Eolss Publishers Co. Ltd.,
Oxford, United Kingdom

Information on this title: www.eolss.net/eBooks

ISBN- 978-1-84826-167-9 (e-Book Adobe Reader)
ISBN- 978-1-84826-617-9 (Print (Color Edition))

British Library Cataloguing-in-Publication Data
A catalogue record of this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data
A catalog record of this publication is available from the library of Congress

Singapore

INDUSTRIAL POLLUTION

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Keywords: industrial, pollution, integrated management, end-pipe treatment, cleaner production, Industrial ecology

Contents

Summary

Industry contributes various kinds of pollutants to the environment. Different countries in the world are facing different types of industrial pollution problems. Industry produces both traditional pollutants such as organic substances, sulfur dioxide, particulates and nutrients, etc., and newly-recognized pollutants such as dioxin and other specific toxic substances. The pollutants are mainly in gas, water, and solid forms that can cause serious damage to the biosystems. Industrial pollution has attracted a lot of attention. Great efforts have been made to solve the problems. The problems of industrial pollution and their control measures are briefly discussed in this chapter. In recent years, the sustainable development concept has been widely recognized, which has promoted the implementation of integrated management of industrial production. The development of "industrial ecology" aims to provide theories and methods to harmonize the industrial sectors with the biosphere, that may bring solutions of sustainable development to the industry and society.

1. Introduction

Industry plays an important role in the process of economic development in the world. It enhances the economic welfare of citizens and supplies the material goods they consume. The way in which society will develop in the future is largely dependent on how the growth which industry generates is distributed.

Industry is also a major consumer of natural resources and a major contributor to the overall pollution load. Based on OECD (Organization for Economic Cooperation and Development) estimates, it accounts for about one-third of global energy consumption of their member states, and for about 10 percent of the total water withdrawal. The relative contribution to the total pollution load is obviously higher for industry-related pollutants. The industrial sector generates both traditional pollutants (e.g., organic substances, sulfur dioxide, particulates and nutrients) and newly-recognized pollutants (e.g., specific toxic substances). The industrial sector includes a number of diverse activities. As a result, there is a wide range of different resource and environmental impacts created by industry.

Thus, industry has particular environmental responsibilities in terms of such factors as plant location and design, environmental pollution, vibration and noise controls, waste disposal, occupational health and safety aspects, and long-range planning.

Generally, the pollutants from industries are divided into three major categories namely gas, solid and water. There are also some other pollutant forms such as noise and odor. Table 1 shows some pollutant types from different industries.

Industrial sectors	Pollutant forms			
	Gas	Solid waste and soils	Water	Others
Iron and Steel	SO_x, NO_x, HC, CO, H_2S Toxic chemicals	Slag, wastes, sludge from effluent treatment	BOD, COD, oil, metals, acids, phenol, cyanide	Noise, particulate
Textiles and leather	SO_x, HC	Sludge (chromium) from effluent treatment	BOD, solids, sulfates and chromium, dyes	Odor, noise, particulate
Pulp and paper	SO_x, NO_x	sludge from effluent treatment	BOD, COD, solids, chlorinated organic compounds	Noise, odor, particulate
Petrochemicals, refineries	SO_x, NO_x, HC, CO, H_2S Toxic chemicals	Spent catalysts, tars, sludge	BOD, COD, oil, phenols and chromium	Noise, odor, particulate
Chemicals	Organic chemicals	Sludge from pollution treatment and process waste	COD, organic chemicals, heavy metals, solids and cyanide	Odor, toxic chemicals

Table 1. Pollutants from different industries

Industrial pollution control has been paid a lot of attention. Increasing efforts have been made to protect the environment, both in terms of reducing point-source emissions, risk management during chemical use and handling of hazardous waste. New legislation, more stringent emission standards, stricter controls and growing consumer demands for environmentally-sound products have been promoting the implementation of environmental friendly technologies and integrated pollution management strategies.

Recent practices in pollution control tend to move towards the core of industrial operation. Nevertheless, end-pipe treatments played and still play an important role in industrial pollution control.

2. Industrial Pollution Facing Different Countries

The industrial pollution problems faced by different countries worldwide are different. Generally speaking, in developed countries, the pressures created by industrial activates (i.e., the emission of traditional pollutants from iron and steel, metal fabrication and petrochemicals) has grown slowly in recent decades. Other types of environmental problems, e.g., contamination of soil and buildings at closed sites, with subsequent high costs for remedial treatments have received growing attention. In developing countries, the environmental pressure coming from the traditional pollutants created by industries is still very heavy. For both developed and developing countries, the growing technology-based industries, created new problems due to the use of toxic material in their production processes, which can cause soil and water contamination.

2.1. OECD Countries

In developed countries, early in the twentieth century, pollutant emissions to air and water were considerable at production sites, and large volumes of waste material were often dumped in the immediate surroundings of the factories. A classic example is the industrial districts in Northern England, where the fallout of soot put a dark coating cover over the whole landscape. In the Ruhr area in Germany, undesirable amounts of dust fallout from the steel industry as well as large amounts of sewage effluents transformed the river Ruhr into an industrial sewer. In the United States and in Japan, similar situations occurred.

The pollution situation in the OECD countries is now quite different from the previous decades. Treatment measures have been introduced to treat much of the pollution. Wastewater tubes do not end up any more at dead bottoms, trees and vegetation surrounding factories are alive and green, and the surrounding air has cleared up substantially. The efforts in many OECD countries to reduce pollution started in the 1980s, after the need for such efforts became apparent. The discharges of early-identified pollutants have been reduced to a large extent since the beginning of the 1970's, and many environmental problems have been solved.

Industrial growth is commonly regarded as being accompanied by an increase in consumption of energy and raw materials. However, industrial experiences in many countries show that the opposite situation can prevail. Industrial growth may favor environmental protection work and govern research and development, thereby promoting new technologies in industry to further minimize environmental risks. It also provides the necessary financial conditions under which large investments in new technology, necessary for further reducing environmental effects, can be made. As a result, the prerequisites are created for a sustainable industrial development of products with lower requirements for natural resources, and enhanced waste recycling and minimization.

However, the environmental problems have not disappeared in many OECD countries. The local, intense industrial pollution has merely been replaced by regional or global diffuse pollution. Local sources and individual contaminants may be found and identified. Clean, non-contaminated reference areas are still difficult to find. The environmental accidents erupt sometimes. The environmental problems in using the industrial products and used up products are absorbing more concern.

2.2. Eastern European countries

Heavy industries predominate in Eastern Europe, which are often concentrated in specific regions. So far, little concern has been given to environmental impacts of industrialization in these regions. As a result, Eastern Europe now faces very serious industrial pollution problem. However, Eastern Europe also faces a time of change with regard to environmental protection. The big change of the social structure has resulted in the changes of the industrial structure. Heavy industries and relative pollution have been markedly reduced in recent years.

