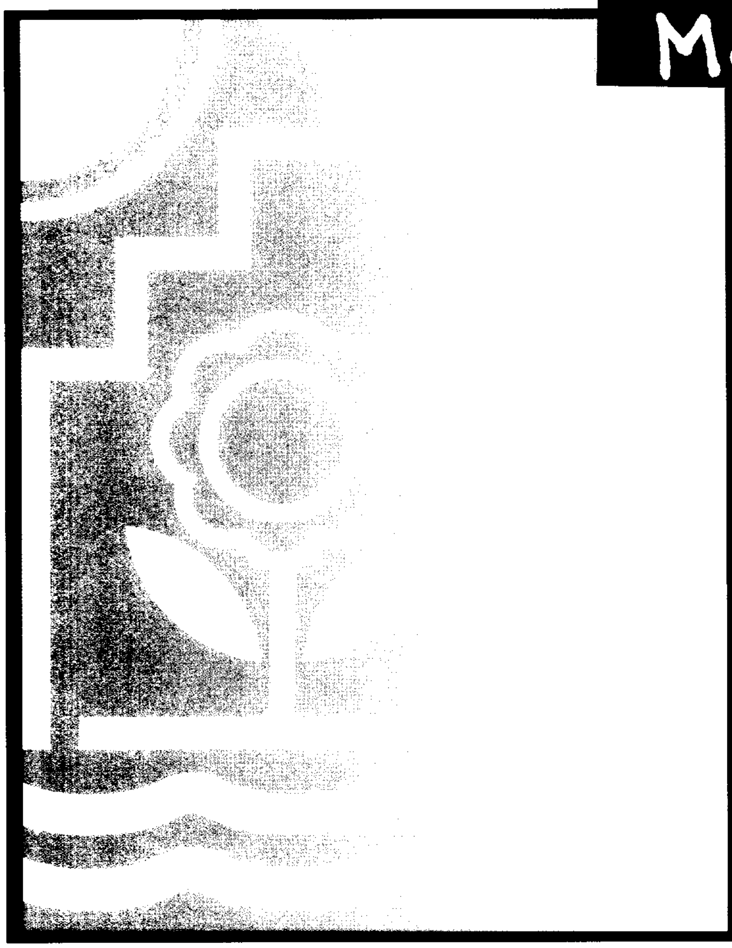
PRIORITIES FOR ENVIRONMENTAL EXPENDITURES IN INDUSTRY

EASTERN EUROPE AND THE FORMER SOVIET UNION



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A REPORT FOR THE ENVIRONMENTAL ACTION PROGRAMME FOR CENTRAL AND EASTERN EUROPE

Priorities for Environmental Expenditures in Industry

Eastern Europe and the Former Soviet Union

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With contribution from Wynne Jones,
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Preface

Large, old-fashioned heavy industrial plants are major sources of pollution in most of the countries of Central and Eastern Europe. Plants which were designed to maximize production with little regard for efficiency or for the protection of workers and the environment are now responsible for a high level of emissions of pollutants and are affecting the pollution conditions and the health status of large areas of these countries.

With the recognition of the impacts of such large polluting plants have come demands for the closure or complete remodelling of the worst offenders, but this is neither feasible nor necessarily desirable. Closure is not an option where plants are still an integral part of the national economies and provide employment for thousands of people. Complete revamping to meet the highest environmental standards is not affordable but, in any case, would not be the best use of scarce resources in protecting the health and welfare of the people.

Changes in the economic system will bring improvements in environmental performance as attention is focused on efficiency and improvements in operations. Typically the oldest and most polluting units or plants are the first to be rebuilt or replaced, and the overall level of pollution emissions will reduce over time.

Such changes, however, will not of themselves be sufficient to achieve the levels of improvement that are required in the short term to remove the most serious threats to health and the environment. Environmental expenditures will be required, but these must be carefully selected to achieve the maximum benefits and to be fully justifiable in the face of competing demands for investment in other sectors such as health and housing.

The detailed studies and analyses on which this report is based were carried out to provide a starting point for the discussions, debates, and decisions which will be required in the process of establishing expenditure priorities for each of the countries in this region.

Acronyms

BOD	biochemical oxygen demand
CBA	cost-benefit analysis
CEA	cost-effectiveness analysis
EBRD	European Bank for Reconstruction and Development
EEC	UN Economic Commission for Europe
ESP	electrostatic precipitator
EU	European Union
H_2S	hydrogen sulfide
NGO	nongovernmental organization
NO_x	nitrogen oxide
NPV	net present value
PAFs	pollution abatement funds
PAH	polyaromatic hydrocarbon
SBR	styrene butadiene rubber
SO_2	sulfur dioxide
USAID	United States Agency for International Development
VOC	volatile organic compounds
WWTP	wastewater treatment plant
UNIDO	United Nations Industrial Development Organization

Executive Summary

The main purpose of this study is to identify environmental expenditure priorities in different sectors of industry, based on estimation of a representative set of cost-effective environmental investments which address the highest priority environmental problems. A comprehensive listing of major plants was prepared for seven main industrial sectors, and detailed studies were carried out on a representative sample to identify and quantify cost-effective interventions. In addition, studies were carried out of the small boiler and household sectors to determine the contribution of these sectors to the overall problems and possible remedial actions.

The seven industrial sectors examined are as follows (full details are provided in the Annexes):

- Power and heat
- Petroleum refining and petrochemicals
- Organic chemicals
- Inorganic chemicals
- Iron and steel
- Non-ferrous metals
- Pulp and paper.

The program involves 18 environmental audits or case studies (at least one, and typically two, in each of the sectors), which were the basis for determining the exact sources of pollution, estimating the quantity of emissions, and reviewing the technical options (and costs) for pollution control at those sites.

Determination of priority expenditures

Priorities for environmental expenditures were developed, drawing on a consensus among experts and policy makers that the most severe and urgent pollution-related problems are those which impact human health and on other studies which identified air pollution as the most serious health concern. This prioritization then required identification of those sources of pollutants which make the greatest contribution to the most severe and urgent health problems. Practical constraints limited the analysis to identifying the plants which *may* pose the greatest threat to health, by matching environmental health "hot spots" with an inventory of major industrial plants. This provides a good first estimate, although the causal links are not directly established and other factors are doubtless involved.

The analysis concentrated on the three main pollutants identified as being of primary concern from a human health standpoint: lead, airborne dust, and sulfur dioxide. It addressed the full range of options for reducing environmental damage at operating plants, from closure of (or part of) plants to the installation of new pollution abatement facilities. Remediation of sites contaminated by past operation was not addressed because the localized impacts and very high costs typically involved mean that this is rarely a short-term priority.

Criterion used

Ideally, all of the potential environmental expenditures would be analyzed on a cost-benefit criterion but in practice the lack of detailed data and the inherent uncertainties in valuation of health effects ruled out this approach for the present analysis. A cost-effectiveness approach was therefore adopted, with a working assumption that the impacts of pollution were related in a simple way to the total population exposed. This approach is unlikely to introduce gross errors and is acceptable for the purposes of setting broad priorities. It would need careful scrutiny, however, before being used for appraisal of specific projects.

Overall findings

A fundamental finding is that the initial emphasis should be on controlling emissions of particulates because their impact is often concentrated close to the source and therefore they make a significant contribution to poor local air quality; particulates carry other pollutants (notably heavy metals) and thus present a particular hazard to health; and they are easier and cheaper to control than gaseous emissions such as SO_2 and NO_x. For example, in the power and district heating sectors, detailed studies show that the costs per ton of pollutant emission avoided range from $10-90 for particulates but from $400-5,000 for SO_2 and $750-45,000 for NO_x. Particulate control systems in this sector can be very cost-effective but depend on a good standard of operation and maintenance. The success of an investment program in these sectors may depend on support for parallel training programs and measures to encourage the development of a local service and maintenance industry.

There is much higher variability in the costs of particulate removal across the industrial sectors studied. There are numerous opportunities for no-cost/low-cost pollution prevention, primarily through improved operation and maintenance. Controls on materials storage and handling and on stack emissions in the iron and non-ferrous industries can be relatively low cost. However, the cost of controlling particulates from the refining and petrochemicals sector is relatively high because the levels produced are low. Reducing particulate emissions from coke ovens is costly because of the extent of rehabilitation that is required for ovens that have been poorly maintained and operated.

Certain other pollution control measures have been identified as priorities in particular industries, such as reduction of volatile organics in the chemicals industry and of hydrogen sulfide from pulp plants.

Sector findings

A comparison of the existing health data and an inventory of major industrial plants identified plants which are located at or near pollution "hot spots" (Annex B). However, the results need to be interpreted with care: there is not necessarily a direct link between a plant and the hot spot, and there are other sources not included in this inventory which contribute to the local pollution. Only in the iron and steel sector are more than half the plants listed located in hot spots, which tends to confirm the sector as one of the worst polluters in the region. On the other hand, only one in six of the pulp mills is located in a hot spot but there is evidence that suggests that individual mills can cause local health impacts.

A summary estimate has been prepared of the capital expenditure that would be required to apply priority air emissions control measures to those plants in the inventory that are located at hot spots (Table 1). These estimates may overstate the expenditures for several reasons: some plants do not need to incur all the costs envisaged by the calculations; in other cases, existing facilities could be repaired and modernized at lower costs than those envisaged; and there are some which are so old and inefficient that expenditure on pollution abatement measures is difficult to justify.

Implementation

Low-cost improvements and changes in economic conditions are likely to bring significant improvements in environmental quality, but specific investments in pollution control and cleaner technologies will also be required to achieve the desired levels of pollution reduction. Decisions about environmental expenditures during the transition period should ensure that actions address priority environmental problems, resources are allocated cost-effectively, and expenditures are also consistent with longer-term priorities.

The role of public environmental financing in the industrial sector needs to be carefully defined. Limited public funds should be allocated to those priority expenditures where they can buy the largest environmental benefits. In the short term the establishment of Pollution Abatement Funds may be an attractive approach to ensure that immediate priorities are addressed and that the adjustment of enterprises to

Table 1 Capital expenditure estimates for priority measures at selected plants

Sector	*Expenditure estimate ($ million)*
Power and district heating	700 - 2,000
Refining and petrochemicals	15 - 200
Inorganic chemicals	10 - 100
Organic chemicals	100 - 200
Iron and steel	600 - 3,000
Non-ferrous metals	10 - 150
Pulp	5 - 15
Small boilers and households	300 - 2,500
Total	1,700 - 8,200

stricter environmental requirements can be accelerated. However, such funds should have the objective of contributing to a well-functioning environmental management system in which enterprises carry their share of the costs of the environmental damage which they cause and where environmental expenditures become part of the cost of doing business. The role of Pollution Abatement Funds (PAFs) should therefore be seen as temporary and their operation should be subject to well-defined constraints.

In the longer term, governments will need to develop policies to ensure appropriate levels of environmental protection. Short-term expenditures should therefore be consistent with longer-term priorities. At the same time, a realistic timetable for achieving longer-term policy objectives will have to take into account the practical constraints of the transitional period.

Chapter 1

Approach

Political changes and the transition to the market economy involve substantial economic hardship and social difficulties for the countries of Central and Eastern Europe. At the same time, the nature and scale of the cumulative deterioration of environmental conditions in many parts of the region impose social and economic costs which can be ill afforded at present but which will become increasingly costly to address if left for the future. Against this background and with a severe scarcity of financial resources for environmental expenditures, the identification of the most pressing environmental priorities becomes crucial.

The Environmental Action Programme

At a meeting in Lucern, Switzerland, in April 1993, ministers from the 50 countries of the UN Economic Commission for Europe (EEC) endorsed an Environmental Action Programme for Central and Eastern Europe. The key objective of the Action Program is to achieve tangible, immediate improvements in the most severe environmental problems in the region, using a range of instruments within national and regional strategies and building on collaboration across the region and with Western Europe.

For the Action Program to be effective, it must involve a combination of:

- Better *economic policies* to introduce an appropriate system of incentives to discourage the profligate use of natural resources and to stimulate the gradual replacement of old and heavily polluting industrial plants by more efficient and cleaner technologies
- The establishment of *environmental policies* that penalize or regulate environmentally damaging behavior and reinforce the incentives to adopt cleaner technologies
- A range of *investments* to finance the installation of appropriate environmental controls or technologies in industrial plants, the public sector, and households
- Ongoing *institutional development* to ensure the existence of an appropriate framework for developing and implementing environmental policies.

A large number of studies related to these issues were undertaken as part of the process of development of the Action Program, including this study of industrial expenditure priorities.

Setting environmental priorities

The question of setting environmental priorities is one of the most critical issues in the development of a program for action because the resources likely to be available for dealing with environmental problems are far less than the amounts initially suggested as being necessary. The practical reality which must be faced is that difficult choices have to be made and that resources have to be concentrated on those problems where the greatest environmental benefits can be gained, relative to the costs involved.

Health concerns

In any examination of environmental priorities, a prime concern is the impact of environmental pollution on human health, since health concerns have long served as a principal basis for government intervention and for regulation in OECD countries. An evaluation was made of the importance of pollution as a determinant of health in Central and Eastern Europe, in comparison with other determinants.[1] That study also compiled available data on areas in CEE where environmental pollution has had a documented impact on human health and tried to identify the principal types of environmental exposure which affect human health and which might be addressed through targeted interventions.

A number of locations were identified where reasonably credible epidemiological data existed to show pollution-related health problems. The objective of carrying out a fully comprehensive survey of the region was not achieved because of the lack of adequate methodologies or of data in some areas, but a summary of "hot spots" was prepared[3] which listed areas where problems existed that could credibly be related to pollution. It has to be emphasized, however, that this list only includes currently identified problems and cannot be regarded as exhaustive.

The problems identified in the health study related primarily to exposures to lead in the air and soil, airborne dust, sulfur dioxide and other gases (usually in combination with airborne particulates), and nitrate in water.

Inventory of sources

In parallel to the health studies, a detailed listing of the major industrial sources of pollution was prepared (as further discussed below). Seven major industrial sectors were examined and an inventory was developed, in the best detail possible, of all the major plants across the region. The seven sectors were as follows (details of the products covered for some of the broader sectors are given in Table 2):

- Power and heat
- Petroleum refining and petrochemicals
- Organic chemicals
- Inorganic chemicals
- Iron and steel
- Non-ferrous metals
- Pulp and paper.

The full inventory of major industrial plants is presented as Annex A to this report. As with the health studies, there are some gaps but it is believed that virtually all the large plants in these key sectors were identified.

Combining the two sets of data (health problems and industrial plants) allowed a correlation to be made of areas with significant health concerns and with major potential pollution sources. This information is provided in Annex B to this report. No causal connections are established through this tabulation (and in some cases they may not exist) but the tabulation clearly indicates where further detailed investigation is warranted.

Sector studies

On the basis of the hot spots listings, detailed studies on each sector were carried out with the overall objective of identifying projects that would offer significant pollution reductions (without unacceptable secondary environmental impacts) and could be implemented rapidly and replicated many times.

The typical studies for each industrial sector included:

- Completion of *rapid environmental audits* of two plants from each sector (as well as reviews of the small boilers and households sectors in two locations) to identify measures which would achieve varying levels of pollution control, and the costs of implementing these measures
- A broad *analysis* of the technical nature of existing environmental problems in each of the sectors in the region and their potential solutions, with the aim of identifying generic pollution control options
- Examination of the *anticipated impact* of the economic and industrial restructuring on the future pattern of environmental problems
- Determination of an *initial set of short- to medium-term priorities* for expenditure to improve the environmental impact of the sectors studied. An important related theme that runs through the whole process of implementing priorities is that investments are required but these will take time to arrange and, in the meantime, good operation and maintenance of existing systems are pressing requirements.

The studies on each sector and the results of the individual plant audits are summarized in Annexes C to J of this report.

Impact of policy reforms

The transition from central planning to markets should help to improve not only the countries' economic per-

Table 2 Products covered in sector reviews

Sector	*Products covered*
Refineries and petrochemicals	• Ethylene • Benzene • Toluene • Xylene
Organic chemicals	• Polyolefins—high- and low-level density polyethylene (HDPE and LDPE) • Ethylene intermediates—ethyl dichloride (EDC), vinyl chloride monomer (VCM), and polyvinyl chloride (PVC) • Styrene and derivatives—ethylbenzene, butadiene and polystyrene • Styrene rubbers—acrylonitrile butadiene and styrene butadiene
Inorganic chemicals	• Chlorine • Caustic soda • Soda ash • Titanium dioxide • Fertilizers
Non-ferrous metals	• Aluminum • Copper • Lead • Zinc

formance in the longer term, but their environments. Among the key factors are increases in energy prices, and hard budget constraints on public and private enterprises. These provide powerful incentives to reduce waste of resources and to improve industrial "housekeeping" in ways that also reduce pollution emissions. Many CEE countries have already made big strides in raising energy prices which are expected to produce measurable environmental improvements.

However, markets are not a magic answer. Targeted environmental policies will also be required to ensure that the potential benefits of economic restructuring are fully realized. To achieve the most cost-effective use of resources, the countries of the region should, where possible, also use economic instruments to achieve environmental goals. Existing systems of pollution charges can be developed to provide an effective incentive for sound environmental practices. Where regulatory policies are more appropriate—for example, to control emissions of heavy metals and toxic chemicals—governments could adopt either the EU framework of standards or an equivalent system but it should provide a long but well-defined (10- to 20-year) adjustment period, reflecting the reality of the speed at which systems in the West have been developed.

The greatest contribution of such policy instruments to achieving a continuing decline in total emissions is likely to come from improving the environmental performance of old plants which continue to operate in the medium term.

Chapter 2

Sector Studies

The purpose of compiling an inventory was to identify potential polluting sources in the sectors under consideration and to collate available information on their key characteristics. As such, it was intended to provide a potential basis for extrapolating the results of the studies of specific plants and the desk research to generate estimates of the total environmental expenditure for the region as a whole in the priority areas.

Inventory

The inventory, which is summarized in Annex A, includes data on location, capacity, process technology, age, pollution control technology, and emissions.

Information for the inventory was drawn primarily from an extensive literature review. Important sources included:

- Published trade directories and sector reviews
- Reports from previous studies undertaken on behalf of international institutions, such as the World Bank, EU, EBRD, and UNIDO and, in particular, reports from the Baltic Sea and Black Triangle programs
- Reports from national organizations providing assistance to the CEE countries, such as USAID.

In addition, information for the inventory was sought from all national governments in the area under study. Only very limited information was obtained in this way, in part because governments typically did not hold plant-specific information.

Overall, despite the information collected as part of this project, there is a paucity of relevant data. At plant level, only very general information is available about the technical characteristics (efficiency, age, condition, use, and effectiveness of pollution control facilities) of industrial plants in CEE countries. Sometimes this data is either out of date or misleading in the sense that the reported characteristics of plants differ from those actually observed. Moreover, the lack of specific data makes it difficult to establish, with any degree of certainty, the link between pollution sources and observed or potential problems.

In addition, although the inventory is likely to include most major plants within the sectors studied, many smaller plants may be missing. This is certainly the case in the power and district heating sectors, for example, where in some countries only the largest public power plants have been identified. In some cases, smaller plants may make a relatively large contribution to local pollution problems by virtue of their proximity to population centers and their technical characteristics.

Environmental audits

The program involved a series of 16 rapid environmental audits or case studies. The case studies were intended to provide examples of the problems encountered in practice, and not to be in-depth studies. They involved visits to specific plants in the region during which an assessment was made of:

- The efficiency of existing manufacturing processes, including maintenance procedures, and equipment

- The raw materials being used
- Existing pollution control measures and emission levels
- Options for reducing pollution and their associated costs
- Investment plans, including expenditure on pollution control.

The various sites were chosen because they were believed to be representative of their sector in terms of the technology used and the potential pollution problems encountered or they were located in severely polluted areas, and hence, potentially priority sites for environmental expenditure. Rapid environmental audits were carried out at the sites listed in Table 3.

Generally, management were willing participants but, understandably, could make only limited time available to our team. At Krivoi Rog iron and steel works, management was unwilling to allow an inspection of certain plant.

Unfortunately, the proposed case study of the copper smelter at Sredneuralsk in Russia proved infeasible owing to difficulties in obtaining permission from the authorities to visit the site.

Technical reviews

The aims of the technical reviews were to identify common problems within each of the sectors studied and to determine remedial measures capable of being replicated at plants within the sectors. The purposes of each technical review were to:

- Identify the main sources of pollution in a typical plant in the sector studied
- Review the nature and likely extent of emissions from these sources
- Review the technical options for achieving varying degrees of pollution control together with their associated costs.

The technical reviews relied primarily on desk research using a wide range of literature sources as well as the existing technical knowledge and understanding of the consultants carrying them out.

An important limitation of the technical reviews is that, in practice, the costs and benefits of particular pollution control measures are highly specific to the local conditions prevailing at a particular plant. For example, they depend on the age of the plant, the efficiency with which it is being operated and has been maintained, and, in particular, the type and effectiveness of existing pollution control equipment.

Economic profiles

Economic profiles were prepared for each of the industrial sectors studied. These provide some insight into the existing structure of each sector and a guide to the likely impact of the economic reform process on

Table 3 Rapid environmental audit sites

Sector	*Sites audited*
Power and district heating	Trebovice thermal power plant, Ostrava, Czech Republic; TEC-2, Riga, Latvia.
Refineries and petrochemicals	Plock refinery and petrochemicals plant, Poland; Burgas refinery and petrochemicals plant, Bulgaria.
Inorganic chemicals	Chimcomplex chlor-alkali plant, Romania; Azot Grodno fertilizer plant, Belarus; PO Kaustik caustic soda and chlorine plant, Volgograd, Russia; Borsod Chem chlorine plant, Hungary.
Organic chemicals	Carom SA styrene and rubber plant, Onesti, Romania; PO Kaustik VCM plant, Volgograd, Russia.
Iron and steel	East Slovak iron and steel works, Kosice, Slovakia; Krivoi Rog iron and steel works, Ukraine.
Non-ferrous metals	Ziar Nad Hronom aluminum smelter, Slovakia; Plovdiv lead/zinc smelter, Bulgaria; Copsa Mica lead/zinc smelter, Romania.
Pulp and paper	Sloka pulp and paper plant, Latvia.
Small boilers and households	Katowice, Poland; Ostrava, Czech Republic.

the future pattern of output and hence on the nature and extent of emissions from each sector. In addition, they provide a basis for assessing the general impact of environmental expenditures on the viability of each sector because they provide an insight into the competitiveness and comparative advantage enjoyed by each sector in each country.

The main sources for the economic analyses were a wide variety of literature obtained from international and national institutions and data base searches. It was intended to use any sector studies carried out as part of the process of developing restructuring plans within each CEE country, as well as any output projections prepared by national governments and international institutions. In the event, it was difficult to obtain the relatively few sector- specific restructuring studies which have been completed because of the commercial sensitivity of the data within them. Similarly, no consistent publicly available output projections were available at the micro-economic level required for the analysis. The limitations of the analysis meant that reliable conclusions could not be drawn about the future pattern of plant closures and, hence, about the likelihood that locations which are currently hot spots will remain hot spots in the future. Despite these obvious limitations, the economic profiles proved valuable because they highlighted those sectors where economic considerations suggest that plant closures are required. In these cases, environmental considerations reinforce the economic arguments for closure.

Determination of expenditure priorities

The final task was to apply the framework for determining environmental expenditure priorities as far as the available data allow the identification of a set of short- to medium-term priorities.

Chapter 3

Analytic Framework

The broad aim of the study is to identify those environmental expenditures which would provide maximum benefit, in terms of avoided damage to human health, at least cost. This focus reflects the consensus among experts and policy makers that the most severe and most urgent pollution-related problems in CEE countries are those that impact on human health, a view which leads in turn to an emphasis on air pollution.[3]

Overall approach

The approach developed for establishing sector expenditure priorities is pragmatic and recognizes the limited amount and reliability of the information likely to be available. This approach, which is described more fully below, assesses the costs of different projects and their likely effectiveness in reducing damage, particularly to human health. In essence, the sector studies focused on the types of problems and remedial actions that had been identified, in general terms, as the most important. In analytical terms, the approach is one of bounded cost-effectiveness rather than full cost-benefit analysis, as further discussed below.

Against this background, the work required the identification of those sources of pollution which make the most significant contribution to the most severe and most urgent problems. Ideally this would have involved a thorough analysis of emissions from a wide range of potential sources and their contribution to pollution-related problems. However, for practical reasons, the scope of the work was limited to the major industrial sectors (and the small boilers and household sectors) and drew on analyses which identified and characterized various hot spots in the CEE countries. Within these limits, it is then possible to identify the plants which may pose the greatest potential threat to health by relating the pollution sources to the list of hot spots.

The potential options for controlling the release of pollutants to the environment and, hence, for mitigating health risks, range from closure of whole (or parts of) enterprises to the installation of new pollution abatement facilities. The analysis addresses the relevance of the full range of options and their effectiveness at both a generic and a specific plant level. The approach concentrates on analyzing each of the technical options for pollution abatement from an economic perspective, on a project-by-project basis. This does not take into account the likely effects of changes in the broader environmental policy context nor the public sector support which might be needed to enable enterprises to undertake the environmental expenditures identified.

Scope

The analysis focuses on projects aimed at reducing ongoing environmental damage from existing pollution sources. While the case for mitigating the effects, or potential effects, of past pollution must not be overlooked, such problems are less widespread and vary significantly in nature and extent from site to site—such as, for example, with the problems and remedies associated with the accumulation of mercury at the Borsod Chem site at Kazincbarcika in Hungary. They may also be very expensive to address and are generally unlikely to be priorities in the short to medium term.

Different types of projects can be designed to address ongoing pollution problems. Three elements are needed for a pollution problem: a pollution source, a receptor affected by the pollutants, and transport of the pollutants from the source to the receptor. Eliminating or modifying one of these elements can avoid or change the nature of the pollution problem. The usual method, however, is to control the emissions at source, and the analysis is focused on such projects. Adaptive measures could be cost-effective in some cases where emissions control is expensive.

The following types of interventions can help control emissions at source:

- Plant closure or output reduction
- Raw material and/or fuel quality improvements
- Process control and/or modification
- Operational and maintenance improvements
- Pollution control equipment improvement and/or installation.

Projects could be aimed at controlling any of a large number of potential pollutants. The report on health identifies three categories of pollutants as being of primary concern from a human health standpoint in CEE countries: *lead; airborne dust;* and *sulfur dioxide* and other gases.

The analysis concentrates on projects that would reduce the airborne emissions of these pollutants, but does not attempt to make judgements on their relative importance.

Conceptual framework

Any proposed new environmental project, program, or policy will lead to costs and benefits. Some means of economic appraisal is needed in order to evaluate the absolute or relative worth of proposals and, hence, facilitate rational decisions about the allocation of scarce resources. Cost-benefit analysis (CBA) represents a comprehensive form of economic appraisal and, therefore, provides a good starting point from which to develop a more pragmatic approach.

In practice, resources are usually committed at the project level, and therefore the cost and benefits of expenditure proposals can be most conveniently discussed in connection with project appraisals. This analysis, therefore, focuses on the project level and is concerned with identifying criteria for deciding how investments should take place so as to allocate resources efficiently.

Project costs and benefits

It is straightforward, in principle, to identify and measure the financial costs and benefits of a project and to incorporate these into a calculation of the net present value of a project's costs and benefits. In practice, of course, observed prices may not necessarily reflect the social value of resources and, therefore, shadow prices may be more appropriate.

Estimating the expected nonfinancial costs and benefits from projects to reduce pollution is more difficult. These can be divided into two broad categories: the wider implications for resource utilization and the direct and indirect effects on the environment. The former effects, which include promotion of a new technology or know-how and reliance on imported technology, are intractable within the context of this study and no account is taken of them.

As regards the latter effects, a key assumption underlying the approach is that the health benefit of reducing pollution in locations were pollution levels are currently no higher than internationally accepted standards or guidelines is insufficiently large to justify the commitment of scarce financial resources in the short to medium term. This point is explored further in the next section.

The net present value criterion

The basic decision rule within the CBA framework is that a project is acceptable in economic efficiency terms if the present value of the net benefits is positive; namely, that the total discounted benefits are greater than the total discounted costs. More generally, in determining the optimal scale of a project or the best of a set of mutually exclusive project alternatives, economic efficiency requires, in the absence of constraints, that the net present value of the project should be maximized; this is generally known as the net present value (NPV) criterion. When applied to project formulation, maximization of the NPV is legitimate only in the rather uncommon situation in which the investor is not subject to capital funding constraints. This point has important implications for setting priorities within the context of this study.

The effect of funding constraints

In certain situations, capital funding may not be a constraint on projects, so investment can proceed up to the point where net benefits are maximized. The reason that unlimited investment does not take place is that diminishing marginal physical returns set in as the project scale increases.

Quite often a public agency is responsible for an environmental program and must determine the optimal levels of investment in all projects, since the agency itself is working within a fixed budget determined by, for example, a higher public authority. If total monetary outlays are constrained, net benefits for the entire program of projects will be maximized when marginal benefit-cost ratios for specific investment alternatives are equalized. When the restriction applies to current capital funding, investments should be made up to the point at which the marginal ratio of NPV per unit of capital is the same for all projects.

Cost-effectiveness analysis

There are a number of practical obstacles to the application of CBA to environmental projects. These include:

- Uncertainties about project costs
- Ignorance of the environmental effects
- Difficulties in assessing the importance of the effects or quantifying them in physical, medical, or other relevant terms
- Problems in valuing the effects.

Only after the effects of a project on environmental quality, and hence on receptors such as humans, natural systems, and buildings, are determined can cost-benefit valuation techniques be applied. Valuation is already controversial enough, and its problems are compounded if the underlying environmental data are weak.

In situations where benefits cannot be measured in economic terms, then cost-effectiveness analysis (CEA) provides a useful framework for appraising projects. CEA can be used to determine the least-cost method of reaching a prescribed objective, such as a given level of emissions or ambient air quality, as well as ways of maximizing some physical environmental improvement with available resources. This approach is applied, within the limitations of the data, to set broad priorities within the context of this study.

In practice, the main problem in the use of CEA revolves around the definition and achievement of a project's objectives. Where objectives cannot be specified precisely, their attainment cannot be measured, and where the alternatives being compared would not attain a project's aims to the same extent, CEA becomes ambiguous. Where a project has several objectives, and the different options satisfy certain aims more fully than others, CEA does not yield one clearly superior solution. Thus, the application of CEA still involves an element of judgement.

Measuring human health gains

The ultimate objective of any project will be the realization of human health gains. Unfortunately, there are no reliable means of quantifying the link between observed pollution levels, ambient quality, and damage to human health. However, provided some knowledge exists about the environmental situation in the location of a source and in the area where the impact is felt, then one can begin to make judgements about the benefits arising from any proposed project.

The relationship between human health damage and exposure to a pollutant is a complex one, which depends on quantity and duration, as well as on the presence of other pollutants and environmental stresses. But, in broad terms, the relationship between damage and pollutant level will typically have a generally linear relationship, with a lower threshold. No significant damage will occur below a certain level, after which damage will rise directly with pollution level until eventually no more damage can occur.

Thus, the working assumption is made that in severely polluted locations a given reduction in the ambient level of a specific pollutant provides the same benefit for each exposed person. So, provided a location remains above the threshold level, it is the incremental improvement in pollution levels that affects the health gain and not the absolute level from which the improvement is made. We believe that this assumption is unlikely to introduce gross errors and is acceptable for the purposes of setting broad priorities. The assumption would need careful reexamination, however, for the purpose of a specific project appraisal.

It is straightforward to take account of both the different impact that emission reductions from different sources will have on pollution levels, as well as of the different populations that would be affected. We simply define the benefit of an emissions reduction in the following way:

> *Benefits = (Reduction in annual emissions) × (Factor (<1) to account for the relationship between changes in emissions and ambient levels) × (Total population exposed)*

This formula provides a crude measure of a projects's effectiveness in reducing health damages associated with a given reduction in emissions. Account could also be taken of the toxicity of different pollutants by incorporating a harmfulness index in the above formula.

The formula above can be used to show the relative benefit of reducing emissions from low stack sources compared with high stack sources. Total emissions from low stack sources such as households can be assumed to contribute to air pollutant concentrations in the vicinity of the emissions. On the other hand, only a relatively small fraction of total emissions from a high stack source would normally be expected to contribute to increased urban air pollutant concentrations—the bulk of the emissions will be rapidly dispersed. Suppose that some 10 percent of total emissions can be considered as contributing to increased urban air quality at a particular location; then the health benefit of a given reduction in emissions from such a source will be an order of magnitude down on the benefit of an equivalent emissions reduction from a low stack source.

Some projects will have additional costs or benefits arising from increased or reduced damage to other parts of the natural or built environments. In some cases, these additional costs or benefits may be significant and could affect the ranking, or even acceptability, of projects. It is difficult to assess this within the context of setting broad priorities because of the diversity of effects and their dependence on local conditions. It should be possible, however, to combine different environmental impacts within the overall evaluation framework for a specific project appraisal.

Structural and policy changes

Structural changes brought about by ongoing economic reform programs in CEE countries might reduce substantially levels of emissions from certain industrial and other sources without any specific expenditures for environmental improvement. It is possible, therefore, that locations that are currently hot spots may not remain hot spots in the future.

An important step in establishing priorities is, therefore, to gain an understanding of the likely impact of the economic reform process on the future pattern of output and hence on the nature and extent of emissions from each sector. There is, however, a lack of useful economic information at both the sector and enterprise level. This is exacerbated by the rate of change and consequent uncertainty. It is difficult, for example, to assess a sector's competitiveness because observed prices of inputs do not necessarily reflect true economic costs. Similarly, enterprises have not, in the past, faced the discipline of hard budget constraints which makes their future under such constraints uncertain. The results of restructuring studies which have looked at underlying competitiveness represent a potentially important input to our economic analysis.

This analysis seeks to identify the most attractive environmental expenditures by ranking alternative projects to abate pollution on the basis of a simple comparison of their likely costs and benefits. Translating this ranking into a prioritized action plan for environmental improvement requires consideration to be given to which policy instruments are likely to be most efficient and effective in ensuring that the most attractive project expenditures are implemented.

For practical reasons the range of products included in the analysis of the refineries and petrochemicals, organic and inorganic chemicals, and non-ferrous metals sectors was limited to those shown in Table 1. In the iron and steel and non-ferrous metals sectors the focus was on primary metal production which is a much larger source of pollution than other activities in these sectors. In the paper and pulp sector pulp production was singled out for the same reason.

Chapter 4

Results of Sector Studies

The technical and economic analyses of the pollution control options in the sectors studied (summarized in Annexes C to J) have been used to identify broad expenditure priorities both within and across sectors. The inventory has then been used, along with information on hot spots, to derive expenditure estimates for the region as a whole. The accuracy of the total expenditure estimates is constrained by the limitations of the methodology (as discussed in the previous section) and the totals must therefore be regarded as indicative. These limitations do not detract from the central conclusions although they do make detailed discussion of the implications at the enterprise level difficult. Box 1 draws on selected case studies to illustrate the diversity and site-specific nature of pollution problems and their possible remedies in the sectors studied.

Overall findings

The pollution control measures which are likely to offer the most cost-effective opportunities for reducing airborne emissions of pollutants from the various sectors studied are presented in Table 4 and these should be regarded as short- to medium-term priorities. Other potential options for controlling particular pollutants have been excluded because they are relatively expensive, they achieve relatively low levels of abatement, and/or they have only a limited beneficial impact on human health.

Overall, it is believed that the emphasis should be on controlling emissions of particulates because:

- Their impact is more likely to be concentrated close to their source, especially if they are emitted from low stacks, and they therefore make a significant contribution to poor local air quality
- They present a particular hazard to health because they carry other pollutants, notably heavy metals
- They are easier and cheaper to control than gaseous emissions such as SO_2 and NO_x

To illustrate the last point, Table 5 shows the costs of controlling particulates, SO_2, and NO_x emissions from coal-fired plant in the power and district heating sectors using pollution abatement devices. The results highlight the relatively low cost of controlling particulates compared with either SO_2 or NO_x emissions.

In contrast, the health-related benefits of reducing gaseous emissions from tall stacks, which are generally widely dispersed, may well be less attractive relative to the cost in many cases. Moreover, control of fugitive particulate emissions by pollution control devices has been excluded because they can achieve only a relatively low level of abatement. For example, comparison of the costs of controlling stack emissions and fugitive emissions from iron and steel making suggests that the latter may not be justified on public health grounds. Control of fugitive emissions is, however, a matter to be examined in the context of concerns about workers' exposure to pollution.

The relevance and likely effectiveness of the options vary significantly from plant to plant depending on:

- The age of the plant and the technology used—some older plants were built without any pollution control facilities

Table 4 Priorities for pollution control within the sectors studied

Sector	*Plant/process*	*Pollutant*	*Technology/technique*
Power and district heating	Boilers	Particulates	ESPs or bag houses
Refineries and petrochemicals	Catalytic cracker	SO_2	de-SO_x catalyst
	Ethylene	VOCs	Improved vesting, good housekeeping
	BTX	VOCs	Floating roof tanks
Inorganic chemicals	Chlor-alkali	Mercury	Good housekeeping
	N fertilizers	Particulates	Prill scrubber
Organic chemicals	LDPE	VOCs	Improved venting
	EDC/VCM/PVC	VOCs	VCM stripping column, residue incineration
	Butadiene	VOCs	Improved venting
	Ethylbenzene	VOCs	
	Styrene	VOCs	Good housekeeping, residue incineration
	Polystyrene	VOCs	Improved venting, good housekeeping
	SBR	VOCs	Improved venting, good housekeeping
Iron and steel	Raw materials handling and storage	Particulates	Water sprays, gas collection and cleaning system (bag house)
	Coke ovens	Particulates	Repair and rehabilitation
	Steel making	Particulates (stack gases)	Gas collection and cleaning system (bag houses or scrubbers)
Non-ferrous metals	Raw materials handling and storage	Particulates	Water sprays
	Smelters	Particulates	Gas collection and cleaning system
Pulp	Chemical pulp	VOCs	Gas collection and cleaning system
		H_2S	Gas collection and cleaning system
Small boilers and households	Boilers, coal stoves	Particulates, SO_2	Basic insulation measures, boiler control, fuel switching
		Particulates	Particulate control devices (boilers), replacement coal stoves

Table 5 Costs of controlling emissions from the power and district heating sectors

Pollutant	*Abatement technology*	*Removal efficiency (percentage)*	*Abatement cost ($ per annual ton emission avoided)*
Particulate	ESP	97 - 98	15 - 65
	High-efficiency ESP	99 - 99.9	20 - 90
	Bag house	99 - 99.9	15 - 65
	Mechanical Collector	50 - 90	10 - 70
SO_2	Dry sorbet	50 - 80	400 - 3,500
	Semi-dry FGD	80 - 95	600 - 4,000
	West FGD	96 - 98	800 - 5,000
NO_x	Lower NO_x burners	30 - 70	750 - 7,000
	SCR	80 - 90	5,000 - 45,000

- How well the plant has been operated and maintained
- The effectiveness of any pollution control facilities that are installed
- The output of the plant relative to its capacity.

For example, the results in Table 5 need careful interpretation because conditions at specific plants may differ significantly from those of the "typical" plant and so too may the effectiveness of the alternative abatement measures. In particular, it may be possible to repair existing particulate control facilities that are not working properly, or at all, at lower cost than those given in the table. Most large plants in the power and district heating sectors have ESPs that offer some degree of control. Most smaller district heating plants have no control or only mechanical collectors.

Mechanical collectors offer a reliable and relatively low-cost method of controlling particulate emissions in terms of capital and maintenance costs. They are, however, relatively ineffective overall, and particularly at controlling smaller dust particles (< 10 microns).

ESPs and bag filters offer considerable advantages over mechanical collectors in terms of particulate removal efficiency at all particle sizes. Furthermore, since the abatement costs of the most effective method of particulate emissions control are well below those of the cheapest methods of abating either SO_2 or NO_x emissions, it makes sense to opt for the most effective particulate control technology that can be afforded.

The advantages of ESPs and baghouses over mechanical collectors depend on a good standard of operation and maintenance practices. Bag filters need to be kept clean and bags need to be monitored for leaks and periodically replaced. With ESPs, failure to replace worn or failed components can lead to a permanent deterioration in performance. The success of an investment program in these technologies may, therefore, depend on support for parallel training programs and measures to encourage the development of a local maintenance and service industry.

Priority should be given, therefore, to:

- Fitting *particulate control devices* to plants that currently have no such facilities installed; and
- Identifying opportunities to *repair* or *upgrade existing* facilities that are currently not working to design capacity.

Table 6 compares the unit cost of controlling particulate emissions using abatement devices in various sectors. The results show the significant variations within and across sectors. The high unit cost of controlling particulate emissions from the refining and petrochemicals sector and, to a lesser extent, the inorganic chemicals sector reflects the low levels of particulate produced. On the other hand, the relatively high unit cost of controlling emissions from existing coke ovens reflects the high cost of rehabilitating ovens that have been poorly maintained and operated.

There are likely to be numerous opportunities for no-cost/low-cost pollution prevention, primarily through improved operation and maintenance practices. Examples in the energy and industrial sectors include:

- More effective use of energy and materials
- Better-quality fuels and materials
- Better process and energy control
- Preventative maintenance strategies supported by monitoring.

Table 6 Costs of controlling particulate emissions in various sectors

Sector	*Source*	*Abatement cost* [a] *($ per annual ton emission avoided)*
Power and district heating	Boiler	15 - 90
Refining and petrochemicals	Catalytic cracker	3,200 - 22,000
Inorganic chemicals	Fertilizer plant	400 - 800
Iron and steel	Raw materials storage and handling	30 - 800
	Coke ovens	1,500 - 10,000
	Iron and steel making:	
	Stack emissions	20 - 600
	Fugitive emissions	500 - 40,000
Non-ferrous metals	Smelter	20 - 2,000

Note: [a] Capital costs only.

Box 1 The diversity of pollution problems and remedies

This box draws on selected case studies to illustrate the diversity and site-specific nature of pollution problems and their possible remedies in the sectors studied.

The case study at *Trebovice power and district heating plant in the Czech Republic* revealed that three of the eight boilers at the plant (representing 65 percent of total capacity) are only fitted with mechanical collectors. The remaining boilers are fitted with ESPs, some of which have been operating for 15-20 years and are in poor condition. Parts such as collecting and discharge electrodes are likely to be worn out. Replacement of existing mechanical collectors and repair and modernization of existing ESPs would substantially reduce particulate emissions.

During the visit to the *Kosice iron and steel plant in Slovakia*, burnt lime fines were being deposited on the iron ore beds. As a result, the area around the yard was being covered with dust, despite moderate wind conditions. This material would be better returned to the sinter plant landing yard which is covered. All four units of the sinter plant have cyclones fitted, while two have ESPs fitted to the sinter breaker and screening areas but not the sinter exhaust stack. As a result, emissions from the stacks are dirty and will almost certainly contain relatively large amounts of fine oxide dust. The solution to these problems would involve changes in operating practices to improve sinter quality, and replacement of the ignition and filtration systems. The total cost of these measures is estimated at $12–18 million. The coke ovens at Kosice display signs of age and need repair. Most of the doors were leaking and there was a constant haze emanating from the top of the ovens. Detailed studies would be needed to determine the precise measures needed to reduce the emission levels but replacement or rehabilitation of the coke ovens may be necessary in the medium term. This would cost $100 million or more for Kosice.

Significant pollution control has already been achieved at the *Plovdiv lead smelter in Bulgaria* by installing bag houses at the sinter-handling, crushing, and refinery ventilation systems; replacing existing filter bags for smelter stack gas cleaning by better-quality bags; installing water sprays to control particulate emissions from materials handling areas; rehabilitating the smelter gas collection and ducting systems; installing a pollution monitoring system to assist in identifying plant failures; and improved operation and maintenance practices. The overall impact of these measures seems to have brought levels of lead emissions to within Western European standards at an investment cost of only $2–3 million.

At the *Copsa Mica lead smelter in Romania* much of the lead reaching the environment comes from the concentrate stage and handling. The site needs cleaning to remove deposits of concentrate that have accumulated around the site. Enclosing the storage building and equipping handling operations with water

However, site-specific environmental audits are required to identify the scope for these no-cost/low-cost actions since the specific opportunities are very sensitive to local conditions. The case study at Copsa Mica, for example, highlighted the need to replace torn bag filters in existing bag houses. More generally audits are also required to identify specific threats to human health and least-cost ways to ameliorate them, reflecting the diversity of pollution problems and their possible remedies. Box 1 draws on the results of selected case studies to illustrate the diversity and the wide range of costs that would be required to take action.

Adaptive measures, not requiring capital expenditures, which might also have a role to play include:

- Changing the pattern of output from centrally dispatched power plants to reflect both financial and environmental considerations
- Load shedding from specific plants during periods at high pollution, where the adverse air quality is linked to emissions from that plant.

Sector findings

Only in the iron and steel sector are more than 50 percent of the plants identified in the inventory located in hot spots. This tends to confirm this sector as one of the worst polluters in the region. Many of the largest iron and steel plants based on outdated open hearth steel-making technology are located in hot spots.

In contrast, pulp mills do not feature much—less than 15 percent are located in hot spots. But this does not imply that pulp mills are not a potential public health hazard. For example, a health study of Razlog in Bulgaria showed increases in the incidence of asthma, skins diseases, and conjunctivitis following the opening of a nearby pulp mill, which emits high levels of H_2S and VOCs.

Table 7 summarizes the estimates of the capital expenditure that would be required to apply the measures noted in Table 3 to those plants from the inven-

Box 1 The diversity of pollution problems and remedies *(continued)*

sprays and filter systems would substantially reduce emissions. These measures would cost about $0.5 million. Simply closing the side of the existing concentrate building would give a worthwhile improvement at a cost of less than $20,000. The installation of better process control would improve overall process and energy efficiency, and hence reduce pollution. Basic instrumentation and control systems would cost about $0.5 million. Other priority actions at Copsa Mica include: replacement or repair of the ESP fitted to the acid plant which was not operational during the visit and obviously had not been so for some time; use of the hoods fitted to lead kettle operation which can be swung into position over the kettles, but which were not being used during the visit; and replacement of torn filter bags in existing bag houses.

The *Azot fertilizer complex at Grodno, Russia,* has already made environmental improvements not found at comparable enterprises. These include catalytic conversion of tail gases from nitric acid production, recycling of ammonia plant purge gas after clean-up, and good prill tower operation through process control. The major remaining problems relate to the emissions of VOCs from diffuse sources in the caprolactam plant. A detailed study would be required to identify the size of the problem and possible solutions. But the sort of measures likely to be required include: efficiency improvement; replacement of seals; and vent gas recovery. The total cost of these measures at the plant would be about $30 million.

At the *PO Kaustik plant at Volograd in Russia,* a new membrane process plant has been delivered to the plant but the funds are not available for its installation. This plant would replace the existing mercury and diaphragm units, thereby eliminating mercury and asbestos pollution.

At the *Carom SA organic chemicals plant at Onesti in Romania* the SBR plant needs attention to the dryer section, which is leaking styrene and butadiene. This could be ameliorated by improving the venting and control of vapors. The investment required would only be about $200,000. Generally, better monitoring at the site would identify leaks and enable appropriate repairs to be made.

The case study at the *Plock refinery and petrochemicals plant in Poland* identified a number of cost-effective measures to control VOCs. These include: improved sealing on asphalt oxidation to reduce emissions of polyaromatic hydrocarbons (PAHs) at around $1 million; modernization of existing equipment to better engineering design, venting of process units to appropriate devices such as flares, floating roof tanks, etc., for approximately $5–10 million; and improving maximum enclosure and venting of air from around the loading point to a control device at a cost of around $200,000.

Table 7 Capital expenditure estimates for priority measures at selected plants in CEE countries

Sector	*Expenditure estimate ($ million)*
Power and district heating	700 - 2,000
Refining and petrochemicals	15 - 200
Inorganic chemicals	10 - 100
Organic chemicals	100 - 200
Iron and steel	600 - 3,000
Non-ferrous metals	10 - 150
Pulp	5 - 15
Small boilers and households	300 - 2,500
Total	1,700 - 8,200

tory that are located at hot spots. Expenditure estimates in the power and district heating sectors represent the costs of fitting new ESPs to all plants; the costs would be lower at plants where existing facilities can be rehabilitated and modernized. The expenditure estimates for the iron and steel sector assume that the worst pollution problems from coke ovens can be addressed for $10 per annual ton of raw steel. Measures to reduce particulate from the power and district heating sectors could be replicated in combustion boilers in the other sectors; this would not add significantly to the overall estimates.

Although aggregate data on emissions from the small boilers and households sectors do not form part of the inventory, indicative expenditure estimates have been made to enable broad comparison with other sectors. These estimates have been made on the basis of taking measures such as installing basic insulation, switching to gas, or fitting modern coal stoves in 0.5–1 million households at a cost of $1,000–$2,000 per household and introducing basic insulation, boiler control, or particulate control devices in 10,000–25,000 small boilers at a cost of $5,000–$15,000 per boiler.

The proposed expenditures would significantly reduce emissions of particulate and VOCs from the worst pollution sources. They would not deal with the major sources of SO_2 and NO_x, which are at present generally considered too expensive for implementation since their inclusion would increase the total expenditure estimates by an order of magnitude.

The estimates in Table 5 may overstate the expenditures for several reasons. Some of the plants, probably the minority, are already operating to relatively high environmental standards and do not need to incur all the costs envisaged by the calculations. At others, existing pollution control facilities could be repaired and modernized at lower costs than those envisaged by the calculations. There are also others which are so old and inefficient that expenditure on pollution abatement measures is difficult to justify, particularly in industries which need to bring their capacity closer into line with potential demand.

Indeed, the economic analysis suggests that some enterprises within the sectors studied in the CEE countries are unlikely to be viable following economic reform, once prices are liberalized and subsidies removed. A central issue for governments and enterprises is, therefore, to determine which plants should face closure. Any restructuring program can potentially be used to eliminate sources of ongoing pollution and, as a result, locations may not continue to be hot spots. However, the underlying competitiveness at the enterprise and plant level is generally insufficiently well documented to allow judgements about which enterprises should be closed and the potential contribution to address the short-term priorities.

To the extent that closure programs do go ahead in the short to medium term, the analysis suggests that the pattern of closure should take full account of environmental as well as financial and other social considerations. This would imply closing plants located in rather than elsewhere, because of the environmental benefits. It would also reduce the capital expenditure needed to achieve a given reduction in emissions.

Next steps

The analysis has established a broad set of priorities for environmental expenditure in the short to medium term on the basis of a simple comparison of the costs and benefits of alternative control options. The next steps fall into two broad categories:

- Establishment of appropriate financial and institutional arrangements to implement the priorities in the short to medium term
- Development of longer-term environmental policy.

Chapter 5

Implementing Priorities

In principle, the joint pressures of economic reform and an appropriate environmental policy framework are expected to provide enterprises in CEE with the incentives needed to implement some of the most attractive options for pollution abatement. In practice, various constraints exist that hinder this process.

Economic and environmental management background

The change of environmentally harmful macroeconomics policies (for example, the elimination of energy price subsidies) is slow, still sending wrong signals to economic agents (producers and consumers). The privatization of large public enterprises is also proceeding slowly. Tight budget constraints are not always imposed, preserving old management practices and making it difficult for market signals to work.

The political willingness to tackle environmental problems seriously is frequently missing, as environmental protection is typically not strongly represented in the budgeting process due to (i) limited public information about environmental problems; (ii) the weaknesses or lack of political parties representing environmental protection causes; and (iii) the lack of strong NGO and community organizations. Additionally, environmental institutions are relatively weak with limited capacity to set clear priorities and enforce regulations.

Dysfunctional and underdeveloped financial and capital markets restrict the access of enterprises to financial resources. The banking sector in most CEE countries is undergoing serious changes and reorganization, while capital markets are in the stage of infancy. The availability of medium- and long-term credit is typically restricted or carries prohibitively high interest rates due to prevailing high inflation rates and uncertainties about long-term economic prospects. Additionally, traditional accounting and financial indicators are unavailable for lenders to reliably assess the performance and future prospects of borrowers. Small and medium enterprises face increased problems with access to financing sources at reasonable terms due to (i) their limited internally generated cash resources; (ii) the relative high transaction costs of loan application; (iii) the lack of conventional credit securities; and (iv) the lack of adequate information about project preparation and credit application.

Approach to setting environmental expenditure priorities

While low-cost measures and changes in producer and consumer behavior are likely to bring significant improvements in environmental quality, investments in cleaner production and emission control technologies are also necessary beyond the "automatic" benefits of economic changes to reduce the impacts of harmful substances emitted to the environment.

Decisions about environmental expenditures during the transition should ensure that:

- Immediate actions are taken to address priority environmental problems

- Resources are allocated cost-effectively
- Expenditures in the short term are consistent with longer-term priorities.

There is also an urgent need to ensure that environmental considerations are integrated more effectively into the development and implementation of industrial restructuring programs. More generally, there is a case for considering whether and how the use of the underlying resource costs (and benefits), rather than observed—often distorted—prices would influence the choice of priorities. In practice, this may best be done as part of the industrial restructuring programs. An assessment of the potential wider environmental impacts of these programs, therefore, will be needed. There are likely to be significant environmental benefits from the closing of certain plants that are major contributors to the severe problems in environmental hot spots. These environmental benefits should be taken into account when decisions are made about plant closing and other restructuring measures.

The role of public environmental financing in the enterprise sector should be carefully defined, and special attention needs to be paid to the cost-effective use of public funds. During the transition from central planning to market economy, traditional ties and blurred government-enterprise financing responsibilities are changing. The reform process increases the role of the private sector, increasingly delegates investment decisions to the micro level, and tightens the previously soft budget constraints of the public sector. Limited public funds should be allocated, therefore, to priority expenditures where they can buy the largest environmental benefits.

Public funds may be used to bring environmental expenditures forward in time, and support the adjustment of enterprises to changing environmental requirements. The majority of environmental investment should increasingly come, however, from enterprise sources. The operation and maintenance of pollution control technology and housekeeping measures are recurrent costs to be funded from operating revenues, while capital investments may be financed from internally generated cash or commercial financing sources (bank loans, stocks, or bonds). Currently, such investments may be limited by (i) inertia and reluctance to act due to old management practices; (ii) uncertainties about future environmental regulations and requirements; (iii) the lack of information about the availability and merits of various pollution abatement solutions; (iv) lack of knowledge and expertise in applying for financing; and (v) the lack of capital available on the domestic financial markets at reasonable terms. Public funds, therefore, may play a catalytic role in improving the willingness of enterprises to undertake investments that bring environmental improvements, and facilitate their access to commercial financing sources. The state, however, should avoid crowding out commercial financing.

Most transition economies have a large portfolio of inefficiently operating public enterprises that are likely to stay in public ownership for an extended period without having the resources to undertake investments to improve their operations. In most cases, these enterprises are major sources of pollution. Frequently, relatively modest investments can result in significant environmental improvements in these enterprises. Several sectors can be identified where environmental expenditure can be considered as an immediate priority. These include metal manufacturing; power and district heating plants, the operation of which exposes large populations to particulate matter; heavy metals; and other harmful substances. The use of public funds for low-cost investments in carefully selected priority sectors, therefore, may be justified to avoid large social costs.

By identifying low-cost measures and other priority actions to abate pollution and improve the environmental performance of plants, environmental audits can be useful tools of pollution abatement. Environmental audits have not, however, been carried out in CEE countries regularly. Training, therefore, should be provided in order to transfer know-how and to develop the necessary skills locally.

The estimated costs of pollution control options merit further examination since those frequently quoted are based largely on prices pertaining in the West. To the extent that the necessary technology and/or skills are available locally, these costs may need to be adjusted to reflect local input prices. More importantly, there may be a case for reviewing the capacity of the pollution abatement industry in the CEE countries. Abatement options for which indigenous capability exists may be more attractive because they alleviate the need for imports and hence foreign exchange. Moreover, the implementation of priority environmental expenditures can be used to help develop indigenous capacity. This longer-term benefit needs to be factored into the analysis.

Financing mechanisms

In the short and medium term, the establishment of Pollution Abatement Funds (PAFs) may be an attractive approach to (i) ensure that immediate environmental priorities are addressed; (ii) induce the compliance of enterprises with environmental regulations by offering co-financing schemes; (iii) provide a framework for eliminating the obstacles of market financing; and (iv) provide a mechanism for donor financing. The main role of PAFs would be to accelerate the adjustment of enterprises to changing—or tightening—environmental regulations. They should, however, ultimately contribute to a well-functioning environmental management system in which enterprises carry the burden of the environmental damage they cause and environmental expenditures become part of the cost of doing business. The role of PAFs, therefore, should be temporary, and their operation should be subject to strict conditions:

- Resource allocation should be based on clear priorities defined by the Ministry of Environment or regional/local authorities.
- A well-targeted set of spending priorities rather than broadly defined goals should ensue the effectiveness of funds.
- Project selection should be based on cost-effectiveness criteria.
- Environmental objectives should be defined in measurable terms.
- Improved compliance to environmental regulations should be conditions of financing.
- Taking into account funding from PAFs, projects should be financially viable.
- Enterprise commitment should be ensured by co-financing requirements.
- Environmental achievements should be measured and monitored also on a project-by-project basis.

PAFs may be funded by (i) budget allocations; (ii) donor contributions; and (iii) earmarked environmental charges and taxes. Explicit budget allocations or donor contributions, however, are the preferred mechanisms, since these avoid the establishment of self-perpetuating mechanisms created by earmarking. PAFs may (i) co-finance pollution abatement projects; (ii) support environmental audits; and (iii) provide assistance with project preparation. Financing may be allocated in the form of grants, loans, and guarantees. Grant financing—that can be combined with commercial financing to achieve the desired financing conditions—is more transparent. However, appropriate blending with other financing sources may be hindered by the weaknesses of financial markets in CEE countries calling for soft lending schemes. A set deadline for closing the operation of PAFs is desirable as the improvement of environmental management systems and financial markets are expected to establish a framework for market financing. A set deadline is likely to have a positive affect on the timing of pollution abatement investments.

Institutional issues

The institutional capacity of environmental management will significantly influence the implementation of environmental policies, and the integration of environmental considerations into the economic restructuring process. Institutions will have to ensure that rules, regulations, and standards imposed on pollution sources are consistent with priorities based on the impact on human health and the available resources. In the longer term, CEE countries may wish to move towards the adoption of EU standards and environmental quality objectives. In the short term, however, realistic and enforceable targets should be defined and priority expenditures identified.

Institutional capacity building is an area where support from international financial institutions and bilateral aid agencies may be most needed. Specifically, assistance with creating local capabilities of economic and environmental assessments, priority setting, and project evaluation may enable the institutions of CEE countries to speed up the implementation of priority projects and allocate scarce resources effectively.

There is a scope for improving the understanding of the nature and extent of the environmental problems and better identifying all the major contributing sources to these problems. The development and improvement of existing environmental monitoring systems should be part of this process. By improved information, a better appreciation and understanding of the likely benefits of pollution abatement and other environmental measures can be developed, the identification of environmental priorities can be enhanced, and the role of environmental protection on the political agenda can be strengthened.

The response of polluters to environmental policy measures—implemented by direct regulations, market-based incentives, or a mixture of these instruments—depends on the perceived willingness of the environmental protection institutions to enforce them. The capacity and commitment of these institutions to enforce environmental rules and regulations, therefore, are essential for the improvement of environmental performance at the enterprise level.

Longer-term policy development

In the longer term, governments will need to develop their environmental policies to ensure appropriate levels of environmental protection. Two issues are relevant here: first, expenditures in the short term need to be consistent with longer-term priorities. For example, short-term expenditure to reduce emissions at a particular plant should not be jeopardized because it is incompatible with long-term environmental objectives, which would require further replacement investment. Second, and related to this point, the timetable for achieving longer-term policy objectives needs to take account of the transitional period.

Endnotes

1. The work is detailed in a companion report on "Environment and Health in Central and Eastern Europe."
2. See Annex 4 of "Environment and Health in Central and Eastern Europe."
3. Water pollution, though severe in many parts of Central and Eastern Europe, can generally be avoided by people and, therefore, does not tend to cause health problems. The costs of treating water pollution are also typically much higher than treating air pollution. In Poland, for example, the Ministry of Environment expects that some 75 percent of the $70 billion it believes needs to be spent on pollution abatement should be spent on water protection. It seems unlikely that such massive expenditures could be justified as priorities for the short to medium term.

Annex A

Inventory of Major Pollution Sources

Introduction

This annex presents a summary of an inventory of major pollution sources within each of the following industrial sectors:

- Power and heat
- Petroleum refining and petrochemicals
- Organic chemicals
- Inorganic chemicals
- Iron and steel
- Non-ferrous metals
- Pulp and paper.

The purpose of compiling the inventory was to identify potential pollution sources in the sectors under consideration and collate available information on their key characteristics. As such it was intended to provide a potential basis for extrapolating the results of specific plant studies and desk research to generate estimates of the total environmental expenditure for the region as a whole in the priority areas.

The inventory, which is described more fully in a separate working paper, includes available data—subject to availability—on location, capacity, age, processes, technology, pollution control facilities and emissions.

The process of compiling the inventory

Information for the inventory came primarily from an extensive literature review. Important sources included:

- Published trade directories and sector reviews
- Reports from previous studies undertaken on behalf of international institutions such as the World Bank, EC, EBRD, and UNIDO and, in particular, reports from the Baltic Sea and Black Triangle programs
- Reports from national governments providing assistance to the CEE countries.

Generally speaking these sources provided limited information about a large number of plants and detailed information about a small number.

We also sought information for the inventory from all national governments in the countries of study. Only very limited information was obtained in this way, in part because governments tend not to hold plant specific information.

Environment Ministry officials from some of the countries of study were kind enough to review the inventory in draft form and provide helpful corrections and additions.

Limitations of the inventory

The main shortcoming of the inventory is the paucity of data. In many instances, the only information available relates to the existence of a plant. This limits the potential uses of the inventory. In particular, it means that only very crude use can be made of the inventory for the purposes of aggregation.

