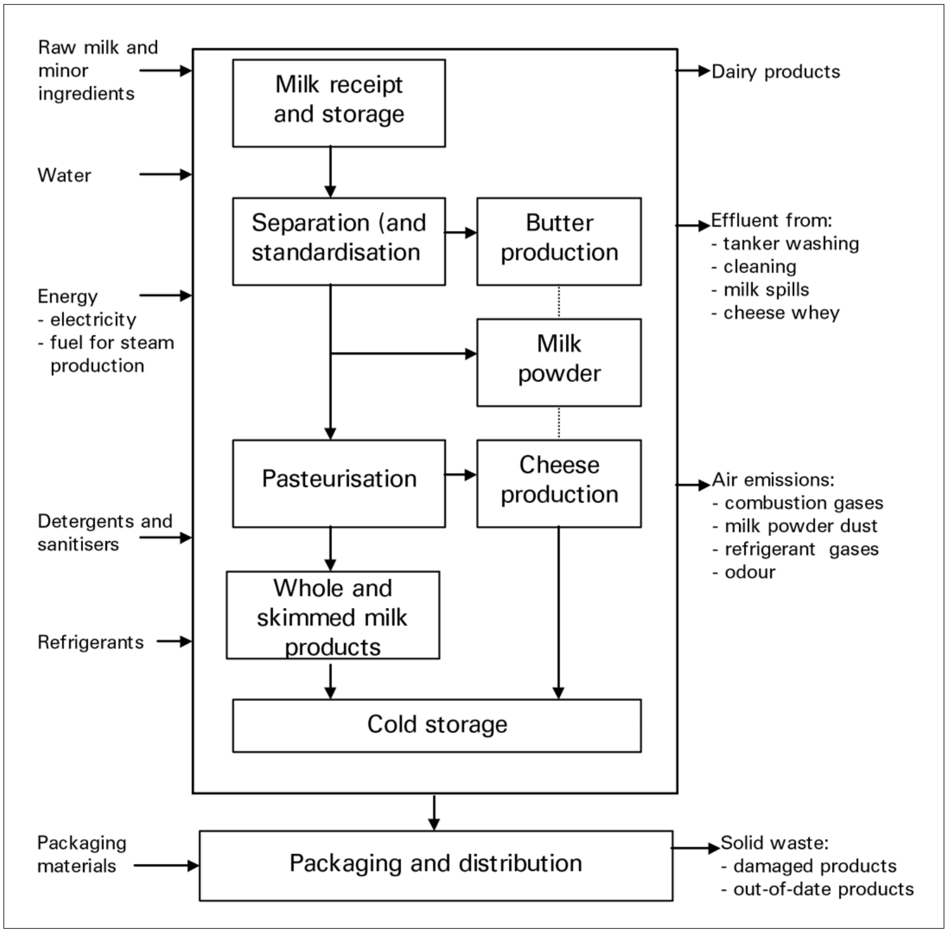
- Use continuous rather than batch processes to reduce the frequency of cleaning.
- Use automated cleaning-in-place (CIP) systems for cleaning to control and optimise water use.
- Install fixtures that restrict or control the flow of water for manual cleaning processes.
- Use high pressure rather than high volume for cleaning surfaces.
- Reuse relatively clean wastewaters (such as those from final rinses) for other cleaning steps or in non-critical applications.
- Recirculate water used in non-critical applications.
- Install meters on high-use equipment to monitor consumption.
- Pre-soak floors and equipment to loosen dirt before the final clean.
- Use compressed air instead of water where appropriate.
- Report and fix leaks promptly.

Reducing Effluent Pollution Loads

Effluent Cleaner Production efforts in relation to effluent generation should focus on reducing the pollutant load of the effluent. The volume of effluent generated is also an important issue. However this aspect is linked closely to water consumption. Therefore efforts to reduce water consumption will also result in reduced effluent generation.

Opportunities for reducing the pollutant load of dairy plant effluent focus on avoiding the loss of raw materials and prod-

Figure 1.4 *Inputs and outputs from milk receipt and storage vessels.*



ucts to the effluent stream. This means avoiding spills, capturing materials before they enter drains and limiting the extent to which water comes into contact with product residue. Improvements to cleaning practices are therefore an area where the most gains can be made.

A checklist of ideas for reducing pollutant loads in effluents:

- Ensure that vessels and pipes are drained completely and using pigs and plugs to remove product residue before cleaning.
- Use level controls and automatic shut-off systems to avoid spills from vessels and tanker emptying.
- Collect spills of solid materials (cheese curd and powders) for reprocessing or use as stock feed.
- Fit drains with screens and/or traps to prevent solid materials entering the effluent system.
- Install in-line optical sensors and diverters to distinguish between product and water and minimise losses of both.
- Install and maintain level controls and automatic shut-off systems on tanks to avoid overfilling.
- Use dry cleaning techniques where possible, by scraping vessels before cleaning or pre-cleaning with air guns.
- Use starch plugs or pigs to recover product from pipes before internally cleaning tanks.

Energy

Energy is an area where substantial savings can be made almost immediately with no capital investment, through simple housekeeping and plant optimisation efforts. Substantial saving are possible through improved housekeeping and the fine tuning of existing processes and additional savings are possible through the use of more energy-efficient equipment and heat recovery systems.

In addition to reducing a plant's demand for energy, there are opportunities for using more environmentally benign sources of energy. Opportunities include replacing fuel oil or coal with cleaner fuels, such as natural gas or biomass, purchasing electricity produced from renewable sources, or cogeneration of electricity and heat on site. For some plants it may also be feasible to recover methane from the anaerobic digestion of high strength effluent streams to supplement fuel supplies.

A checklist of energy saving ideas:

- Implement switch-off programs and installing sensors to turn off or power-down lights and equipment when not in use.
- Improve insulation on heating or cooling systems and pipe work.
- Favour more energy-efficient equipment
- Improve maintenance to optimise energy efficiency of equipment.
- Maintain optimal combustion efficiencies on steam and hot water boilers.
- Eliminate steam leaks.
- Capture low-grade energy for use elsewhere in the operation.

Receipt and Storage of Milk

Raw milk is generally received at processing plants in milk tankers. Some smaller plants may also receive milk in 25–50 L aluminium or steel cans or, in some less developed countries, in plastic barrels. Depending on the structure and traditions of the primary production sector, milk may be collected directly from the farms or from central collection facilities. Farmers producing only small amounts of milk normally deliver their milk to central collection facilities.

At the central collection facilities, operators measure the quantity of milk and the fat content. The milk is then filtered and/or clarified using centrifuges to remove dirt particles as well as udder and blood cells. The milk is then cooled using a plate cooler and pumped to insulated or chilled storage vessels, where it is stored until required for production.

Empty tankers are cleaned in a wash bay ready for the next trip. They are first rinsed internally with cold water and then cleaned with the aid of detergents or a caustic solution. To avoid build-up of milk scale, it is then necessary to rinse the inside of the tank with a nitric acid wash. Tankers may also be washed on the outside with a cold water spray. Until required for processing, milk is stored in bulk milk vats or in insulated vessels or vessels fitted with water jackets. Figure 1.4 is a flow diagram showing the inputs and outputs for this process.

Water is consumed for rinsing the tanker and cleaning and sanitising the transfer lines and storage vessels. The resulting effluent from rinsing and cleaning can contain milk spilt when tanker hoses are disconnected. This would contribute to the organic load of the effluent stream.

Table 1.1 provides indicative figures for the pollution loads generated from the receipt of milk at a number of plants. Table 1.2 provides indicative figures for the pollution loads generated from the washing of tankers. Solid waste is generated from milk clarification and consists mostly of dirt, cells from the cows' udders, blood corpuscles and bacteria. If this is discharged into the effluent stream, high organic loads and associated downstream problems can result.

Cleaner Production opportunities in this area focus on reducing the amount of milk that is lost to the effluent stream and reducing the amount of water used for cleaning. Ways of achieving this include:

- Avoiding milk spillage when disconnecting pipes and hoses.
- Ensuring that vessels and hoses are drained before disconnection.
- Providing appropriate facilities to collect spills.
- Identifying and marking all pipeline to avoid wrong connections that would result in unwanted mixing of products.
- Installing pipes with a slight gradient to make them self-draining.
- Equipping tanks with level controls to prevent overflow.
- Making certain that solid discharges from the centrifugal separator are collected for proper disposal and not discharged to the sewer.
- Using 'cleaning-in-place' (CIP) systems for internal cleaning of tankers and milk storage vessels, thus improving the effectiveness of cleaning and sterilisation and reducing detergent consumption.
- Improving cleaning regimes and training staff.
- Installing trigger nozzles on hoses for cleaning.
- Reusing final rinse waters for the initial rinses in CIP operations.
- Collecting wastewaters from initial rinses and returning them to the dairy farm for watering cattle.

Main product	Wastewater (m^3/tonne milk)	COD (kg/tonne milk)	Fat (kg/tonne milk)
Butter plant	0.07–0.10	0.1–0.3	0.01–0.02
Market milk plant	0.03–0.09	0.1–0.4	0.01–0.04
Cheese plant	0.16–0.23	0.4–0.7	0.006–0.03
Havarti cheese plant	0.60–1.00	1.4–2.1	0.2–0.3

Table 1.1 *Indicative pollution loads from the milk receival area.*

Main product	Wastewater (m^3/tonne milk)	COD (kg/tonne milk)	Fat (kg/tonne milk)
Market milk plant	0.08–0.14	0.2–0.3	0.04–0.08
Havarti cheese plant	0.09–0.14	0.15–0.40	0.08–0.24

Table 1.2 *Indicative pollution loads from the washing of tankers.*

2 – Pulp and Paper Industry

1. The Pulp and Paper Industrial History

In the 1800s, there was a shift away from using cotton rags to make paper. Instead, industrialisation helped wood become the most important source of fibre. The switch from a scarce fibre supply to a plentiful one opened up a vast, renewable, low cost source of fibre raw material, making large-scale paper production possible. Since that time, first mechanical and then chemical methods have been developed to produce pulp from wood.

The pulp and paper industry converts wood or recycled fibre into pulp and primary forms of paper. *Pulp mills* separate the fibres of wood or from other materials, such as rags, linters, wastepaper, and straw in order to create pulp. *Paper mills* primarily are engaged in manufacturing paper from wood pulp and other fibre pulp, and may also manufacture converted paper products. Other companies in the paper and allied products industry use the products of the pulp and paper industry to manufacture specialised products including paper board boxes, writing paper, and sanitary paper.

The Sources

Mazgaj, M., Yaramenka, K., Malovana, O., Cherre, E., Ibraimova, L. *Cleaner Production Measures for Pulp and Paper Industry*. Project report. Section of Industrial Ecology, Royal Institute of Technology, Sweden, 2006.

Miljöinfo från Skogsindustrierna. Skogsindustrierna, 1995.

Brännland, R. *Miljöskydd i cellulosatekniken.* Dept. of Pulp and Paper Technology, Royal Institute of Technology, Sweden, 1994.

Morin, R. (Environmental Manager, SCA Graphics Sundsvall AB.) A lecture in *Cleaner Production*, at the Royal Institute of Technology, Sweden, 2006.

Kraft Pulp Mill Compliance Assessment Guide. US EPA, May 1999.

Profile of the Pulp and Paper Industry. EPA Office of Compliance Sector Notebook Project, 1995.

See also *Case Study 5* on Pulp and Paper Production.

The manufacture of wood pulp is the single most important method for chemically converting wood into useful products, and as such is a highly important component of the global manufacturing industry in both economic and environmental terms. In certain regions, pulp and paper manufacture is a dominant industry and is responsible for a large portion of regional economic activity.

At the same time, pulp and paper manufacture can have potentially serious impacts on environmental quality and hence the health of both human and wider ecosystems.

Environmental Concerns

The presence of resin acids and other unidentified constituents continue to present toxicity problems for all kraft mills, regardless of bleaching chemicals. Ecosystems close to pulp mills which meet relatively tough existing environmental regulations continue to experience significantly reduced diversity in the plants and animals able to live near them. These facts emphasise the need to pursue closed loop strategies.

Additionally, the effects of mill process changes on workers and local communities have rarely been factored into the mainstream debate on best routes forward. Exposure to bleaching chemicals, process gasses, emissions from water treatment ponds, and bacteria and fungi on wood chips and sludge all directly impact the health and safety of the people working in the mill and the people who live near by. Decisions on how to make an ecologically responsible pulp mill must take these issues into account.

For mass-balance, environmental impact evaluation and cleaner production measures identification, the production process (in a life-cycle perspective) can be divided into 7 sub-processes:

1. Raw materials processes.
2. Wood-yard.
3. Fibre line.
4. Chemical recovery.
5. Bleaching.
6. Paper production.
7. Products and recycling.

2. Main Process Technologies

Pulp Production

The objective of the paper production technology is to separate cellulose fibres from the wood structure. The free fibres in the pulp are then the main raw material for paper production. Pulping processes can be of different types that determine what chemicals and amounts of water and energy used in the processes and, consequently, the environmental impacts of production.

Possible types of pulp production are Kraft (68%), mechanical (22%), semi-chemical (4%), sulphite (4%) and dissolving (2%).

Mechanical pulping is a process that uses mechanical force to separate fibres from the wood structure. *Ground wood pulping* was the first type of mechanical pulping process developed in Germany in the 1840s. In this process, wood is mechanically ground against large sandstone cylinders. The pulp is then screened to remove large pieces such as knots, etc. Next, the pulp is washed and bleached for use in paper making. One of the main things to note here is that this kind of pulp still contains lignin (essentially the glue that holds the cellulose fibres together), which means that its strength and brightness are low compared to pulp made from other processes. On the other hand the pulp yield is about 90% (defined as the amount of wood fibres produced per amount of wood raw material used).

Refiner mechanical pulping was introduced in the 1960s. In this process, wood chips pass between disks rotating in reverse directions to separate the fibres. The most common refiner pulping methods are Thermo-mechanical pulping (TMP) and Chemo-thermo-mechanical pulping (CTMP). In these processes, the wood is chopped into chips and then preheated with steam to about 120°C before mechanical force is applied in a disc refiner. In the CTMP process the wood chips are impregnated with sodium sulphite (Na_2SO_3). CTMP produces a pulp that is stronger and somewhat more light-coloured than TMP pulp. Thermo-mechanical pulp is mainly used in the production of newsprint as it is relatively cheap to produce and delivers adequate strength for this end-use. CTMP gives a pulp that has many usage areas, e.g. printing and writing paper and tissue paper.

Chemical pulping, as its name suggests, uses chemical rather than mechanical means of separating the cellulose fibres from each other by removing the lignin, leaving behind the fibre used in paper making. Here, the wood chips are "cooked" in a chemical solution, which dissolves lignin and other impurities.

Since chemical pulping removes lignin and other impurities, it produces a strong, bright pulp that is suited for the production of grades that require these properties, such as fine writing paper.

The first type of chemical pulping developed was *soda pulping*. This process used caustic soda as the chemical solution and was developed in England in the 1850s.

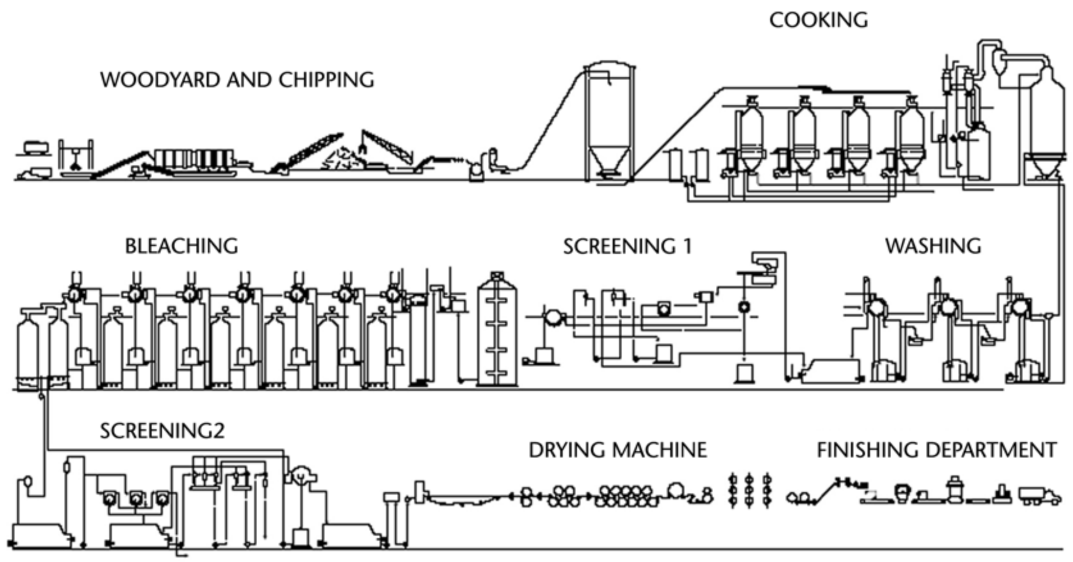


Figure 2.1 *Simplified flow diagram of an integrated pulp and paper mill (chemical pulping, bleaching and paper production) [EPA, 1995].*

A few years later in 1867, *sulphite pulping* was introduced. This process uses calcium, sodium, magnesium or ammonia salts of sulphurous acid as the chemical solution for dissolving lignin.

Sulphate or Kraft Pulping

Sulphate or Kraft pulping was invented in Germany in 1884 and remains the dominating technology today. It produces pulp with much higher strength compared to sulphite pulping. Note that "kraft" means strong in several European languages, including German and Swedish and both Germany and Sweden have long paper industry traditions. Kraft pulping can also use a wider variety of wood species than the sulphite pulping process as it is more effective at removing impurities like resins.

In the kraft pulping process, wood chips are "cooked" in a digester in a solution of sodium hydroxide and sodium sulphide called white liquor. In Kraft pulping the pulp yield is less than 50%.

A bonus of Kraft pulping is that the chemicals can be recycled and re-used in the mill. Another is that kraft fibre is exceptionally strong.

The fact that kraft pulping is the dominant pulping process in the world is the reason why we concentrate on this type of pulping when describing sub-processes within the industry.

Sulphate pulping starts in the *wood yard*: bark and dirt is removed from the wood logs (dry or wet *debarking*), reduced to chip fragments in chippers (*chipping*) and screened for separating fines and oversize chips (*screening*). During *digestion* chips are cooked in a chemical solution called *white liquor*. Batch digesters were developed first and this concept was further developed to create a continuous digester process. Both batch and continuous digesters are used in modern mills today.

In the batch process, the chips are cooked in the white liquor in a digester for several hours under pressure and at high temperature. Following the cooking stage, the chips are then blown into a blow pit which helps to break apart the fibre bundles.

In the continuous process, the chips are first steamed before being continuously fed into the top of the digester. The chips are impregnated with white liquor and cooked as they move downwards through each stage of the digester. The brown stock *washing* is done in several countercurrent stages in the lower half of the digester. The filtrate from this washing is called *black liquor* which is sent to the chemical recovery system. Then knots, bark, shives and other contaminants are removed from the pulp by *screening*. Before the pulp is sent to the bleaching stage (where required), an *oxygen delignification* stage usually is included as the final stage of the cooking section of the process. This process involves treating the pulp with oxygen to further oxidise and dissolve the remaining lignin in the pulp. It is designed to lower the "*kappa number*" of the pulp, which is a measure of its remaining lignin concentration. After the digester a typical coniferous pulp has a kappa number of between 20 and 30, which has a rather dark brown colour. The oxygen delignification stage reduces the kappa number to 10-12. During further *oxygen delignification* approximately half of the remaining lignin can be removed.

Bleaching

Bleaching is needed to remove colour associated with remaining residual lignin. Bleached kraft pulp is mainly used for printing and writing grades, while unbleached kraft pulp is used in the production of packaging grades. The three general approaches to bleaching are:

1. Elemental Chlorine Bleaching.
2. Elemental Chlorine Free Bleaching (ECF).
3. Totally Chlorine Free (TCF) bleaching.

The bleaching chemicals are *injected* into the pulp and the mixture is *washed* with water. This process is repeated several times and generates large volumes of liquid waste. Additionally, vents from the bleaching tanks emit hazardous air pollutants including chloroform, methanol, formaldehyde, and methyl-ethyl-ketone.

Depending on the bleaching chemicals used, the wastewater streams from the bleaching process may contain chlorine compounds and organics. The mixture of chemicals may result in the formation of a number of toxic chemicals (such as dioxins, furans and chlorinated organics). Although this effluent is generally released to a wastewater treatment plant, the chemicals named above simply "pass through" the plant (i.e. the treatment plant does not significantly reduce the concentrations of these pollutants) and accumulate in the rivers, lakes and oceans to which the treatment plant discharges.

Commonly used bleaching chemicals are elemental chlorine (C), sodium hypochlorite (H), chlorine dioxide (D), oxygen (O), ozone (Z) and hydrogen peroxide (P). In ozone and hydrogen peroxide bleaching it is necessary to stabilise the bleaching chemicals by removing metals from the pulp with a complexing agent (Q) such EDTA or DTPA. The E extraction stage uses sodium hydroxide to extract water insoluble chlorinated lignin and other coloured compounds from the pulp.

The bleaching process generally consists of a series of stages utilising alternating acidic and alkaline bleaching agents. Figure 2.2 shows some examples of typical bleaching sequences.

The Process Flowsheet

The process flowsheet of the kraft process is designed to recover the cooking chemicals and heat. In the recovery line, spent cooking liquor and the pulp wash water are combined to form a weak black liquor which is concentrated through *evaporation* from 16% to 60-80% solids in a multiple-effect evaporator system. The strong black liquor is then incinerated in a *recovery boiler.* Combustion of the organics dissolved in the black liquor provides heat for generating process steam. The carbon dioxide formed in the combustion reacts with part of the sodium in the black liquor to sodium carbonate (Na_2CO_3) and the sulphur content is converted to sodium sulphate (Na_2SO_4). The sulphate is converted to sodium sulphide (Na_2S) by reduction with carbon present in the melted slag at the bottom of the furnace.

The smelt is dissolved in water to form *green liquor*, which is transferred to a causticizing tank where quicklime (calcium oxide) is added to precipitate the carbonate content in the green liquor as calcium carbonate and instead produce the sodium hydroxide needed to convert the solution back to white liquor for return to the digester system. The precipitate from the causticizing tank is calcined in a lime kiln to regenerate quicklime.

Production of paper starts with *stock preparation* where various grades of pulp are mixed in a *mixing chest* to obtain the desired properties, *refined* to increase the strength of the paper, *screened* and *cleaned*. After that, different dyes, defoamers, fillers and retention agents are added (*filling*) and the consistency is adjusted with the addition of water ("white water") before the pulp suspension enters the head box of the paper machine.

In the paper machine the fibre suspension is introduced to the wire net, where water is drained assisted with rolls, foils, and vacuum boxes (*dewatering*). It is further dewatered by *pressing* (up to a solid content of around 50%), and *drying* (to about 95% solids content).

Examples of *finishing operations* are sizing, coating, dyeing, and calendering. It includes not only the processes that take place at the factory itself, but also those of raw materials and products, such as transportation and final disposal. This life-cycle approach can be useful to define cleaner production measures as they can probably involve product modification or raw materials substitution.

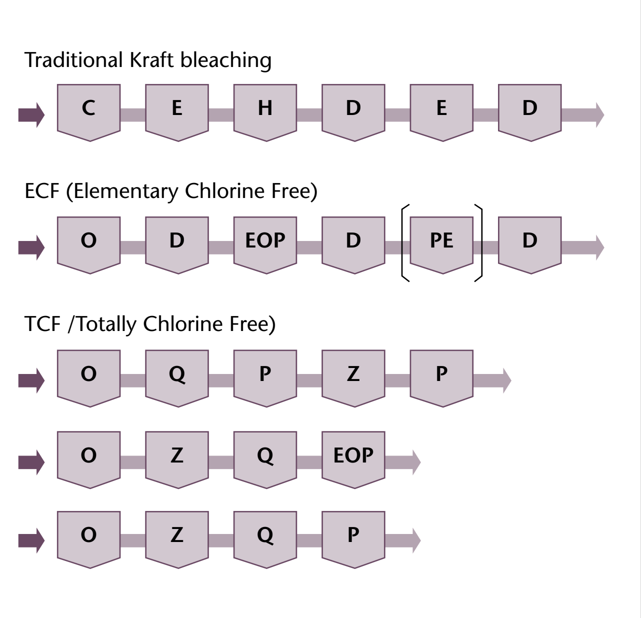


Figure 2.2 *Examples of bleaching sequences [adapted from Miljö-info från Skogsindustrierna, 1995].*

3. The Most Important Cleaner Production Measures

The following CP measures are the most important in pulp and paper industry:

- *Chlorine-free production* – decreasing wastewater and air emissions toxicity. Almost without exception, the literature indicates that oxygen based bleaching sequences have also a superior efficiency over chlorine dioxide based sequences in this area. Even when combined with potential increased energy consumption in some oxygen based configurations, these mill designs are the most energy efficient available. Oxygen based kraft pulp show no appreciable shortcomings in quality relative to chlorine dioxide bleached products whereas oxygen based bleaching chemicals present the least immediate and long term hazards for workers and the general public.
- *Co-production* – recovering by-products from main production residue (decreasing solid wastes and wastewater amount and decreasing recourse consumption by creating a type of industrial symbiosis).
- *Closed loop operations* – decreasing discharges and saving water and resource consumption.
- *Chemicals recovery* – decreasing recourse consumption, wastewater amount and accident risks connected with chemicals transportation.
- Increasing the amount of *product recycling after use* (decreasing recourse and energy consumption and solid wastes to landfill).
- *Effective waste management* – segregating waste streams, waste separation prior to disposal for further recycling;

increasing recycled wastes within a company (chips, pulp, paper); producing energy from wastes; training employees in hazardous waste regulations.
- *Reduction of water consumption* – monitoring and analysing water consumption; reducing or elimination freshwater use where possible (wood-yard, brown stock washing, screening, causticizing system); replacing pump seals with mechanical seals; choosing less water-demanding process types (e.g. dry debarking).
- *Energy conservation* – choosing less energy-demanding process types (e.g. dry debarking); generating company's own power (e.g. from wastes or steam); improving the efficiency of high energy consumption equipment; steam meters provision; using "clean" fuels.
- *Effective wastewater treatment* – avoiding excessive treatment chemicals; conducting chemical analyses; comparing analytical results with compliance levels on a daily basis; recycling a part of the treated effluent back into the process.
- *Equipment maintenance* – effective belts for drainage, filtration, pressing etc.; design for decreasing discharges.
- *Effective air pollution prevention* – removing hazardous substances from the air by effective gas collection and gas treatment systems.
- *Increasing processes efficiency* – choosing more effective process types (e.g. kraft pulping instead of soda pulping).
- *Safe product and raw material handling and storage* – training employees to keep accurate records of chemicals used; keeping minimum supply of chemicals needed; labelling areas with keeping hazardous substances.
- *Reducing employees' hazards* – eye protection and noise reduction measures; spill collection systems; training employees on safety handling spills and spill reporting.

Thus, an *ideal paper mill* from cleaner production point of view is a chlorine-free and zero-discharge one, with minimised quantity and toxicity of air pollution and solid wastes. It is seen that closed loops represent the most effective approach to save both energy and resource consumption and at the same way to decrease all kind of wastes production. Such an approach is developed in the form of paper recycling, different types of substances reuse during production processes, co-production and chemicals recovery; nonetheless, it still provides opportunities to improve the processes. *Future research* can develop more sustainable reuse options for kraft pulping solid wastes, as well as pulping methods that result in purified by-products that can serve as feedstock for other manufacturing processes.

4. The Raw Materials

Wood

Raw materials for the pulp and paper production processes start with the forestry or chemical industry, which is followed by transport to the place of use and storage.

Important cleaner production measures include:

- Maintaining *moisture content* of the raw materials constant all year around.
- Keeping *chemical inventory to a minimum* (only as much as needed for current production) and buying small containers of infrequently used materials.
- *Labelling* storage area for hazardous substances.
- Providing *spill containment and collection systems* during storage.
- *Genetically modifying* forest trees.

Pulp and paper industries exploit biological raw materials, which are synthesised, modified and degraded in nature by microbes using a vast array of specific enzymes. Even though the pulp and paper industries have traditionally relied on mechanical and chemical processes, the potential for biotechnology is significant. Today, there is an increasing interest in biotechnology in order to develop environmentally compatible processes, to lower the energy consumption in mechanical pulping procedures and to develop new tools for improving the quality and the performance of the products.

Lignin is the main wood component that must be effectively removed from the pulp in order to guarantee high brightness of the subsequent paper products. The biochemistry and molecular biology of lignin biosynthesis are currently well understood, so it has been possible to use genetic engineering to modify lignin content and/or composition in poplars.

For example, suppression of the final enzyme in the biosynthesis of lignin monomers results in lignin with altered structure. Suppression of an enzyme involved in syringyl (S) lignin synthesis, results in dramatic reduction in S lignin content.

Kraft pulping of the transgenic tree trunks showed that these genetic modifications had improved characteristics, allowing easier delignification, using smaller amount of chemicals, while yielding more high-quality pulp.

Owing to the genetic modification savings in energy and pollutant chemicals were also achieved, thus leading to an environmentally more sustainable process.

The Wood-yard

Raw materials for the pulp and paper production processes start with the forestry or chemical industry, which is followed by transport to the place of use and storage.

Important cleaner production measures include:

- Maintaining *moisture content* of the raw materials constant all year around.
- Keeping *chemical inventory to a minimum* (only as much as needed for current production) and buying small containers of infrequently used materials.
- *Labelling* storage area for hazardous substances.
- Providing *spill containment and collection systems* during storage.

Wood-yard process includes debarking, slashing, chipping of wood logs and then screening of wood chips/secondary fibres (some pulp mills purchase chips and skip this step). The process is designed to supply a homogenous pulping feedstock.

The bark is usually either stripped mechanically or hydraulically with high powered water jets in order to prevent contamination of pulping operations. Hydraulic debarking methods may require a drying step before burning the bark. Usually, hydraulically removed bark is collected in a water flume, dewatered, and pressed before burning. Treatment of wastewater from this process is difficult and costly, whereas in dry debarking methods the removed bark can be channelled directly into a furnace.

Wet debarking produces 3-20 m³ wastewater/t processed material containing 15-50 kg suspended solids/t and 5-10 kg BOD_5/t and consumes about 20 kWh energy/t. Dry debarking will give 0-5 m³ wastewater/t processed material containing 0-10 kg suspended solids/t and 0-3 kg BOD_5/t and consumes about 20 kWh energy/t.

Important cleaner production measures include:

- Pulp *mills integrated with lumbering facilities*: acceptable lumber wood is removed during debarking; residual or waste wood from lumber processing is returned to the chipping process; in-house lumbering rejects can be a significant source of wood furnish.
- *Avoiding hydraulic debarking* – saving energy and water consumption, reducing wastewater amount.
- *Reusing leachate water*.
- *Co-production from bark*: mulch, ground cover, charcoal.
- *Burning bark* from debarking and small chips from chipping for energy production (depends on the moisture content).

Chemicals Recovery

Chemical recovery serves several important functions in a modern pulp mill: it removes water from the weak black liquor in evaporators and concentrators to enable incineration of the black liquor; it selectively removes organic contaminants from the water to allow for reuse in the pulp mill; it incinerates the concentrated black liquor in the recovery boiler; it recovers heat from the incineration process for steam generation and it dissolves the produced chemicals in water for future processing for pulping liquor generation.

Kraft pulping is a closed loop process in which the chemicals used to make pulp are recycled and reused in a digester. The recovery boiler is crucial to the process. It serves three critical functions in this process. Firstly it makes use of chemical energy in the organic portion of the liquor, to generate steam for the mill, secondly, it plays a major part in the sulphate process as a chemical reactor, and thirdly it destroys the dissolved organic matter and thus eliminates an environmental discharge. The black liquor recovery boiler functions as both a steam boiler and chemical reactor. It generates steam from the energy liberated during combustion of the organic constituents of black liquor, while chemicals from pulp digesting, such as sulphur and sodium, are recovered as smelt.

Important cleaner production measures include:

- Use of *new technologies* (Combined Heat and Power generation (CHP), heat transfer, heat exchange).
- Improvements of the *technical parameters of the recovery boiler* or furnace (geometrical shape etc.).
- *Use of light gas strippers and gas separation systems* which will remove hazardous and foul smelling pollution from the air and increase work place safety.
- *Deaerator tanks ahead of the boilers* to help reduce the intake of freshwater.
- Air emissions control devices.
- Providing *spill containment and collection systems*.

Use of Recycled Paper

After the production stage the product is transported to the place of distribution and use; after use it becomes either solid waste (and disposed to landfill or burnt) or can be considered as secondary resource for production.

Important cleaner production measures include:

- *Increasing recycling rates.* Recycling reduces energy consumption, decreases combustion and landfill emissions, and decreases the amount of carbon dioxide in the atmosphere. When paper products are reduced or recycled, trees that would otherwise be harvested are left standing. These living trees absorb carbon dioxide, a greenhouse gas. This process also saves money since recycling fibre is cheaper than harvesting and processing virgin fibre.
- Possibility for *easy packaging recycling*.
- Using *“green” fuel for transportation*.

Almost any kind of paper (newspaper, cardboard, packaging, postal mail, wrapping paper, catalogues) can be recycled. The use of recovered paper for new paper production substitutes the wood fibre and extends the life cycle. This is described as "the urban forest" as opposed to "the natural forest". The wood fibre, depending on quality can be reused four to six times in process of forming new paper. The recycling of paper is a perfect example of the paper industry's sustainable use of resources.

The Recycling Process

In Europe an average of 56% of used paper is recovered. The recycling process includes following stages:

Sorting: not all paper can be recovered. There are paper products that cannot be either collected or recycled. The portion of such paper products, which consist, for example, of cigarette papers, wallpaper, tissue papers and archives, is estimated to be about 19% of the total paper consumption. Sorting is the first stage of conversion of waste paper into the new one. Waste paper is divided into categories (newsprint, computer paper, magazines). The part that is suitable is shipped to further processing.

Dissolving: in this stage of paper recovery stickies and dioxins are eliminated. Paper is soaked and broken in giant washers and treated with chemicals. Stickers – sticky contaminants such as tapes or plastics covers – reduce paper quality and cause paper machines downtime. To eliminate sticky contaminants paper fibres should be grounded to particles size of <0,5 mm. Then the paper is extracted with CO_2 in 60°C and 34.5 MPa. Extraction efficiency for stickers removal is 55-75%. Another problem is presence of small quantities of dioxins and other chlorinated organic compounds. Kraft pulp may contain small but detectable levels of dioxins and related compounds, especially if their bleaching process used elemental chlorine. To eliminate dioxins recycled paper also is grounded to particles size of <0,5 mm. CO_2 solvent extraction conditions are 71°C and 34,5 MPa. Dioxin extraction efficiency is up to 95%.

De-inking: it is one of the key operations performed in recycling paper. The heat used in laser printing makes ink hard to remove because it deposits ink on the fibres. Traditional deinking processes rely on chemical and mechanical actions to remove ink from fibres and include several dispersion, flotation and washing steps. They thus reduce fibre strength, which must be compensated for with the addition of fortifying chemicals. A new technology, based on the electric field has been developed. The reactor comprises an anode and a cathode. Applying the direct current field to a reactor full of fibre slurry attracts the ink particles away from the fibres and causes the ink to coagulate. The massed particles float to the surface of the slurry with some help from gas bubbles generated by the electric field. The coagulated ink is then skimmed off the top of the slurry using rotation scoops, continuous conveyors. The current also helps remove dust particles from the fibre and creates oxygen in the reactor, both actions improve fibre brightness and whiteness.

Mixing: finally, the wet, shredded waste paper is blended with another material (wood pulp, chemicals) according to the type of end product is desired. Paper cannot be recycled indefinitely. Each time it is recycled, its quality degrades slightly because the fibres become more and more broken. At some point recycled paper has to be mixed in with virgin material, and eventually after repeated uses, it ends up in a landfill or and incinerator.

The paper making process itself is pretty much the same whether one uses virgin materials, recycled materials, or a mixture of the two.

Internet Resources

EIA Renewables

http://www.eia.doe.gov/cneaf/solar.renewables/at_a_glance/wood/woodenfa-03a.htm

EUROPA – Forest-based industries

http://europa.eu.int/comm/enterprise/forest_based/pulp_en.html

Reach for Unbleached Foundation – Human Health

http://www.rfu.org/cacw/pollutionhealth.htm

Paperonline

http://www.paperonline.org/

EIA Forest Products Industry Analysis Brief – MECS 1998

http://www.eia.doe.gov/emeu/mecs/iab98/forest/sources.html

Energy Conservation in the Pulp and Paper Industry

http://www.caddet.org/reports/display.php?id=995/

Environmental Impact assessment and environmental auditing in the pulp and paper industry, FAO Forestry Paper 129, 1996

http://www.fao.org/docrep/005/V9933E/V9933E00.htm

Vu Tuong Anh CLEANER PRODUCTION AUDIT IN THE PULP AND PAPER INDUSTRY: A CASE STUDY IN VIETNAM – Thesis submitted in partial fulfilment of the requirement for the degree of Master of Science

http://www.faculty.ait.ac.th/visu/Data/AIT-Thesis/Master%20Thesis%20final/Tuong%20pdf%2096.pdf

Gouvernement du Canada

http://www.biostrategy.gc.ca/english/view.asp?x=540&mid=50

Pulp and Paper Industry EPA Office of Compliance Sector Notebook Project Profile of the Pulp and Paper Industry 2nd Edition November 2002

http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/pulppasn.pdf

Reach for Unbleached Foundation – Sludge from Pulp and Paper Mills

http://www.rfu.org/cacw/pollutionSludge1.htm

The Irish Scientist

http://www.irishscientist.ie/2002/contents.asp?contentxml=02p153b.xml&contentxsl=is02pages.xsl

Damage Caused by the Paper Industry

http://www.cwac.net/paper_industry/

Inland Paper board and Packaging, Rome Liner board Mill Energy Assessment

http://www1.eere.energy.gov/industry/bestpractices/pdfs/inlandpaper.pdf

De-inking Recycled Paper: A brighter future thanks to Georgia Tech de-inking research

http://gtresearchnews.gatech.edu/reshor/deink.html

3 – Textile Industry

1. Introduction

Industrial Processes in the Textile Industry

The textile industry is comprised of a diverse, fragmented group of establishments that produce and or process textile-related products (fibre, yarn, fabric) for further processing into apparel, home furnishings, and industrial goods. Textile establishments receive and prepare fibres; transform fibres into yarn, thread, or webbing; convert the yarn into fabric or related products; and dye and furnish these materials at various stages of production.

The process of converting raw fibres into furnished apparel and non-apparel textile products is complex; thus, most textile mills specialise. Little overlap occurs between hitting and weaving, or among production of man-made, cotton, and wool fabrics. The processes consists of:

1. Yarn formation.
2. Fabric formation.
3. Wet processing.
4. Fabrication.

These stages are highlighted in the process flow chart shown in Figure 3.1.

Material Use

The twentieth century has seen the development of the fist man-made fibres (rayon was first produced in 1910). Although natural fibres (wool, cotton, silk, and linen) are still used extensively today, they are more expensive and are often mixed with man-made fibres such as polyester, the most widely used synthetic fibre.

Man-made fibres include 1) cellulosic fibres, such as rayon and acetate, which are created by reacting chemicals with wood pulp; and 2) synthetic fibres, such as polyester and nylon, which are synthesised from organic chemicals. Since man-made fibres are synthesised from organic chemicals, yarn formation of man-made fibres does not involve the extensive cleaning and combing procedures associated with natural fibres. Man-made fibres, both synthetic and cellulosic, are manufactured using spinning processes that simulate or resemble the manufacture of silk.

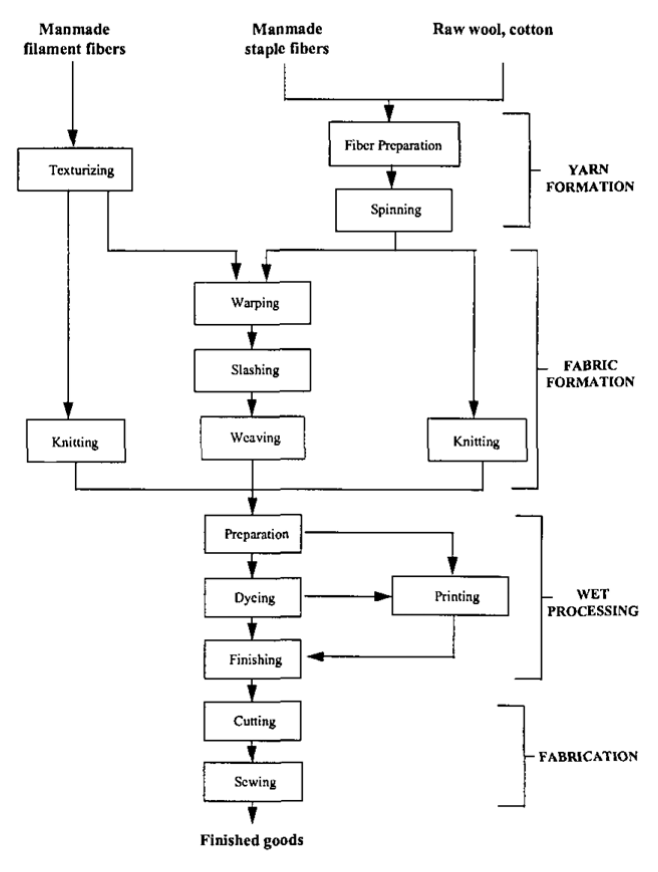


Figure 3.1 *Typical textile processing flow chart [US EPA, 1997].*

The Sources

Sector Notebook Project: Profile of the Textile Industry. US EPA, Office of Compliance, 1997. http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/textilsn.pdf

Best Management Practices for Pollution Prevention in the Textile Industry. US EPA, Office of Research and Development, 1995.

Additional references are cited in the text.