2.3. Developing Countries

The situation with regard to industrial pollution is more heterogeneous and complex in developing countries. The process of industrialization in these countries is far less advanced. Typical industries in these countries are steel mills, mining activities, textile industries, tanneries and pulp and paper industries. Many of these industries are linked to multinational industrial enterprises supplying important raw materials on the world market, to some extent favored by low-paid labor. A large number of the more traditional, small-scale industries are also typical of developing countries. They typically induce severe environmental pollution. On the other hand, technology-based industries have sprouted in some of the developing countries too. Both the traditional pollutants and newly-recognized pollutants function together, which makes environment protection more difficult.

Many developing countries have set aside areas called "industrial free zones" or "export processing zones". These zones are regarded as extra-territorial land from perspectives of, custom regulations, taxation, rules for employment, salaries, working hours, occupational safety and even environmental protection. During the 1980's, some industries unable or unwilling to meet more stringent environmental standards in the OECD countries have moved to "industrial free zones" in many developing countries, which makes the environmental pollution situation in these countries more complex.

3. Industrial Air Pollution

Air pollution emissions can be caused for technical reasons, but may also be caused by unsuitable, worn-out or defective facility components. Figure 1 gives an overview of the origin and causes of air pollution from industrial facilities, showing on the left side those processes where primarily gaseous emissions are generated, e.g., by evaporation, chemical reactions and valve discharges. The most common origins from process-technological methods of dispersing, sorting, and classifying and other specialized processes are listed at top right.

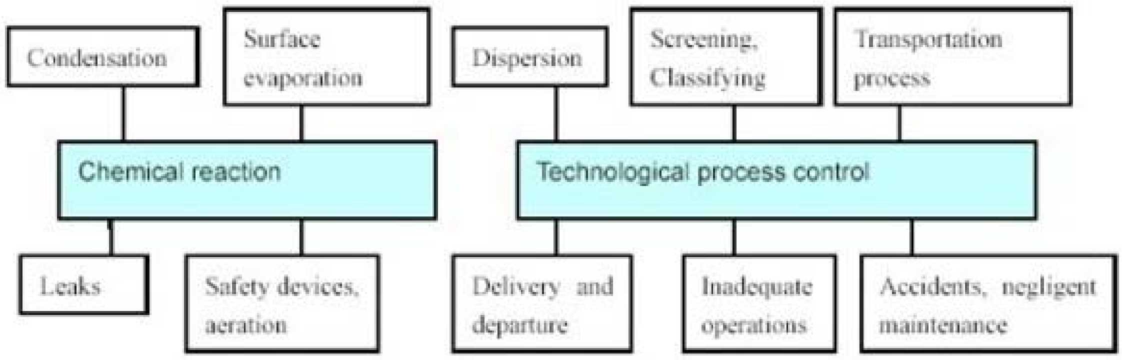

Figure 1. Causes for the generation of industrial air pollutants

3.1 Air Pollution Emissions from Industrial Processes

The major pollutants from industrial emission include gaseous emissions (SO_2, NO_x, etc.) and particulate emissions.

3.1.1 Gaseous Emissions

Depending on the fuel, the SO_2 content of flue gases is 1 to 4 g/m^3; an average size coal fired power plant, with an output of 700MW, produces 2.5 million m^3 of flue gases per hour, emitting about 2.5 tons of sulfur per hour. Compared to power plants, SO_2 emissions from other industrial sources are low and originate primary from the heating of reactors with sulfurous fuels, in roasting processes in the non-ferrous heavy metal and blackening metallurgy and coal enrichment processes (low-temperature carbonization, coking, gasification, etc.). Sulfur dioxide can be oxidized into sulfuric acid by either the "wet" or the "dry" method. A third possibility is the "catalytic" oxidation of soot and dust particles containing heavy metals. This reaction is facilitated by the presence of small droplets of water as fog and these droplets become strongly acidic. The resulting "acid smog" has a particularly deleterious effect on the respiratory system.

Nitrogen oxides are formed in every combustion process and in the production and conversion of nitric acid and nitrates. The most important forms of air pollution from combustion processes are nitrogen oxide (NO) and nitrogen dioxide (NO_2). Mixtures of both oxides are generally summarized as "NO_x". It is customary to report the mass concentrations for NO_x as NO_2 in mg/m^3. Nitrogen dioxide forms from nitrogen oxide through oxidation with atomic or molecular oxygen, ozone, or organic radicals. A special problem is the use of nitrous-containing spent sulfuric acid in super phosphate production, where up to 50% of the nitrogen oxides are released and emitted. At normal temperatures, the breakdown of NO_2 is affected by light (photolysis). As a photochemically very active compound, NO_2 absorbs the sunlight reaching the lower atmosphere at several magnitudes greater than all other gases. This overall reaction is by far the most important trigger of atmospheric radical chain reactions and thus plays a key role in atmospheric chemistry, especially in forming photochemical smog. "Photosmog" also contains a high share of toxic ozone.

Chlorinated exhaust gas is emitted primarily from chlor-alkali electrolysis. Especially critical is the discontinuously occurring "stack chlorine", which is generated for short periods of time in large quantities during startup or shutdown and during malfunctions. Furthermore, during the chlorination of inorganic and organic feedstocks into aluminum chloride, hydrogen chloride, basic detergents, chlorinated hydrocarbons, pesticides, etc., it is possible that up to 30% of the input chlorine is released in the exhaust gas. Non-negligible quantities of hydrogen chloride are released in the drying of potash fertilizer salts.

The scale of health effects from air pollution ranges from irritants to poisons. Causes of diseases of the breathing organs, conjunctivitis, rickets, as well as infections can be collectively related to air pollution. Epidemiological studies have concluded that chronic exposure to sulfur dioxide results in repeated occurrences of sinus infections, respiratory diseases, and breathlessness (emphysema). With respect to the damage occurring to forests today, there is much evidence to suggest that it is caused not only by natural forces, but also primarily by airborne pollutant in dry deposition and/or wet or acid precipitation. The precipitation of the airborne pollutant also can damage the surface water, soil and even further the underground water. The nitrogen dioxides and sulfur dioxides emitted into the atmosphere dissolve and form acids in the water droplets of fog, clouds, and rain. Besides acids (3/4 sulfuric acid, 1/5 nitric acid, and about 1/20 hydrochloric acid), precipitation also contains other pollutants (salts, heavy metals, and organic substances). Air pollution causes damage to historic buildings, to sculptures and stained glass, to industrial and consumer goods, as well as to archived material. SO_2, NO_x and other acid-forming gases, as well as particulates and various photo-oxidants accelerate the natural weathering and aging processes.