Other potential problems include:

- Some inconsistencies were found between data sources, for example relating to plant capacities
- Only the approximate location of plants is generally known—for example, the nearest large town.

But the impact of pollution from a plant on a population centre will depend on the details of the relative locations and factors that affect the transport of pollutants between source and receptor

- The inventory includes 'large' plants, but will inevitably exclude smaller plants that, because of their location, may have a greater impact on human health
- Some plants that have been included in the inventory on the basis of information that is a number of years old, may have recently closed down
- Some plants that have changed names may be included twice under their old and new names.

Despite the obvious problems, the inventory still represents a useful and sensible basis for extrapolating results of plant-based studies to the regions as a whole.

The following tables present summary information on each of the study sectors. Plants have been collated by country within each of the sectors.

Table A.1 Thermal power and heat plants in Central and Eastern Europe

Country	#	#	Plant name	Location	Fuel	Type	Electrical capacity MWe	Heat capacity MWt	Electrical output GWh	Heat output TJ
Belarus	1	1	Lukomskaya (Lukoml)		FO		2,400	-		
	2	2	Berezovskaja - GREC	Berezovsk			920	-		
	3	3	Minskaja - TEC 3	Minsk						
	4	4	Novopolotckaja - TEC	Novopolotck						
	5	5	Gomelskaja - TEC	Gomel						
	6	6	Minskaja - TEC 4	Minsk						
	7	7	Mozurskaja - TEC							
	8	8	Svetlogorskaja - TEC	Svetlogorkoje						
	9	9	Grodneiskaja TEC2	Grodno						
	10	10	Mogilevskaja TEC2	Mogilev						
Bulgaria	11	1	Bobov Dol	Sofia	BC		630			
	12	2	Devnia	Devnia	HC, G		166			
	13	3	Dimo Ditchev	Haskovo	BC		840			
	14	4	Maritsa Istok 2	Dimitrovgrad, Haskovo	BC		1,020			
	15	5	Purva Komsomolska (formerly Maritsa 1)	Maritsa	BC		200			
	16	6	Iztok	Rousse	HC		400			
	17	7	Varna	Varna	HC, G		1,260			
	18	8	Republica Power	Pernik						
	19	9	Kremijkovtsi		BC, FO, G		178			
	20	10	Burgas	Burgas	FO, G		257			
Czech Republic	21	1	Chvaletica	Chvaletee	BC, FO	E	800			
	22	2	Detmorovice	Detmorovice	HC, FO	E	800			
(continued)	23	3	Ledvice 1	Ledvice	BC, FO	E	200			

Table A.1 Thermal power and heat plants in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Fuel*	*Type*	*Electrical capacity MWe*	*Heat capacity MWt*	*Electrical output GWh*	*Heat output TJ*
Czech Republic	24	4	Ledvice 2	Ledvice	BC, FO	E	440			
	25	5	Melnik 1	Melnik	BC, FO	E	330			
	26	6	Melnik 2	Melnik	BC, FO	E	440			
	27	7	Melnik 3	Melnik	BC, FO	E	500			
	28	8	Pocerady I	Pocerady	BC, FO	E	1,200			
	29	9	Prunérov 1	Prunérov	BC, FO	E	640			
	30	10	Prunérov 2	Prunérov	BC, FO	E	1,050			
	31	11	Tisová 1	Tisová	BC, FO	E	220			
	32	12	Tisová 2	Tisová	BC, FO	E	300			
	33	13	Komorany	N Bohemia	BC	E	196			
	34	14	Trebovice 2	Ostrava	HC, FO	EH	80	470		
	35	15	Porici 2	N Bohemia	HC, FO	E	165			
	36	16	Tusimice 1	N Bohemia	BC, FO	E	660			
	37	17	Tusimice 2	N Bohemia	BC, FO	E	800			
	38	18	Hadonin	Hadonin	BC, FO	E	210			
	39	19	Oslavany	Oslavany	HC, FO	E	94			
	40	20	Karvina		HC, G	E	47			
	41	21	Trmice		BC, FO	EH	48	..		
	42	22	Malesice		BC, FO, G	EH	122	..		
	43	23	Karlovy Vary		BC, FO	EH	18	..		
	44	24	Ceske Budejovice		BC, FO	HE	49	..		
	45	25	Nachod		BC, FO	EH	17	..		
	46	26	Dvur Kralove		BC, FO	EH	18	..		
(continued)	47	27	Plzen 2	Plzen	BC, FO	EH	55	..		

Country	#	#	Plant name	Location	Fuel	Type	Electrical capacity MWe	Heat capacity MWt	Electrical output GWh	Heat output TJ
Czech Republic	48	28	Strakonice		BC, FO	EH	18	..		
	49	29	Otrokovice		BC, FO	EH	37	..		
	50	30	CSA		HC, G	EH	24	..		
	51	31	TP Brno	Brno	FO, G	EH	93			
	52	32	TP Prerov	Prerov	HC, FO	EH	25			
	53	33	Spalovna Vysocany		BC, FO	EH	26			
	54	34	Veleslavin		BC, FO	EH	12			
	55	35	Sucha		HC, FO	EH	12			
	56	36	Liberac		FO	EH	12			
	57	37	Michle		BC, FO	EH	12			
Slovakia	58	1	Nováky A	Nováky	BC		130			
	59	2	Nováky B	Nováky	BC	E	440	..		
	60	3	Vojany 1	Vajany	BC		660			
	61	4	Vojany 2	Vajany	BC	E	660			
	62	5	Bratislava 2	Bratislava	FO, G	EH	24			
	63	6	Martin		BC, FO	EH	15			
	64	7	Bratislava 1	Bratislava	FO, G	EH	14			
	65	8	Bratislava zapad	Bratislava	FO. G	EH	14			
	66	9	Trnava		HC, FO, G	EH	17			
	67	10	Kosice		HC, FO	EH	121			
	68	11	Zllina		BC, FO	EH	49			
Estonia	69	1	Estonskaya	Narva	Oil shale	EH	1,610	84	8,980[2]	130[2]
	70	2	Pribaltiiskii	Narva	Oil shale	EH	1,435	470	7,606	6,327
(continued)	71	3	Kohtla Yarve power plant	Kohtla Yarve	Oil shale	EH	39	416	82	3,823

Table A.1 Thermal power and heat plants in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Fuel*	*Type*	*Electrical capacity MWe*	*Heat capacity MWt*	*Electrical output GWh*	*Heat output TJ*
Estonia	72	4	Ahtme power plant	Kohtla Yarve	Oil shale	EH	20	102	87	2,148
	73	5	Iru power plant	Tallinn		EH	190	690	654[2]	4,426
	74	6	Ulemiste power plant			EH	-	339	36	2,927
	75	7	Tallinn boilerhouse	Tallinn		H	-	334	-	1,612
	76	8	Mustamae boilerhouse			H	-	560	-	3,195
	77	9	Kadaka boilerhouse			H	-	278	-	1,922
	78	10	Karjamaa boilerhouse			H	-	60	-	5992
	79	11	Tartu boilerhouse			H	-	201	-	1,595
Hungary	80	1	Ajka	Ajka	HC	EH	113	322		
	81	2	Banhida		HC	EH	100	16		
	82	3	Borsod	Borsod	HC,G	EH	171	532		
	83	4	Gagarin	Gagarin	BC	EH	800	47		
	84	5	November 7	Inota	HC,FO	EH	270	138		
	85	6	Oroszlany	Oroszlany	HC	EH	235	42		
	86	7	Pécs	Pécs	HC	EH	245	537		
	87	8	Tiszai 1	Tiszapalkonya	FO,G	EH	250	278		
	88	9	Tiszai 2	Tiszapalkonya	HC,G	E	860	-		
	89	10	Dunamenti I		FO,G	EH	514	394		
	90	11	Dunamenti II		FO,G	E	1,290	-		
	91	12	Salgotárjan		FO	H	-	80		
	92	13	Komlo		FO	EH	10	58		
	93	14	Tatabanya		HC	EH	32	230		
	94	15	Dorog		HC	EH	12	177		
(continued)	95	16	Kelenfold		FO					

Country	#	#	Plant name	Location	Fuel	Type	Electrical capacity MWe	Heat capacity MWt	Electrical output GWh	Heat output TJ
Hungary	96	17	Kobanya		FO					
	97	18	Kispest		FO, G	EH	24	435		
	98	19	Ujpest		FO, G	EH	10	367		
	99	20	Angyalfold		FO, G	EH	10	285		
	100	21	Gyor I		FO, G	EH	8	67		
	101	22	Gyor II		HC	H	-	39		
	102	23	Sopron		FO	EH	9	107		
	103	24	Szekesfenervar		FO	H	-	136		
	104	25	Szegad		G	H	-	84		
	105	26	Békéjcsaba		G	H	-	45		
	106	27	Debrecen		FO, G	H	-	422		
	107	28	Myíregyhaza		PO, G	H	-	249		
Latvia	108	1	Riga TEC1	Riga	FO, G, peat		130	66		
	109	2	Riga TEC2	Riga	FO,G		330	1,200		
	110	3	Termocentrale "Andrejsala"	Riga	FO,G		-	409	-	2,950[1]
	111	4	Termocentrale "Imanta"	Riga	FO,G		-	262	-	2,540
	112	5	Termocentrale "Zasulauks"	Riga	FO,G		-	219	-	1,685
	113	6	Termocentrale "Kangarags"	Riga	G		-	197	-	1,960
	114	7	Termocentrale "Vecmilgravis"	Riga	FO,G		-	98	-	769
Lithuania	115	1	Electrenai power plant	Vilnius	FO,G		1,800			
	116	2	Vilnius CHP plant	Vilnius		EH	394	..		
	117	3	Kaunas CHP plant			EH	190	..		
	118	4	Mazeikiai CHP plant			EH	210	..		
(continued)	119	5		Vilnius	G,FO	H	-	1,419		10,441[2]

Table A.1 Thermal power and heat plants in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Fuel*	*Type*	*Electrical capacity MWe*	*Heat capacity MWt*	*Electrical output GWh*	*Heat output TJ*
Lithuania	120	6		Marijampole		H	-	338		2,521
	121	7		Kaunas		H	-	220		2,143
	122	8		Druskininkai		H	-	157		1,184
	123	9		Jonava		H	-	142		1,382
	124	10		Utena		H	-	336		2,456
	125	11		Alytus		H	-	594		4,434
	126	12		Klaipeda		H	-	684		6,735
	127	13		Varena		H	-	157		1,174
	128	14		Taurage		H	-	98		963
	129	15		Siavliai		H	-	760		5,081
	130	16		Radviliskis		H	-	94		626
	131	17		Mazeikiai		H	-	155		1,034
	132	18		Panevezys		H	-	707		5,164
	133	19		Kedainiai		H	-	112		820
	134	20		Rokiskis		H	-	114		833
Moldova	135	1	Moldavia (Moldova Moldavskaya)		HC,F		2,480			
Poland	136	1	Adamov	Konin, Koninskie	BC	E	600	-	2,537[3]	
	137	2	Belchatow	Belchatow, Piotrkowskie	BC	E	4,320	-	24,700	
	138	3	Dolna Odra	Dolna Odra, Szczecin, Szczecinskie	HC	E	1,600	-	6,550	
	139	4	Jaworzno I	Jaworzno, Katowickie	HC	E	146	-	237	
	140	5	Jaworzno II	Jaworzno, Katowickie	HC	E	350	-	829	
	141	6	Jaworzno III	Jaworzno, Katowickie	HC	E	1,200	-	5,979	
	142	7	Konin	Konin, Koninskie	BC	E	583	-	3,050	
(continued)	143	8	Kozienice	Kozienice, Radomskie	HC	E	2,600	-	8,375	

Country	#	#	Plant name	Location	Fuel	Type	Electrical capacity MWe	Heat capacity MWt	Electrical output GWh	Heat output TJ
Poland	144	9	Lagisza	Lagisza, Katowickie	HC	E	840	-	3,272	
	145	10	Laziska	Laziska, Katowickie	HC	E	1,040	-	4,228	
	146	11	Ostroleka B	Ostroleka, Ostroleckie	HC	E	600	-	2,435	
	147	12	Patnow	Patnow, Konin, Koninskie	BC	E	1,600	-	6,770	
	148	13	Polaniec	Polaniec, Tarnow, Tarnowskie	HC	E	1,600	-	7,403	
	149	14	Rybnik	Rybnik, Katowickie	HC	E	1,600	-	9,200	
	150	15	Siersza	Siersza, Trzebinica, Wroclawskie	HC	E	740	-	2,342	
	151	16	Skawina	Skawina, Krakowskie	HC	E	550	-	1,972	
	152	17	Turow	Turowo, Koszalinskie	BC	EH	2,000	-	11,341	
	153	18	Siekierki	Warsaw, Warsawskie	HC	EH	622	875	1,565	18,068
	154	19	Stalowa Wola	Stalowa Wola, Tarnobrzeskie			385	-	1,131	17,595
	155	20	Zeran		HC	EH	250	1,477	1,179	18,462
	156	21	Powisie		HC	EH	42	247	88	2,161
	157	22	Pruszkow	Pruszkow, Warsawskie	HC	EH	6	176	15	1,634
	158	23	Wola	Wola, Sieradzkie	FO	H	-	465	-	3,089
	159	24	Lodz I	Lodz, Lodzkie	HC	EH	36	254	74	2,689
	160	25	Lodz II	Lodz, Lodzkie	HC	EH	179	956	444	8,359
	161	26	Lodz III	Lodz, Lodzkie	HC	EH	199	860	628	7,048
	162	27	Lodz IV	Lodz, Lodzkie	HC	EH	110	860	461	8,303
	163	28	Ostroleka A	Ostroleka, Ostroleckie	HC	EH	94	309	182	4,192
	164	29	Bialystok II	Bialystok, Bialostockie	HC	EH	118	515	453	5,997
	165	30	Kaweczyn		H	HC	-	744	-	5,196
	166	31	Lublin I	Lublin, Lubelskie	HC	H	-	46	-	87
(continued)	167	32	Lublin - Wrotkow	Lublin, Lubelskie	HC	H	-	424	-	4,825

Table A.1 Thermal power and heat plants in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Fuel*	*Type*	*Electrical capacity MWe*	*Heat capacity MWt*	*Electrical output GWh*	*Heat output TJ*
Poland	168	33	Rzeszow - Zaleze	Rzeszow, Rzeszowskie	HC	H	-	373	-	2,310
	169	34	Radom - Polnoc	Radom, Radomskie	HC	H	-	169	-	1,121
	170	35	Zamosc - Szopinek	Zamosc, Zamojskie	HC	H	-	87	-	602
	171	36	Kielce	Kielce, Kieleckie	HC	H	-	203	-	1,390
	172	37	Bedzin	Bedzin, Katowickie	HC	EH	55	555	172	4,037
	173	38	Chorzow	Chorzow, Katowickie	HC	EH	100	490	269	3,018
	174	39	Tychy	Tychy, Katowickie	HC	H	-	559	-	3,137
	175	40	Miechowice	Miechow, Kieleckie	HC	EH	110	248	259	1,315
	176	41	Szombierki		HC	EH	44	184	61	1,457
	177	42	Zabrze	Zabrze, Katowickie	HC	EH	106	307	188	2,899
	178	43	Halemba		HC	E	200	-	783	
	179	44	Bielsko - Biala	Bielsko-Biała, Bielskie	HC	EH	100	536	365	5,691
	180	45	Bielsko - Komorowice		HC	H	-	394	-	1,745
	181	46	Cieszyn	Cieszyn, Bielskie	HC	H	-	178	-	1,036
	182	47	Blachownia		HC	EH	281	294	750	3,139
	183	48	Krakow - Leg	Krakow, Krakowskie	HC	EH	460	1,457	1,434	8,747
	184	49	Czestochowa		HC	H	-	92	-	576
	185	50	Katowice	Katowice, Katowickie	HC	H	-	300	-	2381
	186	51	Wroclaw	Wroclaw, Wroclawskie	HC	EH	267	1,145	918	8,968
	187	52	Czechnica		HC	EH	132	261	256	2,848
	188	53	Poznan - Garbary	Poznan, Poznanskie	HC	EH	20	220	58	2,467
	189	54	Poznan - Karolin	Poznan, Poznanskie	HC,FO	EH	55	475	296	6,107
	190	55	Szczecin	Szczecin, Szczecinskie	HC	EH	48	320	150	3,257
(continued)	191	56	Pomorzany		HC	EH	120	387	362	3,065

Country	#	#	Plant name	Location	Fuel	Type	*Electrical capacity MWe*	*Heat capacity MWt*	*Electrical output GWh*	*Heat output TJ*
Poland	192	57	Kalisz	Kalisz, Kaliskie	HC	EH	9	152	4	1,046
	193	58	Gorzow		HC	EH	87	344	302	3,189
	194	59	Zielona Gora	Zielona Gora, Zielonogurskie	HC	EH	11	238	46	2,052
	195	60	Olowianka		HC	EH	29	72	26	635
	196	61	Gdansk II	Gdansk, Gdanskie	HC	EH	188	831	691	9,965
	197	62	Gdynia I	Gdynia, Gdanskie	HC	EH	30	100	13	1,023
	198	63	Gdynia II	Gdynia, Gdanskie	HC	EH	33	134	28	1,429
	199	64	Gdynia III	Gdynia, Gdanskie	HC	EH	55	437	281	4,683
	200	65	Bydgoszcz I	Bydgoszcs, Bydgoskie	HC	EH	14	185	27	1,695
	201	66	Bydgoszcz II	Bydgoszcs, Bydgoskie	HC	EH	169	756	584	10,680
	202	67	Bydgoszcz III	Bydgoszcs, Bydgoskie	HC	EH	33	142	18	999
	203	68	Torun - Grebocin	Torun, Torunskie	HC	H	-	279	-	1,833
	204	69	Elblag	Elblag, Elblaskie	HC	EH	62	395	103	3,132
	205	70	Grudziadz	Grudziadz, Torunskie	HC	H	-	36	-	650
Romania	206	1	Borzesti	Onesti	FO		655			
	207	2	Craiova-Isalnita		BC		1,035			
	208	3	Doicesti		BC,FO,G		400			
	209	4	Mintia	Deva	HC, FO		1,260			
	210	5	Paroseni		HC		300			
	211	6	Rovinari		BC, FO		1,720			
	212	7	Turceni		BC, FO		2,310			
	213	8	Braila		FO		960			
	214	9	Brazi		FO		510			
(continued)	215	10	Ludus	Lernut	..		800			

Table A.1 Thermal power and heat plants in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Fuel*	*Type*	*Electrical capacity MWe*	*Heat capacity MWt*	*Electrical output GWh*	*Heat output TJ*
Romania	216	11	Bucuresti-Sud	Bucharest			550			
	217	12	Galati	Galati			535			
	218	13	Fintinele	Fintinele			250			
	219	14	Bucuresti V	Bucharest			250			
	220	15	Palas	Constanta			220			
	221	16	Govora I	Govora			200			
	222	17	Iasi I	Iasi			150			
	223	18	Navodari	Navodari			150			
	224	19	Grozavesti	Bucharest			125			
	225	20	Pitesti	Pitesti			136			
	226	21	Bucuresti Progresu	Bucharest			150			
	227	22	Craiova	Craiova			240			
	228	23	Borzesto	Onesti-Bacau			100			
	229	24	Borzesti	Onesti-Bacau			150			
	230	25	Drobeta Turnu Severin	Drobeta Turnu Severin			205			
	231	26	Giurgiu	Giurgiu			150			
	232	27	Oradea II	Oradea			150			
	233	28	Oradea I	Oradea			205			
	234	29	Govora II	Govora			100			
	235	30	Iasi II	Iasi			100			
	236	31	Suceava	Suceava			100			
Western Russia	237	1	Kashira	Kashira, Moscow region	BC		2,070			
	238	2	Ryazan	Ryazan	BC,G		2,800			
(continued)	239	3	Novocherkassk	Novocherkassk, Rostov	HC,FO,G		2,400			

Country	#	#	Plant name	Location	Fuel	Type	Electrical capacity MWe	Heat capacity MWt	Electrical output GWh	Heat output TJ
Western Russia	240	4	Kolskaya	Kalskaya, Karelia			..			
	241	5	Petrozavodsk	Petrozavodsk, Karelian	FO		280			
	242	6	St. Petersburg (Leningrad)							
	243	7	Kirischi	Kirischi, St. Petersburg	FO		2,070			
	244	8	Moscow	Moscow						
	245	9	Konakowo	Konakowo, Tver	FO,G		2,400			
	246	10	Kostroma	Kostroma	FO,G		3,600			
	247	11	Nizhny Novgorod	Nizhny Novgorod			..			
	248	12	Nowomoskowsk	Nowomoskawsk			..			
	249	13	Nowoworonez	Nowowaronez			..			
	250	14	Woloszilograd	Woloszilograd			..			
	251	15	Saratov	Saratov						
	252	16	Perm	Perm	HC,G		2,400			
	253	17	Karmanowo	Karmanowo, Moscow	FO		1,800			
	254	18	Magnitogorsk							
	255	19	Stavropol	Stavropol	G		2,400			
	256	20	Inta							
	257	21	Archangelsk	Archangelsk						
	258	22	Zainsk	Zainsk, Tatarstan	FO,G		2,400			
	259	23	Cherepet	Cherepet, Tula	BC		1,500			
	260	24	Nevinomiisk	Nevinomiisk, Stavropol	HC		1,430			
Ukraine	261	1	Krivoi Rog 2	Krivoi Rog	HC		3,000			
	262	2	Pridneprovsk	Dnepropetrovsk	HC,G		2,400			
(continued)	263	3	Starobeshevo	Donetsk	HC		2,300			

Table A.1 Thermal power and heat plants in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Fuel*	*Type*	*Electrical capacity MWe*	*Heat capacity MWt*	*Electrical output GWh*	*Heat output TJ*
Ukraine	264	4	Zaporozhe	Zaporozhe	HC,FO,G		3,600			
	265	5	Zmiev (Smijew)	Zmiev, Charkov			2,400			
	266	6	Slavyansk	Slavyansk, Donetsk region	HC,G		2,100			
	267	7	Burshtyn	Burshtyn, Ivano-Frankovsk	HC,FO,G		2,400			
	268	8	Ladyszin	Ladyszin			1,800			
	269	9	Kanev	Kanev, Kiev region						
	270	10	Uglegorsk	Uglegorsk, Donetsk	HC,FO,G		3,600			
	271	11	Lugansk (formerly Voroshilvgrad)	Lugansk, Donetsk region			2,300			
	272	12	Tripolye	Tripolye, Kiev region			1,800			

Key:

Fuels: HC = hard coal; BC = brown coal; OF = fuel oil; G = gas.
Type: E = electricity; H = heat only; EH = electricity and heat.

Notes:

1 = 1988
2 = 1989
3 = 1991

Table A.2 Iron and steel plants in Central and Eastern Europe

Country			Plant name	Location	Pig iron capacity th.t/y	Steel-making capacity th.t/y Total	OH	BOF	EF/DR
Belarus	1	1	Zhlobin Metallurgical Works	Zhlobin		1,095			1,095
Bulgaria	2	1	Burgas Steelworks	Burgas	-	900			900
	3	2	Kremikovtsi Iron & Steel Works	Sofia-Botounetz	1,800	2,265		1,765	500
	4	3	Stomana Works (formerly Lenin works)	Pernik	235	1,500	350		1,150
	5	4	Kamet steel plant	Pernik					
Czech lands	6	1	Nová Hut sp	Kuncice, Ostrava	3,500	4,300	3,700	1,000	100
	7	2	Poldi United Steel Works	Kladno	-	1,750	550		1,200
	8	3	Trinec Iron & Steel Works	Trinec	2,500	3,000	500	2,100	400
	9	4	Vitkovice Steel Works	Ostrava	1,600	2,250	1,350	500	400
	10	5	Skoda Works (formerly Lenin works)	Plzen	-	900	500	200	200
	11	6	Sverma Steel Works	Podbrezova	-	400			400
Slovakia	12	1	Kychodoslovenske Zeleziarnesp (East Slovak Works)	Kosice	4,500	4,800		4,800	
Hungary	13	1	Csepel Works	Budapest (Csepel Island)		400	250		150
	14	2	Dimag-Diósgyór Metallurgical Stock Corp	Diósgyör, Miskolc, Borsad - Abaujzemiplén	600	1,100		700	400
	15	3	Danai Vasmu (Danube Metallurgical Works)	Dunaujváros	1,100	1,815	600	1,200	15
	16	4	Ózd Steelworks Co	Ózd, Borsod-Abauj-Zemiplén	750	1,000	1,000		
Latvia	17	1	Sarkanais Metalurgs	Liepaja, Western Latvia					
	18	2	Red Metal Worker Plant	Liepaja (formerly Libau)		600			
Moldova	19	1	Moldavian Iron and Steel Works	Ribnitsa		700			700
Poland	20	1	Huta Baildon, BHH	Katowice, Katowickie		125	50		75
	21	2	Zaklad Huta Bankowa (Huta Dzierzynski)	Dabrowa Gornicza, Katowickie	150	300	300		
	22	3	Huta Batory	Chorzow, Katowickie	500	850	800		50
	23	4	Huta Bobrek	Bytom, Katowickie	300	1,300	1,300		
(continued)	24	5	Huta Czestochowa (formerly Huta Bierut)	Czestochowa, Czestochowskie	700	1,000	..		..

Table A.2 Iron and steel plants in Central and Eastern Europe (*continued*)

Country			*Plant name*	*Location*	*Pig iron capacity th.t/y*	*Steel-making capacity th.t/y*			
						Total	*OH*	*BOF*	*EF/DR*
Poland	25	6	Huta Katowice	Dabrowa Gornica, Katowickie	5,700	4,500		4,500	
	26	7	Huta Kosciuszko	Chorzow, Katowickie	300	800	800		
	27	8	Huta Ostrowiec (formerly Huta Nowotko)	Ostrowiec-Swietokrzyski, Kielckie		1,000			1,000
	28	9	Huta Pokoj	Nowy Bytom, Katowickie		..			..
	29	10	Huta im Tadeusza Sendzimira (formerly Huta im Lenina)	Nowa Huta, Krakow, Krakowskie	6,000	6,300	3,000	3,000	300
	30	11	Huta Szczecin	Szczecin, Szczecinskie	500	-			
	31	12	Huta Warszawa	Warsaw, Warsawskie	-	250	..		..
	32	13	Huta Zawiercie	Zawiercie, Katowickie	500	2,700	1,500		1,200
	33	14	Stawola Wola	Stawola Wola, Tarnobrzeskie		500			500
	34	15	Huta Florian	Swietochlowice, Katowickie	200	300	300		
	35	16	Huta Jednose	Siemianowice, Katowickie	-	1,050	800		250
Romania	36	1	CSR SA Resita	Resita jud Caras-Severin	650	800	800		
	37	2	Siderurgica SA Hunedoara	Hunedoara	2,500	3,200	2,800		400
	38	3	Sidex SA Galati (CSG)	Galati	8,700	10,000		9,800	200
	39	4	Calarasi Iron & Steel Works	Calarasi	3,500	3,800		3,600	200
	40	5	Otelul Rosu Works	Otelul Rosu		600	300		300
	41	6	Tirgovistz/Utas	Tirgovistz		1,000			1,000
	42	7	Uzina Metalurgica Iasi	Iasi		250			250
	43	8	Cimpia Turzii Works	Cimpia Turzii		250	150		100
Western Russia	44	1	Cherepovets Iron and Steel Works	Cherepovets, Volgodonskaya region	11,500	17,000	5,000	5,000	
	45	2	Elektrostal Metallurgechesky zavod Imeni Tevosyan	Elektrostal (formerly Noginsk), Moscow					
	46	3	Izhevsk Iron & Steel Works	Izhevsk					
(continued)	47	4	Red October Steel Works	Volgograd			..		..

Country			Plant name	Location	Pig iron capacity th.t/y	Steel-making capacity th.t/y			
						Total	OH	BOF	EF/DR
Western Russia	48	5	Novolipetsk Iron and Steel Works	Lipetsk	12,000	10,600		10,200	400
	49	6	Kursk works	Stary Oskol		3,120			3,120
	50	7	Hammer and Sickle Works	Moscow					
	51	8	Svobodny Sokol Works	Lipetsk	500	-			
	52	9	Vyksa Iron and Steel Works	Vyksa, Nizhegorod region			..		..
	53	10	Kostamuksha Iron Pellet Combine	Kostamus					
	54	11	Taganrog Iron and Steel Works	Taganrog		800	800		
Ukraine	55	1	Azovstal Iron and Steel Works	Mariupol (formerly Zhdanov)	6,000	9,200			
	56	2	Dzerzhinsky Works	Dneprodzerzhinsk, Dnepropetrovsk region		2,200		2,200	
	57	3	Dnieper Special Steel Works	Zaporozhye	-				..
	58	4	Donetsk Iron and Steel Works	Donetsk					
	59	5	Elektrostal (Novokramatorsk) Machine Building Works	Kramatorsk, Donetsk region			..		..
	60	6	Kommunarsk Iron and Steel Works	Kommunarsk, Lugansk region	4,600	4,100	..		..
	61	7	Konstantinovka Frunze Iron and Steel Works	Konstantinovka, Donetsk region	..		..		
	62	8	Krivoi Rog Iron and Steel Works	Krivoi Rog, Dnepropetrovsk region	10,000	11,500	3,000	8,500	
	63	9	Kuibyshev Iron and Steel Works	Kramatorsk, Donetsk region	950		..		..
	64	10	Makeyevka Kiror Iron and Steel Works	Makeyevka, Donetsk region	3,000	9,200	6,000	3,000	200
	65	11	Nizhnedneprovsky Tube Rolling Works	Dnepropetrovsk		850	850		
	66	12	Petrovsky Iron and Steel Works	Dnepropetrovsk	..		..	..	
	67	13	Yenakiyevo Iron and Steel Works	Yenakiyevo, Donestsk region	..	3,500		3,500	
	68	14	Zaporozhye Steel Works	Zaporozhye	..	1,000	1,000		
	69	15	Ilyich Works	Mariupol (formerly Zhdanov)	5,000	5,300	1,300	4,000	

Key: OH - open hearth; BOF - basic oxygen furnace; EF - electric arc furnace; DR - direct reduction.

Table A.3 Pulp mills (including integrated mills) in Central and Eastern Europe

Country	*#*	*#*	*Plant name*	*Location*	*Total pulp capacity th.t/y*	*Principal grades*
Belarus	1	1	Svetlogogorsk pulp & paper mill	Svetlogorsk	34	..
Bulgaria	2	1	Darjavna Knijna Fabrika, Vassil Kolarov Mill	Kostenetz	10	SG
	3	2	Kombinat za Tzeluloza i Hartia, Mizia Mill	Mizia	10	SG, BSK
	4	3	Kombinat za Tzeluloza i Hartia, Stephan Kiradjiev Mill, Zelchart Co.	Stamboliiski	45	NSSC, U/SB SK
	5	4	Pirinhart Ltd	Razlog	70	U/SB SK, RF
	6	5	Rullon-Iskaz AD, Gara Iskar Mill	Sofia	..	NSSC
	7	6	ZKMO-Kotcherinovo, Nikla Waptzarov Mill	Kocherinovo	5	SG
Czech Republic	8	1	Jihoceské Papíry s.p.	Vterní u Ceského Krumlova	100	SG, U/SB SS
	9	2	Jihoceské Papíry, Papíry Vltavský Mlýn	Loucovice	..	..
	10	3	Olšanské Papirny a.s.	Lukavice	..	..
	11	4	Severoceské Papirny a.s., Ceská Kamenice	Ceská Kamenice	15	..
	12	5	Severoceské Papirniy Steti s.p., Sepap Stetí	Stetí	350	SG, BSK, U/SB SK, RF
	13	6	Biocel s.p.	Paskov, North Morovia	210	BSS
Estonia	14	1	Kekhra Pulp & Paper Combine	Kehra	50	U/SB SK
	15	2	Tallinn Pulp & Paper Combine	Tallinn	47	..
Hungary	16	1	Dunapack AG, Dunaújvárosi Papirgyár	Dunaujvaros	95	SG, NSSC, St
	17	2	Dunapack Co, Csepel Papírgyár	Budapest	15	NSSC, Soda
Latvia	18	1	Sloksky Pulp & Paper Mill	Yurmaia	66	USS, SG, RF
Lithuania	19	1	Grigishky Experimental Paper Combine	Grigishkes	31	SG, RF
	20	2	Klaipeda Pulp & Paperboard Mill	Klaipeda	53	..
Poland	21	1	Bydgoskie Zaklady Papiernicze	Bydgoszcz, Bydgoskie	5	St
	22	2	Glucholaskie Zaklady Papiernicze	Rudawa, Opole, Opolskie	11	SG
(continued)	23	3	Kaletanskíe Zaklady Celulozowa Papiernicze	Boruszowice, Katowice	2	SG

Country	#	#	Plant name	Location	Total pulp capacity th.t/y	Principal grades
Poland	24	4	Karkonoskie Paper Mill, Fabryka Papìerce Karpacz	Karpackie, Jeleniogorskie	1	SG
	25	5	Kluczewskie Zaklady Papiernicze	Olkusz, Katowickie	4	SG
	26	6	Kostrzynskie Zaklady Papiernicze	Kostrzyn, Gorzowskie	57	BSK, USK
	27	7	Glucholaskie Zaklady Papiernicze	Glucholazy, Opolskie	8	SG
	28	8	Krapkowice, Zaklady Celulozowo-Papiernicze	Krapkowice, Opolskie	40	UBK, U/SB SK, Soda
	29	9	Lodzkie Zaklady Papiernicze	Lodz, Lodzkie	20	SG
	30	10	Myszkowskie Zaklady Papiernicze	Myszków, Czestochowskie	67	SG
	31	11	Zaklady Celulozowo-Papiernicze w Kwidzynie	Kwidzyn, Elblagskie	220	NSSC, BSK, RF
	32	12	Myszkowskie Zaklady Papiernicze	Czestochowa, Czecstochowskie	2.5	SG
	33	13	Szczecinskie Zaklady Papiernicze	Szczecin, Szczecinskie	60	SG
	34	14	Warszawskie Zaklady Papiernicze s.a.	Jeziorna, Warszawskie	..	SG, BSK, BHK, U/SB SK, BSS, U/SB SS
	35	15	Swiecie Pulp & Paper Mill	Swiecie, Bydgoskie	288	NSSC, U/SB SK
	36	16	Zaklady Papiernicze	Wloclawek, Wloclawaskie	12	SG
	37	17	Kaletanskie Zaklady Celulozowo-Papiernicze	Kalety, Czestochowskie	23	U/SB SK
	38	18	Slaskie Zaklady Papiernicze	Tychy, Katowickie	15	SG
Romania	39	1	Ambro s.a., Suceava Pulp and Paper Integrated Mill	Suceava	120	USK, RF
	40	2	D.I.L., SC Celohart s.a.	Zarnesti, Judet Brasov	50	BSS, U/SB SS, RF
	41	3	ICPCH, "Comuna Din Paris," Piatra Neamt Paper and Board	Piatra Neamt, Judet Neamt	6	SG
	42	4	ICPCH, "Letea" Bacau Pulp and Paper Integrated Mill	Bacau, Judet Bacau	110	SG, BSS, U/SB SS
	43	5	ICPCH "Reconstructia" Piatra Neamt Pulp and Paper	Piatra Neamt, Judet Neamt	40	BSK, U/SB SS
	44	6	ICPCH Braila Pulp and Paper Integrated Mill	Braila, Judet Braila	105	BSK
	45	7	ICPCH Dej Pulp and Paper Integrated Mill	Dej, Judet Cluj	120	BSK, USK
(continued)	46	8	ICPCH Petresti Paper Mill	Petresti, Judet Alba	25	SG

Table A.3 Pulp mills (including integrated mills) in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Total pulp capacity th.t/y*	*Principal grades*
Romania	47	9	ICPCH, SC Comceh s.a.	Calarasi, Judet Ialomita	38	BSK, St
	48	10	S.C. Celrom s.a.	Drobeta-Tr. Severin, Mehedinti	140	NSSC, BHK, U/SB HK, SCP
	49	11	S.C. Vrancea s.a., Adjud Pulp and Paper Integrated Mill	Adjud, Vrancea	95	USK
	50	12	S.C. "Palas" Constanta Pulp and Paper Mill	Constanta	7	St
	51	13	S.C. "Hicart" s.a.	Bistrita Nasaud	2	SG
	52	14	S.C. "Hirtia" s.a. Busteni, Busteni Paper Mill	Busteni, Judetul Prahova	70	SG
Western Russia	53	1	Arkangelsk Pulp & Paper Combine	Novodvinsk, Arkangelskaya obl.	924	K
	54	2	Astrakhan Pulp & Paperboard Combine	Astrakhan	111	
	55	3	Balakhna Pulp & Paper Combine	Pravdinsky, Gorkovskaya obl.	564	SG, TMP
	56	4	Balakhna Pulp & Paper Combine	Balakhna, Gorkovskaya obl.	53	..
	57	5	Kaisky Pulp Mill	Sozimsky, Kirovskaya obl.	3.5	..
	58	6	Kaliningrad Pulp & Paper Mill	Kaliningrad, Kaliningradskaya obl.	118	UB/SB HS
	59	7	Kaliningrad Pulp & Paper Mill No. 2	Kaliningrad, Kaliningradskaya obl.	5	..
	60	8	Kamsky Pulp & Paper Combine	Krasnokamsk, Permskaya obl.	220	
	61	9	Kotlas Pulp & Paper Combine	Koryazhma, Arkhangelshaya obl.	993	K
	62	10	Lyskelsky Paper Mill	Lyaskelya, Karelia	32	..
	63	11	Mariysky Pulp & Paper Combine	Volzhsk	112	..
	64	12	Neman Pulp & Paper Mill	Neman, Kaliningradskaya obl.	100	..
	65	13	Okulovka Pulp & Paper Combine	Okulovka, Novgorodskaya obl.	30	..
	66	14	Perm Pulp & Paper Combine	Perm	190	..
	67	15	Pitkyaranta Pulp Mill	Pitkyaranta, Karelia	80	..
	68	16	Segezha Pulp & Paper Combine	Segezha, Karelia	660	K
	69	17	Sokol Pulp & Paper Combine	Sokol, Vologodskaya obl.	106	..
(continued)	70	18	Solikamsk Pulp & Paper Combine	Solikamsk, Permskaya obl.	673	SG, TMP

Country	#	#	Plant name	Location	Total pulp capacity th.t/y	Principal grades
Western Russia	71	19	Solombalsky Pulp & Paper Combine	Arkangelsk	322	..
	72	20	Sovetsk Pulp & Paper Mill	Sovetsk, Kaliningradskaya obl.	92	..
	73	21	Sukhonsky Pulp & Paper Mill	Sokol, Vologodskaya obl.	65	..
	74	22	Svetogorsk Pulp & Paper Combine	Svetogorsk, St. Petersburgskaya obl.	417	K, NP
	75	23	Syassky Pulp & Paper Combine	Syastroy, St. Petersburgskaya obl.	184	..
	76	24	Vishera Pulp & Paper Mill	Krasnoviishersk, Permskaya obl.	47	..
	77	25	Vyborsky Pulp & Paper Combine	Sovetsky, St. Petersburgskaya obl.	50	BSK
Slovakia	78	1	Bukoza a.s.	Vranov n.T.	72	RF, BSS
	79	2	Chemiceluloza s.p., Zilina	Zilina	70	BHS
	80	3	Harmanecke Papierne a.s.	Harmanec	35	SG, U/SB SS
	81	4	Juhoslovenske Celulozky a Papierne a.s.	Sturovo	245	BSCM, NSSC, RF
	82	5	Severoslovenske Celulozky a Papierne a.s.	Ruzomberok	200	SG, BSK, BHK, USK
	83	6	Slavosovske Papierne s.p.	Slavošovce	6	SG
Ukraine	84	1	Izmail Pulp & Paper Mill	Izmail, Odeesskaya obl.	34	..
	85	2	Kherson Pulp & Paper Mill	Tsyurupinsk, Khersonskaya obl.	35	..
	86	3	Kievsky Pulp & Paperboard Combine	Obukhov, Kievskaya obl.	210	..
	87	4	Lvov Paperboard Mill	Lvov, Lvovskaya obl.	22	..
	88	5	Zhidachev Pulp & Paperboard Mill	Zhidachev, Lvovskaya obl.	48	..

Abbreviations

BHK	bleached hardwood kraft
BHS	bleached hardwood sulfite
BSS	bleached softwood sulfite
BSK	bleached softwood kraft (pulp)
CTMP	chemi-thermomechanical pulp
K	kraft (pulp)
RF	recycled fibre
DP	dissolving pulp
NP	non-paper (pulp)
NSSC	Neutral sulfite semi-chemical (pulp)
SC	semi-chemical (pulp)
TMP	thermo-mechanical pulp
SB	semi-bleached
SG	stone groundwood
SS	softwood sulfite (pulp)
St	straw
UB	unbleached

Table A.4 Petroleum refining and petrochemical plants in Central and Eastern Europe

Country	#	#	Plant name	Location	Crude oil capacity ('000 b/d)	Petrochemical capacity ('000 t/y)			
						Ethylene	Benzene	Toluene	Xylene
Belarus	1	1		Mozyr	321				
	2	2	Petroleum Organic Synthesis Production Association	Polotsk	510				
Bulgaria	3	1	Neftochim	Burgas	240	380	148	45	32
	4	2	Plama	Pleven	30				
	5	3	Bimas	Ruse	30				
Czech Republic	6	1	Paramo	Pardubice	28				
	7	2	Chemopetrol	Litvinov	210	450	250		30
	8	3	Chemicke Zavody Litvinov	Most	112	450			
	9	4	Deza (formerly Urxovy Works)	Ostrava			20	5	
	10	5	Kaucuk s.p.	Kralupy	70				
	11	6	Ostramo	Ostrava					
	12	7	Benzina	Prague					
	13	8	Koramo Kolin	Kolin	6				
	14	9	Novaky			50			
Slovakia	15	1	Slovnaft	Bratislava	144	300	92	55	160
	16	2	Zyolen						
	17	3	Petrochema Dubova	Dubova					
	18	4		Stratzje					
Hungary	19	1	Dunai kv, Danubia Refinery	Szazhalombatta	165				
	20	2	Dunamont, Dunastyr	Szazhalombatta			110	110	95
	21	3	Tiszai KV, TKV-TIFO Refinery	Tiszaujvaros (Leninvaros)	60	260			
	22	4	Zalai KV	Zalaegerszeg	10				
	23	5	Komarom Refinery	Komarom					
Lithuania	24	1		Mazeikiai	226				
Poland	25	1		Kralaty, L. Warynski	41				
	26	2	PP Rafineria Nafty Czechowice	Czechowice, Katowickie	13				
	27	3	PP Rafineria Nafty Glinik Mariampolski	Gorlice, Nowosadeckie	2				
	28	4		Blanchownia		140	100	60	
	29	5	PP Rafineria Nafty Jedlicze	Jedlicze, Krosnienskie	4				
	30	6	PP Rafineria Nafty Jaslo	Jaslo, Krosnienskie	3				
	31	7	PP Rafineria Nafty Trzebinia	Trzebina, Katowickie	10				
	32	8	Mazovian Refinery and Petrochemical Works	Plock, Plockie	200	380	160	55	100
	33	9	Petroleum Refinery Gdansk	Gdansk, Gdanskie	60				
	34	10	Planned petrochemicals site	Kedzierzyn	45				
Romania	35	1	Arpechim SA	Pitesti	125	130			
	36	2	Astra SA	Pitesti	56				
	37	3	Petrotel, Petrotel	Ploiesti	104	200			
	38	4	Darmanesti Refinery	Darmenesti	33				
	39	5	Petrobrazi	Ploiesti	159				
	40	6	Petrolsub	Becau	8				
	41	7	Petromidia	Navodari	110				
	42	8	Rafo	Onesti	108				

Country	#	#	Plant name	Location	Crude oil capacity ('000 b/d)	Petrochemical capacity ('000 t/y) Ethylene	Benzene	Toluene	Xylene
Romania	43	9	Chimcomplex SA Borzesti/Carom	Onesti					
	44	10	Steaua	Cimpina	9				
	45	11	Vega	Ploeisti	18				
	46	12		Brasov					
	47	13		Rimnicul-Sarat					
Western Russia	48	1		Perm	278	60			
	49	2		Grozny	387	30			
	50	3		Ishimbai	160				
	51	4		Izhevsk					
	52	5		Kirishi	386		100		120
	53	6		Michurinsk					
	54	7		Moscow	243		220		
	55	8		Nizhnekamsk	120	450	200		
	56	9		Nizhny Novgorod	435	300	180		
	57	10		Salavat	246				
	58	11		Grozny-Sheripov	40				
	59	12		Orenburg					
	60	13		Ryazan	370		125		
	61	14		Saratov	176	30			
	62	15		Syzran	210				
	63	16		Tuapse	45				
	64	17		Ufa (3 complexes)					
	65	18		Ukhta	125				
	66	19		Volgograd	188				
	67	20		Yaroslavi	357				
	68	21		Pyatigorsk					
	69	22		Krasnodar	33		130		
	70	23		Samara (formerly Kuibyshev)	119				
	71	24		Gubakha			20		
	72	25		Novokuibysten	307	60			
	73	26		Cherepovets			90		
	74	27		Kazan		360	210	200	
	75	28		Lipetsk			70		
	76	29		Budyennovsk		250	100		
	77	30		Gpetsk		70			
Ukraine	78	1		Drogovych	77				
	79	2		Kherson	172				
	80	3		Kremenchug	372				
	81	4		Lisichansk	469	350			
	82	5		Lvov					
	83	6		Nadvornaya	73				
	84	7		Odessa	78				
	85	8		Vinnitsa					
	86	9		Vannovskiy	40				
	87	10		Zaporozhye					
	88	11		Kalush		250	120		

Table A.4 Petroleum refining and petrochemical plants in Central and Eastern Europe (*continued*)

Country	*#*	*#*	*Plant name*	*Location*	*Crude oil capacity ('000 b/d)*	*Petrochemical capacity ('000 t/y)* Ethylene	Benzene	Toluene	Xylene
Ukraine	89	12		Severodonetsk			100		
	90	13		Gorlovka			25		
	91	14		Donestsk			30		
	92	15		Dneprodzerzhinsk			50		
	93	16		Avdayevka			25		
	94	17		Dnepropetrovsk			65		
	95	18		Kharkov			20		
	96	19		Kommunarsk			20		
	97	20		Krivoi-Rog			20		
	98	21		Miakayevka			25		
	99	22		Yasnov			60		
	100	23		Yenakijeva			25		

Table A.5 Major inorganic chemical plants in Central and Eastern Europe

Country			*Plant name*	*Location*	*Fertilizers*	*Ammonia*	*Chlorine*	*Caustic soda*	*Soda ash*	*Titanium dioxide*
Belarus	1	1	Grodno PA Azot	Grodno	N					
	2	2		Soligorsk	P					
	3	3	Gomel Chemical Plant	Gomel	P					
Bulgaria	4	1	Sodi	Devnia	NPK	•	•	•	•	
	5	2	Neocuim	Oimitrovgrad	NPK	•				
	6	3		Shara Zagora	N	•				
	7	4	Chimko	Vratza	N					
	8	5	Agropolcium	Povelyasovo	NP					
Czech Republic	9	1	Spolana	Neratovice			•	•		
	11	2	Tonaso	Nestermice					•	
	12	3	Precheza	Prerov						24
	13	4	Chempetrol	Litvinov	N	•				
	14	5	Norm Czech Chemical Works	Lovosice	•					
	15	6	Sokolov Chemical Works	Sokolov	•					
	16	7	Fosfa	Postorna	P					
Estonia	17	1	Share Chemical Production Association	Kohtla Yarve	NP					
Hungary	18	1	Borsod Chem	Kazincbarcika			•	•		
	19	2	Peremarton Chemical Company	Peremarton	P					
	20	3	Budapest Chemical Works	Budapest	•					
	21	4	Pet-Nitrogenmurck	Varpalota	NP					
	22	5	Tisza Vegyikombinat	Tiszaujvaros (formerly Leninvaros)	•					
	23	6	Tiszamenti Vegyimuvek	Szolnok	P					
Latvia	24	1	SKTB Inorganics	Riga						
	25	2		Ventspils	NP					

Table A.5 Major inorganic chemical plants in Central and Eastern Europe (*continued*)

Country			*Plant name*	*Location*	*Fertilizers*	*Ammonia*	*Chlorine*	*Caustic soda*	*Soda ash*	*Titanium dioxide*
Lithuania	26	1		Ionava	N					
	27	2	Kedalniai Chemical Combine	Kedianiai	P					
Poland	28	1	Krakowskie Zaclady Sodowy	Kakow, Krakowski				•		
	29	2	Inowroclaw Chemical Works	Inowroclaw, Bydgoskie					•	
	30	3	Zaclady Farb Wloclawek	Wlocklawek, Wloclawskie			•			
	31	4	Janikosoda	Janikowo					•	
	32	5	Zaclady Azstowe Police	Police, Szcezecinskie	N	•				36
	33	6	Zaclady Azotowe Kedzierzyn	Kedzierzyn	N	•				
	34	7	Zaclady Azotowe Pulawy	Pulawy, Lubelskie	N					
	35	8	Zaclady Azotowe Tarnow	Tarnow, Tarnowskie	•					
	36	9	Zaclady Azotowe Wloclawek	Wloclawek, Wloclawskie	•	•				
	37	10	Fosfory Lubon	Lubon	P					
	38	11	Fosfory Szczecin	Szczecin, Stczecinskie	P					
	39	12	Fosfory Torun	Torun, Torunskie	P					
	40	13	Fosfory Ubocz	Ubocz	P					
	41	14	Fosfory Wroclaw	Wroclaw, Wroclawskie	P					
	42	15	Fosfory Gdansk	Gdansk, Gdanskie	P					
	43	16	Kombinat Koplan Tarnobrzeg	Taranobrzeg, Tarnobrzeskie	P					
Romania	44	1	Verachim	Giurgiu			•	•		
	45	2	Uzinele Sodice	Govora					•	
	46	3	Upsoln	Ocna Mures					•	
	47	4	Dero	Ploiesti						
	48	5	Oltechim	Rimnicu-Vilcea			•	•		
	49	6	UCT	Turda			•			
(continued)	50	7	Archim	Arad	NPK	•				

Country			Plant name	Location	Fertilizers	Ammonia	Chlorine	Caustic soda	Soda ash	Titanium dioxide
Romania	51	8	Sofert	Bacau		•				
	52	9	Doljchim	Craiova	N	•				
	53	10	Nitramonia	Fagaras	N	•				
	54	11	Fertilichim	Navodari	P					
	55	12	Azochim	Piatra Neamt	N	•				
	56	13	Amonil	Slobozia	N	•				
	57	14	Azomures	Tirgu Mores	NPK	•				
	58	15		Turnu Magurele	NPK	•				
	59	16	Romfosfochim	Calugareasca	P					
Western Russia	60	1		Novomoskovsk	N	•	•	•		
	61	2		Berezniki	N	•				
	62	3		Novgorod	•					
	63	4		Shchekino						
	64	5		Dzerzhinsk	N	•				
	65	6	Kuybyshev Chemical Plant	Togliatti, Kuybyshev	NP					
	66	7		Nevinnomyssk Stavropol	N	•				
	67	8	Orgsteklo	Nizhny Novgorod	•					
	68	9		Balakovo, Saratov	NP					
	69	10	Krasnodar Chemical Plant	Krasnodar	NP					
	70	11	Cherepovers Chemical Combine	Cherepovets	NP					
	71	12	Dorogobuzh Nitrogen Fertilizer Plant	Dorogoduzh, Smolensk	N					
	72	13	Kingisepp-Fosforit Combine	Kingisepp, St Petersburg	NP					
	73	14	Rossoch-Pridonisk Chemical Works	Rossoch, Voromezh	NP					
(continued)	74	15		Uvarovo	P					

Table A.5 Major inorganic chemical plants in Central and Eastern Europe (*continued*)

Country			*Plant name*	*Location*	*Fertilizers*	*Ammonia*	*Chlorine*	*Caustic soda*	*Soda ash*	*Titanium dioxide*
Western Russia	75	16		Voskrsensk, Moscow	N					
	76	17		Yaroslavi						4
Slovakia	77	1	Istrochem	Bratislava	•					
	78	2	Duslo	Sala, Oskava	•					
	79	3	Chemko	Strazke	NP					
	80	4	Jurajo Dimstrova Chimicke Zavody	Dimitrova, Bratislova	•					
Ukraine	81	1	Lysichansk Soda Works	Lysichansk, Lugansk region					•	
	82	2		Cherkassy	NP	•				
	83	3	Rovno Chemical Combine	Rovno	NP					
	84	4	Azot Fertilizer and Chemicals Combine	Severo-Donetsk, Lugansk region	N	•				
	85	5		Dneprodzerzhinsk, Dnepropetrosk region	N	•				
	86	6		Gorlovka, Donetsk region	N	•				
	87	7		Yuzhniy, Odessa	N	•				
	88	8		Sumy						115
	89	9		Armyansk						200
	90	10		Krym						•

Table A.6 Major organic chemical plants in Central and Eastern Europe

Country			*Plant name*	*Location*	*HDPE*	*LDPE*	*VCM*	*PVC*	*Ethyl-benzene*	*Butadiene*	*Styrene*	*Poly-styrene*	*ABS*	*SBR*
Belarus	1	1		Novopolotsk		•								
Bulgaria	2	1		Devnia			•	•						
	3	2		Burgas	•	•			•	•	•	•		•
Czech Republic	4	1	Spolana Chemical Works	Nertovice			•	•						
	5	2	Spolchemie Chemical Plant	Usti nad Labem			•	•						
	6	3	Chemopetrol	Lituivov	•				•					
	7	4		Kralupy					•	•	•	•	•	•
Hungary	8	1	Borsod Chem	Kazincabrcika			•	•						
	9	2	Chemocmplex	Tiszaujvaros (formerly Leninvaros)	•	•								
	10	3		Szazhalottbatta					•		•	•		
Poland	11	1	MZRIP	Plock, Plockie		•			•	•				
	12	2	Zaclady Chemiczane Blachownia	Blachownia		•			•		•			
	13	3	Zaclady Chemiczne Oswiecim	Oswiecim, Bielskie			•	•			•	•	•	•
	14	4	Zaclady Azotowe Tarnow	Tarnow, Tarnowskie			•	•						
	15	5		Wlockawek, Wloclawskie			•	•						
Romania	16	1		Midia	•	•			•		•	•		
	17	2	Arpechim SA	Pitesti	•	•			•	•	•			
	18	3		Teleajen	•						•	•		
(continued)	19	4	Petrobrazi	Brazi		•				•				

Table A.6 Major organic chemical plants in Central and Eastern Europe (*continued*)

Country			*Plant name*	*Location*	*HDPE*	*LDPE*	*VCM*	*PVC*	*Ethyl-benzene*	*Butadiene*	*Styrene*	*Poly-styrene*	*ABS*	*SBR*
Romania	20	5	Chimocomplex	Borzesti			•	•	•	•	•	•	•	•
	21	6	Oltchim	Rimuicu-Vilcea			•	•						
	22	7	Biocapa	Tirnaveni			•	•						
	23	8	UCT	Turda			•	•						
	24	9	SC Solventui	Timisoara	•									
Western Russia	25	1		Cherepovets					•		•			
	26	2		Novomoskovsk			•	•						
	27	3		Voronezh					•	•	•	•		•
	28	4		Dzerzhinsk			•	•						
	29	5		Kazan	•	•				•				
	30	6		Perm					•		•			
	31	7		Nizhnekamsk		•			•	•	•			•
	32	8		Novokuibyshev	•	•				•				•
	33	9		Volzhskiy			•	•		•				
	34	10		Volgograd			•	•						
	35	11		Grozny	•									
	36	12		Budyenovsk	•					•				
	37	13		Yaroslavi						•				•
	38	14		Zhilevo								•		
	39	15		Uzlovaya									•	
	40	16		Yefremov						•				
	41	17		Nishny Navgurod						•				
	42	18		Togliatti, Kuybyshev						•				
Slovakia (continued)	43	1	Novacke Chemicke Zavady	Novaky			•	•						

Country			Plant name	Location	HDPE	LDPE	VCM	PVC	Ethyl-benzene	Butadiene	Styrene	Poly-styrene	ABS	SBR
Slovakia	44	2	Istrochem	Bratislava		•								
	45	3	Povazske Chemicke	Zilina										
Ukraine	46	1		Kalush			•	•		•				
	47	2		Severodonetsk		•			•		•			
	48	3		Gorlovka					•		•	•		
	49	4		Donetsk					•		•			
	50	5		Cherkasy			•	•						
	51	6		Dneprodzerzhinsk					•		•	•		
	52	7		Pervomaysk			•	•						

Table A.7 Non-ferrous metal plants in Central and Eastern Europe

Country			*Plant name*	*Location*	*Main products*	*Process*	*Capacity*
Bulgaria	1	1	Georgi Damanyov Copper Smelter & Refinery	Pirdop	Copper		120
	2	2	D Ganev Copper Mining Works		Copper		
	3	3	Isker Ingot Works	Sofia	Copper (sec.)		
	4	4	Medet Copper Combine		Copper		
	5	5	Dimitar Blagoev Combined Works	Plovdiv	Zinc & Lead	C/P RLE	Lead 40/40 zinc 60
	6	6	Kurdzhali Lead-Zinc Smelter	Kurdzhali	Zinc & Lead	C/P RLE	Lead 18/18 zinc 30
Czech Republic	7	1	Kovohute Pribram	Pribram	Lead (sec.)	B/P	31/30
	8	2	Kamenice Remelting Plant	Jihlave, central Bohemia	Lead (sec.)		
	9	3	Velvary Remelting Plant	Velvary, central Bohemia	Lead (sec.)		
	10	4	Kamenice Remelting Works	Near Jihlave, central Bohemia	Aluminum (sec.)		
	11	5	Kovohute Mnisek	Head office - Prague	Aluminum (sec.)		
	12	6	Rokycany Copper	Plzen	Copper		
Slovakia	13	1	Kovohute Krompachy	Krompachy	Copper		
	14	2	ZSNP Ziar nad Hronom	Ziar, Slovakia	Aluminum		65
Hungary	15	1	Ajka smelta	Ajka	Aluminum		22
	16	2	Motim Works	Motim	Aluminum		
	17	3	Inota smelter	Inota	Aluminum		35
	18	4	Tatabanya smelter	Tatabanya	Aluminum		17
Poland	19	1	Glogow #1	Glogow, Legnickie	Copper		190
	20	2	Glogow #2	Glogow, Legnickie	Copper		130
	21	3	Legnica, Legnickie	Legnica, Legnickie	Copper		115
	22	4	Zaklady Gorniczo-Hutnicze Bolelsaw	Bukowno, Katowickie	Zinc & Lead (secondary)	RR E	Lead 35 zinc 60
(continued)	23	5	Huta Metali Niezelaznych Szopienice	Szopienice, Katowickie	Zinc & Lead (secondary)	P E	Lead 30 zinc 25

Country			Plant name	Location	Main products	Process	Capacity
Poland	24	6	Huta Cynku Miasteczko Slaskie	Tarnowskie Gory, Katowickie	Zinc & Lead	ISP/P ISP	Lead 25/35 zinc 50
	25	7	Dambinat Gérniczo Hutniczy	Lubin, Legnickie	Lead	PR	7
	26	8	Konin Aluminum Works	Hutnicza, Konin	Aluminum		48
	27	9	Zaklady Metalurgiczne Skawina	Skawina, Krakowskie	Aluminum		
	28	10	Zaklady Metali Lekkich Kety	Kety	Aluminum		
Romania	29	1	Phoenix Copper Smelter	Baia-Mare	Copper		
	30	2	Neferal Metallurgical Works	Branesti	Copper & Aluminum		
	31	3	Zlatna Metalwrgical Works	Zlatna	Copper		
	32	4	Copsa-Mica, Sometra	Copsa-Mica	Zinc & Lead	ISP/E ISP	Lead 40/40 zinc 60
	33	5	Romplumb Lead Smelter	Baia-Mare	Zinc & Lead		Lead 8
	34	6	Crisana Alumina Plant	Oradea, Jud. Bihor	Aluminum		
	35	7	Slatina Aluminum Enterprise	Slatina, Jud. Olt	Aluminum		256
	36	8	Zlatna Aluminum Plant	Zlatna	Aluminum		
	37	9	Tulcea Alumina Plant	Tulcea	Aluminum		
Western Russia	38	1	Karabashki Gorno Metallurgical Combine	Karabashki	Copper		
	39	2		St. Petersburg	Copper		
	40	3	Kirovgradsk Copper Smelter	Kirovgrad	Copper		
	41	4		Kirovsk	Copper		
	42	5		Revdensk	Copper		
	43	6		Moscow	Copper		40
	44	7		Pechenga	Copper		
	45	8	Kandalaksha Aluminum Smelter	Kandalaksha, Murmansk	Aluminum		70
	46	9	Leningrad Secondary Aluminum Smelter	St. Petersburg	Aluminum		
(continued)	47	10	Moscow Secondary Aluminum Smelter	Moscow	Aluminum		

Table A.7 Non-ferrous metal plants in Central and Eastern Europe (*continued*)

Country			*Plant name*	*Location*	*Main products*	*Process*	*Capacity*
Western Russia	48	11	Nadvoytsy Aluminum Smelter	Karelia	Aluminum		70
	49	12	Volgograd Aluminum Works (VgAZ)	Volgograd	Aluminum		125
	50	13	Volkhov Aluminum Smelter	Vohuov	Aluminum		30
Ukraine	51	1	Podolsk Chemical-Metallurgical Works	Podolsk	Copper & Zinc		
	52	2	Wlectrozinc Plant	Ordzhonikidz, Catleasus	Zinc & Lead	C/P E	Lead 140/150 zinc 180
	53	3	Ukrzinc Lead-Zinc Plant	Konstantinovka	Zinc & Lead	C/P E	Lead 25/25 zinc 80
	54	4	Dnieper Aluminum Smelter (DAZ)	Zaporozhye	Aluminum		120
	55	5	Brovary Aluminum Smelter	Brovary, Kiev region	Aluminum		