2. Industrial Processes

Yarn Formation

Textile fibres are converted into yarn by grouping and twisting operations used to bind them together. Although most textile fibres are processed using spinning operations, the processes vary depending on whether the fibres are natural or man-made. Natural fibres, known as staple when harvested, include animal and plant fibres, such as cotton and wool. These fibres must go through a series of preparation steps before they can be spun into yarn, including opening, blending, carding, combing, and drafting. Man-made fibres may be processed into yarn or staple-length fibres so that they can be spun. Filament yarn may be used directly or following further shaping and texturising.

Yarn formation can be performed once textile fibres are uniform and have cohesive surfaces. Natural fibres are first cleaned to remove impurities and are then subjected to a series of brushing and drawing steps designed to soften and align the fibres.

Tufts of fibre are conveyed by air stream to a *carding machine*, which transports the fibres over a belt equipped with wire needles. A series of rotating brushes on top of the belt causes the fibres to tease out and align into thin, parallel sheets. Several card slivers are fed to the *combing machine* and removed as a finer, cleaner, and more aligned comb sliver. Slivers are then combined into a continuous, rope-like strand and fed to a machine known as a *drawing frame*. The drawing frame contains several sets of rollers that rotate at successively faster speeds. As the slivers pass through, they are further drawn out and lengthened, to the point where they may be five to six times as long as they were originally. *Drafting* then uses a frame to stretch the yarn further and winds it onto a rotating spindle.

The fibres are now spun together into either spun yarns or filament yarns. Filament yarns are made from continuous strands of man-made fibre (e.g. not staple length fibres). Spun yarns are composed of overlapping staple length fibres that are bound together by twist. Filament yarns may be used directly to make fabric or further twisted to the desired consistency.

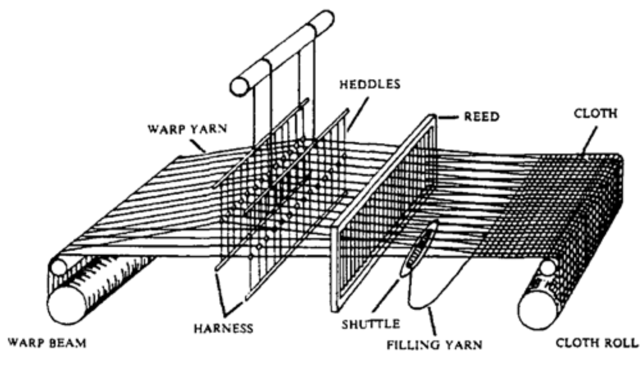


Figure 3.2 *Typical shuttle loom [I.B. Wingate, Fairchild's Dictionary of Textiles, Fairchild Publications, 1979].*

Man-made *fibre spinning* is the process of forming fibres by forcing a liquid through a small opening beyond which the extruded liquid solidifies to form a continuous filament. Following spinning, the man-made fibres are drawn, or stretched, to align the polymer molecules and strengthen the filament. Man-made filaments may then be texturised or otherwise treated to simulate physical characteristics of spun natural fibres.

Fabric Formation

The major methods for fabric manufacture are weaving and knitting. *Weaving*, or interlacing yarns, is the most common process used to create fabrics. Weaving mills classified as broad woven mills consume the largest portion of textile fibre and produce the raw textile material from which most textile products are made.

Weaving is performed on modern looms, which contain similar parts and perform similar operations to simple hand-operated looms. Fabrics are formed from weaving by interlacing one set of yarns with another set oriented crosswise. The warp yarns are then unwound and passed through a sue solution (sizing klashing) before being wound onto a warp beam in a process known as beaming.

Shedding is the raising of the warp yarns to form a shed through which the filing yarn, carried by the shuttle, can be inserted. The shed is the vertical space between the raised and un-raised warp yarns.

The filling yarn is wound onto a quill, which in turn is mounted in the shuttle. As the shuttle moves back and forth across the shed, it weaves an edge. Conventional shuttle looms can operate at speeds of about 150 to 160 picks per minute. With each weaving operation, the newly constructed fabric must be wound on a cloth beam.

Knitted fabrics may be constructed by using hooked needles to interlock one or more sets of yarns through a set of loops. Tufting is a process used to create carpets, blankets, and upholstery. Tufting is done by inserting additional yarns into a ground fabric of desired weight and yarn content to create a fabric.

Wet Processing

Woven and knit fabrics cannot be processed into apparel and other finished goods until the fabrics have passed through several water-intensive wet processing stages. Wet processing enhances the appearance, durability, and serviceability of fabrics by converting un-dyed and unfinished goods, known as gray or greige (pronounced gri[zh]) goods, into finished consumers' goods. Also collectively known as finishing, wet process-

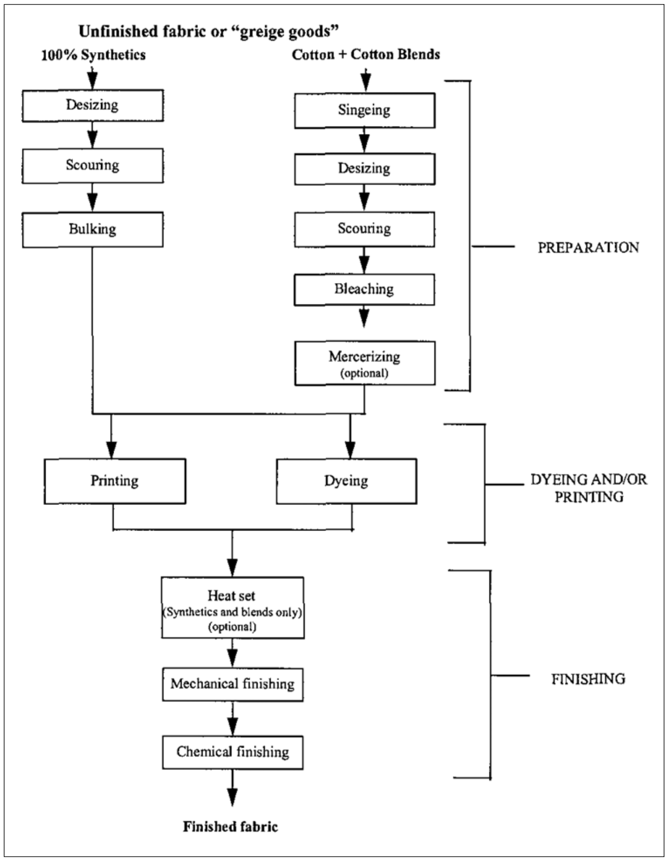


Figure 3.3 *Typical wet processing steps for fabrics [ATMI, Textiles: America's First Industry, 1997].*

ing has been broken down into four stages: fabric preparation, dyeing, printing, and finishing. In terms of waste generation and environmental impacts, wet processing is the most significant textile operation.

Much of the waste generated from the industry is produced during the wet processing stages; Relatively large volumes of wastewater are generated, containing a wide range of contaminants that must be treated prior to disposal. Significant quantities of energy are spent heating and cooling chemical baths and drying fabrics and yarns [Snowden-Swan, 1995].

Fabric Preparation

Most fabric that is dyed, printed, or finished must first be prepared. In preparation, the mill removes natural impurities or processing chemicals that interfere with dyeing, printing, and finishing. If fabrics contained no contamination upon arrival for wet processing, preparation processes would be unnecessary, eliminating about half the pollution outputs from wet processing and a significant amount of wastewater. The primary pollutants from preparation is wastewater containing alkalinity, BOD, COD, and relatively small amounts of other contaminants such as metals and surfactants.

If a fabric is to have a smooth finish, *singeing* is essential. Singeing is a dry process used on woven goods that removes fibres protruding from yarns or fabrics. These are burned off by passing the fibres over a flame or heated copperplates.

Desizing is an important preparation step used to remove size materials applied prior to weaving. Man-made fibres are generally sized with water-soluble sizes that are easily removed by a hot-water wash or in the scouring process. Natural fibres such as cotton are most often sized with water-insoluble starches or mixtures of starch and other materials. Enzymes are used to break these starches into water-soluble sugars, which are then removed by washing before the cloth is scoured.

Scouring is a cleaning process that removes impurities from fibres, yarns, or cloth through washing. Alkaline solutions are typically used for scouring; however, in some cases solvent solutions may also be used. Scouring uses alkali, typically sodium hydroxide, to break down natural oils and surfactants and to emulsify and suspend remaining impurities in the scouring bath.

Bleaching is a chemical process that eliminates unwanted coloured matter from fibres, yarns, or cloth. Bleaching decolorises coloured impurities that are not removed by scouring and prepares the cloth for types of chemicals are used as bleaching agents. The most common bleaching agents include hydrogen peroxide, sodium hypochlorite, sodium chlorite, and sulphur dioxide gas.

Mercerisation is a continuous chemical process used for cotton and cottoned polyester goods to increase dye ability, lustre, and appearance. This process, which is carried out at room temperature, causes the flat, twisted ribbon-like cotton fibre to swell into a round shape and to contract in length. During mercerising, the fabric is passed through a cold 15 to 20% solution of caustic soda and then stretched out on a tenter frame where hot-water sprays remove most of the caustic solution.

Dyeing and Printing

Dyeing operations are used at various stages of production to add colour and intricacy to textiles and increase product value. Most dyeing is performed either by the finishing division of vertically integrated textile companies, or by specialty dye houses. Dyes used by the textile industry are largely synthetic; typically derived from coal tar and petroleum-based intermediates. Dyes are sold as powders, granules, pastes, and liquid dispersions, with concentrations of active ingredients ranging typically from 20 to 80%.

Dyeing can be performed using continuous or batch processes. In batch dyeing, a certain amount of textile substrate, usually 100 to 1,000 kilograms, is loaded into a dyeing machine and treated with a solution containing the dye. The dye molecules attach to the fibres over a period of minutes to hours. Auxiliary chemicals and controlled dye bath conditions, mainly temperature, accelerate and optimise the action. The dye is fixed in the fibre using heat and/or chemicals, and the tinted textile substrate is washed to remove unfixed dyes and chemicals.

Fabrics are often printed with colour and patterns. Of the numerous printing techniques, the most common is rotary screen. Other methods used include direct, discharge, resist, flat screen and roller printing. Pigments used in most printing operations do not require washing steps and generate little waste [Snowden-Swan, 1995]. Compared to dyes, pigments are typically insoluble and have no affinity for the fibres. Resin binders are typically used to attach pigments to substrates. Solvents are used as vehicles for transporting the pigment and resin mixture to the substrate. The solvents then evaporate leaving a hard opaque coating.

Finishing

Finishing encompasses chemical or mechanical treatments performed on fibre, yarn, or fabric to improve appearance, texture, or performance. Mechanical finishes can involve brushing, ironing or other physical treatments used to increase the lustre and feel of textiles. Application of chemical finishes to textiles can impart a variety of properties ranging from decreasing static adherence to increasing flame resistance. The most common chemical finishes are those that ease fabric care, such as the permanent-press, soil-release, and stain resistant finishes. Chemical finishes are usually followed by drying, curing, and cooling steps. Application of chemical finishing is often done in conjunction with mechanical finishing steps.

Mechanical and Chemical Treatments

Heat setting is a dry process used to stabilise and impart textural properties to synthetic fabrics and fabrics containing high concentrations of synthetics. When man-made fibres are heat set, the cloth maintains its shape and size in subsequent finishing operations and is stabilised in the form in which it is held during heat setting. Brushing and napping decrease the lustre of fabrics by roughening or raising the fibre surface and change the feel or texture of the fabric. Calendering or ironing can be used to reduce surface friction between individual fibres, thereby softening the fabric structure and increasing its sheen. Lustre can be added to yarns by flattening or smoothing the surfaces under pressure. This can be achieved by beating the fabric surface or passing the fabric between calendering rolls. Shearing removes surface fibres bypassing the fabric over a cutting blade. Compacting compresses the fabric structure to reduce stresses in the fabric.

Optical finishes added to either brighten or delustre the textile. Absorbent and soil release finishes alter surface tension and other properties to increase water absorbency or improve soil release. Softeners and abrasion-resistant finishers are added to improve feel or to increase the ability of the textile to resist abrasion and tearing. Physical stabilisation and crease-resistant finishes may include formaldehyde-based resin finishes, stabilise cellulosic fibres to laundering and shrinkage, imparting permanent press properties to fabrics.

Fabrication

Finished cloth is fabricated into a variety of apparel and household and industrial products. The simpler of these products, such as bags, sheets, towels, blankets, and draperies, often are produced by the textile mills themselves. Apparel and more complex house wares are usually fabricated by the cutting trades. Before cutting, fabrics must be carefully laid out. Accuracy in cutting the lay fabric is important since any defects created at this point may be carried through other operations and end up in the final product. For simple household and industrial products, sewing is relatively straightforward. The product may then be pressed to flatten the fabric and create crisp edges.

3. Environmental Impacts

Management of Chemicals in the Production Process

USA 1997 data indicate that about 57% of the toxic wastes were managed on-site through recycling, energy recovery, or treatment. About 11% of the wastes were managed off site. The remaining portion of toxic chemical wastes (about 33%) were released to the environment through direct discharges to air, land, water, and underground injection, or were disposed off-site.

The releases and transfers are dominated by large volumes of solvents which are used extensively in coating textile materials with plastic and other synthetic materials. The top three chemicals released by volume are methyl-ethyl-ketone (MEK), toluene, and methanol. These three account for about 64% of the industry's total releases.

Wastewater

Wastewater is, by far, the largest waste stream for the textile industry. Large volume wastes include wash water from preparation and continuous dyeing, alkaline waste from preparation, and batch dye waste containing large amounts of salt, acid, or alkali. Primary sources of biological oxygen demand (BOD) include waste chemicals or batch dumps, starch sizing agents, knitting oils, and degradable surfactants. Wet processing operations, including preparation, dyeing, and finishing, generate the majority of textile wastewater.

Types of wastewater include cleaning water, process water, non-contact cooling water, and storm water. The amount of water used varies widely in the industry depending on the specific processes operated at the mill, the equipment used, and the prevailing management philosophy regarding water use. Because of the wide variety of process steps, textile wastewater typically contains a complex mixture of chemicals.

Desizing, or the process of removing size chemicals from textiles, is one of the industry's largest sources of wastewater pollutants. In this process, large quantities of size chemicals used in weaving processes are typically discarded. More than 90% of the size used by the U.S. textile industry, or 90,000 tons, is disposed of in the effluent stream. The remaining 10% is recycled [EPA, 1996]. Desizing processes often contribute up to 50% of the BOD load in wastewater from wet processing.

Dyeing operations generate a large portion of the industry's total wastewater. The primary source is spent dye bath and wash water, typically containing by-products, residual dye, and auxiliary chemicals. Additional pollutants include cleaning solvents, such as oxalic acid. Of the 700,000 tons of dyes produced annually worldwide, about 10 to 15% of the dye is disposed of in effluent from dyeing operations [Snowden-Swan, 1995]. The average wastewater generation from a dyeing facility is estimated at between one and 8 thousand m³ per day. Dyeing and rinsing processes for disperse dyeing generate about 150 litres of wastewater per kg of product [Snowden-Swan, 1995].

Table 3.1 Typical BOD Loads from Preparation Processes.
PVA=polyvinyl alcohol; CMC=carboxy methyl cellulose;
1 pound= 450 g. [US EPA, 1995].

Process	Pounds of BOD per 1,000 Pounds of Production
Singeing	0
Desizing	
starch	67
starch, mixed size	20
PVA or CMC	0
Scouring	40-50
Bleaching	
peroxide	3-4
Hypochlorite	8
Mercerising	15
Heat setting	0

Many textile mills have few or no metals in their effluent. Dyes may contain metals such as zinc, nickel, chromium, and cobalt. In most dyes, metals are simply impurities generated during dye manufacture.

Salts in textile-dyeing wastewater is a potential problem area. Salt is used mostly to assist the exhaustion of ionic dyes, particularly anionic dyes, such as direct and fibre reactive dyes on cotton. Typical cotton batch dyeing operations use 20% to 80% of the weight of goods dyed, and the usual salt concentration in such wastewater is 2,000 ppm to 3,000 ppm. According to one study, a moderate-sized mill that dyed about 200 tonnes per week of cotton knit fabrics produced well over 25 tonnes of salts and a pH of over 10.

Emission to Air

The textile industry is a relatively minor source of air pollutants, but does emit a wide variety of chemicals in small amounts. Acetic acid and formaldehyde are two major emissions as well as solvent vapours. Nitrogen and sulphur oxides are emitted from boilers, and formaldehyde, acids, softeners, and other volatile compounds emissions from resin finishing and drying operations. Carriers and solvents may be emitted during dyeing operations.

Solid waste

Typical efficiency for using fabric averages from 72 to 94%. Cutting room solid waste generates a high volume of fabric scrap. This can be reduced by increasing fabric utilisation efficiency in cutting and sewing. Fabrication solid waste from carpets amounts to about 2% of an annual 900 million square yards of production (a value of $100 million). Although a large portion of cutting waste goes to landfill, some innovative programmes being implemented to recycle this material. Some facilities collect cotton lint for resale. Cotton trash, leaves, and stems collected during the yarn formation have been sold to farmers as animal feed.

4. Cleaner Production Opportunities

Most of the pollution prevention activities in the textile industry have focused on reducing chemical use, reusing process water, and reducing all solid waste forms – pallets, cardboard, etc. This section describes some of the pollution prevention opportunities for textile facilities. Much of the following section is based upon *Best Management Practices for Pollution Prevention in the Textile Industry* by the U.S. EPA Office of Research and Development.

The best way to reduce pollution is to prevent it in the first place. Some companies have creatively implemented pollution prevention techniques that improve efficiency and increase profits while at the same time minimising environmental impacts. This can be done in many ways such as reducing material inputs, re-engineering processes to reuse by-products, improving management practices, and employing substitution of toxic chemicals.

Management of Raw Materials

Raw material quality control programmes can be implemented by establishing specific and appropriate purchasing, packaging, and inventory control policies to prevent the ordering and use of untested materials. Textile companies can work with suppliers and develop purchasing codes that commit companies to using less-polluting raw materials. Facilities can also work with vendors to set acceptable guidelines for the purity and content of chemicals, like chemical specialities, which are typically of unknown composition to the textile mill.

Mills in the United Kingdom adopted *purchasing policies* as a way to reduce pollution. Researchers determined that 70% of woollen mills in the United Kingdom emitted pentachlorophenol (PCP), a harmful agricultural residue in wool, from their finishing plants. A study determined that it originated in the incoming greige goods. By specifying in company purchasing policies that they would not accept PCP-containing greige goods, the presence of PCP in wastewater decreased by 50%.

At its Monroe, North Carolina facility Bloomsburg Mills uses dye carrier chemicals, such as tetrachloroethylene, biphenyl, and trichlorobenzene, to promote level dyeing. In an effort to reduce regulatory burdens reporting, Bloomsburg Mills discussed with vendors the elimination of these chemicals. The company substituted a dye carrier containing methyl naphthalene with non-photochemically reactive solvents. This subsequently reduced the release of hazardous air pollutants by 91%.

Pre-screening raw materials can be used to determine interactions with processes, substrates, and other chemicals, as well as environmental effects, proper handling, and emergency procedures for chemicals. This can enable the early detection of mislabelled drums and changes in the formulation of a chemical specialty, and reduce the occurrence of costly production mistakes stemming from untested chemicals being processed. Protocol for incoming chemical quality control may consist of:

- Marking the date the container was opened.
- Checking pH, viscosity, density, conductivity, and colour.
- Comparing data with previous history and vendor's standard values.
- Entering data on a control chart for display.
- Maintaining records; and reviewing data with the vendor.

A committee at a facility in Lumberton, North Carolina pre-screened raw material (dyes and chemicals) to ensure that offensive smelling, toxic, and other objectionable material use were minimised in the production facility. In the event that raw materials with undesirable properties had to be used due to lack of alternatives, these raw materials were identified to all workers before use. This process entailed no capital costs. Benefits, such as the ability to dispose of waste treatment sludge since they did not contain toxics or metals, were realised.

Facilities can work with vendors to ensure that *packages* can be returned without being cleaned on site. Off site cleaning transfers chemical wastes back to the production facility, which may be better able to handle wastes. Chemical specialities should be purchased in returnable, reusable containers. Purchase of chemicals in bulk containers and intermediate bulk containers eliminates waste packing materials, and reduces spillage, handling costs, and worker exposure to chemicals.

At its Monroe, North Carolina facility, Bloomsburg Mills eliminated the disposal of 50 drums to the landfill each week by receiving and storing process chemicals in reusable totes and plastic drums. Amital began purchasing dyes and chemicals in intermediate bulk containers (IBCs) or in bulk. Drum disposal decreased by 69 per week, or about 3,500 annually. Pallet disposal decreased by 40 per week, or 2,000 annually.

Chemical Substitution

Since textile manufacturing is a chemically intensive process, a primary focus for pollution prevention should be on substituting less-polluting chemicals for textile process chemicals. Chemical substitution can eliminate chemical waste and the need for costly pollution control equipment. Opportunities for chemical substitution vary substantially among mills because of differences in environmental conditions, process conditions, product, and raw materials.

By *replacing solvents*, facilities can reduce waste, reduce costs associated with treatment systems, and increase worker safety. This is one of the best methods to prevent pollution. Some textile chemicals that can be substituted include desizing agents, dyes, and auxiliaries. For instance, replacing enzymes with hydrogen peroxide to desize starch can be cost-effective.

Improved fixation reactives can be used to reduce unreacted and degraded dye in spent bath and improve the reuse potential of wash water. High-temperature reactives can also be used in dyeing for simultaneous application of disperse and reactive dyes. This reduces energy use and eliminates the caustic bath required after disperse dyeing. Finally, auxiliaries, such as phosphates, can be substituted with acetic acid and EDTA to reduce phosphorus load in wastewater. New washing agents can also be used to increase wash efficiency, decrease water consumption, and improve fastness of reactives [Snowden-Swan, 1995].

Bloomsburg Mills substituted a solvent containing isopropanol and heptane as a suitable spot-washing alternative for trichloroethane, a hazardous air pollutant. Cleveland Mills Company reduced formaldehyde emission to the air by 84% by switching to low-shade change resins in the production process. Formaldehyde emissions at the mill dropped from 3,500 to 580 pounds per year. One textile facility found that they could replace 100 parts sodium sulphide with 65 parts alkaline solution containing 50% reducing sugars plus 25 parts caustic soda. As a result, sulphide levels dropped substantially to below 2 ppm [Snowden-Swan, 1995].

Waste can be reduced by replacing chemicals in some processes with mechanical or other *non-chemical treatment*. Instead, some textile mills add chemicals to counteract harmful side effects of other chemicals. In many cases, offending chemicals should be adjusted, substituted, or removed from a process, rather than adding chemicals to offset undesired side effects of other chemicals.

JP Stevens and Company, Inc. substituted chemical biocides, used in disinfecting air washers and cooling towers, with the use of ultraviolet light. During a 6-month test period, results showed improved worker safety, reduced discharge of biocides to the sanitary sewer, reduced chemical inventory and handling, improved work place air quality, and reduced pH and foaming problems in wastewater. The facility also showed enhanced air washer performance and more consistent control of work place air quality. The UV system operated with no required maintenance or repairs during the test. Based on chemical savings, the pay back is expected to be 11 to 18 months.

Process Modification

Process changes that optimise reactions and raw materials use can be used to prevent pollution. Modifications may include improved process control systems or changes in chemical application methods.

Mills have been moving towards *reduced bath ratio dyeing*. Bath ratio is defined as the weight of goods (or fabric) divided by the weight of the bath. Some chemicals, such as salt and lubricants, act on the dye bath, whereas others, such as dyes and softeners, act on the fabric. In each case, these chemicals are factored into either the weight of the bath or the weight of the fabric. Low bath ratio dyeing can save energy and reduce chemical use, because energy and chemical use depend on bath volume. At its Lumberton, North Carolina facility, Alamac Knits upgraded jet dyeing machinery to low-liquor-ratio machines with shorter cycles. This modification resulted in a decrease of between 60 and 70% of consumption of dye chemicals.

Table 3.2 *Example of costs and savings for dye bath reuse [US EPA, 1995].*

Description of Cost/Savings	Value ($)
Total Costs	
Lab and support equipment	9,000
Machine modifications, tanks, pumps, pipes	15,000-25,000
Annual Operating Costs	1,000-2,000
Total Savings (Annual)	
Dyes and chemicals	15,000
Water	750
Sewer	750
Energy	4,500

Use of *pad batch (cold) dyeing* for cotton, rayon, and blends conserves energy, water, dyes and chemicals, labour, and floor space. Pad batch dyeing methods do not require salt or chemical specialities, so this method can be a good way for facilities to reduce waste and save money. While pad batch dyeing is a cost-effective way for facilities to apply reactive dyes to cotton and rayon, this method may not achieve the desired initial fabric properties for all cottons. Pad batch dyeing is also not appropriate for dyeing synthetic fabrics. Salt consumption can be reduced from as much as 100% of weight of goods to zero. Water consumption for pad batch dyeing with beam wash-off is only 10% of the amount used to dye fabrics using beck methods, or 10 litres per kg of dyed fabric. Energy consumption can be reduced from about 20,000 BTUs per kg of dyed fabric for beck methods to under 4,000 BTUs per kg for pad batch methods with beam washing. In addition, labour costs and chemical use can be reduced up to 80% as compared to atmospheric beck methods.

Counter current washing decreases wastewater from preparation processes. Counter current washing is simple, easy to implement, and relatively inexpensive. Counter current washing is a technique to reuse the least contaminated water from the final wash for the next-to-last wash and so on until the water reaches the first wash stage. Wash water from the first stage is discharged. Counter current washing equipment can be retrofitted to any multi stage continuous washing operation, whether it is installed for different fabrics or for dyeing, printing, or reparation operations. Flow optimisation is usually a good pollution prevention activity to run in conjunction with counter current washing. Bloomsburg Mills uses counter current washing to conserve water during the scouring process.

The cleaner wash water enters the exit wash unit and counter flows back toward the dirtier units.

It is possible to reduce waste and increase production efficiency by *optimising process conditions*, such as temperature and time. Also, the processes themselves can be modified to increase efficiency. An American Corporation improved dyeing exhaustion by extending the length of time fabrics were dyed by 15 minutes. Results showed about a 60% drop in BOD and chemical oxygen demand (COD), a 20% drop in fats, oils, and grease, and a 98% drop in ammonia-nitrogen. This resulted in a saving of $35,000 annually.

A possibility to reduce waste and increase production efficiency is to *combine operations*. For instance, combined scouring and bleaching can save energy and water. Cold pad-batch methods can be used at room temperature for long desizing, scouring, and bleaching cycles.

Recovery, recycling, and reuse can be effective tools for minimising pollutant releases to the environment. By recovering solvents and raw materials, textile mills can reduce raw materials costs and can reduce pollution with little modification of existing processes. Water is widely used in the industry for processes ranging from dyeing to preparation and finishing. Raw materials, such as un-exhausted dyestuff and additives, can also be recycled.

Dye bath reuse is the process of analysing, replenishing, and reusing exhausted hot dye baths to dye further batches of material. Although not applicable to all processes, in some processes, dye bath reuse can reduce pollution concentrations and effluent volume and generally requires a smaller capital cost than pre-treatment plant construction. It also saves on the costs of dyes, chemicals, and energy. Dye bath reuse principles can also be applied to bleach baths. Depending on the machine, types of fabrics, and range of shades, after a couple of years, dye bath reuse could save companies about $21,000 per year for each machine. Amital saved a large amount of money by reusing dye baths and non-contact cooling water. The facility reduced its water consumption from 1,280 to 400 m³ per day and simultaneously increased production from 12 to 20 batches per day. Additionally, energy consumption for heating dye bath decreased substantially. The investment saved the company about $13,000 a month and paid for itself 30 days after implementation [Snowden-Swan, 1995].

Table 3.3 *Typical water savings using counter current washing [US EPA, 1995].*

Number of washing steps	Water savings (%)
2	50
3	67
4	75
5	80

Wet processing consumes a large amount of water from rinsing of textiles. *A yarn finishing company* drastically reduced wastewater pollution, soda (Na_2CO_3), and caustic consumption by implementing recycling. The new process involved reusing the rinse bath three times following mercerising rather than dumping the bath water after each use. The spent rinse water was then processed in an evaporator and concentrated caustic was reused in mercerising. The facility reduced suspended solids by 80%, COD by 55%, and neutralising soda in the wastewater by 70%.

Equipment Modification

An additional method to reduce waste is to modify, retrofit, or replace equipment. Some facilities are switching to computer-controlled dyeing systems, which analyse the process continuously and respond more quickly and accurately than manually controlled systems. In many cases, modifying equipment can provide source reduction by reducing the ratio of water and chemicals to textile goods.

The use of *automated process control equipment* has had a significant effect on the textile industry. Chemical dosing systems can be optimised to deliver the right amount of the right chemical at just the right time. These systems improve the efficiency and reliability of chemical reactions in the dye bath, ensuring more consistent and reproducible results. In addition, these systems reduce the tendency to overuse environmentally harmful chemicals, which may pass through treatment systems un-reacted or may react to produce undesirable by-products. Dosing systems can also reduce handling losses and equipment cleanup. Automated dosing systems are commercially available and are being adopted throughout the textile industry.

Amital, which produces acrylic yarn, implemented computer technology to automate dye bath flow and temperature in a new facility. This enabled the facility to precisely control the addition of auxiliary chemicals, such as retarders and levelling agents. Bloomsburg Mills upgraded instrumentation and process controls for the dyeing process from manual to computer control. The controlled time of the wash after dyeing has reduced water usage by 28% and fuel heat consumption per yard produced by 15.9%.

Continuous horizontal washers can conserve energy and water. Horizontal washers work for woven fabrics in a narrow weight range. These washers operate by spraying clean wash water on the top half pass of fabric as it makes a series of horizontal traverses upward in the machine.

Many textile companies use *continuous knit bleaching ranges* to reduce water consumption. These ranges consume less water, energy, and chemicals than batch preparation knitting equipment.

Companies can improve production efficiency and maintain low operating costs by incorporating *pollution prevention codes* into their management procedures. These codes can include a written commitment by senior management to ongoing waste reduction at each of the company's facilities and to include pollution prevention objectives in research and new facility design. Establishing training and incentive programmes and improving record keeping are other ways that companies can prevent pollution without changing industrial processes.

In dyeing operations, start ups, stop offs, and colour changes often result in losses of substrate, potential off-quality work, and chemically intensive cleaning of machines and facilities. *Scheduling dyeing operations to minimise machine cleaning* can have a considerable effect on pollution prevention. Changes required by scheduling activities generate significant amounts of waste for the textile mill. Machine cleaning is a significant contributor to waste load for textile facilities. A well planned dyeing schedule may reduce the number, of machine cleanings required and the pollution that results from start ups, stop offs, and colour changes.

Modifying *equipment cleaning practices* may reduce wastewater discharges and reduce solvent use. Substituting cleaning solvents with less toxic solvents can reduce hazardous waste generation and can simplify treatment of wastewater.

Good inventory management can reduce waste by using materials efficiently and reducing the likelihood of accidental releases of stored material. Although it may seem simplistic, housekeeping and work habits of chemical mixers can account for 10 to 50% of a mill's total effluent load in BOD, COD, metals, and organic solvents. Improvements in housekeeping generally cost little or nothing and improve employee morale, work place safety, and product quality.

Companies should establish safety procedures for receiving, storing, and mixing chemicals, and implement *workers training programmes*. These programmes should inform workers of the environmental impacts of chemicals and identify those most harmful to the environment.

References

Snowden-Swan, L. J. Pollution Prevention in the Textile Industries, in *Industrial Pollution Prevention Handbook*, Freeman, H. M. (Ed.), McGraw-Hill, 1995.

4 – Glass Industry

1. Glass Production

The Products and the Industry

The glass industry in the European Union is extremely diverse, both in the products made and the manufacturing techniques employed. Products range from intricate hand-made lead crystal goblets to huge volumes of float glass produced for the construction and automotive industries. Manufacturing techniques vary from small electrically heated furnaces in the ceramic fibre sector to cross-fired regenerative furnaces in the flat glass sector, producing up to 700 tonnes per day.

The total production of the glass industry within the EU in 1996 was estimated at 29 million tonnes, excluding ceramic fibres and frits (Table 4.1).

Container glass production is the largest sector representing around 60% of the total glass production. The sector covers the production of glass packaging i.e. bottles and jars. In 1997 the sector produced over 17.3 million tonnes of glass products from the 295 larger furnaces operating in the EU. The beverage sector accounts for approximately 75% of the total tonnage of glass packaging containers. The main competition is from alternative packaging materials steel, aluminium, cardboard composites and plastics. A significant development within the sector has been the increased use of recycled glass. The average rate of utilisation of post consumer waste within the EU container glass sector is approximately 50% of total raw material input, with some installations utilising up to 90% waste glass.

The diversity of the glass industry results in the use of a wide range of raw materials. A main environmental issue is the control of dust from the handling of fine materials. The main raw materials for melting are glass forming materials (e.g. silica sand, cullet), intermediate/modifying materials (e.g. soda ash, limestone, feldspar) and colouring/decoloring agents (e.g. iron chromite, iron oxide).

Table 4.1 *Approximate sector based breakdown of glass industry production (excluding ceramic fibre and frit sectors).*

Sector	% of Total EU Production (1996)
Container Glass	60
Flat Glass	22
Continuous Filament Glass Fibre	1.8
Domestic Glass	3.6
Special Glass	5.8
Mineral Wool	6.8

The Sources

The text is a summary of the IPPC (European Commission Integrated Pollution Prevention and Control) *Reference Document on Best Available Techniques in the Glass Manufacturing Industry,* December 2001.

The most widely used classification of glass type is by chemical composition, which gives rise to four main groupings:

1. Soda lime glass.
2. Lead crystal glass and crystal glass.
3. Borosilicate glass.
4. Special glasses.

The first three of these categories account for over 95% of all glass produced. The thousands of special glass formulations produced mainly in small amounts account for the remaining 5%. With very few exceptions most glasses are silicate based, the main component of which is silicon dioxide (SiO_2). Stone wool is an exception to this classification of glass types in that the typical chemical composition does not fit into any of these categories.

The vast majority of industrially produced glasses have very similar compositions and are collectively called soda-lime glasses. A typical soda-lime glass is composed of 71-75% silicon dioxide (SiO_2 derived mainly from sand), 12-16% sodium oxide ("soda" Na_2O from soda ash – Na_2CO_3), 10-15% calcium oxide ("lime" CaO from limestone – $CaCO_3$) and low levels of other components designed to impart specific properties to the glass. It is obvious that glass manufacturing leads to important CO_2 emissions.

Historical Origins

Glassy materials do occur naturally, for example, obsidian is often found in volcanic areas and has a composition comparable to man-made glass. This material, which consists mainly of silicon dioxide, and sodium and calcium compounds, was used by early man to make arrowheads, spearheads and knives.

It is thought that glass making originated in Egypt and Mesopotamia, but developed later and independently in China, Greece and the Northern Tyrol. Ancient glass manufacture is believed to be linked with the production of ceramics or bronze, where it could have originated as a by-product. Glass manufacturing in Europe developed further in the Middle Ages, and Venice became the European centre of glass art. In the 14th century, glass workshops were set up all over the continent and at the same time the manufacture of flat glass for glazing developed in France.

Drinking glasses and bottles were main products. For centuries, window glass was blown with a glass-blowing pipe into large cylindrical bodies, cut up and ironed flat while still hot. Only limited glass quantities could be handled and the window glass was very small.

In the 18th century, some factories were already producing more than 1 million bottles per year (around 3 tonnes/day), by manual mouth-blown techniques. During the industrial revolution of the 19th century, technical progress accelerated: furnaces were heated with coal instead of wood; the first automatic machines were used; and blowing was done using compressed air in metallic moulds. At the end of the 19th century, the continuous furnace was invented by Friedrich Siemens, allowing large-scale continuous production and the use of machinery.

Two important steps were taken in the 20th century: The full mechanisation of bottle manufacture with the introduction of the first automatic IS (individual section) machine around 1920, and the invention of the float process for flat glass in 1962. Today, the production of an IS machine can be above 500 bottles/minute and the production of float can be up to 900 t/d.

2. The Technologies

Glass Melting Technologies and Energy Use

Melting, the combination of the individual raw materials at high temperature to form a molten glass, is the central phase in the production of glass. The melting process is a complex combination of chemical reactions and physical processes, and melting can be divided into several stages: heating; primary melting; fining and homogenisation; and conditioning. Glass making is a very energy intensive activity and the choice of energy source, heating technique and heat recovery method are central to the design of the furnace. The same choices are also some of the most important factors affecting the environmental performance and energy efficiency of the melting operation. The three main energy sources for glass making are natural gas, fuel oil and electricity.

The ovens used were originally not energy saving, but today several energy efficient ovens are in common use.

Regenerative furnaces utilise regenerative heat recovery systems. Burners are usually positioned in or below combustion air/waste gas ports. The heat in the waste gases is used to preheat air prior to combustion, by passing the waste gases through a chamber containing refractory material, which absorbs the heat. The furnace only fires on one side at a time. After about twenty minutes, the firing is reversed and the combustion air is passed through the chamber previously heated

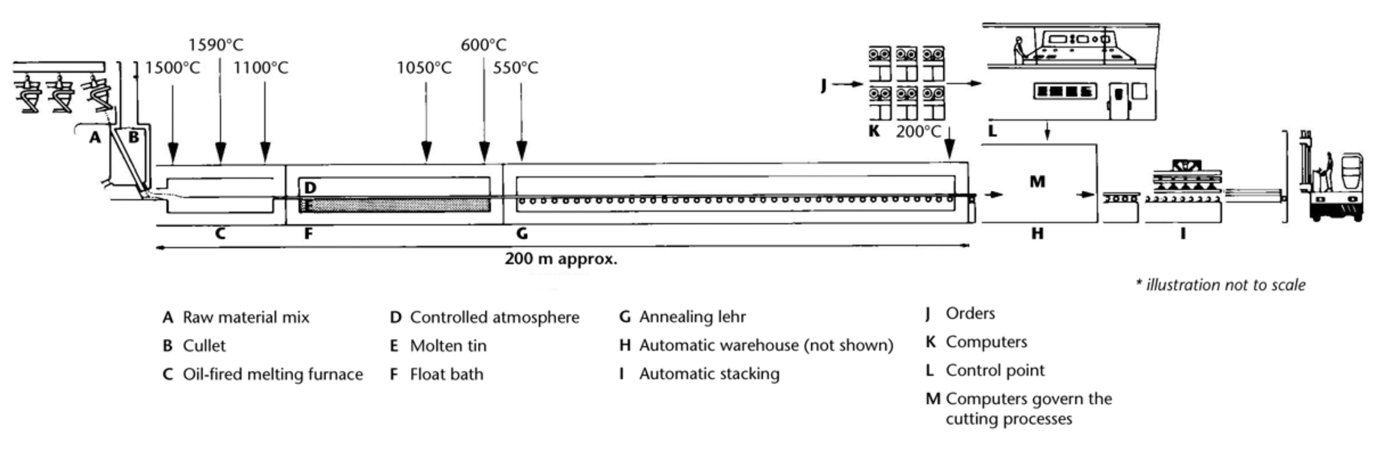


Figure 4.1 *The float glass process.*

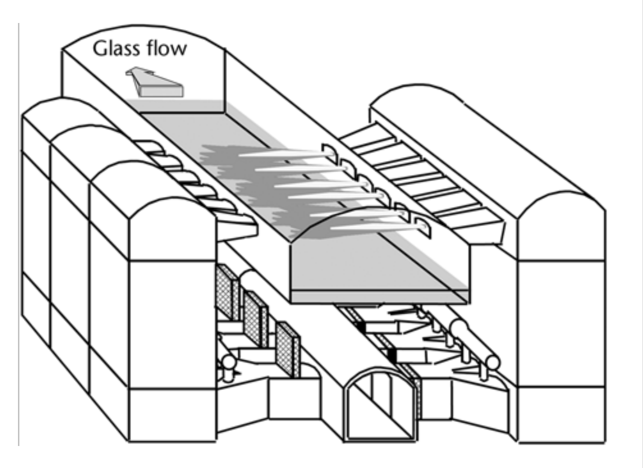


Figure 4.2 *A cross-fired regenerative furnace.*

by the waste gases. Preheat temperatures up to 1400°C may be attained leading to very high thermal efficiencies.

Recuperative furnaces utilise heat exchangers (termed recuperators) for heat recovery, with continuous preheat of combustion air by the waste gases. Air preheat temperatures are limited to around 800°C for metallic recuperators. The specific melting capacity (per unit of melter area) of recuperative furnaces is around 30% lower than for a regenerative furnace. The burners are located along each side of the furnace, transverse to the flow of glass, and fire continuously from both sides. This type of furnace is primarily used where high flexibility of operation is required with minimum initial capital outlay, particularly where the scale of operation is too small to make the use of regenerators economically viable.

Oxy-fuel firing involves the replacement of the combustion air with oxygen (>90% purity). The elimination of the majority of the nitrogen from the combustion atmosphere reduces the volume of the waste gases by about two thirds. Therefore, furnace energy savings are possible because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames. The formation of thermal NO_x is also greatly reduced. In general, oxy-fuel furnaces have the same basic design as unit melters, with multiple lateral burners and a single waste gas exhaust port. However, furnaces designed for oxygen combustion do not utilise heat recovery systems to pre-heat the oxygen supply to the burners.

Electric furnaces consist of a refractory lined box supported by a steel frame, with electrodes inserted either from the side, the top or more usually the bottom of the furnace. Energy for melting is provided by resistive heating as the current passes through the molten glass. The technique is commonly applied in small furnaces particularly for special glass. There is an upper size limit to the economic viability of electric furnaces, which depends on the cost of electricity compared with fossil fuels. The replacement of fossil fuels in the furnace eliminates the formation of combustion products.

Combined fossil fuel and electric melting can take two forms: predominantly fossil fuel firing with electric boost; or predominantly electrical heating with a fossil fuel support. Electric boosting is a method of adding extra heat to a glass furnace by passing an electric current through electrodes in the bottom of the tank. A less common technique is the use of gas or oil as a support fuel for a principally electrically heated furnace.

Process Inputs and Outputs

The core process inputs can be divided into four main categories:

1. Raw materials (those materials which form part of the product).
2. Energy (fuels and electricity).
3. Water.
4. Ancillary materials (processing aids, cleaning materials, water treatment chemicals, etc).