3.1.2. Particulate Emissions

Fine particulates are arousing a lot of concern from both scientific circles and the public. Because they not only pollute but also provide huge surface to absorb other pollutant such as heavy metals, toxic organic materials, etc., they may cause many serious health problems and damage the environment. Particulates, or simply particles, is a term that refers to fine solid matter, which is dispersed and spread by the movement of air. Smoke is the dispersion of the smallest still visible solids in a carrier gas and is generated in combustion processes. This finely dispersed matter in the air is generally called aerosol. The most important characteristic of smoke, fog, and dust is their small particle size, between 1 to 0.1μm. Coarser particles settle after a period of time. They are filtered from the air by the nose and the bronchi; finer particulates, such as particles with a diameter below 5μm, are able to enter the lungs.

Particulates are characterized by their mineralogy (lattice structure), their chemical composition, concentration, particle size distribution, and their morphological data. Other important physical characteristics are density, bulk and packing density, angle of slide and repose, abrasion factor, and specific surface. After particulates are generated, they are classified as either primary particulates, which are newly generated particles, or secondary particulates, which are caused by the disturbance of existing particles. In urban areas, secondary particulates can constitute up to 30% of the total particulate load. From the perspective of toxicity, substances like quartz, asbestos, soot, lead, cadmium and vanadium compounds and radioactive particulates deserve special attention. Table 2 lists the important industrial emission sources and particulate type.

Source	Particulate types	Origin, occurrence	S/U
Fertilizer industry	phosphates, urea, potassium chloride, anhydrite, and other sulfates	pulverizing, processing, drying, sintering, granulating, gases	WSCy/Rc
Carbo-chemistry	coal + coke particulates, soot, condensed products	Degasifying, gasifying pulverizing	BP/En
Electro-chemistry	metal + oxide particulates	Electrolysis in the dry method	EP
Calcium-carbide	coke, lime, calcium hydroxide	coke pulverization + drying, lime sintering	Cy/Co
Paint industry	ocher earth, + other particles, heavy metal compound	Pulverizing, dispersing	CyFS
Biocide-industry	insecticides, herbicides, carrier matter	drying, mixing	Cy/Rc
Detergent industry	sodium phosphate, soda, Na-borates	Mixing, dispersing, granulating	Cy/Rc
Rubber and plastics	rubber + plastic particles, talcum, soot; other filler	Mechanical treatment, extracting, dispersing	FS/FM
Smelting	Ores, coke, metal-, metal oxide-, and slag particles	Pulverizing, sintering, throat gas	Cy/Cm
Metal processing	Metal and metal oxide	Converter and smelting furnace, waste gas	Cy/Rc
Foundries	Metal and metal oxide dust, silicates	Smelting furnace waste gas, moulding foundry sand treatment	FS/Rc
Bonding agent and constructio n material	Raw meal and cement dust, rock and mineral dust	Raw material WS extracting, pulverizing, transporting, firing	EPCy/Rc
Ceramics and glass industry	Quartz and silicates, metal and non-metal oxides	Processing + treatment processes WS	FSCy
Wood	Wood dust, sanding	Grinding, sawing,	

processing	and polishing agents	milling, size reduction	Cy/C
Textile industry	Cotton fiber and other textile fiber dust	Treatment (picking, combing), friction	Cy

S = separation: EP = electrostatic precipitator, WS = wet separator Cy = cyclone, FS = filtration separator
U = utilization: Rc = recycling/recirculation, En = Energy generation, FM = filler material, CM = cement manufacture, Co = construction material, C = composting, A = auxiliary filtration material

Table 2. Important industrial emission sources and particulate type

Control methods for industrial air pollutant will be discussed in other articles. (see Technologies for Air Pollution Control).

3.2. Industrial Odor Control

3.2.1. The Problem

Odor is a major factor in the total air-pollution picture because it is easily noticed and frequently the source of complaints. In recent years the problems caused by odor have received a lot of concern. Industrial sources are often considered the main source of offensive odors, and the nature of the company, its raw materials, and the finished products will influence the type of odor produced.

Sensation of odor is an effect caused by odorants when they reach chemo-receptors in the nose. Odor measurements may utilize two different approaches. The identity and the concentration of odorants in the air can be established by appropriate analytical methods. The odor sensation, which is a physiological and psychological effect, can be evaluated using sensory methods that evaluate human responses to the odorous air. In addition, procedures such as the gas chromatogram/odorogram technique may combine both approaches (analytical and sensory) and help in solving some problems.

In a purely analytical approach, the concentrations of know odorous substances in air or an emission are measured. Since many odorants evoke an odor sensation at concentrations as low as 10^{-9} ppb, such measurements may require very specialized techniques. However, analytical data must be interpreted by reference to some target level. Usually the target level is related to the detectability of the odorant by the nose. For example, if a substance begins to smell at a concentration of 10ppb, the analytically determined concentration of 15ppb would possibly be considered odor evoking. In reality, such interpretations are rarely clean cut. An analytical method may focus on some single substance if it is know that its concentration is the prime cause of odor, or that its concentration varies in proportion to other odorants, is found to correlate with the odor of the entire emission, and can be used as an odor index.

Other analytical methods may measure the combined concentration of compounds for chemically related substances. Total reducible sulfur and total aldehyde content are two examples. The most adequate approach involves scanning the composition for all possible odorants and measuring the concentrations of those which are found to be present.

In the sensory approach, individuals called "panelists", "judges", "observers", "participants", etc. are presented with odor samples and asked to indicate their responses. The panelists serve as sensory instruments. Odor sensation has several sensory dimensions: intensity, detectability, acceptability, and quality (character). Intensity and detectability are inter-related. As the sample is diluted more and more, the odor becomes weaker, and finally reaches an odor intensity that is too weak to be consistently noticed. Of these four dimensions, most regulations deal with detectability, and some with acceptability.

3.2.2. Source of Industrial Odor and Its Control Method

Many industries produce odor problems. Chemical and petroleum industries are major sources of odor. The pharmaceutical industry, rubber, plastics and glass industries, etc. are sources of odor too. The types of odor are many and varied. More often than not, sources of odors are complex, with several compounds contributing simultaneously.

Due to the wide range of odor types, sources, and concentrations experienced within different industries, the methods used to combat them are also numerous and varied. In treating an odor, the degree of difficulty frequently varies inversely with the concentration. The most common control techniques are process change, catalytic/thermal combustion, diffusion, counteraction, absorption, and adsorption.

In many applications, especially in refineries, a combination of two methods may be required for adequate control. For example, absorption of soluble odorous compounds followed by catalytic combustion of insoluble odorous compounds followed by catalytic combustion of insoluble/noncondensable odorous compounds.

In textile industries the most common odor source is organic solvents. These may be absorbed in alkaline solutions or adsorbed on carbon. The concentrated odorant may then be combusted to destroy the odor.

In the petroleum industry, absorption and combustion are the control methods most often used. Flare systems are installed to take care of odorous emissions, but more important to handle emergency situations. Incineration is used most effectively for exhaust gases from vulcanizing rubber. The paint industry, similar to the textile industry, may emit vaporized solvents which can be controlled by absorption followed adsorption or combustion.