Annex B

Major Industrial Plants Located in Pollution "Hot Spots"

Table B.1 Major industrial plants located in pollution "hot spots"

			Nature of environmental problems			*Number of plants*						
Country	*Location*	*Pop'n ('000)*	*Epidemio-logical links*	*High levels of dust, SO_2, or both*	*High levels of lead*	*Power and district heating*	*Iron and steel*	*Non-ferrous metals*	*Refining and petrochem.*	*Organic chemicals*	*Inorganic chemicals*	*Pulp*
Bulgaria	Dimimtrovgrad	56.2	A, P	•		2					1	
	Srednogorie	25.0	A, C	•								
	Devnya	30.0	A, C	•		1				1	1	
	Panagiurishte			•								
	Kurdzhali	58.0	Pb	•				1				
	Sofia	1,221.4	A	•		1		1				1
	Ruse	210.2	A, C	•					1			
	Plovdiv	374.0	Pb, C	•				1				
	Stara Zagora	186.7		•							1	
	Asenvgrad		Pb, A, C	•								
	Pernik	97.2	Pb, C	•		1	2					
	Vratsa	80.5	A, C	•							1	
	Kuklen		Pb									
	Voden		Pb									
	Kremikovtsi		Pb, A, C			1	1					
	Jana		Pb									
	Shvistov		A									
	Gabrovo		A									
	Varna		A			1						
	Kameno		A									
	Burgas		A			1	1		1	1		
	Razlog		C									1
(continued)	Other					2	-	3	1	-	1	4

Country	Location	Pop'n ('000)	*Nature of environmental problems*: Epidemio-logical links	High levels of dust, SO_2, or both	High levels of lead	*Number of plants*: Power and district heating	Iron and steel	Non-ferrous metals	Refining and petrochem.	Organic chemicals	Inorganic chemicals	Pulp
Czech Republic	Northern Bohemia:											
	Usti nad Labem	106.4	A, C	•						1		
	Litvinov	29.9		•					1	1	1	
	Decin	56.1	A, C	•								
	Most	70.8	A, C	•					1			
	Teplice	55.5	A, C	•								
	Chomutov	56.2	A, C	•								
	Central Bohemia:											
	Beroun	24.1		•								
	Prague	1,215.6		•					1			
	Kladno	73.3		•			1					
	Melnik	19.7		•	•	3						
	Pribram		Pb					1				
	Neratovice		A							1	1	
	Kralupy		A						1	1		
	Southern Bohemia:											
	Sokolov	28.5		•							1	
	Plzen	174.7		•		1	1	1				
	Ostrava	331.5				1	2		2		1	
	Brno	392.2				1						
	Other					31	2	4	3	-	4	6
Slovakia	Bratislava	442.9	A	•		3			1	1	1	
	Ziar nad Hronom	21.4		•				1				
(continued)	Other					8	1	2	2	2	3	6

Table B.1 Major industrial plants located in pollution "hot spots" *(continued)*

			Nature of environmental problems			*Number of plants*						
Country	*Location*	*Pop'n ('000)*	*Epidemio-logical links*	*High levels of dust, SO_2, or both*	*High levels of lead*	*Power and district heating*	*Iron and steel*	*Non-ferrous metals*	*Refining and petrochem.*	*Organic chemicals*	*Inorganic chemicals*	*Pulp*
Hungary	Borsod-Abauj-Zemplen industrial zone:											
	Izsofalva			•								
	Miskolc		C	•								
	Karincbarcika		C							1	1	
	Ozd			•			1					
	Sajoszentpeter			•								
	Budapest		C, P	•	•		1				1	1
	Northern Transdanibian region:											
	Dorog	13.0	Pb	•		1						
	Esztergom	29.8		•								
	Komarom	19.6		•					1			
	Tata	24.8		•								
	Tatabanya	73.8		•		1		1				
	Central Transdanibain region:											
	Ajka		Pb	•		1		1				
	Baranya County:											
	Pecs			•		1						
	Szaszvar			•								
	Szolnok			•	•						1	
	Romhany		Pb									
	Other					24	2	2	4	2	3	1

			Nature of environmental problems			Number of plants						
Country	*Location*	*Pop'n ('000)*	*Epidemio-logical links*	*High levels of dust, SO_2, or both*	*High levels of lead*	*Power and district heating*	*Iron and steel*	*Non-ferrous metals*	*Refining and petrochem.*	*Organic chemicals*	*Inorganic chemicals*	*Pulp*
Poland	Katowickie:											
	Dgbrowg Górnicza	139.2	M	•	•		2					
	Chorzów	131.5	M	•	•	1	2					
	Mystowice	94.6	M	•								
	Swietochowice	60.6	M	•	•		1					
	Katowice	366.9	M, P	•	•	1	1					1
	Puda Slaska	171.6	M	•	•							
	Chrzanów	42.8	M	•								
	Tarnowskie Góry	74.4	M	•	•				1			
	Zawiercie	57.1		•			1					
	Wodzistaw Slaski	112.2		•								
	Rybnik	144.8		•		1						
	Gliwice	215.7		•								
	Pilica	<10		•								
	Toszek	<10	Pb	•								
	Bytom	323.2	Pb	•	•		2					
	Zabrze	205.8	Pb	•								
	Szopienice		Pb					1				
	Miasteczko		Pb									
	Zyglin		Pb									
	Lubowice		Pb									
	Bajszow		Pb									
(continued)	Brzozowice		Pb									

Table B.1 Major industrial plants located in pollution "hot spots" (*continued*)

			Nature of environmental problems			*Number of plants*						
Country	*Location*	*Pop'n ('000)*	*Epidemio-logical links*	*High levels of dust, SO_2, or both*	*High levels of lead*	*Power and district heating*	*Iron and steel*	*Non-ferrous metals*	*Refining and petrochem.*	*Organic chemicals*	*Inorganic chemicals*	*Pulp*
Poland	Jeleniogórskie:											
	Kemienna Góra	23.5		•								
	Bolkow			•								
	Lubawka			•								
	Zgorzelec	36.5		•								
	Krakowskie:											
	Kraków	751.3	A, C, M, P	•		1	1				1	
	Legnickie:											
	Legnica	106.1	Pb					1				
	Gtogow	73.9	Pb					2				
	Chojnów	14.8		•								
	Piotrkowskie:											
	Tomaszów Mazowiecki	69.9		•								
	Poznanskie:											
	Gniezno	70.6		•								
	Torunskie:											
	Torun	202.0		•		1					1	
	Wa-brzyskie:											
	Zarow			•								
	Swiebodzice	24.8		•								
	Jaworzyna Sl.			•								
	Strzegom	17.3		•								
	Swidnica	63.8		•								
(continued)	Lazdec			•								

Country	Location	Pop'n ('000)	*Nature of environmental problems* Epidemio-logical links	High levels of dust, SO_2, or both	High levels of lead	*Number of plants* Power and district heating	Iron and steel	Non-ferrous metals	Refining and petrochem.	Organic chemicals	Inorganic chemicals	Pulp
Poland	Wa_brzych	141.2		•								
	Dlugopole Zdrój			•								
	Polanica			•								
	Wroc_awskie:											
	Wroc_aw	643.6		•		1					1	
	Other					64	6	5	10	5	13	17
Romania	Bucharest	2,325.0		•	•	4						
	Piatra Neamt	117.3		•							1	2
	Zlatna	9.3		•	•			2				
	Brobeta Turnu Severin	108.0		•		1						
	Galati	305.0		•		1	1					
	Craiova	297.5		•		2					1	
	Tirgu Jiu			•								
	Tirgu Mures	166.0		•							1	
	Slatina	74.0	A, P	•	•			1				
	Medias	72.6		•								
	Satu mare	137.9		•								
	Hunedoara		A	•			1					
	Isalnita			•								
	Copsa Mica		Pb, P					1				
	Baia Mare		Pb, A					2				
	Tasca		A									
	Savinest		A									
	Suceava		A			1						1
(continued)	Mintia		A			1						

Table B.1 Major industrial plants located in pollution "hot spots" *(continued)*

			Nature of environmental problems			*Number of plants*						
Country	*Location*	*Pop'n ('000)*	*Epidemio-logical links*	*High levels of dust, SO_2, or both*	*High levels of lead*	*Power and district heating*	*Iron and steel*	*Non-ferrous metals*	*Refining and petrochem.*	*Organic chemicals*	*Inorganic chemicals*	*Pulp*
Romania	Otelul Rosu		A				1					
	Navodari		A			1			1		1	
	Remicu-Vilcea		A							1	1	
	Turda		C, P							1	1	
	Other					20	5	3	12	7	10	11
Estonia	Narva	82.3	A, C, P	•		2						
	Tallinn	484.4		•		2						1
	Kunda		A, C									
	Kohtla-Jarve		A, C, P			2					1	
	Sillamae		A, C, P									
	Kehra		P									1
	Other					5					-	-
Latvia	Ventspils	50.4		•							1	
	Daugaupils			•								
	Liepaja			•			2					
	Riga			•		7					1	
	Olaine		A, C	•								
	Other					-	-				-	1
Lithuania	Kaunas		A,C	•		2						
	Siauliai			•		1						
	Kedainai			•		1					1	
	Vilnius			•		3						
(continued)	Klaipeda			•		1						1

Country	Location	Pop'n ('000)	Nature of environmental problems: Epidemio-logical links	High levels of dust, SO_2, or both	High levels of lead	Number of plants: Power and district heating	Iron and steel	Non-ferrous metals	Refining and petrochem.	Organic chemicals	Inorganic chemicals	Pulp
Lithuania	Jonava		A, C	•		1					1	
	Other					11			1		-	1
Belarus	Orsha			•								
	Vitebsk			•								
	Polotsk			•					1			
	Magilev			•		1						
	Grodno			•		1					1	
	Gomel			•		1					1	
	Minsk			•		2						
	Novopolotsk			•		1				1		
	Brest			•								
	Other			•		4	1		1	-	1	1
Western Russia	Volsk (Saratov oblast)			•								
	Lipetsk			•			2		1			
	Makachkala			•								
	Novgorod		Pb, M	•							1	
	Kaluga			•								
	Smolensk			•							1	
	Rostov-na-Dony		Pb	•								
	Shakhly (Rostov oblast)			•								
	Zheleznodorozhnyy (Moscow oblast)			•								
	Kashira (Moscow oblast)			•		1						
	Nizhnckamsk (Tatariya)			•					1	1		
(continued)	Segezha (Karelea)			•								1

Table B.1 Major industrial plants located in pollution "hot spots" *(continued)*

			Nature of environmental problems			*Number of plants*						
Country	*Location*	*Pop'n ('000)*	*Epidemio-logical links*	*High levels of dust, SO_2, or both*	*High levels of lead*	*Power and district heating*	*Iron and steel*	*Non-ferrous metals*	*Refining and petrochem.*	*Organic chemicals*	*Inorganic chemicals*	*Pulp*
Western Russia	Taganrog (Rostov oblast)			•								
	Krasnodar			•					1		1	
	Ulanovak		Pb	•								
	Novorossiyak (Kransnodar kray)			•								
	Balakovo (Saratov oblast)			•							1	
	Gubakha (Perm oblast)			•					1			
	Podolsk (Moscow oblast)		Pb	•								
	Volgodonsk (Rostov oblast)			•								
	Onega (Arkhangelsk oblast)		A	•								
	Dzerzhinsk (Nizhegorod oblast)		M	•						1	1	
	Saratov			•		1			1			
	Astrakhan Stepnoy		Pb	•								1
	Novokuybyshevak (Samara oblast)			•						1		
	Kirovo-Chepetsk (Kirov oblast)			•					1			
	Novocherkassk (Rostov oblast)			•		1						
	Zapolyamyy (Murmansk oblast)			•								
	Syzran (Samara oblast)			•					1			
	Tolyatti (Samara oblast)			•							1	
	St. Petersburg		Pb, A, M			1		2			1	
	Berezniki		Pb, A, M								1	
	Yaroslavl		Pb								1	
	Samara		Pb						1			
	Nizhnyy		Pb, M						1			
(continued)	Kursk		Pb									

			Nature of environmental problems			Number of plants						
Country	*Location*	*Pop'n ('000)*	*Epidemio-logical links*	*High levels of dust, SO_2, or both*	*High levels of lead*	*Power and district heating*	*Iron and steel*	*Non-ferrous metals*	*Refining and petrochem.*	*Organic chemicals*	*Inorganic chemicals*	*Pulp*
Western Russia	Voskresensk		A								1	
	Chehoksary		A									
	Sterlitamak		C									
	Ufa		C						3			
	Chaykouskiy (Perm oblast)		C									
	Other					20	9	10	20	15	7	23
Ukraine	Donetsk	1,110.0		•		2	1		1	1		
	Krivoi Rog	713.0		•		1	1		1			
	Odessa	1,115.0		•					1		1	
	Zaporozhe	884.0	A, P	•		1	2	1	1			
	Dneprodzerzhinsk	300.0		•			1		1	1	1	
	Dnepropertrovk	1,179.0		•		1	2		1			
	Marioupol	517.0	P	•			2					
	Makeeva			•			1		1			
	Kiev	2,602.0		•				1				
	Konstantinovka		Pb				1	1				
	Other					7	4	2	16	5	8	5

Key:
A = places where there are documented associations between acute respiratory diseases and air pollution.
C = places where there are documented associations between chronic respiratory diseases and air pollution.
M = places where there is reasonably strong evidence of a connection between mortality and air pollution.
P = places where there are documented associations between abnormal physiological development and air pollution.
Pb = places where there is a problem with overexposure to lead among children.

Annex C

Power and District Heating

Introduction

In this annex, we summarize our analysis of the technical and economic aspects of environmental protection in the power and district heating sectors of CEE countries. The focus is on coal-fired plants, both because coal is the dominant fuel and because coal-fired generation gives rise to the sectors' major environmental problems. These features are most pronounced in the district heating sector, in which inefficient and dilapidated plants are often linked to environmental problems in urban centers. The focus is also on atmospheric pollution since this represents the primary threat to human heath. While the environmental problems associated with solid and liquid wastes should not be ignored, these streams from power and district heating sectors are unlikely to be particularly hazardous: any potential health threats—linked for example, to soil or groundwater contamination—can be avoided if the wastes are disposed of with care.

Below we summarize the key issues and conclusions arising from our analysis, which is based on desk research and two case studies. An annex provides details of the case study at the Trebovice power and district heating plant in Ostrava, the Czech Republic, and the TEC-2 power and district heating plant in Riga, Latvia. A separate working paper provides an economic profile of the sectors and an analysis of the atmospheric pollution problems in the sectors and their possible solutions.

Structure of the sectors

Table C.1 summarizes the existing power generation capacity in CEE countries. The table shows total capacities and the amount of thermal, nuclear, and hydro/other capacity in each country. The capacity data may not always be totally reliable. We understand, for example, that Tusceni, Romania's largest coal-fired plant, can only operate at 1,200 MW, compared with its posted capacity of 4,000 MW.

A significant share of the generation capacity in CEE countries is in old and obsolete plant. In Poland, for example, approximately 30 percent of existing capacity is over 25 years old

Table C.2 gives electricity production figures for 1990. Production declined in all CEE countries over the period from 1988 to 1990 and, we believe, this has continued in some countries. In Bulgaria, for example, production in 1991 was 20 percent lower than in 1990, and in Romania 6 percent lower. Bulgaria, the former Czechoslovakia, and Hungary each produce a sizeable share of their electricity requirements from nuclear capacity.

Table C.3 summarizes the share of production from thermal plants by type of fuel in 1990. Coal is the dominant source of fuel in most countries. Table C.4 shows the amounts of hard coal and lignite used in thermal power plants in 1990. Large quantities of lignite—a low-quality and highly polluting fuel—are used for power generation throughout the region.

Table C.5 shows the pattern of electricity supply in CEE countries in 1990. Hungary and, to a lesser extent, Romania are significant importers of electricity. But imports are also important in other countries in order to ensure that peak demands can be met.

It has not been possible to obtain reliable data on district heating capacity and production levels. But district heating is certainly used extensively in CEE countries to supply heat and hot water to the industrial, commercial, residential, and public administration sectors and steam to the industrial sector. In Poland, for example, district heating systems supply 20 percent of urban dwellings with heat and 50 percent with hot water. The bulk of the heat is supplied by large district heating plant; smaller plants make a minor but significant contribution.

Existing district heating plants typically suffer from major technical problems: poor physical condition, poor operation, and lack of maintenance. The distribution networks, which are large and inefficient, are also often in a poor state of repair.

Pollution problems in the power and district heating sectors

The power and district heating sectors are major sources of atmospheric pollution. The combustion of fuels in power and district heating plants gives rise to emissions of particulates (which can contain trace metals), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), carbon monoxide, and carbon dioxide. The amount of each emission depends on the type and size of the plant, its condition, the type and quality of fuel, and the manner in which it is burned.

Table C.6 shows indicative emission levels of particulates, SO_x, and NO_x for a typical 500 MW coal-fired plant operating as base-load plant. Since the factors affecting emission levels vary greatly between plants, the normal range given is wide. But it does not represent the extremes; an inefficient plant burning lignite that has a high ash content, for example, could generate emission levels in excess of 150 t/GWh.

Table C.1 Power generation capacity in CEE countries at the end of 1991

Country	*Total capacity, GW*	*Thermal capacity GW*	*Nuclear capacity GW*	*Hydro/other capacity GW*
Bulgaria	12.2	7.4	2.8	2.0
Czech Republic[1]	15.3	12.1	1.8	1.4
Slovakia[1]	6.4	2.9	1.8	1.7
Hungary	7.2	5.3	1.8	<0.1
Poland	32.1	30.1	-	2.0
Romania	20.6	14.9	-	5.7
Former Soviet Union[2]	344	241	38	65

[1] 1990 data.
[2] 1990 data. Data for individual republics are not available.

Table C.2 Electricity production in CEE countries in 1990

Country	*Total Twh*	*Thermal %*	*Nuclear %*	*Hydro/other %*
Bulgaria	42.1	63	32	5
Former Czechoslovakia	86.6	67	28	4
Hungary	28.4	51	48	1
Poland	134.7	97	-	3
Romania	64.3	82	-	18
Former Soviet Union	1,684	73	12	15

[1] 1991 data. Russia accounted for 1070 Twh, Ukraine 277 Twh, Belarus 39 Twh, Moldova 13 Twh, Latvia 7 Twh, Lithuania 28 Twh, and Estonia 17 Twh.

Table C.3 Share of electricity production from thermal plants by type of fuel in 1990

Country	Coal %	Fuel Oil %	Gas %
Bulgaria	67	8	25
Former Czechoslovakia	97	<1	2
Hungary	70	6	24
Poland	>99	<1	-
Romania[1]	26	28	40
Former Soviet Union[1]	33	21	44

[1] Balance is generated from other solid fuels such as peat and wood.

Table C.4 Consumption of coal and brown coal/lignite in thermal power plants in 1990

Country	Hard coal mt	Brown coal/lignite mt
Bulgaria[1]		
Former Czechoslovakia	4.7	46.0
Hungary	1.4	12.4
Poland	45.6	69.9
Romania	3.8	29.7
Former Soviet Union[1]		

[1] Data not available but lignite is known to be widely used for power generation.

Table C.5 Pattern of electricity supply in CEE countries in 1990

Country	Production Twh	Net import Twh	Losses Twh	Consumption Twh
Bulgaria	42.1	3.8	4.4	41.5
Former Czechoslovakia	86.6	4.5	5.8	85.4
Hungary	28.4	11.1	4.0	35.5
Poland	136.3	(1.1)	10.6	124.7
Romania	64.3	9.5	5.9	67.9
Russia	1,078	(13)	85	984

Pollution control options in the power and district heating sectors

The control of particulates, SO_x, and NO_x emissions can be achieved in a variety of ways, including:

- Coal cleaning and switching to better-quality coal to reduce emissions of particulates, SO_x, or both
- Switching to gas to eliminate emissions of particulates and SO_x and to reduce emissions of NO_x. This would be prohibitively expensive at large plants but could be a viable option at smaller district heating plants with access to gas supplies
- Combustion modifications such as the installation of low-NO_x burners to reduce NO_x emissions
- Efficiency improvements to boilers, turbines, and auxiliary plant to control emissions of all three pollutants. Only limited improvements can be made, because of the original plant design constraints, without major plant replacement programs, which would be expensive. Modest plant upgrade and

Table C.6 Typical emission levels from a 500 MWe coal-fired power plant

	Untreated emission level	
Pollutant	*th.t/yr*[1]	*t/GWh*
Particulates	200 - 500	60 - 150
SO_x	30 - 90	10 - 25
NO_x	6 - 15	2 - 4

1. The plant is assumed to be operating with an annual load factor of 75 percent.

improvement programs could ensure that the plant achieves its original design efficiencies

- Installation of pollution abatement equipment. Particulate emissions can be controlled using electrostatic precipitators, bag filters, or mechanical collectors. All of these are well-established technologies. Wet scrubbers are not used to control particulate emission from power and heat plants. SO_x and NO_x emissions can be controlled using a variety of flue gas treatment methods
- Improvements to power transmission and distribution networks and to heat distribution networks. There is considerable scope for reducing losses from these networks and, hence, improving overall efficiency. But such modernisation programs are expensive and must be considered as part of the longer-term restructuring and rationalisation program for the sectors.

Only coal cleaning and fuel switching (where these are feasible) and the installation of pollution abatement equipment are likely to offer the potential for significant emission reductions in the short term without the need for major investments.

Other means of reducing emissions that merit consideration for inclusion in a short-term action program include:

- Closure of the least efficient and most polluting plants—the recent reductions in demand for electricity and heat in CEE countries may make this feasible. The economic and environmental benefits of closure would need to be weighed against the political and social costs of higher unemployment levels
- Changing the pattern of public power plants dispatch to reflect both financial and environmental considerations
- Load shedding from specific plants during periods of high pollution, where the adverse air quality is linked to emissions from that plant
- Building tall stacks to disperse pollutants beyond locally affected areas. Although this option does not reduce the generation of emissions it could effectively control their impact and should be considered provided that any new impacts at a distance are judged to be acceptable.

The costs and benefits of each of these options will be sensitive to local conditions. But the options could represent some of the lowest cost means of controlling the worst pollution problems in the region arising from the power and district heating sectors.

Turning to the option of using pollution abatement equipment, Table C.7 provides details of the likely costs of installing selected technologies for a typical plant. It also provides details of the likely effectiveness of the different methods of reducing emissions of the specified pollutants. Care is needed in interpreting the results from the table because:

- The abatement cost estimates are based on plants operating at or near full capacity
- The abatement costs also reflect only the capital costs. Total abatement costs include operating costs, which will differ between options. Also, the impact of the capital cost on the total abatement cost will depend on the discount rate and lifetime of the investment
- The problems at specific plants may differ significantly from those of the typical plant and so too may the effectiveness of the alternative abatement measures.

Table C.7 provides a useful insight into the relative costs of using different control methods to abate emissions, despite the limitations noted above. In particular, Table C.7 highlights the relatively high costs of controlling SO_x and NO_x emissions using abatement technologies, compared with the costs of controlling particulate emissions. Furthermore, where existing particulate control facilities are not working properly, or at all, then these may be repaired at lower

Table C.7 Summary of pollution control costs of typical plants—power and district heating sectors

Pollutant	*Untreated emission tonnes/year*	*Technology*	*Removal efficiency %*	*Investment costs $/kWe*	*Abatement cost[1] $/annual tonne*
Particulates	200,000 - 500,00	ESP	97 - 99.9	15 - 40	20 - 90
		Bag house	99.7 - 99.9	15 - 30	20 - 60
		Mechanical	50 - 90	7 - 14	10 - 70
SO_x	30,000 - 90,000	Dry sorbet	50 - 80	50 - 110	400 - 3,500
		Semi-dry FGD	80 - 95	100 - 210	600 - 4,000
		Wet FGD	96 - 98	130 - 290	800 - 5,000
NO_x	6,000 - 15,000	Low-NO_x burners	30 - 70	15 - 25	750 - 7,000
		SCR	80 - 90	85 - 420	5,000 - 45,000

1 Investment cost per annual tonne of emission avoided.

costs than those given in the table. On the other hand, the emissions avoided would also be lower where existing facilities offer some degree of control.

Particulates

Mechanical collectors offer a reliable and relatively low-cost method, in terms of capital costs and maintenance costs, of particulate emissions control. They are, however, relatively inefficient overall, and particularly ineffective at controlling the smaller dust particles (<10 micron). In Western Europe, therefore, the use of mechanical collectors is now limited to small stoker-fired units.

A case study of the Trebovice power and district heating plant in Ostrava, in the Czech Republic, revealed that three of the eight boilers (representing 65 percent of the plant's thermal capacity) only have mechanical collectors. The two hot water boilers have three stage ESPs which have been operating for 15 to 20 years. These are likely to be in poor technical condition. Worn-out parts could include collecting and discharge electrodes and castings. The remaining three stream boilers have more modern ESPs, but these are unlikely to achieve a removal efficiency better than 98 percent, compared with Western European standards of, typically, 99.5 percent.

Particulate emissions at the Trebovice plant could be significantly reduced by replacing the existing mechanical collectors on the main boilers with ESPs and upgrading the existing ESPs on the other boilers to more efficient modern units. Existing units can be upgraded in a variety of ways: retrofitting modern components and controls; installing additional electrodes with an existing unit; and installing an additional ESP in series with the existing unit.

ESPs and bag filters offer considerable advantages over mechanical collectors in terms of particulate removal efficiency—at all particle sizes. But these advantages depend on a good standard of operation and maintenance practices. Bag filters need to be kept clean and bags need to be periodically replaced. Bag filters can also be damaged by high flue gas temperatures resulting from poor control of the boiler gas outlet temperature. With ESPs, failure to replace worn or failed components—such as the transformer rectifier, rapping system, or discharge electrodes—can lead to permanent deterioration in performance. Failure to control the flue gas outlet temperature from the boiler can lead to reduced efficiency as well as severe corrosion. The success of an investment program in these technologies may, therefore, depend on support for parallel training programs and measures to encourage the development of a local maintenance and service industry.

Flue gas desulfurisation

The main processes used for controlling sulfur emissions are:

- Dry sorbet injection in which the desulfurisation process takes place in the boiler during combustion
- Spray drier process in which milk of lime is atomised as finely as possible inside a reactor through which the flue gases are passed

- Wet (limestone/gypsum) process with limestone as reagent and gypsum as an end product.

The dry sorption process can be implemented with relatively simple equipment. It also requires less space than either the spray drier or limestone/gypsum process. The desulfurisation efficiency with this process is influenced by various parameters, including fuel type, firing system, and reaction conditions. Desulfurisation efficiencies of up to 80 percent can be achieved at lignite-fired boilers and up to 60 percent can be achieved at hard coal-fired boilers.

Desulfurisation efficiencies of approximately 90 to 95 percent can be achieved with the spray drier process, and up to 98 percent with the limestone/gypsum process.

All of these FGD processes have a slight adverse effect on overall plant efficiency due in part to their energy requirements. They can also have a variety of other effects on plant operation. For example, use of the dry sorbet injection raises dust concentration in the flue gas and, hence, results in a greater risk of boiler fouling. The limestone/gypsum process may cause corrosion in the absorption system and the flue gas ducts which, in turn, may reduce plant availability.

Costs associated with operation and maintenance are heavily dependent on local conditions. They are particularly sensitive to the costs of consumables (mainly reagents) and waste disposal. The dry sorption process is likely to have the lowest operation and maintenance costs and limestone/gypsum the highest.

Nitrogen oxides emission control

As noted above, NOx emissions can be reduced by either combustion modification (low-NOx burners) or flue gas treatment. The purpose of combustion modification is to suppress the formation of NOx in the furnace by lowering the maximum firing temperature. The alternative flue gas treatment controls NOx emissions by catalytic conversion.

NO_x reduction efficiencies of approximately 30 to 70 percent can be achieved using low-NO_x burners depending on the fuel characteristics, type of boiler, and combustion conditions. Additional flue gas treatment must be used to obtain greater reductions. Selective catalytic reduction (SCR) is the only proven technology for coal-fire plants. The use of SCRs can reduce NO_x emissions by approximately 80 to 90 percent. But SCRs can be extremely difficult and costly to retrofit to existing plants. The physical size of an SCR reactor precludes its incorporation in existing ductwork.

Sector prospects

Coal, and in particular lignite, will continue to be the major fuel source for power generation and district heating in CEE countries for the foreseeable future.

Uncertainty surrounds the future of the nuclear subsector, which is undergoing major safety overhauls. Construction of new capacity is delayed in Hungary and the former Czechoslovakia, and Poland has halted development of its nuclear program. Nuclear's share of electricity generation in the region may, therefore, have peaked. Gas may emerge as the preferred fuel for future new capacity in countries with access to supplies at an acceptable cost.

The current economic downturn in Central and Eastern Europe may occupy much of the next three to five years, and will give rise to a substantial drop in overall demand for energy. The introduction of energy prices which more adequately reflect the costs of supply than at present will exacerbate the situation. The inevitable decline of the power sector's traditional industrial consumers is likely to create a capacity surplus in most CEE countries.

In the longer term, significant demand for electricity may emerge in the growing light industries sector as well as from the residential sector, which uses relatively little electricity compared with countries with development energy markets. But the pace and extent of any growth in demand from new markets remains uncertain.

Meanwhile, the next few years many present opportunities to close the least efficient and those with the least capacity, thereby, meeting both economic and environmental objectives.

Conclusions

Table C.8 shows the estimated capital cost of installing pollution abatement technology to control particulate, SO_x, and NO_x emissions at all coal-fire public power plants, which includes CHP plants used for supplying heat and hot water through district heating, in CEE countries. Additional expenditure would be required to control emissions from district heating plants utilizing heat-only boilers.

The expenditures shown in Table C.8 do not represent priorities. Rather they illustrate the scale of costs involved in an overall environmental improvement program for the sector as a whole. And they highlight the need to set priorities.

The process of setting priorities will substantially reduce the estimated expenditure levels. We know that some of the plants, perhaps the minority, are already operating to relatively high environmental standards and do not need to incur all the costs envisaged by the calculations. There will also be opportunity at some plants, perhaps the majority, to repair or upgrade existing equipment at a lower cost than is implied by Table C.8. We also know that there are others which are so old and inefficient that expenditure on pollution abatement measures is difficult to justify. At some plants, other cheaper options for pollution control may be possible such as fuel changes, closure, or load management. There will be others which are in locations where the environmental conditions are not such as to justify immediate priority action to reduce emissions either because the problems are not severe or because they are not related to the emissions arising from the power or distracting heating sectors. There may also be cheaper options to control emission from other sectors.

Table C.8 Overall environmental expenditure estimates—power and district heating

Pollutant	*Capital cost ($ billion)*
Particulates	1 - 6
SO_x	8 - 45
NO_x	2 - 60

[1] Assumes that 50 percent of total capacity in the former USSR is located in Western Russia, Ukraine, Belarus, or Moldova.

Ostrava case study

Introduction

A case study was undertaken to assess the existing atmospheric pollution problems and to identify feasible pollution control techniques for the Trebovice Power and District Heating Plant in Ostrava in the Czech Republic. The plant is an integral part of the power, process steam, and district heating network in the Ostrava area.

The report summarizes the key findings. A separate working paper includes, as background information, a general view of power generation and district heating in the Czech Republic and the associated atmospheric emissions.

Background

The Ostrava industrial region consists of several towns lying on the upper reaches of the Oder River in northeast Moravia. The center of the region is the city of Ostrava and the adjacent towns of Karviná, Havírov, Frydek-Místek, and Trinec.

The main sources of electrical power for the Ostrava area are CEZ (power plant Detmarovice), the local privatised power and district heating company, Moravskoslezsk Teplárny (MST), and local industrial companies (the Vítkovice steel works, the New Metallurgical Works, and the Odra and Sverma mines). Ostrava is a net importer of electrical energy.

Trebovice Power and District Heating Plant is located approximately 4 km east of Ostrava town center. With Sverna power and district heating plant it forms the core of a private company, Moravskoslezsk, Teplárny (MST), which was formed on 1 May 1992 to supply power and district heating to the region of Ostrava. The company also includes five other district heating plants.

Ostrava has a high concentration of industrial production within its boundaries. In addition to coal mining, the region includes metallurgical plants, engineering works, heavy chemical plants, an automotive plant, and other industrial companies. Thus Trebovice is among a number of industrial pollution sources located close to the town center.

Trebovice supplies power to the national grid, process steam to local industry, and district heating to domestic consumers. The process steam and district heating network are connected to Sverna to ensure security of supply. The power plant was originally constructed as a pure power plant in 1933 and since then has undergone many changes, being extended, replanted, and the subject of plant life extension programs.

The two power-generating plants represent the main source of income for the company. The returns from the domestic heating plants are severely restricted by the current levels of tariffs charged.

Technical description

General

The plant currently comprises 3 × 55 MW_t steam boilers (interconnected) supplying 1 × 33 MW turbine/generator set and 3 × 161 MW_t steam boilers (interconnected) supplying 1 × 50 MW turbine/generator set in addition to the process steam and district heating networks. The plant also includes 1 × 38 MW_t and 1 × 58 MW_t hot water boilers.

The current maximum plant output is 83 MW electrical power, 400 MW hot water, and 70 MW process steam.

The hot water is produced according to a schedule based on ambient temperatures. The process steam is produced at a consistent pressure. As security of supply of process steam is subject to guarantees, there is a connection to the Sverna plant. During the winter period, steam production takes priority over power production.

Commissioning dates of the current plant were:

- Steam boilers (55 MW)—1963/65
- Steam boilers (161 MW)—1952/54 (original dates, since subject to replanting)
- Hot water boilers—1982/83.

The overall plant efficiency, based on average summer-winter electrical and heat loads, is some 42 percent. This figure is based on yearly average power, process steam, and hot water production figures for last year and is of questionable accuracy. The figure is included as an indicative value only. While the overall plant efficiency is dependent on the actual power and heat balance, typical efficiencies in West-

Steam boilers - K3 to K4	
Type	Benson type boilers, corner fired with 3 rows of burners (i.e., 12 burners).
Manufacturer	Vilkovice
Performance:	
Steam output	80 t/h
Steam pressure	127.5 bar
Steam temperature	500 deg C
Efficiency	83 percent
Airheater gas outlet temperature	160 deg C
Steam boilers - K12 to K14	
Manufacturer	Vilkovice
Performance:	
Steam output	220 t/h
Steam pressure	107.9 bar
Steam temperature	540 deg C
Efficiency	87 percent
Hot water boilers - HK1 and 2	
Manufacturer	CKD Dukla
Performance:	
Heat output	58.15 MW (50 gcal/h) at 170 deg C/70 deg C
Efficiency	80 percent

ern Europe are some 60–80 percent for similar plants. Power plant cycle efficiencies of typical Eastern plants are, in general, 2 percentage points lower than Western plants, reflecting the use of less efficient steam cycles and plant technology.

The plant burns either hard coal with a calorific value (VC) of 23 MJ/Kg or lignite with a CV of 15-17 MJ/Kg. The average sulfur content was advised as some 0.8 percent. However, this would appear to be low in view of an overall trend to use lignites with a higher sulfur content. Figures for the relative use of lignite and hard coal were not available. The use of lignite instead of hard coal results in greater emissions regulating from:

- The greater amount required to be burnt to achieve the same plant output due to lignite's power calorific value
- The higher ash content of lignite.

The hard coal is mined in Ostrava and the lignite in Karvina, with delivery to the power station by rail.

The power station has a 100 m tall stack which is unlikely to give adequate levels of dispersion taking into consideration the built-up nature of the area.

Boiler plant

Boiler plant with the following characteristics are installed at Trebovice:

Typical efficiencies in the West would be some 88 percent for the smaller steam boilers and over 90 percent for the larger steam units.

The lower boiler efficiencies at Trebovice are due to the high airheater gas outlet temperature of 160 deg. C. Typically, Western plants would have temperatures of 120 deg C. In addition, the combustion of lignite with its high moisture content will lower boiler efficiencies.

Turbine plant

Turbine plant with the following characteristics are installed at Trebovice.

Operation and maintenance

The station employs some 150 people on a shift basis for routine preventive maintenance, who also cover normal corrective maintenance requirements. However, where specialist services are required for the boilers and turbo-generators this is provided from Moscow. The station reported no difficulty in obtaining this support.

The plant has been subject to major plant life extension programs in recent years. This has included the virtual complete replacement of boiler unit K12 with the exception of the original boiler steel work. In addition, original mechanical dust collectors have

Turbine TG33	
Manufacturer	Pruni brnenská strojirna
Steam inlet pressure	122.6 bar
Steam inlet temperature	500 deg C
Generator Skoda Pizen 30 MW	
Turbine TG14	
Manufacturer	Skoda Pizeh
Steam inlet pressure	106.9 bar
Steam inlet temperature	530 deg C

been replaced by precipitators and existing precipitators upgraded and/or replaced. At least one unit, however, still relies on mechanical collectors for dust emission control. The station also reported that low-NO_x burners have been fitted to the boilers.

Overall, the boiler house and turbine hall equipment appear to have been maintained in very good condition. There were no visible steam or water leaks and the overall standard of housekeeping was high. The coal and ash areas at the rear of the plant were not so well kept but are not untypical for coal-fired plants in Europe.

Pollution problems

Typical emission levels for a plant of this type would be:

- SO_2: 1500 - 3000 mg/m^3 at 6 percent O_2
- NO_x: 580 - 900 mg/m^3 at 6 percent O_2 and
- dust: 330 mg/Nm^3.

The SO_2 and NO_x figures are similar to Western plants burning the same fuel. The figures for dust are higher than for Western plants.

The abatement equipment fitted is as follows:

- SO_2 emission: none of the boiler plant has been fitted with any FGD equipment and will therefore not comply with the present regulations (see Working Paper J)
- NO_x emission: figures for NO_x emissions for individual units were not given but stated to be around 650 mg/Nm3 which is typical of U.K. plant fitted with low-NO_x burners
- Fly ash and dust emissions: the hot water boilers have three stage ESPs and the 55 MW steam boilers that were converted from two stage to four stage ESPs in 1989/90. It is considered unlikely that the present units will be greater than some 98 percent efficient compared with Western European requirements of some 99.5 percent. The 161 MW steam boilers only have mechanical collectors which are likely to be some 80-90 percent efficient. It can be assumed that the electrostatic precipitators which have been operating for 15-20 years will be in a poor technical condition. Worn-out parts would include collecting and discharge electrodes and casings which are subject to corrosion/ erosion.

No specific plant emissions appeared to have been measured. Instead, measurements are made by Czech Republic Environmental Agencies at numerous points around Ostrava to determine ground-level concentrations. However, with the concentration of industry in the area it would be difficult to attribute high ground-level measurements to one specific plant.

Fly ash is used as an additive in the building industry. Originally 50-70 percent of the fly ash collected was disposed of in this way. However, as a result of the generally depressed market 25-30 percent is currently disposed of. The remainder is sent to the ash lagoon. The ash lagoon is subject to the normal pollution problems of leaching, overspill, and dust but is not considered to be a major source of airborne emissions.

Until recently there has been no incentive to monitor overall plant efficiency due to the low cost of fuel, availability being achieved at the expense of efficiency.

Now that the plant is part of a private company, management is actively looking at ways to improve profitability. However, their room for action will be limited by the original plant/component design which dictates the overall plant cycle efficiency. Increases in cycle efficiency above the original design level can only be achieved by replanting with modern high-efficiency plant at high capital cost.

Remedial actions

Overall, boiler, turbine, and system performance should be continuously monitored to ensure that plant is both maintained and operated to achieve levels of efficiency at or near original design values. Areas where improvements could be expected include fuel combustion; low levels of excess air; reduction of furnace, ductwork, and air heater leakage; and control of back-end temperatures. The reduction in emissions, however, will depend on how far the plant is operated away from original design values.

On-line emission monitoring equipment would assist in operating the plant at optimum conditions to minimize emissions. For example, a modern oxygen measurement/monitoring system could be installed at a cost of US$15,000.

With regard to airborne pollution, fly ash/dust emissions could be considerably improved by replacing the mechanical collectors on the 161 MW steam boilers with ESPs and continuance of conversion of the existing ESPs on the other boilers to more efficient modern units.

In absolute terms, SO_2 emissions will be reduced in proportion to the overall improvement in cycle efficiency. However, SO_2 emissions cannot be substantially reduced without installing flue gas desulfurisation plant.

In uncontrolled pulverized coal combustion the NO_x produced is predominantly from the fuel nitrogen (typically 75 percent of the total). The contribution from thermal NO_x is of the order of 20 percent. As low-NO_x burners affecting thermal NO_x generation are already fitted, any further reduction in NO_x emissions can only be achieved by more sophisticated and high capital cost solutions such as selective catalytic reduction.

An alternative option would be to convert the plant to gas firing. While the modifications to the burners and fuel/burner management systems are straightforward, the effect on the boiler would have to be analyzed in detail. The emissivity of gas is much higher than coal/lignite and thus requires a smaller furnace. Major modification to the existing boiler pressure parts may be required to achieve the correct furnace heat distribution.

Riga case study

Introduction

A case study was undertaken to assess the existing atmospheric pollution problems and to identify feasible pollution control techniques for TEC-2 Power and District Heating Plant in Latvia. The plant is an integral part of the power, process steam, and district heating network in the Riga area. This report details the case study findings.

Background

TEC-2 is the largest of two power and district heating plants in the Riga area. The plant is located some 8 - 10 km southeast of the city center and supplies electrical power to the national grid, process steam to local industry, and district heating to Salaspis. The plant was constructed and commissioned from 1973 to 1979.

Technical description

General

The plant comprises 4 x 480 t/h steam boilers coupled to 1 x 60 MW and 3 x 110 MW turbine/generators. The arrangement allows any boiler to supply any turbine.

Maximum electrical power output is 390 MW while supplying 730 MW_t of district heating at 125 deg C.

The station also has 4 x KVGM-100 hot water boilers to provide additional capacity for the district heating system.

Boiler plant

The steam boilers are TGM 96B natural circulation drum type manufactured by Taganrogas Katlu Rupnica with the following design performance/ boiler:

- Steam output: 480 t/h
- Steam pressure:
  boiler outlet - 140 bar
  turbine inlet - 130 bar
- Steam temperature:
  boiler outlet - 550 deg C
  turbine inlet - 540 deg C
- Fuel consumption:
  gas - 370,000 m^3/h
  oil - 32.5 t/h
- Boiler gas outlet temperature:
  140 - 155 deg C - gas firing
  after 165 - 170 deg C - oil firing airheater
- Burner location: front wall, 2 rows of 2: all four boilers exhaust into a single 110 m stack.

Overall cycle efficiencies for the type of plant installed are probably of the order of some 35–36 percent whereas modern Western plant would typically have values of some 38–39 percent.

Gas is the main fuel and oil is burned when gas is not available. Both fuels are supplied from Russia, gas by pipeline and oil by rail tanker. In 1991, the ratio was 50:50 gas/oil and in 1992 the ratio was about 65:35 gas/oil.

The contract specification of the fuel oil calls for a sulfur content of 2–2.5 percent. The station reported that in 1991 they received oil with 2.2 percent sulfur but in 1992 the sulfur level had risen to 3.0 percent. Currently there are no facilities for importation of fuel oil from an alternative source.

Fuel oil storage is for 23 days with 10 days of residual fuel oil giving a total of 33 days at MCR operation. This is equivalent to 45 days at average load.

District heating and process steam

The district heating network, approximately 6–7 km, is supplied with water at a pressure of 14–15 bar and a temperature of 125 deg C. Steam is supplied to local process industries at a rate of 15 t/h.

The main steam plant has the capacity to supply district heating heat demand down to an ambient temperature of –10 deg C. When the ambient temperature falls below this figure the station can bring on up to four hot water boilers giving an overall station heat production capacity of 1,280 MW_t. Heat losses are understood to be considerably higher than for equivalent European systems due to the poor levels of insulation in the homes the system serves. With a low relative fuel cost there has been little incentive to improve overall system efficiencies.

As the ambient temperature rises and the district heating demand falls, electrical output is restricted. Without the "condensing capacity" of the district heating network, the maximum available plant electrical output is 150 MW.

It was reported that, to date, there had been no problems with access to the required spares and the specified maintenance program was being followed. However, it was not possible to predict what would happen in the future.

The boiler house and turbine hall were inspected and found to be in good visual condition, with insulation/cladding in place, no visible steam or water leaks, and no visible rubbish.

The outside condition of the plant, buildings, and roadways indicated that a significant degree of maintenance was required. It is assumed that budget allocation has concentrated on the plant rather than the buildings.

Pollution problems

The TEC-2 plant has no emission control equipment, having been designed to burn gas as the primary fuel. While utilizing this fuel there are no problems with regard to SO_x and particulate emissions. However, when the plant burns fuel oil with a sulfur content of some 2.0–2.5 percent, SO_2 emissions are significant. When normal supplies of gas and oil are restricted, the plant has to burn residual fuel oil with a sulfur content of 3–3.5 percent.

The Riga area has the highest levels of SO_2, NO_x, and particulate emissions in Latvia with average measured concentrations of 0.004.06 and 0.1 mg/m^3, respectively, and maximum concentrations of 0.14, 0.74, and 1.8 mg/m^3, respectively. It can be assumed that when burning residual fuel oil, the plant is a major contributor to SO_2 emissions.

Currently there are no statutory regulations concerning emission requirements for either new or existing plants.

Remedial actions

Significant reductions in SO_2 emissions would be effected if the plant could rely on adequate supplies of gas. If long-term operation on existing fuel oil is envisaged then FGD plant would be required to comply with Western European standards.

The installation of additional condensing capacity in the form of a cooling tower would permit the unit to operate at full electrical output during the summer.

The control room and control systems at TEC-2 are representative of 1970s technology. Significant benefits could be gained in plant operation and reliability by the introduction of modern Western power plant control systems.

The plant was constructed between 1975 and 1979 with a design life of 20 years. It is clear that as it forms a major part of Latvia's independent power generation capability it will be included in plant life extension programs. These will not materially improve the overall cycle efficiency which is limited by the design conditions of the plant.

With the present state of the Latvian economy it is very difficult to establish hard and fast investment plans related to the development of power and district heating plants in Latvia. There is, however, a very strong movement to make Latvia independent in electrical power generation as soon as possible and to reduce dependence on imported energy. To this end the authorities are examining a number of proposals including:

- Increasing the capacity of TEC-1 and TEC-2 with new projects
- Construction of a new plant at Dangavpils and Liepaja
- Increasing the efficiency and output of existing plants
- Looking at the possibilities of importing coal to burn in new plants with modern clean coal combustion technology
- Looking at increasing the fuel oil handling and storage facilities at the ports
- Looking at energy conservation in the domestic and industrial sectors.

Annex D

Refineries and Petrochemicals

Introduction

In this annex we summarize our analysis of the technical and economic aspects of environmental protection in the refining and commodity petrochemicals sector of the CEE countries. The sector is a large one which plays an important role in the economies of the CEE countries. For the purposes of this study, we have focused on the following products and processes:

- Refinery production
- Manufacture of a few key commodity petrochemicals—ethylene, benzene, toluene, and xylene.

Our analysis is based on desk-based research and two case studies of the refineries and petrochemicals works at Plock in Poland and near Burgas in Bulgaria. Two annexes provide details of the findings from the case studies. A separate working paper provides further details of our analysis and the supporting data.

Structure of the industry

Refining capacity in the CEE countries is shown in Table D.1 together with capacity for the production of commodity petrochemicals. Table D.2 shows production levels.

More than half of the refineries are in the former Soviet Union or Romania. In general, the refineries in the CEE countries:

- Have small unit capacities
- Have smaller conversion capacities than in OECD countries
- Are old—crude distillation capacity is more than 30 years old and catalytic reforming capacity is more than 15 years old on average.

Although the basis feedstock, crude oil, and the required range of products is similar throughout the region, the history, the location, process developments, company policies, and economic pressures have meant that the configuration of nearly all refineries differs. The continuing changes in the economic climate, the world political situation, and market demands mean that each refinery often operates a different regime from year to year if not from month to month.

Pollution problems in the sector

The sources of pollution which typically arise in oil refining and the production of the bulk commodity

Table D.1 Refining and petrochemicals capacity

	Total	
	No. of plants	*Capacity ('000 tons)*
Refining	61	549,700
Ethylene	40	6,300
Benzene	29	3,600
Toluene	11	1,000
Xylene	6	800

Source: Chem Systems.

Table D.2 Refinery production and petrochemicals output, 1988 (*'000 tons*)

	Bulgaria	*CSFR*	*Hungary*	*Poland*	*Romania*
Refining					
Ethylene	198[1]	683	262[2]	322[2]	320[3]
Benzene		368	102[2]	273	110[4]
Toluene		58	114	102	189[5]
Xylene	32[1]	125	93	89	394[6]

Source: EIU, Chem Systems.
[1] 1987.
[2] 1989.
[3] 163 in 1991.
[4] 50 in 1991.
[5] 60 in 1991.
[6] 120 in 1991.

petrochemicals considered in the study are summarized in Table D.3. Also shown are the various options for abating emissions of each of the pollutants.

These tables need to be interpreted with some considerable caution as they mask significant differences in the circumstances at individual plants in the CEE countries. In particular, the pollution problems which arise depend on many different factors, notably:

- The age of the plant and the technology employed
- How the plant is operated and maintained
- The level of output relative to capacity
- The pollution abatement equipment already installed (and operational).

Nonetheless, in the absence of detailed environmental audits at all of the refineries and petrochemicals plants in the CEE countries, which is beyond the scope of the present studies, we believe the information provides a useful basis for understanding the na-

Table D.3 Typical pollution problems in the refining and petrochemicals sector

Product	*Process*	*Pollutant*	*Prevention technology*
Refining	Sulfur recovery unit	SO_2	Third reactor
			Improved reactor design
			Improved catalyst
			Tailgas clean-up unit
	Catalytic cracker	SO_2	De-SO_x
			FGD
			Regenerative FGD
			Caustic soda scrubbing
		Particulates	Cyclone
			Multicyclone
			Electrostatic precipitator
			Wet gas scrubber
		NO_x	Thermal de-NO_x
			Selective catalytic reduction
	Combustion process	NO_x	Thermal de-NO_x
	Wastewater	VOCs	Floating cover
		H_2S	Amine removal of H_2S
		Oily water	De-oiling (API/CPI)
		Oil/chemical sludge	Centrifuges, dryers, incineration, flue gas treatment
Ethylene		Flue gas	Burners
		Polymer wastes	Improved screening
		Organics in wastewater	Oily water separator
		Spent caustic	Plate separator
BTX		Benzene	Floating roofs
		Toluene	
		Xylene	
		Sludge	Centrifugation or incineration

ture of the environmental problems arising from the sector and their possible solution.

Pollution control priorities within the sector

Table D.4 summarizes the costs of pollution control in the refinery and commodity petrochemicals area.

Within the refinery itself, there are three priority issues:

- The sulfur recovery unit
- Catalytic cracker
- Wastewater.

Sulfur recovery units predominantly discharge SO_2. Refiners in the CEE countries have limited sulfur recovery capacity. The situation in the CEE countries is similar to that of Western Europe in 1960. It is not uncommon to have several units working at 70 percent capacity. To improve the yield, and hence the capture of sulfur emissions, four technologies could be applied: fitting a third reactor, improving reactor design, using new catalysts (or refitting existing plant), and finally, addition of a tail gas clean-up unit. The use of improved catalysts offers the least capital cost way of reducing SO_2 emissions.

Fluid catalytic cracking emits SO_2, catalyst fine and NO_x. SO_2 emissions can be reduced by between 30 and 70 percent by adding de-SO_2 catalyst in small amounts to the cracking catalyst. This approach can sometimes lead to bottlenecking of the H_2S handling facilities, and, for a typical plant, increases operating costs by $0.5 million per annum. Other more efficient alternatives include flue gas desulfurization (FGD), which produces gypsum as a by-product. Regenerative FGD increases energy consumption but has the greatest efficiency. Caustic scrubbing is also a useful

Table D.4 Summary of costs of pollution control—refining and commodity petrochemicals

Plant	*Pollutant*	*Technology*	*Capital cost ($ million)*	*Reduction in pollution (metric tons/year)*	*Capital cost per unit of pollution abated ($ per kg)*
Refining					
Sulfur recovery unit	SO_2	Additional reactor	3.0	1,800	1.5
	SO_2	Improved reactor design	3.0	1,800	1.5
Catalytic cracker	SO_2	De-SO_x catalyst	0	6,500	0
	SO_2	Caustic scrubbing	15.0	5,300	2.9
	Particulates	Cyclone	1.5	150-450	3.2
	Particulates	Multicyclone	3.0	350-450	4.1
	Particulates	Electrostatic precipitator	6.0	420-460	8.9
	Particulates	Wet gas scrubber	15.0	420-460	22.0
Combustion process	NO_x	Thermal de-NO_x	4.6	2,000-3,500	1.3-2.3
Wastewater	Oily sludge	Centrifuges, incineration	18.0	20 million	0.0002
	Slop oil	Slop oil recovery	10.0	20 million	0.00
Ethylene	Flue gas (NO_x)	Burners	9.0	110,000	0.08
		Plate separator	0.2	16	13.0
	Spent caustic	Improved venting/reduced leakages	0.5	1,000	0.5
	Ethylene				
Benzene Toluene Xylene (BTX)	BTX	Floating roof tanks	5.0	770	1.3-4.0
	Sludge	Sludge concentration/ incineration	5.0	3,300	0.5

technique giving high efficiency at moderate costs but leads to a separate water pollutant, Na_2SO_4. These options increase annual operating costs by $1.0–1.5 million, $1.0 million, and $2.5 million, respectively.

Particulate (catalyst fines) can be reduced by either single or multiple cyclone arrangements to achieve up to 80 percent removal. Increased performance is achievable with electrostatic precipitators and wet gas scrubbers. Selective catalytic reduction can reduce NO_x emissions by 85 percent.

Refinery wastewater can arise from several sources: sanitary water, rain run-off, process water, and ships ballast. Some can be treated by slop oil recovery units which separate oil from the oily water, tank bottoms, spillages, etc., and are used with considerable success in the West.

Ethylene plants in the CEE countries are generally smaller scale and have relatively dated technology compared to modern ethylene crackers. This means they are less energy efficient and more susceptible to leaks and maintenance problems. The major gaseous pollutants are flue gases from the furnaces. Low-NO_x burners can reduce these emissions substantially. Spent caustic solution can be reduced by plate separators prior to water discharge. Relatively high losses of up to 1 percent of ethylene have been recorded at some Eastern European plants. This could be reduced by improved venting and better housekeeping

Table D.5 Competitive strengths and weaknesses

Country	*Strengths*	*Weaknesses*
Bulgaria	• Good location, particularly for exports	• Few indigenous hydrocarbon resources—but less tied to Russia • Little recent investment—aging capital stock • Neftochim output subject to 35% levy—uncompetitive
CSFR	• Technically advanced • Existing pipeline network, for example ethylene Germany • Slovnaft has good communications • Recent Western investment (e.g., Dow, Enichem)	• Dependence on Russian oil and gas
Hungary	• Focused industry • Decentralized industry • Modern technology at TVK; DVK modern, efficient • Foreign interest in sector	• Unfavorable logistics • Dependence on Russian crude oil; lack of feedstock • Olefins plant separated from main domestic refinery
Poland	• Autonomous companies • Tradition of coal-based organics • Good indigenous process technology • Vertically integrated plant at Plock	• Dependence on imported energy—pipeline link to Russia
Romania	• Long tradition of oil and petrochemicals—supporting infrastructure exists • Good location • Exporter of refined products • Integrated industry	• Lack of investment during 1980s • Central control
Former Soviet Union		
Russia	• Shift of industry eastwards to Siberia—new investment planned • Major producers • Indigenous hydrocarbons	• Many plants operated beyond economic life • Limited dependence on Western technology • Reliance on indigenous coal and limited hydrocarbons
Belarus		• No indigenous hydrocarbons
Baltic States		• No indigenous hydrocarbons

Table D.6 Overall environmental expenditure estimates—refineries and petrochemicals

Plant	*Technology*	*Capital cost ($ million)*
Ethylene	Burners	360
	Plate separator—spent caustic	10
	Ethylene losses—vents/leakage	20
Benzene Toluene	Floating roof tanks	NA
Xylene	Sludge concentration incineration	NA
Refining:		
Sulfur recovery unit	Additional reactor	185
	Improved reactor design	185
Catalytic cracker	De-SO_x catalyst	0
	Caustic scrubbing	915
	Cyclone	90
	Multicyclone	185
	Electrostatic precipitator	365
	Wet gas scrubber	915
Combustion process	Thermal de-NO_x	280
Wastewater	Centrifuges, incineration	1,100
	Slop oil recovery	610

Note: NA = not available.

at relatively small cost. Overall, however, ethylene plants are not a major source of pollutant.

Benzene toluene xylene (BTX) plants are relatively small, polluting plants except for fugitive emissions of BTX, which are a health hazard. These can be contained by floating roof tanks with adequate venting to reduce the benzene emissions. Sludge from the wastewater plant should be concentrated by filter press prior to incineration. In the CEE countries, even centrifuging would result in good volume savings.

In 1991 the Plock refinery emitted 60,000 tons of SO_2 and nearly 8,000 tons of hydrocarbons. These latter emissions, which derive mainly from the wastewater plant, mean that the site and its immediate vicinity are designated as unsuitable for continuous occuption. Various options exist for reducing these emissions including more controlled loading and unloading, improving sealing on asphalt oxidation, and improved equipment integrity. The total cost of these measures would be around $15 million and would reduce emissions of hydrocarbons by at least 1,500 tons per annum.

Sector prospects

Table D.5 summarizes our assessment of the competitive strengths and weakness of the refining and petrochemicals sector in the CEE countries.

Conclusions

Table D.6 shows the total estimated potential cost of installing each of the pollution abatement options for each producer if we assume that all plants in the CEE countries require the expenditure. These estimates represent an upper limit to expenditures for several reasons. We know that some of the plants, perhaps the minority, are already operating to relatively high environmental standards and do not need to incur all the costs envisaged by the calculations. We also know that there are others which are so old and inefficient that expenditure on pollution abatement measures is difficult to justify, particularly in industries which need to bring their capacity closer into line with potential demand. There are still others which are in locations where the environmental situation is not such as to justify immediate priority action to reduce emissions, either because the problems are not severe or because they are not related to the emissions arising from the plants. In addition, the expenditure should not be taken to be a priority; a comparison is needed with other options for controlling emissions of the same pollutant in different sectors. This issue is considered further in the overview report.

Plock case study

Summary

The environmental problems at this large refinery are dominated by the emission of 60,000 metric tons per year of sulfur dioxide. The expenditure required to resolve this question would be substantial. The bulk of the sulfur dioxide is emitted by the power station, which burns vacuum residues. Flue gas desulfurization is estimated by Chem Systems to cost around $150 million. Other technical options are available, as is interface with the refinery process operations. A detailed study would be required to select the optimum approach.

More cost-effective measures may be those to reduce the emissions of hydrocarbons to the air. Techniques to be adopted include site-specific modifications, such as improvements to the oil catchers on the wastewater system or replacement of heat exchanger tubes. In addition, the introduction of good engineering practice in the control of vents will probably be of significant benefit at moderate cost.

The total cost of environmental improvements depends upon the result of detailed site investigations and design work by the company. Including flue gas desulfurization, the total investment cost could be around $250 million.

Background

The plant

Mazowieckle Zaklady Rafineryjne i Petrochemiczne (MZRiP) at Plock is Poland's largest refinery. It is linked with crude oil pipelines from Russia and from the coast at Gdansk in the north.

The facility has a crude oil capacity of 12.6 million metric tons per year. The products include transport and heating fuels, asphalts, and lubrication oils. Commodity petrochemical production on site includes the major aromatics BTX (benzene, toluene, and xylenes). A cracker produces ethylene and propylene, from which polyolefins are made on site, and C_4s from which butadiene is extracted. Phenol and acetone are also produced.

Economic perspective

In general, MZRiP operates at a sufficient scale and with adequate technology to allow it to be economically viable in the medium to long term. This depends, of course, on the vigor of the market it serves and on the availability of crude oil. It should also be noted that the vintage of technology employed varies considerably between the various units, and modernization will be required in certain areas. The plant began operations in 1964.

Overall, the configuration of process technologies and the range of products manufactured is comparable to Western installations. This contrasts to some other CEE plants, which are based on artificially priced feedstocks and on centrally planned product slates.

Location

The plant is located approximately four kilometers northwest of the town of Plock, which is itself to the west of Warsaw. The plant itself occupies a 815 hectare site and there is a 900 hectare exclusion zone surrounding the plant. Local facilities in the exclusion zone, such as housing or hotels in which people spend more than a working day, are being relocated.

The nearest surface water body is the small River Brezeznica which joins the larger River Wisla approximately three kilometers downstream of the plant.

Surface soils are around four meters to six meters of mixed sand and clay. Estimated depth to groundwater is approximately four to six meters. There is a

Table D.1.1 Refining process plants

Plant	*Total capacity (thousand tons per year)*	*Year built*
Crude oil distillation I-IV	12,600	1964-1975
Reformer I-IV	1,230	1964-1989
FCC I-II	2,300	1966-1976
Kero HDS	100	1975
Gas oil HDS I-III	1,760	1967-1975
HF Alkylation	150	1976
Sulfur recovery	50	1971
Asphalt oxidation	630	1983
Furfural extraction	400	1967
Solvent dewaxing	180	1967
Hydrofinishing	215	1967

second aquifer at around 40 meters below ground surface.

Process review

Refinery

The refinery has several streams of processing units, as shown in Table D.1.1. Although the overall crude distillation capacity is 12.5 million metric tons per year, in 1991 the actual production was only 8.4 million metric tons.

Crude oil distillation units comprise atmospheric and vacuum distillation. Vacuum residue and other heavy fractions are the feed for asphalt and heavy fuel oil production. This does not account for all the vacuum residue, and it is the main fuel source for the site power station.