Glass industry raw materials are largely solid inorganic compounds, either naturally occurring minerals or man-made products. The glass industry as a whole is not a major consumer of water, the main uses being cooling, cleaning and batch humidification. Glass making is an energy intensive process and therefore fuels can form a significant input to the processes.

The core process outputs can be divided into five main categories:

1. Product.
2. Emissions to air.
3. Liquid waste streams.
4. Solid process residue.
5. Energy.

All of the sectors within the glass industry involve the use of powdered, granular or dusty raw materials. The storage and handling of these materials represents a significant potential for dust emissions. The major environmental challenges for the glass industry are emissions to air and energy consumption. Glass making is a high temperature, energy intensive activity, resulting in the emission of products of combustion and the high temperature oxidation of atmospheric nitrogen; i.e. sulphur dioxide, carbon dioxide, and oxides of nitrogen. Furnace emissions also contain dust and lower levels of metals. It is estimated that in 1997 the glass industry emissions to air amounted to around of 0.7% of total EU emissions of these substances. Total energy consumption by the glass industry was approximately 265 PJ.

The emissions from downstream activities can vary greatly between the different sectors. Although there are similarities in the melting techniques used in many sectors the downstream activities tend to be specific. Emissions to air can arise from: coating application and/or drying; secondary processing (e.g. cutting, polishing, etc); and from some product forming operations (e.g. mineral wool, and ceramic fibre). In general, emissions to the water environment are relatively low and there are few major issues that are specific to the glass industry.

A characteristic of most of the sectors is that the great majority of internally generated glass waste is recycled back to the furnace. The main exceptions to this are the continuous filament sector, the ceramic fibre sector and producers of quality sensitive products in the special glass and domestic glass sectors. The mineral wool and frits sectors show a wide variation in the amount of waste recycled to the furnace ranging from nothing to 100% for some stone wool plants.

3. Cleaner Technologies Options

Primary Techniques

A glass furnace is a very dynamic environment and any changes to the chemistry or operating conditions can have consequent effects within the melting process and on emissions. A low level of emission from material carry over is achieved by maintaining a level of moisture in the raw materials and by controlling the batch blanket coverage, particle size, gas velocity and burner positioning. The most important factors affecting volatilisation are temperature, water vapour content in the furnace atmosphere, and the velocities of the gases at the surface of the melt.

Sodium chloride can be a significant factor in emissions of dust and chlorides. It is used in some special glasses as a refining agent, but is more usually present as a low level impurity in soda ash made by the Solvay process. Pressure from the Glass Industry has led soda ash producers to lower NaCl levels significantly in recent years (now generally around 1 kg/tonne).

The emission levels achievable using primary techniques are difficult to quantify, because of the wide range of factors that can affect the results and the wide variation in furnace types and glass formulations. Average mass emissions are around 0.4 kg/tonne of glass melted, and the majority of the emission concentrations fall into the range of 100-300 mg/m³. In general, for other compositions the optimisation of primary techniques could be expected to reduce emissions by 10-30%.

Melting Technique Selection

The choice of melting technique depends on many factors but particularly the required capacity, the glass formulation, fuel prices, and existing infrastructure. The choice is one of the most important economic and technical decisions made for a new plant or for a furnace rebuild. From an environmental perspective, melting techniques that are inherently less polluting or can be controlled by primary means are generally preferred to those that rely on secondary abatement.

Regenerative furnaces are generally more energy efficient than other conventional fossil fuel fired furnaces due to the more efficient combustion air preheating system. The low energy use per tonne of glass melted leads to reductions in many of the pollutants associated with combustion. However, the high preheat temperatures favour higher NO_x formation. Recuperative furnaces are less energy efficient than regenerative furnaces, but still recover a substantial amount of heat via the recuperator system. Further improvements in energy efficiency are possible using further techniques, e.g. electric boost, waste heat boilers, gas preheating, and batch/cullet preheating.

Materials Handling

The diversity of the Glass Industry results in the use of a wide range of raw materials. The majority of these materials are solid inorganic compounds, either naturally occurring minerals or man-made products. They vary from very coarse materi-

Table 4.2 *Theoretical energy requirements for melting common glass formulations.*

Parameter	Type of glass		
	Soda-Lime (Flat/Container Glass)	Borosilicate (8% B_2O_3)	Crystal Glass (19% PbO)
	Energy requirement (GJ/tonnes)		
Heat of reaction	0.49	0.41	0.40
Enthalpy of glass	1.89	1.70	1.69
Enthalpy of gases emitted	0.30	0.14	0.16
Theoretical energy requirement	2.68	2.25	2.25

als to finely divided powders. Liquids and, to a lesser extent, gases are also used within most sectors. There are very few issues regarding emissions to air from materials handling that are specific to the Glass Industry. Bulk powder materials are usually stored in silos, and emissions can be minimised by using enclosed silos, which are vented to suitable dust abatement equipment such as fabric filters. Where practicable collected material can be returned to the silo or recycled to the furnace.

4. Techniques for Controlling Emissions to Air

Particulate Matter – Dust – and Metals

The nature of the dust (particulate matter) emission from glass furnaces varies for different processes, but depends mainly on the furnace design and operation, and on the glass composition. The three main sources of dust from melting are:

- Batch material carry over.
- Volatilisation and reaction of substances from batch materials and the glass melt.
- Metals impurities in the fuels.

The main sources of metals are impurities in raw materials, metals in raw materials/additives used to impart specific properties (e.g. lead oxides, and colorants/decolorants), cullet and fuel. External cullet is an important source of metal contamination particularly for lead (in some cases >400 ppm) but also for other metals for example, mercury contamination can occur if cullet contains mercury vapour light tubes.

There are three main approaches to controlling emissions of metals either within the dust or as gaseous components.

1. Raw material selection to minimise contamination and where practicable to use alternative additives. Raw material selection includes cullet sourcing and sorting.
2. Dust abatement techniques, particularly bag filter systems and electrostatic precipitators. Where emissions contain significant metal concentrations high efficiency dust abatement systems can generally reduce emissions to less than 5 mg/Nm³.
3. Gaseous metal emissions (e.g. selenium) can be substantially reduced by the use of dry or semi-dry scrubbing techniques in combination with dust abatement. In some instances, and particularly in Germany, a major factor in the driving force for the installation of dust abatement combined with dry or semi-dry scrubbing has been the reduction of metal emissions.

The collection of particulate emissions use most importantly electrostatic precipitators and bag filters. The electrostatic precipitator (EP) consists of a series of high voltage discharge electrodes and corresponding collector electrodes. Particles are charged and subsequently separated from the gas stream under the influence of the electric field. EPs are very effective in collecting dust in the range 0.1 µm to 10 µm, and overall collection efficiency can be 95-99%. Actual performance varies depending mainly on waste gas characteristics and EP design.

In practice the collected dust can be recycled in most cases and depending on the sorbent chosen the material can replace a portion of the other raw materials particularly sodium sulphate (and where appropriate fluoride and lead containing materials). Problems could occur in the Container Glass Sector where the sulphate requirements for a reduced glass, especially with high cullet levels, are very low. This could limit the potential for recycling dust especially if high sulphur fuel oil is used, and a portion of the collected dust would have to be disposed of off-site.

Oxides of Nitrogen, NO_X

Due to the high temperatures in glass furnaces (up to 1650°C and 2000°C in the flame) the major source of NO_X is thermally generated NO_X, arising from the oxidation of nitrogen in the combustion atmosphere at temperatures above 1300°C. The main sources of the nitrogen are combustion air, atomising air (in oil fired furnaces), and air leakage into the furnace. The predominant species is NO (90-95%) formed by the reaction $N_2 + O_2 \rightarrow 2NO$. Levels of NO_2 are very low, and most NO_2 detected in the emissions results from atmospheric oxidation of NO. The conditions in the furnace are such that nitrous oxide (N_2O) is not detected in the emissions.

The main factors influencing NO_X formation are, flame temperature, oxygen content in the reaction zone and the residence time in the high temperature zone of the flame. The primary control measures for NO_X seek to generate those conditions least favourable for NO_X formation, i.e. to avoid the simultaneous presence of nitrogen and oxygen at high temperature. The flame temperature can be reduced by reducing the combustion air preheat temperature. For example, the combustion air temperatures in recuperative furnaces are significantly lower than in regenerative furnaces, resulting in lower flame temperatures and lower NO_X concentrations. If the fuel and air/oxygen are injected at the same place in the burner, a flame is produced with a hot oxidising primary zone close to the port and a cooler secondary zone further away. The majority of the NO_X is produced in the hottest zone. Therefore, by reducing the proportion of either the air or the fuel injected at the burner the maximum temperature and the NO_X formation are reduced. The remaining fuel or air is added later in the combustion zone. Emission reductions of up to 35% can be achieved using this technique.

Special furnace designs have been developed which reduce NO_x emissions, e.g. the low-NO_x melter. These designs have been very successful but there are certain process constraints that limit their applicability. The FENIX process is a combustion optimisation package based on primary measures, that is tailored for a specific furnace. Results of 510 mg/Nm³ and around 1.1 kg/tonne of melt have been reported. Oxy-fuel firing involves the replacement of the combustion air with oxygen. The elimination of the majority of the nitrogen from the combustion atmosphere reduces the volume of the waste gases by about two thirds. Therefore, energy savings are possible because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames.

Nitrates are used in glass manufacture as oxidising agents and also as fining agents. By far the most common nitrate used is sodium nitrate, but in some special glass applications potassium or barium nitrate are also used. Although sodium nitrate acts as a fining agent, its primary use is as an oxidising agent, and in most applications sodium sulphate would be the preferred fining agent. During the melting process the nitrates dissociate to form NO, NO_2, N_2, and O_2. The O_2 is used to oxidise the melt (particularly iron Fe^{2+} to Fe^{3+}) to give a very clear glass, and to oxidise any organic components of the batch materials.

Oxides of Sulphur, SO_x

The main techniques for controlling SO_x emissions are fuel selection, batch formulation and acid gas scrubbing. In oil fired processes the main source of SO_x is the oxidation of sulphur in the fuel. In conventional glass making, sulphates are the main source of SO_x emissions from batch materials. Sulphates are the most widely used fining agents and are also important oxidising agents. In most modern glass furnaces the levels of batch sulphates have been reduced to the minimum practicable levels, which vary depending on the glass type. With closed loop filter dust recycling, the SO_x emission levels observed today, are generally in the range of 200-800 mg/Nm³ for natural gas firing and 800-1600 mg/Nm³ with 1% S fuel oil. The majority of installed SO_x scrubbing systems operate with dry lime scrubbing at a temperature of around 400°C, which is the waste gas temperature obtained from an efficient regenerative type furnace. At these temperatures, an SO_x reduction of around 50% can be achieved. An improved SO_x reduction rate can be reached at temperatures around 200°C and with a humid atmosphere but this involves further considerations.

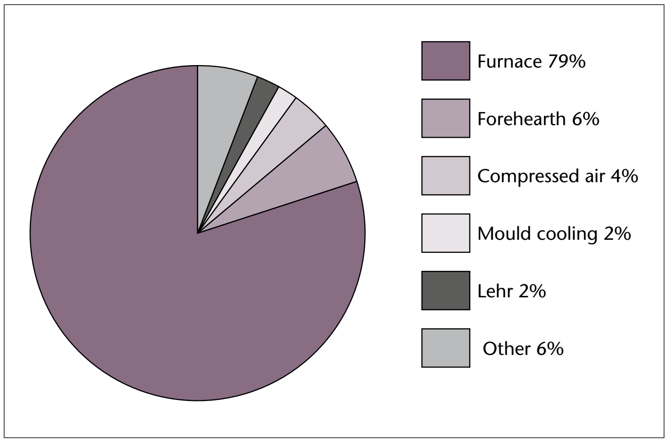


Figure 4.3 *Energy usage in a typical container glass plant.*

The most obvious way to reduce SO_x emissions is to reduce the sulphur content of the fuel. The use of natural gas is increasing within the industry. For example, almost all fossil fuel fired glass wool furnaces, most continuous filament glass fibre furnaces, and around 50% of all container furnaces are fired on natural gas. The general experience within the industry is that conversion to natural gas results in higher NO_x emissions, 25-40%, although with increased experience the differential is narrowing.

Oxides of Carbon

Oxides of carbon include carbon dioxide (CO_2) and carbon monoxide (CO). Carbon monoxide arises as a product of incomplete combustion and is rarely emitted from Glass Industry installations at a level to cause environmental concern. Significant levels are encountered in stone wool cupolas, but most plants are fitted with an afterburner to oxidise the emissions before release. Carbon dioxide arises from the combustion of fossil fuels or other organic materials, and from the decomposition of carbonate batch materials. Carbonates such as soda ash and limestone are the main sources of alkali metal oxides and alkali earth metal oxides in glass making. The only real alternative sources of these oxides are post consumer waste and process waste. That is cullet for glass processes, and process wastes, recycled product and slag (stone wool only) for mineral wool.

5. Energy Saving

Melting Technique and Furnace Design

The energy necessary for melting glass accounts for over 75% of the total energy requirements of glass manufacture. The cost of energy for melting is one of the largest operational costs for glass installations and there is a significant incentive for operators to reduce energy use. The choice of melting technique can have a great effect on the energy efficiency. The choice is largely determined by a range of economic considerations. The main factor is the desired production rate and the associated capital and operating costs over the life of the furnace. An important aspect of the operating costs is the energy usage, and in general the operator will choose the most energy efficient design possible.

In conventional fossil fuel fired furnaces the main difference in furnace design is whether the heat recovery system is based on regenerators or a recuperator. One of the main factors in the choice is the furnace size. Regenerative furnaces achieve a higher preheat temperature for the combustion gases, up to 1400°C compared with 800°C for recuperative furnaces, resulting in better melting efficiencies. The generally larger size of the regenerative furnaces also makes them more energy efficient than the smaller recuperative furnaces. This is because structural losses are inversely proportional to the furnace size, the main reason being the change in surface area to volume ratio. A modern regenerative container furnace will have an overall thermal efficiency of around 50%, with waste gas losses around 20%, and structural losses making up the vast majority of the remainder. The thermal efficiency of a recuperative furnace without heat recovery will be closer to 20%.

The energy recovered by regenerators may be maximised by increasing the quantity of refractory bricks employed. In practice, these may be organised in enlarged regenerator chambers or in separate but connected structures, giving the term multi-pass regenerators. The maximum theoretical efficiency of a regenerator is 80% because the mass of waste gases from a furnace exceeds that of the incoming combustion air and the heat capacity of exhaust gases exceeds that of the combustion air. In practical terms the efficiency will be limited by cost, and structural losses become more significant as the size of the regenerators increases. It is difficult to conceive a cost effective regenerator design with an efficiency greater than 70-75%.

Combustion Control and Fuel Choice

In recent decades the predominant fuel for glass making has been fuel oil, although the popularity of natural gas is increasing. Natural gas firing results in lower SO_X emissions but generally gives rise to higher NO_X emissions. This is because the natural gas flame is less radiant and has generally resulted in higher energy consumption, approximately 7-8%. However, as experience of gas firing increases performance levels progressively approaching those associated with oil firing can be achieved. Natural gas has a higher ratio of hydrogen to carbon and its use reduces overall emissions of CO_2 by up to 25% for a given pull rate. The developments in low NO_X burner systems have also resulted in energy savings. By reducing the amount of combustion air to close to stoichiometric levels, less energy is lost in the waste gas. The improvements made to the combustion system, the heat transfer systems and general process control during developments intended for NO_X reduction, have in many cases also led to improvements in furnace operation and efficiency.

Use of Recycled Glass, Cullets

The use of cullet, that is recycled glass, in a glass furnace can significantly reduce the energy consumption and its use is generally applicable to all types of furnace i.e. fossil fuel fired, oxy-fuel fired and electrically heated furnaces. Most sectors of the glass industry routinely recycle all internal cullet. The main exceptions are continuous filament glass fibre (where it is not considered possible due to quality constraints) and stone wool and frit production (where cullet as such is not produced). The base internal cullet level in the batch will usually be in the range of 10 to 25%. Cullet has a lower melting energy requirement than the constituent raw materials because endothermic chemical reactions associated with glass formation have been completed and its mass is 20% lower than the equivalent batch materials. Therefore, increasing the cullet level in the batch has the potential to save energy, as a general rule each 10% of extra cullet results in a 2.5-3.0% reduction in furnace energy consumption. The use of cullet generally results in significant cost savings as a result of the reduction in both energy and raw material requirements.

Distinction should be made between internal cullet (recycled glass from the production line) and external cullet (recycled glass from consumer or external industrial sources). The composition of external cullet is less well defined and this limits its application. High final product quality requirements can restrict the amount of foreign cullet a manufacturer can use. However, the Container Glass Sector is uniquely placed to take advantage of using significant quantities of foreign cullet from bottle recycling schemes. At the time of writing, except where special schemes are established, the significant use of external cullet is restricted to the Container Glass Sector and some areas of the Mineral Wool Sector. Glass sectors with higher quality demands or low availability of external cullet (e.g. flat glass) may try to contract large consumers to recycle the waste glass they generate.

Cullet use in container glass production varies from <20% to >90%, with an EU average in the region of 48%. Recycling rates vary widely between Member States depending on the material schemes for post-consumer glass collection. High quality container glass products have lower cullet levels than standard products.

In the Domestic Glass Sector, quality considerations generally prevent the use of external cullet in the process. Internal cullet usage is limited by the availability of cullet at the correct quality and composition. The average amounts of internal cullet used are 25% for soda-lime products, and 35% for lead crystal.

In addition to the substantial energy savings possible with cullet usage, there are a number of other important associated environmental benefits. In terms of furnace operation high cullet levels can also give other benefits such as low particulate emissions. Cullet is easier than batch to pre-heat. Emissions of CO_2, SO_X, NO_X and dust are greatly reduced due to reduced fuel usage and lower furnace temperatures. Emissions of other volatile substances may also be lower due to the reduced temperatures. The increased cullet usage reduces these raw material derived emissions and reduces the consumption of virgin raw materials.

Waste Heat Boiler

The principle of this technique is to pass waste gases directly through an appropriate tube boiler to generate steam. The steam may be used for heating purposes (space heating and heating of fuel oil storage and piping) or, via a suitable steam motor or turbine to drive electricity generation equipment or plant items such as air compressors or IS machine ventilator fans. Incoming gases from regenerators/recuperators are usually in the temperature range from 600°C to 300°C. The outlet temperature determines the available recoverable heat, which is limited to approximately 200°C due to the risk of condensation in the boiler and to ensure correct stack operation. Boiler tubes exposed to furnace waste gases can become coated with condensed materials (e.g. sodium sulphate, depending on the composition) and must be periodically cleaned to maintain recovery efficiency (less important for boilers operating downstream of dust removal devices). In situ cleaning may be carried out automatically by steam, by mechanical means, or by periodic maintenance.

Batch and Cullet Preheating

Batch and cullet is normally introduced cold into the furnace, but by using the residual heat of the waste gases to preheat the batch and cullet, significant energy savings can be possible. This only applies to fossil fuel fired glass furnaces. In the stone wool industry, predominantly cupola furnaces are used, which have a design that preheats the raw materials intrinsically.

Direct preheating involves direct contact between the flue gas and the raw material (cullet and batch) in a cross-counter flow. The waste gases are supplied to the preheater from the waste gas duct behind the regenerator. They pass through the cavities in the preheater, thereby coming into direct contact with the raw material. The outlet temperature of the cullet is up to 400ºC. The system incorporates a bypass that allows furnace operation to continue when preheater use is either inappropriate or impossible.

Indirect preheating is in principle a cross-counter flow, plate heat exchanger, in which the material is heated indirectly. Depending on the throughput, the material will normally be heated up from ambient temperature to approximately 300°C. The waste gases flow horizontally through the individual modules and will be cooled down by approximately 270°C-300°C.

These techniques have a number of environmental effects. In general, the energy savings have been between 10 to 20%, NO_X emission have been reduced, and emission of acidic compounds have been reduced to between 50% and 90%.

5 – Chlor-Alkali Manufacturing Industry

1. The Chlor-Alkali Industry

Industrial and Economical Development of the Chlor-Alkali Sector

The electrolytic production of chlorine from sodium chloride solution (brine), the chlor-alkali process, was introduced on an industrial scale around 1890, both with the diaphragm cell and the mercury cell process. The membrane cell process was not developed until 1970. Currently, 95% of world chlorine production is obtained by the chlor-alkali process.

Since the 1940s world chlorine production has risen enormously, on the back of the burgeoning demand for plastics, notably polyvinylchloride (PVC) and polyurethanes, the production of chloroaromatics such as chlorobenzene, solvents containing chlorinated hydrocarbons, and inorganic chlorine compounds. In 1995 it was about 44 million tonnes, EU accounting for about 24% of that capacity. After a fall at the beginning of the 1990s, production in western Europe now seems to be stabilised at around 9 millions tonnes per year (9.2 million tonnes in 1999).

The chlor-alkali process is one of the largest consumers of electrical energy. The chlorine production of a country is an indicator of the state of development of its chemical industry. The total value of western European chlor-alkali sector in 1995 production is 3 billion euros and the turnover generated by chlor-alkali related products amounted to some 230 billion euros, that is about 60% of the turnover of the west European chemical industry. Euro Chlor estimates that there are 46,000 employees involved in the direct production of chlorine in the EU. When chlorine derivatives and chlorine-dependent industry are included the number of employees is approximately two million.

The Sources

The text is a summary of the IPPC (European Commission Integrated Pollution Prevention and Control) *Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing Industry,* December 2001.

Technologies In Use

The main technologies applied for chlor-alkali production are mercury, diaphragm and membrane cell electrolysis, mainly using sodium chloride as feed or to a lesser extent using potassium chloride for the production of potassium hydroxide.

The co-production of chlorine and sodium hydroxide in fixed proportions – 1.128 tonnes of caustic (as 100% NaOH) per tonne chlorine produced – has always been a problem for the chlor-alkali industry. Both products are used for very different end uses with differing market dynamics and it is only by rare chance that demand for the two coincides. Depending on which demand is dominant, either can be regarded as a by-product and the price varies dramatically accordingly.

Chlorine itself is difficult to transport long distances; however it can be, and is, readily exported as ethylene-di-chloride (EDC), a precursor for PVC. Caustic soda is a globally traded commodity. Hydrogen is also a co-product (28 kg for 1 tonne of chlorine). Hydrogen is generally used on-site as a combustible or sent as a fuel to other companies. It can also be used on integrated sites for certain applications in particular because of its high purity: synthesis of ammonia, methanol, hydrochloric acid, hydrogen peroxide, etc.

Environmental Relevance of the Chlor-Alkali Industry

Inputs and pollutant outputs from the chlor-alkali industry are quite specific to the cell technology used, the purity of the incoming salt and the specifications of the products. Because of the huge amount of electricity needed in the process, energy can be considered as a raw material.

Historical mercury and PCDD/F (dibenzodioxin and dibenzofuran) contamination of land and waterways from mercury and diaphragm chlor-alkali plants is a big environmental problem at some sites. For many years, the mercury cell has been a significant source of environmental pollution, because some mercury is lost from the process to air, water, products and wastes. Inorganic mercury can be metabolised to form highly toxic methyl mercury by anaerobic bacteria, and this organic mercury is bioaccumulated in the food chain.

In the 1950s a chemical plant producing acetaldehyde discharged a spent catalyst containing organic mercury into Minamata Bay, Japan. A number of people (mostly fishermen) became seriously ill and some were disabled. This event was at the origin of environmental regulations in Japan and caused changes into mercury free technologies in some industrial sectors.

The chlor-alkali industry was the largest domestic user of mercury in 1989-90 in the USA and this could be expected to be the same in Europe. According to Euro Chlor, the total mercury emission to air, water and products from chlor-alkali plants in western Europe was 9.5 tonnes in 1998, ranging between 0.2-3.0 g Hg/tonne of chlorine capacity at the individual plants. Decision 90/3 of 14 June 1990 of the Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPARCOM) recommends that existing mercury cell chlor-alkali plants should be phased out as soon as practicable, and no later than 2010.

As regards the diaphragm technology, due to the potential exposure of employees to asbestos and releases to the environment, the use of good practices is needed and some efforts are being made to replace the asbestos with other diaphragm material.

2. Processes and Techniques

The Basic Processes

Industrial chlor-alkali production, consisting of electrolysis of molten sodium salts (Figure 5.1), depends on three basic processes, the diaphragm cell, the mercury cell, and the membrane cell process. Each process represents a different method of keeping the chlorine produced at the anode separate from the caustic soda and hydrogen produced, directly or indirectly, at the cathode.

At the anode, chloride ions are oxidised and chlorine (Cl_2) is formed. At the cathode in the mercury process a sodium/mercury amalgam is formed. Later hydrogen (H_2) and hydroxide ions (OH^-) are formed as sodium in the amalgam reacts with water in the denuder. In membrane and diaphragm cells, water decomposes to form hydrogen (H_2) and hydroxide ions (OH^-) at the cathode.

The *anode* reaction for all processes is:

$$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$$

The *cathode* reaction is:

$$2Na^+(aq) + 2H_2O + 2e^- \rightarrow H_2(g) + 2Na^+(aq) + 2OH^-(aq)$$

The *overall* reaction is:

$$2Na^+(aq) + 2Cl^-(aq) + 2H_2O \rightarrow 2Na^+(aq) + 2OH^-(aq) + Cl_2(g) + H_2(g)$$

The operation of a chlor-alkali plant is dependent on the availability of huge quantities of direct-current (DC) electric power, which is usually obtained from a high voltage source

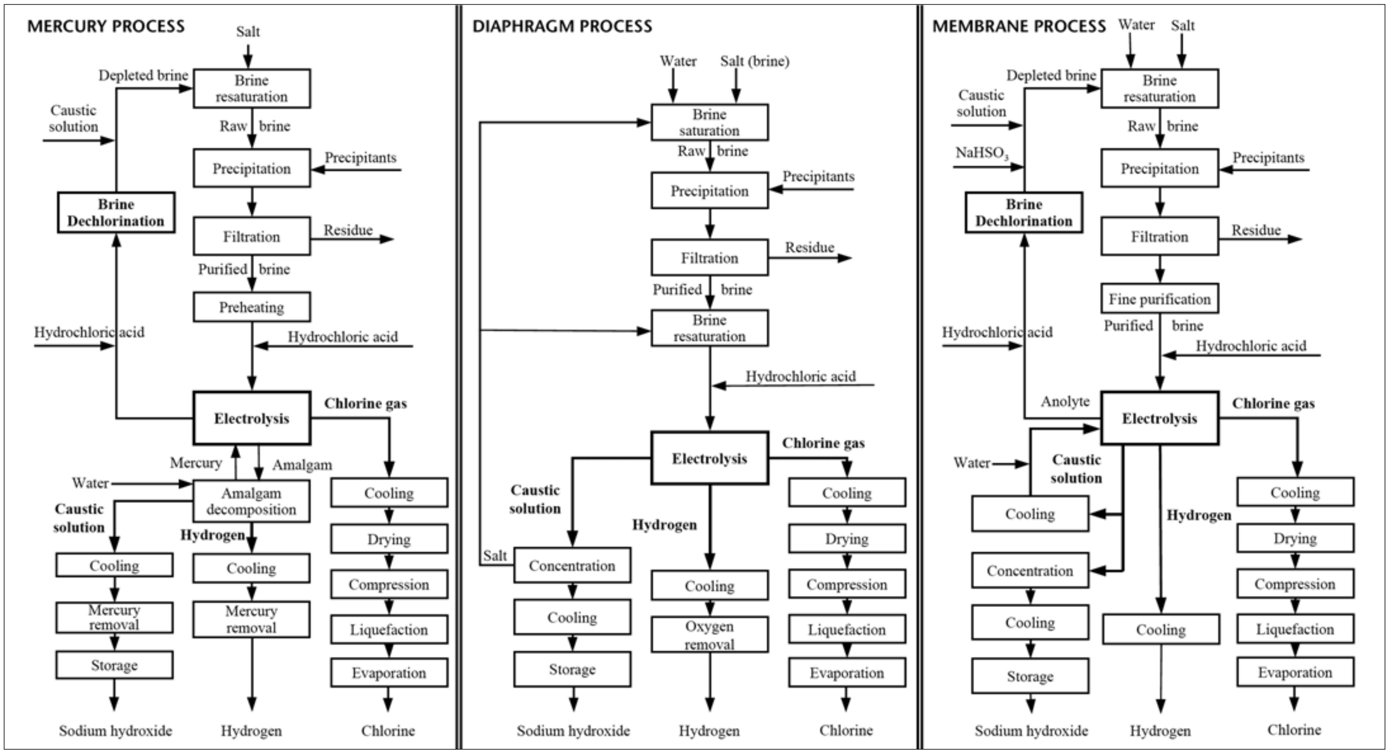


Figure 5.1 *Flow diagram of the three main chlor-alkali processes.*

of alternating current (AC). The lower voltage required for an electrolyser circuit is produced by a series of step-down transformers. Silicon diode rectifiers convert the alternative current electricity to direct current for electrolysis. The voltage is increased with increasing distance between the anode and the cathode. On the other hand, a close distance means a higher frequency of short-circuiting in the amalgam cell.

The Mercury Cell Process

The mercury cell process involves two “cells”. In the primary electrolyser, the brine cell, purified and saturated brine, 25% sodium chloride, flows through an elongated, slightly inclined trough. In the bottom of this trough a shallow film of mercury (Hg) flows along with the brine. Closely spaced above the cathode, an anode assembly is suspended (see Figure 12.1a).

Electric current decomposes the brine passing through the narrow space between the electrodes, liberating chlorine gas at the anode and metallic sodium at the cathode. The chlorine gas accumulates above the anode and is discharged to the purification process. At the surface of the mercury cathode, the sodium forms a liquid amalgam (0.2-0.4% Na by weight) which flows to a separate reactor, called the decomposer or denuder, where it reacts with water in the presence of a graphite catalyst to form sodium hydroxide and hydrogen gas. The sodium-free mercury is fed back into the electrolyser and reused. The brine anolyte leaving the cell is saturated with chlorine and must be dechlorinated before being returned to the dissolvers.

The mercury process has the advantage over diaphragm and membrane cells that it produces a chlorine gas with nearly no oxygen, and a 50% caustic soda solution. However, mercury cells operate at a higher voltage than diaphragm and membrane cells and, therefore, use more energy (caustic soda concentration excluded). The process also requires a pure brine solution with little or no metal contaminants to avoid the risk of explosion through hydrogen generation in the cell. The amalgam process inherently gives rise to environmental releases of mercury.

The Diaphragm Cell Process

In the diaphragm process all reactions take place within one cell and the cell effluent contains both salt and caustic soda. A diaphragm is employed to separate the chlorine liberated at the anode, and the hydrogen and caustic soda produced directly at the cathode. Without the diaphragm to isolate them, the hydrogen and chlorine would spontaneously ignite and the caustic soda and chlorine would react to form sodium hypochlorite (NaClO) and sodium chlorate ($NaClO_3$). The diaphragm is usually made of asbestos. The saturated brine percolates through the diaphragm into the cathode chamber, where it is decomposed to approximately 50% of its original concentration. Heating caused by passage of current through the diaphragm cell raises the operating temperature of the electrolyte to 80-99ºC. The cell liquor containing ca. 11% caustic soda and 18% sodium chloride is evaporated to 50% NaOH by weight at which point all of the salt precipitates out.

Diaphragm cells have the advantage of operating at a lower voltage than mercury cells and operating

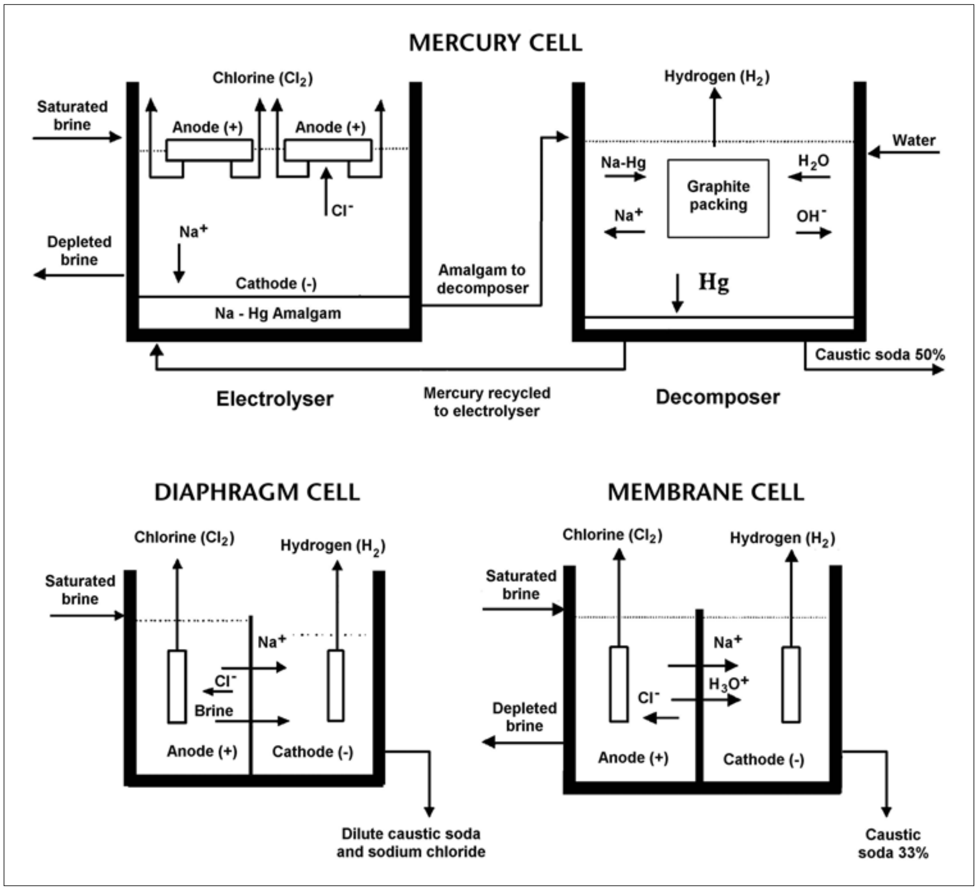


Figure 5.2 *Simplified scheme of chlorine electrolysis cells.*

with less pure brine than required by membrane cells. A disadvantage is that asbestos diaphragms inherently gives rise to environmental releases of asbestos. At the beginning the diaphragms were made of asbestos only and were rapidly clogged by calcium and magnesium ions coming from the brine. Beginning in the early 1970s, asbestos diaphragms began to be replaced by diaphragms containing 75% asbestos and 25% of fibrous fluorocarbon polymer polytetrafluoroethylene (PTFE) of high chemical resistance.

In western Europe electrolytic cell anodes were made of graphite until the late 1960s, when anodes of titanium coated with ruthenium oxide (RuO_2) and titanium oxide (TiO_2) were developed. The use of RuO_2 and TiO_2 coated metal anodes reduces energy consumption by about 10% and their life expectancy is higher. When graphite anodes were used, the diaphragm became inoperable after 90-100 days due to plugging of the diaphragm by particles of graphite. Nowadays, all plants in the European Union use metal anodes and the lifetime of the diaphragm is over one year.

The Membrane Cell Process

In this process, the anode and cathode are separated by a water-impermeable ion-conducting membrane. Brine solution flows through the anode compartment where chloride ions are oxidised to chlorine gas, while the sodium ions migrate through the membrane to the cathode compartment which contains flowing caustic soda solution. Water added to the catholyte circuit is hydrolysed, releasing hydrogen gas and hydroxide ions, forming caustic soda typically at 32-35%. The solution is recirculated before it is discharged from the cell. The membrane prevents the migration of chloride ions from the anode compartment to the cathode compartment; therefore, the caustic soda solution produced does not contain salt as in the diaphragm cell process. Depleted brine is discharged from the anode compartment and re-saturated with salt.

The cathode material used in membrane cells is either stainless steel or nickel. The cathodes are often coated with a catalyst that is more stable than the substrate and that increases surface area and reduces over-voltage. The anodes used are metal. The membranes used in the chlor-alkali industry are commonly made of perfluorinated polymers and generally reinforced with PTFE fibres to improve the membrane mechanical strength.

Membrane cells have the advantage of producing a very pure caustic soda solution and of using less electricity than the other processes. In addition, the membrane process does not use highly toxic materials such as mercury and asbestos. Disadvantages of the membrane process are that the caustic soda produced may need to be evaporated (using steam) to increase concentration to 50%, and the chlorine gas produced may need to be processed to remove oxygen. Furthermore, the brine entering a membrane cell must be of a very high purity, which often requires costly additional purification steps prior to electrolysis.

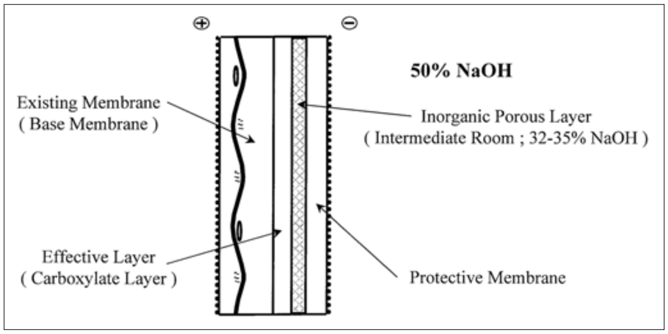


Figure 5.3 *Structure of Fx-50 membrane producing 50% caustic soda.*

The membrane electrolysis process uses ion exchange membranes. Asahi Glass (Flemion) installed the first industrial membrane plant in Japan in 1975 due to the pressure of Japanese environmental regulations and Japan was the first country to install the membrane process on a massive scale in the mid-1980s. Today, it is the most promising and fast-developing technique for the production of chlor-alkali and it will undoubtedly replace the other two techniques in time. Since 1987 practically 100% of the new chlor-alkali plants world-wide apply the membrane process. The replacement of existing mercury and diaphragm cell capacity with membrane cells is taking place at a much slower rate because of the long lifetime of the former and because of the high capital costs of replacement.

Auxiliary Processes

Apart from the cells, which remain the heart of the chlorine production line, there are other processing steps or equipment, common to amalgam, diaphragm and membrane technologies. These are:

- Salt unloading and storage.
- Brine purification and re-saturation.
- Chlorine processing.
- Caustic processing.
- Hydrogen processing.

The brine purification process consists of a primary system for mercury and diaphragm technologies and an additional secondary system for membrane technology. This operation is needed to avoid any undesirable components (sulphate anions, cations of Ca, Mg, Ba and metals) that can affect the electrolytic process.

Apart from sulphates and hardness ions, the brine may contain ammonium ions or organic nitrogen which are converted to nitrogen trichloride in the electrolytic cell. If concentrated in liquid form in downstream processes, NCl_3 may explode with disastrous results. Chlorination at a pH higher than 8.5 or hypochlorite treatment of the brine is capable of destroying a large proportion of the ammonium salt impurity.

Mercury and membrane systems usually operate with brine recirculation and re-saturation. Some diaphragm cell lines have a once-through brine circuit, whilst others employ brine saturation using the salt recovered from the caustic evaporators.

Chlorine and Caustic Soda Production, Storage and Handling

The products of the chlor-alkali process, chlorine and caustic soda, are both very reactive, toxic and corrosive and requires special precautions.

The chlorine mostly goes through a series of processes for cooling, cleaning, drying, compression and liquefaction before it can be used, although partly it is used as a dry gas, and very occasionally directly from the electrolysers. In the primary cooling process, the total volume of gas to be handled is reduced and a large amount of moisture is condensed.

Chlorine from the cooling system is more or less saturated with water vapour. Drying is accomplished in countercurrent sulphuric acid contact towers which reduce the moisture content to less than 20 ppm. After drying, chlorine gas might be scrubbed with liquid chlorine or treated with ultra-violet irradiation to reduce levels of nitrogen trichloride and then it may be compressed in a variety of compressors. Because of heat build-up from compression, multistage units with coolers between stages are usually necessary. The chosen liquefaction pressure and temperature chosen influence the choice of cooling media and the safety precautions necessary to operate safely.

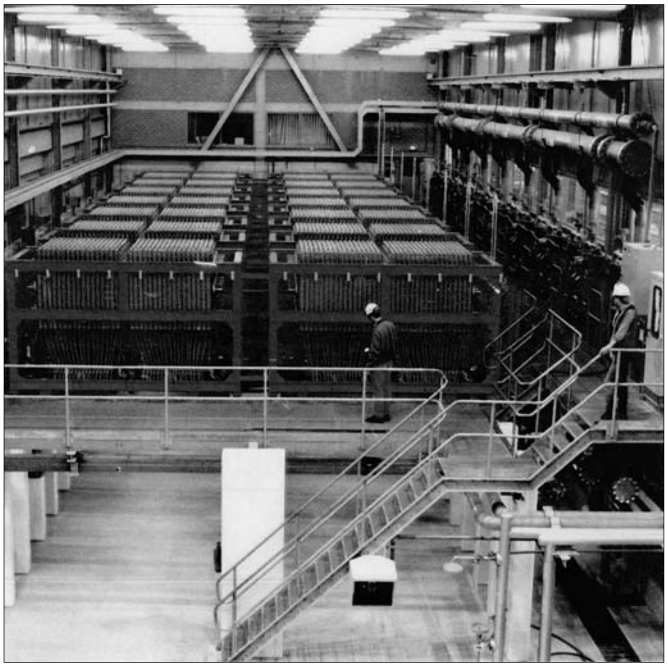


Figure 5.4 *View of a membrane cell room equipped with bipolar electrolysers.*

The caustic soda produced is normally pumped through a cooler, then through a mercury removal system (for the mercury process) and then to the intermediate and final storage sections. Because of its highly reactive and corrosive properties, caustic soda requires resistant construction materials for handling and storage. The solutions also require steam or electrical heating where temperatures can fall below the upper freezing point.