4. Wastewater Pollution

4.1. Industrial Wastewater Sources and Properties

Industrial wastewater emanates from the myriad of industrial processes that utilize water for a variety of purposes. About two-third of the total wastewater generated by U.S.

manufacturing plants results from cooling operations. In electric power generation, the proportion is nearly 100%. In addition to the large quantities used for cooling purposes, water is used extensively throughout industry in processes operations. This water is usually altered considerably in the industrial process and may contain contaminants that degrade the water quality.

The compositions of industrial wastewater are depending on the industrial sectors and processes. Generally speaking, industrial wastewater contains relatively higher levels of recalcitrant organic compounds than domestic wastewaters. Table 3 gives the characteristics and components of typical industrial wastewater.

High temperature	Power plants, all industries, laundries, bottle washing plants of breweries and the beverage industry
High share of organic substance(BOD_5)	Paper mills, cardboard factories, pulp mills, cellulose plants, wool, scouring plants, canning factories, coal washers;
High share of dissolved solid	Slaughterhouses, meat plants, flaying house, glue factories, tanneries, leather factories, sauerkraut factories, canning factories, soap factories, cellulose plants;
Acids	Oleo & sauerkraut factories, manufacture of synthetic fatty acids soap factories, bleaching plant, sulfur mines, pickling plats, electroplating plants, gunpowder & explosives plants, chemical industry, candle factories, coal pits, viscose factories, wool scouring plants(acid treated wastewater);
Bases	Textile factories, metal wares factories, chemical industry, tanneries, laundries, gas utility, wool scouring plants;
Oils and fats	Dairies, oleo plants, meat plants, slaughterhouses, soap factories, oil industry, tanneries, wool scouring plant, candle factories, metal working plants;
Toxins	Tanneries, leather factories, dyeing plants, carbonization plants, gas utilities, coking plants, electroplating plants, explosives factories, textile mils, chemical industry, herbicides;
Radioactive substances	Uranium mining, laboratories, hospitals, nuclear power plants;
Detergents	Soap factories,, textile mills, dyeing plants, laundries;
Dyes	Paper & cardboard mills, tanneries, dyeing plants, paint factories, rayon plants, electroplating plants;
Infectious properties	Flying houses, animal carcass removal, tanneries, glue factories;
Odor	Tanneries, yeast factories, distilleries, fishmeal factories, slaughterhouses, flaying houses, brown coal carbonization plants, coking plants, and gas utilities.

Table 3. Characteristics and components of typical industrial wastewater

Depending on the nature and industry and the projected uses of the waters of the receiving stream, various contaminants may have to be removed before discharge. These are summarized in Table 4.

The volume and strength of industrial wastewaters are usually defined in terms of units of production and the variation in characteristic by a statistical distribution. In any one plant there will be a statistical variation in waste flow characteristic. The magnitude of this variation will depend on the diversity of products manufactured and of process operations contributing waste.

Contaminants	Reasons for importance
Physical	
Suspended solids	Suspended solids are important firstly for esthetic reasons. Deposition of solids in quiescent stretches of a stream will impair the normal aquatic life of the stream. Sludge blankets containing organic solids will undergo progressive decomposition resulting in oxygen depletion and the production of noxious gases.
Chemical	
Biodegradable organics	Composed principally of proteins, carbonhydrates, and fats, biodegradable organics are measured most commonly in terms of BOD (biochemical oxygen demand) and COD(chemical oxygen demand). If discharged untreated to the environment, the biological stabilization of these materials can lead to the depletion of natural oxygen resources and to the development of septic conditions.
Nitrogen and phosphorus	When effluents containing nitrogen and phosphorus discharged t lakes, ponds and other aquatic environment, these nutrients can lead to the growth of undesirable aquatic life, enhance eutrophication. When discharged in excessive amount on land, they can also lead to the pollution of groundwater.
Refractory pollutants	These pollutants tend to resist conventional biological methods of wastewater treatment. They will cause tastes and odors in water and in some cases are toxic and carcinogenic. Typical examples include surfactants, phenols, and agricultural pesticides.
Heavy metals	Due to their toxic and persistence nature, certain heavy metals can negatively impact upon biological waste treatment processes and stream life.
Color and turbidity	These present aesthetic problems even though they may not be particularly deleterious for most water uses. In some industries, such as pulp and paper, economic methods are not presently available for color removal.
Oil and floating material	These produce unsightly conditions and in most cases are restricted by regulation
Aquatic toxicity	Substances present in the effluent that are toxic to aquatic species and are restricted by regulation.

Table 4. Contaminants important in wastewater treatment

4.2. In-plant Wastewater Control and Water Reuse

Before end-of-pipe wastewater treatment or modifications to existing wastewater treatment facilities to meet effluent criteria are considered, a program of waste minimization should be initiated.

Reduction and recycling of waste are inevitably site- and plant-specific, but a number of generic approaches and techniques have been used successfully to reduce many kinds of industrial wastes. Generally, waste minimization techniques can be grouped into four major categories: inventory management and improved operations, modification of equipment, production process changes, and recycling and reuse. Such techniques can have applications across a range of industries and manufacturing processes and can apply to hazardous as well as non-hazardous wastes.

Many of these techniques involve source reduction. Others deal with on- and off-site recycling. The best way to determine how these general approaches can fit a particular company's need is to conduct a waste minimization assessment. In practice, waste minimization opportunities are limited only by the ingenuity of the generator. In the end, a company looking carefully at bottom-line returns may conclude that the most feasible strategy would be a combination of source reduction and recycling projects. Table 5 lists the waste minimization approaches and techniques developed by the U.S. EPA. Although it is theoretically possible to completely close up many industrial process systems through water reuse, an upper limit on reuse is imposed by product quality control.

Inventory management and improved operations	
	·Inventory and trace all raw materials
	·Purchase fewer toxic and more nontoxic production materials
	·Implement employee training and management feedback
	·Improve material receiving, storage, and handling practices
Modification of equipment	
	·Install equipment that produces minimal or no waste
	·Modify equipment to enhance recovery or recycling options
	·Redesign equipment or production lines to produce less waste
	·Improve operating efficiency of equipment
	·Maintain strict preventive maintenance program
Production process changes	
	·Substitute non-hazardous for hazardous raw materials
	·Segregate wastes by type for recovery
	·Eliminate sources of leaks and spills
	·Separate hazardous form non-hazardous wastes
	· Redesign or reformulate end products to be less hazardous
	·Optimize reactions and raw material use
Recycling and reuse	
	·Install closed-loop systems
	·Recycle on site for reuse
	·Recycle off site for reuse
	·exchange wastes

Table 5. Waste minimization approaches and techniques

4.3. Industrial Wastewater Treatment

Primary and secondary treatment, i.e., biological treatment processes, handle most of the nontoxic wastewaters; other waters have to be pretreated before being added to this flow. These processes are basically the same in an industrial plant as in a publicly owned treatment works (POTW). Many existing wastewater-treatment systems were built just for primary and secondary treatment, though a plant might also have systems for removing materials that would be toxic to microorganisms. This was once thought adequate, but it is not, and so new facilities have to be designed and old facilities retrofitted to include additional capabilities to remove priority pollutants and residuals toxic to aquatic life.