Part of the naphtha is directly blended to gasoline. Some is reformed, also for gasoline. Reformate from two of the reformers provides feedstock for BTX extraction. Naphtha also feeds the ethylene cracker.

Part of the gas oil is hydrotreated. The remainder passes directly to the gas oil pool or to cut heavy fuel oil.

Distillates from the vacuum unit feed the FCCs, fluidized bed catalytic crackers. The liquid product is used as gasoline blendstock, either at Plock or in other refineries. The light olefins are used in alkylation, in the MTBE plant, and as propylene for polymerization.

Asphalt oxidation operates by the action of compressed air on the heavy feeds. Tail gases are scrubbed in oil and incinerated.

Hydrogen sulfide from the HDS, or hydrodesulfurization, units passes to Claus plants, which produce elemental sulfur.

Lubrication oil operations include furfural extraction, acetone-toluene dewaxing, and hydrofinishing.

Petrochemicals

Although large units as chemical plants, the petrochemical units are a small part of the total production at Plock. Table D.1.2 lists the process units.

Aromatics are separated from the reformate and from pyrolysis gasoline from the crackers by solvent extraction. The raffinate is returned to the gasoline pool.

Ethylene from the crackers provides the feedstock to the low-density polyethylene (LDPE) plants and also to the ethylene glycol facility. Propylene is supplied from the crackers and from the FCC. It is used in the polypropylene units, for alkylation in the refinery, and for the phenol/cumene plant. Butadiene is extracted from the C_4 stream from the ethylene crackers.

Table D.1.2 Petrochemical process plant

Plant	*Total capacity (thousand tons per year)*	*Year built*
Aromatics	480	1976-1979
benzene	40	
toluene	25	
xylenes		
o-xylene	21	
p-xylene	30	
Ethylene crackers I and II	363	1969-1980
LDPE I and II	140	1971-1978
Polypropylene I and II	84	1974-1976
EO/EG I and II	902	1969-1983
Phenol/acetone	35/22	1967
Butadiene I and II	40	1967
MTBE	60	1991

Sources of pollution and control measures

Atmospheric emissions

Probably the largest environmental issue at Plock is that of the emission of sulfur dioxide to the atmosphere from the power station and the refinery itself. Other typical combustion products—NO_x, dust, and carbon monoxide—are also of interest. Hydrocarbon emissions are another characteristic issue, both as a general VOC load and because of health aspects of specific materials such as benzene or butadiene. Unlike sulfur dioxide and combustion products, hydrocarbons may be emitted at relatively low heights. The region of the site and its immediate vicinity is judged by local regulatory authorities as not suitable for continuous occupation. It is understood that hydrocarbons are the main issue of concern here.

The consent to discharge to the air is valid until the end of 1993 for most plant sections.

Plock is one of Poland's largest emitters of sulfur dioxide. The sources of the 60,000 metric tons emitted in 1991 are shown in Table D.1.3.

The total emission of sulfur dioxide is around seven kilograms per metric ton of crude oil. This compares to a figure of two kilograms per metric ton of crude oil for CONCAWE refineries in Western Europe in 1989. CONCAWE refineries used crude oil with an average of 1.1 percent sulfur.

Table D.1.3 Emissions of sulfur dioxide in 1991 *(metric tons)*

Power station	41,800
Distillation	8,000
FCC	3,900
Reforming	2,400
Claus	1,600
Others (approximate)	2,000
Total	**59,700**

Around one-third of the crude oil used at Plock is now relatively low-sulfur North Sea oil. The remainder is from the former Soviet Union. Further measures are also necessary, and are described below.

The power station serves as the outlet for vacuum residues containing 2.5-3 percent sulfur. Flue gas desulfurization is a possibility, although it entails a capital cost of around $150 million. Conversion of the power station to an integrated gasification combined cycle (IGCC) system would allow high-sulfur fuel to be used with low atmospheric emissions. This would be very costly as a retrofit option. Another option could be to upgrade the residues by visbreaking, with hydrodesulfurization of product streams. This would allow the use of gas or other fuels in the power station. A substantial reduction of the sulfur dioxide presently emitted from the power station would result. Selecting the correct option can only be achieved by a detailed technical study.

On-site fuel use in fired process heaters will be reduced by planned hydrodesulfurization of fuel oil. Other potential decreases in sulfur dioxide emissions are intended modifications on the FCC units and improvements to the Claus plant.

The emissions of hydrocarbons from the plant are shown in Table D.1.4.

It is striking that most of the reported hydrocarbon emissions originate from the wastewater treatment plant. This apparently represents losses of hydrocarbons through leaks and minor spills into the site effluent system. Part of this material is removed in phase separators and returned as slop oil. The company assumes that the remainder evaporates. These losses would be largely eliminated by proper mechanical integrity of the equipment and piping, and by control of loading and unloading of hydrocarbon materials. Initial oil-water separators are not efficient in catching the oil and MZRiP is improving them.

Table D.1.4 Emissions of hydrocarbons in 1991 *(metric tons)*

	Aromatics	*Aliphatics*
Wastewater treatment	403	3,871
Power station	50	496
Distillation	70	1,168
FCC	52	221
Reforming	65	113
Ethylene block	250	107
AO	5	128
Oil products	18	31
Waste burner	21	43
Polymers	-	602
BTX	70	9
Total	**1,004**	**6,789**

In other areas, good design practice for control of vents and losses will be necessary to reduce hydrocarbon emissions.

The plants are briefly reviewed below for all emissions.

With the exception of the emissions of aliphatic hydrocarbons, the boiler discharges appear to be within the limits of the present consent. The NO_x, dust, and carbon monoxide also match good practice, such as the limits set for new plant in the EC Large Combustion Plant Directive. The company is, however, intending to fit low-NO_x burners.

Sulfur dioxide is around 1,600 mg/m^3 compared to the new plant limit in the EC Directive of 400 mg/m^3. Emissions of hydrocarbons are significant; improved handling and containment may be needed.

Fired heaters are the main emitters of sulfur dioxide at 1,200 mg/m^3. The emission is around four times that permitted by the regulators. There are also significant emissions of hydrocarbons, at over 1,000 metric tons per year. This indicates a lack of state-of-the-art containment and vent disposal.

The quoted emissions from the catalytic crackers are within the limits presently set by regulators and within the guidelines of the German TA Luft regulations. However, it is intended to close the older of the two units by 1995 and revamp the newer unit. This will reduce FCC emissions of sulfur dioxide by 60 percent. Hydrodesul-phurization of the vacuum gas oil feed would also be installed.

There were significant carbon monoxide emissions in 1991; we understand that an afterburner is now fitted. The consent to discharge for this plant is valid to the end of 1995.

In the Claus plant, hydrogen sulfide is removed from process gas streams and sulfur is recovered as a product. It is intended to replace two streams, and install Sulfreen tail gas treatment.

Compared to emission from the refinery, those from the petrochemical plants are less significant. A significant part of the emission of aromatics arises from the ethylene cracker and BTX blocks. A thorough upgrade of containment practices, particularly in the storage and handling of environmentally sensitive chemicals such as benzene, is probably advisable. There is a loss of ethylene of a few hundred metric tons per year from degassing the LDPE pellets. This could be reduced by purging with water into a vented barrel extruder.

Aqueous effluents

The main sources of aqueous effluents are as follows:

- De-salter effluent and water from crude distillation units
- Blow-down from the eight cooling water systems. This may contain quite high concentrations of oil, around 200 mg per liter, because of heat exchanger leaks
- Water from slop oil distillation
- Tank from drains
- Storm water, collected separately in the refinery and petrochemical areas.

There are a number of systems for treating the wastewater:

- Physical sand trap and oil boom for the refinery storm water. Average flow is around 200 m^3 per hour
- Oil skimming for the petrochemical storm water. Average flow is around 300 m^3 per hour
- Settling and physical separation of refinery process and drain water, chemical coagulation, and transfer to API separator. Average flow is around 1,400 m^3 per hour
- Screening and equalisation of petrochemical plant process and drain water, followed by coagulation and clarification, then a first stage activated sludge system. The flow is approximately 250 m^3 per hour
- All wastes are mixed and treated in a second stage activated sludge system. They pass to a check basin before final discharge to the river.

The quality of the effluent is typically as shown in Table D.1.5. The oil concentration is a little higher than the Baltic Sea Convention limit of five mg per liter. Oil ingress into the water, and lack of efficient separation, seems a problem in general. Not only is the oil in the effluent a little high, but the oil imposes a load on the treatment system which will tend to reduce the COD and suspended solids removal capability. Hydrocarbon ingress results also in the emissions to the atmosphere reported above.

A detailed review of the complex wastewater treatment system would be necessary to define areas of overall improvement potential. A significant upgrade would be costly for a plant of this size.

Table D.1.5 Average treated wastewater

Flow	2,200	m^3 per hour
COD	146	mg per liter
Suspended solids	58	mg per liter
pH	7.6–9.0	
Hydrocarbons	5.8	mg per liter
Phenol	0.03	mg per liter

Solid wastes

Solid wastes and disposal methods include the following:

- Part of the sludge from wastewater treatment is incinerated; a new incinerator is under construction. Some sludge is temporarily stored in steel tanks
- Some biological lime and oily wastes are stored in waste basins outside the plant boundary. The basins are not lined. The biological waste contains some heavy metals, e.g., chromium at 726 ppm and cadmium at 70 ppm
- Hazardous wastes such as spent catalysts and waste oils are stored in drums in an area with secondary containment for storm water
- Non-hazardous solid wastes are stored in an unlined landfill within the fence
- Construction debris is deposited on a landfill operated with the local municipality.

Areas which probably require modification include the provision of a secure landfill for hazardous wastes and an appropriately designed area for non-hazardous landfill.

Table D.1.6 Indicative environmental expenditure

Modification	*Pollution reduced*	*Reduction (tons per year)*	*Investment cost ($ million)*
Refinery			
Claus plant tail gas	SO_2	1,000	5.0
HDS own fuel oil	SO_2	6,000	35.0
Emission control FCC	SO_2	2,200	7.0
Asphalt oxidation mods	PAH		1.0
Vent containment	Hydrocarbons		2.0
Losses on loading	Hydrocarbons		0.2
Petrochemicals			
Vent containment/ducting	Hydrocarbons		5.0
General process			
Maintenance: improved integrity	Hydrocarbons	1,500	8.0
Site			
Power station FGD	SO_2	40,000	150.0
Power station LNB	NO_x		6.0
Improved oil catchers	HC to air		0.3
Wastewater treatment mods	Organics		1-12.0[1]
Solid waste landfills	Soil contamination		10.0[1]
Storage tank containment	Soil contamination		0.3
Recovery of oil from ground	Soil contamination		0.7
Remediation of old dumps	Soil contamination		1.0
Soil/groundwater remediation			1-12.0[1]

[1] Heavily dependent on detailed study.

Groundwater and soil contamination

The plant has had a number of spills, including around 1,000 m^3 of gasoline from a tank in 1979.

The plant has installed a product recovery well in the gasoline area which is producing around one metric ton per day. It intendeds to install two more. There is contamination in various other areas: general aromatics, phenol, benzene, free product oil. An extension of the extraction and recovery scheme to contain the pollution and to speed up decontamination is advisable.

The basins for lime, biological, and oily wastes are potential sources of contamination. Remediation and reclamation of these basins is appropriate as a means of controlling the risk of further pollution.

Summary of costs of pollution control

MZRiP is a complex facility, and a detailed study is required to properly define and cost rectification measures. Table D.1.6 shows some of the possible elements of expenditure, with rough indicators of the pollution reduction if it can be estimated.

In investment cost terms, the picture is dominated by the emission to atmosphere of sulfur dioxide. This in turn is dominated by the cost of flue gas desulfurization on the power station. This of course needs to be seen in the context of reduction of SO_2 emissions regionally. In addition, the possibility of a process revamp such as visbreaking the residues needs to be investigated. This could result in a substantial reduction of SO_2 presently emitted from the power station. In environmental terms, more benefit may be gained by subsidizing a process revamp that is not justifiable on purely economic terms. This would require a careful review with respect to technical and market feasibility of different options, as well as to economic policy implications.

Measures to control emissions of hydrocarbons include projects at a lower cost than those for SO_2 reduction. These include the following:

- Improved sealing on asphalt oxidation, to reduce the emissions of polyaromatic hydrocarbons (PAHs), at around $1 million
- Introduction of good engineering on refineries and petrochemical plants: equipment of a high integ-

rity design, venting of process units to appropriate devices such as flares, floating roof tanks, etc. Definition of this requires study by the plant. Considerable improvements should be possible for, say, $7 million for the facility

- Losses to atmospheric on loading and unloading can be minimized by maximum enclosure and venting of air from around the loading point to a control device. Although difficult to measure, these losses are usually significant. The cost of control can be relatively low, around $200,000
- Improvement of oil-water separation in the wastewater should be a relatively economic way of reducing the load on the water treatment plant. It would also reduce the losses of hydrocarbons to air from the wastewater treatment plant. The cost is estimated at around $0.3 million
- Improved equipment integrity will also be an important contributor to reducing hydrocarbon losses into the water and from there to the air. The cost in Table D.1.6 includes a program for the extensive replacement of heat exchanger tubes.

Containment and remediation of pollution of groundwater caused by hydrocarbon spills is already in place. Installation or upgrade of these facilities is important and relatively economical.

The company is aware of its environmental problems. Many of the items in Table D.1.6 are on its own environmental investment plan. One of the main constraints, particularly for flue gas desulfurization, is the shortage of funds.

Burgas case study

Background

Neftochim is Bulgaria's largest refinery and petrochemicals complex. The original refinery units were constructed on a greenfield site about 30 years ago. There has been significant expansion with the building of new production units and the modernization of the original plant in the intervening period.

The complex is situated about 11 km due west of the city of Bourgas (on the Black Sea) on the main road and rail links to Sofia.

The complex is an enormous facility consisting of a central power and utilities generation plant, refinery, and petrochemical process units, storage and loading facilities, and other ancillaries, including an extensive wastewater treatment plant. The refinery and petrochemical complex is supported by various off-site facilities, including an oil terminal seaport and pipeline distribution system.

The crude oil throughput capacity of the refinery is about 12 million tons per year. Over the years the plant has gone through debottlenecking revamps, so that it can probably process up to 14 million tons of crude oil per year. In the past about 60 percent of the crude oil processed was former Soviet export and the remainder came from Middle Eastern countries. Due to recent problems in both the CIS and the Middle East and to the shortage of hard currency, Neftochim received only 30 to 40 percent of its crude capacity during 1991 and 1992. Most of the catalysts, chemicals, and additives are also imported.

Neftochim's management are currently planning to develop and operate the refinery at the 1990 crude capacity of 7.5 million tons per year. Management believe that this throughput can be sustained by sales into both the domestic and export markets. Overcapacity will be overhauled and then mothballed to allow the company to quickly respond to any mid-term growth in sales.

The refinery has several operational catalytic reformers, but the octane value of the reformate is relatively low and, for example, the grades of leaded gasoline produced vary in octane number only from 86 to 96. Other refinery products include liquidfied petroleum gas (LPG), jet fuel, diesel fuels, fuel oils, petrochemical feedstocks, bitumen, and sulfur. Heavy residues are processed partly in a thermal cracker, with the remainder converted to bitumen.

The petrochemical feedstocks are used in downstream plants to produce the common aromatic and oleofin derivatives and a wide range of polymers. Some medium sulfur diesel fuel oil and a small quantity of unleaded gasoline is produced for export.

Most of the electricity for the complex is produced on site although the generators are also connected for export to the national grid. Cooling water used in the complex is pumped from a nearby lake and the liquid effluent, after treatment, pumped back downstream eventually flowing to the Black Sea.

The steam to the refinery is supplied by the central power plant which is fuelled by the refinery gases and by imported natural gas. Some relatively high-sulfur fuel oil is also used in this plant.

At the time of the study, the refinery complex was operating significantly below its capacity due to difficulties in obtaining sufficient crude supplies and in selling products into depressed home and export markets. Several of the process units were shut down and others were operating at significant turndown ratios. The latest overall material balance information available for the Bourgas refinery was for the entire year 1990, and is presented in Table D.2.1.

Production operations

Staffing

Neftochim currently employs just over 10,000 staff, down on the peak complement of 11,500 reached in 1990. At the current production levels, only 30 to 40 percent of full capacity, the complex is significantly overmanned and management intend to gradually reduce manning to the levels appropriate to the target 7.5 million tons per year crude throughput.

Production facilities

The crude oil processing nameplate capacity of the refinery and petrochemical units is 11.0 million tons per year. Management report the refinery has a capacity of 12.0 million tons per year, although following earlier minor debottlenecking revamps the overall processing capability may have been increased to nearer 14.0 million tons per year.

The refinery began with two units each of 1.5 million tons per year and a further three units each of

Table D.2.1 Overall material balance, 1990

Steam	*Tons per year*	*Percent*
Inputs		
Crude oil	7,355,000	99.45
Methanol	41,000	0.55
Sub-total	7,396,000	100.00
Outputs		
Gas	15,000	0.20
LPG	77,000	1.04
Virgin Naphtha	834,000	11.28
Automotive gasolines	1,126,000	15.22
Jet fuel	203,000	2.74
Motor diesel fuel	1,658,000	22.42
Industrial diesel fuel	803,000	10.86
Fuel oil	2,434,000	32.92
Marine oil	75,000	1.01
Liquid paraffins	24,000	0.32
Bitumen	128,000	1.73
Sulfur	14,000	0.19
Losses*	5,000	0.07
Sub-total	7,396,000	100.00

*Normal losses are reported to be around 1 percent.

3 million tons per year then followed, giving a design capacity of 12 million tons per year. Currently, one of the original plants is shut down and mothballed while the remainder are operating at reduced capacity. Production history, configurations, and capacities in each area are summarized in Table D.2.2, and the major refining and petrochemical processing units are described below.

Crude refining

Crude distillation units

There are five atmospheric distillation units, each with their own desalters, crude heat exchanger trains, fired heaters, strippers, and associated equipment. Recent operations have primarily utilized the newest units (AD-4 & AD-5) since insufficient crude supplies have been available to permit continuous operation of the other distillation units and because these units include naphtha stripping and naphtha splitting columns. The light naphtha is routed directly to gasoline blending; and heavy naphtha is further processed in the catalytic reforming units.

The complex also contains two vacuum distillation units processing the atmospheric residue and providing feeds to the thermal cracking, fluid catalytic cracking, and bitumen units.

Light ends processing units

These units include the gas desulfurization and gas separation units. The light gases produced in the various process units are initially desulfurized and subsequently fractionated to produce a variety of petrochemical feedstocks (C1, C2, and C3) and feeds to the sulfuric acid alkylation and MTBE Units.

The sour H_2S containing gases from the gas desulfurization unit constitute the feed to the sulfur recovery unit.

Naphtha processing

The majority of the straight-run light naphtha product separated in the atmospheric distillation units is sent directly to the gasoline pool. Some of this material can be processed in the light naphthaisomerization unit and a small portion of the straight-run naphtha is sent to the petrochemical plant.

The heavy naphtha fraction is hydrotreated in two naphtha hydrotreating units. The resulting material is then further octane upgraded in the two catalytic reforming units within the refinery. A portion of the hydotreated naphtha is sent to the petrochemical section of the complex for further processing to produce a range of specialty chemicals.

Distillate processing

There are three distillate hydrotreating units within the refinery; one processes the jet fuel and kerosene fractions, while the other two process the diesel fractions from the atmospheric distillation units.

Table D.2.2 History of Neftochim production units

Area	*Unit*	*Capacity tons/year*	*Date installed*	*Licenser/ designer*
Refiner	AD-1	$1.5X10^6$	1963	USSR
	AD-2	$1.5X10^6$	1963	USSR
	AD-3	3 million	1969	USSR
	AD-4	3 million	1973	USSR
	AD-5	3 million	1974	USSR
	Cat Reforming 1	300,000	1964	USSR
	Cat Refoirming 2	300,000	1970	USSR
	Hydrotreating 1	300,000	1964	USSR
	Hydrotreating 2	500,000	1970	USSR
	Hydrotreating 3	600,000	1975	USSR
	Vacuum Distill. 1	1.68 million	1974	USSR
	Vacuum Distill. 2	2 million	1982	USSR
	FCC	1.5 million	1982	USSR
	Visbreaking (thermal cracking)	1.5 million	1982	USSR
	Alkylation	215,000	1982	USSR
	$H_2 SO_4$	280,000	1983	USSR
	Gas Fractionation	280,000	1983	USSR
	MTBE	80,000	1988	Huela
	Merox	-	1991	UOP
Petrochemicals	Aromatics			
	Benzene	-	-	USSR
	Xylene	-	-	Eurotechnica
	Pyrotecol	-	-	Krupp-Koppers
	Olefines			
	Ethylene 1	-	-	USSR
	Ethylene 2	-	-	Technipetrol
	Ethylene Oxide	)	-	Scientific Design
		)80		
	Ethylene Glycol	)	-	Scientific Design
	Ethylene diamine	-	-	Societa Italiana Reoine
	Acetaldehyde	-	-	USSR
	Octanol-Butanol	30,000	-	Hemadex
	Phenol-Acetone	-	-	Chimmetdlurg- proekt
	Synthetic Rubber	-	-	USSR
	Hydrocarbon Resins	-	-	Bulgaria
	Poly Acrylonitrile	-	-	AKZO/FABQTA
	LDPE	80,000	-	Technip-ICI
	HDPE	-	-	USSR
	Polystyrene	-	-	Kozden-USA
	Poly Propylene	80,000	-	Hercules-USA

Gas oil conversion

The vacuum gas oil (VGO) fractions separated in the vacuum distillation units are routed through the hydrodesulfurization (HDS/fludic catalytic cracking FCC) units for upgrading to more valuable end products. The unit appears to be one of the most important process units within the refinery as it is by far the largest gasoline producer. It is capable of producing 90+ octane gasoline at a yield of over 50 percent. The FCC unit light gas by-product is eventually processed in the sulfuric acid alkylation unit.

Residual processing units

A visbreaking unit (thermal cracker) is used to upgrade the residual material separated in the vacuum fractionation units. The cracked fractions are routed to gasoline, kerosene, diesel, and fuel oil storage as applicable. The heaviest material is further processed in the bitumen unit to produce an asphaltic product.

Hydrogen production unit

A single hydrogen production unit provides the high-purity hydrogen requirements for some of the petrochemical process units.

Sulfur recovery unit

A single Claus-type sulfur recovery unit is operational.

Petrochemicals

Aromatics

The aromatics plant comprises three units producing benzene, xylene, and their derivatives (toluene, ethylbenzene, ortho and para xylene isoprene and various others, and solvents). Pyrolysis gasoline (fractions C_5 - C_9) and other mid-fractions (62 - 140° C) are processed in various catalytic reforming, rectification, extraction, and purification operations.

Olefins

Ethylene and other low olefines are produced in two units by the pyrolysis of the respective refinery fractions. This is followed by either direct cooling, absorption, and low-temperature rectification or by condensation and low-temperature rectification. The process is also a further source of aromatic hydrocarbons. A new bulk cryogenic ethylene storage facility is nearing completion.

Ethylene oxide and glycol

Ethylene oxide is produced by direct vapor phase oxidation of ethylene over a silver catalyst. The synthesis of ethylene glycol is carried out by neutral hydration of ethylene oxide.

Ethylene diamine

This plant produces ethylene diamine, diethyl diamine, and other higher amines from dichloroethane, ammonia, and sodium hydroxide.

Acetaldehyde

Acetaldehyde is produced by direct two stage catalytic oxidation of ethylene with atmospheric oxygen in a water solution of copper and palladium chlorides.

Octanol – butanol

The plant produces both octanol and butanol by the Aldon process as well as a range of other derivatives including hexanol and other higher alcohols. These by-products are obtained after vacuum rectification of the heavy products formed during the synthesis of the butyric aldehyde, butanol, and octanol.

Phenol and acetone

Phenol and acetone are produced by the cumene route using sulfuric acid as a catalyst. This process involves the initial autocatalytic oxidation of cumene followed by concentration and decomposition.

Synthetic rubbers and latexes

Neftochim produces a wide range of sythetic rubbers and latexes using both copolymerization and emulsion polymerization routes. Coagulation is carried out by the salt/acid method.

Hydrocarbon resins

Pyrolen hydrocarbon resins are produced by the cationic polymerization of unsaurated hydrocarbons from pyrolysis gasoline. Depending on the raw material used, olefine, aromatic, or alkyl-aromatic resins are produced.

Polyacrylonitrile

Polyacrylonitrile is produced by copolymerization in a suspension of acrylonitrite, methylmethacrylate, and sodium vinylsulfonate. The fibres are produced by wet forming in dimethyl formamide.

Low-density polyethulene (LDPE)

Neftochim has two LDPE plants; the first uses autoclave polymerization (the ICI process) while the second plant operates by the continuous polymerization in a tubular reactor.

High-density polyethylene (HDPE)

HDPE is produced by the polymerization of ethylene in a suspension using a Ziegler Natta complex orhano metallic catalyst.

Polystrene

Polystrene homopolymer, impact-resistant polystrene, styrene acrylonitrite co-polymer acrylonitrile-butadiene-syrene co-polymer (ABS), and foam polystyrene are produced by a range of suspension, tree radial polymerization, and copolymerization processes.

Polypropylene

Polypropylene is produced by the polymerization of propylene in n-hexane in the presence of a Ziegler catalyst.

Production planning

Production in the refinery and petrochemicals plants is planned against forecast demand with no material being produced to stock.

The Soviet equipment design in the refinery does not appear to provide for much process and production flexibility. Unit operation does fluctuate significantly, in part due to the lack of crude blending. The company is currently building a further two 50,000 m^3 crude storage tanks in addition to those recently completed, and this combined increase in storage capacity should allow some crude blending and provide buffer stocks. This will help to limit the impact of crude source changes and uncertainties, as well as reducing the sulfur content of the more sour crudes to improve product quality and specification.

The crude feedstock to the refinery complelx has become progressively heavier and has contained higher concentrations of sulfur over the past several years. These crudes are significantly heavier that the design parameters of the atmospheric distillation units and the downstream processing units and could conceivably bottleneck the processing capacities of the lower sections of the atmospheric distillation columns and the units designed to process the heavy crude oil fractions. The higher feedstock sulfur concentration could also affect the operation of the sulfur recovery unit and could result in unacceptable corrosion rates in the bottom processing units.

Capacity and flexibility

The original nameplate capacity of the five atmospheric distillation units is 11.0 million tons per year. The current actual operating capacity is approximately 14.0 million tons per year achieved either through simply operating the units at higher-than-design throughput, or though minor debottlenecking modifications to the units. Recent actual and projected crude processing is outlined in Table D.2.3.

Table D.2.3 Crude throughput

Year	*Million tons/year processed*	*Percent actual capacity*
1989	12.0	85.7
1990	7.5	52.9
1991	5.0	35.7
1992 (projected)	5.0	35.7

The refinery management appears to be having an extremely difficult time obtaining sufficient crude oil to efficiently and effectively operate the complex. In the recent past, Neftochim has received approximately 80-90 percent of its total crude from two primary sources, the former Soviet Union, and Iraq. Both have become unreliable suppliers. The CIS would prefer to export its crude to Western countries (to obtain much needed hard currency), hence, it has limited its sales to Bulgaria. Iraqi crude has gone off the World Oil Market since its invasion of Kuwait. Additionally, the crudes that are being obtained are increasingly heavier, more sulfurous, and more difficult to process.

The complex operated at only 30 to 40 percent of rated capacity during 1991 and 1992. Management expect that Neftochim will continue to have great difficulty in securing a stable crude supply in the future.

Supply and distribution

Raw material supply

Crude oil feedstocks are supplied through a dedicated terminal on the Black Sea which is linked by a 27 km pipeline system to the Neftochim complex.

The terminal, which is also operated and owned by Neftochim, comprises berths for 75,000 ton, 30,000 ton, and 5,000 ton tankers and floating roof storage tanks for up to 250,000 tons of crude. Most of the facilities were constructed at the same time as the refinery complex, although two new 50,000 ton tanks were completed last year and a further two tanks are under consideration.

The crude is transferred to a storage facility at the refinery complex via two underground pipelines.

A separate line is used for methanol which is also supplied by tanker and stored at the facility. Water ballast from the tankers is treated mechanically in a small water treatment plant and in three lagoons, before being returned to the sea. Vapor from the tankers and from the storage tanks is vented to atmosphere and is not recovered, even during loading/unloading operations. All other raw materials are supplied by road and by rail.

Finished product distribution

About 25 percent of the gasoline and the LPG is distributed by a pipeline network linking Neftochim to the sea terminal and to Varna and Sofia for diesel and gasoline.

Up to 25,000 tons of diesel and 10,000 tons of gasoline can be stored at the terminal.

The remaining diesel and gasoline, and around 90 percent of all other refinery and petrochemical projects, are distributed by rail, with the rest being moved by road.

Utilities, services, and off-sites

Central power station

The central power station is designed for the delivery of up to 600 MW, producing 60 percent as steam and 40 percent as electricity. The power station is connected to the electric power grid and regularly supplies electricity to the national system, which in turn covers the needs of Neftochim if locally generated power is inadequate.

Steam system

Steam for the entire refinery and petrochemical complex is generated in the central power station and distributed to all process consumers on a multiple ring system. A total of 11 Soviet-designed and -built boilers produce steam at present of 140 bar (6 units) and 100 bar (5 units of which 2 are not operating). this steam is let down through the turbo-generators to produce 40, 20, 15, and 10 bar steam for distribution. Steam is also available at the units 1.5 and 0.6 bars. Only about 20 percent of the steam generated is returned, at reduced pressure, or as condensate to the power station. A new 140 bar, 320te unit has been purchased to replace the two 100 bar, 160te boilers not operating, but has yet to be installed.

Electric power

The plant obtains electricity from two independent sources:

- The Bourgas substation, which is connected to the national grid, at 40KV, through two 110KV overhead lines
- The central power station owned by Neftochim where up to 240MW can be provided by six generators driven by steam turbines.

Electric power distribution within the refinery is structured as follows:

- Motors 200 KW and above which are supplied at 6,000 Volts/3 phase/50 Hz
- Motors up to 200 KW which are supplied at 380 Volts/3 phase/50 Hz
- Lighting with is supplied at 200 Volts/single phase/50 Hz, although dangerous area lighting is at 12, 24, or 36 Volts. Emergency light (DC) is provided by storage batteries
- Instrumentation and repair tools which are supplied at 220 Volts/single phase.

Water systems

The refinery process raw water is obtained from the man-made Mandra dam lake about 7 kilometers from the refinery. The wastewater after treatment is returned below the dam and discharges into the Bay of Bourgas. Drinking and sanitary water is supplied from the City of Bourgas' water system. Total water use in the complex is about 8,100 cubic meters/hour as follows:

- Boiler feed water — 1,300 cubic meters/hr
- Cooling tower water — 5,000 cubic meters/hr
- Process water (softened) — 500 cubic meters/hr
- Wash water, fire, water, and losses — 1,200 cubic meters/hr
- Drinking and sanitary water — 116 cubic meters/hr

The refinery uses a circulating closed cooling water system, using both forced and natural draught towers on the ringmains, although a considerable amount of fresh water make-up is still required.

Fire-fighting system

The refinery has a common firewater system for all the process units which operates at a header pressure of approximately 4.5 bar. Emergency firewater pumps can raise the header pressure to 10 bar and hydrants and monitors are well distributed throughout the process areas.

Fuel system

The fuel used to fire the refinery heaters is a combination of gas and oil. The fuel gas is a mixture of light refinery process gases and imported natural gas and the blend averages about: 195 H_2, 73.8 percent CH_4, the remainder C_2 +.

The fuel oil is predominantly the unconverted heavy material processed in the refinery and has a high sulfur content, varying between 1.0 percent by weight.

Instrument and plant air

Instrument and plant air are available from a ring main at a pressure of 4.0 bar.

Inert gas

Nitrogen is supplied at a purity of 99.9 percent and is produced by an on-site air liquefaction unit and is distributed on an as-required basis.

Works management

History

Neftochim's maintenance policy is in a state of change, and has been severely affected by the production philosophy, plant organization, past budgetary constraints, state central planning, and the lack of systems to plan and schedule work to monitor and control inventories and to provide equipment historical data.

Current practices

Practising maintenance and attempting to solve mechanical engineering problems without the benefit of installed and portable measuring and text equipment is normal at Neftochim. The lack of historical statistical recording of mechanical performance makes it difficult to initiate a preventive maintenance program or to research problem parts, assemblies, or machines.

However, the maintenance/mechanical engineering department is strong on practical maintenance and has recently introduced a preventive maintenance computer program and has begun to develop an historical data base.

On-site fabrication and refabrication includes the production of complex vessels and exchangers, making catings to one ton, balancing machines to five tons, and machining using sophisticated programmable repeating tools. Large workshops are occupied with the repair of pumps, valves, motors, and other plant equipment. The dearth of equipment manufacturers and repair shops in Bulgaria along with mostly non-domestic equipment installed in the plant are the principal reasons for these comprehensive facilities. On-site engineering consumables and spare part warehousing exist at numerous locations complicating the control of inventory, requisitioning, and costs.

Viability

Overview

Neftochim is the largest refinery and petrochemical and utilities complex in Bulgaria and has a capacity of 12.0 million tons of crude oil annually. However, this refinery is unlikely to operate at more than 7.5 million tons per year in the short term.

The country's second refinery located near Pieven is much smaller and is capable of processing only 1.2 million tons of crude oil per year.

Crude sourcing

The Bourgas refinery was strategically located on the Black Sea, with access to the crude oils from the former Soviet Union, Middle East, and North Africa. The crude oil for the Pleven refinery is supplied by railroad between Varna (a port located north of Bourgas) and Pleven.

Until 1990, Bulgaria received most of its crude oil from the USSR, and some from Iraq, Libya, and Iran on both a cash and barter basis. Due to the close ties with the Soviets, there was little direct effect from the oil crises experienced by Western countries during the early seventies. In 1990, crude oil supply was seriously threatened partly by the Gulf crisis and partly by the internal problems of the Soviet Union. Political instability amongst its suppliers, the internal thrust of privatization, and the growth of a free market economy, have forced Bulgaria into seeking other worldwide sources of crude oil.

Impact on industry of changes in crudes and/ or products

The Bulgarian market for the unleaded and superleaded gasolines is expected to grow in 1991 and beyond. The experiences of other Eastern European countries would suggest that the demand for diesel fuels and fuel oils will grow quickly as a free market economy is fully established.

In large Western refinery and petrochemical installations, adequate crude oil storage capacity can typically provide from one to two months' supply. This capacity allows crude blending and buffering, resulting in a blended crude with properties close to that of the design crude and the smooth operation of the refinery. The Pleven refinery does have over three weeks storage capacity, however, the Neftochim refinery has a very limited crude tankage. The refinery does not presently have the required storage and blending capability although two 50,000 m_3 tanks are now being constructed and a further two were completed last year (equivalent in total to two weeks operation at 7.5 million tons per year).

The current per capita consumption of refined products in Bulgaria is significantly lower than that of Western European nations. With the growth of privatization and a free market economy in Bulgaria, gasoline demand can be expected to grow faster than other petroleum products. Crude oil demand will also be influenced by the expected increase in the portion required for petrochemicals production. Some petrochemical production is currently exported to provide the hard currency needed to purchase the crude feedstock.

Market structure

Old system

The old system in Bulgaria was based on government-to-government crude purchases from the Soviet Union, Libya, Iraq, and Iran. Hard currency was therefore not an issue. Products were produced for the domestic market with some exports. The primary performance criteria was to satisfy the domestic market with on-specification products and cost was a very secondary consideration. A monopoly distribution-marketing network was built for gasoline, diesel, and fuel oil. A fixed margin was allocated to his monopoly and retail prices were then set by the state.

Under this system, management planned to extend the degree of integration of the Bourgas complex by utilizing refinery products such as propylene, butylene, naphtha, and reformats to make primary petrochemicals such as ethylene, propylene, butylene, butadiene, benzene, toluene, and xylene. Some of these were in turn converted to secondary petrochemicals such as acetone, pheonol, acetaldehyde, styrene monomer, and n-paraffins, as well as polymers such as polyethylene, polyproplene, polystyrene, and synthetic rubber. Until 1989, most of these products were consumed domestically with the rest exported into markets throughout the world. Tight cost control and profitability were not major considerations.

New system

The new system in Bulgaria has resulted in much lower trade of government-to-government crude from the CIS as well as reduced supplies from Iraq, Iran, and Libya. Hard currency is now required to buy the remaining crude required but only a limited amount is available. A processing deal using around half the effective capacity of the Bourgas refinery was entered into a couple of years ago with an international trading company in which Bulgaria purchases the fuel oil for hard currency allowing unleaded gasoline, diesel, and other products to be exported. This provides hard currency revenue (the processing fee) and flexibility in importing fuel oil to meet domestic demands. The octane of the exported gasoline is relatively low and the sulfur content of the exported diesel is relatively high. This results in lower than normal market prices for these exported products in a limited (and contracting) market. However, in principle, such processing agreements are probably more advantageous as it is always better to import lower-priced crude to make needed refined products than to import higher-priced refined products. Less hard currency is required and the available refinery capacity is being used.

Under the new system with limited hard currency and therefore limited crude availability, few petrochemicals and polymers are available for export and many of the plants are under-utilized. Processing agreements for these products with international companies providing hard currency feedstocks and receiving products would stimulate hard currency earnings.

In time, government intends to make Neftochim and Pleven shareholder companies (private companies) and reduce monopolization. However, at present Neftochim is further penalized by a government which requires that all taxes and excise duties are paid on home-produced gasoline and petroleum products but does not levy duty (at 35 percent) on equivalent imported products. In spite of these difficulties and market preferences, Neftochim is currently operating in profit, having generated about 130 million Leva in the 11 months to December 1992.

Comparisons with international trends

In Bulgaria, tetraethyl lead is still used as an octane booster in most of the gasoline produced as most cars in the country are manufactured to operate on leaded fuel. There is a small amount of unleaded gasoline produced for imported cases. The practice in Western countries is now to provide mainly unleaded gasoline for cars, and a small amount of leaded gasoline for older cars and farm machinery.

The diesel fuel produced currently contains about 0.2 percent to 0.2 wt percent sulfur in the relatively near future, and certainly before the end of this decade the sulfur content of diesel fuel all over the world is expected to be set below 0.05 wt percent. The aromatic content of both Bulgarian gasoline and diesel fuels will also have to be reduced if these products are to meet tightening world standards.

The domestic fuel oil market uses two kinds of oils; light fuel oil which contains almost 1 wt percent sulfur and heavy fuel oil which contains as much as 3 wt percent sulfur. These sulfur contents are much higher than normal fuel oils used in Europe and the USA, for example.

Environmentally, the refineries do not meet current Western European regulations in most areas. However, the companies are aware of the problems and are trying to modify and revamp waste treatment and disposal facilities, working toward a goal of meeting the current regulations by 1995. Eventually, national regulation and enforcement is expected to come closer to Western European standards.

Impact of product market changes

At present, the refinery production is oriented only toward the domestic market although some of the petrochemical products do compete in foreign markets. Any future development of a free market economy and the potential privatization of the refinery will have a profound impact on the operation of the Bourgas complex. Refinery products will have to compete with imported products, both in terms of quality and value.

It is expected that increased production of higher-octane gasoline products will become necessary. Additionally, lead and benzene reductions in gasoline will eventually become a reality. Neftochim currently is not in a position to produce significant quantities of high-octane, high-specification leaded and unleaded gasoline.

Changes to the diesel fuel product market may dictate similar product property improvements as reduction in aromatics and sulfur concentrations are inevitable. Of these, sulfur is probably the most severe and the first likely to receive attention, although aromatics will certainly follow.

Impact of legislation and social changes

The potential legislative and social changes could profoundly affect the operation and/or competitive position of the Bourgas refinery both in the immediate and longer term. Legislated changes could include:

- Initially reduction and eventually complete elimination of lead additives which improve the octane rating of the gasoline products
- Reduction of the aromatics concentration of the gasoline projects
- Reduction of both the sulfur and the aromatics allowed in the diesel fuel product
- Environmental pollution reduction to prescribed limits particularly for volatile organic compounds (VOCs), sulfur, and particulates along with elimination of specific toxic materials in the refinery water system
- Environmental testing around the refinery and petrochemical complex to monitor potential toxic pollution of the surface and groundwater.

Given the condition of the refinery waste collection and treatment systems, it is almost certain that significant capital expenditure will be necessary to bring the refinery into compliance with the future changes in national legislation noted above.

Potential social changes could include:

- The movement to a free market economy in Bulgaria
- Privatization of the state-owned refining industry
- Increased domestic consumption of petroleum products (particularly gasoline and some petrochemicals).

Plant limitations

Unit capacities

During the study the refinery complex was operating substantially below its capacity and it is difficult to predict which process units would limit the overall plant capacity since none of the process units have been 'pushed' to capacity in the recent past. Actual capacity is also likely to be constrained by the quality of the crude feedstock which has become progressively more heavy and sulfurous.

Product requirements

More stringent product specification requirements will probably limit the overall plant operations in the near future. the two reforming units were designed to operate at temperatures substantially below today's standards, and do not have the ability to produce the high octane gasolne required. The distillate hydrotreating units are processing a feedstock with significantly higher sulfur content than the original design anticipated and may limit the throughput o the complex as more stringent diesel product specifications appear.

Other limitations

The major limitation to the throughput of this refinery and petrochemicals complex would appear to be the procurement of an adequate supply of crude oil of an appropriate specification, (a political and economic, not technical limitation), and the development of home and export markets for its products.

Environmental performance

Overview

The environmental performance of the complex is reviewed in detail under the following headings:

- Air emissions
- Water pollution
- Solid waste disposal
- Heavy metal pollution
- Energy management
- Other problems.

Previously, management have mainly been interested in reducing wastewater pollution, the most visible environmental impact, and were little concerned with atmospheric emissions. Changes in local weather conditions, for example due to regional air pollution inversions, and increasing respiratory and other related health problems at the complex and in the nearby city are beginning to broaden their concern and action.

Neftochim is currently heavily fined both nationally and locally for continual breaches of legislated discharge requirements and consents. For example, the company pays 1 million Leva each month for its power station emissions and a further 2 million Leva for pollution from leaks in the underground pipeline supply system.

There are no specific air pollution control standards currently in effect. It is anticipated that future location regulations will force the plant to control the SO_2, NO_x, particulate, and volatile organic compounds within the next few years.

The wastewater quality as it leaves the final clarifier or the third lagoon does not meet the legislative standards although the wastewater treatment plant's basic design as originally installed has the potential to meet these standards.

The disposal of hazardous solid wastes is currently uncontrolled. A new rotary kiln incinerator system has been installed but the capacity of this unit is inadequate for the volume reduction of the hazardous oily sludges. The fly ash also has to be handled as a potential hazardous waste.

Air emissions

The principle air emissions comprise:

- Flue gas combustion products (SO_x and NO_x)
- Hydrocarbons
- Carbon monoxide.

The plant has developed a preliminary estimate of the facility emissions which is included as Table D.2.4. A comprehensive sampling program to assess both the pollutant concentrations and discharge rates is planned, but it will be constrained by the manual sampling and analytical equipment available. Management would like to develop a full dispersion model to determine how the emissions from the complex affect local health and what action should be taken.

Flue gas combustion products

The fuel gas used in the various process heaters contains an excess of hydrogen sulfide (H_2S) and the fuel oil fired in the power plant contains an excess amount of sulfur. The result of firing these fuels is a release of approximately 38,000 tons of SO_2 each year.

Some sulfur is recovered by the Claus process, although without a tail gas treatment unit, producing sulfuric acid and sodium sulfite at an efficiency of only 95 to 96 percent. Therefore, because of the low effi-

Table D.2.4 Air emissions

Emissions	*Bourgas tons per year*	*Typical U.S. refinery tons per year*
Hydrocarbons		(est. Total) 40,000
Saturated	186,600	
Unsaturated	37,000	
Aromatic	7,000	
Miscellaneous	6,000	
H_2S	200	
CO	13,000	6,000
NO_2	6,000	1,500
SO_2	38,000	7,000

ciency of sulfur recovery and the high sulfur content of the fuel oil, the sulfur content of the atmospheric emissions is relatively high.

An approximate sulfur balance based on a crude feed rate of 7.5 million tons per year and a typical sulfur content of 20 wt percent (usual range is 1.5 to 3.5 wt percent) is shown in Table D.2.5.

Hydrocarbons

A second major air pollution problem requiring a long-term solution is the excessive amount of lost hydrocarbons. The plant estimates that hydrocarbon release exceed 237,000 tons per year, although this figure was developed from a very limited sampling and without using any standardized estimating method. The regional pollution inspectorate estimates that these emissions are typically 3 to 6 times legislated TLV, and that for the principal pollutant, styrene, emissions are usually 6 to 10 times TLV, with obvious consequences to local health.

The distribution of these losses are as follows:

- Tank farms—65 percent
- Wastewater treatment plant—25 percent
- Process leaks—6 percent
- Cooling towers—3 percent
- General losses—1 percent

Although there is a common flare relief header and a gas recompression system in the refinery, which markedly reduces hydrocarbon emissions to atmosphere, there is no equivalent system for the petrochemical plants. Similarly headspace gases in atmospheric storage tanks and from toad and rail tankers are also vented untreated to atmosphere during filling and loading operations.

Water pollution

Source

The refinery and petrochemical complex is losing an excessive amount of oil to the wastewater treatment plant (WWTP). The excess is coming from the desalters, heat exchangers, and particularly from poor housekeeping and operational practices. These waste flows can also contain high concentrations of sulfates and chlorides and can be very alkaline.

Treatment

The current wastewater treatment processes and problems are described below. The WWTP was built in two

Table D.2.5 Sulfur balance

Sulfur source	*Sulfur equivalent tons/year*
Inlet	
Total in with crude oil	150,000
Outlet	
Recovered in Claus Unit	19,978
Estimated recovered in sulfuric acid	1,136
Estimated to sodium sulfite	1,136
Estimated from heaters	13,636
Estimated from boilers	29,545
Estimated in petroleum products shipped	85,568
Total out	150,000

stages; most of the plant was installed to serve the original refinery units with a smaller parallel extension in 1982. There has been little subsequent investment in new dedicated plant even though new production units have introduced waste streams which exceed the design capabilities of the existing WWTP. For example, the synthetic rubber and latex facility produces a wastewater stream containing sticky polymer crumbs, which can agglomerate and cause some WWTP operations to fail. The WWTP does not contain any process operations which could adequately separate this waste material from the water effluent.

The original wastewater sewer plan was to have four separate sewer systems:

- Rain water from non-process areas
- Rain water from process areas
- Desalters at the crude units
- General alkaline/sulfuric acid water sewer (chemical sewer).

During the numerous developments and expansions, the separation of the sewers was not enforced and the wastewater was directed into the closest sewer. Certain sections of sewers have also collapsed and again the water was rerouted to the closest sewer. Due to the excessive loss of products both in the refinery and in the petrochemical units, some sewers have become plugged with solids from the process units or with reaction products as various flows co-mingled sewers. When this occurred, the wastewater was again rerouted to the closest sewer.

The existing intermingled sewer system and surface drainage system must at least be investigated and the existing cross-connection identified and corrected. This will allow for specific and separate pre-treatment at the central WWTP. Barring this, effective wastewater treatment is probably not at all or only expensively and intermittently able to be achieved.

The existing collection sewers were also constructed with joints using a low-quality grout which fails and allows groundwater and sand to enter the system and at least surface water drainage inlets, a direct connection is made to the sewer system. The sewers therefore carry very large quantities of sand and other particulates which significantly impair separation. The inlets at least should be replaced with sand settling traps which must be inspected and cleaned routinely.

The sewer systems as they enter the central WWTP are equipped with basins to equalize the flows, but these are undersized and do not operate effectively. The basins encourage settling and allow the large particles of sand to sink and some free oil to float. The basins cause an additional operational problem because of the need for frequent cleaning.

A cyclonic type concrete basin separation is installed between equalization tanks and the pump stations. In theory the centralized flow will cause the sand to settle from the main flow, pumping to overhead hopper bottomed storage bins for dewatering and disposal. The cyclones have apparently never worked and no sand is being removed at this stage.

Oil separators

The wastewater from the cyclone sand separators then flows through a group of oil separators. The existing units are rectangular manually cleaned units and because of the excessive oil and sand in the incoming wastewater, the basins soon become ineffective. There are not enough people or equipment to keep these basins cleaned and operating effectively. Some of the basins are being equipped with travelling bridge type sludge/oil skimming devices which may relieve some of the oil and sludge problems. Without these API type units working, the oil/water/sand feed is well mixed at the pump station.

The wastewater is raised to a higher elevation at the pump station. The station is equipped with screw type pumps which also mix the oil, water, and sand. The excess oil is therefore partially oxidized and coated on the sand before the flow is directed to any or all of four equalization tanks.

The four 12,000 m_3 tanks do offer an opportunity for the various sewerage streams to mix and be equalized. Also, since the oil and sand have not been removed from the pump station, the free oil has an opportunity to separate while the coated sand/sludge settles to the bottom. The tanks are manually emptied and cleaned.

The wastewater flows to the dissolved air flotation unit. The free oil is pumped to an oil/water separator tank where the separate is pumped to the refinery for recycling and the water is returned to the WWTP.

The oily/sand sludge is pumped to one of two 75,000 m_3 waste holding tanks. Both tanks are full and a further tank is now being considered. Some gravity oil separation does occur and is pumped to the refinery for recycling.

The oily/sandy sludge is processed through a rotary kiln incinerator.

The design of the original rotary kiln considered the combustion of waste sludge, oily sludge, and solid wastes. The two sludges are treated in tanks and centrifuges. The centrifuges are used to separate oil and water from the sludges. The water is returned to three WWTP, the oil to the refinery, and the sludge to a blending/feed tank. The thick slurry of solid waste is then fed into the rotary kiln.

The exit gas from the kiln flows through a heat recovery boiler. After this, the cooled gas passes through a dust settling chamber and cyclone before the induced draft fan which discharges to a short stack. The dust from the chamber is collected and disposed of as hazardous waste.

A second unit was installed two years ago to a similar design, with a design capacity of up to 12 tons/hr of petrochemical and biological slurries. The original unit now only operates infrequently, principally due to rapid corrosion of the kiln lining by the aggressive waste materials.

Although the new German-French-built unit has been designed specifically to handle Neftochim's waste material, a throughput of only 5–6 tons/hr has never been exceeded. In practice this means that the plant can only treat the material being produced by the complex (operating at 30–40 percent of design crude throughput) and has no spare capacity to treat the very large quantities of stored slurry.

The partially treated wastewater then flows by gravity to a multiple DAF unit which is largely ineffective. The mix of water and oil flow from the DAF to the biological section of the WWTP.

The biological section of the WWTP was designed to be a two stage oxidation system. From DAF treatment, wastewater flows to the first stage where the aeration is provided by platform-supported turbine aerators. Recycled biological sludge is added to the wastewater flow before entering the first stage aeration unit. The outlet from the first stage flows to a circular clarifier to separate the activated sludge from the wastewater. Most of the settled sludge is recycled to the first stage unit. The excess sludge is pumped to a sludge lagoon for thickening.

The effluent from the first stage clarifier flows to the second stage aeration unit. The influent is mixed with recycled activated sludge from the second stage clarifier. Aeration in the second stage is again provided by platform-supported turbine aerators. After flowing through the second stage aeration unit, the wastewater flows to the second stage clarifier. The clarified wastewater is then pumped to the oxidation lakes near the Bay of Bourgas.

The aeration units of the WWTP are not capable of treating the influent wastewater because:

- There is excess oil entering the aeration unit.
- At any time many of the turbine aerators are out of service because of failed gear boxes.

The partially treated wastewater is pumped to a series of oxidation lagoons (lakes) approximately 15 km away from the refinery site, in marshlands near the receiving stream. The receiving stream is the Aitosky River which discharges to the Bay of Bourgas, approximately 3 km from the outlet of the last oxidation lake.

Originally there were four lakes with an estimated retention time of 30-40 days. Currently, there are three lagoons operating with an appropriate 22 days retention time.

The original first lake is now bypassed, and is partially backfilled and covered as following an earlier accident the bottom sediment and sludge is toxic. The plant has chosen to backfield and cover the material in the lake to keep the water from resuspending the toxic material and carrying it to the Bay of Bourgas.

The current first lake, the second old lake, is divided into two parts. The first part, approximately a third of the lake, is covered with a light oily mass of biological sludge and oil. A floating boom contains most of the float and a boat skimmer removes the float and pumps it to a storage plant. The sludge from the tank is blended with sawdust and sent to a power plant.

The current mechanical condition of the WWTP does not permit operation of the plant to meet the national legislative standards, as shown below in Table D.2.6.

The regional pollution inspectorate has measured concentrations of petrochemical products of up to 10mg/l in the sea water in the Bay of Bourgas, although not all of this pollution is due to Neftochim's discharges. Table D.2.7 summarizes the results of an intensive sampling and measurement program in 1991 in the Bay of Bourgas and at Neftochim's sea terminal.

Table D.2.6 WWTP concentrations

Property	*Decree #8 Stds*	*Outlet of WWTP (mg/liter)*	*Outlet 3rd lake (mg/liter)*
BOD	<5	150 - 400	60- 70
COD	<25	300 - 800	170-300
TOC	<10		
Oil	<0.05	20 - 50	5 -12
Total susp. solids	N/A	40 - 60	25 - 40
Surfactants	N/A	N/A	15 - 30
NH_4	0.05	N/A	15 - 30
NO_3	0.02	N/A	N/A
Total N	1.0	N/A	N/A
P	0.1	N/A	0.5 - 5
Fe	0.1	N/A	N/A
Pb	0.1	N/A	N/A
Phenol	0.001	N/A	N/A
Hg	0.001	N/A	N/A
A1	0.05	N/A	N/A
Ph	6 - 9	7 - 9	6.5 - 7.5

Impact of operations and maintenance practices

It was evident that the lack of preventative maintenance and the limited repair of out-of-service equipment has a very serious impact upon the emissions levels. This starts at the process block as is evident by the amount of excess hydrocarbon-containing streams released to the sewer. At the various pollution control treatment systems, the observed number of pumps, clarifiers, dissolved air flotation units, and aerators not working due to the lack of quality spare parts or of directed capital investment significantly reduced the effective capacity stored in a number of shallow lagoons. Many of the plant failures have been caused by the aggressive conditions in some parts of the WWTP, which exceed the design-specified conditions of the equipment.

Solid waste disposal

The plant has two separate solid waste disposal systems. The first is for the normal solid waste generated at a production plant such as scrap paper, wood, construction debris, and office material. This waste is currently being hauled to an approved off-site land fill site.

The second, and more pressing solid waste problem is the oily sludges currently being stored in various tanks, lagoons, and basins throughout the facility. It was estimated there is over 500,000 m^3 of these various oily sludges.

With current technology and Western practices, there would appear to be only two basic solutions to this sludge problem, either a reliable, appropriately sized and continuously operating rotary kiln incinerator, or chemical treatment and stabilization of the sludges.

Heavy metal pollution

The potential sources of heavy metals include:

- Basic sediment and water wastes
- Desalter water waste
- Oily sludges

Table D.2.7 Sea water pollutants, 1991

Pollutant	*Bay of Bourgas (mg/1)*	*Terminal (mg/1)*	*Legislation (mg/1)*
Ammonium slats	0.05	0 to 1.15	
Nitrates	0.02	0 to 0.02	
Phosphates	0.1		
COD	10	5.4 to 8.8	
BOD	5	2.2 to 6.8	
Petrochemicals		5	3.8

- Combustion of heavy oils
- Combustion of water and wastewater sludges
- Spent catalysts and precipitated fines.

The tank bottoms from the storage tanks, process units, or the API separators are sources of accumulated heavy metals which were typically burned in the rotary kiln incinerator. The hot gases exit the heat recovery boiler without any particular control and a portion of the heavy metals that are volatile and which oxidize in the combustion zone are present as heavy metal oxide particulates in the stack gas. The bottom ash which also includes non-volatile heavy metals is currently stored in a large concrete-liner bunker.

The burning of the vacuum unit bottoms in the power plant and process heaters releases heavy metals to the flue gases although no control devices are installed on either the boilers or the process heaters. If the flue gas desulfurization (FGD) system is installed for the boiler, a major portion of the heavy metals in the flue gas will be captured in the sulfur scrubbing material. The disposal of the FGD sludge will then have to be managed to prevent further environmental pollution.

The crude oil storage tank water drainage and the water from the desalter can also contain heavy metals. Both of the waters are routed to the wastewater treatment plant where some of the heavy metals may settle in the PI and enter the environment by being burned in an incinerator. A portion of the remaining heavy metals will be accumulated by the biological sludge in the activated sludge treatment system and may be released to the environment either in the incineration emissions or in the dust removal from the flue gas by the cyclones. The dust from the cyclones is currently being stored in a large concrete bunker.

The spent catalyst and fines are currently being stored in piles above ground and some of the fines can become airborne and migrate throughout the environment. Any rainwater falling on the dust could leach heavy metals to either the river, groundwater, or wastewater treatment plant.

The regional pollution inspectorate currently monitors heavy metal soil pollution at five monitoring points as part of the national network, which currently are within permitted levels for lead, zinc, copper, and arsenic.

Energy management

One of the most significant problems at Neftochim is the lack of a comprehensive energy (efficiency) policy. In the past, the refinery was concerned with production of on-spec products, with little regard for the energy requirements to produce these products. It is absolutely necessary for Neftochim to develop an energy policy appropriate to the current and particularly for the planned complex capacity. This may now be more critical since the refinery is having difficulty in obtaining sufficient crude to operate the complex at design capacity.

The 1991 USAID study reported that there were several areas where significant energy inefficiencies are occurring, notably:

- Fired heater efficiencies are not regularly checked, and it is suspected that oxygen requirements to the furnaces are substantially exceeded.
- The fuel gas to the furnaces does not appear to be monitored properly which also could lead to heater inefficiencies.
- The atmospheric distillation columns appear to be doing a poor job of fractionation. An outdated design contributes to the poor product split and energy inefficiency.

Other problems

Groundwater

There is a significant potential for groundwater pollution in many areas. Considering the location of the complex near the Bay of Bourgas, the probable groundwater flow is toward the Bay and areas of suspected or potential groundwater contamination should be investigated.

The second area of concern is the plant site itself. All the refineries that have investigated the groundwater under their plants have found it to be polluted clearly dependent on subsoil geology and working practices. However, the pollution varies from refinery to refinery. The amount of pollution found has varied from traces of hydrocarbons in the groundwater to a discrete layer of hydrocarbon material on top of the water table.

Neftochim is currently developing a groundwater sampling network based on a grid of 18 wells (which will probably be further extended in future). Samples are analyzed against up to 22 characteristics and have generally shown that little contamination is present. However, samples from two wells near the WWTP do contain high concentrations of various petrochemicals, although management were reluctant to provide these results.

Oil-water slurry storage lagoons

The slurry storage lagoons are mostly earth and clay constructions without any secondary interlining to limit concentration of the banks by the contents.

Evaporative losses of light hydrocarbon fractions from the black surface of the slurry contained in the lagoons and other store tanks is very high and was very noticeable and nauseating even on a cold winter day with little direct sunlight. The slurries have been accumulated over 20 years' operation and the total evaporative area of all the lagoons now exceeds 1 km^2.

Management have added lagoons on an as-required basis to cope with the steady increasing quantities of slurry. The existing and new rotary kilns for beating the slurry are making little impact on the vast amount of stored material to be located.

Supply and distribution

There have been few significant pollution incidents at the sea terminal. The only major incident occurred in 1988 when 10 tons of crude was spilled. Of greater concern is that there are few facilities available at the terminal to treat any major spills, for example with brooms, skimmers, or chemical sprays.

Waste and ballast waters at the terminal are locally treated to remove any oil residues before being returned to the bay. The existing facilities are in need of significant improvement.

The underground pipelines frequently rupture and leak causing significant ground and water contamination at points along the route. The pipelines are now almost 30 years old and inadequately protected against corrosion, as well as being badly designed, installed, and monitored. The most significant recent incident contaminated 15 hectares of fertile farmland with crude oil.

At the complex, rail tank cars are loaded by a dip pile through an open-top manway with no recovery of the hydrocarbon vapors and air displaced during loading, currently vented to atmosphere. The ground in and around the tank car loading areas is heavily contaminated by fuel oil, diesel, kerosene, and gasoline and by sulfur in an adjacent loading area. Tank cars often overflow and excess material is usually washed to drain.

Improvement opportunities

Overview

In summary, the opportunity, and need, for improvement in environmental performance, energy conservation, and operating practices are significant and fundamental to the continued operation of the complex. The improvement opportunities are reviewed in detail against the following headings:

- Products and markets
- Environmental performance
- Energy conservation
- Operational flexibility.

The principal issue affecting any potential opportunities has been and continues to be the lack of available operating capital and of external investment, grants, or loans to fund the significant operational and environmental improvements now required.

Products and markets

Against the background of the above report it is clear that Neftochim will have to extensively upgrade and modernize the complex to meet future national demands, particularly:

- Changing product specifications both nationally and in export markets and especially an increased requirement for unleaded gasoline and for low-sulfur diesel and fuel oils
- Increased demand for gasoline and diesel fuels as the economy recovers, and for plastics, synthetic rubbers, and other consumer-/market-driven petrochemicals.

This upgrade would mean adding processing units to produce high-octane unleaded gasolines including a reformer for high-octane isomerization and dehydrogenation. Existing alkylation, fluidic catalytic cracking, and MTBE production units would also have to be upgraded. Similarly additional hydrodesulfurization capacity will be needed to produce low-sulfur diesel and fuel oils.

In many areas process development and new capital projects have been slowed or stopped to minimize further debt and maintain the low levels of profitability. Examples of these projects include:

- Construction of a 28,000 tons per year polyacrylic fibres unit, stopped due to lack of investment
- Replacement of the 50,000 tons per year LDPE plant by an LDPE unit, stopped due to lack of investment requiring a likely penalty payment of up to \$10 million by Neftochim to the licensors
- Various process improvements to reduce the current environmental impact of certain steps and particularly:

- reforming, by introducing a new catalysis unit
- dearonitization, to reduce the sulfur content of diesel fuels
- hydrocracking, to reduce the sulfur content of the fuel oils.