3. Environmental Impacts

Overall Consumption and Emission Levels of All Cell Plants

Inputs and pollutant outputs of the chlor-alkali industry are quite specific to the cell technology used but also depend on the specifications of the products (O_2 or CO_2 content, for example), the purity of the incoming salt and the geographical location of the plant. The inputs are primarily salt and water as feedstock; acids and chemical precipitants used to remove impurities in the input brine or output chlorine/caustic soda; cooling agents (CFCs, HCFCs, HFCs, ammonia, etc.) for liquefying and purifying the chlorine gas produced. The chlor-alkali process needs huge amounts of electricity and electrical energy is a major input. The main pollutant outputs which are common to all three electrolytic processes are chlorine gas emissions, spent acids, cooling agents, impurities removed from the input salt or brine.

The amalgam technology emits mercury through air, water, wastes and in the products. At present some 12,000 tonnes of mercury are contained in mercury cells in the EU. When the plants are converted or shut down, this mercury has the potential to be released into the global environment. Currently, there is no European Union policy or legislation on how to deal with this huge amount of pure mercury. In 2007 a proposal to outlaw export of Hg is developed by the EU Commission and prepares for long-term storage.

The main issue with the diaphragm technology is asbestos. Both the potential exposure of employees to asbestos and releases of asbestos to the environment are of concern. Historical mercury and PCDD/F (dibenzodioxin and dibenzofuran) contamination of land and waterways from mercury and diaphragm chlor-alkali plants is a big environmental problem at some sites. The contamination is due to fallout of mercury and historical disposal of graphite sludges, from the use of graphite anodes, and other wastes on and around the plant sites.

The membrane cell process has inherent ecological advantages over the two older processes, as it does not use mercury or asbestos, and it is the most energy efficient process. Despite these advantages, the change of technology to membrane cells has been slow in western Europe because most existing chlorine plants were installed in the 1970s with a plant life of 40-60 years and there has been no need for new production capacity. Nor has there been a legislative drive to change technology.

Inputs for the Production

Water is used in the process for preparation of the brine, for maintaining the water balance in the reaction to form NaOH in the membrane and mercury cells. Apart from the water needed for cooling, generally 2-2.5 m³ of water is consumed per tonne of chlorine produced for plants using a brine recirculation process. For waste brine processes, about 10 m³ of water per tonne of chlorine produced is required.

Energy is used both as electricity and as heat. About half of the energy expended is converted into the enthalpy of the products. The rest is converted into heat transferred to the air in the building and the products, which have to be cooled. The heat is partly recirculated through preheating of the brine. Surplus heat might also be used for heating surrounding buildings or for the concentration of caustic soda. Insulation of the cells and salt dissolvers reduces the need for ventilation of the cell room and increases the amount of heat transferable. The hydrogen produced in chlor-alkali plants can be used as a raw material in the synthesis of chemicals or as a fuel.

The total energy use associated with Best Available Technique (BAT) for producing chlorine gas and 50% caustic soda is less than 3,000 kWh (AC) per tonne of chlorine when chlorine liquefaction is excluded and less than 3,200 kWh (AC) per tonne of chlorine when chlorine liquefaction and evaporation are included. For a plant with an annual capacity of 150,000 tonnes of chlorine this approaches 500 GWh.

Chlorine, Mercury and Asbestos Emissions

Because chlorine is a hazardous gas, leakage from electrolytic cells should be avoided. However, small amounts of chlorine might be emitted through leakage and handling of the cell covers. Chlorine detectors are used for immediate indication of any significant leakage. Chlorine concentration in the electrolysis hall can be below odour detection level if the cells are operated in a slight vacuum. Estimated emissions vary from close to zero to 16 g chlorine per tonne of chlorine produced.

The total mercury emission to air, water and products from chlor-alkali plants in western Europe was 9.5 tonnes in 1998, ranging from 0.2-3.0 g Hg/tonne of chlorine capacity at the individual plants.

The majority of mercury losses occur, however, in the various process wastes. For 1997, OSPARCOM reported 31 tonnes of mercury in solid wastes not recycled. Mercury in solids disposal plant-by-plant were in the range of 0-84 g Hg/tonne chlorine capacity in 1998, as reported by Euro Chlor. Euro Chlor reports 27 g in 1977, 8 g in 1987 and around 2 g in 1997 mercury per tonne chlorine. The industry moved in the 1990s to membrane cell process. The first European membrane plant opened in 1983 at Akzo in Rotterdam.

Mercury-contaminated waste water streams are collected from all sources and generally treated in a waste-water treatment plant. The mercury level in chlorine is negligible, i.e. less than 0.001 g/tonne. Hydrogen and caustic soda from amalgam chlor-alkali plants contain a certain amount of mercury, and purification is needed before the products are sold.

Asbestos emissions from the baking furnace were calculated as being about 5 g per year, corresponding to an emission of 0.036 mg of asbestos per tonne of chlorine capacity in a plant of 140,000 tonnes annual chlorine capacity. Asbestos is considered to be carcinogenic and enter the human body by either inhalation or ingestion. At the end of the lifetime of an asbestos diaphragm, the asbestos is removed from the cathode can by means of high pressure water-jet cleaning. Asbestos is collected with the rinsing water and can be discharged. A filter press can be installed to remove asbestos from the rinsing water. Reported emissions give values of under or equal to 30 mg/l.

Solid Wastes

Solid wastes in the diaphragm process consist of wastes generated during brine purification and scrapped cell parts, including cell covers, piping and used diaphragms. The asbestos diaphragms in modern diaphragm chlor-alkali plants have a lifetime of approximately one year. Reported figures are in the range of 0.09 to 0.2 kg solid residue per tonne of chlorine capacity (13.5-30 tonnes of asbestos per year, with a chlorine capacity of 150,000 tonnes). 0.1 kg per tonne chlorine capacity is the medium average reported by the industry. Discarded cell parts are either landfilled on-site or sent off-site for disposal, depending on the legislation of the country.

Chlorinated Hydrocarbons

Chlorinated hydrocarbons ($C_XCl_YH_Z$) are formed in a reaction between organic contaminants in the electrolyser and free oxidants. Examples of chlorinated hydrocarbons found in the effluent of chlor-alkali plants are chloroform (CCl_3H), dichloromethane (CCl_2H_2), carbon tetrachloride (CCl_4), tetrachloroethylene (C_2Cl_4). The emissions of chlorinated hydrocarbons from chlor-alkali plants have decreased significantly after the switch from graphite to metal anodes. The releases of chlorinated hydrocarbons is normally low but can be higher for plants that destroy the produced bleach in the chlorine destruction unit and discharge the remaining liquid. Discharges to water measured as extractable organic halogens (EOX), were in the range of 0.03-1.16 g/tonne chlorine capacity, where the higher figure is reported from a plant with bleach destruction.

Safety Aspects of Chlor-Alkali Plants

Safety aspects are of much concern in the chlor-alkali industry. Production, loading, storage and transportation of chlorine require compliance with certain provisions designed to minimise the possibility of incidents giving rise to danger to operators, the public or the plant. A general policy for the prevention of and response to industrial accidents is usually based on the prevention principle (e.g. Annex IV to IPPC Directive), i.e. the plant is constructed and operated in such a way as to prevent any uncontrolled development and to reduce the consequences of accidents.

In the European Union the SEVESO Directive (82/501/EEC), regulates control of major industrial hazards. The “SEVESO II” Directive (96/82/EC) represents a fundamental revision of the Directive. Storage and processes using chlorine are part of the scope of the Directive starting from 10 tonnes, along with hydrogen starting from 5 tonnes, while the alkali solutions are not covered.

4. Cleaner Production Opportunities

Safety Measures

In hazard and risk assessment studies, the design of chlor-alkali installations and equipment and the operating and maintenance routines are examined in detail to reduce the risks for people and the environment at source as much as possible. The most important substance to consider is chlorine. Preventative measures are the most important, although corrective and emergency measures are also of importance. General measures related to safety are mainly linked to reliable and efficient safety management systems based on:

- Training of personnel including basic knowledge of chlorine properties, correct operating practice, emergency procedures.
- Identification and evaluation of major hazards including written information for personnel about safety measures in normal and abnormal conditions.
- Instructions for safe operation including permanent monitoring of the installations under the responsibility of a designated person, good compliance with safety parameters defined in the safety report, including periodic inspection and control of materials specified according to safety hazards, and maintenance programmes for the installations.
- Planning for emergencies and recording of accidents and near-misses.

The safety management systems should be completed with appropriate technical measures, such as high quality preventive and protective systems, enhanced leak detection and leak isolation, and good protection of employees and temporary workers on the site with appropriate and well maintained equipment.

On-Site Re-Concentration of Spent Sulphuric Acid

Concentrated sulphuric acid (92-98%) is used to dry chlorine. Up to 20 kg of acid is consumed per tonne chlorine produced. The spent acid usually becomes a waste product or one that requires reprocessing. The spent acid can be used to control pH in process and waste water streams or to destroy surplus hypochlorite. It can be returned to an acid producer for reconcentration or sold to any user who can accept this quality of acid. Sulphuric acid can also be re-concentrated on-site in closed loop evaporators which reduces the consumption to 0.1 kg of acid per tonne of chlorine produced. The spent sulphuric acid is concentrated to 92-98% by indirect heating with steam. Materials used must be highly corrosion-resistant to avoid corrosion problems, in particular if the feed acid is polluted. Main achievements leads to significant reduction in sulphuric acid consumption.

Treatment of Wastewater Containing Free Oxidants, Including Bleach Destruction

The chlor-alkali industry potentially discharges waste water containing free oxidants such as Cl_2, Br_2, hypochlorite (OCl^-), hypobromite (OBr^-) and NH_XBr_Y. The free oxidants can be destroyed by chemical reduction, by catalytic reduction or by thermal decomposition. It is also possible to recover the chlorine by acidification of the waste hypochlorite stream. This would seem especially attractive to large chlorine plants when considerable amounts of spent acid are available (spent sulphuric acid from chlorine drying). If the quantities are low, the hypochlorite produced can be recycled in the cell brine at low pH.

Carbon Tetrachloride-Free Chlorine Liquefaction and Purification

Although outlawed, carbon tetrachloride is still used at some locations for removal of nitrogen trichloride (NCl_3) and for absorption of tail gas. However, other alternatives which do not use CCl_4 are available and applicable to existing plants. First of all, if chlorine can be used directly without liquefaction it may not be necessary to remove the NCl_3. A preventative measure to avoid the accumulation of NCl_3 is to specify low ammonium ion concentration in purchased salt (for example vacuum salt without addition of ferrocyanides to avoid caking). Another is to purify the brine to remove ammonium ions (for example by chlorination at a pH higher than 8.5 or hypochlorite treatment of the brine). Available techniques for NCl_3 destruction, not using CCl_4, include adsorption with activated carbon filters, ultraviolet light, and high metal temperatures, particularly of copper base alloys at temperatures of 80-100°C, to decompose NCl_3.

Mercury Emission Abatement

Although mercury emissions have been greatly reduced, it is understood from comparing performances of applied abatement techniques that improvements are still possible. Good housekeeping based on motivated staff is of great importance for the reduction of air emissions. Monitoring of possible leakages and recovery of mercury is important to react as quickly as possible to avoid mercury evaporation. Continuous monitoring of mercury concentration in the cell room, removal of mercury spillage and immediate intervention at leakage (aided by appropriate housekeeping and continuous monitoring) and immediate isolation of Hg in closed vessels are important measures.

After treatment, mercury can be recovered and reused. Recuperation of mercury is possible from caustic treatment sludges, hydrogen and waste gas treatment when using chemical processes, water treatment sludges, the mercury distillation unit, the area for handling mercury-contaminated parts (for example, when changing the decomposer graphite). In most cases, the mercury-containing solid residue that result from treatment need stabilisation before being disposed of. Stabilisation serves to transform metallic mercury to a less soluble, more stable chemical state in order to reduce the risk of leaching from the final disposal site in the short and long term. In many cases, mercury is treated with sulphur or sulphur compounds to transform it to mercury sulphide or with selenium to mercury selenide. This can also be combined with physical stabilisation, for example in cement-based materials.

For final disposal, the residue can be sent to a waste landfill (hazardous or non-hazardous, depending on mercury content), to deep rock storage (now implemented in Sweden) or to salt mines.

Conversion of Mercury Cell Plants to Membrane Technology

The conversion of mercury cell plants to membrane technology has the advantage of avoiding any future losses of mercury to the environment and reduces the energy consumption. At the Borregaard plant in Sarpsborg (Norway) recently installed membrane cells have resulted in electrical energy savings of 30% per tonne of 100% NaOH. According to Euro Chlor an estimated typical electrical energy saving after conversion is 15% and the total energy saving about 10%.

Table 5.1 *Comparison of typical energy use by the mercury, diaphragm and membrane cell chlor-alkali technologies, assuming production of 50% caustic soda and before liquefaction of chlorine.*

Parameter	Amalgam Technology	Asbestos/ Diaphragm Technology	Membrane Technology
Theoretical voltage (V)	3.15	2.19	2.19
Current density (kA/m²)	8-13	0.9-2.6	3-5
Cell voltage (V)	3.9-4.2	2.9-3.5	3-3.6
Caustic strength (% by weight)	50	12	33
Electrical energy use (alternating current) (ACkWh/t Cl_2)	3,360 at 10 kA/m²	2,720 at 1.7 kA/m²	2,650 at 5 kA/m²
Electrical energy use by other electrical equipment (pumps, compressors, etc) (ACkWh/t Cl_2)	200	250	140
Total energy use (ACkWh/t Cl_2)	**3,560**	**2,970**	**2,790**
Energy use by steam to concentrate caustic to 50% (ACkWh/t Cl_2)	0	610	180
Adjusted total energy use (ACkWh/t Cl_2)	**3,560**	**3,580**	**2,970**

To realise the conversion most membrane cell operators have either built a brand new "green field" plant or expanded production capacity with a new plant alongside their mercury facilities. Some have completely converted their existing plant, but there are also examples of partial conversion. The saving of space makes it theoretically possible to install up to four times more capacity with membrane technology in an existing building, but a clean space is needed for the membrane cells.

The main changes include the following measures: For the brine system the main concern is the purity of the brine feed to the existing cell room system. The design and operation of the electrolysers are essentially different and no old parts can be reused. Reuse of the rectifiers of the power supply depends on the type of membrane cell configuration and power requirements. While mercury cell technology produces 50% caustic soda membrane cells require a recirculating system with associated heat exchange and dilution and produce 33% caustic soda. If more concentrated caustic soda is needed, an evaporator system is also necessary. The reuse of existing process piping is not appropriate when converting to a membrane process, as the physical location is often very different from that required by membrane electrolysers.

Box 5.1 Data from the Conversion of the Borregaard Chlor-Alkali Plant to Membrane Technology

Context of old production units
- Cell room built in 1949: 3 floors, 122 cells.
- Mercury air emissions: 1.4 g/tonne chlorine capacity.
- Mercury water emissions (water ion exchange process): 0.25 g/tonne chlorine capacity.

Driving force for conversion
- Demand from the Norwegian authorities to switch to a mercury-free process.
- Demand for higher production of sodium hydroxide and wish to lower operating costs.

The conversion
- Decision made to convert: autumn 1995.
- Conversion carried out: autumn 1997.
- Shutdown time: 7 weeks.

Characteristics of new plant
- 40000 tonnes Cl_2 capacity/year at 4.35 kA/m^2.
- Supplier: Asahi Glass Co. Ltd. Japan.
- Engineering: Krebs-Swiss.
- Electrolyser: AZEC-B1 bipolar, 4 electrolysers, each 75 cells.
- Membrane area: 2.88 m^2 per cell.
- Membrane: Flemion 893.

Reused equipment
- Rectifiers.
- Hydrogen treatment and HCl production units.
- Chlorine liquefaction section and compression.

New equipment
- Cell room for electrolysers: The existing building was considered old and mercury-contaminated.
- Electrolysis section.
- Brine circuit: brine filtration unit, ion exchange unit, brine dechlorination unit.
- Sodium hydroxide concentration unit and evaporation system.
- Chlorine gas drying unit and chlorine gas absorption unit.
- Power supply and wiring (excluding rectifiers).
- Pumps, instruments and piping.

Cost of conversion
- Total cost of conversion was about 210 million NOK (26.6 million euros October 1997) corresponding to about 665 euros/tonne chlorine capacity. This figure includes 2.4 million euros for the clean-up of the old plant and the storage of mercury-contaminated waste but excludes the cleanup of soil pollution.

Economic benefits
- Electricity: 30% reduced per tonne 100% NaOH.
- Personnel: 25% reduced.
- Some mercury sold for batteries, instruments and to mercury chlor-alkali plants.
- Return on investment: 5 years (depending on the caustic market).

Decommissioning
- No cleaning-up of mercury-contaminated soil.
- Monitoring of mercury emission to air from old cell room.
- Construction of a sealed disposal facility for mercury-contaminated wastes: 1800 ^{m3}, 3 special membranes with sand filter seals between. The bunker is ventilated and the vented air led through a carbon filter. The majority of the wastes (about 55%) was mercury contaminated process equipment (steel and rubber lined steel).
- 95 tonnes of mercury drained from the cells.

Abatement of Asbestos Emissions in Diaphragm Cell Plants

In its various formulations, the polymer modified asbestos (PMA) diaphragm, containing a minimum of 75% of chrysotile asbestos mixed with PTFE fibres, is the most common diaphragm in use today. The major potential sources of air emissions are during diaphragm deposition, treatment of operating cells with asbestos slurry and the disposal of spent asbestos. Contaminated water also needs to be collected and recycled as far as possible. Laboratory tests using asbestos-free diaphragms began in the mid-1980s, following the increasing pressure to reduce the use and emissions of asbestos. Suitable alternatives have been developed at industrial scale with the objective of bringing the new asbestos-free diaphragm technology to the same commercial level as the polymer modified asbestos (PMA) diaphragms.

Changing from Diaphragm Cells to Membrane Technology

Conversion of a diaphragm plant to membrane technology can be an attractive choice because of removal of the hazardous asbestos, the high energy efficiency, and the pure 33% caustic produced directly from the cells. This is especially the case when there is a need for high purity 50% caustic, due to the reduced costs of evaporation and the higher caustic quality of the membrane technology. A conversion to asbestos-free diaphragms requires substantially less change in the existing cell room than a conversion to membranes, and thus a lower capital investment. A comparison of the manufacturing costs is dependent on steam costs and the required caustic quality.

The important changes to an existing plant when converting from diaphragm cells to membrane technology include additional brine purification, including hardness removal ion exchange techniques; additional brine dechlorination to protect the ion exchange resin, by adding primary and secondary dechlorination and possibly re-saturation to the brine recirculation loop; inclusion of a cell room caustic soda recirculation system; and change of electrolysers and details of the cell room system.

Hydrogen Usage

Hydrogen should be used as a chemical or as fuel in order to conserve resources.

Heat Usage

Heat produced in the electrolysis should be used in several of the processes in the plant, including the production of steam, heating caustic soda for concentration and heating buildings.

High Performance Membranes

New high-performance membranes are now commercially available to equip electrolysers. There are high-performance membranes for use in narrow and zero gap electrolysers (low cell voltage, reduced energy use) for the production of chlorine and 30-35% caustic soda. They are all reinforced composite membranes, having sulphonate and carboxylate polymer layers. In the design of a membrane electrolyser using standard membranes, minimising the voltage drop through the electrolyte gap is accomplished by reducing the gap.

New Cathode Designs

A number of new promising techniques are being developed with energy savings as the main driving force. An interesting example is a specific development of activated cathode technology, the pre-cathode concept. Oxygen depolarised cathodes in membrane cells have the potential to save around 500-600 kWh/tonne of chlorine produced (an approximate 15% reduction) and are now being tested at the industrial scale. At least one supplier is developing a membrane that can produce high concentration (50%) caustic soda and believes that it could be available at an acceptable cost within a few years. The life time of the diaphragm has also been found to be improved by introduction of the pre-cathode.

The utilisation of oxygen depolarised cathodes (ODCs) in the chlor-alkali electrolysis is an integration of the fuel cell process into the membrane electrolysis cell: the cathode half cell reduces oxygen instead of producing hydrogen. This lowers the cell voltage by about 1 volt and means a substantial energy saving, as predicted from the theory. The ODC is a gas diffusion electrode which separates caustic from the oxygen side, from where the gas diffuses into the porous electrode structure to the catalyst centres and reacts with the cathodic water to produce OH^- ions. All other functions are the same as in the normal membrane electrolysis. An energy gain of about 500-600 kWh/t chlorine produced was achieved.

6 – Cement Manufacturing Industry

1. The Cement Industry

Cement Production

Cement is a basic material for building and civil engineering construction. Output from the cement industry is directly related to the state of the construction business in general and therefore tracks the overall economic situation closely. The production of cement in the EU-12 in 1995 was 172 million tonnes.

In Europe the use of cement and concrete (a mixture of cement, aggregates, sand and water) in large civic works can be traced back to antiquity. Portland cement, the most widely used cement in concrete construction, was patented in 1824. In 1995 there were 252 installations producing cement clinker and finished cement in the EU-15 and a total of 437 kilns. In recent years typical kiln size has come to be around 3000 tonnes clinker/day.

There is generally little import and export of cement, mainly as a result of the high cost of road transport. Road deliveries of cement generally do not exceed distances of 150 km. Consequently, the rate of consumption equals the rate of production for many EU member states, with the exception of Greece and Denmark. Their export accounts for approximately 50% of their cement production.

Technologies

Cement is a finely ground, non-metallic, inorganic powder when mixed with water forms a paste that sets and hardens. This hydraulic hardening is primarily due to the formation of calcium silicate hydrates formed by mixing water and the cement components.

The Sources

The text is a summary of the IPPC (European Commission Integrated Pollution Prevention and Control) *Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries,* December 2001.

See also Case Study 1 on Kunda Cement in Book 4 of this series.

Naturally occurring calcareous deposits such as limestone, marl or chalk provide the source for calcium carbonate. Silica, iron oxide and alumina are found in various ores and minerals, such as sand, shale, clay and iron ore. Power station ash, blast furnace slag, and other process residue can also be used as partial replacements for the natural raw materials. To produce 1 tonne of clinker the typical average consumption of raw materials in the EU is 1.57 tonnes. Most of the balance is lost from the process as carbon dioxide emission to air in the calcination reaction:

$$CaCO_3 \rightarrow CaO + CO_2$$

The cement industry is thus main emitter of the greenhouse gas carbon dioxide, both because of its large energy use and the calcination reaction. About 5% of global CO_2 emissions is due to cement production.

In 1994 Europe's cement industry produced 44%, Portland-composite cement 43%, Portland cement while Blastfurnace, Pozzolanic and other cements accounted for the rest. 78% of the production relied on dry process kilns, the rest is accounted for by semi-dry, semi-wet process and wet process kilns. The choice of manufacturing process is primarily motivated by the nature of the available raw materials.

The cement industry is an energy intensive industry with energy typically accounting for 30-40% of production costs. Various fuels can be used to provide the heat required for the process. The most commonly used fuels were pet coke (39%) and coal (36%) followed by different types of waste (10%), fuel oil (7%), lignite (6%) and gas (2%) (1995 statistics).

The emissions from cement plants which cause greatest concern are nitrogen oxides (NO_X), sulphur dioxide (SO_2) and dust. Other emissions to be considered are carbon monoxides (CO), volatile organic compounds (VOCs), polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs), metals, and noise.

2. Production Technologies

The Basic Processes

The basic chemistry of the cement manufacturing process begins with the decomposition of calcium carbonate ($CaCO_3$) at about 900°C to leave calcium oxide (CaO, lime) and liberate gaseous carbon dioxide (CO_2); this process is known as calcination. This is followed by the clinkering process in which the calcium oxide reacts at high temperature (typically 1400-1500°C) with silica, alumina, and ferrous oxide to form the silicates, aluminates, and ferrites of calcium which comprise the clinker. The clinker is then ground or milled together with gypsum and other additives to produce cement.

There are four main process routes for the manufacture of cement; the dry, semi-dry, semi-wet and wet processes:

In the *dry process*, the raw materials are ground and dried to raw meal in the form of a flowable powder. The dry raw meal is fed to the preheater or precalciner kiln or, more rarely, to a long dry kiln.

In the *semi-dry process* dry raw meal is pelletised with water and fed into a grate preheater before the kiln or to a long kiln equipped with crosses.

In the *semi-wet process* the slurry is first dewatered in filter presses. The filter cake is extruded into pellets and fed either to a grate preheater or directly to a filter cake drier for raw meal production.

In the *wet process*, the raw materials (often with high moisture content) are ground in water to form a pumpable slurry. The slurry is either fed directly into the kiln or first to a slurry drier.

Figure 6.1 shows an overview of a dry process precalciner route.

The choice of process is to a large extent determined by the state of the raw materials (dry or wet). A large part of world clinker production is still based on wet processes. However, in Europe, more than 75% of production is based on dry processes thanks to the availability of dry raw materials. Wet processes are more energy consuming. All processes have the following sub-processes in common:

- Winning of raw materials.
- Raw materials storage and preparation.
- Fuels storage and preparation.
- Clinker burning.
- Cement grinding and storage.
- Packing and dispatch.

Raw Materials

Naturally occurring calcareous deposits such as limestone, marl or chalk provide the source for calcium carbonate. Silica, iron oxide and alumina are found in various ores and minerals, such as sand, shale, clay and iron ore. Power station ash, blast furnace slag, and other process residue can also be used as partial replacements for the natural raw materials as can fly ash,

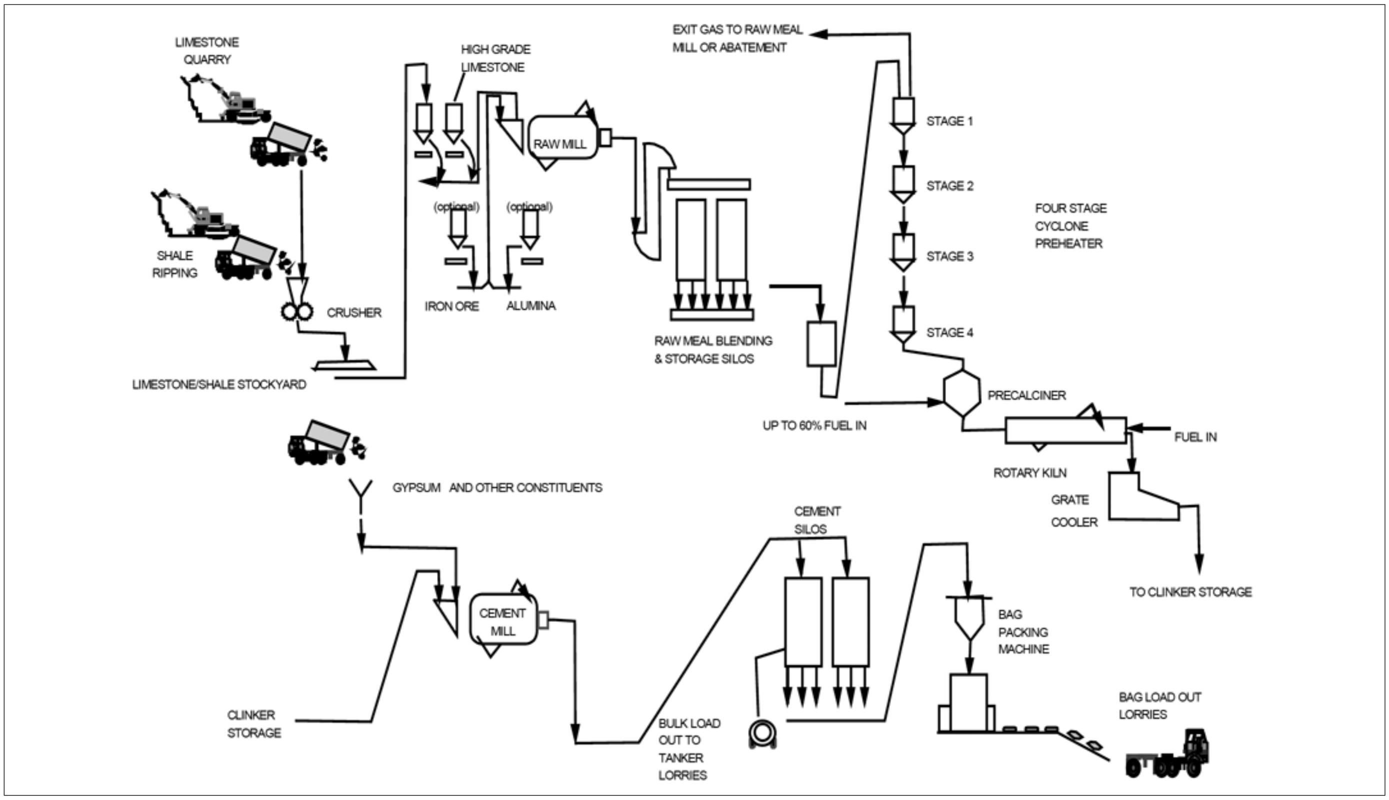


Figure 6.1 *A typical precalciner dry process.*

blast furnace slag, silica fume, iron slag, paper sludge, pyrite ash and phosphogypsum (from flue gas desulphurisation and phosphoric acid production).

The natural raw materials are most often obtained from open surface quarries, by rock drilling, blasting, excavation, hauling and crushing. In most cases the quarry is close to the plant. Preparation of the raw material is of great importance to the subsequent kiln system both in getting the chemistry of the raw feed right and in ensuring that the feed is sufficiently fine.

The raw materials are ground and mixed together to form a homogeneous blend with the required chemical composition. For dry and semi-dry kiln systems, the raw material components are ground and dried to a fine powder, making use mainly of the kiln exhaust gases and/or cooler exhaust air. The fineness and particle size distribution of the product leaving a raw grinding system is of great importance for the subsequent burning process.

Fuels

Three different types of fuels are mainly used in cement kiln firing; in decreasing order of importance these are pulverised coal and pet coke; (heavy) fuel oil; and natural gas. The main ash constituents of these fuels, silica and alumina compounds, combine with the raw materials to become part of the clinker.

The high temperatures and long residence times in the kiln system destroys completely all organic substances, which makes a wide variety of alternative fuel options possible, in particular different types of wastes. Wastes, that are fed through the main burner, will be decomposed in the primary burning zone, at temperatures up to 2000°C. The types of waste most frequently used as fuels in Europe today are used tyres, waste oils, sewage sludge, rubber, waste woods, plastics, paper waste, paper sludge, and spent solvents.

In order to keep heat losses at minimum, cement kilns are operated at lowest reasonable excess oxygen levels. This requires highly uniform and reliable fuel metering allowing easy and complete combustion. This is possible with all liquid and gaseous fuels. For pulverised solid fuels, good design of hoppers, conveyors and feeders is essential. Solid fuel preparation (crushing, grinding and drying) is usually carried out on site.

Clinker Burning

This part of the process is the most important in terms of emissions and of product quality and cost. In clinker burning, the raw meal is fed to the rotary kiln system where it is dried, preheated, calcined and sintered to produce cement clinker. The clinker is cooled with air and then stored. In the clinker burning process it is essential to maintain kiln charge temperatures of between 1400 to 1500°C and gas temperatures of about 2000°C. The clinker needs to be burned under oxidising conditions, why an excess of air is required in the sintering zone. Since the rotary kiln was introduced around 1895 it has become the central part of all modern clinker producing installations.

The first rotary kilns were long wet kilns, where the whole heat consuming thermal process takes place in the kiln itself. The introduction of the dry process allowed drying, preheating and calcination to take place in a stationary installation rather than in the rotary kiln.

The rotary kiln consists of a steel tube with a length to diameter ratio of between 10:1 and 38:1. The tube is supported by two to seven (or more) support stations, has an inclination of 2.5 to 4.5% and a drive rotates the kiln about its axis at 0.5 to 4.5 revolutions per minute. The combination of the tube's slope and rotation causes material to be transported slowly along it. In order to withstand the very high peak temperatures the entire rotary kiln is lined with heat resistant bricks (refractories). All long and some short kilns are equipped with internals (chains, crosses, lifters) to improve heat transfer.

The fuel introduced via the main burner produces the main flame with flame temperatures around 2000°C. For process-optimisation the flame has to be adjustable within certain limits. In a modern indirectly fired burner, the flame is shaped

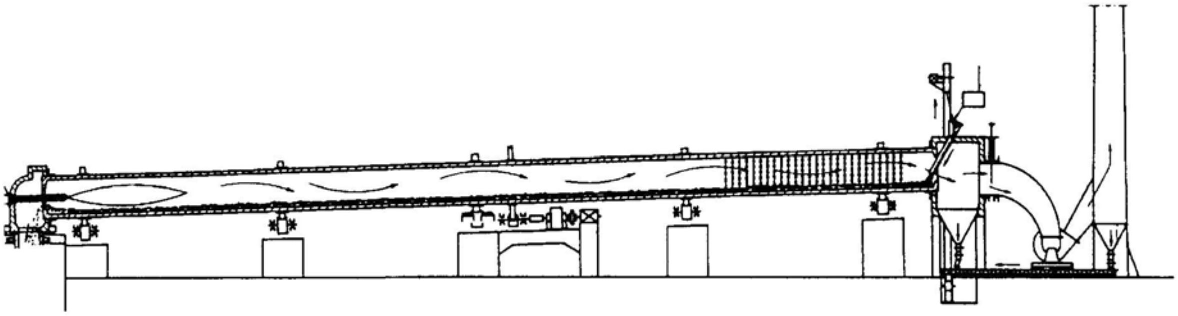
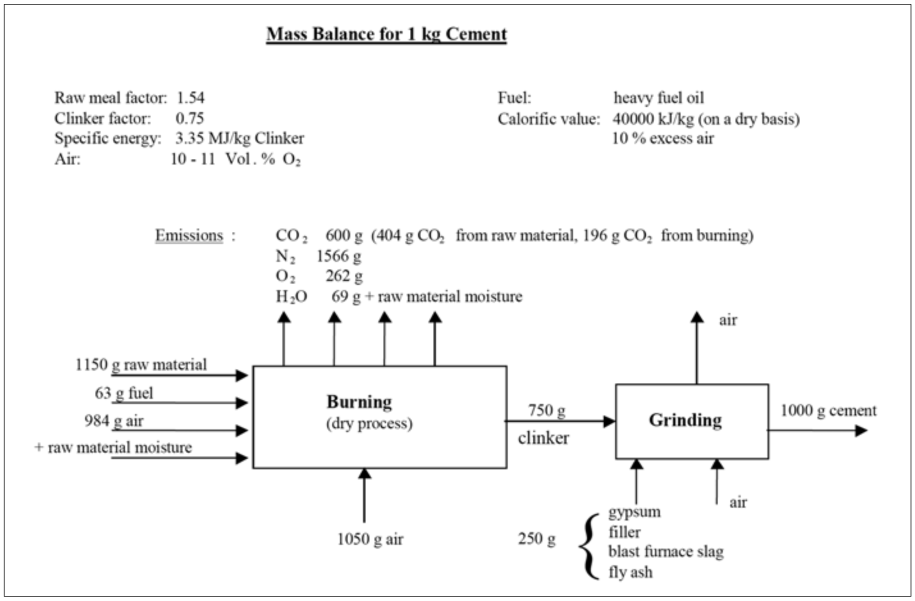


Figure 6.2 *Long wet rotary kiln with chains.*

Figure 6.3 *Mass balance for the production of 1 kg cement.*



and adjusted by the primary air (10-15% of total combustion air).

The largest long kilns have a length-to-diameter ratio of 38:1 and can be more than 200 m long. These huge units produce around 3600 tonnes/day using the wet process (Belgium, US, former Soviet Union). Long dry kilns were developed in the US based on batch type dry homogenising systems for raw material preparation. Because of the high fuel consumption only a few have been installed in Europe.

Grate preheater technology, better known as the Lepol kiln, was invented in 1928. It represented the first approach to letting part of the clinkering process take place in a stationary installation outside the kiln. This allowed the rotary kiln to become shorter and reduced the heat losses and increased energy efficiency. The rotary kiln exhaust gas enters the preheater with a temperature of 1000-1100°C. As it flows through the layer of material in the hot gas chamber the exhaust gas cools down to 250-300°C, and leaves the drying chamber at 90-150°C.

The invention of the suspension preheater in the early 1930s was a significant development. Preheating and even partial calcination of the dry raw meal takes place by maintaining the meal in suspension with hot gas from the rotary kiln. The considerably larger contact surface allows almost complete heat exchange, at least theoretically.

The four-stage cyclone preheater kiln system was standard technology in the 1970s when many plants were built in the 1000 to 3000 tonnes/day range. The exhaust gas, which has a temperature of around 330°C is normally used for raw material drying. Almost all four-stage suspension preheaters operate with rotary kilns with three supports.

The precalcination technique has been available to the cement industry since about 1970. In this procedure the heat input is divided between two points. Primary fuel combustion occurs in the kiln burning zone. Secondary burning takes place in a special combustion chamber between the rotary kiln and the preheater. In this chamber up to 60% of the total fuel can be burnt in a typical precalciner kiln. This energy is basically used to calcine the raw meal, which is almost completely calcined when it enters the kiln.

Clinker Coolers

The clinker cooler is an integral part of the kiln system and has a decisive influence on performance and economy. The cooler has two tasks: to recover as much heat as possible from the hot (1450°C) clinker so as to return it to the process; and to reduce the clinker temperature to a level suitable for the equipment downstream. Heat is recovered by preheating the air used for combustion in main and secondary firing as close to the thermodynamic limit as possible. However, this is hindered by high temperatures, the extreme abrasiveness of the clinker and its wide granulometric range. Rapid cooling fixes the mineralogical composition of the clinker to improve the grindability and optimise cement reactivity.

There are two main types of coolers, rotary and grate. The tube cooler uses the same principle as the rotary kiln, but for reversed heat exchange. Arranged at the outlet of the kiln, often in reverse configuration, i.e. underneath the kiln, a second rotary tube with its own drive is installed. Cooling in grate coolers is achieved by passing a current of air upwards through a layer of clinker lying on an air-permeable grate. Introduction and development of modern technology reciprocating grate coolers started around 1983. The design was a step closer to optimum heat exchange and also more compact coolers using less cooling air and smaller dedusting systems.

Cement Grinding and Storage

Clinker and other cement components are stored in silos or in closed sheds until further processed. Portland cement is produced by intergrinding cement clinker and sulphates such as gypsum and anhydrite. In blended cements (composite cements)

Table 6.1 Consumption of raw materials in cement production.
A typical cement plant has an annual production of about 1 Mt (1 million tonnes) clinker.

Materials (dry basis)	per tonne clinker	per tonne cement	per Mt clinker
Limestone, clay, shale, marl, other	1.57 t	1.27 t	1,568,000 t
Gypsum, anhydrite	-	0.05 t	61,000 t
Mineral additions	-	0.14 t	172,000 t

there are other constituents, such as granulated blast furnace slag, natural or artificial pozzolanas, limestone, or inert fillers.

Grinding plants may be at separate locations from clinker production plants. Commonly used finish grinding systems are tube mill, closed circuit, vertical roller mill, and roller press. The crushed material leaving the mill is transported to a separator, the oversize fraction being returned to the mill. Mineral additions are usually ground together with the clinker and gypsum. The particle size distribution of the product leaving the cement grinding system is of great importance for the cement quality. The ready product is stored in silos until shipped.

3. Consumption and Emission Levels

Consumption of Raw Materials and Energy

For cement on average, energy costs in the form of fuel and electricity represent 50% of the total production cost. 80% of this is used in the burning process. The chemical reaction takes in a modern process about 60% of the burning energy use and becomes part of the product. The theoretical energy use for the burning process (chemical reactions) is about 1700 to 1800 MJ/tonne clinker. Total burning energy requirement is in MJ/tonne clinker about 3000 for dry process, multi-stage cyclone preheater and precalciner kilns, 3100-4200 for dry process rotary kilns equipped with cyclone preheaters, 3300-4500 for semi-dry/semi-wet processes (Lepol-kiln), up to 5000 for dry process long kilns, and 5000-6000 for wet process long kilns.

Electrical energy represents approximately 20% of the overall energy requirement or 90-130 kWh/tonne cement. The main use is for the mills for finish grinding and raw grinding and the exhaust fans from kiln/raw mill and cement mill, which together account for more than 80% of electrical energy usage.

Emissions

The main environmental issues associated with cement production are emissions to air and energy use. Waste water discharge is usually limited to surface run off and cooling water only and causes no substantial contribution to water pollution. The storage and handling of fuels is a potential source of contamination of soil and ground water.

The releases to air from the kiln system derive from the physical and chemical reactions of the raw materials and the combustion of fuels. The main constituents are nitrogen from the combustion air; CO_2 from calcination and combustion of fuel; water vapour from the combustion process and from the raw materials; and excess oxygen.

In all kiln systems the solid material moves counter currently to the hot combustion gases. This counter current flow acts as a built-in circulating fluidised bed. Thus many components that result from the combustion of the fuel or from the transformation of the raw material remain in the gas phase only until they are absorbed by, or condensed on, the raw material flowing counter currently.

Typical kiln exhaust gas volumes expressed as m³/tonne of clinker (dry gas, 101.3 kPa, 273°K) are between 1700 and 2500 for all types of kilns. There are also releases of particulates from all milling operations i.e. raw materials, solid fuel and product. There is potential for the release of particulates from outside storage of raw materials and solid fuels as well as from materials transport systems, including cement product loading.

Oxides of Nitrogen

Nitrogen oxides (NO_X) are of major significance with respect to air pollution from cement manufacturing plants. NO_X emission measurements revealed a mean value of 2.1 g NO_2/kg of clinker, which corresponds to 1050 mg NO_2/m³. The mean values varied from 371–964 mg NO_X/m³. NO and NO_2 are the dominant nitrogen oxides in cement kiln exhaust gases (NO >90% of the nitrogen oxides).

There are two main sources for production of NO_X:

- Thermal NO_X when part of the nitrogen in the combustion air reacts with oxygen to form oxides of nitrogen in the kiln burning zone, where it is hot enough, above 1200°C. The reaction increases with temperature and oxygen content (air excess factor). Hard-to-burn mixes which require hotter burning zones will tend to generate more thermal NO_X than kilns with easier-burning mixes.
- Fuel NO_X when nitrogen chemically bound in the fuel either form N_2 gas, or react with oxygen in the air to form various oxides of nitrogen. In a precalciner the prevailing temperature of 850-950°C is too low to form significant thermal NO_X, but fuel NO_X will occur.

