ESTs are available to address the problems of air pollutants, including noxious gases, liquid and vapour particles, dusts and fumes.

ESTs for pollution control 6

A wide range of environmentally sound technologies (ESTs) is available for controlling air and water pollution, treating contaminated wastewater, handling the huge volumes of solid waste produced by industry and households, and monitoring environmental performance – vital for effective abatement strategies. These technologies are not a substitute for cleaner production solutions, but they are effective. This chapter reviews the main ESTs in each category, and assesses their features and benefits.

The portfolio of environmentally sound technologies available today for controlling and abating pollution, rather than preventing it, is an extensive one, and includes the following:

- air pollution control – reducing and eliminating gases and particulates;
- water and wastewater treatment – removing pollutants from sewage, and purifying pollutants and contaminated drinking water and industrial wastewater;
- waste management – reducing the amount of solid waste produced, and treating and disposing of what waste is left;
- recovery and recycling;
- clean-up activities – contaminated land remediation and treating environmental disasters;
- environmental monitoring – assessing environmental quality and performance.

They are well-tried technologies (some of them many years old). Their costs range from moderate to high and they are continually being improved. They fall far short of a cleaner production approach to pollution problems and are essentially an interim solution, but they are effective in reducing pollution levels.

Air pollution

Air pollutants come in many forms: noxious gases (hydrogen chloride, nitrogen oxides or sulphur dioxide, for example), liquid particles, vapour particles, dusts, fumes and entrained particles. ESTs are available to address all these problems.

- Flue gas desulphurization is the main technology for post-combustion pollution control in coal burning. Both ‘dry’ and ‘wet’ processes use lime or limestone to ‘scrub’ carbon dioxide from emissions. Flue gas desulphurization processes can remove more than 90 per cent of sulphur dioxide and can be fitted to existing power plants. A combination of flue gas treatment and combustion modifications can control the formation of nitrogen oxides.
- Wet scrubbers remove gas and liquid particulates by causing the contaminants to stick to a large wetted area before they are washed or dissolved away. Capital investment, operating and maintenance costs are moderate to high.
- Venturi scrubbers are a relatively low-capital investment system offering good chemical and particulate recovery efficiencies. They differ from wet scrubbers in relying on the pneumatic pressure of a high-velocity gas stream rather than hydraulic pressure for atomizing the scrubbing liquid.
- Dry collection systems use fabric filters, a device similar to a large vacuum cleaner bag, to separate suspended impurities from

BOX 6.1
Emissions control at an incineration plant

Luxembourg is one of the smallest countries in Europe, with just 400,000 people. Yet around 200,000 tonnes of municipal solid wastes are generated there every year – of which an average 135,000 tonnes is incinerated in a waste-to-energy plant at Leudelange.

The plant is over 20 years old. When first built, it was fitted with electrostatic precipitators for flue gas cleaning – at the time, state-of-the-art technology. In 1986, a semi-dry flue gas cleaning system was added, together with bag filters. At the end of 1995, extensive modifications were carried out to improve combustion controls and reduce emissions to a level even lower than the stringent targets proposed by neighbouring Germany.

The upgrade provides three new 8-tonne-an-hour furnaces, as well as an extensive flue gas recirculation system, a catalytic reactor and the injection of ammonia to reduce nitrogen oxide emissions to about one-third of European Union limits.

BOX 6.2
New lithography technology

One company has developed a lithographic printing system that could stop the industry from emitting some 500,000 tonnes of volatile organic compounds (VOCs) into the air every year. It features a 100 per cent vegetable oil based lithographic ink that washes off presses with a water solution, eliminating the use of VOC-emitting solvents. The United States Environmental Protection Agency has proposed control technique guidelines that limit VOCs in press wash to less than 30 per cent of total weight. The company has introduced the system in more than 50 of its own plants, and has already reduced VOC emissions by more than 50 per cent.

process liquids. The cloth filters can control dust concentrations ranging from sub-micrometre fumes to powders 200 micrometres in diameter.

- Electrostatic precipitators can achieve efficiencies up to 99.9 per cent and handle large volumes of gas at low power consumption. They operate like a glass rod rubbed with a silk cloth, giving the rod an electrostatic charge so that it attracts uncharged bits of lint and paper. Capital investment, operating and maintenance costs are moderate. Electrostatic precipitators are used for:
  - ventilating low operating temperature processes exposed to heavy fumes and dust, such as asphalt saturators and converters, glass melting, aluminium reduction pot lines and carbon plants;
  - collecting pollution generated during grinding operations, such as cement or gypsum grinding;
  - drying cement, gypsum, bauxite and various ores;
  - controlling air pollution from the processing of materials such as cement, gypsum, alumina and magnesite;
  - treating gases from blast furnaces and other processes used in producing non-ferrous metals;
  - recovering sulphuric and phosphoric acid, leaving the cleaned gases to be discharged into the atmosphere or sent to a scrubber for removing the remaining sulphur dioxide;
  - recovering fly ash from coal-burning boilers.
- Cyclones make use of centrifugal force to separate dust, liquid droplets and gas. Because they are easy to make, and contain no moving parts, they can be built from a wide variety of materials, covering operating temperatures up to 1,100 degrees C. Capital investment, operating and maintenance costs are low.
- Direct-flame and catalytic combustors in fume control oxidize organic pollutants in exhaust gases to form non-polluting by-products. Applications include: chemical processing, metal finishing, rubber and plastic processing, and sewage disposal. Capital investment, operating and maintenance costs are moderate to high.

- Gas adsorbers use the ability of certain solids to concentrate specific substances from the gas stream on their surfaces. They can remove two major condensable impurities – carbon dioxide and water vapour. Investment costs are moderate; operating and maintenance costs are moderate to high.

Water and wastewater treatment

Less than one-hundredth of the world's water supply is usable in its natural state. The increasing need for safe, reliable water supplies has created new requirements for water and wastewater treatment systems. The major treatment processes are outlined below.