In 1993 a team from the U.S. contractor Bechtel is due to visit the refinery for the World Bank. This team intends to further appraise the economic and technological viability of the complex and determine an overall strategy for Neftochim. This strategic plan takes into account the political, economic, and business environment and in particular the raw material, production, and marketing programs which need to be implemented and the resources, investment, and sources of funding required.

Environmental performance

There are no short-term, low-cost development or capital projects which would significantly improve the current environmental performance of the complex. To specify and determine the priority and cost-effectiveness of the projects will require further detailed but practical study supported by on-site measurement sampling and testing. These further studies should be carried out with management from the complex and should particularly address the treatment of wastewaters and oil sludge residues and the control and reduction of air emissions. However, these studies should only be started if there is a firm, quantified commitment by the national government and/or by international agencies to fund the significant improvements required. There is no value for Neftochim in repeatedly appraising problems which will never otherwise be corrected.

In the short term, environmental impacts could be reduced by assisting with the supply of spare and replacement mechanical parts, particularly for critical control and treatment units. This assistance should be supported by a program to raise employee awareness of environmental problems and encourage better housekeeping and operational practices.

Environmental improvement projects

As mentioned earlier, the refinery is already failing to meet current Bulgarian government regulations, particularly in respect of its water and air emissions. Potential legislated and social changes in the environmental area will increasingly affect the operation and/or competitive position of the Neftochim refinery, both in the immediate and long term. Legislated changes could include:

- Initial reduction of and eventually complete elimination of lead additives which are currently used to improve the octane rating of the gasoline pool
- Reduction of benzene concentration (which is also used to enhance octane values) of the gasoline pool as it is a reported carcinogen
- Reduction of both sulfur and aromatics allowed in diesel fuel
- Reduction of sulfur in fuel oils to minimize SO_2 release to the atmosphere
- Environmental pollutant reductions to prescribed limits. These would include volatile organic compounds (VOC), sulfur, and particulates to air, along with specific toxic materials in wastewaters
- Groundwater testing around the complex to monitor and then remediate any potential contamination of the water table.

To bring the complex into compliance with reasonable environmental standards the following actions should be taken:

- Reduce the amount of oil and petrochemicals lost to the various sewers
- Determine and treat source of excess sand in the sewer systems
- Identify and remove the cross-connections between separate sewer systems
- Remove and treat all the accumulated oily sludge
- Reduce the current high levels of oil circulating in the cooling water systems
- Revamp and repair the wastewater treatment plant
- Use alternative fuels or add on flue gas controls to the boiler plant
- Initiate a program of volatile organic compound emission control
- Improve the loading and unloading facilities to recover hydrocarbon emissions
- Improve the operation of all flare and incineration systems to ensure complete combustion
- Improve housekeeping and operational practices.

Neftochim's program for protection of the environment during the period, which addresses all of the above actions, is included as Table D.2.8 at the end of this section. For comparison, the program proposed by the 1991 USAID study is included as Table D.2.9, also at the end of this section.

The management at the complex appear to have a poor view of the recommendations of the USAID study principally because these do not fully reflect their view of what should now be done. Their belief that the report gives disproportionate emphasis to some lesser projects is perhaps more justifiable.

Costs

The estimated overall costs of improving and sustaining the environmental performance of the complex are summarized in Table D.2.10.

Table D.2.10 Overall cost breakdown

	Funding		
Study	*Millions (USD)*	*Millions (Leva)*	*Progra (years*
Neftochim (1992)	6.5	1,190	5
USAID	60	-	5

The Neftochim estimates are further made up as follows:

- Capital investment—685 million Leva
- Equipment overhaul—15 million Leva
- Government funding—160 million Leva, $3.5 million
- Interest free credit—330 million Leva
- International agency loans—3.0 million Leva.

Energy conservation

The management is aware of the need for a comprehensive energy savings program. However, the implementation of these programs could not be financed in the present situation even though it could be readily cost justified.

A summary of some of the 1991 USAID study recommended energy efficiency improvements is presented below:

- Neftochim must develop and implement a comprehensive energy conservation program particularly as savings should pay for any additional investment required.
- The largest users of fuel are the process furnaces and steam-generating boilers. Neftochim should improve furnace operation by replacing obsolete burners, by minimizing the excess air for combustion, and by fitting air preheaters and/or waste heat boilers to improve the efficiency of these units. However, many of the furnaces are of somewhat primitive and highly inefficient design and should be ultimately replaced with modern designs.
- Neftochim should implement a program to minimize steam condensate contamination and maximize the return of the condensate to boilers to reduce the high supply cost by the selection, operation, and maintenance of steam traps.
- An appropriate power recovery system should also be considered to improve overall energy efficiency and particularly of the FCC operations.
- The use of extraction steam turbines in the process units should be considered as these turbines can provide reliable operation and heating steam for process use. Overall steam, electric power, and fuel balance should be optimized, resulting in lower utility costs.
- Neftochim should consider revamping the acid gas removal system by replacing the solvent or increasing its concentration, saving heat energy in the solvent regeneration process. This might also extend to installing liquid ring pumps on crude vacuum distillation units, for example.

Operational flexibility

The refinery downstream equipment design was based principally on Soviet export blend crude oil, and there is little operational flexibility to allow for variations in feedstocks with the product specifications set primarily for the domestic market. Now with the opening of Bulgaria to world trade and the development of the free market economy in the country, feedstocks can be purchased from any source and refinery products will have to compete on the international market.

A summary of the USAID study's major observations to improve the operational flexibility and product specifications for the Neftochim refinery and petrochemicals complex is presented below:

- The refinery has only a limited crude oil storage capacity which constrains limited flexibility for reasonable feedstock blending to match the properties of the crude feed with the design case or to meet new market demands. Operating in this manner reduces operating efficiency and production output and yield. The refinery should consider at least one month above-ground storage capacity along with adequate mixing and blending facilities.

- The refinery needs a working linear programming model to predict day-to-day operation based on the varying feedstock and the changing markets for products. To support the model they will also need to develop process simulation models which are also needed to analyze refining systems through mathematical modeling to optimize unit operators.
- Neftochim needs to optimize the gasoline blending operation by installing octane monitors and a computer-assisted or -controlled blending operation.
- The refinery must in the mid-term install a catalytic reformer for the production of high-octane gasoline to improve the overall octane value of the gasoline pool. The other refinery units, fluid catalytic cracking (FCC), alkylation, isomerization, MTBE production unit, and the thermal cracker, have to be integrated with the new reformer to meet the future demand for non-leaded gasoline. Some of the major projects that are suggested for reformation of gasoline are presented below:
  - install a catalytic reformer with continuous catalyst regeneration
  - convert the existing reformer to an isomerization unit
  - revamp the FCC unit by adding a catalyst cooler and high-efficiency cyclones
  - modernize and optimize the alkylation operation
  - replace reciprocating compressors with more reliable and flexible centrifugal machines.
- The crude and vacuum units should be revamped to improve operational flexibility, for example, by the addition of pumparounds to the atmospheric columns, optimization of the crude heat exchange train, replacement of internals in the crude, and vacuum columns.
- Diesel fuel oils produced at the refinery are relatively high in sulfur content and additional hydrotreating capacity is needed to meet the current and future product specifications.
- The process control equipment and instrumentation should also be modernized with the incorporation of advance control methods to improve and optimize operations, resulting in improved profitability.
- The complex also needs a structured maintenance and spare part inventory program. There are commercially available computer programs to reduce downtime through more efficient planning and maintenance execution resulting in greater throughput and increased production for the investment in place. Effective spare parts and inventory control and procurement will yield operating cost savings.

Table D.2.8 Neftochim's program for protection of the environment for the period 1992-96

Unit Description	*Unit Status*	*Period for Realisation Quarter/Year*	*Funding Thousands USD*	*Required Thousands LEVA*	*Funding Sources*	*Expected Results*
Local treatment of waste water from ethylene unit/150 000 T/Y and ethylene unit/250 000 T/Y	The project is ready	IV-92	2,000		Capital investment	Reduction of sulphides content in waste water
Unit for neutralisation and local treatment of the pyrolen plant	The project is ready	IV-93	800		Capital investments	Reduction of pollutants in waste water
Revamp and reconstruction of the SBR unit: Replacement of the cooling of polymerizes and gland packings	First stage in execution			12,000	Overhaul	Reduces the amount of rubber crumbs in waste streams
System for burning waste gases and rubber drying	Realisation in stages offers, discussions	1994	1,000	300	Government funding	Reduction of emissions of styrene in the atmosphere, whose concentration is 450-550 Mg/m^3
Development of an own cooling water cycle from the unit B-15 in the rubber and latex plant	Regulations for design construction site offers	IVth quarter 1993-first stage 1996-second stage		200 20,000	Interest free credit	Prevention of pollution of the recycle cooling
Development of an own cooling water cycle from the LDPE unit	Inquiry for design	1993		1,500	Interest free credit	
Construction of a local treatment station for waste water from the FCC plant	Re-evaluation of studies and process design to begin	1993	3,000		Interest free credit	Reduction of water pollution

Table D.2.8 Neftochim's program for protection of the environment for the period 1992-96 *(continued)*

Unit Description	*Unit Status*	*Period for Realisation Quarter/Year*	*Funding Thousands USD*	*Required Thousands LEVA*	*Funding Sources*	*Expected Results*
Safety and de-watering facilities for the whole site in three stages:					Capital construction	Improvement of waste water treatent in all operating conditions
Stage 1						
Stage 2	In progress 1992		54,400			
Stage 3	Finalised design 1993		24,091			
	Contract		39,111			
Reconstruction of sewer system for separate outflow of waters from the central water treatment facility	Design 1994	1995-1997	3,000		Interest-free credit	To reduce water put to treatment
Elimination of oil slops from the central water treatment station and oil terminal	Review of offer Making business plan	1993-1995	2,500	1,100	Government funding	Pollution clean-up
Incinerator for solid wastes to the incinerator for oil slops, biological sludge/polymer products, resins and other wastes	Unit to be started up	1993	13,620		Credit without interest	Soil and groundwater pollution
Depot for solid process waste from the whole site on the land of Bulgarovo Town	Finalised project No persmission for construction landfill site	1993	13,620			
Automated railway filling piperack	Project step-preliminary studies and selection of offer	1995	3,055	147,000	Interest free credit	Reduction of hydrocarbon emissions to atmosphere and prevention of spills
Automation of tankcar filling piperack	Inquiry for offer	1996	3,000		Interest free credit	Reduction of emissions and spills

Unit Description	*Unit Status*	*Period for Realisation Quarter/Year*	*Funding Thousands USD*	*Required Thousands LEVA*	*Funding Sources*	*Expected Results*
Reconstruction of API separations (biological water treatment)	III-92 Detailed designs	1996	5,200		Capital construction	Improvement of API separation operation
	IV-92					
Construction of local stations for entire treatment of waste water from polystyrene plant	Studies completed, design work to begin	1993-1995 in stages	25,000		Government	
Construction of local station of waste water containing latex from latex and rubber production	Detailed engineering II-92	1994 1995	2,500		Government funding	Avoiding latex contamination in waste water
Construction of new neutralisation station for waters from chemical water treatment plant and power from power plant	Design work to begin	1994-1995	35,000		Interest free credit	To reduce water volume in the central water treatment station
Reconstruction and upgrading of central water treatment plant	Finished process study, design to begin	1995-1997	26,000		Interest free credit	Increasing the efficiency of treatment of waste water from the central water treatment plant
Treatment of oxidation lakes and optimisation of their function via intensification of treatment process	Studies in progress and design to begin	1993-1994	2,000		Interest free credit	Improvement of environment at the outflow in the Black Sea

Table D.2.8 Neftochim's program for protection of the environment for the period 1992-96 (*continued*)

Unit Description	*Unit Status*	*Period for Realisation Quarter/Year*	*Funding Thousands USD*	*Required Thousands LEVA*	*Funding Sources*	*Expected Results*
Reconstruction and upgrading of acrylic fibre plant, utilisation of wet waste fibres	Final design construction work in progress	1993	620,748		Construction	Reduction of emissions and avoiding off-spec production
Implementation of a modern process control equipment and optimisation of combustion of the power plant	Consultations and 1996 design work to begin		30,000		Interest free credit years	reduction of harmful emissions to the atmosphere and savings of fuel
Implementation of automated control emissions and imissions control of the atmosphere of the chemical complex	Consultations and inquiries for offers	1996	35,000		Government funding	Improvement of environmental discipline and data compilation
Separate power source for alkylation plant	Finalised design	1993	1,000		Interest free credit	Containment of pollution in the system to avoid outflow of waste water in emergency cases
Construction of neutralisation in the alkylation unit for collection and treatment of H_2SO_4	Finalised project	1993	9,000		Interest free credit	
Furnace for burning waste from polymer production equipment	Study in progress	1995	11,000		Interest free credit	

Table D.2.9 USAID 1991 program for protection of the environment

Description	*Cost*	*Pay-Off*
1. Immediate Opportunities		
Portable volatile organic (VOC) analyser will allow the plant to identify areas and equipment with high product loss. These data accumulated from a refinery VOC survey will allow the plant to establish a program of VOC control based upon fact	$12,000	The savings will be in the prevention of product leaks and loss. The instrument will pay for itself if the identified losses are corrected as identified
Pollution source study to evaluate the process blocks for pollution contribution and the sewer systems delivering the wastewater to the treatment plant	Not less than $70,000	The identification of the major sources of pollution load. A waste reduction plan can then be developed
2. Medium Term Opportunities		
Revamp the oil/water interface control of the desalters to the control loss of oil	Not less than $15,000 each	Reduce the amount of oil released to the sewer by about 200 000 tonnes/y
Install 10 belt oil skimmers in the cooling tower return basins/sumps	Not less than $10,000 each	Minimise the oil carry-over to the cooling towers. Recover about 100 tonnes/day of oil
The refinery has 5 - two compartment API separators requiring manual cleaning. The plant is currently installing mechanical equipment in one two compartment unit	Not less than $300,000 (Total)	Prevent the carryover of sludge/oil to the equalisation basins. Improve the recovery of oil to reycle to the slop tank
Install in the other three two compartment mechanical unit		
Revamp the existing 6 non-operating dissolved air flotation units and add covers	Not less than $250,000	Allow for the DAF to remove oil before the activated sludge unit and the oxidation lakes. Recover about 9000 tonnes of oil per day.
The three sewers have been inter-connected as an expendiance. Sewers should be separated - storm water, refinery wastewater and petrochem waste water.	Not less than $1,000,000	Reduce the hydraulic loading on the WWTP's for the both refinery and petrochemical plants
The waste reduction study recommended will identify which sewers and where they are inter-connected.	Actual costs are unknown	Also could reduce the amount of sand in the waste water
Excavate, blend, stabilise and bury 400,000 cubic meters of oil sludge currently being stored in some of the wastewater treatment units	Not less than $50,000,000	Safely dispose of the hazardous oil and sludge. Return the many wastewater treatment tanks to their full operating capacity and prevent additional oil loss to the river

Table D.2.9 USAID 1991 program for protection of the environment (*continued*)

Description	*Cost*	*Pay-Off*
The first and second stage activated sludge tanks of the wastewater treatment plant has 192 fixed platform type of turbine aerators. The quality of the existing gear boxes are such the plant cannot keep up with the maintenance. There are typically 50% of the aerators operatingat anytime. All of these units should be replaced appropriate to the current operating requirements.	Not less than $4,500,000	The initial saving will be in maintenance cost. The second saving is to provide the plant with reliable equipment which will provide the appropriate amount of oxygen capacity for the activated sludge process. This will allow the plant to meet the effluent standard.
Determine the extent of groundwater pollution and direction of the plume flow pattern	Not less than $100,000	Identify the amount and location of the groundwater pollution The groundwater cleanup system can not be designed or estimated until the test work is completed Prevent contamination of the additional groundwater
Old aeration lake needs to have the bottom sludges tested and stabilised Test for the groundwater contamination and flow pattern would then follow requiring about 50 wells to be drilled 50 wells 50 samples If sludge contains leechables and require treatment, the estimated amount of material requiring treatment is 70,000m^3	Not less than $13,000,000	Prevent contamination of Bourgas Bay from the groundwater flowing through the deposited sludge

Annex E

Inorganic Chemicals

Introduction

In this annex we summarize our analysis of the technical and economic aspects of environmental protection in the inorganic chemicals sector of the CEE countries. The sector is a large and diverse part of the chemicals industry but, for the purposes of this study, we have focused on the following products and processes:

- Chlor-alkali plants which produce chlorine and caustic soda as co-products
- Synthetic soda ash
- Titanium dioxide
- Nitrogenous, phosphate, and compound fertilizers which include the production of ammonia, nitric acid, ammonium nitrates, urea, phosphoric acid, phosphates, and NPK.

Below we summarize the key issues and conclusions arising from our analysis, which is based on desk-based research and four case studies. Details of the case studies of the Chimcomplex chlor-alkali plant in Romania, Azot Grodno nitrogenous fertilizer plant in Belarus, the PO Kaustik Volgograd caustic soda and chlorine plant in Russia, and Borsod Chem, a chlorine manufacturing plant in Hungary, may be found in annexes. A separate working paper provides an economic profile of the sector and an analysis of the pollution problems arising from each of the processes and products considered and their possible solutions.

Structure of the industry

Table E.1 summarizes the current structure of inorganic chemicals capacity in Central and Eastern Europe. Tables E.2 and E.3 indicate the most recent production levels for which we have data; in many cases, levels have fallen very significantly since these statistics were prepared and the level of capacity utilization in the region is low.

Pollution problems in the sector

The pollution problems which typically arise during the manufacture of each of the products considered in this part of the study are summarized in Table E.4. Also shown are the various possible options for abating emissions of each of the pollutants.

It is difficult and potentially misleading to generalize about the nature and scale of environmental problems arising from the inorganics sector in the CEE countries on the basis of a small number of site visits and limited detailed information about the design and operating procedures and processes at each plant. As a consequence, the relevance and likely effectiveness of the different options identified may vary significantly from plant to plant depending on a variety of factors such as:

- How recently the plant was built and the technology used – some plants were established before the installation of at least some pollution control procedures became the norm
- How well the plant has been maintained and operated
- The output at the plant relative to its capacity
- Whether the enterprise has been able to afford the investments necessary to operate the plant effi-

Table E.1 Inorganic chemicals capacity

		Total	
Process	*Product*	*No. of plants*	*Capacity*
Chlor-alkali	Chlorine	43	3,700
	Caustic soda	43	4,200
	Soda ash	13	7,100
	Titanium dioxide	4	100
Fertilizers	Ammonia	62	21,700
	Nitric acid	44	3,400
	Ammonium nitrates	42	6,700
	Urea	36	6,600
	Phosphoric acid	32	6,900
	Phosphates	32	6,900
	NPK	6	16,200

Source: Chem Systems.

Table E.2 Production of inorganic chemicals, 1989 *('000 tons)*

	Chlorine	*Caustic soda*	*Soda ash*	*Titanium dioxide*
Bulgaria	69[1]	104[4]	1,025[4]	
CSFR	50[1]	337[1]	112[1]	30-35
Hungary	168[1]	204	482	
Poland	364	434	1,005	
Romania		800[3]	900[2]	
Former Soviet Union		1,400[4]		

Source: EIU.

Table E.3 Production of fertilizers, 1989 *('000 tons)*

			Phosphoric	*Fertilizers*[5]		
	Ammonia	*Urea*	*acid*	*Nitrogenous*	*Phosphatic*	*Potassic*
Bulgaria	1,376	371	145[1]			
CSFR	941[1]	75	65[1]	596	277	111
Hungary	692[1]	114	39[1]	501	144	
Poland	2,360[1]	447*	523[1]			
Romania					1,000[6]	
Former Soviet Union						

Source: EIU.
1 - 1988.
2 - 1990 (470 in 1991).
3 - 1990 (460 in 1991).
4 - 1990.
5 - 1987.
6 - 1991.

ciently and safely in an environmentally benign way.

Pollution control priorities within the sector

Table E.5 provides details of the likely costs of installing selected methods of pollution control for a typical plant using each of the processes considered. It also provides details of the likely effectiveness of the different methods of reducing emissions of the specified pollutants. We focus on those options which offer the most cost-effective potential reductions in emissions of particular pollutants.

Care is needed in interpreting the table because:

- The cost estimates are based on plants operating at or near full capacity
- The problems at specific plants may differ significantly from those of the typical plant and so too may the environmental effectiveness of the alternative abatement measures.

Table E.4 Typical pollution problems in the inorganic chemical sector

Product	*Process*	*Pollutant*	*Prevention technology*
Chlor-alkali	Mercury cell	Mercury in air and hydrogen	Activated carbon Copper/aluminum oxide or silver/zinc oxide Good engineering practice
		Mercury in wastewater	Reuse Good practice Chemical treatment Solvent extraction
		Mercury in solids/sludge	Improved operation Retorting Change to titanium anodes
		Mercury in soil	Excavation and retorting
		All mercury	Membrane cell
	All	Chlorine to air	Caustic scrubber
	Utilities	SO_2	Low sulfur fuel Semi-dry lime scrubbing Limestone-gypsum
		NO_x	Primary measures SCR
		Dust	Electrostatic precipitators
Soda ash	Soda ash-aqueous	Solids in distiller effluent	Limebeds Return to brine cavity
		Total ammonia	Improved liming
		Chloride	Crystallization
	Soda ash-solid	Lime	Dewater (and sell) Limebed management
	Utilities	As per chlor-alkali	
Titanium dioxide		SO_x acid mist	Absorption plus irrigated ESP
		Sulfate	Neutralization Acid recovery
		Copperas	Management of deposit and leachate Export for sale Roasting
Nitrogenous fertilizers	Ammonia plant	NO_x	Primary measures
		Ammonia to air	Vapor containment Good design practices
		Process condensate to water: Ammonia Methanol, etc.	Strip, reuse condensate, recover ammonia

(Table continues on the following page.)

Nonetheless, given the information available, we have little alternative if we are to provide an insight into expenditure priorities and their likely costs.

For chlor-alkali plants relying on mercury cells, mercury losses are the usual source of concern. Evidence from plants in the CEE countries suggests that emission levels are typically very considerably greater than those elsewhere: over 100 grams per ton of chlo-

Table E.4 Typical pollution problems in the inorganic chemical sector (*continued*)

Product	*Process*	*Pollutant*	*Prevention technology*
Nitrogenous fertilizers	Nitric acid plant	NO_x	Selective catalytic reduction
	Ammonium nitrate	Prill toner to air: Ammonia Dust	 Wet scrubber Convert to granulator
		Other	Wet scrubber
	Urea	Dust to air	Wet scrubber Convert to granulator
		Ammonia to air	Process modification
		Aqueous	Process modification
	Site	Aqueous: COD	Conventional
	Utilities	As per chlor-alkali	
Phosphatic fertilizers	Sulfuric acid plant	SO_2	Convert to double absorption Tail gas scrubber
	Phosphoric acid plant	Fluorine compounds to air	High-efficiency scrubbing
		Dust (phosphate rock)	Fabric filters
		Aqueous effluents—fluorine, $P_2 0_5$	Process recycles
		$P_2 0_5$	Gypsum dump management
		Solids-gypsum, calcium fluoride	Beneficial use Recover fluorine
	Superphosphate granulator vent	Fluorine compounds	High-efficiency wet scrubber
	MAP/DAP process vents	Fluorine compounds Ammonia	High-efficiency wet scrubber
	NPK	Ammonia SO_2 Dust	Wet scrubbers
	Site	COD	Conventional

rine compared to two to five grams. Indeed, at Borsod Chem, ground contamination is by some way the most significant issue. One control option is to switch to membrane cells. The case study of Chimcomplex SA at Onesti in Romania showed a plant which was switching from mercury cell technology to a less environmentally sensitive German technology. The case study of PO Kaustik in Russia shows the unusual situation of a plant which possesses membrane cell equipment but lacks the funds to install it. If the expensive technology change is not made, other shorter-term options include the introduction of minor equipment modifications to recover lost mercury. This, and attention to operating practice, would probably effect the largest reduction in mercury losses in some plants. Other possible changes include conversion from graphite to titanium anodes. Conversion to brine recirculation and installation of containment devices on effluent streams could also be worthwhile means of reducing the level of mercury on wastewater.

At Chimcomplex, the case study highlighted several important sources of polluting emissions although any assessment of their severity was complicated by the absence of adequate monitoring information, a problem also found at other sites. Nonetheless, the process plant was adversely affected by inadequate maintenance and spare parts. Remedial measures to control workplace emissions would cost about $100,000 whereas more extensive measures such as better design, venting of process units, and installation of floating roof tanks would cost around $10 million although they would bring about considerable improvements.

The main problem in soda ash plants, particularly inland, is high chloride emissions in the liquid effluent. There is no obvious or easy answer. However, the impact of the solids on the aqueous effluent can be reduced by returning the solids to the brine boreholes or selling the solids from the limebeds as soil conditioner. At Sterlitamak, the solution is pumped to oil wells. In addition, proper management of the lime waste dumps will contain potential pollution of ground or surface water bodies. Most plants in the CEE countries already have standard equipment to control emissions to the atmosphere and, for this reason, there is little scope for modest measures. For example, the PO Kaustik case study also highlighted the desirability of improved management of water effluents. In particular, segregation of the chlorinated waste—before incineration at a new plant—and recycling of saline effluent to the brine wells could lead to significant environmental improvements at relatively modest cost ($20 million).

All titanium dioxide plants in the region rely on the sulfate route. The major problem is the discharge of aqueous effluents. Where no control measures are installed on titanium dioxide plants, neutralization of the acid effluent is probably the least-cost option. Potentially, the resulting gypsum can be used to manu-

Table E.5 Summary of costs of pollution control at typical plants—inorganic chemicals

Plant	*Pollutant*	*Technology*	*Capital Cost ($ million)*	*Reduction in pollution (metric tons/year)*	*Capital cost per unit of pollution abated ($ per kg)*
Mercury cell chlor-alkali	Mercury	"Good practice"	0.1-2.0	32	0.003-0.06*
	Mercury	Titanium anodes	3.0-4.0	9	0.33-44*
	Mercury	Other upgrades	1.0-10.0	4	0.25-2.5*
Soda ash	Solids	Settling solids to brine	3.0-8.0	45,000	0.05-0.19
	Solids	Sale of lime solids	2.0-5.0	45,000	0.03-0.13
	Saline pollution	Limebed management	1.0-3.0	-	
Titanium dioxide	Sulfate to water	Neutralization	2.0-3.0	45,000	0.04-0.07
	SO_2	Scrubbing/ESP	1.0-3.0	625	2.0-8.0
N Fertilizers	NO_x	SCR de-NO_x	2.0-4.0	2,000	
	Dust	Prill scrubber	0.1-0.2	240	
	NH_3			200	
P Fertilizers	SO_x F compounds	Convert sulfuric acid plant	10.0-15.0	4,000	
	P_2O_5 to water	High-efficiency scrubber	0.5	75	
		Manage gypsum pile	3.0-6.0	2,500	0.6

* per gram of pollutant

facture wallboard. The alternative is to recycle the acid, as practiced at one plant in the region, although reuse may adversely affect quality. Containment of sulfur dioxide emitted to atmosphere is also important. Wet scrubbing and electrostatic precipitation are possible techniques for reducing emissions from the calciner off-gas.

At nitrogenous fertilizer plants, the tail gas at the nitric acid plant is often a relatively concentrated source of NO_x. In many cases, the appropriate solution is to install selective catalytic reduction although evidence suggests this is less attractive than at power plants because the tail gas is dispersed. Dust from the prill tower of ammonium nitrate and urea plants is also a major potential emission problems; installation of wet scrubbers is often feasible and inexpensive compared to conversion to a granulation system. Reducing emissions of ammonia is likely to require significant process modifications and may thus be expensive; the case study at Grodno suggests that significant revamping should be needed at a cost of $20 million to reduce annual emissions by about 20 tons. Although there would be some offsetting performance improvements, such an investment is unlikely to be a priority. However, at the related caprolactam plant, replacement of the seals at a cost of $5 million could reduce emissions of VOCs by 300 tons each year.

Sulfuric acid plants have been considered as part of phosphatic fertilizer complexes although they may be present in many other installations. Emissions of SO_x and acid mist can be significant on older, single-conversion plants although most modern plants are double-conversion double-absorption. Conversion to double conversion is an expensive way of reducing these emissions, particularly in capital cost terms, although it may improve yield. A cheaper alternative would be to install a caustic scrubber.

At phosphoric acid and fertilizer plants, fluorine compounds are characteristic emissions. High-efficiency scrubber systems, typically using venturi

Table E.6 Competitive strengths and weaknesses of the inorganics sector

	Strengths	*Weaknesses*
Bulgaria	• Location on Black Sea • Relatively skilled but low-cost labor • Major exporter of soda ash	• Unavailability of indigenous raw material • Few indigenous hydrocarbons • Current constraints on investment
CSFR	• Technologically advanced • Technically skilled labor force	• Few indigenous sources of raw materials and energy • Small scale
Hungary	• Attractive to overseas investors	• Few indigenous sources of raw materials and energy • Small domestic market • Aging, inefficient capital stock
Poland	• Availability of coal, sulfur, and fluorspar • Competitive indigenous technologies • Technically skilled labor force • Established non-CEE export markets • Tight environmental controls provide incentive to improved efficiency • Large potential domestic market	• No indigenous hydrocarbons • Aging capital stock; but some new investment
Romania	• Indigenous hydrocarbons • Potential growth in domestic demand • Availability of raw materials • Access to Black Sea	• Poor, old technology; inadequate repair and maintenance • Low-capacity utilization
Former Soviet Union	• Availability of indigenous raw materials and energy (not all republics) • Potential domestic demand	• Inefficiency

Table E.7 Overall environmental expenditure estimates for the inorganics sector

Plant	*Technology*	*Capital cost ($ million)*
Mercury cell chlor-alkali	"Good practice"	5–85
	Titanium anodes	130–170
	Other/upgrades	45–450
Soda ash	Settling solids to brine	40–100
	Sale of lime solids	25–65
	Limebed management	15–40
Titanium dioxide	Neutralisation	10
	Scrubbing/ESP	5–10
N Fertilizers	SCR de-NO_x	90–175
	Prill scrubber	5–10
P Fertilizers	Convert sulfuric acid plant	320–480
	High-efficiency scrubber	15–30
	Manage gypsum pile	95–190
Total		800–1,815

scrubbers, are a way of reducing these environmentally sensitive emissions. Disposal of gypsum from the production of phosphoric acid is also a major problem throughout the world. Effective management of the gypsum pile to ensure that leachate is collected for treatment reduces the potential environmental damage.

Sector prospects

Table E.6 summarizes our assessment of the competitive strengths and weaknesses of the bulk inorganics sector in each of the CEE countries considered. It provides the basis for assessing the industry's medium- to long-term prospects.

Overall, the immediate prospects facing the bulk organics sector in the CEE countries are bleak compared to those of some of the more specialist products of the sector. This reflects the existence of many old, small plants which are uneconomic because of their dependence on limited indigenous raw materials and energy sources but despite the comparatively low costs of skilled labor and, in some countries, the strong technical base. It also reflects the substantial overcapacity which exists. The longer-term prospects are more encouraging but depend on there being significant investment and the recovery of the domestic markets. Nonetheless, substantial restructuring appears to be required.

Conclusions

Table E.7 shows the total estimated potential cost of installing each of the pollution abatement options for each product if we assume that all plants in the CEE countries require the expenditure. This provides an upper limit to expenditures for several reasons. We know that some of the plants are already operating to relatively high environmental standards and do not need to make all the changes indicated. For example, the Grodno case study illustrated a plant which had made many environmental investments which other comparable Russian plants have not.

We also know that there are some plants which do not give rise to acute environmental problems in their locality, in particular those affecting human health. In addition, the scale of overcapacity in the sector is such that it is difficult to justify expenditure on all the plants in the sector since some rationalization is required to bring demand and supply closer into line. In addition, the expenditures should not be taken to be a priority; a comparison is needed with other options for controlling emissions of the same pollutants in different sectors. This issue is considered further in the overview report.

Chimcomplex case study

Summary

Chimcomplex chlor-alkali plant has found a solution to its aging mercury cell plant by replacement with modern technology from Germany. There are several opportunities to reduce pollution at moderate cost by better design of valves and vents, and improved housekeeping. The cost is estimated at approximately $10 million. The wastewater treatment plant has big problems with overload and substantial corrosion. This needs urgent attention and it will cost in the order of $10 million to extend the existing facilities to cope with the pollutant load. However, much more reasonable expenditure of approximately $200,000 would enable the extent of the pollution problem to be accurately measured via a mobile laboratory. A detailed envi-

Table E.1.1 Principal production units

Installation	*Process*	*Licensor*	*Year of start-up*	*Capacity (thousand metric tons per annum)*
Diaphragm Electrolysis	NaCl diaphragm	USSR	1976	80
Caustic Evaporation	Evaporation	USSR	1976	75
Hydrochloric acid	Synthesis Cl_2/H_2	Romania	1976	65
Liquid chlorine	Liquefying chlorine	Romania and USSR	1976 1983	115
Sodium hypochlorite	Neutralization	Romania	1976	28
Mercury cell	Electrolysis of NaCl	De Nora Italy	1964	40
Calcium chloride	Chlorination of lime	Romania	1965	25
Ammonia chloride	Synthesis	Romania	1981	5
PVC	Emulsion process	USSR	1964	10
PVC	Suspension process	USSR	1964	24
Trichloroethylene	Reduction of carbon tetrachloride	Romania	1964–78	22
Tetrachloroethane	Acetylene	Romania	1974	17
Monochloroacetic acid	Hydrolysis of trichloroethylene	Germany	1967–80	14
LAB (Linear Alkyl Benzene)	Alkylation	Germany	1981	7.5

Table E.1.2 Local communities

Locality	*Direction from Chimcomplex*	*Distance*
Onesti - town	N-W	8 km
Viisoara - village	E	2.5 km
Stefan cel Mare - village	S-E	2 km
Gura-vaii - village	N-E	3.3 km
Power Station	N-W	1.5 km
River Trotus	E	0.8 km

ronmental audit of the site needs to be undertaken to establish the size of problems as very little data are available at present.

Background

The facility is split into three elements, chlor-alkali, chemicals, and pesticides. By far the largest volume production is in the chlor-alkali plant. The breakdown is as follows:

- Caustic soda
- Hydrochloric acid
- Chlorine
- Inorganic chlorides
- PVC (polyvinyl chloride)
- Organic solvents
- Linear alkyl benzene (LAB)
- Monochloracetic acid
- Herbicides.

Table E.1.3 Gaseous emissions in the workplace

Plant	*Pollutant*	*Legal maximum allowable concentration (mg/m^3)*	*Measured concentration (mg/m^3)*
Mercury cells electrolysis	chlorine	1	0.02-1.7
	mercury	0.15	0.005-0.17
Calcium chloride	chlorine	1	0.05-7
Hydrochloric acid	hydrochloric acid	5	0.3-1.37
Liquid chlorine	chlorine	1	0.04-0.06
	ammonia	30	9.86-51
Diaphragm cell	chlorine electrolysis	1	0.02-3.76
Ammonium chloride	hydrochloric acid	5	0.5-1.8
Alkylamine	ammonia	30	48-16.8
	isopropylamine	10	14-67
Alpha pyrolidene	ammonia	30	0.0-3.2
Insecticide	benzene	30	37-63
	phosphorus trichloride	5	6.2-13.3
Captan	sulfuric chloride	5	1.3-19.9
	mercaptan	1.5	1.2-7.2
	carbon disulfide	20	2.5-5.7
Phosphorus trichloride	hydrochloric acid	5	0.10-6
	phosphorus trichloride	5	3.6-43.6
Criptodin	mercury	0.01	0.25-0.98
Methylene chloride	chloroform	50	25-100
	hydrochloric acid	5	1.5-4.37
	ammonia	30	42.9-63.9
Acetic acid	phenol	10	2-18
	hydrochloric acid	5	0.87-2.37
Cooling system	ammonia	30	27-48

Table E.1. lists the major process lines within the complex, which differs from Carom SA in that nearly all the processes are batch type operations. These are less energy efficient than continuous operations and suffer from neglect on this site in that some plants are often exposed to open air. There are also a number of small-scale herbicide and fungicide plants producing very small quantities of products.

Location

Chimcomplex SA is situated adjacent to the Rafo SA refinery and forms part of the same complex with Carom SA. Local communities are shown in Table E.1.2.

The site has received no enforcement notices nor has it been closed down by regulatory authorities for environmental, health, or safety reasons.

Neither has the site been subjected to an environmental audit to accurately define the current environmental situation in terms of air, aqueous, and hazardous waste pollution.

Process review

The site had started with De Nora mercury plants for electrolysis of brine in 1964 along with emulsion and suspension PVC plant of Soviet design. The mercury plant is being replaced by mercury cells of German design (Uhde) which will be far more environmentally acceptable. The 1970s brought electrolysis and caustic plant along with chlorine liquification facilities with mainly Soviet technology. Development was completed in the early 1980s with smaller-scale chlorine derivatives and a LAB (Linear Alkylbenzene) plant with German technology.

The general appearance of the plant was of desolate, run-down facilities. The LAB plant in particular was in poor condition and operated only intermittently.

Sources of pollution and control measures

Atmospheric conditions

Atmospheric pollution from the plant is not measured either on or around the site. This needs to be remedied as a priority.

Table E.1.4 Abatement equipment used for gaseous emissions

Plant	*Gaseous pollutant*	*Equipment used*
Sodium chloride	chlorine	neutralization columns chimney
Calcium chloride	gases (CO, CO_2, CH_4)	stack chimney
Methyl pyrolidene	gases (CO, CO_2, CH_4)	chimney
Captan	residual gases CS_2, CCl_4,	chimney S_2Cl_2, $CSCl_4$
Alkylamine I	amine, CO, CO_2, CH_4	scrubber
Alkylamine II	amine ammonia	flaring of gas scrubber H_2, CO, CO_2
Herbicide	powder	bag filter scrubber chimney
PVC	powder	bag filter
Hydrochloric acid	HCl	scrubber washing column with water
Sodium chloride	chloride	neutralization with NaOH
Tetrachlorethane	acid gas	scrubber
Acetic acid	acid gas	scrubber

Table E.1.5 Sources and destinations of wastes

Type of waste	*Evacuation method*	*Destination*
Carbide sludge	pipeline	recycled to neutralize acid
Pyrolidene sludge	barrels/truck	dump
CaO sludge	truck	dump
Ash from mercury sludge incinerator	truck	dump
Sodium chloride sludge	truck	recycled
Sulfur monochloride	truck	dump
LAB sludge	truck	dump
Tetrachlorethane sludge	pipeline	neutralization
Ammonia from insecticide	bags/truck	dump
Aluminium chloride sludge	truck	dump
Spent catalysts	barrels	dump
Used bentonite	truck	dump
packaging	truck	dump
glass	truck	recovered
wood	truck	recovered

Workplace emissions

Table E.1.3 shows the gaseous emissions in the workplace at Chimcomplex although they are measured at infrequent intervals.

The major pollutants are chlorine and ammonia, which are the result of old equipment and inadequate venting. These problems can be substantially reduced by better engineering design and new valves, fittings, and venting at moderate cost, say $100,000.

A listing of process equipment used on gaseous emissions is shown in Table E.1.4.

Aqueous emissions

The neutralization station O19 is the cause of many problems for the treatment of inorganic wastes. The principal problem is the quantification of the flowrate and composition of wastes using correct instrumentation. The critical parameters such as pH and chlorine concentration also need to be recorded on a regular basis.

The consents are controlled by the regulatory authorities as follows—Accord 332/1977, Decret 414/1979 and STAS 4706/1988. The wastewater treatment facilities follow traditional steps for separation of wastes, neutralization, and biological treatment. The station O19 has a desolate look about it and there is evidence of severe corrosion—one of the aerators had corroded off the drive shaft and was at the bottom of an acid sludge pit. Deposited sludge needed to be dug out. The conclusion is that insufficient control is put into the neutralization step as well as inadequate aeration tank capacity and design basis. There is a concern that sludge resulting from this treatment is inadequately treated prior to dumping and will create a further problem at the dump site with groundwater contamination.

Solid wastes

The waste products generated at Chimcomplex SA are shown in Table E.1.5.

The acid-based sludges are being transported to dumping sites in the locality without adequate treat-

Table E.1.6 Chimcomplex environmental investment plan, 1992–95

		Lei
I	Wastewater treatment Chimcomplex objectives . Increase capacity final station such as new separation/neutralization equipment/homogenization/sand trap . Combustion of deposit of sludge resulting from neutralization and separation stage . Combustion of industrial and household garbage. . Increase capacity for deposit HCI and used salt solution.	5 billion
II	Extension of deposit of sludges from neutralization and separation.	75 million
III	Biological treatment of deposit containing non-activated b HCH benzene deposit and garbage disposal.	95 million
IV	Construction of hydrometric surveillance points (determine flowrate sent out from complex—automatic sampling) on the flows to river Trotus.	3 million
V	Instrumentation for automatic sampling of used wastewater.	2 million
VI	Supply laboratory for checking up air/water pollution, with instruments in order to analyze the samples (spectrohotometer, pH meter, COD, conducivity).	10 million
VII	Studies to evaluate status of various systems—sample of wastewater and proposal for revamping/updating samples.	4 million

ment. This problem needs to be quantified further upstream of the plant although thickening techniques such as centrifugation, filter processes, etc. would reduce the volume of waste arriving at the dump sites.

Summary of costs of pollution control

The Chimcomplex site has the following budget for investments in the environmental area as shown in Table E.1.6.

This expenditure is realistic and the initial priority should be put on quantifying the wastewater problems. Total cost is $11.6 million at 430 Lei per dollar.

The figures shown in the Table E.1.6 are Chimcomplex internal budget estimates and focus on the wastewater treatment plant 5 billion Lei ($11.6 million at the current exchange rate in January 1993). There is a lack of process control at the wastewater plant in terms of neutralization of acid sludges. There appears to be inadequate segregation of waste streams as well as lack of measurement of the basis parameters such as pH, flowrate, suspended solids, etc.

The current wastewater plant is being overloaded and extending the budget of 5 billion Lei is much needed, as it includes new mechanical aerators, settling tanks, as well as sludge compaction followed by incineration.

The general state of the process plant suffers from inadequate spare parts and maintenance. Good housekeeping in terms of better design, venting of process units, floating roof tanks, etc., would bring about considerable improvements. A sum of around $10 million would be adequate around the plants.

Some of the plant requires replacement both for reasons of natural lifetime and technology advances such as has been the case with the mercury cells being replaced by external credit arrangements.

A thorough audit of the combined facility including Rafo and the local power station is strongly recommended. It is very likely that considerable SO_2 emissions are being generated at the power station.

Azot Grodno case study

Summary

Azot Grodno is typical of the many nitrogenous fertilizer complexes in the former Soviet Union, although considered to be one of the better in environmental matters. It has four lines of ammonia and urea production, built over the last 30 years in phases, and also produces ammonium nitrate (AN) and caprolactam, although AN solids production will soon be stopped in favor of urea ammonium nitrate solutions, for environmental reasons. The oldest units of the factory are virtually all closed down now.

The Azot factory contains very large process units for ammonia and urea production, several of which are reasonably modern. The complex is at present profitable, and exports a small proportion of its production. However, the cost of natural gas feedstock and fuel is a significant proportion of manufacturing costs, and the impact of a higher natural gas cost is likely to be severe. It will be necessary to find energy savings by revamping the plants and improving instrumentation.

The plant is located two kilometers east of the city of Grodno, which has about 300,000 inhabitants. Grodno is in the northeastern corner of Belarus, close to the Polish and Lithuanian borders. The river Neman runs through the city and close to the plant, then onward through Lithuania (as the Namunas) to the Baltic Sea at Klaipeda.

The plant has had relatively enlightened environmental management, and is therefore better than other comparable facilities in other republics. For instance:

- The nitric acid plant is fitted with catalytic tail gas clean-up
- Urea plant prill tower emissions are low
- Wastewater treatment for nitrogenous and other wastes is effective.

The significant investments which are considered desirable include:

- Installation of continuous monitoring equipment on the plant and in the surrounding sanitary cordon
- Better treatment for soda ash wastes
- Reduction in aromatic hydrocarbon emissions through better instrumentation and spare parts
- Plant efficiency improvements to reduce fuel consumption and energy losses. The modifications, to the ammonia plant, would be costly.

The indicative cost is $60 million. Energy savings would recoup part of the cost.

Background

Azot Grodno was selected for study because it is typical of the many nitrogenous fertilizer factories built in the 1960s and 1970s to try to increase harvests in the FSU (Former Soviet Union) and its neighbors. It is also close to the border between Belarus, Poland, and Lithuania, and thus potentially a cross-border polluter.

The factory occupies a site measuring 3 kilometers x 1.5 kilometers, situated about 2 kilometers east of Grodno, which is 11 kilometers east of the Polish border. Prevailing winds are west-southwest. The factory is surrounded by a two kilometer-wide cordon sanitaire, from which all inhabitants have been relocated. Grodno has a number of other industries including glass but the fertilizer factory is the main industrial enterprise. The factory is regarded as the main polluter in the Grodno region.

Water is extracted and returned to the Neman River, which flows westward about 350 kilometers to reach the Baltic Sea at Klaipeda in Lithuania. There is a very large lagoon at the mouth of the river, formed by a sand bar, so any pollution could concentrate here causing, for example, algal bloom, although this has not been checked.

Plant review

The factory comprises four ammonia plants, four urea plants, a nitric acid plant, and an ammonium nitrate plant, and two caprolactam plants. It was built in four stages, in 1963, 1971, 1979, and early 1980s. Urea ammonium nitrate solutions production has recently been added.

Ammonia I was started up in 1964 with two lines of 90,000 metric tons each using the Montecatini high pressure process (now Ammonia Casale). As with all ammonia processes, carbon dioxide must be removed from the synthesis gas stream for rejection to the atmosphere or, as on this site, for use in urea production. CO_2 removal is by the Vetrocoke process, using hot potassium carbonate and arsenic. One line is now closed and the other is producing only hydrogen for caprolactam production. It is planned to stop this second line in 1992, when Monsanto separators become operational to recover H_2 from purge gas on ammonia lines III and IV.

Ammonia II also has two trains with a combined capacity of 250,000 to 260,000 metric tons per year. It was built in 1971 with Czechoslovak and Soviet technology. It is planned to convert this to produce methanol. It has MEA (monoethanolamine) CO_2 removal.

Ammonia III is a single train unit of 1,360 metric tons per day (450,000 metric tons per year capacity) built by Toyo Engineering Corporation (TEC) to Kellogg design, starting up in 1971. There were 30 such plants ordered by the USSR at the same time. The CO_2 removal process is Benfield—potassium carbonate activated with DEA (diethanolamine).

Ammonia IV is almost identical to Ammonia III, the only differences being in cooling design and reversion to MEA for CO_2 removal. It was built by Czechoslovak and Soviet teams.

Urea I is a partial recycle plant designed by Soviet specialists from Dzerzhinsk, now trading as Goskarbamidproject. The plant originally had a capacity of 70,000 metric tons per year but this was subsequently expanded to 94,000 metric tons per year. It was making crystal urea, but has now been converted to make solutions. Synthesis has been stopped.

Urea II is a Soviet version of Stamicarbon liquid recycle technology, with two lines, originally each of 90,000 metric tons per year capacity, but then expanded to 135,000 metric tons per year. Urea is prilled in a tower with a fluidized cooling bed and V-rake.

Urea III and IV were licensed from Stamicarbon, using CO_2 stripping technology, and built by Chemoproject/Chepos of Czechoslovakia. The design capacity was 330,000 metric tons per year, debottlenecked to 350,000 metric tons per year. All the urea is prilled in 88 m towers. The first unit was started up in 1979 and the second in 1986. About 15 such plants were built in the USSR.

The nitric acid plant first produced acid in 1963, based on imported ammonia. It uses Soviet technology and equipment, and has five lines to give a total of 290,000 metric tons per year of 55 percent acid. Unusual for the FSU it has been fitted with catalytic tail gas purification.

The ammonium nitrate plant uses off-gases from urea I and II to provide ammonia for its capacity of 240,000 to 250,000 metric tons per year of prilled ammonium nitrate. In 1991 the production of UAN was started, and pure AN reduced by 60 percent of production. From this year all AN will go to solutions and AN prilling will stop because of ecological pressure.

The urea ammonium nitrate (UAN) plant is made from bits of the other plants. The consumers will store the UAN at their collective farms.

The caprolactam section comprises two plants and incorporates hydroxylamine sulfate technology bought from BASF and sulfuric acid production. The incorporation of caprolactam into the fertilizer sector is common in Eastern Europe.

The first unit, Caprolactam I, was bought from Stamicarbon and started up in the 1960s. It had an original design capacity of 50,000 metric tons per year, but was expanded to 60,000 metric tons per year later. The process is hydrogenation of benzene to cyclohexane, which is oxidized to cyclohexanol/one.

Caprolactam II was a joint effort of GIAP, the Russian design institute for fertilizers, and the East Germans. It also has a capacity of 60,000 metric tons per year, and was started in 1978.

The hydroxylamine sulfate plant started up in 1978.

The sulfuric acid plant has a capacity of about 250,000 metric tons a year and uses double absorption technology. It burns liquid wastes from the caprolactam plants.

Site boilers are normally fired by gas; there is fuel oil back-up.

Time did not allow a full site inspection, but a drive-round tour and a foot inspection of the wastewater treatment plant was made. Plant housekeeping is reasonable, with few examples of waste laying around, although more could be done to tidy the plant surrounds. Relatively few steam leaks were seen, and no smells noticed. Dust from the ammonium nitrate prill tower was much worse than from the other towers, which had remarkably low levels of emissions. The nitric acid plant stacks were clear of any visible NO_x emissions.

Identification of environmental emissions

Overview

Environmental emissions are reported to the Grodno town environment department and also the Grodno regional authority. Due to lack of adequate measuring equipment the emissions have been calculated by an independent organization, using methodologies agreed with the Research Institute in Moscow and the Ministry of the Environment.

Table E.2.1 shows the types of emission characteristic of the type of process units at the Azot factory.

Data for 1992 were not available in detail as they were being compiled for the annual report to the authorities, but 1991 data was provided with commentary on the relationship between 1992 and 1991.

An environment tax is paid, with penalties for excess. For air pollution the tax is Rbls100 per metric ton for fourth-class pollution, rising to Rbls10,000 per metric ton for first-class pollution. Details of the pollution classes were not obtained. In water it is Rbls200 per 1,000 m^3. Excess of specified limits by up to 10 percent doubles the tax; excess by 100 percent multiplies the tax by five. At the beginning of 1993 the exchange rate in Minsk was Rbls510 per dollar, compared to Rbls 20 at the beginning of 1992. Taxes will be revised in line with inflation. The intended level of fines is a significant financial motivator. At present, however, the rapid inflation rate removes this incentive.

Air emissions

The main air pollutants are SO_2, NO_2, CO, NH_3, ammonium nitrate dust, urea dust, soda ash from burning caprolactam waste, and benzene. In 1991 reported emissions were 11,829 metric tons, exceeding the site limit of 9,600 metric tons, and fines were paid. In 1992 the emission was 10,177 metric tons. The reduction was due to reduced operation of caprolactam of 20 percent and reduced ammonium nitrate prilling. When AN prilling stops in February 1992 the emissions will be within acceptable limits. Also some changes in CO burning will reduce this pollutant. About 450 metric tons of CO are burnt, from caprolactam production, but 0.02 percent cannot be burnt. About 0.003 percent of the nitrogen in the air to burn the CO is converted to NO_x.

The breakdown of the air emissions for 1991 is shown in Table E.2.2. These are quoted as mass flows. In many cases, the flows are calculated by the company, not measured.

These figures include unspecified losses from leakage and spillage, and mostly occur in the caprolactam plants.

Water emissions

Azot has an extensive water treatment facility including rain water run-off. There are two treatment areas, one at the plant, and the second near the discharge to the river.

The volatile organic compounds emitted are shown in Table E.2.3.

At the plant all wastes are passed through three biological treatment stages, before being pumped to one of three cascades of three ponds before discharge to the Neman River. In 1992 26.1 million m^3 were extracted from the river, including 90,000 m^3 for potable

Table E.2.1 Principal emissions from Azot factory

Plant	*Atmospheric*	*Aqueous*	*Solid*
Ammonia	Fugitive ammonia CO and NO_x in furnace flue gas	Contaminated process condensate	Spent catalyst
Urea	Dust from prill towers, fugitive ammonia	Ammonia and urea in wastewater	
Nitric Acid	NO_x in stack gas	Contaminated process condensate	
Ammonia nitrate	Dust from prill tower	Contaminated process condensate	
Caprolactam	Fugitive hydrocarbons, CO	Aromatic hydrocarbons	Soda ash waste

Table E.2.2 Air emissions, 1991 *(metric tons)*

Solids (AN, urea, soda ash)	3,088	
Of which: soda ash	800	Increase to 850 in 1992
Gas and liquids	8,742	
Of which:		
SO_2	685	Reduced by 800 in 1992
CO	3,063	Reduced by 800 in 1992
NO_x	1,290	
VOC	1,020	
Other gaseous waste, mostly NH_3	2,684	Now reduced

Note: The volatile organic compounds emitted are shown in Table E.2.3.

water and fire service. The rest was for industrial use, including the power station, repair shops, etc. The river saw 25.7 million m^3 returned. The quality of this water is shown in Table E.2.4.

Table E.2.3 VOC emissions, 1991 *(metric tons)*

Benzene	41
Cyclohexane	654
Cyclohexanone	177
Cyclohexanol	96
Trichloroethane	38
Monoethanolamine	46

Table E.2.4 Effluent water after treatment *(mg per liter)*

BOD	4.1
Oil products	0.062
Suspended solids	12.8
Solids on evaporation	1 300
Ammonia	0.48
Nitrite	0.13
Nitrate	11.90
NO_x Total	12.5

There is a trace of arsenic, which will cease in February with the closure of the Number 1 ammonia plant.

Analytical facilities were observed to be very rudimentary by Western standards.

Solid waste

The main problem is the disposal of soda ash (sodium carbonate) contaminated with organic matter in the caprolactam process. This is being incinerated to burn the organics in three types of furnace—catalytic at 800°C, cyclones at 900°C, and a special GIAP design. The problem is that the soda ash sublimes and condenses at 510°C. Various grades of soda ash contain impurities, such as NaCl, and a multicomponent system is formed between 500°C and 600°C. The condensed material is like cotton cloth. The gases are scrubbed, evaporating 35 m^3 of water per metric ton of product. The final gas contains 130-140 grams per m^3 in the effluent. A solid waste comprising residual ash and build-up in the equipment is recovered and landfilled.

The other problem is the perennial surplus activated sludge, which is landfilled.

Environmental investment priorities

The factory has undertaken a number of measures to reduce pollution, and will shortly close the old units which cause most problems. This will contain most of the problems characteristic of nitrogenous fertilizer plants, such as dust from the worst of the prill towers. Nevertheless, there are still measures to be taken.

Table E.2.5 shows an approximate estimate of possible environmental investments.

Significant modifications to the ammonia plant would be costly, but the energy saving would partly pay for the expenditure. This would not be a priority for environmental reasons alone. An energy saving of around 10 percent is probably feasible, but a detailed design study would be required to define this. A similar reduction in NO_x would be achieved if it is technically feasible to retrofit low-NO_x burners.

On the caprolactam plant, adequate provision for carbon monoxide burning appears to be installed, although the quoted emissions are a little high. The major problem appears to be the emission of hydrocarbon from diffuse sources. This would require a detailed study to define exactly; Table E.2.5 shows an indication of the type of measures needed. Improve-

Table E.2.5 Indicative environmental expenditure

Modification	*Pollution reduced*	*Reduction tons/year*	*Investment cost ($ million)*
Ammonia	CO	200	
Improved plant efficiency	NO_x	100	60
Low-NO_x burners	NO_x	100	2
Caprolactam			
efficiency improvement program			
replace seals	VOC	200	10
vent gas recovery	VOC	300	5
soda ash incineration	VOC	100	15
	solid waste	250	8
Urea	NH_3 in wastewater, to air	20	20
Improved efficiency			
Site			
General instrumentation	all types	900	6
Automated continuous monitoring, mobile laboratory	identify any episodes		0.1
Water treatment			
Improved instrumentation and control	Aqueous pollutants	-	5
Sludge incineration			
	Solid waste	2,000[1]	2

[1] Estimated.

ments to the soda ash waste treatment are also advised. This is quite a specialist application.

Significant revamping would probably be needed to improve emissions of ammonia to air and contaminated condensates to water from the fertilizer plants. End-of-pipe treatment, such as vent scrubbers, are technically feasible but may distort the process water balance and heat requirement. A deep revamp of the type shown in Table E.2.5 would have economic benefits of improved performance. This type of work is likely to be difficult to justify on purely economic grounds.

Other general recommendations are also made for monitoring equipment and for upgrade of the site water treatment system.

It should be considered, when contemplating the modest list above, that the Azot factory at Grodno has made environmental investments which other comparable factories in Russia have not. These include, for instance, catalytic conversion of tail gases from nitric acid production, recycle of ammonia plant purge gas after clean-up, and good prill tower operation through good process control.

Kaustik case study

Summary

The production organization Kaustik is typical of many factories in the region producing caustic soda and chlorine and a variety of chlorine derivatives. Caustic soda is generally sold as such to aluminum and other factories. The location of the Kaustik plant is of particular sensitivity, lying at the lower reaches of the already polluted Volga River, and it was found that wastewater was in fact not returned to the river. The alternative, dilution within municipal effluents followed by evaporation also has drawbacks, particularly in allowing chlorinated hydrocarbons to possibly enter the food chain, but also in causing desertification because dried salt is blown around in the region of the evaporation ponds.

The factory also produces CFCs which will be phased out by the end of the century. The plant management do not see it as their problem to provide CFC replacements.

The site visit prompted the more general question of disposal of organic chlorine residues in the Volga basin and in the wider region.

In the view of the consultants, pollution control measures at the site should include:

- Installation of the existing equipment for a membrane cell for chlor-alkali production: this cannot be erected at present for lack of finance
- Management of the wastewater system to treat wastes as close to the source as possible
- Incineration of all chlorinated wastes, possible with an incinerator to serve the entire Volga basin.

Background

The region

The Volga River is the largest river in Europe, and runs though the industrial heartland of Russia into the Caspian Sea. There are many chemical and other factories on the banks of the Volga and its tributaries, including very large complexes at Gorky, Kazan, Nizhnekamsk, Saravat, and Volgograd. Pollution of the Volga is affecting the caviare industry which is important from Volgograd south to Astrakhan.

Volgograd is a city of 1 million people, and is the southern end of the industrialized zone of the river. Below Volgograd the river flows to the Caspian Sea. A canal at Volgograd connects the Volga to the Don, and hence to the Black Sea.

Volgograd is one of the 10 most polluted cities in Russia, and nearby Volzhkiy is another. Problems in the region include municipal wastes, sewage treatment, air pollution from an aluminum works in the north, and power generation using high sulfur fuel oils.

There is no prevailing wind, but north or south winds are more troublesome because they move pollution across the inhabited zone, which runs along the riverside for about 90 kilometers.

The factory

There are several chemical factories in Volgograd. The Kaustik plant produces chlorine and its derivatives, including VCM and PVC, CFCs, and pesticides. It is typical of chemical plants in Russia, being of average size and complexity.

The factory occupies a site 3 km x 4 km in the southern part of Volgograd, and is surrounded by a three-kilometer "cordon sanitaire." It employs 6,000 production workers and 1,200 social services employees, including cooks, housing, creche, and similar communal services.

The majority of the plants are housed in buildings, spaced well apart. The general condition of the site is untidy, and in places derelict.

Economic perspective

The Kaustik factory is suffering from a common problem in Central and Eastern Europe — how to dispose of the chlorine by-product from caustic soda production. It is eager to find new markets for chlorinated products to allow an increase in caustic soda production. At present the factory is barely profitable, and has no finance for environmental projects, not even to complete an existing project to replace the chlor-alkali units with a new, less polluting plant.

Plant review

The base process units are two chlor-alkali plants, one based on mercury cells, built in the mid-1960s, and the other, based on diaphragm technology from De Nora, which started up in 1984. Each has a capacity of around

100,000 metric tons per year of caustic soda and 90,000 metric tons per year of chlorine. Equipment for a 200,000 metric ton per year membrane plant has been received from Asahi but not installed due to lack of funds. Brine for the chlor-alkali plants is brought about eight kilometers from solution mines. Power is supplied by the Volgograd dam and an adjacent thermal power station which also supplies steam.

Ethylene and acetylene are co-produced in equal amounts by a furnace which cracks a pentane-hexane mixture. The technology is Japanese-Kureha. The ethylene and acetylene are used to produce vinyl chloride monomer in a balanced chlorination reactor. All other products of the reaction are used as fuels. The VCM is converted to PVC in a Russian suspension process. There is also production of polyvinylidene chloride film.

In another section, CFC 11 and 12 are produced via methyl chloride using Italian technology. It is planned to stop CFC production, but no date has been set. The plant will then be used for chloromethane production. Hydrogen fluoride for the manufacture of CFCs is purchased from Perm and transported by rail.

Herbicides and pesticides are produced. Phenazone is a herbicide, used to control weeds in beet fields. The active component is 4-amin-5-chloro-1-phenylpyridazon and chlorofos is an antifungal agent.

Plant utilities include an air separation unit. Some steam is supplied from an adjacent power station. The factory has extensive chlorine bottling facilities, and also exports liquid chlorine by rail.

The water treatment plant operated by PO Kaustik handles effluents from other plants.

Capacities of the process plants at the site are shown in Table E.3.1.

A tour of the site was made by car. The site is large, with substantial separation between buildings. In addition to the process facilities, the enterprise also owns a stock of rail cars, and has facilities to repair them.

The general condition of the site was poor. There were abandoned construction facilities, and old equipment laying about. Clearly, the general appearance and housekeeping could be improved.