Sulphur Dioxide

Sulphur dioxide emissions from cement plants are primarily determined by the content of the volatile sulphur in the raw materials. Kilns that use raw materials with little or no volatile sulphur have little problems with SO_2 emissions.

Dust

Traditionally the emission of dust, particularly from kiln stacks, has been the main environmental concern in cement manufacture. The main sources of dust are kilns, raw mills, clinker coolers and cement mills. In all these processes large volumes of gases are flowing through dusty materials. The design and reliability of modern electrostatic precipitators and bag filters reduce dust emissions to levels, often below 10 mg/m³, where they cease to be significant.

Carbon Dioxides CO_2

The emission of CO_2 is estimated at 900 to 1000 kg/tonne clinker, related to a specific heat demand of approximately 3500 to 5000 MJ/tonne clinker, but also depending on fuel type. Mineral additions reduce CO_2 emission as counted per tonnes of cement. Approximately 60% originates in the calcination process and the remaining 40% is related to fuel combustion. As an example, a specific heat demand of 3000 MJ/tonne of clinker and the use of hard coal with a calorific value of 30 MJ/kg and a carbon content of 88% results in a CO_2 emission of 0.32 tonne per tonne of clinker, when regarding fuel part only. Using natural gas instead reduces this level by approximately 25%. Emissions of combustion CO_2 have been progressively reduced about 30% in the last 25 years mainly by more fuel efficient kiln processes.

Other Emissions

The emission of *carbon monoxide CO* is related to the content of organic matter in the raw material, but may also result from poor combustion when control of the solid fuel feed is sub-optimal. Depending on the raw material deposit, between 1.5 and 6 g of organic carbon per kg clinker are brought into the process with the natural raw material. Control of CO levels is critical in cement kilns when EPs are used for particulate abatement. If the level of CO in the EP rises (typically to 0.5% by volume) then the electrical system is tripped (switched off) to eliminate the risk of explosion. This leads to unabated particulate releases from the kiln. CO trips can be caused by unsteady state operation of the combustion system.

In combustion processes in general, the occurrence of *volatile organic compounds* is often associated with incomplete combustion and CO formation. In cement kilns, the emission will be low under normal steady-state conditions, due to the large residence time of the gases in the kiln, the high temperature and the excess oxygen conditions. Concentrations may increase during start-up or upset conditions.

Any chlorine input in the presence of organic material may potentially cause the formation of *polychlorinated dibenzodioxins (PCDDs)* and *polychlorinated dibenzofurans (PCDFs)* in the combustion processes. Their formation is known to oc-

Table 6.2 *Emission ranges data from European cement kilns.*

Parameter	mg/Nm³	kg/tonne clinker	tonnes/year
NO_x (as NO_2)	<200–3000	<0.4-6	400-6000
SO_2	<10–3500	<0.02-7	<20-7000
Dust	5–200	0.01-0.4	10-400
CO	500–2000	1-4	1000-4000
CO_2	400-520 g/Nm³	800-1040	0.8-1.04 million
TOC	5-500	0.01–1	10-1000
HF	<0.4-5	<0.8-10 g/t	<0.8-10
HCl	<1-25	<2-50 g/t	<2-50
PCDD/F	<0.1-0.5 ng/Nm³	<200-1000 ng/t	<0.2-1 g/year
Metals:			
∑ (Hg, Cd, Tl)	0.01-0.3 (mainly Hg)	20-600 mg/t	20-600 kg/year
∑ (As, Co, Ni, Se, Te)	0.001-0.1	2-200 mg/t	2-200 kg/year
∑ (Sb, Pb, Cr, Cu, Mn, V, Sn, Zn)	0.005-0.3	10-600 mg/t	10-600 kg/year

Note: Mass figures are based on 2000 m³/tonne clinker and 1 million tonnes clinker/year. Emission ranges are one-year averages and are indicative values based on various measurement techniques. O_2*-content is normally 10%.*

cur by *de novo* synthesis within the temperature window of cooling from 450 to 200°C. Thus it is important that as the gases are leaving the kiln system they should be cooled rapidly through this range. Emissions of PCDDs and PCDFs is generally low during steady kiln conditions.

Raw materials and fuels will always contain *metals*, but concentrations vary widely from one location to another. In particular, the use of coal and waste fuels may increase the input of metals into the process. The behaviour of the metals in the burning process depends on their volatility. Nonvolatile metal compounds remain within the process and exit the kiln as part of the cement clinker composition. Semi-volatile metal compounds are partly taken into the gas phase at sintering temperatures to condense on the raw material in cooler parts of the kiln system. Thallium and mercury and their compounds are particularly easily volatilised and to a lesser extent so are cadmium, lead, selenium and their compounds. The dusts from the production of cement contain small amounts of compounds of metals.

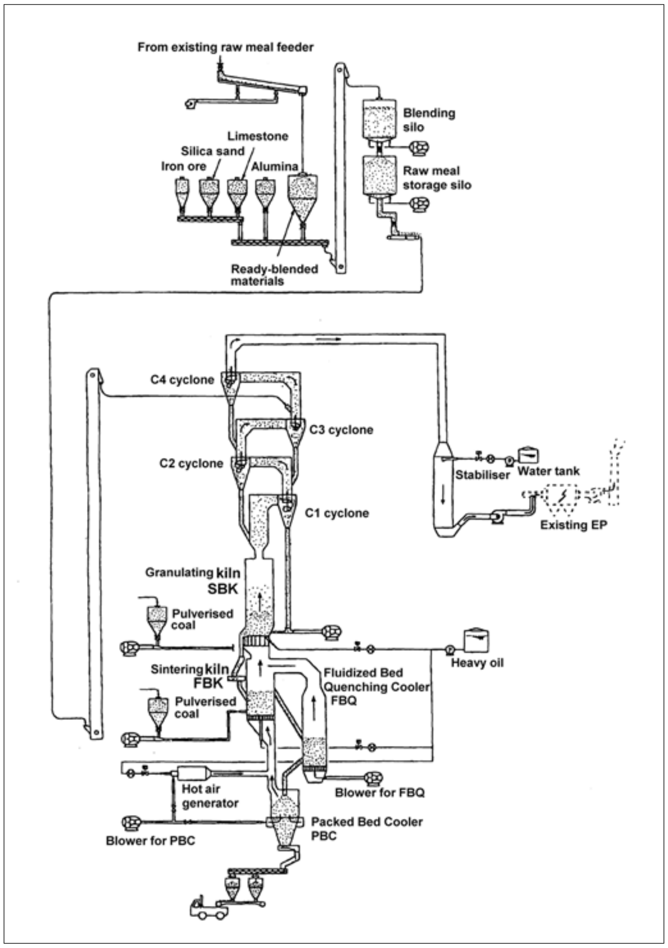


Figure 6.4 *Fluidised bed cement kiln.*

Waste

Waste produced during clinker production consists basically of unwanted rocks, which are removed from the raw materials during the preparation of the raw meal, and kiln dust removed from the by-pass flow and the stack, which is not recycled.

4. Technology Development and Cleaner Production Opportunities

Reducing Material Input

The environmental impact of cement manufacturing is largely caused by clinker production. In Europe the average clinker content in cement is 80-85%. Many manufacturers work to further lower the clinker content, e.g. by adding fillers, such as sand, slag, limestone, fly-ash and pozzolana, in the grinding step. One reported technique claims to exchange 50% of the clinker with maintained product quality/performance and without increased production cost. Cement standards define some types of cement with less than 20% clinker, the balance being made of blast furnace slag.

Recycling of collected dust to the production processes lowers the total consumption of raw materials. This recycling may take place directly into the kiln or kiln feed or by blending with finished cement products.

The use of suitable wastes as raw materials can reduce the input of natural resources, but should always be done with satisfactory control on the substances introduced to the kiln process. Cement production offers one possibility to burn hazardous waste, that otherwise is a problem.

Careful selection and control of substances entering the kiln can reduce emissions. For example, limiting the sulphur content of both raw materials and fuels can reduce releases of SO_2. The same is valid for raw materials and fuels containing other substances, for example nitrogen, metals and organic compounds.

Selection of Process

The selected process will affect the releases of all pollutants, and will also have a significant effect on the energy use. For new plants and major upgrades a dry process kiln with multistage preheating and precalcination is today state of the art. The wet process kilns operating in Europe are generally expected to convert to the dry process when renewed, and so are semi-dry and semi-wet processes. Thus kiln systems with 5 cyclone preheater stages and precalciner are considered standard technology for new plants. Such a configuration will use 2900-3200 MJ/tonne clinker. Reduced energy input in other kiln systems requires short dry process kiln with multi stage preheating and precalcination. The application of the latest generation of clinker coolers and recovering waste heat as far as possible, utilising it for drying and preheating processes, are examples of methods which cut primary energy consumption.

Any kiln system should be run under optimal conditions. Optimisation includes homogenising the raw material, ensuring uniform coal dosing and improving the cooler's operation. To ensure that the feed rate of solid fuel is steady with minimal peaks, it is essential with good designs of hopper, transport conveyor and feeder. Optimisation can include many elements ranging from instruction/training of the kiln operators up to installation of new equipment such as dosing systems, homogenisation silos, preblending beds and new clinker coolers. Reduction of emissions, such as NO_x, SO_2 and dust, are secondary effects of the optimisation of the clinker burning process.

Fluidised Bed Technology

A technology using fluidised bed cement kiln system is a project subsidised by the Ministry of International Trade and Industry in Japan since 1986. A 200 tonnes clinker/day large scale pilot plant was constructed in the end of 1995.

The suspension preheater is a conventional 4-stage cyclone preheater which preheats and calcines the raw meal. The granulating kiln is granulating the raw meal into granules of about 1.5-2.5 mm diameter at a temperature of 1300°C. In the sintering kiln the sintering of the granules is completed at a temperature of 1400°C. The fluidised bed quenching cooler quickly cools the cement clinker from 1400 to 1000°C. Finally, the cement clinker is cooled down to about 100°C in the packed bed cooler.

The cement clinker produced in the fluidised bed kiln are of the same or better quality as the clinker from a commercial plant. The NO_x emission is 115-190 mg/m^3 when heavy oil is used and 440-515 mg/m^3 when pulverised coal is used as fuel. According to a feasibility study of a 3000 tonne clinker/day plant the heat use can be reduced by 10-12% compared with a suspension preheater rotary kiln with grate cooler. It is therefore expected that the CO_2 emission can be reduced by 10-12%.

The final target of the technical development of the fluidised bed cement kiln system based in the feasibility study on a 3000 tonne clinker/day plant is: reduction of heat use by 10-12%; reduction of CO_2 emission by 10-12%; a NO_x emission level of 380 mg/m^3 or less; current SO_x emission levels; reduction of the construction cost by 30%; reduction of the installation area by 30%.

Techniques for Controlling NO_x Emissions

Reduced emissions of NO_x is achieved by reduced flame and burning temperatures and the consumption of fuel, as well as by zones with a reducing atmosphere in the kiln system. Control of oxygen content (excess air) is critical to NO_x control. Generally the lower the oxygen content (excess air) at for instance a cement kiln back end, the less NO_x is produced. NO_x reductions of up to 30% have been reported.

Table 6.3 *Overview of techniques for controlling NO_x.*

Technique	Kiln systems applicability	Reduction efficiency	Reported emissions		Reported costs [3]	
			mg/m^3 [1]	kg/tonne [2]	investment	operating
Flame cooling	All	0-50%	400-	0.8-	0.0 -0.2	0.0-0.5
Low-NO_x burner	All	0-30%			0.15-0.8	0
Staged combustion	Precalciner	10-50%	<500-1000	<1.0-2.0	0.1-2	0
	Preheater				1-4	0
Mid-kiln firing	Long	20-40%	No info.	-	0.8-1.7	No info.
Mineralised clinker	All	10-15%	No info.	-	No info.	No info.
SNCR	Preheater and Precalciner	10-85%	200-800	0.4-1.6	0.5-1.5	0.3-0.5
SCR – data from pilot plants only	Possibly all	85-95%	100-200	0.2-0.4	ca. 2.5 [4]	0.2-0.4 [4]
					3.5-4.5 [5]	No info. [5]

1) *Normally referring to daily averages, dry gas, 273 K, 101.3 kPa and 10% O_2.*
2) *Kg/tonne clinker: based on 2000 m^3/tonne of clinker.*
3) *Investment cost in 106 euros and operating cost in euros/tonne of clinker, normally referring to a kiln capacity of 3000 tonne clinker/day and initial emission up to 2000 mg NO_x/m^3.*
4) *Costs estimated by Ökopol for a full scale installation (kiln capacities from 1000 to 5000 tonne clinker/day and initial emissions from 1300 to 2000 mg NO_x/m^3), operating costs ca. 25% lower than for SNCR.*
5) *Costs estimated by Cembureau for a full scale installation.*

Flame cooling. Addition of water to the fuel or directly to the flame reduces the temperature and increases the concentration of hydroxyl radicals. This can have a positive effect on NO_X reduction in the burning zone. Reduction efficiency from 0-50% has been reported.

Designs of *low-NO_X burners* vary in detail but essentially the coal and air are injected into the kiln through concentric tubes. The primary air proportion is reduced to some 6-10% of that required for stoichiometric combustion (typically 20-25% in traditional burners). The net effect of this burner design is to produce very early ignition, especially of the volatile compounds in the fuel, in an oxygen-deficient atmosphere. NO_X reductions of up to 30% are achievable in successful installations.

Selective catalytic reduction (SCR) reduces NO and NO_2 to N_2 with the help of NH_3 and a catalyst at a temperature range of about 300-400°C. This technology is widely used for NO_X abatement in other industries (coal-fired power stations, waste incinerators). Large NO_X emission reductions are potentially achievable by SCR high dust systems (85-95%). As the catalysts remove hydrocarbons as well, SCR will in general also reduce VOC and PCDD/Fs.

Selective non-catalytic reduction (SNCR) involves injecting NH_2X compounds into the exhaust gas to reduce NO to N_2. The reaction has an optimum in a temperature window of about 800 to 1000°C; sufficient retention time must be provided for the injected agents to react with NO. The right temperature window is easy to obtain in suspension preheater kilns, precalciner kilns and possibly in some Lepol kilns. The most common NH_2X agent is about 25% ammonia in water. The achievable NO_X emission level can in the best of cases be less than 200 mg/m³ if the initial level is not higher than about 1000-1300 mg/m³ (80-85% reduction), although the majority of installations are today operated to achieve an emission level of 500-800 mg/m³ (10-50% reduction). The first full scale plant with SNCR technology has been in operation in Germany in the end of 1999. Two Swedish plants, dry process cyclone preheater/precalciner kilns, installed SNCR in 1996/97. A reduction of 80-85% has been achieved at both kilns. The driving force for these plants to invest in high-performing SNCR installations was the Swedish policy to reduce NO_X emissions.

Staged combustion is applied at cement kilns supplied with several combustion stages. This technique is mostly carried out with specially designed precalciners. The first combustion stage takes place in the rotary kiln under optimum conditions for the clinker burning process. The second combustion stage is a burner at the kiln inlet, which produces a reducing atmosphere that decomposes a portion of the nitrogen oxides generated in the sintering zone. The high temperature in this zone is particularly favourable for the reaction which reconverts the NO_X to elementary nitrogen. Some modern well optimised plants achieve emission levels below 500 mg NO_X/Nm³ with multi-staged combustion.

The addition of mineralisers, e.g. calcium fluoride, to the raw material to adjust the clinker quality allows the sintering zone temperature to be reduced, which leads to less NO_X formation. The NO_X reduction might be between 10 and 15%, but reductions of up to 50% has been reported.

Techniques for Controlling SO_2 Emissions

The first step with respect to SO_2 control is to consider primary process optimisation measures, including the smoothing of kiln operation, choice of oxygen concentration and choice of raw materials and fuels. Increasing the oxygen content in long kilns is decreasing the SO_2 level and increasing the NO_X level. A balance to protect the environment should be sought by optimising $NO_X/SO_2/CO$ by adjusting the back end oxygen content. SO_2 reductions of up to 50% have been reported. The *addition of absorbents* such as slaked lime ($Ca(OH)_2$), quicklime (CaO) or activated fly ash with high CaO content to the exhaust gas of the kiln can absorb some of the SO_2. The SO_2 will react with the lime to $CaSO_3$ and $CaSO_4$, which becomes incorporated into the clinker. SO_2 reductions of 60 to 80% can be achieved by absorbent injection in suspension preheater kiln systems.

To reduce very high SO_2 emissions (more than 1500 mg/Nm³) a separate scrubber is required. One type of *dry scrubber* uses a venturi reactor column to produce a fluidised bed consisting of a blend of slaked lime and raw meal. The intensive contact between gas and absorbent, the long residence time and the low temperature allow efficient absorption of SO_2. The gas leaving the venturi is loaded with absorbent which is collected in an electrostatic precipitator. An SO_2 reduction of 90% may be achieved, that corresponds to a clean gas content of 300 mg SO_2/m³ when the initial SO_2 concentration is 3000 mg/m³. A dry scrubber will also reduce emissions of HCl and HF.

The *wet scrubber* is the most commonly used technique for flue gas desulphurisation in coal fired power plants. The SO_X is absorbed by a liquid/slurry sprayed in a spray tower or is bubbled through the liquid/slurry. The absorbent can be calcium carbonate, hydroxide or oxide. The wet scrubbers currently in use in the European cement industry are all spray towers. The slurry is sprayed in counter current to the exhaust gas and collected in a recycle tank at the bottom of the scrubber where the formed sulphite is oxidised with air to sulphate and forms calcium sulphate dihydrate. The dihydrate is separated and used as gypsum in cement milling and the water is returned to the scrubber. The SO_2 reduction achieved can be more than 90%.

Pollutants such as SO_2, organic compounds, metals, NH_3, NH_4 compounds, HCl, HF and residual dust (after an EP or fabric filter) may be removed from the exhaust gases by adsorption on *activated carbon*. If NH_3 is present, or added, the filter will remove NO_X as well.

Techniques for Controlling Dust Emissions

The three main point sources of dust emissions from cement plants are kiln systems, clinker coolers and cement mills. Various dedusting devices have been used in the past for these three duties but nowadays only electrostatic precipitators (EPs), or fabric filters are standard. Both types have a very high dedusting efficiency during normal operation. A disadvantage of fabric filters is that used filter bags are waste and have to be disposed of according to national regulations. Dust releases from handling and storage of materials and the crushing and grinding of raw materials and fuels, called fugitive dust, can also be significant.

Electrostatic precipitators generate an electrostatic field across the path of particulate matter in the air stream. The particles become negatively charged and migrate towards positively charged collection plates. The collection plates are rapped or vibrated periodically, so the material falls into collection hoppers below. EPs are able to operate under conditions of high temperatures, up to approximately 400°C, and high humidity. Under best conditions EPs can reduce levels down to 5-15 mg/m³ as monthly average.

The basic principle of *fabric filtration* is to use a fabric membrane which is permeable to gas but which will retain the dust. Initially, dust is deposited both on the surface fibres and within the depth of the fabric, but as the surface layer builds up the dust itself becomes the dominating filter medium. Gas for treatment can flow either from the inside of the bag outwards or vice versa. The use of modern fabric filters can reduce dust emissions to below 5 mg/m³. Besides dust, the fabric filter also removes substances that adsorb to the dust particles, such as dioxins and metals if present.

Fugitive emission sources mainly arise from storage and handling of raw materials, fuels and clinker and from vehicle traffic at the manufacturing site. Proper and complete maintenance of the installation always has the indirect result of reducing fugitive dust by reducing air leakage and spillage points. Outdoor storage piles of dusty materials should be avoided. Point sources of dust can be controlled by a water spray injection system. Areas used by lorries should be paved when possible, clean and watered, especially during dry weather.

Case Studies

B

Case Study 1

Vernitas Textile Company Ltd
Lithuania

Vernitas Textile Company – From Environmental Disaster to Environmental Recognition

1. Introduction

Vernitas Textile Company in Marijampole

Marijampole is a town in the southwest of Lithuania, on the Sesupe river in the Marijampole region with a population of 52,100. After World War II Marijampole developed as an industrial city, specialising in manufacturing equipment for the food industry, automotive parts, furniture, building and textiles. In Soviet times there were two major textile companies in Marijampole, but only Vernitas managed to survive.

Vernitas produces yarn based on polyacryl nitrile (PAN) acrylic fibre, which is imported. The technology consists only of mechanical processing except for the initial step where a part of the PAN fibre is processed with steam. The technology is old, but as new types of PAN fibres with improved hygienic and other properties becomes available, PAN yarns are becoming much better. Also there is some market demand for mixed yarns, and Vernitas is now introducing yarns where PAN is mixed with natural fibres.

Vernitas has a capacity of producing 6,000 tons of yarn per year, but has been through a period with much smaller sales. In the last few years the situation is improving through the opening of new markets, and today approximately 70% of the production is exported to European countries.

In the last few years the management has been very enthusiastic about cleaner production (CP) measures. Energy consumption and the environmental issues are given full attention. The project described here was not the first CP project in the company. The previous projects were very successful, and the management became interested in new CP projects. The company has implemented most of the identified improvement solutions, and continues to investigate new improvement measures.

The Cleaner Production Project

The Energy and Cleaner Technology Project of Vernitas was carried out by APINI (at Kaunas University of Technology, Lithuania), CIPAI (Kaunas, Lithuania), and COWI (Denmark); it was supported by the Danish Environmental Protection Agency (DEPA). The project consisted of an energy and cleaner technology audit, resulting in a number of proposed measures for energy savings and reduction of other environmental impacts. The project was carried out in 2002, and the proposed measures were implemented in the following years.

A “top-down” investigation was carried out in the company. The company was viewed as a “black box” and all inputs and outputs of energy and mass of this box, primarily through measurements and emission factors, were analysed. The company was analysed on three levels:

1. Main data for black box overview of the entire company.
2. Main process data enabling a distribution of the energy consumption and the environmental impacts on main processes (building a “layer cake”).

3. Detailed data and measurements for one or two specific processes.

In the initial phase of data collection, the focus was on levels 1 and 2. Later level 3 data were collected/measured for the 2-3 focus areas, which were selected for detailed investigation.

2. Processes to be Audited

The Yarn Production Process

Yarn Preparation. This process consists of the following sub-processes:

- Stretch-breaking.
- Re-breaking.
- Intersecting.
- Finishing.

The main issues here were the ventilation and the working environment. The air was extracted from the ceiling and floor. The suction was poor however. As a result there was a great deal of dust in the air, on the ceiling and walls and on the vents. PAN dust can cause irritation and health problems. But air conditions were continually monitored and, according to the company, the working environment regulations were complied with. The air was humidified to 60% for quality reasons. There was considerable noise from the machines.

Spinning. This spinning was done in 100 spinning machines with 336 elements on each machine. Air was supplied onto the reels of the machines to maintain quality. The process was divided into 10 sections, separated by a half wall to ensure that the different coloured yarns were kept apart. The main issues here were again the ventilation and the working environment. Similar observations were made as in yarn preparation, although the dust content in the air did not appear to be so high. The noise level was higher here than in the yarn preparation process.

Twisting. This process consisted of rewinding onto other reels and double twisting. The main issues here were again the ventilation and the working environment. Similar observations were made as in yarn preparation, although the dust content in the air did not appear to be so high. Air was extracted directly from the machines. Most of the humidifiers were not working. The noise level was high.

Shrinking. The yarn was heated by steam via steam chambers. Because the steam had insufficient pressure to reach the required heat, electric heat was added to increase the temperature. The main issues here were again the ventilation and the working environment. Similar observations were made as in yarn preparation although the dust content in the air did not appear to be so high. Air was extracted directly from the machines.

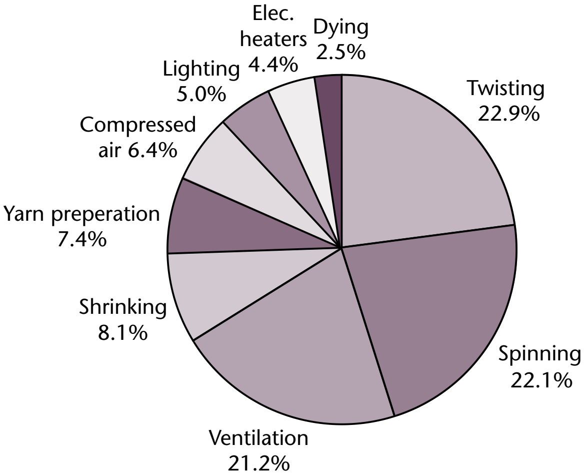


Figure 1.1 *Distribution of the electricity consumption among processes and auxiliary equipment.*

Cleaning for all four processes was carried out with compressed air.

Dyeing

This process was only three years old, using a relatively new technology. The yarns were weighed in order to calculate the correct amount and mixture of dye. The dye mixture consisted of the dye, yarn softeners and retardants. Three main dyes were used:

- Cation dye for polyacryl nitrile.
- Reactive dye for wool.
- Reactive dye for cotton.

The empty dye containers were either returned to the supplier or sold. Dye residue from tapping was stored in open buckets. Insufficient waste had accumulated for it to be sent away for disposal.

The yarns were lifted by winch into a chamber, and dyes and water added. The yarns were then washed in the same chamber. The number of washes depended on the colour. Fresh water was added each time. No water was recycled.

After the final wash, the yarns were lifted out and placed on the floor to dry. Water was drained through holes in the floor to wastewater pipes. This initial drying reduced the energy needed to dry the yarns in the drying chamber.

Final drying took place in a second chamber by hot air from a steam coil. The hot water gathered from this process was collected in a water basin and reused once the temperature had fallen sufficiently. Air from the dyeing process was emitted directly outside.

The water used in the processes was chemically treated, filtered in two tanks, and softened in two other tanks. The water was then stored in large basins. The wastewater was led through a series of sedimentation basins. The water from the last basin was led directly out to the sewerage without any further treatment. No sediment had been removed from the basins in the three years the dyeing process had been operating.

The company measured water consumption and wastewater effluents for this process. This environmental aspect was the main issue in this process.

3. Energy Auditing

Energy Data

An energy balance was established to create a basis for selecting the action areas for detailed investigation. The method was to gather overall actual energy consumption data for year 2000. The registered consumption was:

- Electricity: 11,577 MWh.
- Hot water: 1,756 MWh.
- Steam: 4,073 MWh.

The total heat consumption was thus 5,829 MWh.

Further detailed equipment data (type, fluid flow, pressure head, operation hours etc.) was collected for all power consumers with an electric motor larger than 5 kW. We also collected detailed data on heat consumption in processes and for heat and ventilation.

Finally a memo with the results of the energy mapping was prepared to be approved by Vernitas.

Electric Energy Balances

The result of the mapping of the electricity consumers and their consumption is shown in Table 1.1. The total calculated electricity use added up to 11,878 MWh, which is approx. 300 MWh (≈2.5%) more than actually consumed. The relative data presented in the above figure shows that the major electricity consumption was related to the processes in which a total of 67% of the electricity was consumed and 76% of the total power capacity installed.

The distribution of the electricity consumption by type of equipment is shown in Table 1.2. The main part (69%) of the installed motor capacity was installed on special textile machines in the company and only 25% is installed on so-called service equipment such as fans, pumps and compressors.

The situation is almost the same when it comes to the actual electricity consumption where again the numerous special textile machines and electric heaters accounted for approx.

Table 1.2 *Electricity consumption by type of equipment.*

Equipment	Motor		Electricity consumption	
	kW	%	MWh/ year	%
Machines	5,390	69	7,189	61
Fans	1,500	19	2,717	23
Pumps	110	1	100	1
Compressors	414	5	756	6
Elect. heaters	231	3	520	4
Lighting	204	3	596	5

Table 1.1 *Electricity consumers and consumption at Vernitas, year 2000.*

Process	Motor (kW)	Average load (%)	Operating hours (hours/year)	Electricity consumption (MWh/year)
Yarn preparation	743	64	1850	879
Spinning	1950	77	1750	2,625
Twisting	2377	59	1925	2,717
Shrinking	320	100+	2500	968
Dyeing	360	90	5300	300
Ventilation	1250	72	2700-3700	2,517
Compressed air	414	≈75	2800-4500	756
Electric heaters	231	90	2500	520
Lighting	204	100	≈2920	596
Total plant	7,849	-	-	11,878

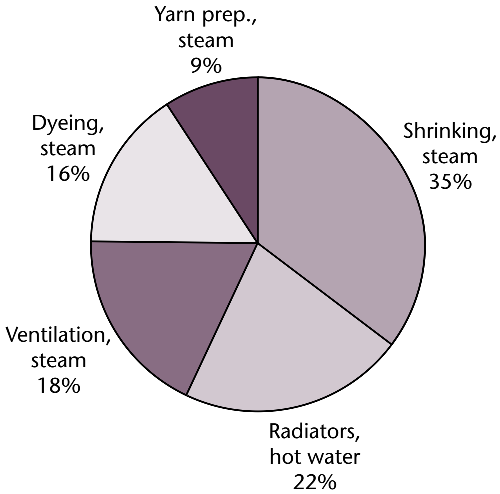


Figure 1.2 *Distribution of the heat consumption at Vernitas, year 2000.*

65% of the total consumption and service equipment accounts for approx. 30%. The remaining 5% was used for lighting.

Possibilities for Energy Efficiency Improvements

The mapping of the electricity consumers and their use showed that 61% of the consumption was related to operation of the numerous textile machines installed at the company and that another 4% was related to electric process heating (T>180ºC) installed in the shrinking machines. In total 65% of the electricity consumption (≈7,500 MWh/year) was related to consumers that were very difficult to optimise as this would require replacement of highly costly textile machines.

This left 35% of the electricity consumption (≈4,100 MWh/year) related to operation of service equipment and lighting, which was of interest in terms of optimisations. In this situation we chose to focus the efforts to identify relevant electricity savings by an analysis of the operation of fans for ventilation of the production halls (≈2000 MWh/year) and the operation of the air compressors (750 MWh/year).

Lighting was left out as a potential for electricity savings as the cost of replacing all the existing fittings was considered too high compared to possible savings.

Heat energy balance

The results of mapping the heat energy consumers and their consumption are shown in Table 1.3.

The total heat consumption based on steam and hot water added up to 5,475 MWh per year. The total actual measured heat consumption was approx. 5,800 MWh. The distribution of the heat consumption is shown in Table 1.3 and Figure 1.2 for the main heat consuming departments and utility systems. The results proved that 60% of the heat consumption was process heat and 40% heating of ventilation air and premises (radiators).

Possibilities for Heat Efficiency Improvements

In 2001, Vernitas installed three new boilers in the company's heating substation, two steam boilers and one hot water boiler. However, the operation of the steam system was not exactly energy efficient as no condensate at all was returned to the boiler station. This does not appear from the above presentation of the mapped heat consumption. Some of the steam was in fact used as steam for injection, which means that the condensate was polluted by effluents from the textiles. But in the heating substation condensate from the steam used to heat water for the ventilation system was actually wasted to the sewer. Water had to be added to cool the sewer water as the allowed temperature limit of sewage was max. 40°C.

We thus chose to focus the efforts of identifying heat savings by analysing how to optimise the operation of this particular heating process and the use of condensate. Furthermore, we looked into the possibilities for heat recovery from the air compressors and the use of steam condensate from the heating processes in the dyeing department as feed water in the dyeing processes.

Table 1.3 *Heat consumers and consumption at Vernitas, year 2000.*

Process	Heat capacity (kW)	Average load (%)	Operating hours (hours/year)	Heat consumption (MWh/year)
Yarn preparation, steam	385	70	1850	500
Shrinking, steam	770	100	2500	1925
Dyeing, steam	1700	25	2000	850
Hot water radiators	1000	50	2400	1,200
Hot water ventilation heating	770	55	2400	1,000
Total plant	4,625	-	-	5,475

4. Energy Saving Possibilities

Optimisation of the Humidification System

The humidification system at Vernitas was used to keep the necessary humidity in the production areas and to keep the dust and fibre content in the air as low as possible. The humidification system was a Russian-made pressure-fed system, using water under pressure (1.0 bar g) and compressed air (2.0 bar g) to atomise the water in a fine spray. The principal construction of such a system is shown in Figure 1.3.

The possibility of saving energy is related to a replacement of the existing spraying nozzles with new ones with a lower consumption of both water and compressed air.

Of the 316 nozzles installed at Vernitas, 66% or approx. 208 nozzles were used during the project. The savings after replacing them was estimated to be about 1.37 mill Nm³/year. This amount of compressed air equals 52% of the 3 bar air production.

The energy saving related to this amount of compressed air was found to be approx. 120,000 kWh/year with a cost of 23,200 LTL (approx. 6000 euros) per year. The reduced operation time of the air compressors meant an additional saving on the maintenance cost of approx. 3,900 LTL/year. The total savings thus amounted to approx. 27,000 LTL (7,000 euros) per year.

The cost of 208 new nozzles was 83,200 LTL. With an estimated cost of automation and design works of 20,000 LTL the total calculated investment amounted to 103,200 LTL. (26,000 euros). Pay back time = 3.8 years.

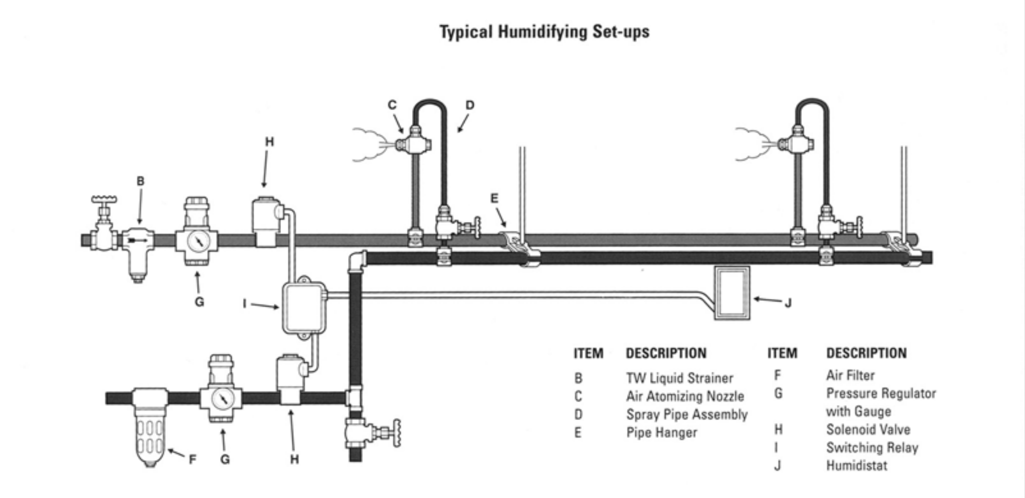
Modernisation of the Heating Substation

The heating substation prepared hot water (80-90°C) for heating the air in the conditioning system using heat exchangers. The nominal (designed) capacity of this system was 1 MW. Normally, this system operated at a 50% load, i.e. 500 kW (≈800 kg steam per hour) and the hot water was cooled to approx. 60°C in the air conditioning heat exchangers and then returned to the heating substation.

This hot water system was heated by steam in two tubular "steam – water" heat exchangers. These heat exchangers were old and close to being worn out, bound to be replaced in the near future. The main problem in the system was that all condensate (T≈95°C) was discharged to the sewer instead of being returned to the boiler. Moreover, in order to fulfill temperature requirements to the sewage (T<40°C), cold water was added to the sewage. Finally, the condensate wasted had to be replaced by adding the same amount of softened water to the steam system.

This was a substantial waste of energy and water, as the condensate could easily be returned to the steam system via the deaerator. Based on 2,400 hours of operation per year the savings potential by returning the condensate was as follows: heat: 160,000 kWh; water: 5,000 m³/year. The value of these savings was calculated based on the cost of natural gas and a reduced amount of sewage. With a heat price of 0.085 LTL/kWh, a discharge fee on sewage of 2.54 LTL/m³, a water price of 0.07 LTL/m³ and a price of softening feed water of approx. 0.30 LTL/m³ the total savings were estimated to be 27,000 LTL (7,000 euros) per year.

The cost of new heat exchangers, valves etc. was 105,000 LTL and with an estimated cost of automation and design work of 35,000 LTL, the total investment amounted to 140,000 LTL (35,000 euros). Pay back time was thus 5.2 years. However, the equipment of the heating substation was in very poor condition and probably due to be rehabilitated in the near future. For this reason a more realistic comparison would be between the investments and pay back time of rehabilitation of the heating station using the same principles as at present, and rehabilitation using the improved technology and principles mentioned above.



ITEM	DESCRIPTION	ITEM	DESCRIPTION
B	TW Liquid Strainer	F	Air Filter
C	Air Atomizing Nozzle	G	Pressure Regulator with Gauge
D	Spray Pipe Assembly	H	Solenoid Valve
E	Pipe Hanger	I	Switching Relay
		J	Humidistat

Figure 1.3 *Pressure fed humidification system.*

Installation of Variable Frequency Drives on Fans

The ventilation and air conditioning system consisted of 9 air supply fans and 9 exhaust fans. Of these 18 fans only 3 were equipped with variable frequency drives (VFD). The remaining 15 units operated at constant speed and the airflow was controlled with dampers.

Installation of VFDs would result in significantly better energy efficiency of the fans at part load (50-90%), which was approx. 75% of the operation time. The results showed that installation of variable speed drives on the 15 fans in the ventilation and air conditioning system would lead to yearly electricity savings of 551,300 kWh. This was equal to approx. 26% of the electricity consumption on these fans. In general the pay back time of the VFDs was estimated as 1.6-3.0 years.

Heat Recovery in the Compressed Air System

After a complete change of air compressors, the company has today three modern screw compressors (1x3 and 2x6 bar) supplying compressed air to the various users in the processes.

All three air compressors are air-cooled and the hot cooling air from the two compressors is exhausted to a technical floor above the engine room and the hot cooling air from the one compressor is exhausted back into to the engine room. At full load the total effect of the heat cooled off amounts to 223 kW.

In principle the waste heat from the compressors is already used for heating purposes but neither the technical floor nor the engine room needs to be heated by the hot cooling air. Therefore, analyses have been made in order to find a better use of this heat.

The most obvious place to direct the heat has been found to be a new raw material storage facility, which is to be erected right next to the engine room.

The energy savings related to directing the hot cooling air from the air compressors to the new storage are based on a heating demand throughout the heating season, which is approx. 28 weeks/year during late fall, winter and early spring.

With 10 average daily operation hours at Vernitas and operation 6 days a week, the total number of hours in which the air compressors are operating close to full load is approx. 60 hours per week.

The remaining hours (when production is shut down) the air compressors may be switched on, but as all machines and the humidification system are shut down, the compressor load will be very low and the potential for heat recovery is close to zero.

Therefore, during the 28 weeks of heating season the total number of operation hours in which heat can be recovered from the air compressors amounts to approx. 1,700 hours. With an average compressor load of 80% the potential for heat recovery amounts to 303,300 kWh/year. Possible savings are 25,800 LTL (about 6,500 euros) per year. With the suggested investment the pay back time of this waste heat recovery system would be approx. 2.0 years.

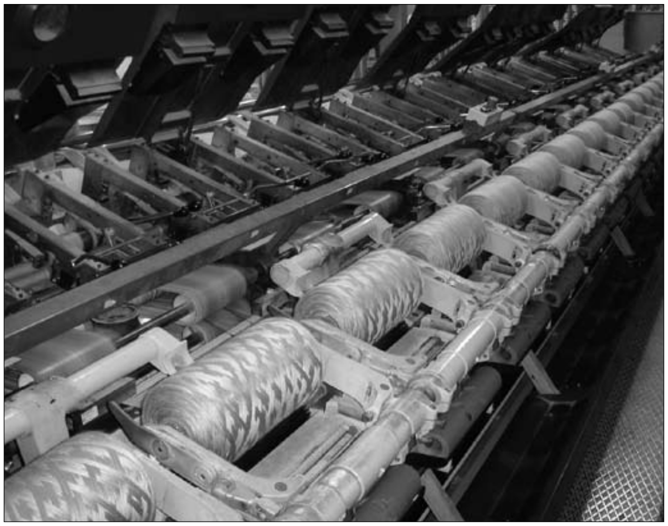


Figure 1.4 *The spinning machines.*

Recycling of Condensate in the Dyeing Department

In the dyeing department steam was used to heat water for dye mixtures, for rinsing of the yarn after dyeing and to heat drying air. The steam condensate (T≈97°C) from these processes is discharged directly to the sewage – thus a lot of heat is wasted.

The potential for heat recovery in the dyeing processes, depends on the direct use of steam condensate as make-up water in the processes. Based on the production data from 2001 the consumption of water (not including dyeing of wool) was 26,600 m³ and steam 2,160 MWh (≈3,300 tons).

Of the total water consumption approx. 24,600 m³/h (≈92%) was needed as warm process water at 50°C. Heating 24,600 m³/h from 8°C to 50°C required approx. 1200 MWh. Today, the water is heated to approx. 35°C by waste heat from cooling of drying air. Thus 770 MWh of the 1200 MWh is covered by heat recovery. This leaves 430 MWh to be covered by steam (660 tons) or by using the steam condensate as make-up water (added back to the process).

The substitution of softened water with steam condensate (T≈97°C) and the reduced steam consumption due to the heat recovery contributes to the recycling of steam condensate. The result is a temperature rise of the warm process water from 35°C to 45°C. The heat recovery would then be approx. 290 MWh/year (≈490 tons of steam) and the heat demand would drop to 140 MWh/year or 170 tons/year of steam. The amount of condensate to be recycled would amount to 2,810 tons/year.

Moreover, chemicals for preparing 2,810 m³ of softened water will be saved and 2,810 m³ of sewage will be saved. The value of these 3 types of savings is:

- Heat: 24,700 LTL/year.
- Chemicals: 800 LTL/year.
- Sewage: 7,100 LTL/year.

The total savings amount to: 32,600 LTL (8,000 euros) per year. Investment analysis of this measure has not been performed as this project was just evaluated in the final stages of the project very close to the deadline. However, the equipment needed to carry out this project was considered to be quite simple (piping, tank, deaeration equipment, valves, filters and a pump) and as a consequence the investment would also be limited, max. 50,000 LTL. The pay back time was thus estimated to be in the order of 1.5 years.