- Filtration, one of the earliest, is still important and becoming increasingly sophisticated. The method, used to separate a relatively small amount of solids from the liquid, involves passing the mixture through a porous filter, which can be cloth, porous metals, porous stone and diatomaceous earth, or graded beds of sand or anthracite coal. This should leave only the smaller, lighter suspended particles and coagulated matter in the discharge stream. When these are brought onto a clean filter bed, they will be retained in the top few centimetres of the bed. They then build up on the bed surface, where a mat is formed which serves as a fine-grain filter and affords a finer screening than when the filter bed is operated initially.
- Aeration involves using air or oxygen to break large volumes of water into droplets, increasing the area available for oxygen transfer for biological treatment using the aerobic process.
- Carbon adsorption can eliminate organics not completely removed by conventional biological treatment. It involves passing the contaminated stream through a vessel with either carbon granules or a slurry. Adsorption removes the impurities. Contactors for granular carbon also function as filters, removing suspended particles from the stream. The carbon adsorption capacity can be rejuvenated after it becomes exhausted. Carbon adsorption does not work well where the molecules are small or highly polar, nor with wastewater with a very high pH value.
- Ion exchangers remove dissolved minerals from aqueous solutions by using specialized insoluble, inorganic compounds (called zeolites) or synthetic organic materials such as ion-exchange resins. The process is called demineralization. Substances to be removed by an ion-exchange system have first to be ionized.
- Air stripping can remove volatile organic compounds (VOCs) from contaminated wastewater and groundwater, through a physical separation process to transfer the VOCs from a liquid to a gaseous phase. The higher the volatility of a compound, the more easily it is stripped. Air strippers can remove VOCs such as vinyl chloride, trichloroethane,

BOX 6.3

Zero wastewater emission in the wiredrawing process

The wiredrawing process contaminates waste rinse waters with sulphate and nitrate salts. A company in Italy has now achieved zero emissions by introducing a range of technologies and new processes.

Its first effort was to install a chemical precipitation plant. Since the early 1980s, full water re-use has been introduced, which enables a partial drag-out recovery. The present process management solved the problem of wastewater pollution, but still left some outstanding critical issues: the disposal of a considerable number of chemicals as hazardous waste; high-energy consumption; and an increase in the salinity of recycled rinsing water due to an accumulation of sulphates and nitrates.

The company introduced a closed-cycle heating system, as well as multiple cascading rinsing at two stages of the process, with the final rinses carried out by recirculating water generated through ion exchange and reverse osmosis respectively. These changes resulted in a 95 per cent reduction in sludge and a 90 per cent cut in chemical consumption, as well as savings in water and energy usage.

THE POWER GENERATION COMPANY OF TRINIDAD & TOBAGO LTD.

The Power Generation Company of Trinidad & Tobago Ltd. – known locally as PowerGen – is a joint venture company formed between the Trinidad & Tobago Electricity Commission (T&TEC), Southern Energy, Inc. and Amoco Power Resources Corporation following the partial divestment of T&TEC's generating plants.

We own and operate 1,178 megawatts of installed capacity across three power stations in Trinidad, and are currently the sole electricity producer there, supplying all the needs of T&TEC, which remains responsible for the transmission and distribution of electricity to all consumers.

PowerGen's shareholders recognized the impact power generation has on the environment in Trinidad & Tobago when the new company was formed – and one of our first undertakings was to include environmental enhancement projects while refurbishing our plants and upgrading our facilities. We have agreed an environmental policy, and we are developing an environmental management programme.

These actions demonstrate that care for the environment is becoming as much a part of our business as the business of making electricity itself.

As the introduction to our environmental policy states: "PowerGen is committed to operating and expanding our business in an environmentally responsible manner. In discharging our responsibilities to stakeholders, we will meet our legal obligations to the preservation of the environment, and continuously improve our environmental performance."

The key aspects of our environmental policy include:

- educating our employees to integrate environmental responsibility into their work
- supporting local environmental education and improvement efforts
- supporting the development of environmental laws and regulations which assist sustainable national development
- reducing waste and improving the efficiency of our work processes
- operating documented environmental management programmes which include performance goal setting and monitoring, and
- allocating appropriate resources to implement our environmental management programmes.

The important thing to recognize in our programme is its cost-effectiveness.

The highest impact areas are the lowest cost areas. Training employees to improve the handling of waste oil, solvents and other hazardous chemicals is inexpensive, and can dramatically reduce harmful discharges. Building proper oil and chemical storage facilities and monitoring environmental performance with modern instrumentation is not costly, and can provide a high degree of reassurance to the company's management, which is ultimately responsible for the organization's environmental performance.

The Power Generation Company of Trinidad & Tobago is committed to protecting and enhancing the environment in which it operates in a sustainable way – one which results in a quality of life that is both environmentally and economically beneficial.

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trichloroethylene and tetrachloroethylene, as well as pesticides such as chlordane, dibromochloropropane and aldicarb, and chlorinated aromatics such as dibromobenzene. Removal efficiencies of 99.9 per cent have been achieved in many cases.

- Membrane separation has been used for many years to separate organic and inorganic solids from solutions. The membrane, usually made from a variety of synthetic polymers, allows some compounds through, but rejects others. Reverse osmosis, ultrafiltration and electrodialysis are all processes that use some kind of membrane to separate a mixture of organic or inorganic substances. Membrane-based processes separate contaminants on the basis of their molecular weight and size: for example, ultrafilters reject oil substances, while reverse osmosis rejects ionic impurities. Experts predict that reverse osmosis, well established in desalination projects for a number of years, is set to expand into other applications such as the recovery of vehicle antifreeze or pressboard manufacturing waste in pulp mills.
- Precipitation is a three-step process for removing heavy metals such as cadmium, chromium, lead and copper from industrial wastewaters by adding acids to adjust the pH value, then aggregating the fine crystallites to form large crystals, and finally removing the heavier crystals by gravity in the sedimentation tank.
- Biological treatment cleans aqueous streams containing organic contaminants. In aerobic biological treatment, both simple and complex organics are eventually decomposed to carbon dioxide and water. In anaerobic biological treatment, only simple organics like carbohydrates, proteins, alcohols and acid can be decomposed (see Chapter 12).

The efficiency of each of these technologies depends on a large number of parameters. But selecting the one most appropriate for the treatment of a particular waste can achieve high removal and destruction efficiencies.

One emerging new trend is the multimedia approach – using a combination of technologies, rather than a single treatment. In the United States, one closed-loop system designed to remove VOCs from industrial wastewater uses nitrogen for removal, activated carbon for adsorption or collection, and steam for recovery and concentration. In this system, nitrogen-stripping, an economic, energy-efficient and fast way of removing VOCs, separates VOCs from the effluent wastewater. The resulting vapour

BOX 6.4

Treating wastewater in the rubber industry

Designing a system to treat the effluent from the processing of latex concentrate and the production of Standard Malaysian Rubber has become an important and challenging goal, since Malaysia has about 80 latex concentrate and 100 rubber factories which produce contaminated wastewater.

One company found a cleaner production alternative to the traditional method of treating the wastewater in biological oxidation ponds as permitted standards for discharge of effluents into waterways have become very stringent.

The new wastewater treatment system is essentially an upward-flow clarification system with integrated filtration and aeration features that makes use of both physiochemical and biochemical processes to reduce the chemical oxygen demand, the biological oxygen demand and the solids content of the effluent.

The system’s features include: instant coagulant ‘penetration’ of the solids barrier, resulting in ultrashort chemical reaction time and optimum precipitation efficiency; dual-stage clarification that maximizes the rate of clarification and produces highly clarified water; closed-loop hydraulic agitation that improves oxygenation of the flocculating mass; cascade aeration following filtration which improves the level of dissolved oxygen.