Identification of emissions

Overview

Table E.3.2 indicates the principal emissions from the plants of PO Kaustik.

Environmental emissions in Russia are policed by the Ministry of Ecology and Natural Resources, through its officers at local level. The Ministry levies an Ecology Tax on producing and extraction industries, and levies fines on enterprises as multiples of the tax. It can also fine the General Director and other responsible employees for violations.

The Ministry conducts independent monitoring but lacks mobile test laboratories.

Air emissions

Data on air pollutants emitted by PO Kaustik in 1992 are presented in Table E.3.3. The data are quoted by

Table E.3.1 Plant capacities (*thousand metric tons per year*)

Chlorofos unit		**Caustic soda solidification**	
Chloral	22.62	Prilling	112
Dimethylphosphite	25.16	**CFCs 11 and 12**	
Phosphorus Trichloride	14.0	CFCs combined	30
Chlorofos (100 percent)	21.6	Hydrochloric acid off-gas	68.9
Methyl chloride	5.9	**Phenazon unit**	
Chlorine/caustic mercury cells		Phenazon (60 percent wettable powder)	2.85
Caustic soda (100 percent)	110.4	Phenyl hydrazine	2.617
Chlorine liquid	80.0	Dichloropyridazone	5.168
Hydrochloric acid	103.2	**Vinylidene chloride and copolymers**	
Sodium hypochlorite	36.0	Vinylidene chloride	15.0
Chlorine/caustic - diaphragm		Co-polymers with VCM	5.0
Caustic soda	100.00	**VCM and PVC**	
Chlorine liquid	99.0	VCM	71
		PVC resin (suspension)	63

the company as mass flows and are, in many cases, calculated.

These emissions are largely the result of leaks and process losses. Fines were paid only for VCM excesses, which are higher than usual Western standards but not the highest seen in Central and Eastern Europe.

No emissions were quoted from the phenazon and chlorofos units.

Aqueous effluents

PO Kaustik generates up to 40,000 m^3 of aqueous effluents daily, averaging 32,000 m^3. However, it also processes effluents from other sources, and handles 180,000 m^3 per day, with a capacity of 240,000 m^3 per day.

Both PO Kaustic and Khimprom are sending saline effluents contaminated with chloro-organic compounds to the treatment plant.

The industrial plants are varied, and include ship building, an iron works, a mustard factory, steel wire drawing, and other industries. Not all their wastes go directly to the treatment plant; some are found in the domestic sewage system.

Wastewater treatment

The effluents from the chemicals plants are passed through sand settling tanks and primary aeration, then to biological treatment and on to secondary settlers. The treated water is pumped to accumulator ponds in the area south of the plant, from which water could in principle be discharged into the Volga River. It is claimed that, in practice, it never is. Instead, it is pumped to evaporation ponds in the Steppe land about 80 kilometers south of the plant. These ponds cover 62 km^2, and evaporate the intake of 48 million m^3 every year. The salt concentration in the final (fifth) pond is 10 percent. Dry salt is blown around in the neighborhood of the plant.

It would appear that chlorinated organic wastes from the two chlor-alkali factories are being diluted with municipal waste and then concentrated by evaporation. There must be significant risk of these products entering the food chain, since the evaporating ponds would be popular with water birds, including perhaps those migrating south from the Urals.

The best approach to these problems is the segregation of effluents at their origin into:

Table E.3.2 Principal emissions

Plant	*Atmospheric*	*Aqueous*	*Solid*
Chlor-alkali (mercury)	Fugitive chlorine, hydrogen, oxygen	Salt, mercury	Mercury spillage
Chlor-alkali (diaphragm)	Fugitive chlorine, hydrogen, oxygen, mercury	Salt	
Ethylene/acetylene	CO, NO_x in flue gases	Carbon, hydrocarbons	
VCM	Fugitive VCM, CO, NO_x	Contaminated process condensate	
PVC	Fugitive VCM		PVC waste
CFCs	Fugitive HF, CFCs, aliphatic chlorides	HCl, chlorides	Spent catalyst

The other contributors of aqueous effluents are:

- Two residential regions of Volgograd with a combined population of 230,000 inhabitants
- A large oil refinery
- Another chlor-alkali factory
- A total of 32 varied factories.

The residential regions are Krasnomiensky region and the Svetlojansky region of Volgograd. It is planned to add the Kirov region.

The Volgograd oil refinery has some pretreatment facilities—probably oil/water separators.

The chlor-alkali factory of Khimprom is of similar size to PO Kaustik, and also produces CFCs and PVC, although the latter is based on carbide acetylene. It also makes long chain chloroparaffins, phenol-formaldehyde resins, phosphorus, dichlorfos, and carbafos.

Table E.3.3 Emissions of atmospheric pollutants, 1992 (*metric tons*)

Sulfuric acid (as H_2SO_4)	2.1
Ammonia	76.0
Hydrogen chloride	125.0
Hydrogen fluoride	1.5
Chlorine	30.0
Organic derivatives	120.6
Inorganic derivatives	69.0
Ethyl chloride	229.0
Methyl chloride	8.0
Aniline	6.0
Furfural	12.0
Caustic soda	14.0
Vinyl chloride monomer	33.0
Vinylidene chloride monomer	48.0
Mixed chlorine compounds	26.0
NO_x as NO_2	21.34
Carbon monoxide	128.0
Chlorofluorocarbons 11 and 12	197.0
Total	**1,146.51**

- Saline, to be recycled to the brine wells—already partially practiced
- Organic chlorine, to be concentrated and incinerated
- Other effluents, for normal treatment.

Special treatment for some of the waste from other local factories may be required.

The installation of a central incineration facility for the region should be considered.

Some organic wastes are being buried in drums in local "chocolate clay," so called because of its color.

Solid wastes

Table E.3.5 shows the solid waste products from PO Kaustik, which are dumped in a landfill site. There is no mention of recurring losses, which may be leaking into the soil around the plant.

The soil in the area is described as a non-permeable chocolate clay.

Measures to reduce pollution

There are several measures which would substantially reduce environmental pollution:

- A new membrane process chlor-alkali plant is awaiting erection. The equipment has already been delivered to the site, but there is no money for project completion. This plant would replace the existing mercury and diaphragm units, thus

Table E.3.4 Water characteristics, December 1992 (*mg/litre*)

	Volga parameter	*After secondary settlers*	*In 5th evaporation pond*
pH	7.98	7.7	8.0
Residue on evap	265	1,824	17,373
Suspended solids	8.4	46	10
Chlorides	36.7	656	9,254
Sulfates	55.8	244.2	868
Nitrogen, as NH_3, NO_2, NO_3	2.31	35.7	0.62
Phosphates	.21	4.37	2.25
BOD	0.5	35.3	9.74
Dichloroethane	-	0.015	-
VCM	-	0.0015	
Chloroform	-	0.006	0.0027
Trichloroethane	-	0.012	-
Carbon tetrachloride	-	0.0025	0.012
Dissolved oxygen	13.2	9.92	11.04

Table E.3.5 Solid wastes (*metric tons per year*)

Catalysts from CFC production	48
Silica gel from chlorine production	2
Silica gel from caustic soda prilling	2.4
Asbestos from diaphragm chlorine plant	1.8

eliminating mercury and asbestos pollution. It would also have low electricity consumption, thus improving the plant economics, and also reducing pollution at the power generation point.

- The practice of mixing water effluents before treatment causes several problems, and the evaporation of effluents in ponds causes salinification of surrounding land and allows chlorinated hydrocarbons to enter the food chain via the birds that use the ponds. Evaporation of these chlorinated products into the atmosphere also contributes to ozone depletion.

It is recommended that effluents be segregated at source:

- Saline effluents should be recycled to the brine wells, with only a modest blow-down to prevent impurity build-up.
- Chlorinated effluents should be incinerated, with possible one incinerator to serve the needs of the entire Volga basin, not necessarily at Volgograd.
- Industrial effluents should be treated as near to source as possible, preferably before leaving the factory.

Table E.3.6 sets out some costs and benefits for improvement programs. Although the measures are complementary, the total saving in pollution obviously cannot exceed the total emissions. It should be noted that the current inflation rates in Russia make any cost estimation extremely difficult.

Table E.3.6 Indicative environmental expenditure

Modification	*Pollution reduced*	*Reduction (tons/year)*	*Capital cost ($ million)*
Chlor-alkali plants			
- Replace existing plants with new membrane plant which is awaiting erection finance	Mercury Chlorine Lower electrical energy demand	20 50	25
Chlorofluorocarbon (CFC) plant			
- replace seals - reduce process losses	CFCs, chlorine, HF, methyl chloride, etc.	100 75	5 5
VCM/PVC plants			
- Improved efficiency	Chlorinated wastes	200	10
- Incineration of chlorinated liquid and vent gas wastes	Chlorinated compounds in aqueous and atmospheric discharges	300	10
Water treatment plant			
- Segregate wastes, recycle spent brine to well	Organic chlorine residues Sodium chloride	10 40,000	10 10
- Improved instrumentation and control	Fewer excursions		2 5
- Activated sludge incineration	Solid wastes		
General site improvement			
- More and better instrumentation and process control	All types reduced	15	6
- Automated continuous monitoring, mobile laboratory	Detect any episodes	5	3

Borsod Chem case study

Executive summary

This case study covers the inorganic chemical production aspects of the much wider operations of Borsod Chem on their site at Kazincbarcika. The objective is to illustrate the environmental and other problems that industries in the former centrally planned economies now face, either from their past activity or from the current economic changes. The site was chosen for its chlorine production facilities. Such production, however, is the precursor to a PVC and fine chlorinated chemicals manufacturing operation.

The plant is located alongside the national road E26 runningnorth west along the Sajo River valley about 25 km from the regional administrative center Miskolc (population 200,000). The area is generally one of heavy and medium industry without any nearby sites of particular ecological interest. There are a number of open cast and deep brown coal mines in the vicinity and a major central washery for coal.

Borsod Chem RT is the successor company to BVK, a Hungarian State PVC and chlorinated organics production enterprise. It is currently being prepared for privatization, either as a whole or as a series of packages.

A series of chlorine production technologies have been employed with the first and oldest unit having been shut down in 1974. Currently there are two units capable together of producing up to 150,000 tons of chlorine per year. This represents a substantial proportion of the Hungarian chlorine production capacity although the vast majority is used directly on site. Some intertrading with TVK (located some 40 km southeast of Miskolc) and other East European sources does occur but only on a small scale.

The plant is in very difficult financial circumstances and saddled with a large historic debt. Some operations are locally profitable and can sell into world markets (PVC into UK, Germany, and Switzerland). Production volumes are well down from previous highs with PVC doing the best at about 50 percent of capacity.

The site has a known history of pollution incidents (e.g., releases of chlorine to the atmosphere, poor disposal of metal-containing sludges, mercury discharges to the local river, etc.) and has probably the worst reputation of any manufacturing operation in the area and possibly the country. There has been within the last couple of years a parliamentary inquiry into the aspect of mercury pollution caused by this plant. The planning for remediation work recommended by the inquiry is now under way.

This case study examines only the aspects of the site associated with the production and storage of chlorine, i.e., salt dissolution, brine electrolysis, chlorine storage, and associated waste disposal and water treatment plants. The site does not generate its own power or steam but buys them from the adjacent power station. Steam, hot water, and electricity (35KV) are available. It also purchases demineralized water from the same source.

The principal polluting operation is the production of chlorine via electrolysis. The preparation of the brine solution is of little concern even though thousands of tons of NaCl are stored on site in the open. The electrolysis uses a mercury electrode cell. Over the years mercury losses have been a major problem: first, to the wastewater system and then on into the river; second, to the ground beneath the unit; and, third, to the air in the work space. The latter is claimed not to be a significant problem.

The company operates its own toxic waste disposal site (approved by the North Hungarian Pollution Inspectorate) adjacent to the plant behind the village of Berente. Discharges to air from the chlorine plant are generally compliant, although occasional accidental releases do occur. Discharges to surface waters are generally compliant although the current discharge still exceeds the permitted sodium chloride levels (for which the company is subject to environmental fines). Past discharges of mercury and ammonia were non-compliant.

Contaminated land issues are the biggest legacy by far that the operation of the chlor-alkali plant has left. About 400 tons of mercury have seeped into the ground beneath the electrolysis plant but investigation of this mercury contamination plant suggests a 50-year delay before the mercury enters the local water resource. Recent investigations of groundwater in the area (80 observation wells have been monitored) have shown no excess of heavy metals and minimal levels of chlorinated solvents.

However, mercury and other heavy metal contamination appears elsewhere. There are a number of waste sludge disposal areas that have been used (some legitimately and others not so). The principal one of these is the area adjacent to the ash ponds of Borsod power station, a number of the other sites have been identified, and the local Green Action group has been funded to try and identify further old sites.

There is some pressure to excavate some of the old waste disposal sites and remove the material to the planned new National Hazardous Waste Facility.

A survey of health statistics by Borsod County Public Health Institute reported excess cases of childhood asthma in the area of Kazincbarcika. These have been attributed to the plant operations. Emissions of fine organics, aniline, TDI and MDI, phosgene, chlorine, VCM, etc., could be the cause but nothing is conclusive. Local coal burning and the vicinity of the power plant could be implicated but the data is not clear.

The plant owners and occupiers face a huge potential liability cost for clean-up on and off site from the identified ground contamination and past metal sludge deposits. The government will have to carry such liabilities if the site is ever to be privatized.

Introduction

This case study under Element 1 of the Central and Eastern Europe study covers the inorganic chemical production aspects of the much wider operations of Borsod Chem on their site at Kazincbarcika. The objective is to illustrate the environmental and other problems that industry in the former centrally planned economies now face, either from their past activity or from the current economic changes. The site was chosen for its chlorine production facilities to be representative of the inorganic chemical sector, but in this case such production activity is only the precursor to a PVC and fine chlorinated chemicals manufacturing operation.

The company is located at Kazincbarcika in Borsod County, Hungary, and dominates the southern end of the town. It is some 25 km north of the regional administrative center of Miskolc.

Background

The plant is in very difficult financial circumstances and saddled with a large historic debt. Some operations are locally profitable and can sell into world markets (PVC into UK, Germany, and Switzerland). Production volumes are well down from previous highs with PVC doing the best at about 50 percent of capacity. It is claimed that other former Comecon countries are still heavily subsidizing power so it makes it difficult to be competitive with their equivalent industry. (Power in CZ is said to be a third of the cost of what Borsod Chem has to pay.)

The plant currently employs 4,300 people, down from 7,000 in 1988, and expects to drop to about 4,000 next year. Approximately 30 percent of the staff are female (the site is the dominant employer in the area). Occupational health statistics will be confused by this rapid shedding of employees. With such a high proportion of female staff in chemical production, teratogenic effects might be traceable through birth statistics.

History and geographical location

Borsod Chem RT is the successor company to BVK. It has been transformed and a number of elements of the previous operation have been separated off into joint venture companies (the phosgene operation and hopefully soon the Di-Isocyanate manufacturing plant). The Hungarian state currently owns 90 percent of the stock but some (10M ft) has been purchased by a Swiss entrepreneur. The company is based around the core business of PVC manufacture, but from it have sprung a multiplicity of fine organic manufacturing operations. The basic driving force for the site is now the production of chlorine by electrolysis. Formerly the site was for the production of inorganic nitrogen-based fertilizers, and this operation only finally closed a couple of years ago. It had begun operation in 1949 but ran down for a mixture of financial and technical reasons. The integrated PVC manufacturing operation began in 1963.

A series of chlorine production technologies have been employed with the first and oldest unit having been shut down in 1974. Currently there are two units capable together of producing up to 150,000 tons of chlorine per year. This represents a substantial proportion of the Hungarian chlorine production capacity although the vast majority is used directly on site. Some intertrading with TVK (located some 40 km southeast of Miskolc) and other East European sources does occur but only on a small scale.

The site has a known history of pollution incidents (e.g., releases of chlorine to the atmosphere, poor disposal of metal-containing sludges, mercury discharges to the local river, etc.) and has probably the worst reputation of any manufacturing operation in the area and possibly the country. There has been within the last couple of years a parliamentary inquiry into the aspect of mercury pollution caused by this plant. The planning for remediation work recommended by the inquiry is now under way.

The plant is located alongside the national road E26 running northwest along the Sajo River valley about 25 km from the regional administrative center Miskolc (population 200,000). The site extends alongside the southern side of the road for a distance of almost 5 km in a relatively narrow site between the road and the adjacent low hills. To the south is the town of Sajoszenpeter and bordering the plant to the north is Kazincbarcika (population about 30,000). The plant site almost completely surrounds a small village, Berente (population about 500), set half-way along the site against the hills.

The plant owns land behind Berente village where an old open caste coal mine has been turned into a company-operated controlled waste and sludge disposal site. The plant also owns (or has recently divested itself of) some of the facilities in the town (Kazincbarcika) and some of the blocks of flats and houses nearby. It has land and facilities on the north side of the road which include the water treatment plant and some old sludge tipping areas.

This water treatment plant and associated settling lagoons are alongside a tributary of the river Sajo known locally as R Bordva. These are adjacent to the coal stock yards of the Borsod thermal power station which lies across the road from the main part of the Borsod Chem site.

Natural environment and weather

The area is generally one of heavy and medium industry without any nearby sites of particular ecological interest. There are a number of open cast and deep brown coal mines in the vicinity and a major central washery for coal.

The river valley is wide at this point and the hills rise to the southwest of the site and are generally wooded.

The area is known for having only light winds and a high proportion of still days. The predominant wind flow is southeastward along the valley towards Sajoszenpeter and Miskolc. The air quality in the valley can be very poor in adverse weather conditions with the build-up of smoke and SO_2. This may be attributable to the use of brown coal in a number of domestic premises and possibly the emissions from the Borsod Power Station (550 MWth fired on brown coal). Where direct fired heat is required Borsod Chem utilizes gas so smoke and SO_2 pollution is unlikely to be ascribable to the plant's current operations. NO_2 may have been an air quality issue in the past (the ammonia fertilizer works) but is not now a major concern in Kazincbarcika. Volatile organic compounds released from the organic manufacturing areas of the site may be adding to the air quality problems.

There are reports that areas of woodland on the slopes of the nearby hills are suffering from dieback. This cannot be directly attributed to the site and the power station may be the chief cause (direct fumigation by SO_2). If the damage is attributable to the plant, the plant management believe that this would be as result of phosgene rather than chlorine leakage.

Transport infrastructure

The plant is well served by the local national road E26. This is rather constricted to the south where it runs through Sajoszenpeter but gives reasonable access to the national road E3 at Miskolc and hence to the rest of the national road network. The E26 going north provides access across the Czech border. Rail facilities supply the site with most transport needs and raw materials and finished products are largely shipped by rail. Linkages are available through to both the Eastern and Western European rail networks. Some materials are regularly shipped by rail to Germany and others to the CIS. The river is not navigable at this point and there are no canals.

Utilities

The site does not generate its own power or steam but buys them across the fence from the adjacent power station. Steam, hot water, and electricity (35KV) are available. It also purchases demineralized water from the same source.

Where direct process heating is required gas is used but most of the heat requirement in the "upstream" chlorine production part of the plant is met by steam. Water is abstracted from various surface water sources including the rivers Bordva and Sajo (no wells). This is used for cooling and other technological processes such as brine preparation. Potable water comes from the local municipal supply.

An ethylene import pipeline runs to the plant from another production enterprise, TVK (some 40 km south of Miskolc). The pipeline allows import of the ethylene raw material from TVK and other sources such as Ukraine.

Process plant

The plant described below relates mainly to the inorganic chemical aspects of the plant operations. Overall production operations include:

- salt dissolution
- brine electrolysis
- ethylene partial oxidation
- VCM production
- VCM polymerization
- PVC granulation
- phosgene production
- MDI and TDI manufacture
- chlorinated solvent production
- fine chlorinated chemicals
- ammonia production (now ceased)
- fertilizer production (now ceased)
- storage in bulk of chlorine, ammonia, etc.
- bottling of hydrogen in cylinders
- industrial gases (N_2O)—operated by Linde
- air separation unit for O_2 (now used for inert gas generation).

A number of trading operations also occur. Not all the production of chlorine and intermediates on site are used on site. Chlorine, phosgene, and ammonia are bought and sold as needed. There are restrictions on the volumes of the main hazardous chemicals stored in bulk on the site (e.g., max of 160 tons chlorine and 300 tons of ammonia—sold to freezing plants, etc.). The principal by-product sold off site is 34 percent sodium hydroxide.

This case study examines only the aspects of the site associated with the production and storage of chlorine, i.e., salt dissolution, brine electrolysis, chlorine storage, and associated waste disposal and water treatment plants.

The size of the production and storage capacities are given in Table E.4.1.

The principal polluting operation is the production of chlorine via electrolysis. The preparation of the brine solution is seen to be of little concern even though thousands of tons of NaCl are stored on site in the open. The electrolysis uses a mercury electrode cell (De Nora of Italy). Over the years mercury losses have been a major problem:

- To the wastewater system and then on into the river
- To the ground beneath the unit
- To the air in the work space.

The latter are claimed not to be a significant problem although any worker who shows early signs of poisoning (routine health monitoring is undertaken) is rotated to another job.

Wastewater treatment is now carried out before the water is discharged to the river. The wastewater treatment plant was upgraded about 10 years ago and because of the reduced production volumes is now able to meet most of the necessary water quality discharge standards.

The water treatment operations (pretreatment of incoming water supply, primary settlement of process effluent, and biological treatment) produce volumes of sludge. Those from the effluent processes contain mercury and require disposal. The company operates its own toxic waste disposal site (approved by the North Hungarian Pollution Inspectorate) adjacent to the plant behind the village of Berente. The facility is described as being lined with 3.5 m of clay. The company used to have a waste disposal site alongside the ash ponds of the power station but have now stopped operations there. Sludge volumes are considerably down on previous production quantities. Approximately 10–15 tons is deposited per day, five days per week. The volumes going to site are estimated by company staff and reported to the pollution control authorities.

Most water is recycled back through the process. Where it is of adequate quality it is put to the production of the brine. Recycled water goes through a cooling tower which is treated to stop bacterial build up.

The site management report that solid waste production is minimal. Filter cloths contaminated with mercury are the worst problem and go to their own waste disposal site. Most other arisings are recycled or sold. This is also the case for gaseous by-products e.g., hydrogen—bottled or used as a fuel in the phosgene plant, and liquid, e.g., caustic soda—evaporated to 34 percent and sold. Electrodes from the chlor-alkali plant are sent back to Italy for refurbishment.

Plant maintenance could not be checked during the visit but a number of substantial surveys associated with the past problems of the plant have been

Table E.4.1 Production facilities at Borsod Chem

Material/production unit	*Design Capacity t/a*	*Current Production t/a*	*Maximum Storage allowed for safety purposes*	*Storage design Capacity*
Chlorine (brine electrolysis)	150,000	100,000	160	4 x 100 m_3 bullets
Brine dissolution	?	?	unlimited	>10,000 tons
Ammonia	0 (now closed)	0	300	1,750 m_3 sphere
Caustic soda (34% solution)	?	?	2,000	2,000 tons

produced. A parliamentary commission involving inspection of the site by staff of the US EPA has been undertaken to ascertain how the large tonnage of mercury had been lost into the soil under the plant over the years. The site management saw their operation and maintenance practices as differing very little from those observed and reported for other plant of a similar nature. Currently the plant is subject to an extensive review by an external consultancy which may reveal more about maintenance practices. Parts of the chlorine plant are fitted with double valving arrangements to minimize loss of product during the breaking and making of pipe connections. However, in the past such precautions have from time to time failed as a number of substantial chlorine leakages have occurred (the last one 2–3 years ago involved the loss of approximately 300 kg of chlorine).

Legislative compliance

Compliance with the requirements of environmental legislation was not investigated per se. However, it appears that some of the past operations which now appear to have been doubtful in environmental terms were permitted by the then control authorities, either regional or local. The status and legality of some of the past toxic sludge disposal operations is in dispute as local authorities gave permission for some of the more dubious dumping operations. It is not clear if they had the authority or technical comprehension to licence such activity, however BVK exploited such sites until instructed by the Regional Inspectorate to cease.

Permission to utilize the waste disposal site alongside the power station ash ponds has been withdrawn and now all permitted solid waste (includes mercury contaminated filters) and sludges go to the authorized company-operated site behind Berente. Other solid toxic wastes coming from the chlorine and organic chemical sites are stored awaiting disposal in a future regional dedicated toxic waste disposal facility.

Discharges to air from the chlorine plant are generally compliant, although occasional accidental releases do occur.

Discharges to surface waters are generally compliant although the current discharge still exceeds the permitted sodium chloride levels (for which the company is subject to environmental fines). Past discharges of mercury and ammonia were non-compliant although current mercury discharge at $0.01 \mu g/m^3$ is well within permit condition.

Environmental problems

Natural environment

As mentioned previously, there are indications that some natural vegetation in the vicinity of the plant is dead or dying. Tree dieback is the most common phenomenon, indicating excessive levels of acid or other toxic gases. It is not clear if the local occurrences can be attributed to this plant.

Water

The plant has had a major impact on the aqueous environment in the past. It has been responsible for grossly polluting discharges of ammonia, mercury, other heavy metals, and brine. It is still exceeding its brine discharge consents.

Mercury from the effluent treatment plant was a major pollutant in the river. However BVK (as it was then) was not the only source of mercury in the river. The river was of very poor quality coming across the border with the Czech Republic being polluted by a large paper and pulp mill just across the border. The river was said to arrive with 10-15μg/liter of mercury and BVK added another 2μg/l. Some of the contamination may be arising more locally from the Ozd coal washing plant. The mercury discharges from the plant have now been reduced considerably. The previously discharged mercury has been apparently washed from the river sediments now as recent analysis has shown only low levels in water and in the sediment.

Currently all discharges (towns sewage works effluent, treated process water, and surface water run-off) all go through some final polishing lagoons (6 × 100,000 m_3). The last basin is considered clean and has wild fowl on it. Water quality at discharge is said to be of better quality than upstream intake.

Recent investigations of groundwater in the area (80 observation wells have been monitored) have shown no excess heavy metals and minimal levels of chlorinated solvents. The site management report that the investigation of the mercury contamination below the electrolysis plant suggests a 50-year delay before the mercury enters the local water resource.

Air

The routine discharges to air from the plant are fairly limited. Air drawn through any part of the mercury cell area of the plant is filtered before discharge. The PVC plant has routine releases of small quantities of VCM during autoclave turn-around. Other discharges come from the phosgene plant where CO is generated and from the rest of the plant during routine and emergency venting operations. What little direct fired process heat is required comes from gas and hydrogen combustion.

Accidental releases do occur but the largest release of chlorine in the last few years has been about 300 kg. The plant is fitted with double-block and bleed fittings to minimize routine and accidental losses. Similar equipment is fitted to the VCM area and rarely does it exceed the occupational level norms. There is an emergency flare system to depressurize the CO manufacturing process.

The fine organic part of the plant handles a lot more solvents and organic liquids than does the chlor-alkali plant and there is no doubt that fugitive organic emissions are noted in the town to the south (Sajoszenpeter).

Contaminated land

Contaminated land issues are the biggest legacy by far that the operation of the chlor-alkali plant has left. About 400 tons of mercury have seeped into the ground beneath the electrolysis plant. Even though the building has a supposed impervious floor, the losses have been quite large (apparently not too uncommon with this type of operation and technology). In the last year, there has been a parliamentary enquiry into the matter and things are still being investigated. Staff from the US EPA have been helping to scale the problem and assist in assessing remedial strategies.

However, mercury and other heavy metal contamination appear elsewhere. There are a number of waste sludge disposal areas that have been used (some legitimately and others not so). The principal one is the area adjacent to the ash ponds of Borsod Power Station. These are no longer in use and restoration work is in hand. The base of the site is likely to be in hydraulic continuity with the river and some degree of leaching is occurring.

A number of other sites have been identified and the local Green Action group has been funded to try and identify further old sites that were used illegally. The current waste disposal site is said to be of a good standard, being clay lined with leachate control. Other assistance in identifying possible environmental impacts is being purchased from a firm of Western European environmental consultants.

Human health

A survey of health statistics by Borsod County Public Health Institute reported excess cases of childhood asthma in the area of Kazincbarcika. These have been attributed to the plant operations. Emissions of fine organics, aniline, TDI and MDI, phosgene, chlorine, VCM, etc., could be the cause but nothing is conclusive. Local coal burning and the vicinity of the power plant could be implicated but the data is not clear.

In the plant there are recorded cases of dermatitic reaction and these seem to be the main health problem admitted. Regular screening of exposed workers picks out excess exposures to mercury and the worker is moved on to another task until levels reduce. There is said to be no record of excessive exposure to VCM and no recorded deaths attributable to this exposure. The plant is monitored as is the MDI and phosgene areas. All workers who come into contact with potential carcinogens are said to have regular health screening.

Summary of environmental performance

This plant has been a major means of one of the more mobile heavy metals entering the environment. The mercury will have dispersed through air, surface waters, and is now residing in a number of locations in sludge form or under the plant itself. These latter sites must be seen as potential long-term contamination sources in the local environment. However, local brown coal does have a recognized mercury content so in a number of cases environmental exposures will not be directly traceable to the plant.

The other aspects of the plant's polluting potential are generally relatively small apart from in disaster scenarios. The shipment and holding of large tonnages of chlorine, phosgene, and VCM is a recognized risk. Emergency planning procedures are in place but it is not at all clear if any of the main actions set out are intended to protect the environment per se.

The plant management are now aware of the prime importance of achieving good environmental standards and have some organization in place to improve matters. Substantial improvements have been achieved over the last 10 years and the downturn in production has allowed older equipment to be retired and existing treatment facilities to produce better results through reduced loading.

Identified priorities for remedial action

The principal actions to limit future environmental damage are already under way. Some 80 groundwater observation wells have been sunk in the area. The characterization of the subsoil areas contaminated by mercury under the plant is planned and some further investigation of groundwater movement is in hand. It is currently estimated that the mercury beneath the site will not impact usable water resources for about 50 years. Further work into identifying the exact siting and state of old toxic waste sites is planned or is in place.

There is some pressure to excavate some of the old waste disposal sites and remove the material to the planned new National Hazardous Waste Facility. This is only likely to be a cost-effective action once it has been conclusively demonstrated that the leachate from the old sites are mobile and likely to impact on a sensitive target.

There is a need to consider the adequacy of the protective surface underneath the electrolysis plant and to ensure that the place is sealed adequately (or otherwise protected to prevent more mercury entering the sub-soil).

In the medium term the electrolysis plant may be considered for closure (it is now approximately 15 years old) and a newer, cleaner technology process be employed in the production of chlorine. This is dependent on unit economics and if the site operations are deemed to need a chlorine production unit in the locality. Modern technologies do away with the use of a mercury electrode (membrane cells, etc.) but it is clear that monies for capital investment will be very difficult to obtain in the current financial circumstances.

The plant owners and occupiers face a huge potential liability cost for clean-up on and off site from the identified ground contamination and past metal sludge deposits. The government will have to carry such liabilities if the site is ever to be privatized.

Annex F

Organic Chemicals

Introduction

In this annex we summarize our analysis of the technical and economic aspects of environmental protection in the organic chemicals sector of the CEE countries. The sector is a large and diverse part of the chemicals sector but, for the purposes of this study, we have focused on the following heavy organic products and processes:

- Polyolefins such as high- and low-density polyethylene (HDPE and LDPE)
- Ethylene intermediates such as ethyl dichloride, vinyl chloride monomer, and polyvinyl chloride (EDC/VCM/PVC)
- Styrene and derivatives such as ethylbenzene, butadiene, styrene, and polystyrene
- Styrene rubbers—acrylonitrile butadiene styrene and styrene butadiene.

Below we summarize the key issues and conclusions arising from our analysis, which is based on desk-based research and three case studies. An annex provides details of the case study at the Carom SA styrene and rubber plant at Onesti in Romania and Annexes D and E contain details of the case studies of the PO Kaustik plant manufacturing VCM at Volgograd, Russia, and the Neftochim petrochemical complex near Burgas, Bulgaria, which are also relevant to the organic chemicals sector. A separate working paper provides an economic profile of the sector, an analysis of the pollution problems arising from each of the processes and products, and their possible solutions.

Structure of the industry

Table F.1 summarizes the current organic chemicals capacity in Central and Eastern Europe. Table F.2 pro-

Table F.1 Organic chemicals capacity

		Total	
		Number of plants	*Capacity*
Polyolefins	HDPE	11	1,100
	LDPE	26	1,700
Ethylene intermediates	EDC/VCM	19	1,900
	PVC	18	1,300
Styrene and derivatives	Ethylbenzene	20	1,400
	Styrene	17	1,000
	Polystyrene	20	500
Styrene rubbers	Butadiene	18	1,200
	ABS	6	100
	SBR	9	1,200

Source: Chem Systems.

vides details of the output of the key products in each of the countries where this is known.

Pollution problems in the sector

The pollution problems which typically arise during the manufacture of each of the products considered in this part of the study are summarized in Table F.3. Also shown are the various possible options for abating emissions of each of the pollutants.

These tables need to be interpreted with considerable caution as they mask significant differences in the circumstances at individual plants in the CEE countries. In particular, the pollution problems which arise from organics plants depend on many different factors, notably:

- The age of the plant and the technology employed
- How the plant is operated and maintained
- The level of output relative to capacity
- The pollution abatement equipment already installed (and operational).

Nevertheless, in the absence of detailed environmental audits at all the organics plants in the CEE countries, which is beyond the scope of the present study, we believe the information provides a useful basis for understanding the nature of the environmental problems arising from the organics sector and their possible solution.

Pollution control priorities within the sector

Table F.4 shows the estimated costs of different possible methods of pollution control in the organics sector for plants of average capacity in Central and Eastern Europe.

High- and low-density polyethylene plants are not large polluters except for ethylene losses to atmosphere at poorly maintained, outdated plants. Atmospheric emissions from LDPE and HDPE plants can be contained by tying the vents into combustion devices such as an incinerator.

EDC/VCM/PVC plants are very often integrated. Most of the adverse effects arise from the effects on health of VCM and chlorinated hydrocarbon pollutants. VCM is a carcinogen and therefore operator exposure needs to be carefully contained. The largest pollution reduction can be achieved through addition to, or improvements of, slurry stripping depending on the site-specific position, although this is potentially expensive ($5-10 million per plant). Incineration of chlorinated organic compounds is also very important although potentially expensive. Fugitive emissions of VCM are rarely measured at plants in CEE countries with the result that they are not always adequately controlled. However, better repair and maintenance of plant could allow cost-effective reductions in pollution. Measurements at plants in Romania and the Czech Republic suggest emission levels very considerably above target levels (100 mg per m^3).

Butadiene plants create air pollution problems due to leaks during storage. These can be reduced by improved venting control. Wastewater pollution control is necessary to remove any residual copper prior to discharge to the watercourse. Steam stripping of copper and ammonia is also good practice. Small

Table F.2 Organic chemical production, 1988 (*'000 tons*)

		Bulgaria	*CSFR*	*Hungary*	*Poland*
Polyolefins	HDPE	111	118	"	"
	LDPE		174	221	159
Ethylene intermediates	EDC/VCM/PVC	31	219	188	191
Styrene and derivatives	Ethylbenzene	..	..	..	
	Styrene	40	96	..	
	Polystyrene	28	74	0.5	35
Styrene rubbers	Butadiene	24[1]	91	..	82
	ABS	25[2]	77[2]	..	127
	SBR				

Source: EIU.
[1] 1987.
[2] Synthetic rubbers.

Table F.3 Typical pollution problems in the bulk organic sector

Product	*Process*	*Pollutant*	*Prevention Technology*
LDPE		Gaseous:	
		Ethylene fumes from storage	Improved venting
		Ethylene from extruder	Underwriter face cutter
		Unreacted hydrocarbons	Purge wastewater into a vented barrel extruder
		Solids:	
		Transition material and off-spec product	Preventive maintenance
		Aqueous:	
		Wastewater containing polymer dust and fumes	Effluent treatment
HDPE		Gaseous:	
		Hydrocarbons from storage and process vents	Incineration
		Flue gases: NO_x and CO	Scrubber
		Solids:	
		Organometallic compounds from spent catalyst	Use 'larger life' catalyst systems
		Transition material and off-spec materials	Equipment upgrade Preventive maintenance
EDC/VCM/PVC	Air	VCM - EDC vents	Incineration of process vents
		VCM - reactor	Purge system Reactor upgrade
		VCM - recovery	Sealing versus vents Carbon absorber
		VCM - downstream	Improved stripping
		VCM - fugitive	Purging equipment High-integrity equipment
		PVC dust	Fabric filters
	Water	EDC/VCM	Stripping
		Copper/other	Ion exchange
		COD	Physico-chemical plus biotreatment
	Solids/sludges	Chlorinated organics	High-temperature incineration
		PVC waste	Fabric filters
		Biosludge	Incineration
Butadiene	CAA process	Air:	
		Butadiene	Improved venting
		Ammonia	

(table continues on the following page)

Table F.3 Typical pollution problems in the bulk organic sector *(continued)*

Product	*Process*	*Pollutant*	*Prevention Technology*
Butadiene		Wastewater:	
		Ammonia	Steam stripper
		Copper compounds	
		Solid wastes:	
		Copper sludge	Caustic treatment
		Charcoal sludge	conversion
Ethylbenzene		Catalyst preparation	Flare/absorber
		Benzene, EB, PEB recover	Vent condensers Floating roof tanks
Styrene		Styrene (from benzene toluene)	Incinerator
		Styrene (storage losses)	Better housekeeping
Polystyrene		Styrene losses to air	Improved venting
		Styrene monomer	Stripping
		Polystyrene residue from separator	Better housekeeping
SBR	Dryer	Butadiene/styrene	New dryer Improved venting
		Latex waste losses	Flotation cells
		Dissolved salts	Change coagulent
		Styrene from vents	Incineration, HMCT
		Styrene from dryers	Incineration, HMCT
	Vacuum pump and dievent	Hydrocarbons	Incineration
		Polymer fumes, sludge off wastewater	Coagulation technology

amounts of copper sludge need to be converted by adding caustic soda to eliminate copper pollution.

Ethylbenzene plants often suffer storage losses of benzene. Revamps of old plants, including improved installation of vents and condensers, represents good practice. The installation of floating roof tanks can reduce benzene and ethylbenzene tank losses but may be expensive and inappropriate due to plant developments and/or additions in past years.

In styrene plants the major atmospheric pollutant is styrene emitted from the benzene toluene columns where the vapors need to be contained with better ductwork and eventually incinerated. Better housekeeping can bring substantial reduction in storage losses at more modest cost.

In polystyrene plants, styrene is emitted to air during storage and as a result of various operational malfunctions in old processes. Losses exceed those typically found at plants outside CEE countries. Plant revamps, including fitting new flanges, valves, and vents, could lead to substantial reductions from this source.

SBR plants have large atmospheric emissions of butadiene and styrene at the dryer end and throughout the plant. In Eastern Europe, these are typically the result of poor plant management, old plant, and inadequate safety procedures. The case study at Carom certainly confirms this. In many cases a new dryer is required with a suitable revamp of the plant. However, as an interim measure, improved venting and

Table F.4 Summary of costs of pollution control—organic materials

Plant	*Pollutant*	*Technology*	*Capital costs ($ million)*	*Reduction in pollution (metric tons/year)*	*Capital cost per unit of pollution abated ($ per kg)*
LDPE	Ethylene	Improved venting—incineration of hydrocarbons	0.6	1,400	0.5
	Ethylene	Extruder for unreacted ethylene	0.3	130	2.5
HDPE	Hyrdocarbons	Improved venting — incineration of hydrocarbons	5.0	1,500	3.0
	Spent catalyst	Reduction in catalyst wastage	1.0	5	200.0
EDC/VCM/PVC	VCM	VCM stripping column	5.0-10.0	1,000	10.0-30.0
	Chlorinated organics	Incineration of chlorinated residues	3.0-6.0	1,000-3,000	2.5-7.5
Butadiene (CAA process)	Butadiene Ammonia	Improved venting from storage	0.5	700	0.7
	Ammonia	Steam stripping	0.3	400	0.7
Ethylbenzene	Catalyst waste	Catalyst reduction	1.0	7	150.0
	Benzene	Condensation of air emissions	0.2	20	10.0
Styrene	Styrene	Losses from benzene toluene column incineration	5.0	180	33.0
Polystyrene	Styrene	Improved venting	0.1	220	0.7
	Polystyrene	PS residue to dump	minor	24	-
Styrene Butadiene Rubber (SBR)	Styrene	New dryer	5.0-10.0	1,500	2.8
	Styrene	Improved venting round dryer	1.0	1,300	0.4
	Latex	Latex waste reduction through flotation	2.0	260	7.9

inert gas blanketing around the plant would reduce the bulk of pollutants substantially. Again, the Carom case study identified the need for remedial measures in the dryer section of the SBR plant to reduce leakage of butadiene and styrene and improve the working environment. This would cost $0.2 million. In addition, treatment of the latex waste at a cost of $300,000 would avoid contamination of the mechanical equipment.

Sector prospects

Table F.5 summarizes our assessment of the strengths and weaknesses of the inorganics sector in each of the CEE countries.

Conclusions

Table F.6 shows the total estimated potential cost of installing each of the pollution abatement options for each product if we assume that all organics plants in the CEE countries require the expenditure.

These estimates represent an upper limit to expenditures for several reasons. We know that some of the plants, perhaps the minority, are already operating to relatively high environmental standards and do not need to incur all the costs envisaged by the calculations. We also know that there are others, for example those manufacturing VCM from acetylene, which are so old and inefficient that expenditure on pollution abatement measures is difficult to justify, particularly in industries which need to bring their capacity closer into line with potential demand. There are still others which are in locations where the environmental situation is not such as to justify immediate priority action to reduce emissions either because the problems are not severe or because they are not related to the emissions arising from the organics plants. In any event, the expenditure cannot be assumed to be a priority; a comparison is needed with other options for controlling emissions of the same pollutant in different sectors. This issue is considered further in the overview report.

Table F.5 Competitive strengths and weaknesses of organic chemicals sector

Country	*Strengths*	*Weaknesses*
Bulgaria	• Autonomy of large organizations • Location of Neftochim (Burgas) (well placed for exports) • Development planned for Burgas and Devnia plants • Already foreign investment	• Reliance on Russian crude and gas imports
Poland	• Plenty of proposed development (will it actually happen?) • Fairly good location of plants for transport	• Lack of investment in past • Reliance on Russian oil (?) (and some rubber imports)
Hungary	• Four large organizations; autonomous • Joint venture trading subsidiaries in West • Some good transport links • Planned development	• Dependence on Russian gas and oil and Ukrainian ethylene
Czech and Slovak Republics	• Lots of new development planned and under construction • Links with (East) Germany	• Autonomy expected by 1990 (slower than other countries) • For organics less production in future
Romania	• Good location for export-oriented plants • Long history of petrochemical production and supporting infrastructure (e.g., research institutions) • Developed technology—priority for investment	• Central control • Poor maintenance—but only limited expenditure needed • Declining indigenous hydrocarbons
Former Soviet Union		
Russia	• Shift of industry eastwards to Siberia—new investment planned • Major producer • Indigenous hydrocarbons	• Many plants operated beyond economic life • Limited dependence on Western technology
Ukraine	• Long tradition of petrochemical sector • Good logistics	• Reliance on indigenous coal and imported hydrocarbons
Belarus		• No indigenous hyrocarbons
Baltic States		• No indigenous hydrocarbons

Table F.6 Overall environmental expenditure estimates for the organic chemicals sector

Plant	*Technology*	*Capital Cost ($ million)*
LDPE	Improved venting	15
	Extruder for unreacted ethylene	10
HDPE	Incineration of hydrocarbons from vents	55
	Reduction in catalyst wastage	10
EDC/VCM/PVC	VCM stripping column	95-185
	Incineration of chlorinated residues	55-110
Butadiene	Improved venting from storage	10
	Steam stripping	5
Ethylbenzene	Catalyst reduction	20
	Condensation of air emissions	5
Styrene	Incineration of losses from benzene toluene column	85
Polystyrene	Improved venting PS residue to dump	5
Styrene Butadiene Rubber	New dryer	45-90
	Improved venting round dryer	10
	Later waste reduction through flotation	20
Total		445-635

Carom case study

Summary

The site visit indicated that significant pollution of the watercourse had taken place from the general complex, which comprises a refinery Ratfo SA, a caustic soda complex, Chimocomplex, as well as an integrated power station.

Pollution control measures at the site should include the following:

- Management of the wastewater system to treat wastes as close to the process source as possible
- Accurate monitoring of the air pollutants as well as aqueous effluent parameters such as pH, flowrate, and BOD (biological oxygen demand)
- Treatment at source of the latex waste which causes major problems at the wastewater treatment plant
- Good practice on venting in the SBR (styrene butadiene rubber) plant.

Carom SA forms part of the Onesti industrial complex in northeast Romania. The Carom SA site started production of styrenic rubbers and catalysts in the early 1960s and developed into polystyrene and ABS copolymer production in 1972. Foreign parties have licensed technology for these earlier plants. Several plants were added in the early 1980s using indigenous technology including MTBE (methyl tertiary butyl ether), latex, NBR (nimile butadiene rubber) rubber, and phenolic compounds.

Location

The Carom site is adjacent to the refinery Rafo SA, a local power plant which is independent from the complex and Chimcomplex SA. The wastewater from all the facilities is treated some eight kilometers to the east of the Chimcomplex site. The site is located on the banks of the river Trotus which flows northeast to southwest direction.

The most important urban complexes located near Carom SA are:

- The town of Onesti, located in the North-East, one kilometer away
- The commune Gura-Vaii, northeast, one kilometer away
- The village of Viisoara, east, eight kilometers away
- The commune Stefan cel Mare, three kilometers away.

Table F.1.1 shows the main process steps on the site.

The site is located on a sub-carpathic depression, Onesti belonging to the mio-pliocene geological zone. Depending on morphology, the subsoil water level is 0.5 to 7.0 m, the variation being related to rain and level variations of the river Trotus. Underground flow is west to east caused by the river drainage.

Process review

The plant consists of the following manufacturing processes: synthetic rubbers and plastics, phenol, bisphenol A, organic solvents, catalysts, gasoline, MTBE (methyl tertiary butyl ether), and aromatic hydrocarbons.

The plant housekeeping varies from reasonable to poor in some areas. The latex process, in particular, had considerable amounts of waste product lying around the process plant and out in the intermediate areas. Some of the plant is rather old and to that extent it is inevitable that some rust and corrosion should be evident.

The phenol plant of 38,500 metric tons per annum capacity uses oxidation of cumene with technology from Progil France and although 10 years old looks in a poor state of repair. Maintenance was being carried out during the visit. The polystyrene plant of the suspension type was licensed from Petrocarbon in the UK and is in a moderate state of repair. The SBR (styrene butadiene rubber) plant is cold emulsion polymerization of butadiene with alphamethylstyrene with Soviet technology which is outdated in Western terms.

Poor housekeeping and poor maintenance can be attributed to the previous regime. This can be improved by management training. The consequences of poor housekeeping lead to process wastes not being treated at source, creating further, more complex problems at the wastewater plant. For example, the latex waste, if not removed around the plant, will clog the mechanical equipment on the treatment plant. Poor maintenance can often be allied to the lack of adequate spare part stocks due to financial constraints on the former and present management. This in turn leads

Table F.1.1 Main processes

Installation	*Process*	*Licensor*	*Year of start-up*	*Capacity (thousand metric tons per annum)*
Phenol/Acetone	Air oxidation of cumene	Progil France	1982	38.5 phenol 23.1 acetone
Polystyrene	Suspension	Petrocarbon England	1972	15.3
ABS copolymer	Blending latex	AIS Italy	1972	
SBR (styrene butadiene rubber)	Cold emulsion polymerization of butadiene with styrene	Ghiprocaucic USSR and local	1963	15.3
NBR rubber	Cold emulsion Butadienes acrylonitrile	Petrodesign Romania	1983	8.3
Synthetic latex	Copolymerization of butadiene and styrene	Romania	1981	5.0
Bisphenol A	Condensation of phenol with acetone	Romania	1980	5.0
Butadiene	Distillation with acetonitrile	Romania	-	26.0
Catalysts	Various	Romania	1963	3.3
MTBE (methyl tertiary butyl ether)	Methanol isobutylene	Romania	1983	22.5
Gumisol	Dissolving rubber scraps	Own	1983	15.0

to increased downtime in the plant and reduced efficiency due to leakages of equipment and possible health and safety hazards.

The phenol plant was shut down for maintenance which was scheduled for 15 to 20 days and is operating at well below nameplate capacity (approximately 50 percent). The age of the plant again creates maintenance downtime averaging over 30 days per annum, which is excessive by Western norms. Even though the plant had been shut down for 15 days there was still a strong smell of phenol in the air. A level of 15 to 20 mg/liter of phenol is discharged to the wastewater treatment facilities, which is well above European norms.

The SBR (styrene butadiene rubber) plant had poor working conditions surrounding the plant, particularly with water on the floor and the smell of butadiene/styrene. The emissions around the dryers need to be monitored on a regular basis and the appropriate investment such as improved venting needs to be made. Fortunately the roof is very high (15 meters), which causes some natural circulation of air. The lack of regular monitoring of workplace emissions makes it difficult to quantify the extent of problems. First priority should be put on securing reliable monitoring equipment.

Sources of pollution and control measures

Atmospheric emissions

The Carom SA site recorded emissions are centered around gaseous workplace measurements and at the common wastewater treatment plant. There appear to be limited attempts to measure atmospheric pollution.

The question of SO_x and NO_x pollutants is particularly relevant bearing in mind that the integrated complex includes its own thermal power station from which gaseous emissions will need monitoring. This needs to be done both within the complex and at various points adjacent to the site to measure the potential impacts on the local communities.

Table F.1.2 shows the average concentration of pollutants at various points on the site.

The methods of measurement and general state of equipment needs modernizing. There is little or no measurement of standard substances regulated by laws such as SO_2, SO_3, CO, NO_x, organic hydrocarbons, mercury, etc. The air pollution measurements should include temperature, wind direction, and speed, humidity, etc. To this end several sampling stations need to be installed inside and outside the complex and monitored regularly.

Workplace emissions

The measurement of workplace concentrations of gaseous emissions is carried out two times a year – this is well below normal practice in Western Europe. Workplace emissions prior to 1989 were carried out by the Ministry of Health but since that time little has been seen of their inspectors. Concentrations measured in the workplace have been monitored albeit very infrequently and are shown in Table F.1.3, which shows actual workplace concentrations against legally enforced norms.

Table F.1.2 Atmospheric pollutants—gaseous

Product	*Range of concentration (mg/m^3)*
Hydrogen chloride	0 to 1.9
Ammonia	0 to 1.1
Phenol	0 to 0.93

The major pollutant is toxic butadiene, which is above the permissible level all around the latex and SBR (styrene butadiene rubber) plants. Improved venting around unit operations such as the dryer can reduce this problem. It is recommended that a more complete study on actual regular emissions of butadiene is conducted to quantify the problem. Recent local legislation has reduced the maximum allowable concentration from 200 mg/m^3 to 22 mg/m^3. This is still short of West German standards at 5 mg/m^3.

Aqueous emissions

Aqueous emissions from the Carom SA site form p of a common wastewater treatment plant some eight kilometers to the east of the overall complex. Thickened sludge of approximately 2 to 4 percent solids content is sent to lagoons without further thickening. Installation of sludge concentration equipment such as centrifuges, filter presses, or belt presses would reduce the sludge volume to be treated by a factor 5 to 10 times dependent on the method chosen and needs to be considered. Typical costs for such a system are $0.5 to $1.0 million for the necessary equipment.

This method is commonplace in Western Europe and as well as reducing the volume of biological, mechanical, and chemical sludges 5 to 10 times with consequent reduced pumping requirements and lagoon volumes. It would also deliver relatively clean water which may in some cases be recycled or dishcarged to the river with tertiary treatment. The concentrated sludge at approximately 15 to 30 percent dry solids by weight sludge can be further treated in a more manageable form for either fertilizers (dependent on the constituents, incinerated or sent for landfill).

The laboratories record the quality of the waters discharged to the river Trotus; Table F.1.4 illustrates typical figures achieved.

The plant was in a poor state of repair. The aeration plant was not being utilized properly as large amounts of sludge were deposited on the tank bottoms. This may be remedied by either increasing the aeration capacity (i.e., increasing size of aerators) or using different techniques for oxygen transfer. Considerable signs of rust and corrosion are present. There has recently been a sampling point installed to measure flowrate at the entrance to the works but otherwise the key parameters such as pH, suspended solids, and flow between unit operations are not monitored. There

Table F.1.3 Gaseous emissions in the workplace

Plant	*Eliminated noxious substances*	*Measured concentration in workplace (mg/m^3)*	*Legal maximum allowable concentration (mg/m^3)*
Isopropylbenzene	benzene	17.4	30
	ispropylbenzene	82	150
Oxidation isopropylbenzene	isopropoylbenzene	70.18	150
Cumene	phenol	8	10
	acetone	300	500
Phenol Acetone	phenol	7.6	10
	acetone	366	500
	isopropylbenzene	82	150
Bisphenol A	phenol	6.3	10
	toulene	128.8	200
Alphamethylstyrene (AMS)	isopropylbenzene	117.9	150
Styrene	styrene	43.2	150
Polystyrene	styrene	34.5	150
Catalysts	chrome	0.0136	0.05
		6.2	10
Dehydrogenation if isobutane	chrome	0.032	0.05
Butadiene	actonitrile	17.6	50
	butadiene	112.8	22
Polymerization	alfamethylstyrene (AMS)	232	350
	butadiene	75.7	22
Coagulation	butadiene	63	22
Butadiene compression	butadiene	63	22
Polymerization	butadiene	83.5	22
Latex	butadiene	66.2	22
	styrene	85.6	150
MTBE	butene	82	-
	methanol	71.2	100
BTX (Benzene toluene xylene)	benzene	20.8	30
	toluene	97.5	200
	xylene	199.8	300
	CS_2	13.9	20
Rubber recovery	toluene	75.1	200
	styrene	56.9	100
	rubber	10	10
Rubber	toluene	107.8	200
	styrene	97.4	100
	xylene	176.1	300
Coagulation	(AMS)	157.9	350
	butadiene	127.9	22
	carbon monoxide	31.7	30

is contamination by the synthetic rubber effluents—this may be alleviated by using flotation cells to separate the solid wastes after screening.

Solid wastes

The waste products generated at the Carom SA site are shown in Table F.1.5.

There are five waste dumps on the periphery of the site where wastes which are not recycled, such as spent catalysts, styrene, polystyrene and ABS mixtures, and various chemical and mechanical sludges, are deposited. The dumps have clay bases and boreholes have been drilled recently, however, the results have not been made available. There is considerable evidence of groundwater pollution from the adjacent Rafo SA refinery. The power station was set on fire recently due to hydrocarbon catching fire in the water fed to the power plant. There have also been instances of local household water being contaminated. A thorough environmental audit of the whole site including power stations and refinery is urgently required. The initial stage would be to assess the levels of pollution and could cost on the order of $30,000 with a further stage costing out the options at $100,000.

Summary costs of pollution control

The Carom SA site has been subject to environmental fines of 4 million lei ($10,000) to October 1992. This is a misleading figure as the local authority will increase this from a current 25 percent to 100 percent charge in the next two years.

The local environmental fines will increase fourfold and to that extent the pressure to commence investment in the environmental area will intensify.

Table F.1.6 gives the local view of a budget for the key environmental investments.

Chem Systems believes that in isolation these figures are broadly correct for the wastewater treatment plant. However the complex, and more particularly, the wastewater treatment complex, is integrated and the issues regarding the monitoring of environmental emissions need to be considered across the whole site including the power station complex with shared costs.

The environmental budget shown is focused around the common wastewater treatment plant and does not cover segregation of waste streams or, more importantly, the fact that Chimcomplex and Rafo share these facilities. The problems of the wastewater treatment plant could be handled by addressing upstream process improvements and better housekeeping.

Chem Systems believes that the rent, or preferably, the purchase of a mobile test laboratory to record gaseous, aqueous pollution parameters as well as water and soil sampling is a priority item. The mentioned process items deserve a higher rating than the Carom SA list as they will in some instances alleviate the downstream problems as well as create a safer and healthier working environment.

Other measures to control process emissions include:

- The SBR plant needs attention to the dryer section which is leaking styrene and butadiene. This could be improved by small investment in improved venting and control of styrene vapors; a budget of $200,000 would be adequate.
- The latex waste product should be treated at the process plant through either flotation or similar technique to take off the floating solids and send to dump rather than allowing them to contaminate mechanical equipment at the wastewater plant. A budget of $300,000 should be allowed for the equipment.
- Improved equipment integrity would alleviate hydrocarbon losses into the air and water.

A more fundamental problem is the lack of monitoring of atmospheric pollution and the relatively in-

Table F.1.4 Wastewater quality

	Entry to wastewater system	*Actual discharge*	*Legislation per Decree 4/4/1979*
pH	6.5 → 8	7 → 8	6.5 → 8.5
Phenol (mg/l)	0.15 → 0.45	0.13 → 1.4	
Copper (mg/l)	0.08 → 0.6	nil	
Chromium (mg/l)	1,500	nil	nil
Suspended solids (mg/l)	8,250	99 → 119	25
BOD (mgO_2/l)	300	41.5 → 55	15
Permanganate (mgO_2/l)	18.3 → 27.9	not measured	

Table F.1.5 Sources and destinations of wastes

Type of waste	*State*	*Qualitative data*	*Method of evacuation*	*Final destination*
Rubber scraps	solid	-	vehicle	Recycling in the plant for rubber processing
Polymer from the mechanical purification stage	viscous liquid	Polymer with 50–60% water	manually	Recycling in the plant for rubber processing
Expanded polystyrene	solid	-	vehicle	It is recycled to the manufacture of the blocks in a mixture with fresh beads
Spent catalysts	solid	Based on iron, chromium, aluminum silicon, magnesium	vehicle	Storage at waste dump
Mixtures of styrene, polystyrene, and ABS from the wastewater clarification	solid	Agglomerates with 25–30% water	containers	Storage at waste dump
Biological, chemical and mechanical sludges from purification	liquid	97–98% water	pumping	Storage at clarifier

frequent measurement of workplace emissions formerly done (pre-1989) by the local health ministry.

A possible solution would be the rent or purchase of suitable mobile pollution measurement facilities to monitor key atmospheric parameters such as NO_x, SO_x, CO_2, and also wastewater parameters such as pH, chlorine, and accurate flowrates of products.

Table F.1.6 Environmental investments

Item	*Cost (billion Lei)*
New aeration facilities	0.12
New mobile test laboratory for treatment of air pollution, metereological parameters, water/soil sampling	0.30
Test laboratory equipment	0.18
Revamping of fibre plant	0.17
Furnace modification	0.15
Sludge processing	0.10
Pretreatment of rubber and polystyrene waste	0.58
Total	**1.70** (*approximately $4 million*)

Annex G

Iron and Steel

Introduction

This annex summarizes the key issues and conclusions arising from our analysis of the economic and technical aspects of environmental protection in the iron and steel industry of Central and Eastern Europe. In particular, the work has attempted to assess the likely costs of reducing particulate emissions, which are known or believed to result in adverse environmental impacts. The analysis is based on desk research and two case studies of the iron and steel works at Kosice in the Slovak Republic and Krivoi Rog in Ukraine. Further details of these studies are provided in this annex. A separate working paper provides an economic profile of the sector and an analysis of the pollution problems arising in the sector and their possible remedies.

Structure of the industry

Table G.1 summarizes our understanding of the current structure of the iron and steel industry in the CEE countries. This structure is rapidly changing as the effects of economic reform work through. In particular, recent declines in demand have led to declines in output and, in some cases, to plant closures. However, it has proved difficult to ensure that we keep abreast of the rapidly changing situation.

The iron and steel industry in Central and Eastern Europe is characterized by pronounced structural weaknesses at both the technical and economic level.

From the technical point of view, the dominance of large-scale and mostly outdated equipment has resulted in low-quality output combined with a strong polluting impact on the environment. From the economic point of view, artificially low energy prices and the certainty of market outlets have traditionally encouraged the use of inefficient, energy-intensive techniques and the production of low-quality goods. In spite of rationalization efforts in some countries (e.g., Hungary), low productivity of capital and labor are still the dominant features of the sector.

Today, all Eastern European countries except Hungary and Czechoslovakia, including the former Soviet Union (in spite of its huge raw material reserves), are experiencing a foreign trade deficit in the iron and steel sector. Production processes in most small and medium-size Eastern European countries rely on imports of raw materials and energy. In the context of rising energy prices, falling demand, and unsecured raw material supplies, enterprises in the sector are extremely vulnerable.

It appears that the only profitable plants are small plants in Poland and some isolated "success stories" in the other countries, e.g., the East Slovak Iron and Steel Works at Kosice in Slovakia and the Danube Metallurgical Works in Hungary. However, as most of their comparative advantage is related to low labor costs and a favorable exchange rate, it is doubtful whether their profitability will be long lasting.

It is hoped that the inflow of Western capital and technology and the attractiveness of the region's geographical location as a gateway to Europe for Japanese and U.S. investors will help the industry to develop. Several Western investors have already shown interest in taking over Central and Eastern European plants or in undertaking joint venture agreements.

Table G.1 Summary of capacity and production in the iron and steel sector

Country	*Capacity ('000 tons)* Total crude steel	Percentage share: open hearth	*Production ('000 tons)* Crude steel	Continuous casting	Number of plants
Bulgaria	3,765	9	1,600[1]	450[2]	4
Czechoslovakia	19,000	40	11,700[1]	1,420[2]	7
- Czech Republic					6
- Slovak Republic					1
Hungary	4,315	43	1,950[1]	1,850[2]	4
Poland	22,600	45	14,800[1]	1,150[2]	16
Romania	21,560	21	7,115[1]	4,925[2]	8
Former Soviet Union	185,440	47	60,100[2]	27,623[2]	
- European Russia	31,500				11
- Ukraine	46,850				15
- Belarus	1,095	0			1
- Moldova	700				1
- Estonia					
- Latvia	600				1
- Lithuania					

[1] 1991.
[2] 1989.