Tertiary-treatment processes are added on after biological treatment in order to remove specific types of residuals. Filtration removes suspended or colloidal solids; adsorption by granular activated carbon (GAC) removes organics; and chemical oxidation also removes organics. Unfortunately, tertiary systems have to treat a large volume of wastewater, and so they are expensive. They can also be inefficient because the processes are not pollutant-specific. Therefore, in-plant treatment is necessary for streams rich in heavy metals, pesticides, and other substances that would pass through primary treatment and inhibit biological treatment. In-plant treatment also makes sense for low-volume streams rich in non-degradable materials, because it is easier and much less costly to remove a specific pollutant from a small, concentrated stream than from a large, dilute one. Processes used for in-plant treatment include precipitation, activated carbon adsorption, chemical oxidation, air or steam stripping, ion exchange, reverse osmosis, electrodialysis, and wet air oxidation. Existing treatment systems can also be modified so as to broaden their capabilities and improve their performance; this is more widely practiced than the above options.

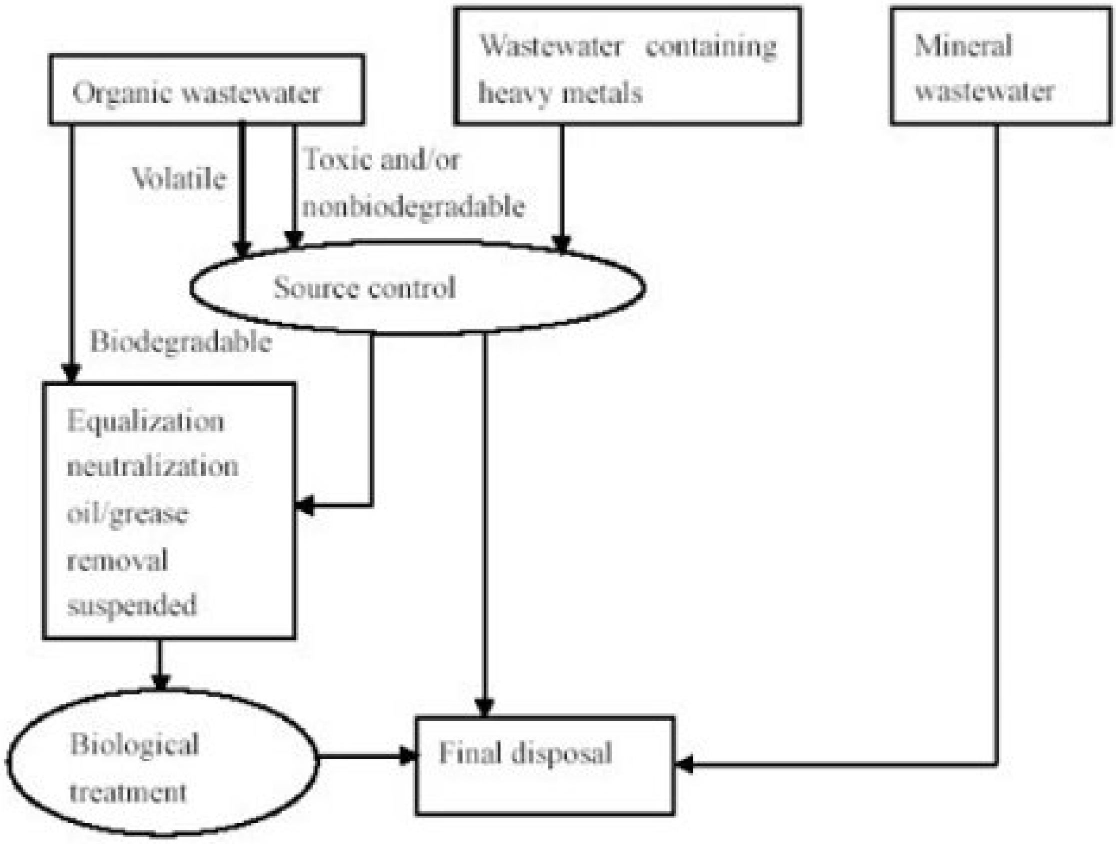

Figure 2. Conceptual approach of management/treatment program for industrial wastewater

All these processes have their place in the overall wastewater-treatment scheme. The selection of a wastewater-treatment process or a combination of processes depends upon: (1) The characteristics of the wastewaters. This should consider the form of the pollutant, i.e., suspended, colloidal, or dissolved; the biodegradability; and the toxicity of the organic and inorganic components. (2) The required effluent quality.

Consideration should also be given to possible future restrictions such as an effluent bioassay aquatic toxicity limitation. (3) The costs and availability of land for any given wastewater-treatment problem. One or more treatment combinations can produce the desired effluent. Only one of these alternatives, however, is the most cost-effective. A detailed cost analysis should therefore be made prior to final process design selection.

For industrial wastewaters containing nontoxic organics, process design criteria can be obtained from available data or from a laboratory or pilot plant program. In the case of complex chemical wastewaters containing toxic and nontoxic organic and inorganics, a more defined screening procedure is necessary to select candidate processes for treatment. Figure 2 describes the management and treatment programs for industrial wastewater containing high strength organic materials or toxic materials.

As indicated in Figure 2, if the industrial wastewater is non-biodegradable or toxic it should be considered for source treatment or in-plant modification. Source treatment technologies are listed in Table 6. The technologies can be used separately or combined. The effluent could be discharged, recycled or gone through further treatment.

Pollutants	Treatment technologies
Heavy metals	Ion exchange, filtration , precipitation, oxidation reduction, reverse osmosis
Organic chemicals	Reverse osmosis, polymeric resins, granular carbon adsorption, anaerobic treatment, wet air oxidation, chemical oxidation
Volatile organics, ammonia	Air or steam striping

Table 6. Applicable technologies for treatment of toxic wastewaters

(see Technology for Water Pollution Control)

5. Solid Waste

Solid wastes are all the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted.

5.1 Hazardous waste

Environmental problems related to hazardous waste may presently be one of the most important issues for industrial protection efforts all around the world. Improvement of hazardous waste management practices is a high-priority action to undertake. This is true not only in developed countries, but, to a greater extent than some-times realized, in developing countries as well.