5. Chemicals Use and Water and Wastewater Management

The Possibilities

In the initial analyses it was decided that the most important environmental aspect at the company is the environmental impacts of the dyeing department. This led to the following cleaner technology measures:

1. Reduction and substitution of chemicals used in the dyeing processes.
2. Treatment of wastewater from the dyeing department.
3. Possibility of recycling wastewater from the dyeing department.
4. Recycling of cooling water from spinning machines.

Minimisation/Optimisation of the Use of Chemicals

In general the overall analyses for minimisation/optimisation of chemicals were performed according to the following steps, recommended by the BREF document for the textile industry [IPPC, 2001]:

1. Investigating the use of the chemicals.
2. Investigating the possibilities of omitting the use of the chemicals.
3. Investigating the possibilities of reducing the use of chemicals (this step should not be considered if the chemicals are assessed to be hazardous, unless substitution is not possible).
4. Investigating the possibilities of replacing the chemicals with alternatives that have less negative impacts on the environment.

Especially step 2 and 3 demanded very detailed knowledge about the specific processes in the company. Therefore the staff and the department manager were involved. The dyeing department used (in the year 2000) a total of about 160 different chemicals in a total quantity of 26,419 kg.

Both the number and the total quantity of chemicals can be critical. The number can be critical because the more different chemicals there are, the more difficult it is to control and minimise the potential risk of each different chemical. The total quantity of chemicals can be critical, because the larger the quantity of hazardous chemicals used, the larger the risk of environmental pollution.

While investigating the use of chemicals at the company, a serious lack of safety data sheets was found. Therefore it was not possible to get an overall assessment of the environmental hazards of these chemicals, and an adequate list of chemicals to be replaced could not be made.

Today Vernitas is not able to reach the limit values for zinc in the effluents from the dyeing department. The local authorities thus have suggested that the company should invest in a wastewater treatment plant. But it seems cheaper and more environmental friendly to find the source of the zinc emission in the effluent. Zinc, which is a chemical ingredient of several dyes, is a heavy metal. Other heavy metals are also common in pigments. Heavy metals are environmentally hazardous. Some are environmentally toxic and all of them are bioaccumulative. That means that the concentration of the heavy metal will increase in the food chain.

By investigating the existing safety data sheets at the company we found that several types of pigments contained heavy metals. The company contacted the suppliers of dyes in Germany to ask what they would propose to reduce especially the zinc emission, but also emission of other heavy metals in the effluent from the dyeing department. The suppliers commented that zinc derivatives traditionally play an important role, as counter-ions, in the formulation of all standard cationic dyes for PAN. But the companies had identified this as a possible ecological problem and addressed the issue, by developing cationic dyes based on Zinc- free formulations. The investigation led to a serious cooperative effort with the chemical suppliers, which so far have enabled Vernitas to substitute part of the dyes with more environmentally friendly ones.

Wastewater Treatment and Reuse

The purpose of this investigation was to reduce the consumption of process water and the quantity of wastewater discharged to the municipal wastewater treatment plant.

The quantity of wastewater from the company was approximately 40,500 m³ per year. The existing wastewater treatment plant of the company consisted of six tanks in series, with overflow between the tanks. The performance of the treatment plant was assessed very low on the basis of measurements of influent and effluent parameters of the plant. After treatment, the company discharged the "treated" wastewater directly to the municipal wastewater treatment plant. The quality of this "treated" wastewater was very low. In particular there were e.g. no equalisation tanks for balancing the inlet flow to the treatment plant. The content of Zn in the treated wastewater was, as mentioned, above municipal limits.

The discharge of wastewater from the company to the municipal wastewater treatment plant can be reduced (both by quantity and degree of pollution) by separating the wastewater into two types: Wastewater for discharge and Wastewater for reuse.

Wastewater for discharge was wastewater from the dyeing process together with the first washing/rinsing step. This wastewater was characterised by high salinity, high content of heavy metals, high content of organic matter, high content of dye residual, and pH≥10. The wastewater from the dyeing processes can be treated by activated carbon or through either aerobic or anaerobic biological treatment.

Wastewater for reuse was wastewater from the second and further rinsing steps, which could reused after membrane filtration (nanofiltration or reverse osmosis). This wastewater was generally characterised by low concentrations of salt, heavy metals, organic matter, dye residual and neutral pH. The quantities of the two types of wastewater are given in Table 1.4. After consulting experts for wastewater treatment, it was concluded that the treatment plant could be designed as shown in Figure 1.5. The recommended treatments require that the wastewater is distributed into two lines. This could be done with the aid of automatic valves to distribute the wastewater according to the actual process step.

Table 1.4 *Quantity of wastewater produced at the company after the recommended separation of the quantity of wastewater for reuse, wastewater for discharge and total wastewater production.*

	Wastewater production			
	m^3/h	m^3/d	m^3/ month	m^3/ year
Wastewater for reuse	2.0	50	1,100	13,000
Wastewater for discharge	4.2	100	2,300	27,500
Total wastewater	6.2	150	3,400	40,500

Treatment of Wastewater for Reuse

The possibility of using membrane filtration to treat wastewater from the rinsing steps was analysed. Membrane filtration is widely used in dairies, for biotechnology applications and for treatment of water and wastewater. The technology has been used in the textile industry for many years for cleaning of wastewater (mix of wastewater and separated wastewater streams). However, membrane filtration has not been used or tested for cationic dyes.

The surface properties of a membrane are similar to the surface properties of a textile material. Therefore cationic dyes might adsorb directly to the generally used membranes, which would result in clogging of the membrane. This means that the membrane would have to be cleaned, which might be difficult with common techniques, or replaced. Nevertheless one of the leading membrane manufacturers en-

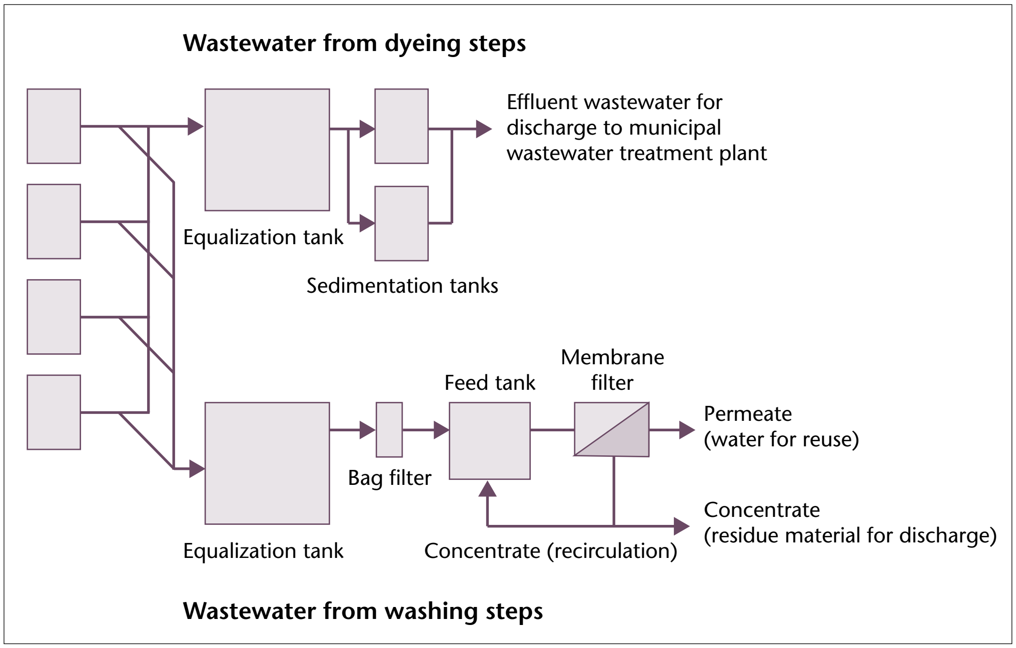


Figure 1.5 *Flow diagram of the proposed wastewater treatment plant at Vernitas.*

sured the company that it would be able to design a membrane for filtration of cationic dyes, even if it is not on the market.

The membrane manufacturer reckons that it is most likely that the membrane filtration system would consist of a nanofiltration membrane followed by reverse osmosis with internal recirculation. This configuration has been used for treatment of wastewater from textile industries. The principle of a membrane filtration system with internal recirculation is shown in Figure 1.6.

Treatment of Wastewater for Discharge

We proposed that the wastewater from the dyeing processes should be treated in the existing treatment plant before discharge to the municipal wastewater treatment plant. The wastewater treatment plant should be extended with an equalisation tank (Figure 1.5) with a volume of approximately 50 m³ for balancing the wastewater flow. Further, it is suggested that the sedimentation tanks be coupled in parallel and not in series as today. Hereby the load on each tank would be reduced and a better performance would be achieved.

The system should also consist of a bag filter with a cut-off value of approximately 10 μm for removal of fibres and other larger particles in the wastewater. For better operation conditions under maintenance, an installation of two parallel bag filters should be considered. The technical advantages of the membrane filtration system with internal recirculation are:

- Possibility of optimising the membrane pressure.
- Small risk of biofouling.
- Possibility of continuous operation.
- Low energy consumption.
- Easy cooling and heating of the system.

The possibility of varying pressure and flow is important. The feed pump delivers the quantity required at a pressure corresponding to the pressure at the concentrate outlet, while the recirculation pump gives the difference pressure and cross flow necessary for minimising the risk for membrane biofouling. The installation of reverse osmosis gives the possibility for removal of salt from the wastewater, which would make a desalination plant unnecessary. The concentrate residual (approximately 1% of the treated wastewater) from the membrane system can be treated in the municipal wastewater treatment plant or in an anaerobic digester.

A new treatment plant will save the company for approximately LVL 50,000 per year. With an investment of LVL 875,000 the project is today not feasible from an economic point of view. But as the costs of process water and discharge of wastewater are expected to increase significantly in the future, we recommended the company to reconsider this project at a later stage.

Because of the poor economy for membrane filtration the following solution was proposed instead:

- Separate the wastewater in the types 1 and 2.
- Bypass the type 2 wastewater.
- Improve the treatment of type 1 by installing an equalisation tank and coupling the sedimentation tanks in parallel.

Reuse of Cooling Water from Spinning Machines

The first process in the PAN yarns production is the stretch breaking process. PAN tops are stretched in 10 stretch breaking machines "SEYDEL". The technological process requires that stretching shafts be cooled. Shafts were cooled with water from their own well (before the year 2001, the production water from the municipal water supplier was used). Because this water is used only for cooling of shafts, it is not polluted and is discharged to the rain (run off) sewerage.

One stretch-breaking machine uses 2 m³/hour of cooling water. The total use of cooling water is 20 m³/hour, assuming that the number of working days is 150, and Vernitas works 8 hours (one shift). Total use of water is about: 24,000 m³ per year (the management provided a figure of 24,090 m³/year). The supplied water temperature is about 9°C or lower, and the outgoing water temperature is about 21°C. Necessary water pressure is about 2.5 atmospheres. At present the company pays 0.07 LVL/m³ (as taxes) for water from a well (not including cost of water pumping from the well and well maintenance). Water discharge to the rain sewerage is free of charge.

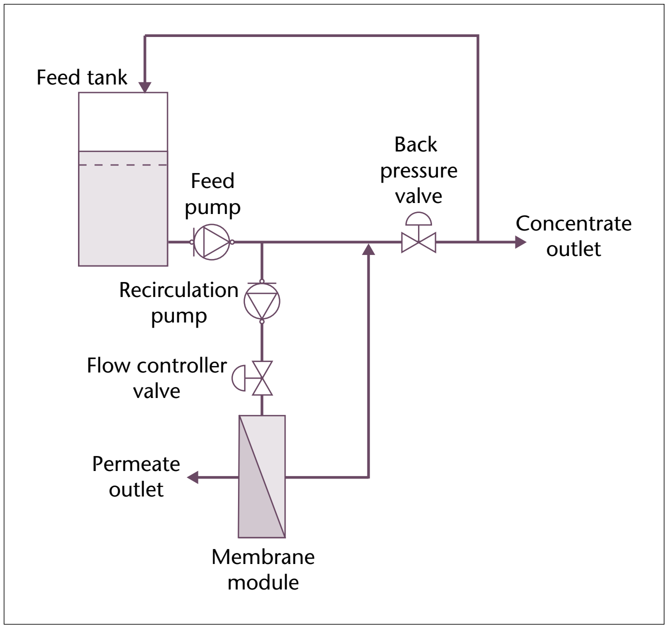


Figure 1.6 *Membrane filtration with internal recirculation.*

The engineers of the company have tried to construct a cooling water recycling system by connecting indoor water capacities. The experiment was unsuccessful because the water temperature drop was not sufficient.

In the initial stage of the investigation it was decided to use another outside underground water reservoir with a capacity of 1000 m³. The reservoir was previously used for storing fire protection water. The large volume of the reservoir and a distance of some 200 m to this capacity should ensure the necessary temperature drop.

According to the company calculations the installation cost for the above project of recycling water is 400 m zinced pipes; two pumps, one of 7.5 kW with a capacity of 50 m³/h and a reserve pump of 10 kW with a capacity of 70 m³/h (the second to be used in case of an emergency). The company already had the two required pumps, thus the cost of these is set to zero.

The company decided to implement this proposal immediately, using its own resources. The construction work took approximately two weeks and was carried out by two workers. The calculated pay back period was 1.67 years. The above calculation does not include the electricity for the pump for water recycling. The reason is that the saved cost of water pumping from the well is not included either and the two costs are estimated to be equal.

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References

IPPC (Integrated Pollution Prevention and Control). BREF Reference Document on Best Available Techniques for the Textiles Industry, 2003.
http://eippcb.jrc.es/

U.S. EPA (U.S. Environmental Protection Agency). Manual – Best Management Practices for Pollution Prevention in the Textile Industry, 1996.
http://www.p2pays.org/ref/02/01099.htm

Case Study 2

Klaipėdos Baldai
Lithuania

Klaipėdos Baldai Furniture Manufacturing

1. Furniture Manufacturing

Furniture Industry in Lithuania

The furniture industry is a rapidly developing and dynamic sector in Lithuania with a growth rate of about 20-25% in recent years. In 2004 a total of 738 registered companies were selling for a total of 373.3 million euros. The companies were mostly small: 1-20 employees (35%), 20-99, (50%) and over 100 employees (15%). The largest producers are also the largest exporters, exporting some 60-80% of their production.

Klaipėdos baldai is the largest furniture manufacturer in Lithuania, with more than 600 employees. The product range of the company includes around 500 types of separate furniture units: bedroom, office, children room furniture and a large variety of different products for export. The company uses different thickness chipboard, covered with natural beech, oak, ash, cherry and other kind of veneer or synthetic foils, laminates.

Like elsewhere in Lithuania, furniture sales increased mainly due to export, which is related to the successful introduction of working Quality and Environment Management Systems. In 2004 Klaipėdos baldai was awarded the National Prize of Quality, and its furniture collection ANDA was recognised as the best product of the year in Lithuania.

The main partner of Klaipėdos baldai AB is Joint Stock Company Klaipėdos baldu prekyba. The Company trades in furniture in Lithuania, the CIS countries, Latvia and Estonia. Foreign partners include SODIM in Belgium and IKEA in Sweden.

The Production

There are many different grades and styles of furniture. Three grades of furniture often are described by the industry as high end, medium end, and low end. Generally, high-end furniture is made of solid wood and wood veneers and has the wood grain showing through the finish. The finishing process includes multiple finishing steps and is labour intensive. Low-end furniture, on the other hand, is often made of medium density fibreboard (MDF) with some plastic components and some natural wood. Also, the pieces often have either a coloured or printed wood grain finish, and the finishing process is less labour intensive. Medium-end furniture may be made of some combination of MDF and solid wood and may or may not show the natural wood grain.

Environmental Certification

Environmental issues are of great strategic importance to Klaipėdos baldai. Environmental work is performed with a focus on long-term sustainability. The Environmental Policy is in conformity with the objectives and strategic programme of environmentally friendly manufacturing.

Klaipėdos baldai was the first certified company in Lithuanian furniture industry receiving ISO 9001 quality certificate in 1998 and ISO 14001 in 1999. This was not only the first EMS certificate in Lithuanian furniture industry, but also a totally new phenomenon in Lithuanian economy. Until then, not many Lithuanian businessmen cared about the responsible use of natural resources and the impact of their activities on the environment. Klaipėdos baldai, while expanding its production volumes, pays more and more attention towards solutions of environmental problems, and today works with long-term environmental protection planning.

Cleaner Production Project Development

The Cleaner Production (CP) programme was performed in the company with a goal to improve the quality of the environment through eliminating, preventing, and/or reducing all waste generated by manufacturing prior to off-site recycling, treatment, or disposal. To effectively accomplish this, the programme included an ongoing, comprehensive assessment of the operations at the facility. As the CP activity would lower costs, the company expected to be able to improve its competitiveness through the programme. The company set up the following goals:

- Protect human health and environmental quality.
- Reduce operating costs.
- Improve employee morale and participation.
- Enhance the company's image in the community.
- Assist in compliance with environmental laws.

Most environmental problems are linked to economic development, and business conditions are becoming more and more complicated due to the increasing environmental concerns. Therefore, the practical application of sustainable development principles in the company is becoming an important aspect of business competition. On the other hand, sustainable development opens new business opportunities, e.g. development of more environmentally friendly products and processes. Additionally, the application of preventive environmental management measures helps to:

- Increase productivity.
- Reduce the use of natural resources and the associated costs.
- Reduce costs for waste management and pollution control and related risks.

In total it amounts to the improvement of environmental, economic and social performance, thus providing for competitive advantages.

2. Environmental and Sustainability Policies

Employee Participation and Social Responsibility

Employees are likely to feel better when they believe that management is committed to providing a safe work environment and the company is acting as a responsible member of the community. By participating in pollution prevention activities, employees have an opportunity to be part of a "team," and interact positively with co-workers and management. Helping to implement and maintain a pollution prevention programme will normally increase each employee's sense of commitment to the company goals. This positive atmosphere helps to retain a competitive work force and to attract high-quality new employees.

The quality of the environment has become an issue of critical importance to society. Klaipėdos baldai's policy and practices for controlling waste increasingly influence the attitudes of the local community at large to become more positive. The company creates environmentally compatible products and avoids excessive use of material and energy resources. Therefore its image is enhanced both in the community and with potential customers and consumers.

The company's CP plan included standard operating procedures that comply with environmental laws and regulations. By following the plan, the company increases its chances of avoiding violations and associated penalties.

Environmental Improvements

The investment policy of the company is not simply assigned for the increase of manufacturing output, but for the reduction of the impact on environment as well. Therefore, the company installed modern and environmentally friendly heating and ventilating equipment and fire protection measures. Important environmental improvement measures were implemented also:

1. Centralised waste collection and sorting.
2. Modernisation of the ventilation system.
3. Implementation of rain water treatment equipment.
4. Modernisation of the boiler house.
5. Hermetization of windows and insulation of walls in production departments and administration.
6. Implementation of new modern technologies, which increased performance of ventilators, reduced the wood dust emission sources by 6 (11 instead of 17); and reduced electrical and heat energy consumption by 30%.

Protect Human Health and Environmental Quality, Air Quality and Emissions

Typical harmful pollutants that can be reduced significantly by pollution prevention techniques include:

- Air emissions, including solvent fumes, fine particulates, and carbon monoxide.
- Land disposal, including ash from incineration, waste solvents, and debris.

- Water disposal, including wastewater contaminated with solvents and other toxic materials.

Volatile organic compounds (VOC) typically make up a significant amount of the solvents used in wood finishing. Many VOCs are damaging to the central nervous system. Long-term exposure may result in behavioural effects. Some VOCs are suspected carcinogens.

The health and safety of employees is threatened by poor ventilation, mishandling of chemicals, and a lack of proper safety equipment. An informative employee training programme is an important way to reduce accidents. Reducing the amount of chemical materials and wastes at a facility is also beneficial, because it reduces the amount of space required for storage and the potential for accidental spills. Furthermore, hazardous waste transportation requirements may be reduced if the volume of pollution is minimised.

Reduce Operating Costs

Cost savings are particularly noticeable when the costs resulting from the treatment, storage, or disposal of wastes are allocated to the production unit, product, or service that produces the waste. Materials costs, or the costs of purchasing materials, can be reduced by adopting production and packaging procedures that consume less resources. This approach uses resources more efficiently and reduces the quantity and toxicity of waste generated.

As wastes are reduced, the percentage of raw materials converted to finished products increases. This results in a proportional decrease in materials costs. Waste management and disposal costs may be reduced when less waste is produced. Required procedures for proper handling of the waste at the facility – in addition to specific treatment, disposal, and transportation methods – are typically labour-intensive and very costly. These requirements and their associated costs are expected to increase. People examine production processes from

Table 2.1 *Typical furniture manufacturing and refinishing operations: materials used and hazardous wastes that might be generated.*

Process/ Operation	Materials Used	Typical Material Ingredients	General Types of Waste Generated
Wood Cleaning and Wax Removal	Petroleum distillates, white spirits	Petroleum distillates, mineral spirits	Ignitable wastes Toxic wastes Solvent wastes
Refinishing/ Stripping	Paint removers, varnish removers, enamel removers, shellac removers, paint solvents, turpentine	Acetone, toluene, petroleum distillates, methanol, methylene chloride, alcohols, ketones, oxygenated solvents	Ignitable wastes Toxic wastes Paint wastes Solvent wastes
Staining	Stains	Mineral spirits, alcohol, pigments	Ignitable wastes Toxic wastes Solvent wastes
Painting	Enamels, lacquers, epoxies, alkyds, acrylics	Toluene, pigments, titanium dioxide, epoxy-ester resins, aromatic hydrocarbons, glycol ether, halogenated hydrocarbons, vinyl acetate acrylic	Ignitable wastes Toxic wastes Paint wastes Solvent wastes
Finishing	Varnish, shellac, polyurethane, lacquers, wood treatments, polish	Denatured alcohols, resins, shellac, petroleum distillates, toluene di-isocyanate	Ignitable wastes Toxic wastes Spent solvents Solvent still bottoms
Brush Cleaning and Spray Gun Cleaning	Paint thinners, enamel reducers, varnish removers, shellac removers, white spirits	Acetone, toluene, petroleum distillates, methanol, methylene chloride, isopropanol, mineral spirits, alcohols	Ignitable wastes Toxic wastes Spent solvents Solvent still bottoms
Maintenance	Antifreeze, spent solvent from parts washers, batteries, spent fluorescent lamps, used computer/electronic equipment		Toxic wastes Solid wastes Spent solvents

a fresh perspective; they find opportunities for increasing efficiency that might not otherwise have been noticed.

Production scheduling, material handling, inventory control, and equipment maintenance are all areas in which facilities can work to reduce the production of waste of all types, thereby controlling the costs of production. Energy costs will decrease as the facility implements pollution prevention measures in various production lines. In addition, by thoroughly assessing how operations interact, companies can reduce the energy used to operate the overall facility.

3. The Air Cleaning System

The Air Cleaning System Review

Klaipėdos baldai had two production departments with a total of 12,355 m² of floor area. The work caused considerable dust emission, which created a bad atmosphere for the workers. Also the areas surrounding the factory were badly polluted, mostly by saw dust. Klaipėda Municipality passed a resolution requesting that the company reduce the emissions. Also according ISO 14001 air pollution was established as a significant aspect that should be solved.

The air cleaning system, called cyclones, used in the company (Figure 2.1) was quite inefficient. The polluted air from the production departments using the cyclone system was treated only up to 70-90%. Therefore it was not possible to return the air to the department and a lot of heat, especially in cold season, was wasted.

Figure 2.1 *Sleeve filters air-cleaning system AAGAARD. Produced in Denmark, in 2001.*

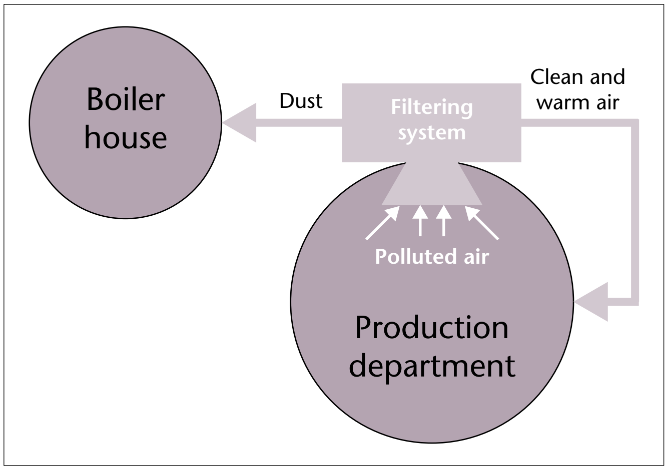

Figure 2.2 *CP project scheme.*

The main findings from the review found that:

- The dust cleaning system was very ineffective, and could not meet environmental requirements.
- There was significant heat and electrical energy losses due to very low performance of the ventilators.
- High noise level.

The CP project aimed to:

1. Reduce saw dust air pollution.
2. Reduce electrical and heat energy consumption.
3. Improve work conditions by regulation of intake and take-out air streams.
4. Reduce noise level.
5. Reduce the general pollution background in the region.

The Installation of a New Ventilation System

In 1998-1999 the company introduced new modern technologies to reduce dust emission sources. New ventilators were installed in the place of the removed old ventilators. For air extraction the old pipe channel system was still be used but for the cleaned returned air a new pipeline system was installed.

The company decided to replace the cyclone system, with a dust extraction and filter system, which allowed clean warm air to return to the working area (Figure 2.2).

The new filtering system consisted of 6 filtering sections with 288 filter bags with a special quick assembly sleeve. Polluted air from the production departments through a special system was transported to the filters. After cleaning, it returned to the production area and was distributed through air channels. Due to the fast speed the air temperature of the returned clean air was only 2-3°C lower than the incoming air.

The system was designed for continuous operation (24 hours). Cleaning of the filters was automatic and could be performed during operation or during stops by means of regeneration fans (1.1 kW), which rinsed the filter bags by blowing a reverse airflow through the bags. The filter hopper was automatically emptied by means of a chain conveyor, which fed the chips to the end of a rotary valve. The chain conveyor was running on bearings and sliding forward on anti-static slide rails.

The company installed a capacity of 45,000 m³/h with three fans and machine groups connected to the filter. The fans were placed outside the building.

The cleaning process, dust transportation, system start and stop as well as safety functions were controlled automatically.

Energy Savings – Recirculation of Warm Air

Also winter/summer valves were installed. They provided the possibility of not returning the cleaned air in summer time. The modular construction of the filtering system provided the company with the possibility of expanding the system according to needs (this type of filter can be supplied to handle up to 250,000 m³/h).

The body of the filtering system is made from galvanised tin, and the filter bags from special anti-static polyester fabric. The collected dust is transported to the company's boiler house by screw conveyor and used as fuel.

The recirculation of clean warm air significantly reduced the energy losses and emissions to the outside air from the company's boiler house. The effective new ventilators of the air cleaning system reduced the electric energy consumption. The installed ventilators had an extremely low noise level. Extra noise reduction, typically 15-20 dB (A), was achieved by building the fan into a sound box. The sound box, which has forced cooling air circulation, was made of galvanised, weather resistant steel sheets and was thus suitable for outdoor use.

Table 2.2 *Environmental results of the CP project.*

Energy consumption Reduction (kWh)	
Electric energy	1,098,452
Heat energy	1,377,600
Reduction of pollution (t/year)	
Atmospheric pollution reduction	2152.6
Wood dust	6.24
Ashes	1.072
SO_x	9.22
CO	6.15
NO_x	0.856
CO_2	2129.06

Table 2.3 *Economical savings.*

Kind of cost reductions	euros
Electric energy savings	54,868
Heat energy savings	35,336
Environmental taxes	310
Annual production costs	90,514

Results – Environmental and Economic Benefits

A summary of the environmental benefits of the new system (Table 2.2) included electric energy savings of some 1,000,000 kWh, heat energy savings of 1,377,600 kWh. The reduction of dust was reduced with more than 2,000 tons per year, pollutants with some 25 tons per year, and carbon dioxide with 2,000 tons per year.

The economic savings from the new ventilation system (Table 2.3) was the results of diminished energy costs and reduced fines for air emissions. A total of 90,514 euros reduced costs is then compared to the investments, which were 228,700 euros. The pay back period was thus 2.53 years.

4. Modernisation of the Boiler House

Review of Local Energy Production

The heat energy to all production facilities at Klaipėdos baldai was generated at a boiler house located in the territory of the company. The capacity of the boiler house was 1.3 MW, but the efficiency only 43.8%, thus very low. Approximately 30% of energy was consumed to operate the boiler itself (mainly for the air supply to the combustion). The fuel was supplied to the boiler house by pneumatic transport, which used a significant amount of electric energy.

The wood waste from the production was used as fuel for heat energy production. Annually 3,754 tons (thin wood waste – 2,628 t/year, nubbly wood waste – 1,126 t/year) of furniture wood waste was available at Klaipėdos baldai.

Emissions from the boiler house exceeded stated CO and NO_x maximum levels by 1.7 and 2 times respectively. The environmental fees for the emissions during 2001 were in total of 1,671 euros. This was mainly due to the insufficient control of the combustion process.

Analysis of the boiler house facilities revealed:

- High losses of heat due to the imperfect construction and worn-out conditions.
- High consumption of electric energy (draught and blowing ventilation, pneumatic transportation of fuel).
- Incomplete combustion resulting in higher emissions (burning process was regulated manually).

After a rapid increase of production the heat energy generation for the company became insufficient. As a result, considerations concerning investments for the constructions of the new boiler house were started. For its own purposes the company would need 4,000 MWh of heat energy. The price would be 12.2 euros per MWh. All together it would make 48,600 euros per year. If the same amount of energy would be purchased from the municipal supplier, the price would be 30.1 euros per MWh and in total would make 75,200 euros. The economic benefit of the locally produced energy would thus be 26,600 euros per year, as compared to the municipally supplied heat energy. This was the strong argument for Klaipėdos baldai to start implementing the CP project "Modernisation of the boiler house".

The New Boiler House

The environmental and economic audit led to the proposal that the old boiler house should be modernised. The main aims of the project was to:

- Decrease ambient air pollution.
- Decrease consumption of electric energy.
- Improve working conditions.
- Improve the environmental situation in the surroundings.

A new boiler house building was erected, and two boilers installed with effects of 1.1 and 2.8 MW, that is 3 times increased capacity, to provide sufficient heat energy, to be used in three production departments and storage facilities.

A new fully automated control system with distribution box, control panel (incl. O_2-regulator, alarm system etc.) was installed. The control system ensured optimal burning through monitoring the oxygen concentration in the emitted smoke and fuel supply processes. The emissions to the atmosphere were thus significantly reduced.

The water system included circulation pumps (120 m³/h), a water treatment system with a capacity of 0.5 m³/h chemical treatment. The chemical water preparation is performed using automatic filtering.

The old boiler was dismantled and sold as scrap. The building of the boiler house was demolished as it was not economical to renovate it, either from environmental and technical, or an economic point of view.

Savings and Profit

The economic benefits of the new boiler house were considerable. The savings were in the following categories:

Savings of electric energy. The operation of the new boiler house facilities required less electric energy as compare to the facilities in the old boiler house. In this respect electric energy consumption was reduced by 79,000 kWh, which made up 4,580 euros of savings per year.

Savings of water. The new installations in the boiler house reduced the consumption of water used for heating by 3,000 m³, which made 2,259 euros of savings per year.

Savings for operation and maintenance. Expenditures for operation and maintenance were reduced from 39,901 to 11,400 euros compared to the old boiler house and made up 28,501 euros per year.

Savings of heat energy. Expenditures for heat energy production in the new boiler house, compared to the old one, were reduced from 172,498 to 83,410 euros, i.e. the savings were 89,088 euros per year.

Table 2.4 *The annual net savings and profitability after implementation of CP project for the boiler house.*

Category of costs	Costs before CP project (euros)	Costs after CP project (euros)	Annual net savings and profit (euros)
Consumption of electric energy	12,488	8,004	4,580
Consumption of water	4,344	2,085	2,259
Operation & maintenance	39,901	11,400	28,501
Heat energy production	172,498 *	83,410	89,088
Environmental fee	1,671	219	1,452
Total net savings			**125,880**
Profit from sold heat energy	39,968	79,935	39,967
INCOMES			**165,847**

** The overall heat energy costs consisted of energy produced by company (48,656 euros) and energy bought from municipal suppliers during the heating season (123,842 euros).*

Reduced environmental fees. Lower emission exhausts of NO_X, CO and solids have reduced environmental fees by 1,452 euros per year.

Profit from the sold heat energy. At the same time the innovations at the boiler house opened the possibilities of Klaipėdos baldai selling energy to the other companies. For the needs of the company, the boiler house was operating 7 months per year. The remaining 5 months' surplus energy was sold to neighbouring companies. Heat energy production made up 600 MWh per month. It means that every year 3,000 MWh of heat energy could be sold to other companies, at a price of 13.3 euros per MWh. The incomes were thus projected to be 39,900 euros.

The investments for the new boiler house and installations were estimated 374,246 euros. The annual net savings and profit after installation of the boiler house gave to Klaipėdos baldai 165,847 euros in income. Thus, the pay backs of investment were 3 years and the return rate was 31.5%.

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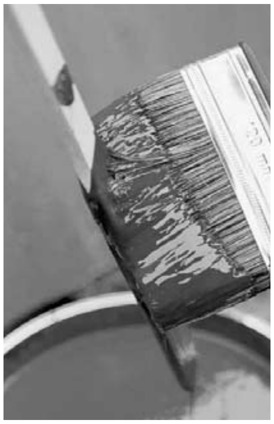
Case Study 3

Greenchem Programme
Sweden



Greenchem Programme – Wax Esters as Wood Coating Material

1. Background

Green Chemistry and the Greenchem Project

One of the largest challenges to chemical technology is to reduce the dependency on fossil resources. The chemical industry is therefore exploring ways to use renewable resources to replace crude oil and improve sustainability. The use of renewable biological resources instead of oil will not only decrease oil dependency, but also decrease carbon dioxide emissions and reduce the emission of other pollutants connected to the use of oil.

Another important concern of green chemistry is to increase the efficiency of chemical transformations and use less energy. The case to be described shows that the use of enzymatic catalysis, often discussed as *bioprocesses*, instead of conventional inorganic catalysis, allows more energy-efficient production. This is still a topic for research but the number of industry-scale bioprocesses in operation started to increase during the last decade. Most of today's commercial enzymatic processes possess a variety of positive features, such as high productivity, high product concentrations, and a lack of undesirable by-products.

The research programme *Speciality Chemicals from Renewable Resources – Greenchem* is a Swedish interdisciplinary research programme at Lund University concerned with the development and application of biocatalysts for the production of fine chemical products from renewable raw materials. The programme includes research activities within both biotechnology and environmental systems analysis and involves cooperation with several industrial partners. Consumer and industrial desire for more environmentally benign paints and coatings is growing rapidly. The production of wax esters to be described here has been developed within the *Greenchem* programme.

Biological Materials for Industrial Purposes – Waxes

Waxes, or wax esters, are esters of long-chain carboxylic acids and long-chain alcohols. In nature one may find them as protective coatings on fruits, for example on apples, or as the material in beehives. As biological substances they are nonhazardous compounds with good biodegradability. The waxes have attracted the industry since they have a number of potential applications. One of them is to serve as ingredients in coatings for wooden surfaces.

Wax esters can be made from renewable resources, such as vegetable oils. High atom economy can be achieved as one molecule of water is the only side-product in the key production step, the condensation of the carboxylic acid and the alcohol. As biological material there are a number of potential enzymatic processes which may be used for their production. Here a lipase was used.

Conventional Industrial Production of Wax Esters

The conventional technology for the production of wax esters is based on the reaction of the alcohol and the carboxylic acid at temperatures above 150°C in the presence of a strong alkaline or acid as catalyst. The reaction is unselective and the waste and catalyst residue need to be removed in post-reaction purification.

In the conventional method neutralisation of the acid, steam treatment for distillation, and both deodorising and bleaching are needed. In post-reaction the product has to be dried. During the post-reaction stages there is a loss in product yield of up to five percent. Finally, the amount of raw materials required is larger than in enzymatic catalysis, since the process is less selective and some of the raw material will turn into by-products. The amount of waste, such as solvents, bleaching residue and by-products generated in conventional chemical production, is up to five times as high as in enzymatic production.

The Green Process

It is clear that there is much to be gained from an enzymatic production of wax esters. The enzymatic production of wax esters is more environmentally friendly than the conventional one. The energy required is much smaller and the yield is larger. The lesser amount of refining needed also results in higher yield.

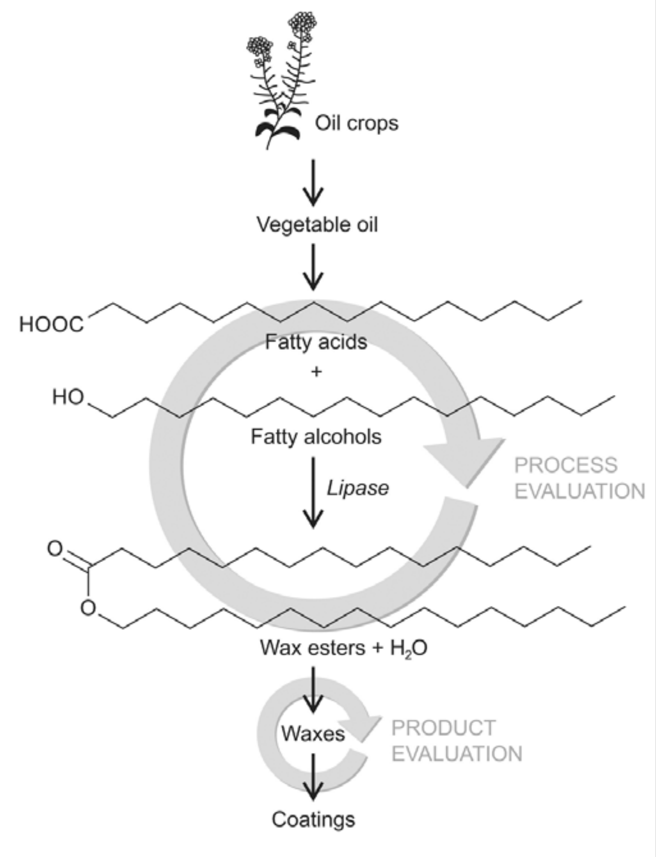


Figure 3.1 *Illustration of wax production from renewable resources.*

Table 3.1 *Molecular formulae of the synthesised wax esters.*

Cetyl palmitate	$H_3C(CH_2)_{15}OOC(CH_2)_{14}CH_3$
Behenyl behenate	$H_3C(CH_2)_{21}OOC(CH_2)_{20}CH_3$
Dibehenyl adipate	$H_3C(CH_2)_{21}OOC(CH_2)_4COO(CH_2)_{21}CH_3$
Dibehenyl sebacate	$H_3C(CH_2)_{21}OOC(CH_2)_8COO(CH_2)_{21}CH_3$

The challenge was thus to develop an attractive, green process for the enzymatic production of wax esters. Key points to address were the evaluation of possibilities for use of a solvent-free process and of finding methods for achieving sufficiently high conversion levels to allow the product to be used with only a minimum of purification.

From an economic point of view, the process had to be efficient enough to prevent the enzyme costs from becoming prohibitive. To this end, a process methodology was developed, which allowed four different wax esters to be produced enzymatically in a litre-scale reactor. Their properties as wood coating waxes were investigated by the industrial partners that participated.

2. Production

Wax Esters

The alcohols used were cetyl alcohol with 16 carbon atoms in the chain and behenyl alcohol with 22 carbon atoms in the chain. The carboxylic acids used were palmitic acid with 16 carbon atoms and behenic acid with 22 carbon atoms as well as adipic acid (1, 6-hexanedioic acid) and sebacic acid (1, 10-decanedioic acid).

Four wax esters were prepared. These were (Table 3.1) two monoesters, cetyl palmitate and behenyl behenate, and two diesters, dibehenyl adipate and dibehenyl sebacate. The numbers of carbon atoms in these compounds were thus 32, or 44 for the monoesters and 50 and 54 for the diesters.

The production of an ester amounts to the joining of the acid and alcohol in a so-called condensation reaction. It is clear that the atom yield in these reactions were very large since the only atoms lost as by-products are those of water during the condensation of the acid and alcohol.

Choice of Enzymatic Processes

The enzyme chosen was a lipase. The enzyme in the cell normally catalyses the hydrolysis of an ester, that is, the splitting of the ester bond. Here such a reaction was run backwards. This is possible as the water is removed, the equilibrium will be pushed towards the ester rather than the alcohol and acid. Of course, the energy required for the synthesis of the bond needs to be available.

The enzyme used, available commercially from Novozymes A/S in Denmark, was lipase B extracted from the yeast *Candida antarctica*. The enzyme was immobilised to a solid carrier and thus could be filtrated off after the reaction and used over again. The enzyme was quite stable. It survived low pH and rather high temperature up to 80°C, without being destroyed.

Choice of Solvents

Choice of the solvent to be used in a process is a key issue from a green chemistry perspective. Super critical carbon dioxide and ionic liquids are often referred to as *green solvents*, but use of a solvent-free process is the most attractive alternative. Solvent-free enzymatic esterification processes were a natural choice in the present study.

Removal of Water

The esterification reaction, which results in esters and water, is reversible. Thus to achieve a high yield, one of the products, water, needed to be removed. The reaction mixture should therefore contain as little water as possible.

Most enzymes need a certain amount of water in order to work. In such cases, water removal at a fixed water activity (relative humidity) is better than extensive drying. There are several methods to control the water activity of the reaction mixture. A practical way of controlling the water activity in a reactor is to measure it continuously with a sensor and to adjust it to a set value by passing air (or nitrogen) through the reaction mixture. Dry air is used to remove water from the reactor and humid air to add it. This can be carried out on a small or a large scale. If needed, the water activity can also be set at different values for separate stages of the reaction. A further advantage of this approach is that the gas bubbles produced improve the mixing in the reactor so that stirring can be reduced or even be avoided entirely, lowering the energy consumption. In this study only passing dry air for removal of water was used.

Several other possible means of water removal, such as vacuum evaporation, pervaporation, addition of cation-exchange resins, use of molecular sieves and azeotropic distillation, were not used.