Pollution problems in the iron and steel sector

The major pollution problems in the iron and steel sector relate to particulate emissions, particularly those containing fine iron oxide dust. The major sources of particulate emissions within an integrated iron and steel works are:

- Raw materials handling and storage
- Sinter plants
- Coke ovens
- Steel making.

Other sources, including blast furnaces, are less significant. Table G.2 summarizes information on the (untreated) levels of particulate emissions from the most important sources at a typical iron and steel works. The amounts of particulate emissions generated at the various processing steps depend upon a wide variety of factors. The quality of t he raw materials, the type and condition of production equipment, and the type of final product are among the most important. These factors vary greatly between plants and so the levels quoted in Table G.2 are only indicative of the likely magnitudes. Reports from the USSR in the early 1980s suggest that the amount of particulate generated by the changing and pushing operations during coking were as much as 3 g per ton of steel—much higher than the levels suggested as normal in Table G.2.

Emissions of gaseous pollutants cause fewer problems within iron and steel works. With the possible exception of the sintering operation in cases where high-sulfur iron ores are used (resulting in large emissions of sulfur dioxide), the total amount of sulfur and nitrogen oxides generated by iron- and steel-making operations is relatively small compared with that emitted from fossil fuel burning operations. Since coking coal must have a low sulfur content, and because some systems for treating coke oven gas remove sulfur compounds, the concentrations of sulfur oxides in many stack emissions are below the lower range of practicable treatment technologies. Consequently, at iron and steel plants, the boilers may represent the major sources of both sulfur oxide and nitrogen oxide emissions. These can be controlled, if desired, by combustion modification or the installation of flue gas treatment technology.

Although some hydrocarbon emissions come from fuel combustion, the major part comes from the volatilization of oils and greases from recycled materials such as scrap and burnings. Large amounts of carbon monoxide are presently recovered for their fuel value and this practice is believed to go on in Central and Eastern European plants.

Badly maintained coke ovens are potentially significant sources of carcinogenic materials. The waters from the by-product operations of coke ovens contain high levels of phenols, cyanides, tarry residues, and ammonia. Their treatment before release to the environment is essential.

The blast furnaces are major sources of solid waste in the form of slag. The disposal of blast furnace and steel-making slag is becoming a problem in Central and Eastern European countries as traditional markets for these materials have declined due to recession and economic restructuring. The slag heap from the Kosice works in Slovakia, for example, is approaching the limits of the available area. Still, problems associated with either solid waste or wastewater, which can be minimized by recycling, present only limited threats to public health compared with atmospheric emissions, provided adequate disposal practices are used.

Pollution control options in the iron and steel sector

Preventing airborne particulates from affecting the ambient air quality requires either that the particulate-generating operations are changed (or shut down) or that the particulates are removed from the air stream prior to discharge. The former option is often neither technically feasible nor prohibitively expensive. Consequently, the most commonly used approach is to remove the particulates from the air stream prior to discharge. The four major types of particulate removal equipment are:

- Cyclones
- Wet scrubbers
- Electrostatic precipitators
- Fabric filters.

Cyclones generally have such low efficiencies – particularly for small particles – that, in Western European works, they are only used either in combination with more efficient devices or where the particle size is large.

Most iron and steel works in Central and Eastern Europe have some form of basic particulate emission control. Much of the equipment is, however, either in a state of disrepair or is less sophisticated than devices installed in Western European works. Many of the constituent plants, such as the blast furnaces and BOS (Basic Oxygen Steel making), would require some modernization and improvement of the existing equipment, but not total replacement, in order to reach their design performance. Minor changes in operating and maintenance practices offer some improvement; but significant changes in emissions will only be possible with changes in technology and repairs to existing abatement equipment.

Table G.3 shows indicative costs of different possible methods of particulate emissions control in the iron and steel sector. The cost of pollution abatement equipment varies with the type of fume that has to be treated. The chemical composition, gas volumes, and the temperature of the fume will all influence the size of the unit and the materials used in its construction. The costs also assume that new pollution abatement equipment is required either because no facilities currently exist or because existing facilities are beyond repair. Where existing facilities can be repaired, this may be achieved at substantially lower costs. The costs presented in Table G.3 are, therefore, only for guidance.

The figures in Table G.3 highlight, in particular, the relatively high costs of controlling secondary emissions.

Raw materials handling and storage

The level of fugitive dust emissions caused by the storage and handling of raw materials (i.e., ore, coal, coke,

Table G.2 Typical particulate emissions in the iron and steel sector

Process/plant	*Indicative levels of untreated particulate emissions (kg per ton raw steel)*	*Comments*
Raw materials storage and handling	5-18	
Coke ovens:		Coke ovens are also sources of SO_2, NH_3, CO, and organics emissions
Secondary fume (charging, discharging, quenching, screening)	<1.8	
Primary fume	6	
Sinter plant:		Sinter plant is also a source of SO_2 emissions
Primary emissions	19 - 38	
Cooling and discharge	2 - 5	
Blast furnace:		Primary fume from blast furnaces is treated as part of normal operation—not for pollution control. Blast furnaces are also a major source of solid waste—slag.
Secondary fume	<0.4	
Desulfurization unit	0.1 - 0.2	
Decanning unit	0.6	
BOS steel plant:		Steel making also produces large quantities of slag as well as suspended solids and oils.
Secondary fume (slag, skimming, charging, tapping, casting)	0.3 - 0.4	
Primary fume	15 - 20	

limestone, sinter, etc.) is difficult to measure as well as to control.

Dust losses occur, if the material is not sufficiently moist, from open storage areas, unloading bays and from conveyor systems. Spillage from trucks may also be a problem due to overloading, the solution to which is apparent. It would be impractical to cover storage areas, which require several thousand square meters, but plants in Western Europe often use large water sprays to minimize the formation of wind-blown dust. The sprays sometimes contain a binding agent or detergent to ensure their effectiveness. If these can be avoided then, clearly, costs are reduced. Spraying may not be needed at all if the materials are sufficiently moist, such as if, for example, the specification of iron ore includes moisture content or the ore is brought over long distances in open trucks where it may be exposed to rain.

Unloading hoppers should be fitted with dust baffles, and either coupled to a dust extraction system or sprayed to help minimize dust emissions. Spray installations are cheaper and may be sufficient in many cases. Dust losses which occur at belt transfer points can also be minimized either by spraying or evacuation to a dust extraction system.

Most conveyor systems used in steelworks are covered by a roof and have side walls in order to minimize the generation of dust. But a combination of poor repair and maintenance coupled with occasional overloading of the equipment cause spillage and dust emissions. Improved operation and maintenance will prevent these problems.

The case study of the Kosice works in Slovakia found that there were no facilities for dust suppression either at the material stockpiles or on the conveyer junctions, although wind shields were being used to reduce the generation of dust. During the visit, burnt lime fines were being deposited on the iron ore beds. As a result, the area around the yard was being covered in dust, despite the moderate wind conditions prevailing at the time. This material would be better returned to the sinter plant blending yard, which is covered.

Table G.3 Summary of particulate emissions control costs—iron and steel

Process/plant	*Untreated emissions Kg/ton steel*	*Technology/technique*	*Removal efficiency (percentage)*	*Investment cost $/annual ton steel*	*Abatement cost $/annual ton emissions avoided*
Raw materials handling and storage	5-18	Bag filters and water sprays, as appropriate	50 - 90	0.5 - 2	30 - 800
Coke ovens:					
Charging	0.2	Replacement of upgrading of existing	50 - 80		
Carbonization	6	equipment—door/lid repairs, new	80 - 95		
Discharge	0.2	cleaning equipment, hoods, and fans.	50 - 80	10 - 60	1,500 - 10,000
Quenching	0 - 1.2	By-product plant repairs	60 - 80		
Screening	<0.1	Redesign quenching tower	60 - 90		
Sinter plant:					
Primary emissions	19 - 38	Replacement ESPs	90 - 98	6 - 8	200 - 400
Cooling and discharge	2 - 5	Replacement ESPs	70 - 95	2.5 - 4	500 - 2,000
Blast furnace:					
Secondary fume	<0.4	Replacement bag filter/ESP	90 - 96	3 - 5	8,000 - 13,000
Desulfurization unit	0.1 - 0.2	Replacement bag filter	80 - 90	1 - 1.8	6,000 - 20,000
Decanting unit	0.6	Scrubber and filter	95 - 98	1 - 3	2,000 - 5,000
BOS steel plant:					
Primary fume	15 - 20	Replacement scrubbers and ESPs	90 - 98	5 - 9	300 - 600
Secondary fume	0.3 - 0.4		50 - 70	3 - 6	10,000 - 40,000
Open hearth steel making	20 - 40	Repairs to existing ESPs and scrubbers	60 - 90		

Sinter plant

The sinter plant is generally equipped with two gas cleaning systems to control dust emissions: the primary cleaning system for the flue gas from the ignition hood on the sinter strand and the secondary cleaning system for dust generated in the materials handling areas and the screening and cooling operations.

Primary control of dust emissions is generally achieved using cyclones in combination with either electrostatic precipitators or high-energy scrubbers. Bag filters are not well suited to cleaning the moist high-temperature dust from the sinter stack. If scrubbing is used to remove particulates, the resulting wastes require treatment to prevent oil, and lead and zinc compounds from passing to the environment.

Suction hoods connected to high-efficiency cyclones or fabric filters are the most commonly used equipment for secondary dust control. The charging and discharging areas of the cooling section should be enclosed in order to maximize dust collection. Ideally, the conveyor system handling raw materials should be connected to the dust extraction system, but it may also be fitted with dust suppression spray systems if the plant layout is such that extending an existing extraction system is impractical. When the sinter is sufficiently moist, such precautions may not be required. The sinter strand itself is under suction so that there are normally only limited fugitive emissions from the main plant items. The ingress of cool air, however, from any leaks in the hoods will lower the operating temperature, which can cause corrosion problems. An important preventative emission control measure is, therefore, the maintenance of a near gas-tight seal around the strand.

Many plants located at iron and steel works in Central and Eastern Europe have no secondary dust control system and only have cyclones fitted to the main fume extraction system for primary dust control. Some works, such as Kosice, have started to fit electrostatic precipitators to the main exhaust and the cooling section.

SO_2 is not normally removed from the sinter stack gas. Alkaline scrubbing liquids can be used to remove both dust and SO_2. This is an expensive system and its potential for fouling, and the need to dispose of the wastewater, can lead to other environmental problems.

Catalytic methods to remove NO_x have been installed at a small number of plants in Western Europe, but these are costly both to install and operate.

Wastewater from sinter plants is not normally difficult to treat, requiring removal of suspended solids before recirculation. If lime is used in scrubbing, clarification and the removal of lime sludges present more difficult problems.

Blast furnaces

The practice of cleaning the blast furnace gas—for recovery as a fuel—means that under ordinary operating conditions negligible amounts of airborne pollutants are emitted through the gas stream. The only airborne pollutants generated as a result of blast furnace operations are, therefore, particulates, from the stock house, cast house, hot blast stoves, desulfurization unit, and slag crushing and screening.

Fugitive emissions from materials handling in the stock house can be controlled through the use of closed conveyors and evacuation through hoods at transfer points to bag filters.

The control of cast house emissions, which include significant quantities of fine iron oxide fume, requires either the use of covered troughs and extraction hoods over transfer points—the extracted gases being passed to a bag filter to capture particulates—or the collection of all the fume in the roof of the building. The former route improves working conditions, but the covers and ducting can interfere with operations and can be easily damaged. Good design and maintenance discipline are essential if this method is to be successful. The latter requires a larger fan to handle the large volumes of air with lower concentrations of particulate matter; nor will it improve the working environment, which will remain extremely dirty.

In integrated iron and steel plants it is standard practice to treat the hot metal to remove sulfur, which is an undesirable element in steel. The operation of the desulfurization unit is not difficult to handle in terms of emissions control. In Western European works, emissions from the desulfurization unit are generally controlled using a bag filter. Some plants in Central and Eastern European countries, however, use either cyclones or have no emission control at all.

Coking plants

The reduction of emissions from coking plants is problematic because the coking operations give rise to several separate sources of emission each of which is difficult to deal with. There is unlikely to be much scope for achieving emissions reduction at low cost from existing plants that have been badly operated and maintained.

Particulate matter in coke oven stacks is mainly soot arising from incomplete combustion. This may be the result of poor setting or maintenance of burners, but is more likely to result from gas leakage through the refractories into the combustion of the battery as a whole and the brickwork in particular. Adherence to a regular pushing/charging schedule and effective control of overheating can help minimize brickwork damage and, hence, gas leakage. Techniques such as silica welding, end-flue rebuilding, and through-wall repairs have been used successfully to maintain older batteries.

High emissions of SO_2 can be avoided by the use of low-sulfur coal. But if this is not possible, effective control requires the installation of either a coke oven gas desulfurization stage or flue gas desulfurization. Both options are expensive. Similarly, retrofitting low-NO_x burners to control NO_x emissions would require major modifications to existing coke ovens.

The maintenance of effective seals on oven doors, lids and caps on ascension pipes is essential to help minimize fugitive emissions. Ovens in Central and Eastern European countries have not, generally, been kept in good condition. At Kosice, for example, most of the oven doors leak and a constant haze emanates from the top of the ovens. Prolonged periods with major leaks from doors and lids can permanently damage the frames as well as the doors and lids themselves, rendering remedial measures extremely difficult and expensive.

The most common method used in Western European plants for controlling emissions during charging involves charging "on the main", i.e., with the oven connected to the gas collecting main. It is probably the least expensive option and can almost eliminate charging emissions. However, it increases the charging time and requires close attention by operators. The coke ovens at Kosice have car-mounted cyclones which appeared not to be working during the site visit.

The most effective system for controlling emissions during pushing involves a fume collecting hood mounted on the coke guide car and extending over the coke collector car connected to a fixed gas cleaning system. Such systems may be difficult and expensive to apply to older ovens, since it may require, for example, redesign of the coke guide and collector cars.

Control of particulate emissions from quenching operations may require redesign of the quenching tower; for example, to incorporate water sprays or baffles.

Steel making

Electrostatic precipitators and high-energy scrubbers are the two types of equipment used for controlling emissions from Basic Oxygen Furnaces. Scrubbers produce a slurry of iron oxide which must be treated prior to discharge.

The Open Hearth Steel making process, which is relatively widely used in CEE countries, is the worst source of atmospheric pollution at works that still use the process. Advances in productivity have been achieved by introducing oxygen blowing to reduce the meltdown line. This operation increases the generation of fume and is the main source of the heavy red dust that comes from open hearth plants. The long-term solution is, undoubtedly, to close the plants as part of a restructuring plan for the sector. In the short term, however, openings in the furnaces can be sealed more effectively and the existing particulate abatement equipment can be renovated. Many plants in Central and Eastern Europe have ESPs that do not work effectively because of inadequate operation and maintenance.

Most secondary fume from Basic Oxygen Furnaces comes from charging and tapping. Submicron particles of iron oxide are sometimes emitted during oxygen blowing. In order to control these emissions, the converter must be fitted with extraction hoods at the charging and tapping side of the bay directly above the sources of fume. Complete control is not generally possible and so additional hoods can also be fitted to the roof. The fume collected can be cleaned in either gab filters or electrostatic precipitators.

Industry prospects

Table G.4 summarizes our assessment of the strengths and weaknesses of the iron and steel sector.

A thorough restructuring of the iron and steel sector is regarded as a necessary condition if the in-

Table G.4 Competitive strengths and weaknesses of the iron and steel sector

Country	*Competitive* *Strengths*	*Competitive* *Weaknesses*	*Restructuring*	*Prospects*
Bulgaria		Inefficient, outdated, energy-intensive plants		Bleak
Czechoslovakia	Low wages costs and low exchange rate increase competitiveness on export markets	Very low capital and labor productivity; high dependence on low-quality raw materials imported from former Soviet Union combined with extremely high costs of switching to alternative supplies	Split of the large integrated steel works into smaller operating units; withdrawal of subsidies and closure of inefficient mines; promotion of energy-efficient and environmentally friendly production techniques	Medium/good
Hungary	Joint ventures with Austrian and German firms	Uncompetitive production costs; threat of cheaper imports combined, falling demand; lack of liquidity	Split of the large integrated steel works into smaller operating units; withdrawal of subsidies	Medium/good
Poland	Small plants still profitable; privatization already started	Outmoded and inefficient equipment; strong impact on environment/bad plant location (close to urban areas); high energy and raw materials consumption	Conversion of some companies into Joint Stock companies; restructuring projects identified based on Western direct participation and commercial cooperation	Medium
Romania		Heavy dependence on imported raw materials; low labor costs; low quality of output; small domestic market	Selection of few economic viable plants and closure of the others; seeking Western capital and technology	Bleak
Former Soviet Union	Huge raw materials reserves (iron ore)	Inefficient plants, high transport costs due to bad plant location, low-quality raw materials, industry traditionally biased towards heavy processes and products	Imported substitution through industrial upgrading and increased production of higher value added products; seeking Western partners for JV and	Medium/bleak

dustry is to survive following economic reform. Development plans in all Central and Eastern European countries envisage the closure of the inefficient plants and the rationalization and upgrading of those few plants which are regarded as commercially viable in future. The desire to maintain employment levels is, however, acting as a major constraint to implementation of these plans. The successful implementation will also depend on the willingness of Western countries to provide support through technology, funds, and even markets for Central and Eastern European products, primarily through trans-national agreements such as joint ventures and countertrading.

However, problems will arise from the point of view of unemployment as soon as restructuring becomes effective. The entire Central Eastern European area has traditionally been characterized by over-reliance on the iron and steel sector. This was due partly to strategic considerations—CMEA countries seeking self-sufficiency in the whole of the heavy industrial sector—and partly to social priorities, heavy industry being one of the main pillars of socialist job creation policy.

Today, Central and Eastern European countries and the former Soviet Union members face a major dilemma. On the one hand, the implementation of an effective restructuring plan heightens the pressure for the closure of most plants and will cause large rises in unemployment in areas heavily dependent on the steel industry. On the other hand, keeping inefficient, loss-making plants open is a considerable waste of resources and leads to an excess of low-quality supply to domestic and especially world markets and to major pollution problems.

Conclusion

Table G.5 shows the estimated potential capital cost of installing each of the pollution abatement options assuming that all plants in the CEE countries require the expenditure.

These estimates represent an upper limit to expenditure for several reasons. We know that some of the plants, perhaps the minority, are already operating to relatively high environmental standards and do not need to incur all the costs envisaged by the calculations. There will also be opportunities at some plants to repair existing equipment at a lower cost than is implied by Table G.5. We also know that there are others which are so old and inefficient that expenditure on pollution abatement measures is difficult to justify, particularly in an industry which needs to bring its capacity more closely into line with potential demand. There will be still other plants which are in locations where the environmental situation is not such as to justify immediate priority action to reduce emissions either because the problems are not severe or because they are not related to the emissions arising from the iron and steel sector. Furthermore, control of secondary emissions, which is relatively expensive,

Table G.5 Overall environmental expenditure estimates—iron and steel

Process/plant	*Capital cost ($ million)*
Raw materials handling and storage	50 - 200
Coke ovens:	
Primary and secondary fume	1,000 - 6,000
Sinter plant:	
Primary fume	600 - 800
Cooling and discharge	250 - 400
Blast furnace:	
Secondary fume	300 - 500
Desulfurization unit	100 - 200
Decanting unit	100 - 300
Basic oxygen steel making:	
Primary fume	300 - 600
Secondary fume	200 - 400
Open hearth steel making	20 - 100
Total	3,000 - 9,500

may be justified only with regard to mitigating threats to workers, health and not public health. In any event, the expenditure cannot be assumed to be a priority; a comparison is needed with other options for controlling emissions particulates in different sectors.

Kosice case study

Summary

Generally the steelworks requires a sustained maintenance effort to bring the operating equipment up to standard. The main exception is the sinter plant, which will require extensive modernization to improve product quality and reduce emissions to an acceptable level. The water treatment facilities are at present adequate but there may be a requirement to improve the quality of the discharge into the river in the future. The planning change in the operation, which will eliminate ingot casting and rolling, will reduce the works' energy requirements and the NO_x and SO_x emissions. When the slabbing mill closes, all the steel will be continuously cast. Energy saving of 1,570 MJ/t, yield improvements of up to 11 percent and an 8.0 g/t reduction in the emission of particulate matter will be possible.

The possibilities for the reduction of energy consumption and emissions from the works are considered to be as follows:

- Replace the exhaust gas boiler system at No. 1 steel plant with a suppressed combustion system and collect the CO-rich gases from No. 1 and No. 2 steel plants for use in the hot rolling mill and the power station; this will improve energy efficiency and collect fuel with the equivalent energy of 600 MJ/t
- Repair or replace the dry filtration system on No. 1 steel plant to eliminate the red oxide emission
- Modify the No. 3 and No. 4 sinter strands to improve the sinter quality and reduce the emission of SO_x and particulate matter by replacing the ignition hood system and fitting electrostatic precipitator (ESP)
- Conduct a detailed survey of the coke ovens to determine possible measures to reduce emission levels
- The power plant is currently undertaking an extensive modernization program which will help reduce the levels of emissions considerably; other projects being planned, such as the closing of the slabbing when the works achieves 100 percent continuous casting, will also help reduce the energy demand and hence the emissions levels
- Installing monitoring equipment to sample the flue gases from several processes for days at a time so that emission patterns can be determined for each process; this will be far cheaper than installing continuous monitoring for each of the flue stacks.

Works description

Vychodoslovenske Zeleziarne sp (East Slovak Iron & Steel Works), was established in 1960. The works is located some 12 kilometers from the town of Kosice and is serviced by a comprehensive bus and tram service to bring the workers to the plant. The prevailing wind is away from the town but there is a small village downwind of the plant which suffers from the fallout of particulate matter from the works.

The works comprises:

- Coke ovens—three batteries (annual capacity 2,550,000 tons)
- Sinter plant—4 strands (capacity 8,000-10,000 tons per day)
- Blast furnaces—three furnaces including two 1,719 m^3 furnaces
- Steel making plant—two melting shops comprising LD basic oxygen converters—No. 1 three 150 ton (annual capacity 3,000,000 tons), and No. 2 two 160 ton (1,800,000 tons)
- Refining plant—one 150 ton vacuum degassing unit
- Continuous casting machines—one 2 strand for slab (190 x 960 to 1,550 mm) (1,000,000 tons) with one 2-strand slab caster under construction
- Rolling mills:
  - one 1,150 mm universal slabbing
  - one wide hot strip—5-strand roughing and 6-strand finishing
  - two cold reduction comprising one 5-strand tandem for coil 9.18 to 1 mm thick and 1,050 mm wide and one 4-strand 1,700 mm for 0.4 to 2 mm x 1,500 mm
  - temper/skin pass
- Tube and pipe mills:
  - one spiral welding mill (60,000 tons)
  - one longitudinal welding mill (100,000 tons)
- Coil coating lines:
  - a ferrostan electrolytic tinning (160,000 tons)
  - five Dubnica hot-dip tinning.

The principal products are:

- Carbon steel—medium plates; heavy plates 1.8 to 10 mm thick, 700 to 1,500 mm wide; hot rolled uncoated sheet/coil; cold rolled uncoated sheet/coil (including high-tensile and deep-drawing, 9.18 to 2 mm thick, 650 to 1,500 mm wide); electro-galvanized sheet/coil; aluminized sheet/coil
- Electrolytic single-reduced tinplate and hot-dip tinplate
- Alloy steel product—electrical sheet/coil—non-oriented silicon.

Modernization and expansion plans

Recent investments have concentrated on automation of the hot and cold strip mills. A new twin strand continuous slab casting machine is being commissioned in No. 1 steel shop. This machine has been bought from Russia and will be commissioned at the end of 1993. A new coal injection facility is being constructed at the blast furnaces. This unit will be operational during 1993.

There are plans for the privatization of the company. The company has a co-operation agreement with Hoogovens of the Netherlands for the supply of know-how, management assistance, and advice on investment and pollution control.

Future developments

Introduction

Many of the future developments are aimed at establishing new markets for cold rolled products and coated steels. Hoogovens of Holland is entering into a joint venture with VZSP to produce "plastic" coated steels. They are also supplying the technology for bath agitation on the converters to improve productivity and quality.

The current maximum capacity of the works is between 4.2 and 4.4 million tons of liquid steel per year (mtpy). Owing to the current market situation they only produce 3.4 to 3.7 mtpy.

Investment programs in the recent past have concentrated on the automation of the rolling facilities. However, there are unsubstantiated claims of problems with the quality of the steel being produced for a major electrical motor manufacturer. It is alleged that the level of silicon in the steel supplied for the motors is often too high and causes damage to their presses. The thickness and shape is also said to be variable and the customer has resorted to buying wider material and using only the more consistent central portion of the strip. The customer still considers this exercise worthwhile as the price of this steel is much lower than higher-quality imported material.

The management's main concern regarding pollution control was the cost of the equipment and the source of finance for the projects already identified. The major projects are outlined below.

Iron making

There are three blast furnaces. No. 2 blast furnace has just completed a major refurbishment which included a cast house pollution control system. No. 3 furnace will undergo repair in 1996 and will be enlarged from 1,860 m^3 to 2,4002 m^3. As a result, No. 1 furnace will be closed in 1997 and production will be concentrated on the other two units. The introduction of coal injection, first on No. 2, will reduce the requirement for imported coke.

Agglomeration plant

There are four sinter strands, all of which are based on old technology. It is planned to close No. 1 and No. 2 strand and to concentrate production on No. 3 and No. 4 strands, which are currently being modified to include secondary fume extraction. The shortfall in sinter feed for the blast furnace will be supplied by imported pellet and concentrate.

Steel plant

Currently 40 percent of the steel produced is continuously cast. The remainder is cast as ingots and then rolled to slabs in the slabbing mill. When the new slab caster is commissioned in No. 1 steel plant during 1993 it will raise the proportion of steel continuously cast to 100 percent by 1994. This process development will improve material yield and substantially reduce the energy requirement of the works as certain facilities become redundant. Energy savings on the order of 1,570 MJ/ton of semi-finished product and a material yield increase from 86 percent to 95 percent can be achieved.

The replacement of ingot casting by continuous casting will have the following environmental benefits:

- By far the most significant saving in energy at the works will be achieved by the closure of the slabbing mill which will eliminate the energy required by the ingot soaking pits and the electricity for the heavy rolling mill. Total energy savings can be as high as 1,570 MJ/ton and SO_x and NO_x emissions can be reduced by 10 percent

- The ingot mould manufacturing facility will not be required and another market must be found for foundry products. There will be a reduction in energy requirements and particulate emissions at the works
- The ingot casting bays and mould repair facilities will close. Continuous casting will improve material yields significantly (11 percent) and reduce fume and particulate emissions by up to 8.0 grams/ton
- If the continuous casting technology is applied correctly, the full slab scarfing unit (slab surface removal with oxygen burning machines) will close and be replaced by selective hand treatment. This will reduce energy oxygen consumption by up to 10 tons/day and improve material yield by up to 0.25 percent.

A new iron desulfurization unit will be installed to improve steel quality. It is expected that EC environmental standards will be adopted in future, therefore, this unit would be fitted with a gab filter to remove the particulate matter as part of any standard supply package. The filter would remove some 45 kg of particulate during every treatment. A cyclone unit would cost less but would only remove around 25 kg of the largest particles during a treatment. Since this is a new process these are new emissions.

The oxygen converters will be fitted with bath agitation equipment to reduce process times and improve steel quality. The emission levels will not change significantly but the slag volumes will be reduced by about 50 kg/ton and material yield will increase by up to 2.0 percent. Also, there will be productivity gains in reducing the operating cycle times.

Rolling mills

The hot strip mill reheat furnace is being completely reconstructed. It will have a more efficient thermodynamic and gas flow profile and will have new refractories to improve the thermal efficiency. New low-NO_x burners will also be fitted by Italimpianti. Depending on the design, the NO_x emissions could be reduced by up to 50 percent.

The future market will require thinner gauge steel with zinc, aluminum, and plastic coating. New equipment for the production of this steel will be installed. The new process will generate new waste streams, zinc dross, chromate, and water. New plant will be provided with suitable pollution abatement equipment.

Observations at the works

The major problem areas at this works are plain to see from the main road to Kosice. These are:

- Coke oven batteries – yellow fume and haze
- Sinter plant exhaust stack – dirty plume
- No. 1 steel plant converter exhaust – thick red plume
- The power plant stack emissions – grey smoke.

The tour around the works confirmed that these were the main sources of atmospheric pollution. There is also a problem disposing of the slag being generated at the blast furnaces and the steel plant. The slag is dumped in the open within a designated area outside the works. Owing to current market conditions the stock is increasing in size and the man-made mountain is approaching the limits of the available site. If the recession in the Slovakian construction industry continues, then the disposal of this material will become a severe problem. However, a plan for a new road to Bratislava is expected to absorb large amounts of the stockpile.

The works appears to be in reasonable order but there were signs of lack of investment. The condition of many areas indicated that parts have been repaired and reconditioned where in the West they would have been replaced.

Raw materials stocking

The iron ore and coal are discharged from the rail wagons by a wagon tippler unit. There was little evidence of dust emissions from the plant as the surrounding area was quite clean.

The ore beds are stacked in the open and there are wind shields around the area to minimize the dust generated by wind whip. The reclaimed material is deposited onto an elevated conveyor which has wind shields along its length but no top cover. There are no facilities for dust suppression on the conveyor junction houses or on the material piles.

During the visit burnt lime fines were being deposited onto the iron ore beds. The wind conditions were moderate during the visit but the whole area around the yard was being covered in the white dust being lifted by wind whip. This is obviously a regular occurrence judging from the condition of the surrounding roads and buildings. This material would be better returned to the sinter plant blending yard, which is covered by a domed concrete roof.

There were barriers erected around some parts of the stock yards to control the movements of site traffic, but this restricted access did not seem to reduce the quantity of mud on the roads. Most of the main site roads were made of concrete but there were still many other unmade roads which made the problem worse. Constructing site roads of crushed slag would be an ideal use for some of the stockpiled waste accumulating along the works boundary.

Coke ovens

The coke ovens battery was located in the open at one end of the works. The oven showed all the signs of age and appeared to need some urgent repair. Most of the oven doors were leaking and there was a constant haze emanating from the top of the ovens.

The charging of coal is potentially the most significant source of atmospheric pollution (200 g/ton). The techniques available for charging are largely dependent on coal quality and the required coal blend. The charging operation of a furnace was observed during the visit and the whole battery was engulfed in a cloud of coal dust.

It is generally accepted that the oven should be connected to the gas collection main during charging to minimize the emissions. The extraction and treatment required for the gases generated during the charging process depend upon the design and size of the battery. It is essential that the top of the ovens and the seal around the top lids and the discharge chutes are maintained to the highest standards if emissions are to be minimized. The main problem with these designs is sealing of the moving car ducting to the fixed ducting for the filter unit. The coke ovens had car mounted cyclones which appeared not to be working or were totally ineffective.

The most effective way of collecting the discharge emission is to enclose the coke guide car and the collecting car in a collection hood. This would then be attached to an extraction system and cyclone separators or filters located on the ground. When the ovens are emptied there is also a significant discharge of coke dust, about 150 g/ton. If the coke is not completely carbonized, then there will also be some fume and black smoke.

The coke is cooled conventionally by quenching in a water tower. This process forms a large steam plume which drifts across the site. The alternative dry coke quenching system (DCQ) is expensive and is generally used only where there is a need for the heat recovered from the nitrogen quenching medium.

The sulfur released into the gas depends mainly upon the level of sulfur in the coal. They are planning to buy higher-quality coals in future which have less than 1.0 percent sulfur. Current coal quality has 2.0 percent sulfur.

At this works the ammonia is removed from the coke oven gas by scrubbing in steam stripping stills. The excess stripped liquor which is not recirculated is further treated to remove the remaining ammonia, phenolic, and thiocyanate compounds to make it suitable for discharge. This wastewater is sent to the municipal treatment works, some 10 kilometers away, where biological processes are available to clean the water. The ammonia is recovered as a saleable product by producing a concentrated ammonia liquor which is processed elsewhere by another company.

The application of reed bed technology to purify this liquor has not been considered and the management did not appear to have heard of it. This method provides an alternative treatment for the waste liquor where the roots of the reed transfer large quantities of oxygen to the surrounding earth to covert the chemicals in the liquor. This biological system has the ability to treat very high concentrations of ammonia liquors, even when passed directly from the stills.

A comprehensive study of the ovens would be required before any solution to these problems can be suggested. The refurbishment of a coke oven battery of this size would cost over $25 million.

Agglomeration

The four sinter strands are of an old design and would need extensive modifications to bring them up to modern pollution abatement standards.

The operating practice observed during the visit does not produce good sinter. The raw mix feeding system did not appear to lay down a protective hearth layer of medium-size sinter fines before laying the actual bed although this could not be confirmed. The design of the ignition hood is very old as it did not fully enclose the strand to prevent air ingress. The bed was not properly leveled before it entered the ignition hood. There were large depressions at various positions along the width and the whole bed thickness tapered off to one end of the strand. These weaknesses may be the main reason for closing two strands and modifying the other two so as to improve the material quality. Most of the problems of leveling and strand characteristics are related to poor maintenance.

All four strands have multiple cyclone cleaning systems on the ignition hoods and no other means of filtration. No. 3 and No. 4 strands, which have a long-term future, have had electrostatic precipitator (ESP) installed on the sinter breaker and screening areas. This will now be extended to the last section of the strand itself. The cooling sections on strands No. 1 and No. 2 have no filtration and only natural cooling. The ESP unit extends over part of this area on No. 3 and No. 4.

The emissions from the stacks are dirty, very moist, and have a yellow tinge. The solution to this problem is expensive. Besides the changes in operating practice required to improve the sinter quality the ignition system and the filtration system will have to be completely replaced. This would involve a new design of ignition hood and burner system, possibly with a recirculation waste gas system ($550,000 per strand). An effective waste gas cleaning system must be installed; an ESP unit, or, one of the new processes such as the Voest Alpine "Airfine" or the Lurgi Hybrid cleaning system. Cyclones are not very effective and not an option as the company has already embarked on a modernization program.

This works is one of only a few which recycles the waste gas slurry from the blast furnaces directly into the sinter plant on an automatic conveyor system. The heavy grit from the blast furnace dust catchers is dropped directly onto a conveyor which takes it back to the sinter feed stock yard. The finer slurry from the water treatment clarifiers is sent to a vacuum filter plant which reduces the water content to around 20 percent. The resulting cake is then sent to the sinter blending beds where it is mixed with the raw material for the mixing drum. In this way all the particulate from the blast furnace is recycled. The sinter blending beds are completely enclosed in a huge concrete building. There is little or no dust generated as it is protected from the weather.

Blast furnaces

The recently repaired No. 2 blast furnace has been fitted with several up-to-date technologies. All the furnaces have bell-less tops. One has a Paul Wurth design and two have a similar type designed by Kosice.

The main gas cleaning system is fairly conventional except that the fines and slurry generated are recycled to the sinter plant. No. 2 furnace now has an extraction system for the iron and slag runners which uses an electrostatic precipitator to remove the particulate matter. Emissions from this area are effectively controlled.

The slag is taken to a remote site where it is granulated and used in the construction industry as aggregate, cement additives, and as backfill material.

There is little wastewater discharged from this plant. The water extracted at the vacuum filtration plant is returned to the circuit and the clarifier water is also retained. The system blowdown is sent to the central treatment plant.

Steel plant

There are two completely separate basic oxygen steelmaking (BOS) shops at the works:

- No. 1 Plant—3 x 150 tons BOS vessels with dry gas cleaning
- No. 2 Plant—2 x 180 tons BOS vessels with wet gas cleaning.

Neither plant has any secondary fume cleaning equipment to collect the fugitive emissions generated during charging and tapping of the converter. The primary gas cleaning has to accept up to 20 kg/t of particulate and the secondary system over 280 g/t. When there is no secondary system, the dust is allowed to escape from the roof of the building. The heavier particles will be deposited inside the building on the plant equipment.

No. 1 shop has a full combustion exhaust system. The CO gas formed during the steel-making process is burned in the hood above the converter to generate steam. The heavy particulate is removed in the down leg of the ductwork and collected with the water from the spray tower. At this point the CO content of the gas is measured and, if it exceeds 4.0 percent, diverted directly to atmosphere through a small stack. At other times the gas enters a stabilizing tower where it is cooled and then passed through three ESP units. The cleaned gas is then discharged to atmosphere. However, during the visit, the stack was emitting a thick plume which deposited red dust around the surrounding area. The instrumentation in the steel plant control room showed the ESP units to be working but they are obviously ineffective and may need repair or replacement.

No. 2 shop uses a wet gas cleaning unit with a suppressed combustion system. In this design the ingress of air into the hood is minimized to retain the gas as CO. The gas is cooled by water and then discharged through a stack. During the visit this plume was clean. The CO gas collection is initiated during the blowing cycle by the operator who checks if the gas holder is full and switches over from the flare stack. This gas is used on burners in the hood boilers at No. 1 plant to maintain the system temperature when those converters are not in operation. The steam is then used as general heating steam in the works.

The dust collected in the ESP is presently mixed with the wet slurry from the No. 2 steel plant cleaning system and sent to a landfill site. Some of it is also stored as dust. There is a research project with an Austrian company to develop a briquetting process which will allow this dust to be returned to the furnace as scrap. There are several companies experimenting with similar processes but as yet no process has been fully developed.

The slurry cannot be returned to the sinter plant as it has a relatively high zinc content which upsets the operation of the blast furnace. Returning the briquetted dust or dried slurry to the BOS vessel does not affect the operation of the process. During the steelmaking process the zinc is given off as a vapor and condenses in the gas cleaning plant. If the dust or slurry is continually recycled the percentage of zinc gradually rises until it becomes a commercial proposition to extracted it from the dust. This process is still under development.

Water treatment

All plants treat their own process water and recycle as much as possible. The blowdown from these processes and all the wastewater from the works is sent via an integrated collection network to a central treatment plant located some 6 kilometers outside the plant. The plant processes some 1,200 liters/second and returns some 500 liters per second to the works.

The exception is the coke oven wastewater which is sent to the municipal treatment plant near Kosice where they use biological processes to clean the water before it is discharged.

Most of the oil in the water from the mill is removed at the plant but the residue oil is removed from the water at the central treatment plant and reclaimed for burning in plant boilers. The water is passed through settling ponds where the sediment is removed and taken to a landfill site. This disposal site has only a limited capacity left and some other solution will have to be found within the next few years. The water then passes through sand filters and pH control before being returned to the works or discharged into the local stream.

Power plant

The highest levels of dust emissions come from the power plant. There is now a program of work under way which will reduce these over the next three to four years.

The SO_x and H_2S levels are to be reduced by burning a higher-quality coal which has only a 1.0 percent sulfur content and desulfurizing the coke oven gas. The coal used now has over 2.0 percent sulfur. The law will require H_2S levels to be restricted to 500 mg/Nm^3; they are currently around 6,000 mg/Nm^3 in the gas received from the coke plant. There are no laws proposed yet to limit NO_x emissions so there is no program included to reduce them.

The power plant produces 95 percent of the heating steam requirements and supplies district heating to a nearby village; Kosice is too far away to use this steam. It produces 60 percent of the electrical power requirement with 6 x 150 mw generators. Each boiler produces 215 tons/hour of steam. Eighty percent of the fuel is anthracite coal and the remainder is a mixture of CO and blast furnace gas.

There are presently six coal-fired boilers. No. 1 will close in the near future and a new No. 7 will be built using fluidized bed technology. No. 2 plant will be converted to burn a mixture of gases. No. 6 plant has a new electrostatic precipitator but the other units, No. 3, No. 4, and No. 5, will be fitted with two bag filters each under a rolling three-year development program.

Pollution monitoring

There are no monitors fitted to the discharge stack on any of the process plants. Emission levels for SO_x are calculated from the input materials. Random samples are extracted from stacks once or twice a year to supply information to the authorities. These measurements are restricted to SO_x, NO_x, and CO. The authorities are not present during the sampling process.

The main source of pollution information comes from four stations located outside the works. These collect dust samples which are analyzed by wet chemical methods. One of the units is an automatic sampling device which is located at a site exposed to the maximum level of emissions from the works. The water below ground is also analyzed at each site.

Opportunities for environmental improvement

The works is equipped with modern plant, much of which was supplied by Russian companies. The sinter plant is in very bad condition and will require extensive refurbishment. The most significant sources of pollution in the steel works have been identified above. The priorities for investment in pollution control are listed below:

- Replacement of the boiler system at No. 1 steel plant with a suppressed combustion system and collection of the gases from No. 1 and No. 2 for use in the hot rolling mill and the power station. This is a more efficient use of the fuel since raising steam by burning this gas in the hood is inefficient. The energy content of the CO gas produced during the process is equivalent to over 600 MJ/ton of liquid steel. The modification to the plant would cost around $15 million. There is little effect on the levels of emissions
- Repair or replacement of the dry filtration system on No. 1 steel plant to eliminate the red plume
- Modification of the No. 3 and No. 4 sinter strands to improve the sinter quality and reduce the emission of SO_x and particulate matter by replacing the ignition system and fitting electrostatic precipitator (ESP). A new ignition hood and control system would cost $500,000–$700,000 per strand; a new ESP unit would cost between $2.0 and $7.0 per ton of annual production
- Conduct of a detailed survey of the coke ovens to determine the possible measures required to reduce emission levels. An overhaul of the battery would cost over $25 million but selective repairs and replacement could cost between $5.0 and $7.0 per ton of steel
- Monitoring equipment should be provided to sample the flue gases from several processes for periods of days at a time so that emission patterns can be determined for each process. This will be far cheaper than installing continuous monitoring for each of the flue stacks.

The environmental impact of the rolling mills and the casting plants is less significant and their emission levels should be addressed when these plants are updated and replaced.

The power plant is currently undertaking an extensive modernization which will help reduce the levels of emissions considerably. Other projects being planned, such as the closing of the slabbing mill when the works achieves 100 percent continuous casting, will also help reduce the energy demand and hence the emissions levels.

Krivoi Rog case study

Summary

The visit to the Krivoi Rog works was less than satisfactory.

Access to the plant was restricted and only the most modern blast furnace and one of the water treatment plants were visited during the four-day trip. Environmental data were limited and actual production figures for each plant were not divulged but the plant is believed to be operating at about 50 percent of its rated capacity.

The impression gained from the overview of the works is that the major sources of pollution are those which would be expected from a plant of this design and level of technology. The sinter plant and blast furnaces have the highest levels of atmospheric emissions. The largest source of particulate emissions was the ore processing plant which is situated near the iron ore mines outside the works boundary. The dust from this area drifted over the works.

The coke ovens belong to another company and were not seen.

The whole of the steel production is cast into ingots. The most effective way to reduce energy consumption and to reduce emissions would be to replace the ingot casting facilities and the ingot rolling mills and install continuous casting. This would also be the most expensive option.

This option would increase the material yield from about 83.5 percent to 94–96 percent, which represents a 12 percent increase in good steel make. This would amount to more than 1.3 million tons each year. The electrical and gas energy consumption would also be reduced.

The only plans for improvement in the emission levels at the works were stated to be secondary fume extraction for the blast furnaces.

Works description

The Lenin Iron and Steel Works is located in the city of Krivoi Rog, some 200 km northeast of Odessa and 400 km southeast of Kiev, the capital of Ukraine.

The annual capacity of the plant is as follows:

- Pig iron: 9,202,300 tons
- Raw steel: 12,848,000 tons
- Finished steel: 8,672,100 tons.

The sinter plant has an annual capacity of 4,125,500 tons.

There are nine blast furnaces at the site:

- One 1,719 m^3
- One 1,361 m^3
- One 1,386 m^3
- One 1,719 m^3
- Three 2,000 m^3
- One 2,700 m^3
- One 5,000 m^3.

The steel making plant comprises:

- Basic oxygen converters:
  - four at 50 tons (1,993,100 tons)
  - six at 130 tons (4,125,500 tons)
- Electric arc furnaces:
  - two 25 ton
  - one 6 ton
  - one 3 ton
- Open hearth furnaces:
  - four 650 ton open hearth furnaces
  - two tandem open hearths, one with two 306-ton hearths and one with two 270 ton.

The combined capacity is 4,451,700 tons.

The rolling mills at the site are:

- Three blooming mills:
  - one (1,250 mm) (300 x 300 mm product) (3,847,900 tons)
  - one 2-high reversing (1,300 mm) (300 x 300 mm–350 x 450 mm product) (6,116,700 tons)
  - one (1,150 mm) (160 x 160 mm - 400 x 400 mm product) (3,084,100 tons)
- Two billet mills:
  - one CLS (730/500 mm) with eight 2-high stands (252,500 tons)
  - one 22-stand 2-high CLS (900/700/500 mm) (661,100 tons)
- Six 23-stand 2-high horizontal light section/bar mills:
  - No. 1 (499,600 tons)
  - No. 2 (610,900 tons)
  - No. 3 250 mm (573,000 tons)
  - No. 4 (939,100 tons)
  - No. 5 250 mm (1,126,800 tons)
  - No. 6 (825,600 tons)

- Three continuous wire rod mills:
  - No. 1 31-stand 2-high (672,900 tons)
  - No. 2 34-stand 2-high (680,200 tons)
  - No. 3 34-stand 2-high (725,200 tons)
- One 15-stand 300 mm continuous hot strip and hoop mill (1,598,000 tons).

The carbon steel products manufactured at Krivoi Rog are: slabs, blooms, billets, wire rod, round bars, square bars, flats, hexagons, light angles, hot rolled uncoated hoop and strip, uncoated skelp (tube strip), and bright wire.

The alloy steel products manufactured are blooms, billets, wire rod, round bars, square bars, flats, hexagons, light angles, hot rolled hoop and strip, and wire.

Meetings were held away from the works at the insistence of Ministry representatives. Access to the works was limited to a short visit to one of the blast furnaces, the most modern, and a wastewater treatment plant. This plant was a recirculation pump house for the slurry ponds and contained mainly redundant filtration equipment. The sinter plant and the steel plant could only be viewed from a distance. Only one representative from the Krivoi Rog Steel Works was present during the visit.

Background

The works is currently producing about 55 percent of its 12.0 million ton design capacity, 8.0 million tons/year (mtpy) of iron and 6.5 mtpy of steel. This is one of the largest steel works in the world and produces long products, with some strip steel, through the ingot casting route.

There is a large ore beneficiation plant nearby which prepares the local iron ore for use in the works and for export. This is the largest source of airborne dust in the area.

The steel works site includes two water settlement ponds for the precipitation of iron dust from the blast furnace and steel plant cooling systems. These ponds cover an area of 40 hectares and 23 hectares.

Pollution monitoring

The works has an environmental department which measures emissions from over one hundred sources several times a year. Measurements are taken more frequently if there has been an accident in a particular area. These points of measurement were not identified. The methods used for analysis were described as "ancient," but the main method is basically extractive sampling with analysis by wet chemical methods.

The coke ovens belong to another company but the water from the plant is treated at the steel works. It was stated that over 3,000 samples of coke oven waste are taken each year. If the ammonia exceeds the allowed limit then all other elements are measured. These are:

- Suspended solids
- Oil
- Phenol
- Ammonia
- Radon (trace)
- Cyanates (trade)
- Nitrates
- Sulfates
- Hardness
- pH.

The pH is maintained at 6.7–8.0 for the cooling water and the temperature is kept below 40° C to prevent algae growth.

In general none of the blowdown water is recycled as the salts content is too high and causes problems with the plant operations. There are proposals for developing a desalination plant with the Moscow Institute and Wärmer of Germany to overcome this problem. There are also plans to develop a biological treatment plant in cooperation with the Kiev Institute.

Works' emission levels

During the visit to the water treatment plant it was possible to have an overview of the whole works. The coke ovens were some distance away from the works and were out of sight. The largest source of emissions was the ore beneficiation plant which sends vast clouds of dust into the atmosphere. It was not possible to visit this plant. There is obvious scope at this plant to introduce dust suppression systems that effectively damp down the material at transfer points and within the process plant. The cost of such a system would range between \$0.5/ton and \$2.0/ton depending on the area of the complex and the equipment used in the processing.

Table G.1.1 gives the average chemical analysis of the wastewater stream for 1992. Table G.1.2 gives the airborne emissions for 1992, 1991, and 1990. It can be seen from Table G.1.2 that the data show a decrease in atmospheric pollution since 1990. This may be due solely to the large reduction in steel production. No other explanation for the reduction was suggested by those present. The accurate production data were not available so the emissions from each plant cannot be calculated as kg/ton with any accuracy.

Figures G.1 and G.2 show the airborne emissions from selected plants for 1992. These figures are based on the actual weight of collected matter multiplied by an assumed collection efficiency. There are no direct measurements taken. The SO_x, NO_x and H_2S figures are calculated from the input materials and the assumed efficiencies of combustion. The reliability of these data is questionable.

Figure G.1 presents two graphs which illustrate the dust and carbon monoxide emissions from the works. The results follow the expected pattern for a works operating the technology used at Krivoi Rog. The sinter plant is the dirtiest plant followed by the No. 1 group of blast furnaces and the Siemens Martins steel plant.

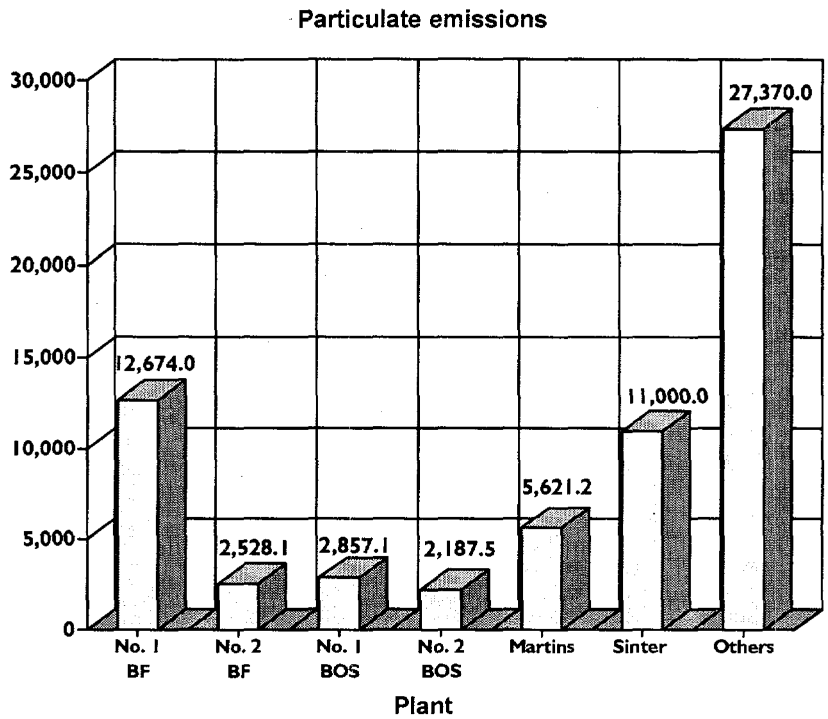
Table G.1.1 Average analysis of wastewater—Krivoi Rog 1992

		Average total	*Plant water*	*Drainage*	*Cement plant*	*Others*
Total Flow Cum X 1000		79,460	55,620	11,384	2,135	5,534
Boc	mg/liter	3.0				
	tons	238.4	238.4			
Solids	mg/liter	15.1		13.8	81.8	
	tons	1,199.8	788.3	157.1	174.4	
Oil	mg/liter	1.5			9.5	
	tons	120.0	94.7		20.3	
Phenol	mg/liter	0.009				
	tons	715.1	683.5			
Ammonia	mg/liter	4.42		0.79	3.89	
	tons	351,213.2	308,074.6	8,993.4	8,305.1	
Iron	mg/liter	0.93				
	tons	73,897.7	60,600.0			13,297.7
Salts	mg/liter	2,022.0		708.0	1,580.0	14,699.0
	tons	160,668.0	58,819.9	8,059.8	3,373.3	81,345.4
Chlorine	mg/liter	824.0		90.0	689.0	8,597.0
	tons	65,475.0	13,261.8	1,024.6	1,471.0	47,585.0
Sulphates	mg/liter	368.0		303.0	414.0	2,067.0
	tons	29,211.3	9,912.8	3,449.4	883.9	11,440.5

Table G.1.2 Atmospheric pollution (*tons/year*)—Krivoi Rog

Pollutant	*Total*	*Works discharge*	*Treated discharge*	*Collected material*	*Material utilized*	*Discharge into air* 1991	*Discharge into air* 1990	*Permitted levels*
Total	211,634.3	148,448.3	978,685.9	951,478.1	778,426.0	238,842.1	299,373.3	
Solid	26,806.5	13,678.0	977,474.9	950,865.3	778,426.0	53,416.0	61,491.8	
Gas & Liquid	1,848,218.0	164,770.2	1,211.0	612.8		185,426.0	237,881.5	
SO_x	21,818.0	20,626.4				21,818.0	32,687.7	32,687.8
CO	150,463.0	132,946.9				150,463.0	188,530.4	182,264.3
NO_x	11,095.0	44,095.0				11,095.2	14,548.2	14,548.3
Carbons	1.7	1.7				1.7	1.6	
VOC	55.9	55.9				55.9	65,797.0	
Others	1,394.0	44.0	1,211.0	612 .8		1,992.2	2,047.8	

Figure G.1 Airborne emissions
Krivoi Rog Steel Works, Ukraine, 1992



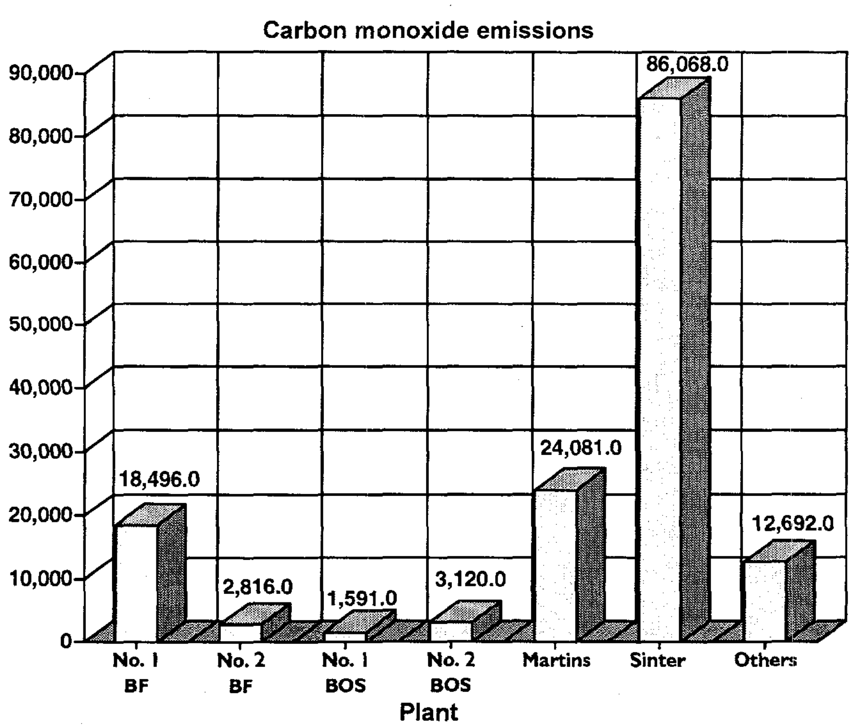
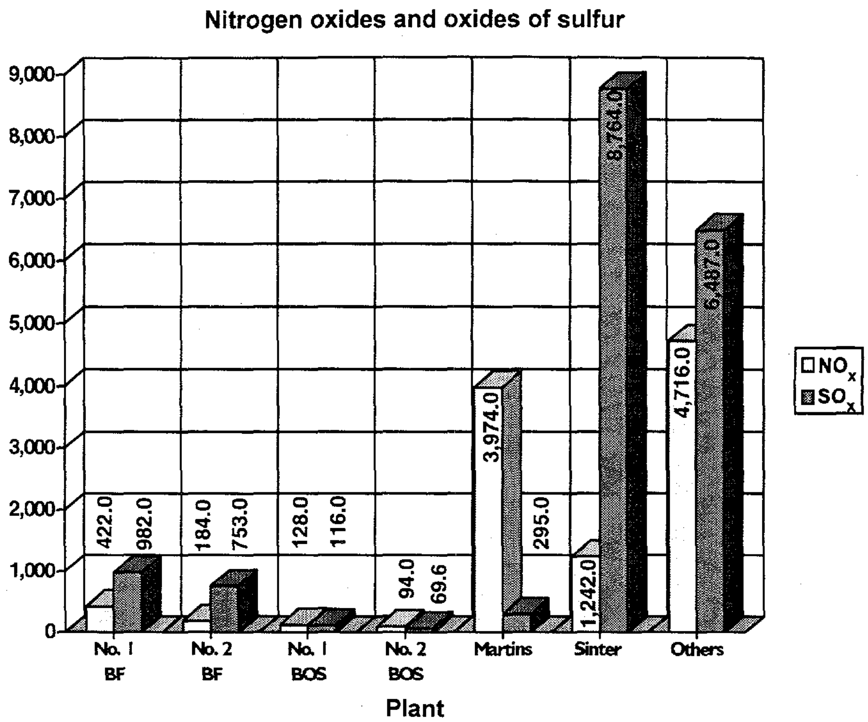
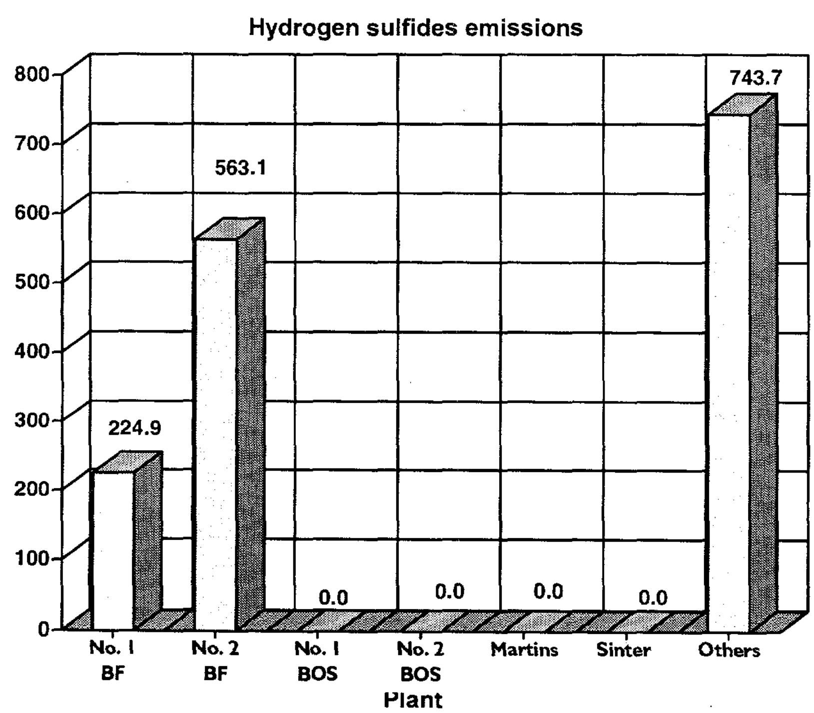


Figure G.2 Airborne emissions
Krivoi Rog Steel Works, Ukraine, 1992





Plant condition

Sinter plant

Since the plant was not visited no conclusion can be drawn on the state of the equipment or the possible solutions to the problems.

Blast furnaces

The No. 1 group of furnaces are being fitted with a new secondary fume extraction system. The existing electrostatic precipitators are being overhauled to improve their efficiency. However, the extraction system will handle 230,000 Nm^3/hr whereas the system offered to them by Thyssen would handle 1,000,000 Nm^3/hr. No more details of the German proposals were made available. The local design will be less effective.

Dust collected from the dust catcher and the sinter plant ESP is recycled to the sinter plant raw material stockyard.

The granulated slag processing area for the latest blast furnace covers a large area and is equipped with modern plant. The product is used in the construction industry for insulation material.

Steel plants

The principal technology used at the works is the basic oxygen steel making (BOS) process. Some of the steel is still being made using the old Siemens Martins process. All the steel is cast into ingots and then rolled. There are no continuous casting facilities.

Since the plant was not visited no conclusion can be drawn on the state of the equipment or the possible solutions to the problems.

Opportunities for environmental improvements

The reduction in energy consumption at the works, which will reduce emissions from the power stations, would cost a vast sum of money.

Replacing the open hearth and tandem steel making furnaces with a BOS steel plant would reduce the emissions and total energy consumption at the works. Comparisons can be made for the two processes operating alongside one another in a different country. During a recent study in a developing country, plant data indicated that even when the BOS plant consumes considerably more energy than a modern European plant, the open hearth process consumes about 2.0 Gj/ton more than the BOS process. This comparison is illustrated in Figure G.3.

Similarly, considerable energy and material savings can be achieved by replacing ingot casting by continuous casting.

Figure G.3 illustrates the potential for energy saving by eliminating ingot casting and ingot rolling. The savings are in the order of 63 kWh/ton for electricity and 1.67 Gj/ton for natural gas. For a works of 12 million tons capacity it is equivalent to a saving of about 86 MW of power.

Continuous casting would increase the material yield at the steel plant by up to 11 percent. This would raise good steel production by the equivalent of around 1.2 million tons of steel a year if all the steel was produced in this way.

There may be additional costs for reheating furnaces for the new rolling methods which would be introduced when continuous casting is adopted.

The installation of more effective gas cleaning equipment would improve the environmental situation but would make no saving in material yield. The new or improved equipment would also increase the total energy consumption.