Hazardous wastes include a broad range of substances, and are surprisingly difficult to define in a straightforward way. The chemical hazards found associated with modern industrial society have increased dramatically over the last decades. Although hazardous wastes originate from industrial activities, surplus pesticides, hospital wastes, used motor oils and household chemical wastes, industrial sources seem generally to be the most important. Broadly speaking, a hazardous substance is a material that may explode, catch fire, be corrosive, exhibit toxicity, or have other dangerous characteristics such that it can endanger the physical environment, living organisms, devices, or materials. If a hazardous substance has been discarded or abandoned, it may be classified as hazardous waste. Three basic approaches to classifying hazardous wastes are (1) a qualitative description by origin, type, and constituents, (2) classification by characteristics largely based upon testing procedures, and (3) by means of concentrations of specific hazardous substances.

Hazardous wastes may be individual substances or mixtures. They are dangerous or potentially dangerous to humans or other living organisms. Direct dangers posed by hazardous wastes include fire, explosion, and toxicity. Some hazardous wastes cause cumulative detrimental effects, such as cancer resulting from repeated or prolonged exposure, some may undergo biomagnification in exposed organisms (through food chains), and many hazardous wastes persist in the environment because they do not degrade. Specific mention should be made of radioactive wastes, which in the U.S.A. are regulated under the Nuclear Regulatory Commission (NRC) and Department of Energy (DOE). Special problems are posed by mixed waste containing both radioactive and chemical wastes.

The management of hazardous wastes and compliance with the regulations pertaining to them occupy an enormous amount of time and effort in the business community.

5.2. Techniques to Reduce Hazardous Waste Quantities

Managing the industrial process itself to minimize the production of hazardous waste, known as waste minimization, is the first stage to manage the hazardous waste. It refers explicitly to in-plant activities, which can result primarily in the reduction of the amount of waste that reaches the plant gate.

Waste reduction has many benefits. Most important, it involves a real reduction in the waste being produced. The experience of a growing number of companies is that waste reduction can have strong economic benefits. Many developed countries have adopted policies at the national level to encourage waste reduction within industry. Such policies to encourage low-waste and non-waste technologies have been especially important in the USA and many European countries. Waste management may turn out to be one of the more important factors in determining the relative success of different countries with regard to environmental protection.

The most common features of waste minimization programs are reuse and substitution. Reuse is to separate the industrial wastes at the source by the companies themselves. It can reduce the volumes of waste and increase recovery volumes and cleaner fractions of both recovery materials and wastes. Substitution of chemical products which have proved to be hazardous to the environment, is in the interest of industry, especially the chemical industry.

The second stage of the solid waste control hierarchy is recycling. This may be done within the plant that generates wastes, and may be carried out in conjunction with some other industrial process in the same facility complex. Recycling is a promising approach to reduce the increasing amount of industrial hazardous waste, and is only the beginning of environmentally-oriented technology developments in this field. The drawback of recycling involves transportation of wastes from one place to another, and it requires greater handling. There is an increased risk for spills or other releases into the environment.

The third stage is treatment capable of destroying or minimizing the hazardous aspects of the substances in question. However, most treatment technologies produce residuals that still need further treatment and perhaps ultimate disposal. The major types of treatment processes are: (1) physical and chemical treatment; (2) incineration; and (3) detoxification, solidification and reduction of hazards.

The fourth stage (and end) of the hazardous waste management process is disposal. When wastes are treated as much as feasible, it is necessary to do something with the residuals. The ultimate residues must be taken care of by some means, usually storage or deposition. The purpose of disposal is to provide a permanent resolution to the hazards posed by the existence of the molecules in question.

6. Toxic Chemicals

New chemicals have been added to the environment at an accelerating rate. While developed countries probably produce more different kinds of chemicals than developing countries, the global list of synthetic industrial chemicals is growing by about 1,000 per year. Environmental pollution associated with industrial mismanagement of chemicals in the developed world has been a major concern. Developing countries have also suffered their share of mishandling of chemicals.

The production of synthetic organic chemicals has risen dramatically. For example, the world-wide production of organic chemicals has increased from about 7 tons in 1950, to 63 million tons in 1970, and to 250 million tons in 1990. Workers in the chemical industry are often those who suffer first from the toxic effects of chemicals. Toxic wastes, often subject to haphazard disposal, have recently been the focus for worldwide debate and concern with regard to environmental pollution. Because the many chemical compounds usually contain diverse and complex mixtures of substances, it is extremely difficult to envision the ultimate effects of release of chemicals on the environment and health. Furthermore, some environmental effects may occur sporadically and long after the initial exposure. It is extremely important to adopt a precautionary principle in the use of chemicals.

7. Noise Control

7.1. Noise and its effects

Noise is any sound – independent of loudness – that can produce an undesired physiological or psychological effect in an individual, and that may interfere with the social ends of an individual or group. These social ends include all of our activities –

communication, work, rest, recreation, and sleep. Noise is a special type of environmental pollutant, a waste product generated in conjunction with various anthropogenic activities.

Only recently has attention been focused on the pollution of noise which is a type of energy residual. The total amount of energy dissipated as sound throughout the earth is not large when compared with other forms of energy; it is only the extraordinary sensitivity of the ear that permits such a relatively small amount of energy to adversely affect us and other biological species.

It has long been known that noise of sufficient intensity and duration can induce temporary or permanent hearing loss, ranging from slight impairment to nearly total deafness. In general, a pattern of exposure to any source of sound that produces sufficiently high levels can result in temporary hearing loss. If the exposure persists over a period of time, this could lead to permanent hearing impairment. Short-term, but frequently serious, effects include interference with speech communication and the perception of other auditory signals, disturbance of sleep and relaxation, annoyance, interference with an individual's ability to perform complicated tasks, and general diminution of the quality of life.

The engineering and scientific community has already accumulated considerable knowledge concerning noise, its effects, and its abatement and control. In that regard, noise differs from most other environmental pollutants. Generally, the technology exists to control most indoor and outdoor noise. As a matter of fact, this is one instance in which knowledge of control techniques exceeds the knowledge of biological and physical effects of the pollutants.

7.2. Source of Noise and Its Control

Transportation is a major source of noise. Aircraft and highway vehicles produce noise. The noise level is dependent on the size, and type of the aircraft and vehicle.

The industrial internal combustion engines and manufacturing machines also make noise. In general, these devices are not significant contributors to average residential noise levels in urban areas. However, the relative annoyance of most of the equipment tends to be high. The eight-hour exposure level is in reference to the equipment operator.

To solve the problem of noise, it is necessary to find out something about what the noise is doing, where it comes from, how it travels, and what can be done about it. A straightforward approach is to examine the problem in terms of its three basic elements: that is, sound arises from a source, travels over a path, and affects a receiver or listener. Solution of a given noise problem might require alteration or modification of any or all of these three basic elements: (1) Modifying the source to reduce its noise output. (2) Altering or controlling the transmission path and the environment to reduce the noise level reaching the listener. (3) Providing the receiver with personal protective equipment.