The system – which is relatively inexpensive and easy to operate – has reduced biological and chemical oxygen demand by as much as 90-95 per cent. Discharge to the waterways is effectively zero and water re-use conserves an important resource.

BOX 6.5

Solid and hazardous waste in Egypt

With a population of over 50 million, and growing, as well as rapid industrialization and urbanization, Egypt has faced the full array of waste issues – particularly in Cairo. Until recently, solid waste was discarded and dumped indiscriminately, but the Egyptian government has recognized that poorly managed waste is harmful to further economic growth.

A study of the problem found that 60 per cent of municipal solid waste is from households, 15 per cent from business, 15 per cent from street sweepings and gardens, and 10 per cent from construction and demolition activities. About 60 per cent of the waste is food, 13 per cent metals, 20 per cent paper and only 2 per cent plastics.

In 1986, sanitary or engineered landfills for solid waste disposal were introduced in the Cairo area, and since the mid-1980s about 80 incinerators have also been installed, though without energy recovery. However, these have proved disappointing because of the high operating, labour and maintenance costs. The decision has now been taken to pursue incineration only for some industrial hazardous wastes. Composting looks to be the most promising solution, and five facilities were built during the 1980s.

Overall, Egypt illustrates the typical evolution of waste management. First, indiscriminate dumping is curtailed and safer, more costly, forms of land disposal are used. Then, attempts at waste treatment are tried, but cost proves a major handicap. The next step is to focus on waste reduction. The question is whether Egypt, and other countries, will follow the traditional waste management hierarchy – which could take several decades – or jump more quickly to a national commitment to waste reduction.

stream is saturated with water, cooled, and then reheated. The VOCs in the gas stream are adsorbed using one of two carbon adsorbers. The resulting condensed steam and VOCs are then available for recovery and re-use. The critical element in the system is an adsorbent-activated carbon, a highly efficient adsorbent, that is combined with on-site regeneration. In refinery operations, this system removes more than 99 per cent of benzene and other VOCs from the waste stream, and these are recycled back to the crude feed tank for re-use, not released into the atmosphere. The system is operating at nine major United States refineries and is also being used by a major electronics company for removing trichloroethylene from groundwater.

Solid waste treatment

Solid waste, like liquid waste, is an inevitable by-product of industrial activity and modern living but is a more immediately visible problem. Industry, homes and shops generate mountains of solid waste every year, a major problem for the developed countries, and a growing one elsewhere. Industrial waste includes slag, bricks, dust, sludge, paper, acid, oil and plastics. Domestic waste includes paper, steel and aluminium cans, bottles, electrical appliances, and even cars. In many western countries, solid waste is the environmental problem people seem to care about most. Municipal waste has actually been growing more slowly than overall economic growth but this does not alter the fact that it is still growing. It still has to be put somewhere. The choices are to bury, burn, compost or recycle it.

Landfill

Most solid waste is landfilled. But in many countries, there are fewer – in some cases, no more – sites available, and landfill space is at a premium. In the United States, the number of legal landfills has dropped by more than two-thirds since 1979. Holland has no landfills left at all. Shortage of land has pushed up the cost of landfill. So have increasingly stringent regulations, designed mainly to make the practice safer, rather than stop it. In developing countries, the open dumping of solid, often hazardous, waste without any controls raises enormous health and safety problems. In most industrialized countries, old and new landfills are being required to meet higher standards to prevent pollution. The best new sites now incorporate sophisticated liner membranes, made from natural or synthetic materials, which contain the pollution, while advanced monitoring techniques continuously test the groundwater quality around the sites. Sealed landfill sites can also produce methane-rich gas which, when harnessed in gas recovery plants, can typically generate enough electricity to serve 10,000 homes.

Waste to energy

There is a vast array of technological options available to treat and reduce the amount of solid waste before it is dumped. Incineration – the main thermal method – is one option. The waste is burned to convert combustible materials into gases, leaving a solid residue of ceramic and metallic materials. Other high-technology forms of thermal treatment include plasma and thermal desorption furnaces for destroying hazardous waste, and methods that convert solid waste into petrol-like liquid or into ceramic aggregate or particulate material.

The problem with thermal methods is their high cost, and environmental concerns about air pollution and residue management. In fact, waste incineration is controversial and fiercely opposed by many environmentalists. Most waste is organic: it has come to the end of its useful life cycle and has no more value if recycled further, yet it has a useful energy content, which can be harnessed for heat and power by burning it in waste-to-energy plants. One tonne of municipal waste contains as much recoverable energy as 2.5 tonnes of steam, or 30 tonnes of hot water at 180 degrees C, or 500 kilowatt hours of electricity produced by a generator. Residues left after burning the waste can be landfilled.

Currently, Europe produces 200 million tonnes of municipal solid waste annually, with 24 per cent being used for energy recovery. Recovering energy from renewable sources saves resources by replacing fossil fuels. Europe is saving an estimated 5.5 million tonnes of coal each year, and the estimated capacity for energy from waste is 33 million tonnes annually, saving 11 million tonnes of coal. The waste is burned in specially designed combustors. Heat exchange from the very hot combustion gases produces hot water or steam. This is used directly to provide heat for local communities, or to drive turbines to generate electricity.

Since the mid-1980s, state-of-the-art technology has been able to reduce gas emissions from household waste combustors dramatically. Advanced flue gas cleaning techniques mean most of the unpleasant gases from incinerators can now be scrubbed from the smoke, so that emissions of acid gas are very low, absolutely and relative to other forms of power generation. Dioxin emissions are also reduced to negligible levels.

Most waste-to-energy plants worldwide use a technology called ‘mass burn’: mixed

BOX 6.6

Waste-to-energy schemes work in Scandinavia

Waste-to-energy schemes are particularly well established in Denmark, Norway and Sweden.

- The Amagerforbraending incineration plant in Denmark processes 320,000 tonnes of household waste every year – one-third of the total from the area – and extracts enough energy to provide 1.5 million gigajoules of heating for the district. All the production stages are controlled by high-technology computers. These are linked to technologies for treating and filtering the flue gas, to keep emissions well within regulatory limits.
- The Grinda plant near Oslo, Norway, handles 50,000 tonnes of domestic waste a year, and uses a new process to convert about 55 per cent of this into fuel briquettes, which are used by a local paper mill as an alternative source of energy in its production processes. Of the remaining waste, 35 per cent is composted and the final 10 per cent – usually metals, stone and glass – is landfilled.
- The fluidized bed combustion plant at Lidköping, near Gothenburg, Sweden, handles 30,000 tonnes of municipal and commercial waste a year, and provides hot water for low-cost heating for a hospital and about 18,000 of the town’s population of 25,000.