Choice of Temperature

The reaction temperatures were chosen so that all the substrates (monoester synthesis) or a major part of them (diester synthesis) were in liquid form. An increase in temperature leads to an increase in reaction rates, but also to an increase in enzyme inactivation rates as well as an increase of the energy consumption. In the temperatures used, the enzyme could be filtered from the product and reused approximately 5–6 times altogether according to another study.

It has been shown earlier that between 65 and 75°C the reaction rate for isopropyl palmitate synthesis increases with increasing temperature. The optimal working temperature for the immobilised enzyme was 70–80°C according to the supplier. The initial reaction rates for the monoesters were approximately twice as high as those for the di-esters, dibehenyl adipate and dibehenyl sebacate. This might possibly be due to the fact that, at the reaction temperature employed, the diacids were not completely melted or dissolved initially. As the reactions proceeded, they dissolved, the reaction mixtures then becoming clear.

3. Results

Reaction Equipment

A batch-wise process was used: all ingredients were added to one reaction vessel from which they were recovered after the reaction. In the beginning a solvent-free synthesis of cetyl palmitate was performed in a 25 ml round-bottomed flask. In the 25 ml-scale, removal of water occurred by simple evaporation to the surrounding air. This did not work on a larger scale.

Later on a one litre reactor containing a sensor for water activity measurement and equipment for the automatic adjust-

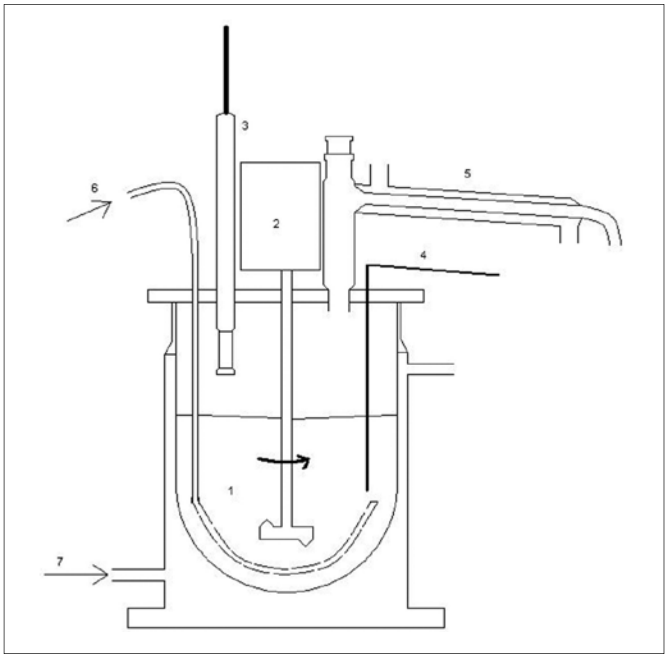


Figure 3.2 Litre scale reactor for enzymatic esterification.
1. Reaction liquid, 2. Stirrer, 3. Water activity sensor, 4. Thermometer, 5. Condenser, 6. Dry air inlet, 7. Heating medium, glycerol, inlet.

ment of water activity by use of dry or humid air was constructed (Figure 3.2).

Monitoring

Two different methods were used to monitor the reaction. The reaction was followed by gas chromatography and/or titration of the remaining acid. These methods produced similar results. Final samples were also analysed by titration of the hydroxyl groups.

Reaction

The small scale synthesis of cetyl palmitate was performed at 65°C in a three-necked round-bottomed flask. The larger scale synthesis of all four esters was performed using a one litre-scale reactor.

The alcohol and the acid were mixed in equimolar amounts and, when the substrates had been melted, the immobilised lipase, i.e. the enzyme, was added to start the reaction. During the reaction, water activity and temperature were measured in the air above the reaction liquid by a relative humidity sensor. The reaction mixture was analysed by gas chromatography and/or titration.

Yields

When the synthesis was performed in the litre-scale reactor with an equimolar mixture of the starting materials carboxylic acid and alcohol, without any deliberate water removal, only 65% conversion was obtained. When the water was removed during the process by a stream of dry air passing through the reactor all four esters were synthesised at high conversion, 95–99% (Table 3.2).

In most cases some conversion could be observed before addition of enzyme, which could be explained by spontaneous esterification during the drying of the substrates. Almost complete, 98%, conversion to cetyl palmitate was achieved when the reaction mixture was dried by use of dry air from the start.

The various reactions differed in initial reaction rate after the enzyme was added. The initial reaction rate was highest for cetyl palmitate, even though this reaction was run at a lower temperature than the others.

4. Industrial Scale Production

Design of the Industrial Scale

The large-scale enzymatic production of wax esters commercially is still under development, and there are only few companies utilising these reactions. In this study some calculations were made on the properties of large-scale synthesis of wax esters. We assumed a production of 25 tonnes annually.

The reactor system most similar to the reactor used in the laboratory-scale experiments described in the present study would be a batch reactor employing air stripping. There are certain differences between the laboratory- and the large-scale systems, however. In large-scale productions there is separate heating of the in going air and the reactor. We assumed drying by heated air from the surroundings rather than by dried air and heat exchange between the in- and outgoing air.

The calculations for industrial-scale production assumed a total of six reactor systems, using air-stripping or evaporation for water removal. Heating of the reactor was achieved by circulating hot water in a mantle around the reactor and/or by preheating the air used for water removal. Both batch and continuously stirred tank reactors were evaluated.

The calculations were based on suitable reactor volumes for an annual productivity of 25 tonnes, which were estimated to be 102 L for batch and 22 L for the continuous systems. For the reactor 20 mm of insulation was used and a heat exchanger was assumed for in- and outgoing air flows when applicable, with an efficiency of 83%. The efficiency of the air heating was assumed to be 90%. The ambient temperature was assumed to be 20°C in all cases.

Energy Requirements

The energy requirements for the large-scale production of 25 tonnes of wax esters were estimated, both for batch and for continuous reactor systems using two different types of water

Table 3.2 Concluding results from ester synthesis.
Conversion results from titration. The initial reaction rate is based on mmoles ester bonds formed.

Ester	Temperature (°C)	Initial reaction rate (mmole min^{-1} g^{-1})	Melting point product (°C)	Final conversion of alcohol (%)	acid (%)
Cetyl palmitate	65-67	3.4	50-51	98	99
Behenyl behenate	85-88	2.9	69-73	99	98
Dibehenyl adipate	90-93	1.4	70-73	99	99
Dibehenyl sebacate	88-90	1.4	71-74	95	99

Table 3.3 *Comparison of the energy requirements for the best enzymatic method and for the conventional production method.*

Energy demand	Enzymatic (MJ/tonne)	Conventional (MJ/tonne)
Preheating	300	540
Heat losses from reactor	40	105
Air heating	55	n/a
Mixing and water removal	25	40
Heat demand for reactor	80	80
Total	500	765

removal systems: air-stripping or evaporation. In addition, estimates were made of the energy requirements of a conventional process. The results of the calculations on the best enzymatic and conventional alternatives are shown in detail in Table 3.3.

The energy requirements for the large-scale reactor systems vary between 500 and 1500 MJ/tonne. The various batch reactors were the most efficient. On the basis of calculations concerning the best enzymatic process (batch reactor), the conventional method had an estimated energy requirement of 765 MJ/tonne, which is one and a half times that of the enzymatic process. The preheating of the substrates is the most energy-consuming step in the process, representing 60% (300 MJ/tonne) of the total energy requirement for the enzymatic process.

For the conventional chemical process conducted at 150°C, the preheating step would require 70% (540 MJ tonne) of the total energy requirements, which is 80% greater than for the enzymatic process. Several post-production steps are needed for the conventional method, although these have not been included in the calculations. Previous calculations [Hills, 2003 show that the chemical method, due to the higher temperature and the post-reaction purification steps, has energy requirements up to two and a half times as high as for enzymatic production.

Measurements of the litre-scale synthesis of wax esters indicate energy requirements of 125–160 GJ/tonne of the product, depending on the wax ester involved. The large difference as compared with the calculations for large-scale production (two orders of magnitude, in fact) clearly demonstrates the need for adequate insulation and energy recirculation for an acceptable level of energy efficiency to be achieved in large-scale production.

Products

Products made with use of enzymatic reactions have a higher consumer appeal than those made using the conventional processes, due to the environmental benefits that result. The wax esters were emulsified in water using a surfactant, the emulsions being treated further to allow them to be used in industrial wood coating equipment.

The monoesters cetyl palmitate and behenyl behenate behaved well in the wood coating equipment and produced waxy surfaces on pine wood, whereas the di-esters formed precipitates in the coating equipment, making further evaluation of them impossible. Since the melting points of the di-esters were only slightly higher than the melting point of the behenyl behenate, it was probably some other property of the di-esters that caused this behaviour.

The monoesters produced surfaces with good resistance to water, almost as good as the existing product, Vaxoline (Table 3.4). (The commercial Vaxoline product contains an acrylate in combination with a wax emulsion: approximately 40% of the dry weight is acrylate and the rest is wax.) However, the resistance to fat achieved was relatively poor. In order to improve the fat resistance, it is likely that the size of the molecules needs to be increased. Work in this direction is continuing with polyesters. Additionally more additives may be needed to gain the desired properties. The wax esters produced in the study will be evaluated for other applications as well.

5. Conclusions

Green Chemistry

The reaction can be carried out catalytically, either using a chemical catalyst, such as a strong acid, or using an enzyme.

Table 3.4 *Evaluation of the use of wax esters as components in wood coatings, as performed by Akzo Nobel Industrial Coatings. Evaluation scale 1-5, 5 being the best, (n/a = not available).*

	Vaxoline	Cetyl palmitate	Behenyl behenate	Dibehenyl adipate	Dibehenyl sebacate
Performance in coating equipment	5	5	5	1	1
Water 16h	5	4	4	n/a	n/a
Fat 6h	5	2	3	n/a	n/a
Fat 24h	4	1	2	n/a	n/a

The enzymatic process presented in this work thus fulfils several of the twelve principles of green chemistry formulated by Anastas and Warner in 1998.

Evaluation

The enzymatic process consumed 34% less energy and generated less waste than chemical esterification using a strong acid as catalyst. Two of the esters worked well in the industrial wood coating equipment employed and produced surfaces resistant to water and somewhat less to fat stains.

Life cycle assessment (LCA) has been recognised as a tool for the environmental evaluation of new, green alternative processes. This involves quantifying the benefits these have compared to the traditional chemical processes. In an ordinary LCA, the total environmental impact is calculated for the complete life cycle of the product, from cradle-to-grave. Such LCAs include feed stock production and the manufacturing, use and final disposal of the product. In considering only the processes, a gate-to-gate perspective can be employed. This is relevant when the systems compared utilise the same raw material and the product they result in are the same. One important parameter of LCA is the input of energy, which is analysed here for the processes involved. A schematic diagram of the chemical and the enzymatic processes is shown in Figure 3.3.

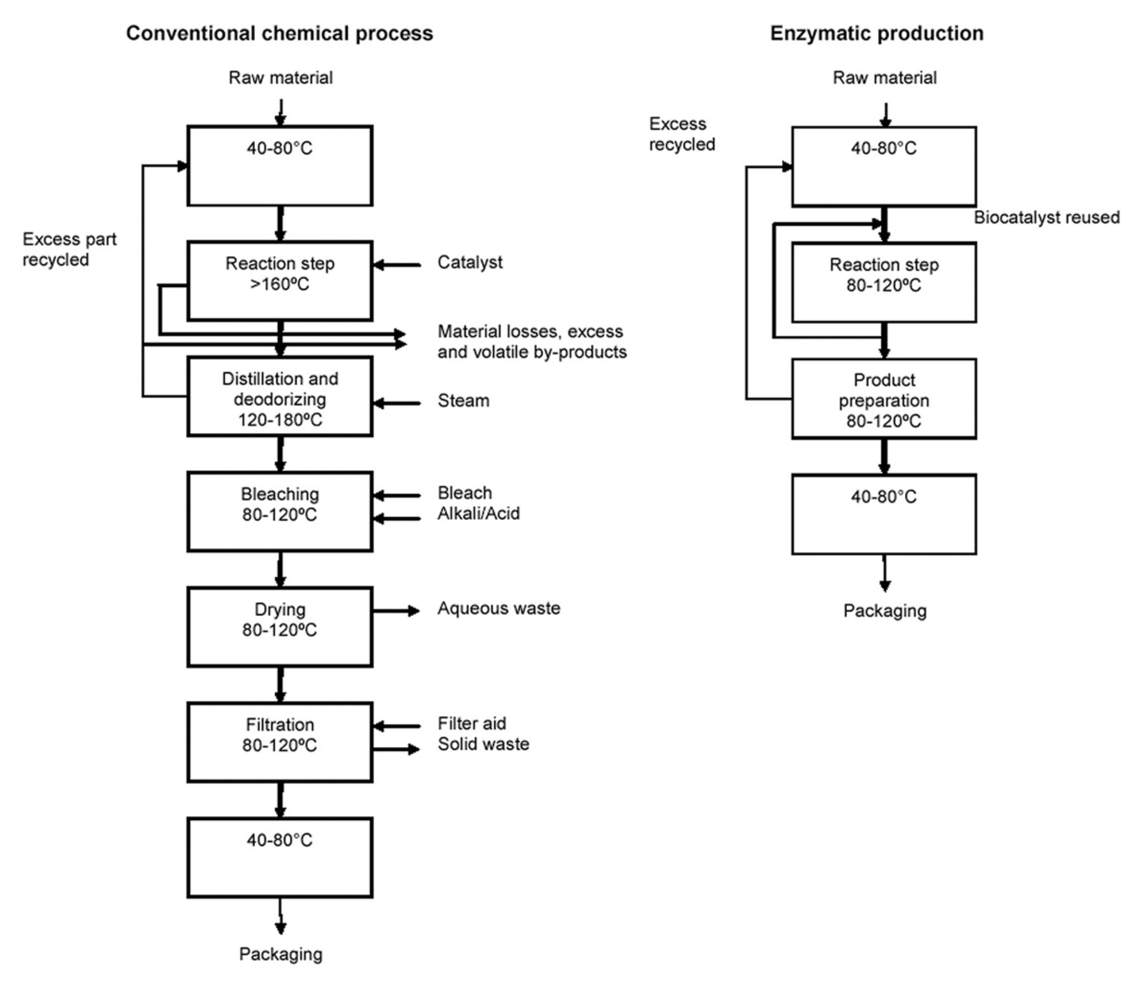


Figure 3.3 *Schematic diagrams of conventional chemical ester synthesis and the corresponding enzymatic process.*

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References

Anastas, P. T. and Warner, J. C. *Green Chemistry: Theory and Practice*. Oxford University Press, 2000.

Derksen, J. T. P., Cuperus, F. P. and Kolster, P. Paints and Coatings from Renewable Resources, in *Industrial Crops and Products*, vol. 3, no. 4, pp. 225–236. Elsevier, 1995.

Hills, G. Industrial Use of Lipases to Produce Fatty Acid Esters, in *European Journal of Lipid Science and Technology*, vol. 105, no. 10, pp. 601–607. WILEY-VCH, 2003.

Petersson, A. E. V., Gustafsson, L. M., Nordblad, M., Börjesson, P., Mattiasson, B. and Adlercreutz, P. Wax Esters Produced by Solvent-Free Energy-Efficient Enzymatic Synthesis and their Applicability as Wood Coatings, in *Green Chemistry*, vol. 7, no. 12, pp. 837–843. Royal Society of Chemistry, 2005.

Schmid, A., Dordick, J. S., Hauer, B., Kiener, A., Wubbolts, M. and Witholt, B. Industrial Biocatalysis Today and Tomorrow, in *Nature*, vol. 409, no. 6817, pp. 258–268. Nature Publishing Group, 2001.

Straathof, A. J. J., Panke, S. and Schmid, A. The Production of Fine Chemicals by Biotransformations, in *Current Opinion in Biotechnology*, vol. 13, no. 6, pp. 548–556. Elsevier, 2002.

Thomas, S. M., DiCosimo, R. and Nagarajan, V. Biocatalysis: Applications and Potentials for the Chemical Industry, in *Trends in Biotechnology*, vol. 20, no. 6, pp. 238–242. Elsevier, 2002.

Case Study 4 | **Meat Processing Industry**
Russia

Energy Management in a Meat Processing Company

1. The Background

The Company

The food processing company to be described here was created in 1992 on the basis of a large meat processing plant from 1933. For years it has been one of the more advanced meat processing industries in Russia.

At present the company occupies an area of 96 hectares. Its east-west extension is 1,150 m and the north-south 1,250 m. 380–500 m from the northern border of the industrial area there is a residential area. The sanitary-protective zone of the enterprise is 1,000 m.

There are several production units at the company. To the Meat Processing Plant No 1 (MPP-1) and No 4 (MPP-4), comes a Shop of Dry Broth (SDP) and a Factory of Medical Preparation (FMP). More than 500 different meat products, sausages and medical preparations are produced. The company has the capacity to manufacture more than 200 tonnes of sausages daily.

The company has its own heat power station, repair-mechanical department, compressor shop, automobile and railway transportation stations, construction shop, wastewater treatment station, trading office and factory shops.

Improvement of the Technology and Environmental Protection

During the last few years the company has replaced outdated equipment and technologies in the main production. At the same time technologies for improved environmental protection were also introduced. As a consequence the emissions of pollutants into air, wastewater to the urban sewage treatment plant, and the quantity of industrial solid waste have decreased substantially.

One of the basic environmental problems remaining unsolved is the relatively large consumption of energy. This constitutes a considerable and unjustified weakness of both the economy and the environmental impact.

Energy Production and the Cleaner Production Project

The Heat Power Station (HPS) of the company is a cogeneration station with combined generation of both heat and electric power. The heat and electricity are used for the entire plant and not easily divided between the individual processes or products.

At the power station fuel expenses are the largest part of the production costs. They are divided between heat (77%) and electric energy (23%).

The cost for heat during summer is 80 RUR/Gcal (RUR = Russian Roubles per Giga calories; 80 RUR = 2.3 euros; 1 Gcal = 1,160 kWh); during the cold winter season the cost increases by some 40% to 110 RUR/Gcal.

The work to reduce heat losses began within the framework of a Cleaner Production programme in 1999. A working group reviewed the production of electricity and heat in detail. The most important result was that the poor insulation of heat

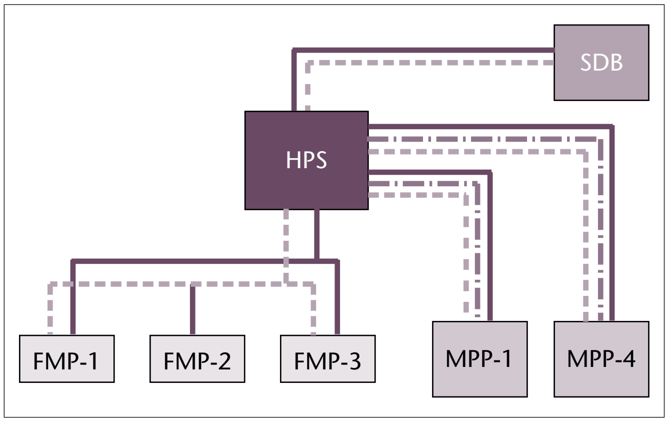

Figure 4.1 Scheme of Emergency Sites of Heat Pipelines. *FMP = Factory of Medical Preparations; MPP = Meat Processing Plant; SDB = Shop of Dry Broth; HPS = Head Power Station.*

pipelines caused heat losses exceeding the norm by 5–25%. The company thus decided to improve the thermal insulation of its heat pipelines.

The objectives of the thermal insulation improvements were to:

- Reduce the heat losses.
- Maintain the heat produced to the factory.
- Create safe conditions for the employees.

The project lifetime was 10 years. The period of project implementation was three months.

2. The Cleaner Production Project

The Heat Pipelines

The heat pipelines were transporting (Table 4.1):

- Steam at 3 atmosphere pressure and 265°C.
- Steam at 8 atmosphere pressures and 395°C.
- Hot water at 60°C for processes.
- Hot water for heating the rooms.

Steam at 3 atmospheres dominates and accounts for about 80% of the heat.

Pipelines in bad condition accounted for about 40% of the total length. It included the pipelines delivering heat to meat production plants 1 and 4, the Shop of Dry Broth and the Factory for Medical Preparation.

Table 4.1 *Distribution of heat consumption between production sites.*

Production	Steam, 8 atm (Gcal/year)	Steam, 3 atm (Gcal/year)	Hot water (Gcal/year)	Heating (Gcal/year)
Temperature	**395°C**	**265°C**	**60°C**	**varying**
MPP-1	892	11,685	862	633
MPP-4	328	8,686	1,034	380
FMP	–	27,273	1,018	1,052
SDB	2,831	–	4,511	284
Total:	4,051	47,644	3,368	2,349
Heat losses	203	2,382	842	587
Losses (%) above permitted	5	5	25	25

Table 4.2 *Diameters (mm) and lengths (meter) of the pipelines on the scheme.*

Diameter of a pipe (mm)	Length pipelines, 8 atm. vapour (m)	Length pipelines, 3 atm. vapour (m)	Length pipelines of hot water (m)
89	–	–	236
100	400	400	–
108	–	–	383
150	–	–	635
250	–	–	400
273	1,020	1,174	311
385	100	–	–
Total length (m)	1,520	1,574	1,965

The loss of a total of some 4,000 Gcal/year basically was occurring where the insulation of the pipelines was broken.

A diagram of the heat pipeline, where replacement of insulation is required, is given in Figure 4.1. Table 4.2 shows the size of the pipelines.

Properties of Thermal Insulation Materials

A study of modern thermal insulation materials was carried out. The properties of several of the most frequently used types of the materials are given at the Table 4.3.

The material need for the insulation of hot water/vapour pipelines is calculated from the required thickness of thermal insulation material. Most important is thermoconductivity and heat losses. The calculation for the "cylinders" of Rockwool is given as an example:

The *pipeline used for hot water at 60°C* needs 20 mm of insulation. The diameters and lengths of the pipelines to be insulated and the required volumes of insulation are as follows:

Diameter	Length	Thickness of insulation	Volume of insulation
89 mm	236 m	20	1.32 m³
150 mm	635 m	20	5.98 m³
250 mm	400 m	20	6.28 m³
273 mm	311 m	20	8.00 m³

The pipelines for steam at 3 atmosphere and 265°C was as follows:

Diameter	Length	Thickness of insulation	Volume of insulation
100 mm	400 m	30	3.76 m³
273 mm	1,174 m	30	30.19 m³

The pipelines for steam at 8 atmosphere and 395°C was as follows:

Diameter	Length	Thickness of insulation	Volume of insulation
100 mm	400 m	20	2.51 m³
273 mm	1,020 m	30	26.23 m³
385 mm	100 m	30	63.63 m³

From the data it is concluded that about 4,500 m of pipelines should be insulated and a total of 91 m³ of insulation material is required. When the same calculations were made for the other materials (Table 4.4) it was found that the same degree of insulation would require 418 m³ of Mineral-wadding Stitched Mats or 412 m³ Mineral-wadding Products with Goffered Structure.

Table 4.4 also shows the costs for various materials according to the prices of Russian suppliers.

Table 4.3 *The properties of thermal insulation materials (RUR = Russian Roubles).*

Material	Average density (kg/m³)	Heat conductivity (Wt/m·K)	Temperature of application (°C)	Life expectancy (years)	Price (RUR/m³)
Mineral-wadding cylinders Rockwool (TU 361180-85)	125	0.035	+40…+600 (incombustible)	5	1,050
Mineral-wadding stitched mats (GOST 21880-86 Sort 100)	120	0.057	+180…+450 (incombustible)	5	600
Mineral-wadding products with goffered structure (TU 36.16.22.8-86)	110	0.05	+60…+400 (incombustible)	5	700

Table 4.4 *The comparative characteristics of thermal insulation materials (RUR = Russian Roubles).*

Material	Average density (kg/m³)	Heat conductivity (Wt/m·K)	Required volume (m³)	Mass (kg)	Price (RUR/m³)	Material costs (RUR)
Mineral-wadding cylinders Rockwool (TU 361180-85)	125	0.035	90.51	11,313.8	1,050	95,036
Mineral-wadding stitched mats (GOST 21880-86 Sort 100)	120	0.057	417.99	50,158.8	600	250,794
Mineral-wadding products with goffered structure (TU 36.16.22.8-86)	110	0.05	411.73	45,290.3	700	288,211

The comparative study thus showed that the most material-effective as well as cost-effective insulation material was provided by Rockwool.

The Outside Protective Layer

On the outside of the insulation is added an outside protective layer. To determine the material needed for the outside layer it was necessary to take into account the increased pipeline diameter due to the mineral-wadding cylinders of Rockwool. The radius of the pipeline was increased by the thickness of this layer. The needed amount of the insulation materials was calculated as shown in Table 4.5.

The comparison of three types of outside protective materials (Table 4.6) showed that the most cost-effective one was glass-fibre. Hence it is advisable to use a combination of mineral-wadding cylinders of Rockwool and an external coating of glass-fibre.

3. Conclusions of the Insulation Project

Calculation of Return of Investment

The investments necessary for thermal insulation change are given in Table 4.7. They include the material cost and the cost for installation. The price per installation of 1 m of thermal insulation was 20 RUR, and the length of the pipeline to be insulated was 5,089 m. The cost was thus:

$$20 \times 5,089 = 101,780 \text{ RUR}$$

The total cost for the investment was thus calculated to 864,547 RUR.

The annual savings due to reduced heat losses were estimated from the cost of 1 Gkal (100 RUR) and the saving of 4,014 Gkal/year which amounted to 401,400 RUR.

Then the pay back *(PB)* time is:

$$PB = I_0/B = 864,547/401,400 = 2.15 \text{ years.}$$

Net Present Value *(NPV)* of heat pipelines modernisation with the terms of service life of insulation of 10 years and nominal interest rate 10%:

$$NPV = B\,k - I_0$$

where k is the discount factor, k = 6.415.

$$NPV = 401,400 \times 6.415 - 864,547 = 1,710,434 \text{ RUR } (55,175 \text{ USD})$$

Table 4.5 *Calculation of the amount of outside insulation material needed.*

Diameters of pipes (m)	Vapour pipeline, 8 atm (m)	Vapour pipeline, 3 atm (m)	Hot water pipeline (m)	Outside protective layer (m²)		
				Vapour pipeline 8 atm	Vapour pipeline 3 atm	Hot water pipeline
0.089	–	–	236	–	–	382.38
0.1	400	400	–	703.36	803.84	0
0.108	–	–	383	–	–	711.95
0.15	–	–	635	–	–	1,515.36
0.25	–	–	400	–	–	1,456.96
0.273	1,020	1,174	311	4,266.13	4,910.23	1,300.75
0.385	100	–	–	558.92	–	–
Total material consumption:				16,609.88 m²		

Table 4.6 *The Properties of materials for an outside protective layer.*

Outside insulation material	Thick-ness (mm)	Life expectancy (year)	Density (m³/kg)	Surface of material (m²)	Price of material (RUR/m²)	Cost (RUR)
Steel zinc-coated (GOST 14918-80)	0.55	10	7,800	16,610	66.25	1,100,405
Glass-fibre (TU 6-11-145-80)	0.4	8	186	16,610	25	415,247
Ruberoid (GOST 10923-83 Sort 420)	0.3	2	1,100	16,610	12	199,319

Table 4.7 *Costs of investments.*

Investment	Cost (RUR)
Documentation and design	3,000
Materials	709,131
Transportation and storage costs	12,282
Labour cost	101,780
Social taxes	38,954
Total (I_o):	**864,547**

Calculation of Natural Resources Consumption

The consumption of natural resources for the chosen combination of thermal insulation materials was calculated using the MIPS methods. Thus the MI factors obtained from the Wuppertal Institute were used to compare the natural resource use for some of the investments (Table 4.8). It is clear that the chosen solution of Rockwool insulation with a protective layer of glass-fibre is the best alternative for a minimum value of MIPS.

Conclusions

The results of the comparative analysis of various types of thermal insulation materials were determined both by means of traditional parameters of profitability and based on the MIPS concept.

The most effective type of thermal insulation is the combination of Mineral-wadding cylinders of Rockwool and outside protective layer of glass-fibre, TU 6-11-145-80.

The insulation of the worst parts of the heat pipelines required a significant investment (27,889 USD), their pay back time is 2.15 years, and for 10 years of operation it will yield a Net Present Value of 55,175 USD.

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Internet Resources

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http://www.wupperinst.org/en/home/index.html

Table 4.8 *Material Input.*

Material	Required mass (kg)	MI-factor (kg/kg)	Natural resources (kg)
Thermal insulation material			
Mineral-wadding cylinders Rockwool (TU 361180-85)	22,627	4.7	106,349
Mineral-wadding stitched mats (GOST 21880-86. sort 100)	100,317	4.7	471,492
Mineral-wadding products with goffered structure (TU 36.16.22.8-86)	90,580	4.7	425,728
Outside protective layer *			
Steel zinc-coated (GOST 14918-80)	71,256	3.0 (iron-coated)	213,770
Glass-fibre (TU 6-11-145-80)	1,544	3.6 (polyester fibre)	5,560
Ruberoid (GOST 10923-83 Sort 420)	27,406	2.0 (linoleum)	27,406

** The outside insulation layer is calculated for mineral-wadding cylinders of Rockwool.*

Case Study 5

SCA Pulp and Paper mills

Sweden

Pulp and Paper Industry in Sweden – An Ideal Case for Cleaner Production

1. Pulp and Paper Production

Pulp and Paper in the Baltic Sea Region

Pulp and paper production is an important industrial branch in the Baltic Sea region. Of world production Sweden, Finland and Russia has about 4% each of pulp and 5% each of paper. Of world export Sweden has 11% of pulp and 12% of paper, only behind Canada and Finland. European Union countries constitute the most important market. Production approximately increased ten-fold during the 20th century. This development had its parallel in the increased production of wood raw material, especially spruce, from the large forests in the region.

Some of Europe's largest paper producers are located in Sweden. The merger of Swedish Stora with Finnish Enso in 1998 created a giant that is now the world's second-largest paper producer, specialising in publication and fine papers (in addition to packaging boards and wood products). Swedish producers have also taken the lead in other niches, aided by the country's strength in research and biotechnology coupled with high-tech chemical processes and supply of primary fibre from native slow-growth forests.

The Companies

Ranked third in Europe after Germany and Finland, Sweden's pulp and paper industry maintains a strong competitive edge. A decade-long round of restructuring has resulted in the global industry becoming highly concentrated in a few players and production plants. In Sweden, the six largest *pulp mills* account for almost 60% of national capacity, which in turn is close to the current annual production level of 11.4 million tons.

The largest pulp producers include Södra, Stora Enso and SCA (Svenska Cellulosa Aktiebolaget) with a number of plants in Sweden and abroad. Also, the development of the plants has gone from many smaller factories to a few very large plants. Concentration is almost as high in the paper sector, with the 12 largest *paper mills* (out of a total of 47) accounting for 65% of the national 11.5 million ton capacity.

Environmental Improvements

It is in connection with this development that a dramatic improvement in the environmental and technical performance of pulp and paper production has taken place. The dominating problems have been the emissions of fibres, BOD and COD, and chlorinated hydrocarbons. In Sweden these were at their worst in the mid 1960s. Since then a systematic effort for improvements has resulted in dramatic decreases in environmental impact and improved economic performance.

Research is still very active and important in the sector. As a result, pulp production is coming closer to the ideal of the "closed factory" or "zero emission factory", where nothing is emitted except the products. Secondly the energy efficiency is increasing to the extent that it is possible to sell lignin as a biofuel, as an additional product from the sector.

2. The Process Technologies

Sulphate or Kraft Pulping

The objective of the paper production technology is to separate cellulose fibres from the wood structure, kept together by lignin. The free fibres in the pulp are then the main raw material for paper production. *Sulphate or Kraft pulping*, dominating production today, produces pulp with high strength and can use a wide variety of wood species. The pulp yield is less than 50%, but the chemicals can be recycled and re-used in the mill. (See *Cleaner Production Practices* for further details.)

Bleaching

Bleaching is needed to remove colour associated with remaining residual lignin. Bleached kraft pulp is mainly used for printing and writing grades, while unbleached kraft pulp is used in the production of packaging grades. The bleaching chemicals are *injected* into the pulp and the mixture is *washed* with water. This process is repeated several times and generates large volumes of liquid waste. Additionally, vents from the bleaching tanks emit hazardous air pollutants including chloroform, methanol, formaldehyde, and methyl-ethyl-ketone.

The Recovery of Chemicals

The process flowsheet of the kraft process is designed to recover the cooking chemicals and heat. In the recovery line, spent cooking liquor and the pulp wash water are combined to form a weak black liquor which is concentrated through *evaporation* from 16% to 60-80% solids in a multiple-effect evaporator system. The strong black liquor is then incinerated in a *recovery boiler*. Combustion of the organics dissolved in the black liquor provides heat for generating process steam. The carbon dioxide formed in the combustion reacts with part of the sodium in the black liquor to sodium carbonate (Na_2CO_3) and the sulphur content is converted to sodium sulphate (Na_2SO_4). The sulphate is converted to sodium sulphide (Na_2S) by reduction with carbon present in the melted slag at the bottom of the furnace.

The smelt is dissolved in water to form *green liquor*, which is transferred to a causticizing tank where quicklime (calcium oxide) is added to precipitate the carbonate content in the green liquor as calcium carbonate and instead produce the sodium hydroxide needed to convert the solution back to white liquor for return to the digester system. The precipitate from the causticizing tank is calcined in a lime kiln to regenerate quicklime.

Production of Paper

Production of paper starts with *stock preparation* where various grades of pulp are mixed in a *mixing chest* to obtain the desired properties, *refined* to increase the strength of the paper, screened and cleaned. After that, different dyes, defoamers, fillers and retention agents are added (*filling*) and the consistency is adjusted with the addition of water ("white water") before the pulp suspension enters the head box of the paper machine.

In the paper machine the fibre suspension is introduced to the wire net, where water is drained assisted with rolls, foils, and vacuum boxes (*dewatering*). It is further dewatered by *pressing* (up to a solid content of around 50%), and *drying* (to about 95% solids content). Examples of *finishing operations* are sizing, coating, dyeing, and calendering.

3. Environmental Problems in Pulp and Paper Industry

Water Use

Pulp mills are – and were even more so in the past – big *water users*. The total requirement of raw water has through cleaner production measures been reduced from about 200-300 m³ per ton of pulp in 1970 to well below 50 m³/ton, in some mills even below 10 m³/ton. Their consumption of fresh water can seriously harm habitats near mills, reduce water levels necessary for fish, and change water temperature, a critical environmental factor for fish.

The level of wastewater treatment varies widely throughout the world depending on individual mill policy, company policy and state legislation. However there are a few general areas of concern that can be identified in a way outlined below. The most common organic pollutants in effluents are suspended solids (SS) e.g. lost cellulose fibre, dissolved organic compounds such as dissolved lignin compounds, carbohydrates, starch and hemi-cellulose (BOD/COD). Acidic compounds are predominantly natural resin acids.

From mills using elemental chlorine in their bleaching sequence, waste waters contain chlorinated organic products formed by elemental chlorine reacting with wood products to form chlorinated organics (AOX). Wastewater flow from a traditional pulp and paper mill constitutes 160-230 m³ per ton of paper.

Solid Waste

Paper production produces a large amount of *solid waste*. Firstly, during the debarking and chipping process, wood chips or fibres often become contaminated with dirt or sand when they fall from conveyors. That renders them unusable to make paper or as a fuel. Bark is also contaminated with sand and dirt. Secondly, within the recovery process, the paper fibres can be recycled only a limited number of times before they become too short or weak to be used for producing high quality paper. The broken, low- quality fibres are separated out to become waste sludge. All the inks, dyes, coatings, pigments, staples and "stickies" (tape, plastic films, etc.) are also washed off the recycled fibres to join the solid wastes.

Energy

The pulp and paper industry uses 84% of the *fuel energy* consumed by the forest products industry as a whole. It is one of the largest producers of greenhouse gas (GHG) emissions. Over the past few years, the pulp and paper industry has considerably reduced its GHG emissions by introducing energy conservation projects and by increasing its use of biomass as an energy source. A modern kraft pulp mill is essentially self-sufficient in energy. The only oil consumer is the causticing oven, where oil can in fact be replaced with bio-fuel.

A paper mill requires between 400 and 1000 kWh electricity/ton paper and 4-8 GJ heat/ton for drying in the paper machine. In an integrated pulp and paper mill this energy is provided from the recovery boiler.

Bleaching

Depending on the bleaching chemicals used, the wastewater streams from the bleaching process may contain chlorine compounds and organics. The mixture of chemicals may result in the formation of a number of toxic chemicals (such as dioxins, furans and chlorinated organics). Although this effluent is generally released to a wastewater treatment plant, the chemicals named above simply "pass through" the plant (i.e. the treatment plant does not significantly reduce the concentrations of these pollutants) and accumulate in the rivers, lakes and oceans to which the treatment plant discharges.

Emissions

Regulated wastes and emissions from the pulp and paper industry include liquid and solid wastes, air emissions, and wastewater.

Air emissions from chemical pulp mills are primarily made up of particulates, hydrogen sulphide, oxides of sulphur and oxides of nitrogen. Micro-pollutants include chloroform, dioxins and furans, other chlorinated and volatile organics. Emissions from kraft mills also contain reduced sulphur gases as methyl mercaptan, dimethyl sulphide and dimethyl disulphide which together with hydrogen.

Wastewater releases contain chlorinated phenolics, dioxins, furans and other chlorinated compounds, phosphates, small amounts of residual organics and suspended sediments.

Paper mills also produce non-hazardous *solid waste* such as sludge derived from their pulping and bleaching operations.

4. Cleaner Production Measures

Increasing Brown Stock Washing Efficiency

After cooking, the brownish pulp needs to be carefully washed. Any remaining cooking liquor will increase the chemical consumption in subsequent stages. It is also of the utmost importance to recover the cooking chemicals and the dissolved organic substances. The brown stock washing is done in several counter–current stages. The filtrate from this washing is the black liquor sent to the chemical recovery system. Efficient washing is critical to maximise return of cooking liquor to chemical recovery and to minimise carry over of cooking liquor (known as brown stock washing loss) into the bleach plant, because excess cooking liquor increases consumption of bleaching chemicals. The most common washing technology is rotary vacuum washing, carried out sequentially in two or four washing units. Other washing technologies include diffu-

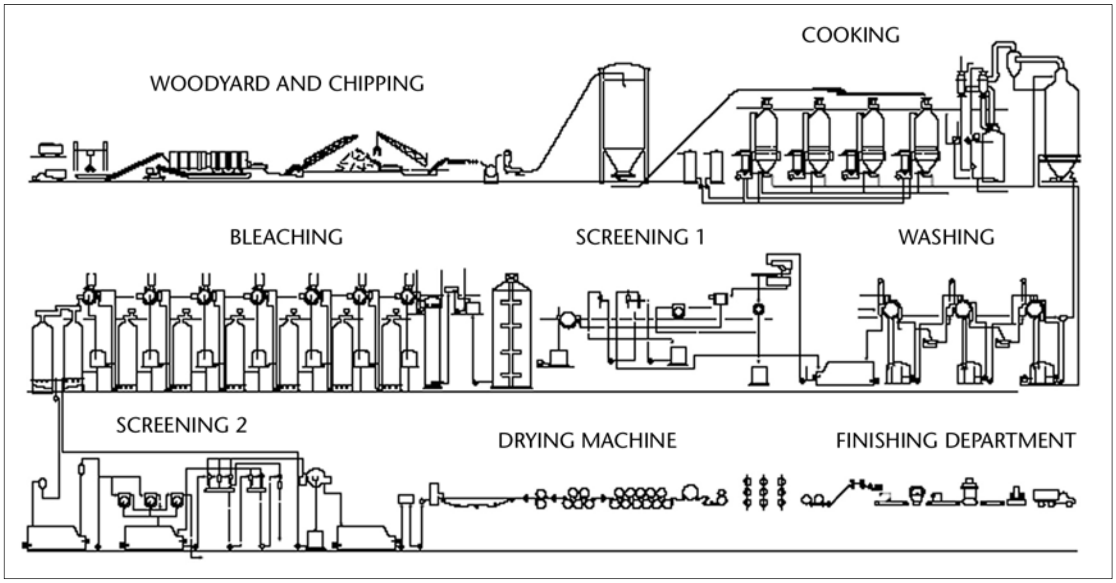

Figure 5.1 *Simplified flow diagram of an integrated pulp and paper mill (chemical pulping, bleaching and paper production) [U.S. EPA, Office of Compliance. Sector Notebook Project: Profile of the Pulp and Paper Industry, 1995].*

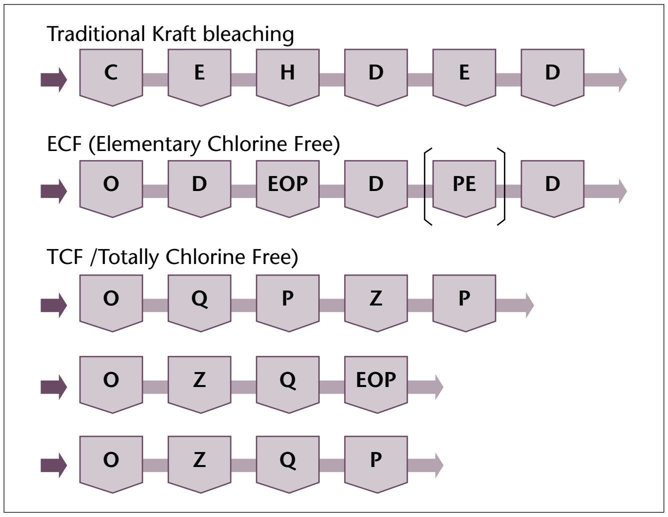

Figure 5.2 *Examples of bleaching sequences. Bleaching chemicals are elemental chlorine (C), sodium hypochlorite (H), chlorine dioxide (D), oxygen (O), ozone (Z) and hydrogen peroxide (P). Metals are removed with a complexing agent (Q) such EDTA or DTPA [adapted from Miljöinfo från Skogsindustrierna, 1995].*

sion washers, rotary pressure washers, horizontal belt filters, wash presses, and dilution/extraction washers.