For source control, carefully designing the machine can accomplish a lot. (1)To reduce the impact forces. Many machines and items of equipment are designed with parts that strike forcefully against other parts, producing noise. Often, this striking action or impact is essential to the machine's function. Several steps can be taken to reduce noise from impact forces. (2) To reduce speeds and pressures. Reducing the speed of rotating and moving parts in machines and mechanical systems results in smoother operation and lower noise output. Likewise, reducing pressure and flow velocities in air, gas, and liquid circulation systems lessens turbulence, resulting in deceased noise radiation. (3) To reduce frictional resistance. Reducing friction between rotating, sliding, or moving parts in mechanical systems frequently results in smoother operation and lower noise output. Similarly, reducing flow resistance in fluid distribution systems results in less noise radiation. (4) To reduce radiating area. (5) To reduce noise leakage. In many cases, machine cabinets can be made into rather effective soundproof enclosures through simple design changes and the application of some sound-absorbing treatment. (6) To isolate and dampen vibrating elements. (7) To provide mufflers/silencers. The best way to solve noise problems is to design them out of the source. However, for existing sources, either because of age, abuse, or poor design, noise is a problem. To redress, or correct the problems as they currently exist, the following ways can be helpful: (1) Balance rotating parts. (2)Reduce frictional resistance. (3) Apply damping materials. (4)Seal noise leaks. (5)Perform routine maintenance.

The following measurements are for controlling the noise in the transmission path. (1) Separation. The absorptive capacity of the atmosphere, as well as divergence, as a simple, economical method of reducing the noise level. (2) Absorbing materials. Place soft, spongy material on walls, floors, and ceiling, the reflected sound will be diffused and soaked up. (3) Acoustical lining. Noise transmitted through ducts, pipe chases, or electrical channels can be reduced effectively by lining the inside surfaces of such passageways with sound-absorbing materials. (4) Barriers and panels. Placing barriers, screens, or deflectors in the noise path can be an effective way of reducing noise transmission, provided that barriers are large enough in size, and depending upon whether the noise is high frequency or low frequency.

The following two ways are often used to protect the receivers. (1)Alter work schedule. Limit the amount of continuous exposure to high noise levels. In terms of hearing protection, it is preferable to schedule an intensely noisy operation for a short interval of time each day over a period of several days rather than a continuous eight-hour run for a day or two. (2) Ear protection. Molded and pliable ear plugs, sup-type protectors, and helmets are commercially available as hearing protector. Such devices may provide noise reductions.

8. Environmental Standards and Voluntary Environmental Programs

Environmental standards as a significant part of environmental laws play a very important role in industrial pollution control. Their development encourages the establishment and practice of a good environmental management system.(see Environmental Standards Concerning Industrial Pollution Discharge).

The systems of good environmental management, adopted by industry, which go beyond (rather than replace) compliance with laws and regulations, is part of the quality revolution impacting both global and local companies and plants. From environmental auditing to environmental management systems, industry is increasingly focusing not just on compliance with laws — as important as that is— but also on continuous improvement in environmental practices as a marketplace demand.

Voluntary industry environmental diligence is labeled by some as an oxymoron, but it need not be so if such diligence facilitates, augments or goes beyond compliance with laws and regulation. Good environmental management was a growing trend in the 1900s. The World Resources Institute has produced an informative publication which catalogs many such voluntary industry environmental activities. Titled "Beyond Compliance" (1992), it was published in the period leading up to the Rio environmental conference of the early 1990s.

The word "beyond" in the title indicates industry processes and projects that are part of industry's commitment to managing the environment but that go beyond what has been required by legislation or regulation. Three points about voluntary environmental processes are as follows: (1) They should not be suggested, nor should they be initiated, to take the place of legal or regulatory requirements, but to build upon them. They work best when the legal requirements allow flexibility and choice adapted to local conditions and culture. (2) In any size company, they will catalyze environmental (including worker health and safety) commitment and action beyond mere regulatory compliance. They require demonstrated top management commitment. (3) They help motivate a plant or company towards environmental excellence, moving the plot of activity towards the right on a normal curve and thus away from serious incident or non-compliance.

At the Rio meetings in 1992, industry convened a two-day seminar on voluntary environmental processes and committed to developing further systematic practices. The slogan that best reflects this approach is "Good environmental management is good management". In Rio, it was recognized that national and sectional industry efforts focused on systematic environmental management, but it was also felt there should be a more truly global and generic environmental management approach which made use of management's interest in quality.

After Rio, industry undertook to define consensus environmental standards, analogous to the ISO (International Standard Organization) 9000 quality standard. These environmental standards, known as ISO 14000, focus on environmental management, auditing, and performance measurements, as well as other parameters, including what is now known as green labeling and life cycle analysis. An environmental management system (EMS) that includes continuous improvement, pollution prevention, and a systematic environmental auditing process is the basis of the voluntary ISO approach on which industry has globally agreed.

The ISO 14000 EMS is a growing self-composed standard for industry, and includes certification (the approach favored by many European companies) or being prepared to conform with ISO guidance and so demonstrate to customers (favored by many U.S. companies). It is also being practiced in many developing countries. In either case, responding to ISO 14000 environmental specifications is customer-driven. A customer might be a multinational, a local company, a government instrumentality, a local municipality, or even a court looking for diligence. It is clear that a customer's insistence that plant or business be certified, or ready for ISO certification, is a compelling reason for adopting good environmental management and auditing systems, as well as striving for the continuous improvement required under the ISO 14000 approach.

Interestingly, there is increasing evidence that courts, regulatory agencies, enforcement groups, municipalities, lending institutions, and financial groups propose to view activity that responds to ISO 14000 conformance requirements as an indication of diligence. And the smallest and largest countries (e.g. Singapore and China, respectively) show great interest in ISO, perhaps because they understand the marketing potential of green products. Such marketplace incentives go beyond simple cost and liability avoidance to development of good systematic environmental management approach – beyond compliance.

Simultaneous with the development of the ISO systematic approach, progressive industry continues to work with the United Nations Environmental Program (UNEP) on the development of "how to" processes for adopting good international environmental management techniques.

9. Industrial Ecology

In discussing the solutions to industrial pollution, it is worthwhile to introduce the idea of industrial ecology. Industrial ecology, which seeks to treat industrial systems in a manner analogous to ecological systems in nature, is an approach based upon systems engineering and ecological principles that integrate the production and consumption aspects of the design, production, use, and termination of products and services in a manner to minimize environmental impact while optimizing utilization of resources, energy and capital. The practice of industrial ecology represents an environmentally acceptable, sustainable means of providing goods and services. An ideal system of industrial ecology follows the flow of energy and materials through several levels, uses wastes from one part of the industrial ecosystem as raw material for another part, and maximizes the efficiency of energy utilization. Whereas wastes, effluents, and products used to be regarded as leaving an industrial system at the point where a product or service was sold to a consumer, industrial ecology regards such materials as part of a larger system that must be considered until a complete system of manufacture, use, and disposal is completed. Therefore, industrial ecology may provide an economically feasible way to fulfill the concept of sustainable development of industry and society.