Almost half of Sweden’s household waste is incinerated with energy recovery and, in total, waste incineration provides 4,400 million kilowatt hours of energy a year, enough to meet the needs of 250,000 homes.

The Helsinki Solution:

Combined Energy Production and District Heating

Ilkka Pohjanpalo, Helsinki Energy

Due to district heating and concentrated energy production, almost all house chimneys have become redundant in Helsinki.

Helsinki's solution for saving energy and protecting the environment is based on the combined production of heat and electricity, and district heating.

The electricity and heat required in Helsinki are produced at Helsinki Energy's own power stations. Helsinki Energy distributes electricity and heat to over 300,000 customers in the Metropolitan Area. In addition, electricity is sold to other parts of Finland. City-owned Helsinki Energy is also selling natural gas to industry replacing heavy fuel oil. Concentrating energy production at our sites means that there are very few chimneys in use, so the air in the Metropolitan Area has become remarkably cleaner. The district heating system (first introduced in the 1950s) has raised the efficiency of energy supplies from 40 percent to 80 percent – with enormous savings on fuel and major benefits for the environment.

The share of natural gas in Helsinki Energy's production has risen to over 50 percent of all fuel used in producing energy to supply customers. This is due to the two natural gas-fired combi power plants operating in Helsinki.

Consumers themselves are extremely energy-conscious. The average heat consumption in homes supplied by the district heating system has fallen from 65 kWh/m^3a to 44 kWh/m^3a.

In addition, the use of modern low NOx combustion technology, desulphurization plants and electrostatic precipitators has led to drastic reductions in emissions of sulphur oxides, nitrogen oxides and dust. The biggest environmental problem in Helsinki today is the floating dust raised by traffic.

The combustion residues (fly ash and the end product of desulphurization from the coal-fired power plants) are used for land filling and as foundation materials. Fly ash is also used as a binding agent in the cement industry. Leftover end products are used to fill old shafts.

Helsinki Energy is also working with other organizations to find new uses for solid waste. In addition, the company is committed to halving the different kinds of chemicals it uses before the year 2000 and is training all its staff to ensure the practical implementation of its environmental policy decisions.

It is not surprising, therefore, that the Helsinki Solution for energy management – and especially the role of district heating – is being followed by many other cities in the world. Helsinki Energy is now playing a leading role in rehabilitating the energy systems throughout the Baltic States and Eastern Europe.

HELSINKI ENERGY MANAGEMENT IN FIGURES

		1960	**1975**	**1990**	**1995**
Electricity Supply	GWh/a	583	1,667	3,117	3,712
District Heat Supply	GWh/a	357	3,305	5,425	6,342
Share of District Heating	%	8	60	88	91
Energy Efficiency of Helsinki Energy	%	47	77	82	85
Specific Heat Consumption in Buildings	kWh/m^3a	65	58	47	44
Emissions (SO_2)/Produced Net Energy	t(SO_2)/GWh	5.8	2.6	1.6	0.6
Emissions (NO_2)/Produced Net Energy	t(NO_2)/GWh	1.9	1.4	1.5	0.7
Emissions (CO_2)/Produced Net Energy	kt(CO_2)/GWh	0.9	0.5	0.4	0.4

Helsinki Energy

unprocessed waste is burned on a continuously fed grate. This basic process has not changed for some years, though it has been improved and upgraded. Mass burn incinerators can handle waste of all shapes and sizes. Its critics say this encourages the widespread burning of materials that could have been recovered.

An alternative way of burning waste for energy recovery is to process it into a more homogenous fuel, then burn it in a fluidized bed boiler. This is typically a cylinder with a bed of sand or similar material. When operating, the fluidized bed consists of a mixture of hot sand, ash particles and a small amount of fuel (the waste). The bed moves constantly because of air injected through it – and the good mixing of air, fuel and sand caused by the turbulence inside the boiler ensures both good combustion and reduced emissions. Its supporters say that the need to reprocess the waste to a uniform size and remove materials such as metals means that fluidized bed technology fits well with materials recycling. Another attraction is that the scale of fluidized bed combustion is typically 30,000-60,000 tonnes a year, against an average 200,000 tonnes or more for mass burn plants – which may make the technology more acceptable to local communities. Fluidized bed combustors are already operational in Japan and Scandinavia.

The Organisation for Economic Co-operation and Development (OECD) says that energy recovery from waste incineration is "particularly attractive" in cities "because it satisfies two important, but apparently separate requirements simultaneously: the need to dispose of substantial quantities of wastes, and the need to provide for heating and electricity demands. It becomes a suitable solution to these two problems due to the coincidence of the relatively high density of waste generation, and heating and electricity loads in the urban environment." However, the OECD makes the point that waste incineration can conflict with recycling policies.

Public opinion in many countries still needs to be won over for an expansion of waste-to-energy projects. It also remains to be seen whether waste incineration is a viable proposition for most developing countries: the high cost and technical complexity of incineration units with extensive pollution control systems make them a risky investment.

Recovery and recycling

Chemical recovery methods are largely used for hazardous waste treatment. They include chemical fixation or stabilization, which blends the waste with carefully controlled liquids to produce a cement-like material that holds in any toxic chemicals. However, while these methods are relatively low cost, the materials still have to be landfilled. Another category of chemical treatment is one that breaks down certain types of toxic organic molecules into simpler, harmless materials. Solid and hazardous wastes can also be treated by biological methods (see Chapter 12).

There is no doubt that chemical recovery has the potential to help solve the problem of waste, especially plastic waste. For this reason, it is attracting significant research-and-development investment by the plastics industry. Plastics waste can be a particular concern, and this is linked to another factor: the changing composition of much waste. A major component now is packaging: cardboard, corrugated fibreboard, wood, polystyrene foam, paper, blister packs and other plastics. The volume of this waste can, and should, be minimized at source by:

- redesigning the packaging structure to eliminate one or more layers;
- modifying production and/or product design of existing packages to reduce weight;
- replacing the packaging with more environmentally acceptable alternatives, preferably completely biodegradable.

For the moment, however, packaging generally remains a significant contributor to the waste problem.

One important new materials breakthrough could help tackle the issue of plastic waste. It is the replacement of conventional low-cost, petroleum-based plastics with agriculturally derived materials made from crops such as corn or potatoes, or from food-processing solid waste. These new 'biopolymers' have similar characteristics to such plastic products as disposable food service utensils and bags, and can be manufactured using the same equipment. But they can be made to be fully biodegradable and compostable under various conditions. The new materials present an attractive option both for industrialized countries, to replace plastics, and developing countries, to overcome the glut of plastic waste dumped openly.