Water Reuse from Evaporators

The evaporation plant is always one of the largest steam consumers in the mill. Black liquor from the cooking plant with a dry solids content of 14-18% is concentrated normally to 65-75% before burning in the recovery boiler. Modern evaporation plants can operate at about 80% solids content. To minimise primary steam consumption, multiple-effect evaporation, with five to seven effects in series is used.

Stripping of foul condensate from the effects is necessary for environmental reasons, and also if the condensate is reused (instead of fresh water) in the mill. The stripper column could be heat-integrated with the evaporation plant.

The evaporation demand normally lies in the range of 6-9 tonnes water/ADMT (air dry metric ton). Differences in heat demand between different mills with the same number of effects in series are largely due to differences in the solids content of the feed (weak black liquor). In the evaporation plant the weak black liquor, which comes from the washing department, is concentrated to as high a concentration as possible depending on the design of the plant.

Recycling of Material

In open screen rooms, wastewater from the screening process goes to wastewater treatment prior to discharge. In closed loop screen rooms, wastewater from the process is reused in other pulping operations and ultimately enters the mill's chemical recovery system. Centrifugal cleaning (also known as liquid cyclone, hydro cyclone, or centricleaning) is used after screening to separate relatively dense contaminants such as sand and dirt from the fibre material.

Solid Waste Recycling

Rejects from the screening process are either repulped or disposed of as solid waste. Pulp screening, removes remaining oversized particles such as bark fragments, oversized chips, and uncooked chips. The selective screening philosophy addresses the removal of unwanted particles from the pulp. The optimal solution is reached by integrating screening into the modern fibre line process;

One way of *sludge utilisation* is by means of land-spreading; this method of sludge disposal is an area of concern, as sludge constituents are not well identified, the sludge in any given mill is highly variable, and the effects of the sludge components on land is not thoroughly researched. The major concerns are possible contamination of soils with heavy metals and organic micro-pollutants. Well-designed, independently monitored pilot projects of significant duration are necessary before this practise can become widespread.

Bleaching

Bleaching is defined as any process that chemically alters pulp to increase its brightness. Typically, 4-8% of pulp is lost due to bleaching agent reactions with the wood constituents cellulose and hemicellulose, but, these losses can be as high as 18%.

Important cleaner production measures include:

Avoid chlorine bleaching. Chemical pulp bleaching has undergone significant process changes since the beginning of the 1960s. At that time, nearly every chemical pulp mill that used bleaching incorporated elemental chlorine (Cl_2) into some of its processes. Initially some of the elemental chlorine bleaching stages were replaced by sodium hypochlorite (NaClO) and chlorine dioxide (ClO_2) Environmental concern has been a strong driving force for the development of new bleaching technologies as Elemental Chlorine Free (ECF) and Total Chlorine Free (TCF) bleaching technologies.

From an environmental point of view, the most important changes in bleaching technology has been the introduction of oxygen delignification and the use of 100% chlorine dioxide in the pre-bleaching stage. Since chlorine dioxide predominantly acts as an oxidant, the formation of chlorinated lignin, low molecular weight phenols and acids can be shown to strongly decrease. At the same time, the formation of chlorinated dioxins and dibenzofurans both in the product and in the effluent is reduced to levels around or below the detection limit.

Because of the different reaction mechanisms different types of bleaching chemicals are utilised in a bleaching sequence. Acid and alkaline stages are used to complement each other. Peroxide bleaching is relatively slow and requires long reaction times and therefore large reactor volumes or increased pulp consistency. Increased pressure makes higher reaction temperatures possible, resulting in a reduced reaction time or improved bleaching outcome. It is necessary to remove metal ions to avoid degradation of the hydrogen peroxide by using metal complexation agents (i.e. EDTA or DTPA) or acid washing. An advantage with peroxide compared with the other oxygen bleaching chemicals is that peroxide bleaching at optimal conditions brightens the residual lignin. A final solution has still not been achieved for either approach. Remaining tasks include:

- *Continuing research on biotechnological bleaching and electrochemical bleaching:* Research has to explore further these processes by synthesising improved mediators, by improving bleaching enzymes and optimising electrochemical processes for bleaching pulp. Ultimately this research may lead to novel, cost-effective, bleaching strategies that are environmentally benign.
- *Air emissions control devices.*
- Providing *spill containment and collection systems*.

Paper Production

Pulp in the stock is heated and mixed. Some different chemicals and fillers like alum, clay, and starch are added to the pulp stock for enhancement of certain paper properties. Next, the pulp suspension is evenly distributed over a travelling belt of fine wire screening, and carried to rolls. Part of the water contained in the pulp suspension passes through the screen with the assistance of vacuum boxes and pressing between rolls. The long fibres are laid down as a fibre layer on the wire net. The fibre layer is carried over to a system of pressing and heated rolls, dewatering the paper to a water content of around 50%. Then the paper is air dried in a steam-heated dryer section. After drying, the sheet may be surface treated and then finished. A considerable portion of the fine fibres and some fillers also pass through the screen wire with the water. Because of its colour, this wastewater is called “white water”. The main sources of waste from paper mills are beaters and paper machines.

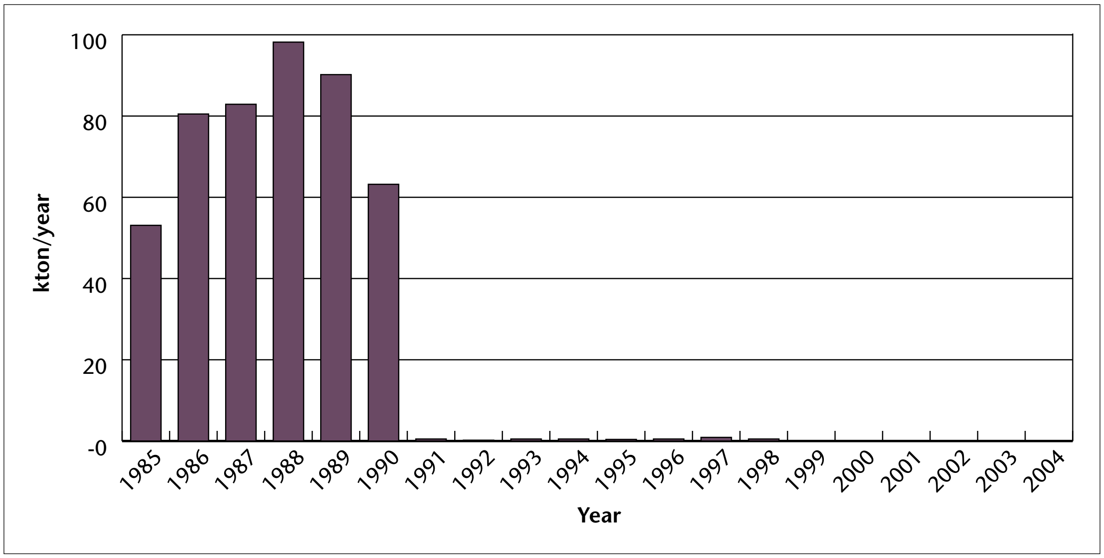

Figure 5.3 *Amount of organic waste sent to landfill from SCA Forest Products, Östrand pulp mill [Roine Morin, Environmental Manager of SCA Graphic Sundsvall AB].*

Important cleaner production measures include:

- *Cleaning the roll* in the paper machines to avoid a broken paper line. This action is an opportunity to improve housekeeping and will reduce the amount of breakage paper and, since it doesn’t need any process changes, can be easily implemented.
- *Adjustment of edge cutter* to reduce side trimming loss. This action concerns process control and can benefit to marginal reduction of pollution load by reduction of paper trimming loss and reduction of reprocessing of paper trimming.
- *Use of soft water as a boiler feed water.* It is also the change to better process control which can reduce pollution to the air by the way of reduced scaling of boiler tube and increased boiler efficiency and capacity; Recycling water evaporated from drying process by condensing.
- *Optimising the thermal effects on water* used in the paper machine and stock preparation area.
- Providing *disk save-all* for paper machine.
- *Repulping rejected paper* in a closed loop manner.

Decreased Water Discharges

The dramatic decrease of water use in the pulp production has also result in very much lower discharges in the waste-

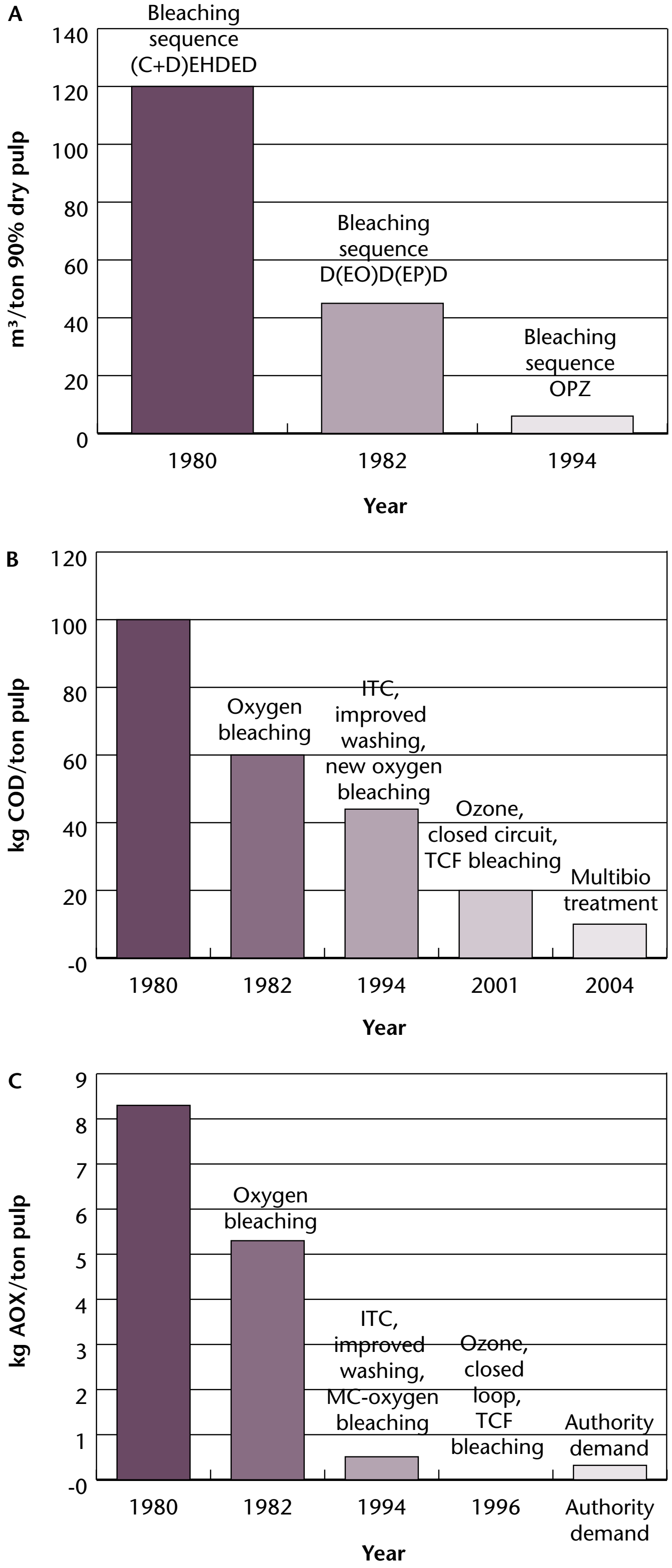

Figure 5.4 *A) Wastewater flows, total volume from SCA Forest Products, Östrand pulp mill. B) COD in the wastewater. C) AOX in the wastewater. Bleaching sequences are shown in Figure 5.2.*

water. This is illustrated in Figure 5.4A, the development of the wastewater flow from a modern pulp mill, the SCA Forest Products, Östrand Pulp mill in Sweden.

Likewise has the content of oxygen consuming material, mostly fibres, decreased due to sometimes rather simple measurers such as sieves, and much better technology. Figure 5.4B shows the development of emissions of COD since 1980 from the Östrand pulp mill. The reductions have been achieved through application of cleaner production measures and wastewater treatment.

Finally the changed technology for bleaching has resulted in much less use of chlorine and chlorine gas. As a result the emissions of chlorinated organic compounds have decreased considerably. Figure 5.4C shows the emissions of adsorbable (that is, those that are biologically problematic) organically bound halogens (mostly chlorine) called AOX, from SCA Forest Products, Östrand pulp mill. This is, from an environmental point of view, one of the most significant achievements in the pulp and paper industry.

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References

Mazgaj, M., Yaramenka, K., Malovana, O., Cherre, E. and Ibraimova, L. Project report, *Cleaner Production Measures for Pulp and Paper Industry*. Royal Institute of Technology, Section of Industrial Ecology, Sweden, 2006.

Case Study 6

Assa Abloy Metallurgic Industry
Sweden

Surface Treatment Processes in a Metallurgic Industry

1. Introduction

Intro

Surface treatment is a very common process in the manufacturing industry. There are also a large number of businesses that work solely with surface treatment. Some of these have very large installations, while others are small enterprises with only a few employees.

Quite another type of industry with substantial surface treatment activity is the electronics industry, in which copper coating and etching of printed circuit boards are important operations.

Surface treatment is a good example of how to combine cleaner production and end-of-pipe measures to reduce a serious emission problem in form of metal polluted wastewaters. In the concept of surface treatment we include a number of operations e.g. pickling, de-greasing, phosphatation, lacquering, chemical surface treatment, galvanic surface coating etc. Some of the environmental problems connected with surface treatment are in addition to emissions of metals, complexation agents as e.g. cyanides, acid and alkaline waste waters and solvents from de-greasing and painting operations.

Assa Abloy Metallurgic Industry

The examples described below are taken from the development of cleaner production methods at a plant for locks in Eskilstuna, Sweden. The plant belongs to Assa Abloy, an important metallurgic industry in the production of locks and security systems. Assa Abloy is the world's leading manufacturer and supplier of locking solutions. The Group has in all some 30,000 employees and annual sales of about 3 billion euros (2005). Number of employees was in 2005 29,500 in more that 150 companies operating in 40 countries. The company thus has a strong global presence and holds more than 10% of the world market. We thus have reason to believe that the achievements at the Eskilstuna plant will be used in many other places.

The plant and methods discussed below are also described on the film available on the accompanying CD.

2. The Technologies

Several Techniques

The surface of metal objects is important for the function, protection and appeal of the products. Thus great concern and much technology have developed to meet the need of surface treatment. The surfaces applied include metal surfaces, for example by chrome, copper or nickel; or they might be a paint or lacquer surface. The application of these surfaces can be made by dipping the product in a bath, by electro-coating with a galvanic method, or by spraying.

Dipping Techniques

This is used to apply a metal surface. The objects are suspended on a frame and dipped into a series of baths, all water solutions. The central part of this process, consists of dipping into of a bath, where the metal to be applied to the surface of the objects is dissolved as a salt in water.

- De-greasing and cleaning using a slightly alkaline bath with tensides.
- Rinsing to remove tensides etc.
- Bath to apply the surface coating. This may be an electrolytic process.
- First rinsing bath.
- Second rinsing bath.
- Possibly a third rinsing bath.

Spraying Techniques

In the classical spraying techniques the paint is dissolved in a solvent and sprayed on the object. The disadvantage of this method is that a substantial part of the paint is not used and that large amounts of solvents are disseminated in the surrounding and needs to be taken care of. Solvents used to be both health-wise and environmentally noxious. Nowadays more often less problematic solvents are used, e.g. alcohols, which are degraded in the environment and not as toxic.

A more modern type of spraying is using a powder to spray on the objects in a small space in which the unused powder can be recovered. No solvent is used. By a following heat treatment the powder melts on the surface of the object and creates the coating desired.

3. Environmental Concerns

Water Consumption

In the traditional method for rinsing, the treated objects were rinsed in a single bath. As the concentration of the treatment components, in particular the metals when a metal surface was applied, increased rapidly, this rinsing bath had to be renewed very often and large amounts of water were used in the process.

Wastewater Containing Metal

The large number of baths in the dipping techniques all give rise to a water solution to be discarded as wastewater, often with a considerable concentration of metals. Some of these are highly noxious, e.g. nickel is both allergenic and carcinogenic; copper as a heavy metal is not good for the environment, and chromium, especially compounds of chromium 6, are very noxious, again being both toxic and carcinogenic. The wastewater could thus not be left to a municipal sewage as it is. Wastewater treatment has thus been an important concern for the industry.

4. Wastewater Treatment Options

Precipitation of Metals

An end-of-pipe solution to the metal emission problem will result in a rather complicated cleaning process. Depending on the type of surface treatment, several treatment stages may be required.

The traditional method of dealing with wastewaters containing metals is to purify the water by chemical precipitation. The most common method is to precipitate the metals as hydroxides. It that case sodium hydroxide or, if the operation is large, lime (calcium oxide) is used, yielding a metal hydroxide precipitate according to the formula:

$$Me^{2+} + 2OH^- \longleftrightarrow Me(OH)_2\ (s)$$

Metals can also be precipitated as sulphides. Metal sulphides are less soluble than the hydroxides. Sulphide precipitation will give a better purification but the process will unfortunately also create problems of other kinds, e.g. risks for formation and release of hydrogen sulphide. There are chemicals available on the market that will produce metal sulphides, without the risk of hydrogen sulphide, but the costs for these chemicals are substantially higher than sodium hydroxide or lime.

A treatment unit for metal precipitation (Figure 6.1) normally consists of three parts. In the first stage the precipitation chemical is added under rapid mixing. The precipitate formed often consists of very small particles that are very difficult to separate by sedimentation. In order to get larger and more easily separated particles, special flocculation agents, e.g. a polyelectrolyte, are added in the second stage. This will cause the small particles to coagulate in larger flocks. These flocks are then separated in the third stage that usually is a sedimentation stage, often in form of a lamella sedimentation unit.

The chemical precipitation of metals is an equilibrium reaction. This means that there will always be a certain remaining concentration of dissolved metal in the purified wastewater. This remaining concentration is determined by the equilibrium equation.

An important factor for the separation efficiency is in fact the choice of pH for the precipitation. Different metals have maximum precipitation at different pH values. If a wastewater contains several different metals is will be impossible to achieve a maximum separation of all the metals. In fact it would require a multi stage precipitation process with different pH in each stage to achieve. This is however generally not economically justifiable. Usually a pH in the interval 9-10 is chosen.

The separation result is also determined by a number of other factors, making the precipitation process a rather complicated purification process. For instance, complexation agents counteract the metal precipitation, which makes it necessary to remove these before the precipitation stage. Further the surface treatment processes are often batch processes, so the purification stage will need a buffer tank in order to even out the flows.

A Second Stage of Wastewater Treatment – Polishing

In order to improve the separation result the chemical precipitation stage can be supplemented with a second purification stage, a so-called polishing stage. About half of the remaining metals in the purified water are bound as metal hydroxides, but these particles are too small to be separated in the sedimentation stage. By adding a filter stage, e.g. a sand filter, the separation can be improved.

Another option is to supplement the process with an ion exchange stage. With the ion exchanger a substantial part of the metal ions that were not precipitated can be separated.

Cleaning the Water of Other Substances

In the case of chromation the wastewater will contain chromium both as chromium (III) in the form of positive Cr^{3+} ions and as chromium (VI) in the form chromate (CrO_4^{2-}), a negative ion that cannot be separated by chemical precipitation. The purification unit has to be supplemented with a chromate reduction stage in which the Cr (VI) is reduced to Cr (III) with for example bisulphite.

If cyanides are used in the surface treatment process, these have to be removed from the wastewater before precipitation as well. Cyanide removal may be achieved either by chemical or electro-chemical oxidation. In chemical cyanide removal the water is treated with e.g. hypochlorite oxidising the cyanide to cyanate and then to carbon dioxide and nitrogen gas.

From the chemical precipitation process an environmentally hazardous metal hydroxide sludge is produced. This has to be de-watered as far as possible. This is normally done in a filter press in which a sludge with a solids content of about 30% can be achieved. The sludge has to be deposited in such a way that water is prevented from penetrating into the depository to leach the metals. According to EU regulations the landfill has to be designed as a so-called Class-1 landfill with very advanced sealing arrangements.

5. Cleaner Production Measures

Replace the Technology

One measure that is easily identified, but that in most cases actually is or at least is considered to be impossible, is to change to a completely different type of surface treatment that will completely avoid the emission problem in question. However, there are examples where this has been accomplished. For example, it has been feasible to, for environmental reasons, replace cadmium coating with other types of surface treatment. Nickel could be replaced by an alloy of copper, zinc and tin.

The use of chromium priming is another surface treatment process that, because of the environmental risks with chromium (VI), has been problematic and reduced substantially. Most often chromium (VI) is replaced by chromium (III).

Process integrating measures also include changing of raw materials and auxiliary chemicals used in a process. In order to avoid many of the problems that are connected with the use of cyanides, some companies are trying to convert to completely cyanide-free surface treatment methods.

Reducing Water Volumes Needed in the Process

In chemical or electro-chemical surface treatment processes the metal items to be treated are immersed in different process baths. Between the different treatment stages the items have to be thoroughly rinsed so that chemicals from one stage do not contaminate the next, impairing the quality of the product.

It is important to take measures to reduce the carry-over, that is, the amount of fluid film that the goods will attach to and carry with them from a bath. If this can be done the volume needed for rinsing will decrease and so will water consumption.

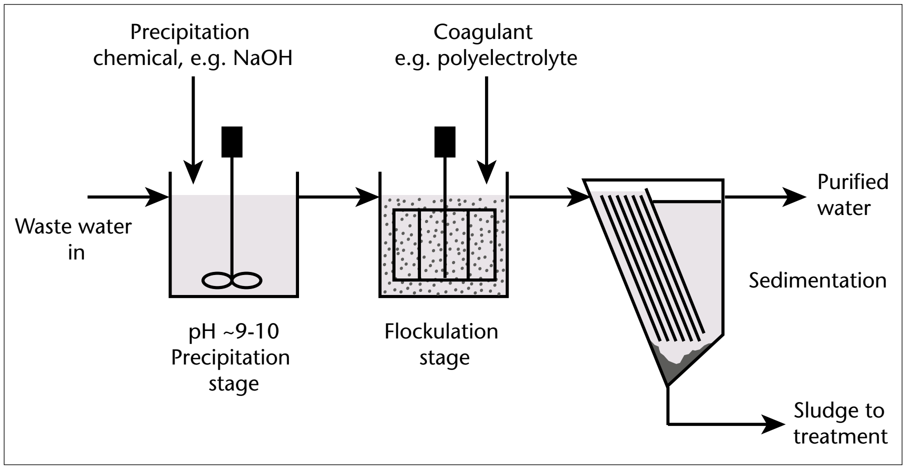

Figure 6.1 *Chemical metal precipitation.*

The size of the carry-over is affected by the following factors:

- *The viscosity of the process liquid.* A lower viscosity gives a thinner liquid film. The viscosity can be influenced by e.g. a temperature increase and the addition of a surfactant.
- *The shape of the goods and the way of mounting.* It is important that the items do not have pockets, in which liquid can be carried from one bath to another. By mounting the goods in a way that drainage is facilitated, the carry-over can be minimised.
- *Time for drainage.* It is necessary to allow sufficient time for the fluid film to drain from the items.
- *Recirculation of carry-over* with the aid of e.g. a wiper device or air blower.
- *The concentration of the bath.* By reducing the concentration of the bath as far a possible, the carry-over loss can be reduced.

Efficient Rinsing – Counter Current and Spray

A very efficient way of reducing the pollutant emissions with the wastewater from an industrial process is to reduce the water consumption in the process. The reason for this is that the concentration of pollutants will increase when the amount of water is reduced. And since a pollutant reduction stage such as a precipitation stage will render purified wastewater with a residual concentration that is independent of the concentration before the treatment stage, the total amount of pollutant emission will be reduced.

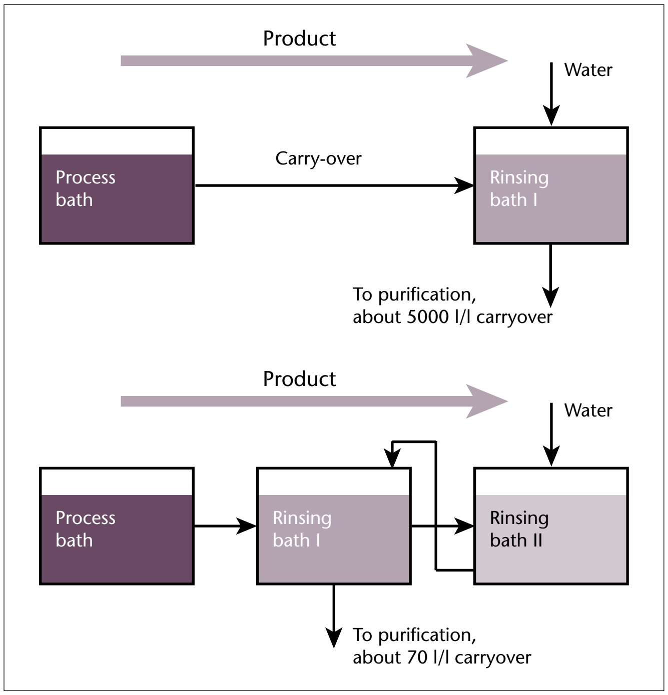

Figure 6.2 *Countercurrent rinsing.*

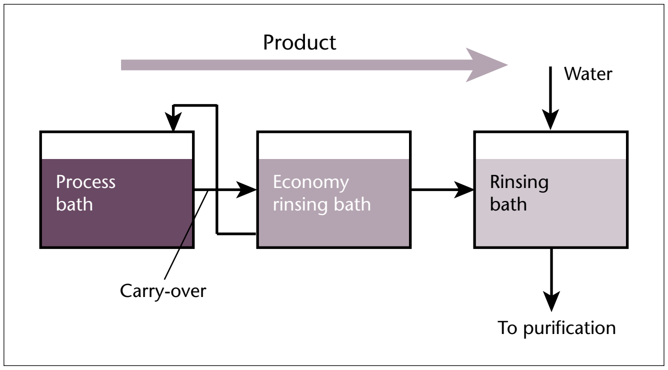

Figure 6.3 *Economy rinsing technique.*

There are a number of measures that may be taken in order to reduce the water consumption of a surface treatment process. Some options are:

In countercurrent rinsing the contaminated goods are rinsed in a first stage with the water from a preceding rinsing stage and the cleanest water is introduced in the last rinsing stage. The water for the different stages is led from one stage to the next in the opposite direction of the movement of the products, hence the name countercurrent rinsing (Figure 6.2).

Spray rinsing instead of rinsing in baths is a water conserving technique. One stage of spray rinsing corresponds in efficiency to about two stages of countercurrent bath rinsing.

Economy Rinsing – Re-circulation of the Process Chemicals

The consumption of rinsing water can be drastically reduced by introducing a so-called economy rinsing stage, placed between the process bath and the regular rinsing stages (Figure 6.3). There is no water inflow to the economy rinsing stage, which in fact will eventually become a diluted process bath. The economy rinsing bath liquid is returned to the process stage to compensate for the loss of liquid because of the carry-over as well as because of evaporation losses. At the same time a large portion (60-90%) of the metals are recovered that otherwise would load the wastewater treatment unit.

With warm surface treatment processes the evaporation losses are considerable and here the economy rinsing technique is particularly advantageous. Some surface treatment plants even utilise shut-downs e.g. during week-ends to evaporate water to enable increased recirculation from the economy rinsing stage in order to increase the recovery of metals lost with the carry-over. Another option for increasing the recovery

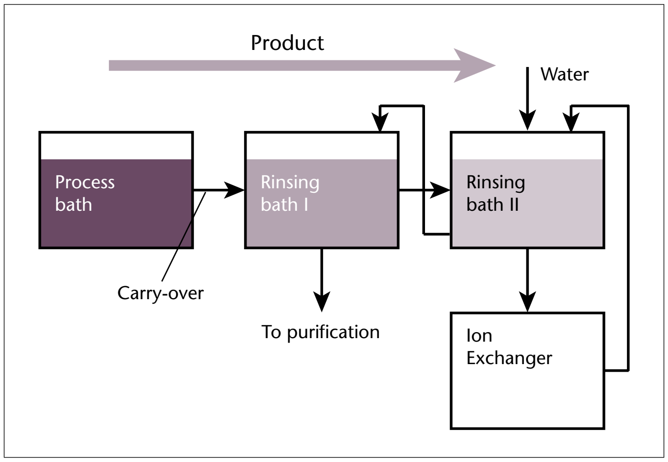

Figure 6.4 *Ion exchange as a kidney stage.*

from the economy rinsing stage is to concentrate the economy rinsing liquid before it is recirculated. This may be achieved by e.g. ion exchange, reversed osmosis or evaporation.

Process Integration – Re-circulation of Chemicals

Purity of the product is governed by the pollutant concentration in the last rinsing stage. The concentration in the last rinsing stage can be reduced either by increasing the influx of water to this stage or by cleaning the water in the last rinsing stage in a so-called kidney stage, e.g. an ion exchange unit. The ion exchange unit functions in fact like a kidney, purifying the water in the last rinsing stage allowing a considerable reduction of the amount of pure water needed to maintain a sufficiently low pollutant concentration in the rinsing stage (Figure 6.4).

The ion exchanges adsorbs the metals in the solution and thus removes and concentrates them. As the ion exchanges are eluted with NaOH (anionic exchanger) or HCl (cationic exchanger) the metals are recovered in a concentrated solution and can be re-circulated to the process.

Conclusion

The different measures accounted for above may be combined in several ways. This enables the almost total closing of the water cycle of some types of surface treatment processes. Especially warm surface treatment processes can be made practically wastewater free. Figure 6.5 shows an example of how different measures for process closing can affect water consumption and metal losses.

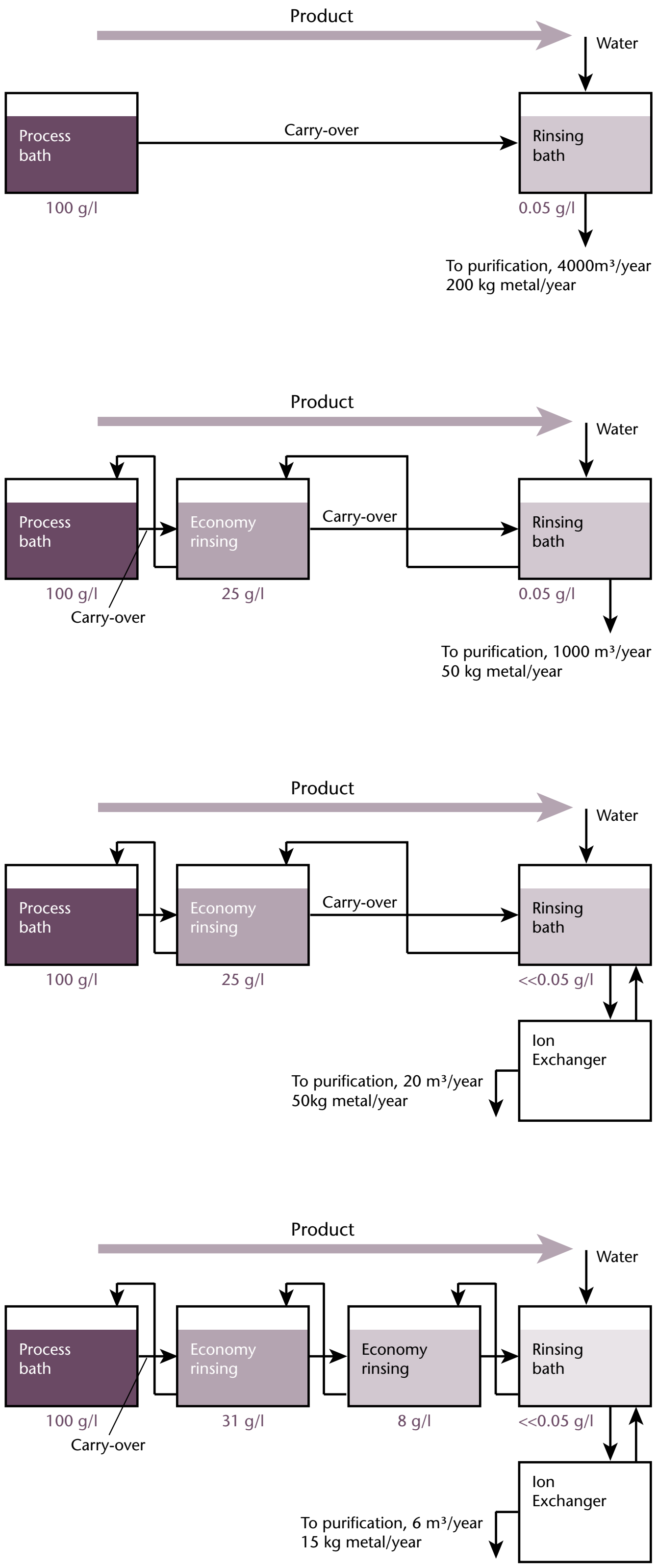

Figure 6.5 *Comparison between different alternatives for process integration of a surface treatment process.*

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The Baltic University Programme

http://www.balticuniv.uu.se

A regional university network

The Baltic University Programme is a network of 190 universities and other institutes of higher learning in the Baltic Sea region. All countries within or partly within the Baltic Sea drainage basin are represented: Belarus, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden and more marginally Czech Republic, Norway, Slovakia, and Ukraine.

A large network of researchers and teachers at the universities has developed. The number of individuals who have contributed at some stage in the Programme are more than 1,500. The network is coordinated by a Secretariat at Uppsala University, Sweden.

Sustainable development and democracy

The Programme focuses on questions of sustainable development, environmental protection, and democracy in the region. The aim is to support the key role that universities play in a democratic, peaceful and sustainable development. This is achieved by developing university courses for students but also to participate in applied projects in cooperation with authorities, municipalities and others.

Many arrangements for students

The Baltic University courses attract close to 10,000 students yearly in some 350 student groups. The courses are run separately by each university but there is much communication between course groups. Video conferencing, audio-telephone conferencing and computer conferencing over Internet allow students from different countries to meet and discuss. During summers many different activities are arranged, including a sailing seminar on the Baltic Sea and other summer courses. Student conferences and a student parliament is organized every year.

A variety of courses

The Programme offers a variety of courses for studies of the region, its environment, social change, and sustainable development. These constitute the combined efforts of a large number of scientific experts from all over the Baltic Sea region. The course material, consists of books, booklets, films and websites. The language is English but some material has been translated into Polish, Russian, and Latvian. Printed material, films and websites contribute to a rich learning environment for the students.

Our courses are multi-disciplinary, international, problem oriented, based on ongoing research at the participating universities and they all have an element of regional studies. This book is one in a series of four on environmental management and also the basic material for a Baltic University course.

The Baltic University Centre at Belarusian National Technical University in Minsk (Photo: Lars Rydén).

Lecture on the ship S/Y Fryderyk Chopin while sailing the Baltic Sea (Photo: Agnieszka Trzupek).

Read more about The Baltic University Programme at http://www.balticuniv.uu.se/

The Baltic University
Environmental Management Courses

Environmental Management is a package of four courses on master level for higher education in the Baltic Sea region. The courses convey knowledge of environmental management in all kinds of organisations, particularly in the industrial sector, and describe how environmental issues are addressed by different stakeholders in a society. The courses describe the environmental authorities and the legal and economic tool used for inspection and control, including the directives of the European Union; the formal management systems, such as ISO 14001 and EMAS, applicable to all kinds of organisations; industrial production and how to reduce environmental impact and increase resource efficiency; finally the design of products and how to asses the complete life cycle of products in society.

The courses provide a platform for environmental management education in all parts of society. They are well suited for competence development of professionals.

The four partial courses each have a course book, accompanied by a CD containing films, work tools, databases, material for training, and the textbook in PDF-format.

Each course corresponds to 7.5 ECTS credits, or the whole set to half a year of full-time studies.

Web support

The web page of the course package features teaching guides for teachers and additional material for students, such as proposed tasks for group work. The links in the books are kept updated on the web page, and new links are added. Figures etc. from the books may be downloaded to be used in PowerPoint or other types of presentations.

You will find the web pages for the EM courses at http://www.balticuniv.uu.se/ under the menu: Courses/ Environmental Management.

1. Environmental Policy
– Legal and Economic Instruments

This course describes legal and economic policy instruments, including environmental impact assessment, environmental legislation permits, and inspections and controls. Special emphasis is made on how companies and organisations can work to improve environmental performance and quality themselves, e.g. by green labelling, certification, and proper management tools. The role of inspections, both for control and in consultation to improve environmental performance in a company, is discussed. Environmental fines and taxes, although mostly of national concern, are described. The EU legislation is treated in some detail as well as the most important national legislation.

Course book:	*Approx. 250 pages; theoretical part and cases.*
Films:	*Cases from Sweden and Lithuania (on CD).*
Data base:	*Central legislative texts (on CD).*
Website:	*Teachers' guide and group work for students.*

2. Cleaner Production

– Technologies and Tools for Resource Efficient Production

Cleaner technologies refer to production processes where pollution is minimized at the source and efficiency of resource use is carefully improved. The course describes a series of production processes and how to improve energy, water and material resource management and improve production technologies. It describes how the implementation of cleaner technologies not only improves environmental performance, but also economic viability and the quality of the production process.

Course book: Approx. 324 pages; theoretical part and 6 cases.
Films: Cases from Sweden and Lithuania (on CD).
Data base: Cleaner Production Practices (on CD).
Website: Teachers' guide and group work for students.

3. Product Design and Life Cycle Assessment

The design of products and their use are major concerns to improve environmental performance and resource flow in society. The course treats this by applying environmental management, ecodesign and life cycle assessment techniques. A series of indicators for environmental impact are examined, throughout the life cycles of products. The techniques are illustrated by many cases of ecodesign, dematerialisation, use of indicators and LCA calculations.

Course book: 312 pages; theoretical part and 7 cases.
Films: Case from the Netherlands (on CD).
Data base: Applications for Life Cycle Assessments (on CD).
Website: Teachers' guide and group work for students.

4. Environmental Management Systems and Certification

The basis of environmental management is the systematic review, or audit, of an activity in an organisation, industry, or business to map environmental impact and resource use. The course describes how this is done and gives a series of tools to reduce impact. The practicalities of ISO 14001 and EMAS certification are described.

Course book: 266 pages; theoretical part and 7 cases.
Films: Cases from Sweden and Germany (on CD)
Data base: Tools for EMS (on CD).
Website: Teachers' guide and group work for students.

Baltic University Press

*Our books are interdisciplinary, international,
and based on latest research*

Environmental Science

© 2003. 824 p. SEK 500.
by: Rydén, L., Migula, P and M. Andersson (eds.).
Contents: Environmental Science is an extensive and interdisciplinary review of environmental issues with a focus on the Baltic Sea region.

English for Environmental Science

© 2003. 166 p. SEK 150.
by: E. Korshuk, I. Kryba, E. Savich, P. Solovyov, A. Tamarina.
Contents: English language course using texts and concepts from the Environmental Science text book.

The Baltic Sea Region – Cultures, Politics, Societies

© 2002. 676 p. SEK 375.
Contents: Regional development; history, culture, languages, democracy, multicultural societies, peace and security, social conditions and economies in the Baltic Sea region.

A Sustainable Baltic Region

© 1997. 10 booklets, 50 pages each. SEK 50 each.
Contents: Sustainable development is treated in ten thematic booklets; energy, material flows, agriculture, industrial production, transport and habitation, ethics and law, ecological economics, and Agenda 21.

Sustainable Water Management

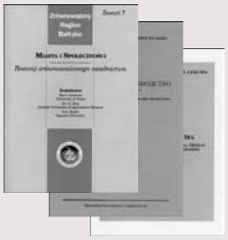
© 2000. 3 books, 230-250 pages each. SEK 200 each.
Contents: Hydrology, water quantity and quality, water management in agriculture, cities and industry, water and cities, transport, fishing, tourism and environmental protection, institutions and law, management plans, water conflicts, and international cooperation.

Sustainable Community Development (Superbs Case Studies)

© 2002. 4 booklets, 80 pages each. SEK 75 each.
Contents: City development, energy, material flows, urban planning, transport and habitation, illustrated by 35 case studies from 10 cities in the Baltic Sea region.

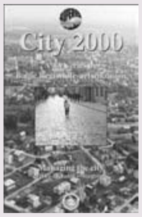
Translations:

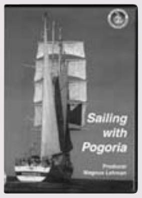
Belarusian
Latvian
Polish
Russian
Ukrainian



Film material

Video tapes/CDs that add to the books, and other written material, are also available for most of the courses.





To order our books and films, please visit: http://www.balticuniv.uu.se/webshop

The Environmental Management Book Series

Environmental issues are becoming increasingly important in all parts of society. Up till now good educational material has largely been lacking. The present Baltic University series of books, and other material connected to them, support master level training in environmental management in higher education. The books can be used for all relevant university level educational programmes, although they are especially suitable for engineering programmes.

The series is the result of a cooperation between specialists at universities and practicians in the Baltic Sea region: Sweden, Denmark, Germany, Poland, Lithuania, Belarus as well as the Netherlands. The material consists of books with theoretical backgrounds and CDs with films, cases, practical exercises, tools, and databases. It covers four courses in environmental management. A web support to the courses offers teachers' guides and student group works, as well as updated links and other material.

Cleaner Production
– Technologies and Tools for Resource Efficient Production

Cleaner Production refers to manufacturing practices in which pollution is reduced at the source or – at best – does not appear at all. This is achieved by improved and precise methods for renewable energy management, materials recycling, chemical pathways and use of products. Throughout this book and on the accompanying CD the practices and strategies introduced are detailed and exemplified, both on a managerial and a technological level. It is clear that techniques with a focus on Cleaner Production are realistic, highly profitable, and sometimes legally required. They constitute an important part of a future sustainable society.

The Baltic University Programme

The BUP is a cooperation between 180 universities in 14 countries in the Baltic Sea region, coordinated by Uppsala University, Sweden. The Programme develops interdisciplinary education on sustainable development and environmental science throughout the Baltic Sea region. It also works with applied projects in cooperation with governmental authorities, local administration and business, as well as with research and information.

The Baltic University
A Regional University Network

www.balticuniv.uu.se

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