People are used to considering the industrial system as separate from the biosphere, with factories and cities on one side and nature on the other, the problem consisting of trying to minimize the impact of the industrial system on what is "outside" of it: its surroundings, the "environment". As early as the 1950's, this end-of-pipe angle was the one adopted by ecologists, whose first serious studies focused on the consequences of the various forms of pollution on nature. Industrial ecology explores the opposite assumption: the industrial systems can be seen as a certain kind of ecosystem. Just as natural ecosystems, industrial system can be described as a particular distribution of materials, energy, and information flow. Furthermore, the entire industrial system relies on resources and services provided by the biosphere, from which it cannot be dissociated.

Industrial ecology has been manifest intuitively for a very long time. Today the concept is progressing with unprecedented vigor. In the past several years, the expression "industrial ecology" has begun to spread in a number of academic and business circles, with the beginning of a perceptible buzzword effect. The two words or concepts of "industrial metabolism" and "industrial ecology" should be clarified. "Industrial metabolism" is the whole of the materials and energy flows going through the industrial system. It is studied through an essentially analytical and descriptive approach (basically an application of a materials-balance principle), aimed at understanding the circulation of the materials and energy flows linked to human activity, from their initial extraction to their inevitable reintegration, sooner or later, into the overall biogeochemical cycles. This word was in use during the 1980's. "Industrial ecology" goes further. The idea is first to understand how the industrial system works, how it is regulated, and its interaction with the biosphere; then, on the basis of what we know about ecosystems, to determine how it could be restructured to make it compatible with the way natural ecosystems function.

Industrial ecology emerges at a time when it is becoming increasingly clear that the traditional depollution approach (end-pipe) is insufficient. It appears sporadically in the literature of the 1970s. As yet, there is no standard definition of industrial ecology. However, whatever the definitions may be, three key elements of perspective are: (1) It is a systemic, comprehensive, integrated view of all the components of the industrial economy and their relations with the biosphere. (2) It emphasizes the biophysical substratum of human activities, i.e. the complex patterns of material flows within and outside the industrial system, in contrast with current approaches which mostly consider the economy in terms of abstract monetary units, or alternatively, energy flows. (3) It considers technological dynamics, i.e. the long term evolution (technological trajectories) of clusters of key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem. By analogy with biological ecosystems, a successful industrial ecosystem should have three key characteristics. (1) renewable energy, (2) complete recycling of materials, and (3)species diversity for resistance to external shocks.

Industrial pollution control turns to the emphasis of pollution prevention and implementation of cleaner production. Pollution prevention and cleaner production are important elements of industrial ecology. The point of industrial ecology is to integrate end-of-pipe approaches and prevention methods into a broader perspective, to which they should be subordinated.

The industrial ecology approach evolves in two main directions. One is "Eco-industrial parks, and islands of sustainability". The most immediate application of the ecological concept of food webs between companies lies in the creation or retrofitting of industrial zones where waste or by-products of one company are used as resources by another company: hence the concept of "eco-industrial park (EIP)". More generally, there is the idea of creating "industrial biocensors" around certain specific industrial activities. Such industrial clusters would have minimal emissions. In fact, the idea of systemic waste exchanges can be extended beyond the boundaries of an industrial zone, and can lead to regional thinking, like the concept of "islands of sustainability". The other one is "dematerialization — decarbonization and the service economy". It relates to the development of concepts and strategies for the optimization of the flows of materials within the economy, which is largely based on technological evolution. This implies an increase in resource productivity, or dematerialization. One very promising approach to what may be called "system dematerialization" is the strategy of the service economy, which promotes the selling of services instead of products. Systemic dematerialization refers to the fact of increasing the resource productivity not only at the level of the product, but at the level of global infrastructures, in order to reduce not only the total material throughput, but also, most importantly, to decrease its speed within the industrial system, thus minimizing the problem of dissipative emissions during normal use.

The industrial ecology concept and methodology are still in their development. But their essence is to take the industrial system as part of the biogeochemical sphere of the nature, to investigate the performance of the system in order to make it most compatible to the biosphere: these will provide a bright perspective to solutions of sustainable development of industry and society. Today, beyond the political ecologist view and fashionable rhetoric on sustainable development, the actual motivation for this evolution obviously lies in an increased economic competitiveness: industrial ecology is a way for corporations to better exploit their products and resources (including their wastes) more efficiently, and therefore, more profitably.

10. Future Perspectives

In industry, the past years have brought about a revolution in awareness of the urgent need to protect the environment. Industries are now making increased efforts in environmental protection, both in terms of reducing point-source emissions, risk management during chemical use and handling of hazardous waste. Still, financial concern is a main motivating factor to many of these activities – not solely environmental concerns. However, new legislation, stricter controls and growing consumer demands for environmentally-sound products will have an impact upon the way industry operates and the types of products it makes. Thus, industry must increasingly take its own initiatives to prevent further environmental degradation.

The characteristics of a country's environmental regulatory system should be likely to encourage economic and environmental growth, examining body traditional approaches that mandate business participation as well as voluntary systems. Combining mandatory approaches with voluntary ones offers great promise for reducing the conflict between economic development and environmental protection.

The future industrial environmental management depends on some critical factors: (1) Sustainability. There must be acceptance and enthusiastic support for sustainability, that is, mutual support of economic and environmental considerations in society to preserve and advance the quality of life today and for future generations. Only cooperation and intelligent pursuit of economic interests and the common environmental good by us, including particularly between the haves and have-nots, will suffice. (2) Economic growth. Continued prosperity and responsible economic growth is essential to environmental progress. The reality is that present and continued investment in environmental protection is predicated on economic well-being. Capital and technology flows are dependent on open trade, and the trade and environmental linkage requires mutual supportiveness for sustainability. (3) Legal requirements. Compliance with environmental laws and regulations is essential, along with evenhanded enforcement. Performance-based environmental laws and regulations that complement and stimulate market-based environmental approaches, as compared to overly prescriptive command-and-control requirements at local, national, regional, and global levels, will afford the best chance of improving the environment. (4) Voluntary programs. Opportunities should be seized and developed by all sectors of society to encourage, support, and implement voluntary programs beyond legal compliance to enhance sustainability.

Glossary

BOD:	Biological oxygen demand
COD:	Chemical oxygen demand
CO:	Carbon oxide
HC:	Hydrocarbon
NO_x :	Nitrogen oxide
OECD Countries:	Organization for Economic Cooperation and Development
POTW:	Publicly owned treatment works
ppb:	concentration unit, parts per billion
SO_x:	Sulfur oxide

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