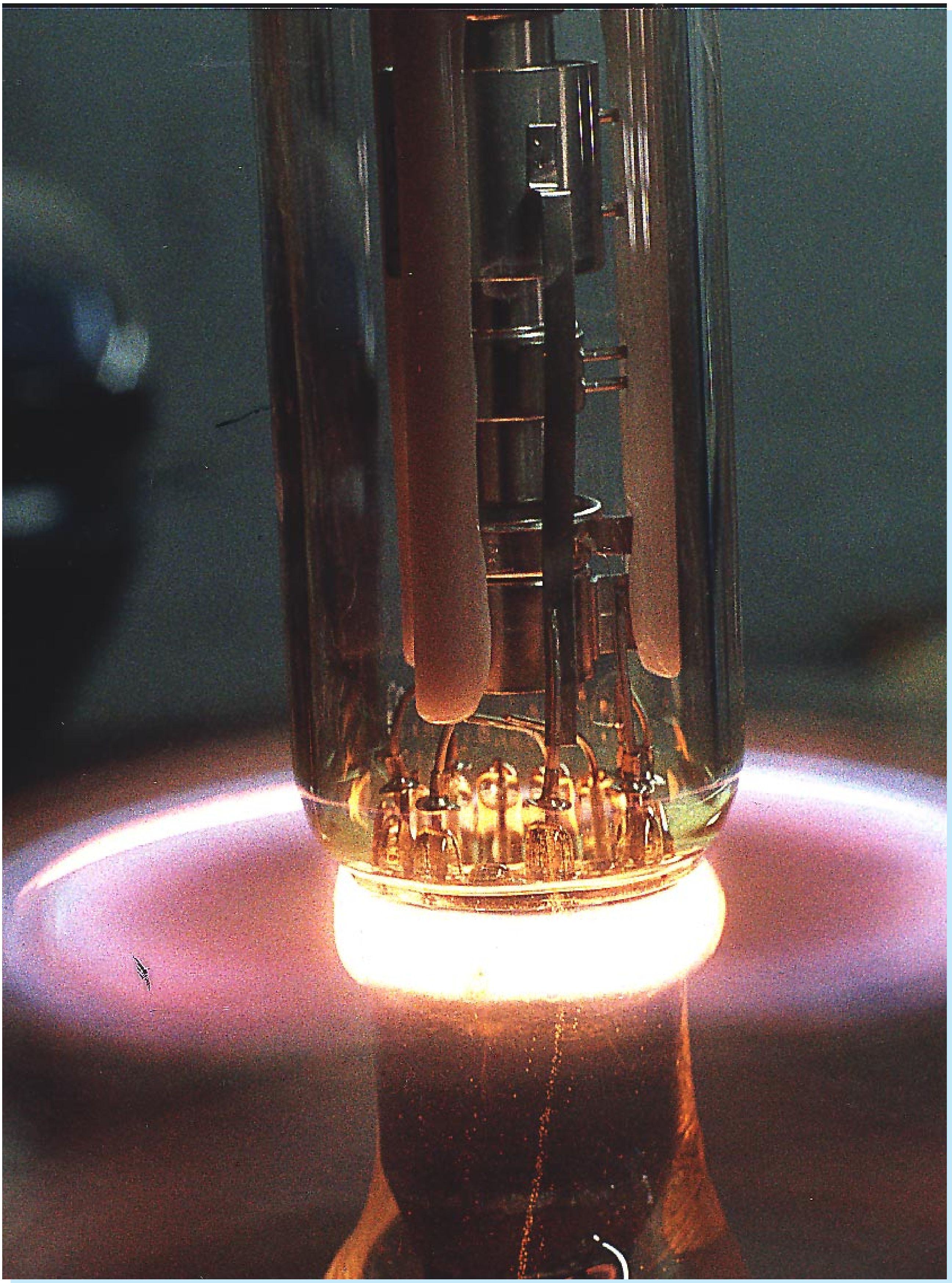
Several major United States companies have invested heavily in developing and commercializing 'biopolymers'. Products made from them include loose-fill packaging 'peanuts', previously made from polystyrene, golf tees, and bags to collect compost that are fully biodegradable and stronger than paper bags. A United Kingdom company is also developing a natural polymer made by bacteria that eat sugar. When discarded and in contact with bacteria found in water and soil, it decomposes leaving only carbon dioxide, water and a small amount of biological material. This could replace some of the plastics now in use, such as starch-based and lactic-acid polymers.

Recycling is a pollution control and a pollution prevention approach, involving both technologies and processes. It has become an increasingly favoured solution to waste management problems in industrialized countries. But it is also a key element in developing a closed-loop approach to industrial and economic activity. There will still be waste from industry and consumers, even with cleaner production approaches. Recycling is based on the principle that waste should be treated as a resource in its own right thereby reducing demand for natural resources and the amount of waste needing final disposal. It can also reduce overall energy consumption and pollution.

Recycling involves three steps: recovering recyclable waste; processing it into new materials or products; and marketing those products. Waste recovery for recycling is called reclamation. The recovery stage can require waste collection and separation, especially when the materials are mixed with other wastes. Recycling can be carried out on site (the waste being reprocessed where it is produced) or off site (in a separate processing facility). Several distinct forms of technologies and processes are used in recycling.

- Mechanical recycling is the processing of recyclable waste into new products without changing its chemical structure. Glass waste can be melted and remoulded, waste textile fibres can be separated and graded, before being turned into new products.
- Chemical recycling involves more fundamental changes to the molecular structure of the recyclable wastes. Plastics can be 'cracked' to produce simpler molecules, to create a range of new products. These forms of recycling are sometimes called feedstock recycling.
- Closed-loop recycling is a process for sending recyclable waste back into the same products. For example, aluminium-can waste is recycled back into aluminium cans.
- Open-loop recycling is a process for transforming one product into another. For example, polyethylene terephthalate (PET) bottles can be made into plastic products for use in engineering.

Using recycled materials reduces the use of virgin material, conserving natural resources as well as minimizing pollution problems in industries that convert raw materials into finished products. For example, steel produced from scrap reduces air pollution by 85 per cent, cuts water pollution by 76 per cent and eliminates mining wastes altogether. Paper made from recycled material reduces air pollutants by 74 per cent and water pollutants by 35 per cent.



Cathode ray tubes are recycled using laser technology. This process saves over 250,000 such tubes that would otherwise be disposed of every year.

BOX 6.7

Recycling – an option for leather tanneries

There are small leather tanneries all over the world – many in developing countries. They pose a number of environmental problems, with end-of-pipe solutions adding considerably to running costs. But there is growing pressure on tanneries to tackle their problems.

A recovery and recycling project in Greece has shown that tanneries in developing countries have the opportunity to skip standard pollution control measures and use a waste reduction approach that reduces operating costs as well as eliminating environmental problems. The project, run from 1988 to 1990, investigated how trivalent chromium – a major tanning agent and the main cause of the environmental problems – could be better managed through recovery and re-use.

The tannery near Athens produces 2,200 tonnes a year of high-quality leather from cattle hides. Its annual revenues are more than US$8 million, making it typical of tanneries in many other countries. The environmental issue is that untreated chromium-contaminated wastewater creates an industrial hazardous waste, and using water treatment pollution control technologies produces hazardous sludge. In chrome tanning worldwide, between 20 and 40 per cent of the chrome purchased is discharged into wastewater.

The Athens project confirmed that with new technology, 95-98 per cent of the waste chrome can be recovered and recycled within a plant. The process involves filtering and pumping the liquids that are left after hides are soaked in a chromium sulphate solution to a treatment tank where magnesium oxide is added to achieve a certain level of alkalinity. This causes precipitation of chromium hydroxide as a sludge. The clear water is removed and the remaining sludge is dissolved in concentrated sulphuric acid. This new liquid is then available for re-use as a tanning solution – and relatively clean wastewater is discharged. The technology can be used in every conventional chrome tanning operation, and reduces the amount of chemicals to be bought, making tanneries more profitable – because chemical costs are a very large proportion of their total operating costs.

Some of the best-known examples of high-value recycling include paper with a very high recycled-paper content, steel and aluminium made entirely from scrap materials, and automotive oil made from reprocessed oils. Refining waste oil from factories and using it to create fuels, and compressing waste paper and wood to make solid fuels, provide alternative sources of energy to oil or coal. However, one drawback can be that the price of products, for example, paper made from recycled materials, is higher than products made from virgin materials because the older, larger facilities that work with virgin materials have a competitive advantage over more expensive, newer and small-scale plants converting recycled materials.

Re-use also includes public and private waste exchanges through which companies can send non-product outputs to be used by other firms to reduce the virgin material they buy. A problem with the waste exchange concept is that relatively small amounts of chemicals with slightly varying amounts of impurities are obtained at irregular intervals. This creates difficulties for users trying to replace standardized types of virgin chemicals that must meet stringent specifications. One solution is to use some discarded materials for their heating value in cement kilns and other specific types of furnaces. Another is to mix a small amount of recycled material into a much larger amount of virgin material.

Market forces of supply and demand play a crucial role in the level of recycling. In some countries, the poor survive by sorting rubbish and selling materials for re-use or recycling. However, as the volume of solid waste in urban areas soars, such small-scale recycling becomes increasingly difficult, dangerous and inadequate to ease the problem. Nor is this situation helped when recycling is subsidized in some countries – as in Europe – and the cheaper, recycled waste is then exported to lower-income countries in Southeast Asia. In industrialized countries, private sector recycling companies create a different problem. By collecting large amounts of material, they cause excess supply, which depresses prices and makes many recycling efforts economically inefficient. The resulting supply-demand imbalance causes a shift to more land disposal. This is becoming a global market issue for some recycled materials because of exports. For example, paper and ferrous metals are often exported from the United States to Asian markets, yet this does not lead to less virgin material being used in the United States.

Indeed, there are a number of question marks over the economics of recycling. Plastics, for example, are expensive to sort. Other waste materials may be contaminated and therefore laborious to sort and, as a result, expensive too. Despite these drawbacks, the tide is running strongly in favour of recycling in industrialized countries, and increasingly recycling laws are the centrepiece of legislative action on waste.

Japan is a good example. The volume of industrial waste rose from 312,000 tonnes in 1985 to over 400,000 tonnes in 1992. In 1992, 40 per cent of this waste was recycled, sharply reducing the amount for final disposal. In the same period, the volume of municipal waste rose from nearly 43,500 tonnes to more than 50,000 tonnes. The recycling rate jumped from 2.5 per cent in 1985 to almost 4 per cent in 1992, again cutting the amount of waste to be landfilled or burned. In 1992, Japan produced 28.3 million tonnes of paper and paper products, equivalent to 228 kilograms for every person. Yet the waste paper recovery rate was 53.1 per cent, one of the highest recycling rates in the world. Some 97 per cent of beer bottles and 83 per cent of sake bottles are recycled in the country. Japan produced nearly 1.4 million tonnes of steel cans in 1993, and a total of 829,000 tonnes (61 per cent) was recycled. The recycling rate for aluminium cans was nearly 58 per cent. About 5.75 million bicycles were discarded in 1992, and 430,000 were recycled for later use.

Steady advances in technologies are also helping to speed the transition to using recycled materials. The electric arc furnace produces high-quality steel from scrap using far less energy than a traditional open-hearth furnace. Since electric arc furnaces can operate wherever there is a supply of electricity and a supply of scrap metal – and can be built on a small scale – they will become an attractive alternative to the traditional steel mills.

One powerful argument in favour of recycling is that it reverses the concept of the throwaway society. However, recycling may not always be the best waste management option. It may not even be the best environmental solution. Recycling can be polluting. Some studies suggest that for paper, incineration with energy recovery can result in lower environmental burdens.

The argument that it almost always takes less energy to recycle an object than to use new, raw materials is correct – to a point. Aluminium takes huge amounts of energy to manufacture from bauxite, but making it from recycled scrap metal takes only 5 per cent of that energy. Recycling plastics shows a similar pattern though some plastics companies say it takes more energy than it saves. Recycling steel uses half the energy of making virgin steel. But recycling paper takes about 75 per cent of the energy needed to make

BOX 6.8

An integrated approach in Madrid

A new waste management plant in the Spanish capital of Madrid is one of the most ambitious resource recovery projects seen in Europe – bringing an integrated approach to handling solid waste through an elaborate materials recycling, energy recovery and composting system.

The recycling and composting facilities have been functional since early 1993. Previously, 55-60 per cent of the material processed was landfilled, but the aim is to reduce this to between 5 and 10 per cent – with 5 per cent materials recovery and the rest composted or burnt in a new incineration plant.

The recycling option is linked to the energy from the waste option – that is, waste materials can be sent to the energy recovery facility if this yields a higher revenue. Steel and glass are exempted from this. In the energy recovery unit, up to 600 tonnes a day of refuse will be directed to a three-stream fluidized bed combustor. The unit, built under licence from a Japanese company, has been equipped for emission control with a three-stage glass cleaning process of cyclones, semi-dry scrubbers and baghouse filter.

TAKING UP THE CHALLENGE

Bhoruka Power Corporation Ltd. is addressing one of the central challenges of sustainable development – by providing people and industry with the energy supplies they need whilst at the same time conserving precious resources.

The Corporation – which is active mainly in the south of India – specializes in low overhead small hydro projects, supplying electricity generation mainly through renewables.

As part of its development programme, six small hydro stations with a capacity of 25 MW have recently been built, plans are being implemented to provide an additional 25 MW of hydro capacity, and the Company aims to increase installed capacity through renewables to 100 MW within the next two years. Co-generation through bagasse in existing sugar factories is also being vigorously pursued.

Renewable energy plays an increasingly important role in breaking the vicious cycle of increasing numbers and increasing needs, causing declining resources and increased wastes. For the sake of future generations we need, urgently, to control the delicate balance of the ecosystem and move towards the goal of sustainable development by applying a philosophy based on Reduce, Recover, Recycle, Reuse, Repair and Restore Resources.

The Government of India is committed to this philosophy. Its plan of action is to generate 10 percent of the country's total electrical energy requirement through renewable energy by the turn of the century. Bhoruka Power Corporation Ltd. is playing its part in helping to achieve this goal.

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BOX 6.9

Coping with scrapped cars

Recycling obviously has its limitations – some materials are very difficult to recycle. Cars and trucks are an example, and in Europe, the number of end-of-life vehicles is expected to grow from 6 million a year in 1980 to about 12 million a year by 2000. Currently, a typical 1,000 kilogram car is 75 per cent recycled, with the remaining 25 per cent ending up as landfill.

Europe, like most of the industrialized world, has a recycling infrastructure in place. This was largely developed in the 1960s as a result of advances in vehicle crusher and shredder technology. Some components are sold as used spares or remanufactured. Others – batteries and exhaust catalysers – are recycled. The vehicle body is shredded and the ferrous content removed by mechanical separation.

The problem is the growing content of plastics and the complexity of modern vehicles. Several steps are needed to make plastic (especially composite) recycling a viable possibility:

- less rapid introduction of new materials;
- materials identification codes;
- parts consolidation;
- design for disassembly;
- materials recycling technology development;
- market acceptance of recycled materials;
- economic viability.

The European vehicle manufacturers themselves – aware of the need for voluntary action as an alternative to legislation – have adopted a range of strategies to recycle end-of-life vehicles. They include pilot dismantling operations, independent recycling infrastructures, bilateral agreements, and collaborative organizations.

A range of disassembly operations has been set up to address the issue of plastics – including establishing the ideal sequence for removing parts, creating special tools and equipment to help disassembly, and identifying problem areas. In one system, the vehicle fluids are drained and major components removed. The remaining body is compressed and shredded before being fed into a high-temperature furnace. Any remaining plastics actually contribute to the energy required for smelting – and the high temperatures (in excess of 2,000 degrees C) destroy any potentially harmful dioxins. One French car manufacturer has set up its own disassembly centres and aims to process 8,000 vehicles a day by 2002.

The main problem with disassembly is that it is labour intensive. In addition, research by automotive companies in Germany shows that, at current levels of technology and with the current state of car design, disassembly of plastics components is no longer economic after about 30 minutes. By this time, about 60 kilograms of plastic components have been removed at a cost of around US$1.4 per kilogram: it takes a further 60 minutes to collect another 10 kilograms of material.

Manufacturers are also making greater efforts to use recycled materials in their vehicles. But, as the *Automotive Environmental Analyst* pointed out in December 1996: “Recycling has become a means of legitimizing new car production. In practice, new cars do not embody a high recyclate content. Recycling of end-of-life vehicles can only be considered an interim measure and partial solution. The danger is that recycling will be seen as an end in itself, not as a basically undesirable activity.”

virgin paper, and it takes almost as much energy to recycle glass as it does to make it from scratch. The picture can change when all the energy that goes into making, using, disposing of and recycling materials is added in. Glass, for example, takes much more fuel than plastic to carry around. So the unrecycled plastic bottle could be ‘greener’ than the recycled glass one.

Therefore, the overall environmental costs of recycling, including energy, are critical. On the one hand, it can be expensive, even prohibitive, because of the collection, separation and reprocessing costs. But this can change when the total economic situation is considered, including such factors as landfill costs, potential groundwater contamination, conservation of resources, undervaluation of virgin materials, and the visible nuisance of dumped materials.

It should be remembered that recycling is part of a hierarchy of waste management options:

- first, avoid using any non-essential items;
- second, directly re-use a product, for example, refill glass beverage containers;
- third, recycle the material to form a new product;

BOX 6.10

Air and water monitoring at a chemical plant

One major United States chemical producer uses state-of-the-art technologies to monitor water and air emissions and implement a continuous programme of pollution abatement at its complex in Canada. The site includes 13 manufacturing plants where, on the one hand, the final effluent from a number of plants is merged before being returned to the nearby river while, on the other, air emissions from point sources are widely scattered.

Gas chromatographs, pH analysis, organic carbon analysis and flow measurement are used to monitor abnormal water releases. The chromatographs are used to detect a variety of chemicals: pH monitoring checks for sources of acids and alkalis; and organic carbon analysis monitors high molecular weight compounds not otherwise detectable. These technologies form part of a long-standing programme to measure concentrations and loadings of priority pollutants at parts per billion, even per trillion.

Stack monitoring is one of two means of checking abnormal air emissions: it monitors chemicals including chlorine, vinyl chloride, ethylene and nitrogen oxides. Area monitors check for chlorine, vinyl chloride and benzene, as well as combustible gases throughout the complex. Other monitoring equipment checks all other air emissions.

- fourth, burn the material to extract whatever energy it contains;
- finally, dispose of any remaining material in a landfill.

Nor is recycling waste an end in itself. Every company should aim to improve economic efficiency by reducing pollution and cutting the amount of final waste.

Land remediation

Industrial sites can be contaminated when chemicals have been disposed of improperly or released accidently either by industry or as a result of farming practices. The problem is a serious one, with a number of possible approaches.

- Soil vapour extraction has been used extensively over the past 10-15 years to remove volatile organic compounds from contaminated soils. The technology involves pumping the vapours out of the ground so that they can be treated by carbon adsorption. It has low operating and maintenance costs, it can be installed rapidly and it achieves permanent remediation.
- Stabilization and solidification technologies encompass a broad, overlapping array of treatment processes, which either convert the hazardous wastes into their least soluble, mobile or toxic form, or turn them into solid monoliths. The techniques include using cement, lime, thermoplastic materials (bitumen, polyethylene, paraffin), organic resins and organic polymerization.
- Soil washing and soil flushing scrub excavated contaminated soils to remove the contaminants.
- Low-temperature thermal desorption is a process which uses heated air and agitation to volatilize contaminants and transfer them from soils to the airstream, which in turn is recovered and treated before being discharged into the atmosphere.
- Bioremediation takes advantage of the ability of certain kinds of bacteria to degrade chemical compounds by using natural microbial metabolic processes to clean up hazardous wastes. It can destroy the contaminant completely, is generally cost-effective and competitive with other available ESTs, and is an ecologically acceptable solution.

Environmental monitoring

Companies need to monitor their environmental performance to:

- assess the impact of their processes;
- identify the areas where pollution prevention or treatment measures have to be taken;
- keep their progress in reducing emissions and waste under ongoing surveillance.

Monitoring systems vary according to the activity or process to be monitored, as well as with the specific monitoring objectives. These objectives include:

- preparing baseline data on the quality of the air, soil, groundwater and surface water;
- continuously checking releases from the plant;
- determining which pollution prevention or control technologies to implement;
- developing effective health and safety measures.

The first element in a monitoring scheme is to measure the flow of wastewater, air emissions or solid waste. This includes identifying the concentrations of basic contaminants, or at least assessing a few basic parameters revealing contamination. For example, the main variables for water effluents are suspended solids, dissolved solids, pH values, and biological and chemical oxygen demand. Particulates, volatile organic compounds, and oxides of sulphur and nitrogen are usually measured for air emissions. However, monitoring should cover all potential sources of emissions, including leaks from vessels, valves and connectors at production, loading and storage sites, as well as fugitive emissions from secondary sources, for example, evaporative leaks from ponds.

Analytical techniques have changed considerably in recent years. Initially based on the main chemical or physical properties of the pollutants to be controlled, they now cover the biological properties too. Some of the main monitoring techniques are highlighted in the section below.

- Atomic absorption spectrophotometry – an instrumentation method for chemically analysing metals in a solution.
- Chromatography – a technique for separating the components of a mixture so that they can be individually identified and measured. Gas chromatography uses one of a range of detection devices – thermal conductivity, flame ionization, electron capture, flame photometric, photoionization, ion trap or mass spectrometer – to identify compounds in a gaseous effluent. High-performance liquid chromatography is used to analyse mixtures containing non-volatile components, which cannot be separated by gas chromatography. Ion chromatography is used to identify chloride, sulphate, carbonate, phosphate and nitrate content.
- Colorimetry – a method of chemical analysis in which chemical reagents are added to the test sample to form coloured compounds with the specific determinands present.
- Conductimetry – which estimates concentrations of salt solution by determining their electrical conductivity.
- Flame photometry – a physical method of analysis for determining lithium, sodium, potassium, calcium and certain other metals. It involves spraying the sample

BOX 6.11

Reducing pollution and waste through improved process control

Producing cement is a complex process, and it is easy to lose control and make a substandard product. Converting the kilns from oil or gas to coal firing makes control even more difficult and, among other things, it slightly increases the dust content of the exhaust gases – which is removed by electrostatic dust precipitators.

The quality of the cement is largely determined by the firing temperature – but levels of both nitrogen and sulphur oxides increase with higher temperatures, so the process must be operated within a certain temperature band – and if it falls too far below the optimum temperature at the lower end of the scale, cement quality is reduced while pollution is increased.

One new process control system, implemented at a cement factory in Indonesia, is designed to maintain optimum process conditions – stabilizing the running of the kiln, reducing fuel consumption and increasing output, producing a consistent quality of product. It monitors the nitrogen oxide, carbon monoxide and oxygen levels, the temperature at the bottom of the four-stage pre-heater and the power needed to run the kiln.

At the Indonesian plant, the system led to a 9 per cent increase in capacity, a 3 per cent saving in fuel, a 40 per cent reduction in off-specification material produced, and some reductions in nitrogen and sulphur oxide emissions.

EGENOR

Clean Energy for Peru

EGENOR is one of the largest private energy producers in Peru. With 405 megawatts of generating capacity – and more planned – and with 300 miles of transmission facilities, we provide electricity to approximately 20 percent of all Peruvians.

We are operated by and owned in part by Dominion Energy, a subsidiary of Dominion Resources, a US$20 billion holding company with global business interests. We are also owned in part by Chilgener, one of South America's largest energy companies, with US$3 billion in assets.

We are big. So is our commitment to the environment.

We believe it is both a good business practice and our duty to protect the natural resources that support our livelihood and enrich the quality of life for our customers, employees and shareholders. Our business practices reflect our longstanding philosophy that economic growth and environmental preservation are complementary ingredients for long-term business success.

EGENOR is committed to sustainable development in Peru. From its 200-mile-long sea coast, to its soaring Andes mountain ranges, to its dense jungle rain forests, we are a diligent steward of Peru's land, water and air for the benefit of all.

At EGENOR we make environmental protection an integral part of our economic planning and decision-making. We willingly commit any resource necessary to implement effective environmental programs. Where opportunities exist, we are eager to assist governmental agencies in framing responsible laws, regulations and standards that will preserve the nation's rich environmental integrity.

We actively educate our employees and encourage them to seek innovative ways of improving the environmental safety of our operations. We work vigorously to maintain open channels of communication with employees, government agencies, public officials, the media and the public at large to provide information about energy and environmental issues.

We promote the efficient use of natural resources through cost-effective conservation and energy management programs when there are practical opportunities at our businesses to do so. We ensure the proper handling and disposal of all wastes and strive to minimize their creation, while pursuing opportunities to recycle and reuse waste materials.

The people of Peru share with us the abundant natural resources of their rich country. In return, we offer reliable, fairly priced electricity. This compact is premised on our responsibility for environmentally sound development. At EGENOR, we take that commitment very seriously.

solution into a coal gas, propane or natural gas, then measuring the emitted light photometrically to assess the concentration of the compound.

- Gravimetry – a method for weighing the substance to be checked.
- Inductively coupled plasma emission spectrometry – applicable to nearly all metals and a number of non-metallic elements. The sample is injected into a high-energy gas plasma, where atoms absorb energy, then emit radiation.
- Infrared spectrophotometry – identifies and measures chemical compounds or groups of compounds according to how they absorb infrared radiation at specific frequencies. Ultraviolet visible spectrophotometry determines them on the basis of how they absorb visible or ultraviolet light at a specific wavelength.
- Ion-selective electrode – an electrochemical device for measuring the concentration of a particular ionic compound, or groups of compounds.
- Potentiometric titration – in which the end point is detected electronically, rather than with a visual indicator.
- Titrimetry – a method of chemical analysis in which measured amounts of a reagent solution are added incrementally to a known quantity of test solution until the end point is reached.

Instruments and test kits that are used in this context include the following: pH meters, redox measurement, conductivity meters, dissolved oxygen meters, turbidity meters, colorimeters and spectrophotometers, ultraviolet fluorescence, chemiluminescence, flame ionization, the atomizing trace gas monitoring system, flame photometry, electrochemical cell, and photoionization detector. The data that are obtained must be comparable between sources and time periods, in order to be able to assess the evolution of releases over different lengths of time.

Environmental monitoring has become an essential tool for effective environmental management, and a key prerequisite for assessing pollution problems and deciding which ESTs to adopt to deal with them. Measuring pollution at its source is the first critical step towards implementing a cleaner production programme that makes use of cleaner technologies.

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