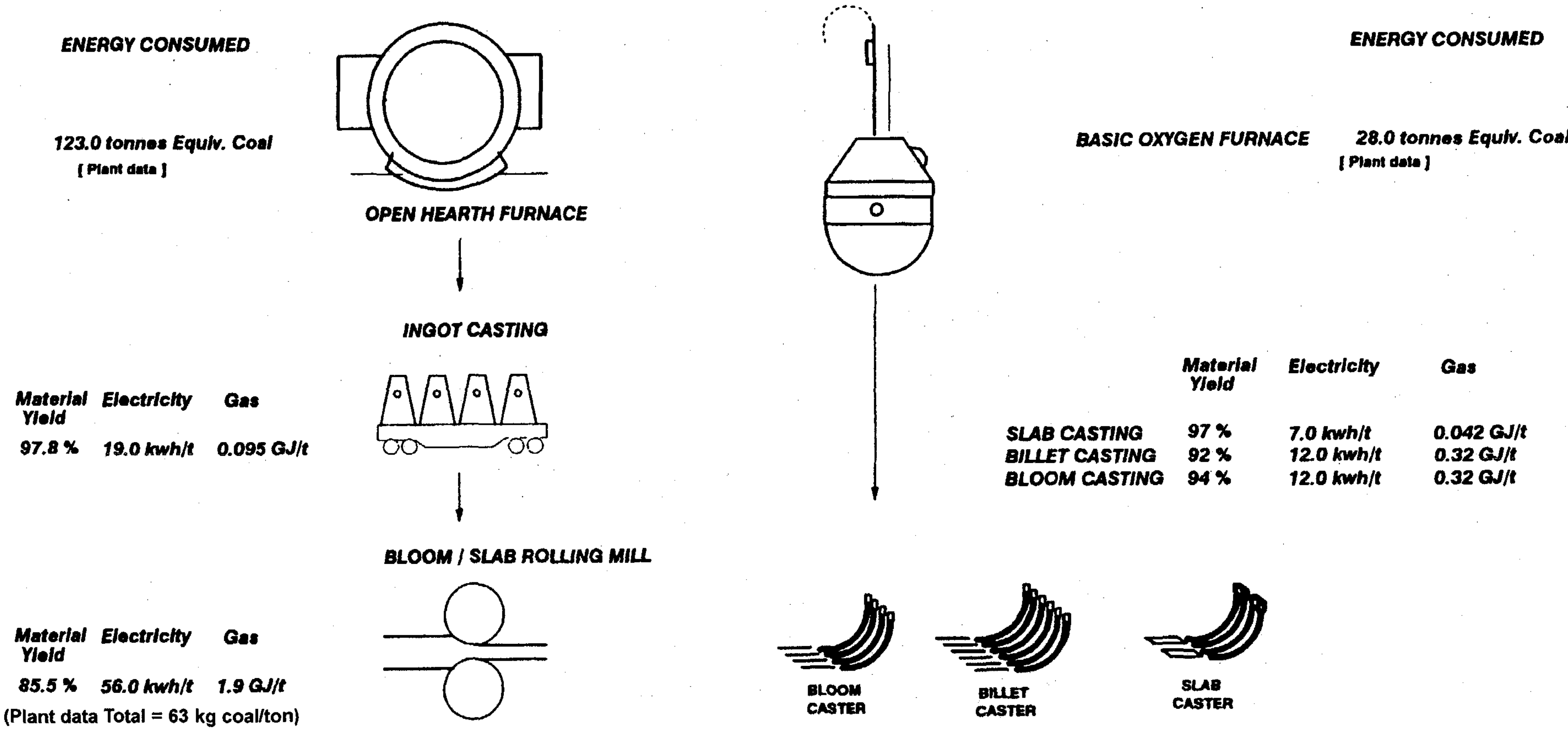
Conclusions

It was not possible to study the condition of the works in great detail but from the limited access to the blast furnaces some conclusions can be drawn. The latest blast furnace looks to be in good condition and compares well with those in the West. However, the older blast furnaces, which are being fitted with secondary filtration systems, are quite dilapidated and require some extensive refurbishment both for operational reasons and environmental reasons.

To reduce energy consumption and emissions the rest of the works would require an extensive modernization program, such as the replacement of the open hearth furnaces and ingot casting. The investment costs for the installation of BOS equipment would be around $200 per ton and $75 per ton of capacity for continuous casting equipment.

The lower-cost option of installing abatement equipment alongside the existing plant would effectively increase the operating cost without reducing the energy consumption or increasing the material yield. A full cost benefit analysis would be required to justify the expenditure.

Figure G.3 Process comparisons for bloom/slab products



TOTAL YIELD FOR INGOT CASTING 83.3% CONTINUOUS CASTING 92–97%

TOTAL ELECTRICITY SAVING USING CONTINUOUS CASTING = 63 kwh/ton (25.2 kg coal/ton)

TOTAL GAS SAVING USING CONTINUOUS CASTING = 1.675 GJ/ton (57 kg coal/ton)

TOTAL ENERGY SAVING REPLACING OPEN HEARTH BY BASIC OXYGEN FURNACES = 2.79 GJ/ton (95 kg coal/ton)

(This is double the expected difference.)

Annex H

Non-Ferrous Metals

Introduction

This annex summarizes the key issues and conclusions arising from our analysis of the economic and technical aspects of environmental protection in the non- ferrous metals industry of Central and Eastern Europe. The report covers the manufacture of the following metals:

- Copper
- Aluminum
- Lead and zinc.

Our work has attempted to assess the likely costs of reducing various forms of polluting emission during the manufacture of each metal. We have focused on those which are known to result in significant adverse environmental impacts. The analysis relies on a desk-based review of the structure and economics of the industry complemented by a similar analysis of the typical environmental problems and abatement options faced by each industry. This latter research has been supplemented by case studies of the aluminum smelter at Ziar Nad Hronom, Slovakia, and the lead/zinc smelters at Plovdiv, Bulgaria, and at Copsa Mica, Romania.

The latter sections of thisn annex detail the findings from the case studies. A separate working paper provides further details of our technical and economic analysis.

Copper

Structure of the industry

Table H.1 summarizes our understanding of the current structure of the copper industry in the CEE countries. The two major producers are Russia and Poland. This structure is changing as the effects of economic reform work through. In particular, recent declines in demand have led to reductions in output and, in some cases, plant closures.

Like much heavy industry in Central and Eastern Europe, the copper industry is characterized by obsolete technology and high pollution. Reliance on low-grade ore reserves is the main reason why Soviet smelters have recently been running well below capacity; the higher grades have been exploited and little exploration has been undertaken. Most of the equipment is old and dates from before 1939. In contrast, Polish mines produce almost 4 percent of the world's copper and export more than half to the West. The quality of product is regarded as quite satisfactory by users.

Pollution problems in the copper industry

Primary copper production in the CEE countries, as in the West, is predominantly based on smelting sulfide concentrates to produce copper. It involves five stages: drying or roasting, primary smelting, conversion of matte, and fire and electrode refining. The major pollutants are:

- Sulfur dioxide gas, in particular from primary smelting and converting
- Particulates, which often contain heavy metals, especially during concentrate handling, drying, and primary smelting
- Liquid effluent discharged without adequate treatment during primary smelting, gas handling, and from the acid plant and refinery tank house

Table H.1 Structure of copper sector

Country	*Capacity ('000 tonnes)*	*Production, 1990 ('000 tons)*[1]	*Number of plants*
Bulgaria		24	4
- Czech Republic	More than 60	24.5	5
- Slovak Republic			
Hungary		6	
Poland		346	21
Romania	50 - 80	30	4
Former Soviet Union	1,300	1,260	-
- Russia	435	425[2]	12
- Ukraine			1
- Moldova		No major plants	
- Estonia			
- Latvia			
- Lithuania			

[1] *Source:* Metal Bulletin's Prices and Data, 1992.
[2] 1989.

- Large quantities of slag and other solid residues, predominantly iron oxide/silica based (fayalite), which contain significant levels of unrecovered metals and minor elements which are soluble and thus a threat to the groundwater system.

Table H.2 indicates the typical emissions from a 150,000 ton capacity copper plant.

In the West a trade-off exists between recovery of copper and the grade of concentrate used. However, in the CEE countries, maximization of metal recovery has been the dominant goal. This has meant that lower-grade concentrates (typically 15–20 percent copper) have been used and this has led to:

- Higher sulfur and iron levels
- Substantial fugitive gas generation and large volumes of SO_2 in off-gas per unit of copper produced
- Greater slag production per unit of copper with a consequent increase in the need for recycling and materials handling
- Lower metal production per unit of throughput in the smelter and hence lower energy efficiency.

Moreover, many CEE plants still utilize obsolete technology such as reverb smelting (with or without roasting), electric smelting, or blast furnaces. These techniques are inefficient and generate low SO_2 concentration off-gases unsuited to fixation by acid plant

Table H.2 Typical emission levels at a copper plant

Pollutant		*Tons per annum*	*Tons per ton of copper*
Atmosphere	SO_2—no sulfur fixation process	300,000 - 450,000	2 - 3
	SO_2—with acid plant	45,000 - 75,000	0.3 - 0.5
	Particulates	19,500	0.13
Solid waste	Slag	300,000 - 400,000	2 - 3
Aqueous	Liquid effluent	15,000 - 150,000	0.1 - 1.0

technology. Although the Kivcet and Vanyukov smelting techniques have been developed which offer better economic and environmental performance, they are not yet widely used. In addition, recovery of SO_2 during copper matte conversion is often poor because gas collection hoods are inadequately sealed. In general terms, CEE plants suffer from inadequate automation and process control, poor environmental control, and low productivity.

Cost of abating pollution

The options for controlling or abating emissions of the main pollutants fall into four categories:

- Replacement/modernization of the technology
- Process and operating practice improvements
- Investment in additional abatement equipment
- Improved repair and maintenance of existing plant.

A key issue in the abatement of pollution from the copper industry in the CEE countries is the smelting technology in use. SO_2 is a particularly significant pollutant but the ease and cost of its control depends critically on the smelting technology in use. The limitations of the old technology used at many smelters in the region mean that the adoption of alternative smelting techniques such as the Outokumpu flash smelter or Noranda process offer both a process efficiency improvement and a reduction in polluting emissions. However, the cost is considerable. In general a "modern" copper smelting plant equipped with oxygen/acid plants and featuring matte conversion in converters with full environmental facilities will range in specific (capital) cost from $2,000 to $3,000 per annual ton of copper production.

There are various other techniques to control pollution. These are summarized in Table H.3.

Table H.4 indicates the estimated cost for various items of pollution control equipment for the copper sector. Where appropriate, specific capital cost figures are included, i.e., cost per ton of installed capacity. These figures have to be treated with caution since the cost of pollution control techniques varies widely depending on several factors including the scale of operation, the technology in use, degree of oxygen enrichment, type of fuel energy. For example, the cost of a bag filter refers to one unit only; but a typical plant may require 10 bag filters, each of varying size.

Beside these specific actions, adoption of best practice currently being applied in the West can remove some of the major problems. For instance, better control of dusting during the handling and transport of the metal concentrates can significantly reduce pollution from heavy metals. However, in the absence of a case study of a copper plant, it is difficult to gauge the likely benefits of such measures.

Industry prospects

Prospects for the copper industry in the CEE countries are uncertain. In spite of the outmoded equipment and decreasing world demand, Russian copper exporters are competing successfully on the international market and the dominant copper enterprise in Poland—KGHM—has already been transformed into a joint-stock company in preparation for privatization.

Table H.3 Pollution control technologies in the copper industry

Pollutant	*Pollution control techniques*	
Sulfur dioxide	Conversion into sulfuric acid	• Sulfuric acid plant
Dust and particulates	Dust and particulate removal	• Efficient gas collecting system • Wet scrubbers • High-efficiency electrostatic precipitators • High-efficiency bag house collectors • High-efficiency dust handling/recirculation systems
Aqueous discharges	Water treatment	• Solids removal • Liming (pH adjustment) • Settling • Ion exchange cleaning
Solid discharges	Dumping	• Granulation

Table H.4 Estimated capital costs of pollution control in the copper industry

Pollution control plant	*Pollutant*	*Capacity*	*Units*	*Capital cost $ million*	*Specific cost $ per annual ton capacity*	*Impact on operating costs*[1] *$/annum*	*Removal efficiency (percent)*	*Tons of pollutant abated per annum*[2]
Sulfuric acid plant	SO_2	1,000	tonnes/ day	50.0 - 70.0	500 - 700	2,000,000[3]	98+	200,000[4]
Wet scrubber	Particulates	100,000	Nm^3/h	1.0	30 - 50	300,000	90 -95	4,900
Electro-static preci-pitator	Particulates	100,000	Nm^3/h	3.0 - 5.0	60 - 100	140,000	90 - 99	3,250
High-efficiency bag filter	Particulates	100,000	Nm^3/h	4.0	70 - 130	450,000	98 - 99	5,400
Cyclones	Particulates	100,000	Nm^3/h	0.1 - 0.2	3 - 6	150,000	90[5]	4,900
Water treatment plant	Heavy metal	100,000	tonnes/ annum	4.0 - 7.0	40 - 70	200,000	90	<100

[1] Depends on number of units and plant configuration.
[2] Estimate based on 150,000 tonne/annum cooper production.
[3] Very dependent on concentrate grade.
[4] Excludes any credit for acid sale.
[5] For particulates >50m.

The main future problems are likely to relate to the deleterious impact of the operations on the environment, particularly in the former Soviet Union where environmental controls are poor. For example, a Soviet smelter was closed in 1989 as its emissions were 200 times permitted limits. Given the amount of capital which would be required to modernize the most polluting plants, the participation of Western investors via joint ventures or other transnational agreements will be crucial to the development of the copper industry.

Aluminum

Structure of the industry

Table H.5 summarizes our understanding of the current structure of capacity and production in the aluminum industry in the CEE countries. This structure is changing as the effects of economic reform work through. In particular, like other parts of the non-ferrous sector, recent declines in demand have led to reductions in output and, in some cases, plant closures. Nevertheless, Russia is by far the largest producer although there are significant production facilities in other countries.

The aluminum industry is characterized by obsolete technology. Inefficient Soderberg technology still dominates the 14 smelters of the CIS; only 3 use the more up-to-date pre-baked electrode method. The same is true of the dominant plants in the Slovak Republic, Romania, and Hungary. Furthermore, the technology in use in the aluminum sector is generally regarded as less sophisticated than other parts of the non-ferrous industry.

Lack of hard currency, particularly for the import of raw materials such as alumina and bauxite, is regarded as the main driving force behind the considerable volume of exports of aluminum from the CEE countries. Exploiting its comparative, albeit temporary, advantage in energy costs, the CEE countries have placed significant quantities of cheap, low-quality aluminum on the world market. This has contributed to the substantial fall in world aluminum prices.

Lack of liquidity is another of the major problems faced by aluminum producers in other CEE countries. To circumvent this, producers are increasingly under-

Table H.5 Structure of aluminum sector

Country	Capacity ('000 tons)	Production ('000 tons)	Number of plants
Bulgaria		No major plants	
- Czech Republic		70[1]	5
- Slovak Republic			
Hungary	75	75[1]	3
Poland		46[1]	3
Romania	263	105[2]	5
Former Soviet Union		2,200[3]	14
- Russia	5,250[4]	425	12
- Ukraine	120		2
- Moldova			
- Estonia			
- Latvia		No major plants	
- Lithuania			

Source: Metal Bulletin's Prices and Data, 1992.
1 1990. 3 1989.
2 1992. 4 1989.

taking deals such as barter or tolling. The latter involves a (Western) trader buying alumina for use by, say, a CIS smelter, paying a charge for its processing and then exchanging it for a shipment of finished product from that smelter. Nevertheless, the three major Hungarian smelters may all close in the near future because they are uneconomic.

Furthermore, the structure of demand inherited does not provide the best basis for the development of a stable supply structure. Production of aluminum in the former Soviet Union was geared mainly to military applications; the proportion of total production for civil uses such as packaging, construction, and transport has been far lower than in the West. As a result, domestic demand is unlikely to exceed previous levels in the near future. At the same time world demand is decreasing and is expected to continue to do so.

Pollution problems in the aluminum industry

The main sources of pollution from an aluminum smelter are:

- Pot line off-gases which contain fluorides, particulate solids containing fluorides, SO_x, NO_x, and tar and its decomposition products
- Solid discard materials—spent pot liners which contain fluorides together with cyanides and cyanate
- Aqueous discharges of untreated wastewater containing fluoride and heavy metal ions.

The gaseous emissions are of particular concern because they adversely affect human health. The tar products are carcinogenic, and fluorides can induce fluorosis and sclerosis when ingested or inhaled. Particularly in the CIS, these problems are compounded by the location of smelters close to densely populated urban areas.

Emission levels of the various pollutants at plants in the CEE countries depend on various site-specific factors such as the age of smelter, the state of the control systems installed, and maintenance levels within the smelter particularly in relation to off-gas handling. However, the pollution problems in the CEE countries are believed to be significantly worse than those in the West because of the heavy dependence on Soderberg technology, poor maintenance standards, inadequate process control and instrumentation, and the poor quality of raw materials. Typical emission levels are shown in Table H.6. These factors are reflected in low current efficiencies which average only 70 percent compared to nearer 95 percent elsewhere. A further problem is the frequency with which the pot liners are repaired and/ or replaced.

The case study of the smelter at Ziar Nad Hronom in Slovakia is, perhaps, typical. Much of the plant is nearly 40 years old with little evidence of modernization. Emissions of pollutants are very considerably in excess of those in Table H.6. For example, emissions of particulates are 38 kilograms per ton of aluminum and SO_2 emissions are 125 kilograms per ton. The company's response to these problems has been to enter a technology transfer agreement with a Norwegian firm which will lead to the construction of a new, larger plant based on modern technology at a cost of $300 million. This is expected to reduce pollution dramatically.

Costs of abating pollution in the aluminum industry

The options for controlling or abating emissions of the main pollutants fall into four categories: replacement/ modernization of the technology; process and operating practice improvements; investment in additional abatement equipment; and improved repair and maintenance of existing plant.

As noted, the pollution problems arising from the aluminum industry in the CEE countries are, to a larger extent, a reflection of the continued reliance on Soderberg technology. With the Soderberg type of operation, pollution abatement typically involves:

- The installation of point feeders for alumina to reduce dusting and gas emissions
- Installation of dry alumina scrubbing systems to remove fluorides and tar
- Modification to gas skirts to improve the efficiency of gas collection.

Table H.7 shows the estimated capital cost of the pollution control equipment. Where appropriate, the cost per ton of installed capacity is also shown. The figures have to be treated with caution as the capital costs will vary significantly from plant to plant.

More efficient gas collection and scrubbing to remove the fluoride and tar components from the gases are the most important measures which can be adopted to reduce pollution in the aluminum sector. The treatment of aqueous discharges from smelters typically requires air flotation of tar and its derivatives and liming and settling to remove fluoride and heavy metal ions. These, and other water treatment technologies, are well understood and used in other industries. As yet, no generally applicable method of safely disposing of the solid wastes from the spent pot liners exists.

A characteristic of these measures is that they involve significant capital cost. Given the doubtful viability of many of the plants in the region, the case for such investment is weak. Instead, there is a need to focus on more limited investments designed to offer a limited reduction in tar and fluoride emissions. The case study at Ziar Nad Hronom suggested few such measures.

Industry prospects

Prospects for the aluminum industry in the CEE countries are not encouraging. Current export performance relies mainly on transitory comparative advantages such as artificially low energy costs. Declining world demand for aluminum has pushed prices steadily down, and there is a danger that demand for low-

Table H.6 Typical emission levels at an aluminum smelter[1]

Pollutant		*Tons per annum*	*Kilograms per ton of aluminum*
Atmosphere	Fluorides	830 - 1,000	8 - 10
	Particulates	800 - 1,000	8 - 10
	SO_x	400 - 600	4 - 6
	NO_x	100 - 300	1 - 3
	Tar	800 - 1,200	8 - 12
Aqueous	Suspended solids	900 - 1,500	9 - 15
	Fluorides	700 - 1,400	7 - 14
	Tar	80 - 1,000	1 - 10
Solid waste	Spent pot liners	5,000 - 15,000	50 - 100

[1]Assumes annual capacity of 100,000 tons.

quality aluminum from the CEE countries will be weak in the long term. Moreover, the dominance of inefficient, polluting technology means that large amounts of capital are needed to make plants competitive and economically viable.

Lead and zinc

Structure of the industry

Lead and zinc ores are frequently found together, along with other metal ores, and both metals are sometimes produced jointly. Thus we analyze them together. Tables H.8 and H.9 summarize our understanding of the current structure of the lead and zinc industry in the CEE countries. Mine and metal production has fallen sharply in recent years, though at different rates in different countries, as industries have been reorganized in response to the political and economic changes which are taking place. Lead and zinc are produced in the former Soviet Union and in four other CEE countries — Bulgaria, the Czech and Slovak Federal Republics (lead only), Poland, and Romania. The smelters are generally relatively small by international standards.

Like other activities in the former Soviet Union's non-ferrous metals sector, the production of lead and zinc is characterized by both technical inadequacy — inappropriate process technology and poor ore grade — and financial weaknesses — high indebtedness and lack of cash. As a consequence, product quality is poor and there is a highly detrimental impact on the environment. Additionally, technical difficulties related to lack of infrastructure (especially transport), equipment, and stable power supplies mean that efficiency is very low all over the CIS.

The situation elsewhere is even more discouraging. Production in Romania is running well below capacity while, due to its adverse impact on the environment, the Bulgarian government announced in 1991 that it intended to stop all primary production of lead and to close the two main smelters.

Pollution problems in the lead industry

Lead is typically produced by eliminating the sulfur from sulfide concentrates by sintering, and then smelting oxide sinter in a blast furnace to produce lead which is refined to eliminate impurities. In the CEE countries, the technology used is very similar to that found in the West. The major emissions of pollutants which arise during this process are:

- Lead-bearing particulates from sinter strand and blast furnace off-gases, during material loading and from the smelter
- Sulfur dioxide
- Aqueous discharges containing lead and other heavy metals from the smelter
- Soluble metals leached from slag dumps.

Typical emission levels for a 100,000 ton plant are summarized in Table H.10. Actual emissions will vary from plant to plant depending on the technology in use, levels of maintenance, plant utilization, and process control standards. However, an important feature

Table H.7 Estimated cost for pollution control in the aluminum sector

Pollution control plant	*Pollutant*	*Capacity (tons per annum)*	*Units*	*Capital cost \$ million*	*Specific cost \$ per annual ton*	*Impact on operating costs*	*Removal efficiency (percent)*	*Tons of pollutant abated per annum*
Dry alumina scrubbing system	Fluorides	200,000	tons/ annum	20 - 60	100-300		F 94-95	1,500-1,900
	Tar						T 98	1,575-2,350
Alumina point feeders	Particulates	200,000	tons/ annum	8 - 25	40-125	Revenue benefit	90	
Modification of gas skirts	Various	200,000	tons/ annum	10 - 20	100-200		95-98	
Air rotation/liming and settling	Aqueous	100,000	tons/ annum	5 - 8	50-60		98	
Total pollution control system—new plant	Various	100,000	tons/ annum	> 75	750		> 97	

of the lead industry in the CEE countries is the use of ores with a low lead concentration. This means that emissions of SO_2 in the off-gas stream are larger; more slag results from smelting; and the process is less efficient.

Costs of abating pollution in the lead industry

The options for controlling or abating emissions of the main pollutants fall into four categories: replacement/ modernization of the technology; process and operating practice improvements; investment in additional abatement equipment; and improved repair and maintenance of existing plant.

The modernization of lead smelters is a relatively straightforward operation. The technology used is expected to remain as the sinter/blast furnace route, with an emphasis on modern process control and instrumentation and pollution control equipment. Possible modernization investments in CEE countries will be targeted at:

- Replacement of sinter strands at a cost of $20-30 million
- Modernization of material handling at a cost of $10 million
- Installation of process control instrumentation at a cost of $15 million
- Investments in off-gas handling systems and sulfuric acid production facilities at a cost of $70 million.

Table H.11 lists the main technologies for abating pollution from lead smelters. Priority must be given to measures aimed at alleviating (lead-bearing) particulate discharges to the atmosphere.

For very small particle sizes and high-temperature gas streams the electrostatic precipitator is the preferred option, while modern bag filters can allow very low dust levels to be achieved. Scrubbers and washers of various types are used as a less expensive alternative to bag filters and electrostatic precipitators. Settling chambers and cyclones are effective as a first stage gas cleaning process, but may need a more sophisticated process.

In most parts of the metals processing industry, sulfur dioxide is a minor pollutant arising from the use of fuel. However, it is released at high concentrations from smelters and can be controlled by conversion to sulfuric acid, or by lime or caustic scrubbing process. Generally, conversion to sulfuric acid is the preferred route from an economic point of view because it avoids the production of large volumes of liquid or solid wastes. This is made more attractive where

Table H.8 Structure of zinc sector

Country	*Capacity ('000 tons)*	*Production ('000 tons)*	*Number of plants*
Bulgaria	40-60	45[1]	2
- Czech Republic		No major smelters or refineries	
- Slovak Republic			
Hungary		No major smelters or refineries	
Poland	137[1]	130[1]	4
Romania	50 - 80	20[1]	1
Former Soviet Union	1,130	720[1]	11
- Russia	200	260	2
- Ukraine	260	240	3
- Moldova		No major smelters or refineries	
- Estonia			
- Latvia			
- Lithuania			

Source: International Lead and Zinc Study Group.
1. Estimated refined production in 1992.

Table H.9 Structure of lead sector

Country	Capacity ('000 tons)	Production ('000 tons)	Number of plants
Bulgaria		50[1]	2
- Czech Republic		25[1]	
- Slovak Republic			
Hungary		No major smelters or refineries	
Poland	146[2]	55[1]	6+
Romania	50 - 80	10[1]	1
Former Soviet Union	1,075	600[1]	8
- Russia	225		2
- Ukraine	25		2
- Moldova		No major smelters or refineries	
- Estonia			
- Latvia			
- Lithuania			

Source: International Lead and Zinc Study Group.
1. Estimated refined production in 1992.
2. Including secondary lead plants.

lead and zinc production are co-located, as is often the case in the CEE countries. Many acid plants in the CEE countries require considerable repair, at a cost of, perhaps, $50-100 per annual ton of (metal) product. Where a new acid plant is required, such as appears to be the case at Copsa Mica, the cost would rise to about $700 per annual ton of (metal) product.

Capital and specific capital costs for pollution control technologies in the lead sector are shown in Table H.12. Where appropriate, the specific capital cost per ton of installed capacity is also shown. These figures have to be treated with caution as the capital costs may vary significantly according to the number of units utilized in the production process, which differs from plant to plant.

In some cases, installation of new abatement equipment may be unnecessary. A case study of the Copsa Mica lead/zinc plant in Romania has highlighted the need for repair and modernization of the particulate control systems and the installation of bag filters and collection hoods at various points. The investment cost of replacing the dedusting equipment would be about $200 per annual ton of product.

In contrast, the case study at Plovdiv in Bulgaria suggests that the recent reduction in emissions of pollutants has been the result of a conscious effort to reduce the output of lead in the 1980s and early 1990s as much as through the upgrading and replacement of old dust collection and gas cleaning equipment.

Table H.10 Emission levels from lead plants

Pollutant		Tons per annum	Kilograms per ton of lead
Atmosphere	Particulate lead	5,000 - 10,000	50 - 100
	SO_2—no acid plant	30,000 - 40,000	300 - 400
	SO_2—acid plant	15,000 - 30,000	150 - 300
Aqueous	Liquid effluent		100 - 1,000
Solid waste	Slag		1,000

Table H.11 Relevant technologies considering the individual pollutants

Pollutant	*Pollution control technologies*
Particulates	• Efficient gas collection systems • High-efficiency electrostatic precipitators • High-efficiency bag house collectors • High-efficiency dust recirculation system
Sulfur dioxide	• Gas cooling and collection • Gas scrubbing systems • Modern sulfuric acid plant or flue gas desulfurization plant
Aqueous pollution	• Liming (pH adjustment) and settling • Ion exchange clean-up

Table H.12 Estimated capital costs of pollution control in the lead sector

Pollution control plant	*Pollutant*	*Capacity*	*Units*	*Capital cost \$ million*[1] *(\$ per annum)*	*Specific cost (\$ per annual ton)*	*Change in operating costs*[1] *(\$ per annum)*	*Removal efficiency (percent)*	*Tons of pollutant abated*[2]
Sinter strand and associated equipment	Particulates	100,000	t/annum	20-30	200-300	Replacement unit	95	3,000
Material handling	Particulates	100,000	t/annum	10	100	50,000	80 - 90	500
Process control instrumentation		100,000	t/annum	15	150			
Gas handling and sulfuric acid plant	SO_2	100,000	t/annum	50 - 70	700	2,000,000	98	200,000[3]
Water treatment plant	Wastewater	80,000	t/annum	5-8	62-100	200,000	90	<100
Particulate removal and recycle	Particulates	80,000	t/annum	15-20	190-250	750,000	85 - 98	10,000

1 Depends on number of units and configurations.
2 Estimate based on 100,000 ton/annum lead production.
3 Very dependent on concentrate grade.

Additionally, some good housekeeping rules can be applied to prevent dusting. These include stocking concentrates in silos or closed buildings at a cost of \$50 per annual ton of product. A cheaper alternative would be to keep the concentrate damp by installing simple water sprays at an investment cost of \$1 per annual ton of product. This was specifically identified as a concern in the Plovdiv case study.

Pollution problems in the zinc industry

Zinc ores are also sulfide based and often contain quantities of lead. They are converted into zinc in three stages:

- Concentration of the ore
- Roasting or sintering to produce an oxide (calcine)
- Refining involving retort reduction with carbon, leaching/electrolytic extraction, or a zinc blast furnace.

The pollutants from these processes are:

- SO_2
- Particulates containing lead, zinc, cadmium, and other heavy metals
- Process slag
- Spent refractory materials
- Other off-gas components
- Hydrometallurgical wastes and residues
- Contaminated wastewater.

Table H.13 summarizes the typical emission levels at a 60,000 ton plant. The two key pollutants are perhaps SO_2 and particulates (dust).

Only two plants in the CEE countries, at Copsa Mica in Romania and Miasteczko Slaskie in Poland, utilize the IS[1] technology for smelting mixed lead and zinc concentrates. This process is currently used in the West. However, as the Copsa Mica case study has confirmed, a major difference is the general condition and level of maintenance of the plants, the level of process control and automation applied, and the management of the facilities. A further explanation of the poorer environmental performance of plants in the CEE countries is the reliance on ores with low metal concentrations. This leads to larger volumes of SO_2 as part of the off-gas stream, greater slag from the smelting operations, and a lower throughput of the metal product particularly from the smelting operations.

One particular problem affecting zinc production is the disposal of the jarosite residue produced from the zinc leaching process prior to electrolysis. The jarosite is currently stored in lined lagoons (either lined with plastic sheet or clay) at the zinc smelter sites. To date the problem of its treatment has not been resolved and continues to be of concern to most zinc leach/electrolysis plants both in the West and in CEE countries.

Costs of abating pollution in the zinc industry

Many of the options for controlling or abating emissions of the main pollutants are similar to those for lead. They fall into four categories: replacement/modernization of the technology; process and operating practice improvements; investment in additional abatement equipment; and improved repair and maintenance of existing plant. We focus on the options for abating SO_2 and particulates.

The capital and specific capital costs of pollution control technologies in the sector are illustrated in Table H.14. These figures have to be treated with caution, as the capital costs may vary significantly according to the number of units utilized in the production process, which differs from plant to plant.

As noted above, conversion of SO_2 into sulfuric acid is the key route to controlling emissions. The Russians have developed the Matros technology which, unusually, is capable of treating lower tenor[2] SO_2 than normally required by acid plants. An alternative would be to install a desulfurization plant. Either way the costs per ton of SO_2 abated are likely to be relatively high.

There are several options for controlling particulates. For very small particle sizes and high-temperature gas streams, installation of an electrostatic precipitator is the preferred option although modern bag filters can allow very low dust levels to be achieved. Scrubbers and washers of various types are used as a less expensive alternative. Settling chambers and cyclones are effective as a first stage cleaning process to remove large particulates. They should be followed by more sophisticated processes. Alternatively, some good housekeeping can be introduced to prevent dusting, such as stocking of concentrates in silos or closed buildings, or keeping concentrate that is transferred by conveyor damp.

Industry prospects

The technology being used in the lead and zinc sector is more akin to the best available technology than that found in other parts of the non-ferrous sectors. Nonetheless, the industry's prospects do not appear to be unduly good, largely because the costs of addressing the environmental problems are likely to be considerable.

Endnotes

1. Imperial smelting technology.
2. Tenor is typically used in the industry to mean concentration.

Table H.13 Emission levels at a zinc smelter/plant

Pollutant		*Tons per annum*	*Kilograms per ton of zinc*
Atmospheric	Dust—concentrate handling	750	4 - 12
	Dust—roasting	3,000	50
	SO_2	8,400	150
Aqueous	Suspended solids	100 - 200	2.4
	Zinc	50 -150	0.5 - 3.0
	Cadmium	0.1 - 0.4	0.001 - 0.01
Solid waste	Jarosite	20,000 - 30,000	300 - 400

Table H.14 Estimated capital cost for pollution control in the zinc sector

Pollution control plant	*Pollutant*	*Capacity*	*Units*	*Capital cost $ million*	*Specific cost $/annual ton*	*Change in operating costs*[1] *$ per annum*	*Removal efficiency (percent)*	*Tons of pollutant abated*
Sulfuric acid plant	SO_2	80,000	t/annum	50.0 - 70.0	625 - 875	500,000	98+	50,000
High-efficiency bag filter	Particulates	100,000	Nm^3/h	5.0		150,000	98 - 99	2,000
Water treatment plant	Solids—heavy metals	80,000	t/annum	8.0 - 10.0	100 - 125	Revenue benefits		

[1] Depends on number of units and plant configuration.

Ziar case study

Introduction

The following report relates to the environmental aspects of aluminum smelting as Ziar Nad Hronom in Slovakia. The smelter visited is considered as typical of those in Central and Eastern Europe (CEE).

The ZSNP aluminum smelter and the associated facilities have been in continuous production for over 40 years; hence it can be regarded as a mature operation. The other factors that make the smelter fairly typical of the CEE aluminum sector include:

- Vertical integration with nearly 70 percent of aluminum produced being converted/fabricated to semi-finished/finished products
- Dependence on the captive raw material supplies within the CEE countries
- Production of unusual (for a primary Al industry location) by-products with what can be regarded as sub-marginal economics
- Absence of any attempt to modernize due to the historical absence of economic and environmental pressures
- Production/operating philosophies that are radically different from rest of the world
- Environmental pollution and little previous attempts to alleviate its impact.

Plant location

The Ziar aluminum works of ZSNP is situated in an area regarded by many as one of outstanding natural beauty. It is in a valley surrounded by virgin forest lands of the Keminica and the Stianvinca hills. Popular ski resorts are also stated to be in the vicinity. Such a location for a aluminum smelter based on old technology (with its relatively high pollution potential) is considered very unfortunate for the operations. The problem is further exacerbated by the presence of the Hronom River, which is one of the tributaries of the Danube.

The population density around the plant location is high. Ziar valley is heavily industrialized; however, it is apparent that amongst all the industrial activities in the region, the aluminum works has been singled out as the chief source of pollution.

Although publicly the effects on the population of the smelter emissions have not been acknowledged, it is clear that there is a growing awareness of the historical/current levels of pollution particularly of fluorides and tar from the smelter.

Products, processes, and utilities of the smelter

Products

The smelter produces aluminum of 99.5-99.7 percent purities; the latter specification corresponds to the LME Grade. The average (over the past few years) production rate is about 60,000 t/a of molten aluminum; 70 percent of the metal produced is utilized in the foundry and the fabricating shops for the production of diverse castings and semi-finished products to satisfy the internal market. The remainder is cast in the form of billets, ingots, and semis for export and for other internal Slovakian consumption; a partial listing of the semis products includes:

- Ingots (12-15 kg)
- Billets (5 m length, 153-357 mm thick)
- Plates for rolling to sheet
- Cast wire.

Closely related to metal production are the facilities for the manufacture of the following:

- Anode materials
- A variety of alumina products.

Of interest in the present context is the carbon anode production: up to 60,000 tons per annum of various carbon electrodes are being produced at the site. These include:

- Carbon for self-baking anodes for aluminum electrolysis—for "internal" use at the smelter
- Carbon for the manufacture of electrodes for electric arc furnaces (steel melting)
- Miscellaneous graphitic products for "ramming" applications.

The main outlet for the carbon plant products is the aluminum smelter.

Processes and utilities employed

Description of the processes in use at Ziar can be conveniently divided into the following sections:

- Production of alumina for aluminum metal production
- Production of other alumina products

- Production of metallic aluminum.

The raw material for electrolysis feed alumina is imported high-grade bauxite (from Yugoslavia and Hungary). The process used for the production of electrolysis grade alumina is the conventional Bayer circuit comprising:

- Comminution of bauxite
- Pressure digestion with caustic in steel autoclaves;
- Solid/liquid separation
- Precipitation of alumina and subsequent calcination to grade alumina
- Caustisizing and recycle of spent caustic liquors.

The Bayer plant, although old, is well maintained. There has been very little modernization of the facility:

- The process control system was found to be rudimentary
- The solid/liquid separation stages, while effective, would be regarded as being archaic and as a consequence probably contributes to significant caustic losses
- The alumina calciner would be regarded as technically unmodern; as a result the energy efficiencies (reflected in the usage of primary fossil fuel) can be regarded as low compared with the more modern installations. A further aspect of the aluminum raw material delivery and reception was noted; due to the fairly old materials handling facilities at site, considerable dusting (and consequent material losses) was apparent.

The production of non-electrolytic grade alumina intended for a variety of applications such as plastic fillers, refractories, etc., was seen to use:

- Low-grade bauxite
- An in-house-developed technology based on soda sintering in rotary kilns.

It is doubtful if the efficiencies achieved at the relatively unsophisticated process plant are high; consequently it is surmised that the operating costs would be regarded as high.

The waste products from the bauxite treatment facilities are combined and disposed of in a walled area covering a few km^2; an estimated 6 million tons of the waste product—red mud—have been stockpiled to date. As with other bauxite treatment facilities, a completely non-polluting method of red mud disposal is not available to the operations. This aspect is discussed below.

Much of the alumina reduction pot lines were originally built in 1958/1960; the design was repeated for an expansion in the mid-1970s to the present capacity. The technology used comprises the standard cryolite bath and self-baking anodes. The 136 pots are arranged in two rows; although the rated capacity of the pot lines was stated to be 60,000t/y aluminum, it is apparent that the utilization is not 100 percent. Alumina feed, metal syphoning, and transfer of hot metal pots were seen to be carried out with much manual effort. In spite of the relative lack of sophistication of the plant, the general maintenance standards are quite high; pot lines and aisle lines were seen to be clear. The pot off-gases comprising CO are burnt with excess air through a simple but effective after burner chamber. Each pot line after burner is provided with an individual off-take before being ducted to stack (after suitable dilution with cooling air). There are no facilities for gas cleaning.

Unfortunately, due to the inherent deficiencies of the technology in place, the in-plant hygiene would be considered unacceptable; crust breaking, tapping, and stud pulling all contribute to severe emission of pot gases—usually laden with tar, fluorides, and particulates. The smelter personnel and the pot line operators have not been provided with or were not using face masks/air filters.

Use of self-baking anodes and the 80 kA cells, results in low current efficiencies of electrolysis and higher carbon consumption; the former is unlikely to exceed 82 percent while the latter is probably two to three times the average for a modern plant.

It was not possible to visit the carbon plant; however, it became apparent from discussions with the smelter personnel, that:

- The technology employed is archaic
- In-plant hygiene is poor
- Considerable variations in the feed stock composition—petroleum coke sourced from the Czech oil refineries, tar and pitch contribute to a high percentage rejection of the products.

Pollutants and sources of pollution

Identification of the main sources of pollution to the environment from the smelter/associated facilities, and a quantitative annual estimate of such pollutants have become recently available; both the operations and the authorities have set up monitoring stations (6) around a 5 km radius of the smelter/fabrication complex. In addition groundwater/river water monitoring facilities have been set up. Based on the above exercise, the ZSNP's environmentalist provided the following information:

Pollutant	*Tons per annum*	*kg per ton of aluminum*
SO_2	6,100	125
Dust/particulates	1,900	38
F (volatile)	847	17
Tar and PAHs	800	17

These figures are considerably higher than the permitted levels allowed by many regulatory authorities, particularly in the West where the levels enforced are:

	kg per ton of aluminum
SO_2	
Dust	8 - 1.5
F	0.5 - 0.25
Tar and PAHs	0.2

While the monitoring of the airborne pollution mentioned above can be regarded as being credible (although actual details of the sampling procedures and aggregation of such data are not known with certainty) data regarding aqueous pollution is not available. It is only in the recent past that operations have started modifications, rectification, and isolation of the red mud disposal area. It is generally conceded that some groundwater pollution would have been unavoidable.

Environmental strategy of ZSNP

ZSNP commenced in 1984, a detailed study of the projected course of the future aluminum smelting at Ziar. Although much has happened since those days, the fundamental philosophy of the strategy remains in place viz, to abandon the older technology and replace it with a modern design incorporating all the proven advances. The works entered into a know-how/technology transfer agreement with Hydroaluminum of Norway and commenced the design and construction of a modern aluminum smelter.

At the time of the visit the new smelter construction was seen to be well advanced. The main features of the new aluminum smelter are:

- Use of higher current cells—180kA
- Use of prebaked anodes
- Installation of modern industry-proven dry scrubbing system for the abatement/elimination of fluoride emissions from the pot lines
- Installation of electrostatic precipitators for the clean-up of particulates
- Recovery, treatment, and recycling of all aqueous discharges.

The main operational features of the pot lines are:

- Nominal capacity is 106,000 tons of aluminum per annum
- Current efficiency is over 92 percent
- Carbon consumption is 20–30 kg per ton.

Extensive process control instrumentation is part of the design.

ZSNP is hoping to bring the new smelter on line by the end of 1994; the old smelter will be progressively shut down.

Impact on pollution

With the installation of the new smelter with modern pollution control technologies, it is confidently expected that the emission levels of the pollutants from the smelter will approach that achieved in the Western World. The guaranteed (Hydroaluminum) pollutant emission levels are:

Pollutant	*t/a*
SO_2	100
Fluoride	66
Dust	300
Tar	0

Investment plans

With regard to pollution-related investment, the approach has been to rebuild. The new smelter described above involves a total investment on the order of US$ 300 million.

It is not appropriate to attempt a detailed economic analysis of the future performance of ZSNP. The following information was provided by ZSNP:

- The company has been transformed as a joint stock company with a clear objective to be commercially successful

- The company has raised finance independently from banks to complete the smelter replacement (US$300 million)
- The company has secured long-term supply contracts from:
  - Yugoslavia for bauxite
  - Hungary for alumina
- Long-term favorable tariff rates for electricity have been agreed with the generator
- The company has developed an extensive marketing network, and believes that as a custom aluminum smelter it can compete effectively in the international market; it is also firmly of the view that the internal Slovakian market will remain largely captive.

Conclusion

The efforts of ZSNP to combat pollution and increase productivity follow a textbook course to success, based on complete plant modernization.

Plovdiv case study

Introduction

The facility at Plovdiv in Bulgaria comprises separate treatment lines for both lead and zinc production, with the major revenue derived from zinc metal sales. Severe environmental problems related primarily to lead emissions have been encountered. Significant improvements have been made, in particular with regard to dust emissions, as a result of a recent action plan. Further work is in hand to address sulfur dioxide and liquid effluent emissions.

Plant location

The KCM-S.A. facility occupies a site adjacent to the main highway some 10 km Southeast of Plovdiv. The area incorporates a number of industrial operations. This industrial area is, however, located within the Upper Thracian valley an area of some 100 km long by 40 km wide bounded by mountains with an average height of 1,000 m. This area is traditionally an agricultural area with fertile alluvial soils on which some large-scale farming is undertaken.

The nearest population centres are villages of 2,000–3,000 people each at distances of a few kilometers with Asenograd, the nearest large town (40,000–45,000), at approximately 3 km distance.

Plovdiv is the next nearest major population center being some 10 km to the northwest of the plant (population 350,000).

Products, processes, and utilities

Products

While the focus of this case study is on lead smelting operations, information on the zinc operation is also included since zinc sales currently represent approximately 70 percent of metal revenues. The major plant products are:

- 30 kg zinc ingots
- 25 kg zinc ingots
- 47 kg lead ingots
- 600-700 kg bismuth lead cakes (7 percent Bismuth).

Zinc production in 1992 was approximately 50,000 tons per year. Sulfuric acid (fertilizer grade) is produced with a nominal 93 percent concentration. Current annual lead production is approximately 32,000 tons.

In addition, the complex produces a number of co-/by-products for sale including:

- 4.4 kg cadmium ingots
- 50 kg bags zinc sulfate
- Speiss and matte intermediate products
- Gold and gold alloys (wire, dental gold, etc.)
- Silver and silver alloys (wire, foil, granules, and amalgam)
- Cermet products (tungsten-cobalt tips, buttons, dies, etc.)
- Polymer concrete products.

Processes and utilities employed

The lead/zinc works at Plovdiv was designed by the Russian GHIPROTSVETMET organization with the first lead productions in 1963.

Crude lead bullion is produced by the conventional sinter, blast furnace route. Subsequently dry refining in kettles is carried out, followed by casting of pure lead ingots or lead bismuth cakes.

A major part of lead sulfide concentrate feed is supplied from local mining/concentrator operations located some 60 km from the Plovdiv smelter. In addition lead-bearing residues and precipitates are treated. The majority of concentrates are delivered by road in covered trucks (50,000–60,000 tons/y). Local concentrates are high grade (predominantly galena) averaging 65 percent Pb. A significant portion of concentrates is supplied from Greece.

Concentrates are off-loaded by grab crane or alternatively tipped from self-tipping trucks into ground-level storage bunkers. The storage/blending facilities are only partially covered and the majority of concentrates are therefore exposed to the weather. This concentrate storage area clearly gives rise to losses and a screen wall has been erected alongside the outdoor stockpile area to reduce concentrate wind pick-up. This has appeared to have resulted in some reduction in wind losses although this cannot be quantified.

Concentrates are transferred with fluxes by means of overhead grab crane and an underground conveyor to the mixing/bedding plant. Here the feed is proportioned from bins and blended according to a predetermined mix together with recycled sinter plant fines. After blending the feed mix is conveyed to the sinter strand facility.

This comprises a single downdraught $50m^2$ Dwight-Lloyd sinter strand. Ignition of the blended feed is achieved by an oil burner, following which combustion proceeds. The sinter is discharged from the sinter strand and passes through a "finger" breaker and cooler prior to conveyer transfer to the sinter screening building.

Because of the low sulfur content in feed and the design of the sinter strand the relatively weak sulfur dioxide content gases exit the sinter strand. These gases are unsuitable for direct treatment in an acid plant. Partial recycle of gases has been introduced to increase gas strengths. Sinter strand gases are split with a portion (approximately 25 percent by volume from the first three sinter strand chambers) ducted to combine with the strong gases from the zinc roasters ahead of the gas cooling/cleaning facilities of the acid plant. The balance of gases are ducted to the central bag house facility where particulates are removed prior to discharge of gas to stack.

The broken sinter is screened in the sinter screening plant which comprises both screening and crushing. Oversize is used as feed to the blast furnaces with undersize conveyed to the crusher plant prior to recycle to the feed/blending area. The screening and crushing plant have each been recently equipped with new bag house facilities. KCM selected bag houses for this duty because of poor experience with wet scrubbing systems. The industry experience indicates either bag houses or scrubbers are preferred for this application.

Smelting of sinter is carried out in conventional water-jacketed blast furnaces. Only one of the two installed units is normally operational with the second unit under maintenance or on standby.

The sinter is blended with proportioned coke feed and conveyed to each side of the top of the blast furnace where it is charged via a gas-seal device incorporating automatic level control. The blast furnace feed operation is fully automated, avoiding the need for operator presence. The design compares favorably with best design practice in Western operations.

Air is blown into the blast furnace via tuyeres arranged in two banks at the base of the shaft. The water-jacketed blast furnace is of the steam-raising type.

Blast furnace off-gases pass through water-cooled settling chamber and cyclones and a wet scrubbing tower prior to final dedusting in bag house units.

Crude lead bullion formed by the reduction of lead oxide in the furnace collects in the hearth of the furnace. From here lead bullion is tapped continuously via a siphon arrangement in the furnace sidewall into a transfer ladle. Slag is continuously tapped from the furnace end-wall, initially into an electric slag cleaning furnace. From this slag cleaning furnace slag can flow directly to a slag fuming furnace. Alternatively slag may be accumulated in the electric furnace to undergo cleaning by electrical reduction, following which the cleaned slag is granulated by a conventional high-pressure water granulation system.

The slag fuming furnace removes zinc and volatiles from the slag by the introduction of heavy fuel oil reductant through tuyeres beneath the slag bath. Oxide fume formed is collected in a waste heat boiler and bag house facility handling the fuming furnace off-gas. Cleaned slag from the fumer is granulated by water in the same way as primary slag. This slag is sold to the cement industry, used for road construction, or dumped at an adjacent military facility. Fumer oxide is roasted in hearth roasters (currently due to be replaced) and leached for zinc sulfate production.

Crude lead bullion is transferred in ladles by an overhead travelling hoist to the lead refinery. Crude lead is treated by sequential dry refining in cast-iron kettles.

The refinery comprises nine kettles of nominally 310 or 260t capacity. Kettles are heated by heavy fuel oil and are currently operating without ventilation covers.

Refining follows conventional processing routes as follows:

- Cooling and separation of matte and speiss
- Copper removal as drosses by sulfur addition
- Softening (removal of arsenic, antimony, and tin) with molten caustic
- Desilvering by zinc addition
- Dezincing
- Bismuth removal by Ca/Mg (Harris Process).

Silver crusts are transferred to the adjacent silver refinery and are processed conventionally by:

- Retorting to volatilize zinc
- Cupellation.

The final 96 percent Ag, 1 percent Au product is sent to Bulgaria's MDK copper smelter at Pirdop for refining.

Refined lead is cast into 25 or 30 kg ingots which are stacked and strapped for shipment, 7 percent Bismuth/lead is cast into 600–700 kg cakes.

The zinc plant comprises charge blending followed by roasting in two Russian-designed fluosolids roasters. Off-gases are dedusted in water-jacketed cyclones and electrostatic precipitators prior to treatment in the two-line sulfuric acid plant.

Zinc calcine passes to two stage leaching and solution purification prior to electrowinning of zinc cathode. Leach residue is treated by Waelz Kilns to produce zinc oxide for recycle to the leach circuit. Cathodes are melted and cast into ingot products for market.

The leach and electrowinning facilities were not viewed as part of this visit. It is, however, understood that the tankhouses use labor-intensive manual stripping of small (1 m^2) cathodes. A recently installed electrolyte cooling tower facility was noted. This should improve in-plant hygiene, by scrubbing acid mist.

Economic viability

As indicated, the plant currently produces around 32,000t/y lead and 50,000t/y zinc, with zinc the major revenue. In terms of capacity viewed either as a zinc or lead smelter this represents a relatively small operation, certainly in the lower quartile of operating plant capacities.

In terms of technology the plant uses conventional, well-proven techniques rather than state-of-the-art technology. It does not therefore benefit from savings in economy of scale or energy efficiency which larger capacity or modernized technology might provide. Modernization programs envisaged by current management are geared towards:

- Increased capacity and higher efficiency units in zinc plant operation (i.e., single large roaster, new acid plant facilities, and modernized tankhouse operation)
- Improvement of reliability and environmental performance with retention of the existing lead plant technology.

The current metal products of KCM are LME registered and are thus readily accepted in international markets (although currently the major markets are more locally distributed).

Feedstock for lead plant is secure in the medium term, zinc plant feed is generally imported (i.e., custom smelted).

The acid by-product appears to have a secure local market (fertilizer/chemicals) with the benefits of short transport distance. The future potential acid capacity increase and its relation to current market is unknown.

Supplies of all consumables, except Ca/Mg are local. Thus:

- Coke is supplied by Bulgaria's Kremikovtsi steel works—a short rail journey away (60 km)
- Coke fines are used in the Waelz process and in fuming of slag
- Heavy fuel oil is delivered from the Burgas refinery—if possible low-sulfur HFO is purchased. Prices are international following the loss of subsidized Russian supplies (current HFO \$108/t or \$125/t for low sulfur)
- Caustic soda is Bulgarian supplied (\$400/t)
- Fluxes are locally sourced; CaO is purchased as residue from local calcium carbide plant
- Electrical energy is currently low cost at 35 Leva/ 1,000 kW hour; the Leva/US\$ exchange rate has remained very stable at 22–26.

The lead market some two years ago was 90 percent internal—related to a large battery production program. This market has now reduced but with LME registration achieved the lead product is readily exportable. Current forecasts indicate 70 percent internal sales and 30 percent export.

There is a secondary lead plant located some 100 km from KCM with a nameplate capacity of 50,000 t/ year. Actual production at this plant is however stated to be only 10,000 t/y.

Total KCM labor force is around 2,000. Of this figure approximately 500 relate to the lead plant, 600 to the zinc plant, 150 to the Waelz plant, and the balance in engineering, maintenance, and administration. Labor costs represented around 8 percent of production costs (excluding materials and energy) some two years ago. This has now risen to 30 percent. In relative terms KCM staff are understood to be well paid.

Despite earlier decrees to close the lead plant operation, management have been able to maintain and consolidate operations while also decreasing production and tackling the most critical environmental issues.

From an overview of the above factors it is considered that while scale and technology would indicate a non-viable operation, the other factors present—in particular secure feedstocks, sound market, product quality, and good integration of by-products locally—make the plant appear in the "middle band," that is, somewhat less than archaic with relatively old technology but still capable of meeting overall economic (profitability) criteria.

Pollutants and sources of pollution

Two earlier assessments of emission profiles at KCM were undertaken in 1992 by a British Council mission and a Dutch Consulting group (Haskoning). These provide detailed information on airborne, liquid, and solid discharges.

The emission of pollutants and its effects at Plovdiv can be broadly split into two areas:

- Large-scale pollution of the surrounding ecosystem by lead-bearing dusts—this is linked to historical operations. For a period lead production was raised to a level of around 70,000 t/y—almost twice the nominal design capacity. This was achieved by operation of both blast furnaces with apparently little regard for maintenance or, more importantly, environmental aspects
- In plant and local emissions leading to worker exposure to lead in dusts, cadmium—sulfur dioxide emissions, and water contamination by heavy metals.

The sources of lead pollution from such operations are well known and documented from similar earlier experience of lead pollution in "Western" plants.

The major sources of airborne lead containing dusts are therefore:

- Dusting and wind losses of concentrates from transport, offloading operations, storage stockpiles, etc.
- Dusting from blending, mixing, screening, and crushing operations
- Fume and dust emissions from sinter strand, blast furnace, fuming, and kettle refining operations.

The major sources of sulfur dioxide are sinter strand off-gases (and fugitive gases). The primary source of sulfur dioxide generation at Plovdiv is, however, the zinc roasting operation.

In order to quantify sulfur dioxide emissions from the lead sources a semi-quantitative sulfur balance was prepared during the plant visit. This is summarized below.

Some 23.2 percent of sulfur in feed is currently collected as acid. S in gases from the sinter strand operation amounts to 77.3 percent of total sulfur in feed and approximately one-third of this is currently fed to the acid plant.

For liquid effluent three main sources are identified:

- Discharges of untreated wastewaters from gas cooling and scrubbing operations
- Wastewater from slag granulation facility
- Rain water and "damping down" water run-off from the site.

Solid effluent mainly comprises waste slag which may contain soluble heavy metals.

Earlier reports indicate that most emissions exceeded EC guideline limits (prior to the implementation of current action programs).

Existing pollution control facilities

As indicated, historical operation led to an increase in plant output to as high as 70,000 t/y of lead without

Sulfur balance—lead plant

Input	*Sulfur ton/ annum*	*Percent*	*Output*	*Sulfur ton/ annum*	*Percent*
Concentrates	7,070	100	Sinter gas to acid plant	1,640	23.2
			Sinter gas to stack	3,829	54.1
			Blast furnace gas to stack	1,263	17.9
			Discard slag	207	2.9
			Speiss	11	0.2
			Matte	120	1.7
			Total	**7,070**	**100.0**

regard for environmental consequences. Pollution of a substantial zone around the plant area has occurred. In the mid-1980s production was cut by around 15 percent and in the early 1990s plant lead production was further reduced to nominal design levels (around 40,000 t/y). Subsequently, as part of the action program to address environmental issues, production was further constrained to below original design levels. This was undertaken specifically to reduce overall emissions of lead and included reduction in blast furnace hearth area from 8.9 to 6.7 m^2 and corresponding blowing rates by 27 percent.

The historical pollution of surrounding countryside remains a serious issue which has been investigated in detail. The scale of pollution, extending for many kilometers, renders soil treatment strategies non-viable, although promising results have been obtained locally with in situ electrolytic clean-up techniques.

In practice, however, this issue will not be readily solved quickly and it is clear that even closure of the lead plant will not solve the existing contamination problem.

The action plan was initiated as a direct result of lobbying by environmental pressure groups, particularly Ecoglasnost which were active in the political changes within Belgium.

Following the implementation of an action plant to tackle the major sources of pollution within the lead plant, significant improvements have been made, particularly with regard to emission of lead-containing dusts and scrubber effluent. This lead plant action program was nearing completion at the time of the visit so this section of the report also refers to "existing" facilities nearing completion.

From discussions, analysis of earlier study reports, and observation of the existing facilities it is evident that the major sources of lead dust emission have been identified and equipped with (new) control equipment. The main thrust of this work which has been carried out in the last one and one half years has been the upgrading/replacement of old dust collection and gas cleaning equipment and the addition of new equipment and process control.

Dust emissions

Previous operations relied on the use of a central bag house facility to treat all gases collected (mainly from the blast furnace and sinter operations). The old system had insufficient capacity and relied in certain areas on wet scrubbing systems which appeared to be of low efficiency (or alternatively were difficult to maintain). A number of areas had no gas treatment or had inadequate hooding and containment to collect fugitive gas and dusts.

The plant, as viewed, incorporates new bag house facilities including:

- New bag house and hooding and extraction systems for the crushing and sinter cooling operations (replacing scrubbers)
- New bag house facility for the sinter screening plant facility (replacing scrubbers)
- New bag house facility for refining plant ventilation
- Incorporating individual dust containment/extraction systems for retorts, cupellation, and short rotary furnaces. As yet no individual kettle hoods have been installed
- Gases/dusts from the fuming furnace, blast furnace, and sinter strand operation pass to an eigtht bag house unit bank forming the central bag house unit. These units were modified to incorporate double bags in 1991 thereby increasing collection efficiency; overall dust discharge levels of 6-7 mg/m^3 were reported for this unit which is within the 10 mg/m^3 limit to be imposed from January 1993
- Details of the dust collection facilities and dust emissions to air are given in Table H.2.1 with data added for December 1992.

Dusting within the concentrate reception/storage area has been partially tackled by the construction of a perimeter wall on one side of the open storage area in order to reduce the impact of prevailing winds. This facility still requires further attention to reduce dusting and spillage losses.

Wetting of roadways has been introduced (although its effectiveness could not be observed because of wet weather during the site visit). It is probable, based on experience elsewhere, that such practice may in itself generate a contaminated secondary pollution problem in the form of washdown water drainage. Plant housekeeping standards were mixed, with some areas good and others poor.

A new control and monitoring system has been purchased, installed, and was being prepared for commissioning during the plant visit. This will provide on-line monitoring of gas/dust emissions from the main lead plant stack and individual bag house discharges.

Table H.2.1 Emissions to air in 1991—lead plant

Process	Dust-catcher	Gas quantity Nm^3/h	Working time	Dust mg/Nm^3	Dec 1992[1]	Content % Pb	Zn	Cd	SO_2 g/Nm^3
Sintering	Bag Filters	220,000	4,794	20					13.15
	URFM-1 No. 6,7,8								
Classification	Scrubber No. 1	10,000	4,794	32		44	0.7	1.8	-
	Scrubber No. 2	6,200	4,794	23	6 - 7	44	0.7	1.8	-
	Scrubber No. 3	9,200	4,794	24		55	7.7	1.2	-
Crushing	Scrubber No. 4	5,000	4,794	20		40	8.0	1.4	-
	Scrubber No. 5	3,000	4,794	40	6	40	8.0	1.4	-
Sinter Cooling	Scrubber No. 6	10,000	4,794	30		40	8.0	1.4	-
Blast Furnace	Bag Filters URFM-1 No. 2,3,4,5	320,000	5,855	12	8[2]	44.7	17.1	8	22.80
Fume Furnace	Bag Filters	100,000	1,400	15	7[2]	18	55	0.7	-
Roaster	Bag Filters FK 4/100 No. 1	4,300	1,400	40	7	12	60	0.1	-
Vent. Gas	Impulse Filter	64,500	6,855	12.3	5 - 6	36.7	31.2	8	-
Refining	FK 4/100 No. 2	10,000	3,121	50	7 - 8	60	7.0	-	-
Comb. System		20,000							4.25
Vent. Gas Refinery	Impulse Filter	50,000			5 - 6				

[1] Values added subsequently for December 1992.

[2] Double bags.

This is intended to assist in identifying plant failures and may be used as a data collection facility on emissions.

SO_2 emissions

The major SO_2 source is, as discussed, the zinc roasting operation, which currently includes a two-line sulfuric acid plant of Russian design. This unit is in generally poor condition with clear evidence of severe corrosion and leakage particularly with regard to acid coolers. It is probable that acid leakage is occurring as well as acidification of groundwater and consequent corrosion and solubilization of heavy metals and other deleterious compounds. No detailed information on this area was however obtained.

One line of the acid plant incorporates the Russian Matros process or reversing catalysis system which is in use in about 10 plants in the former USSR. This technology permits treatment of generally lower-tenor SO_2 gases than normally acceptable to acid plants, which is clearly beneficial where significant dilution occurs.

As previously discussed a portion of sinter strand gases from the lead plant is collected and ducted to the acid plant (when possible) for cotreatment with the main SO_2 gases from zinc roasters. It is clear that the proposed investment in zinc plant/acid plant will itself facilitate treatment of more sinter plant gases. It is surmised that consistent processing even of the small proportion of sinter gases at present is problematic.

Liquid effluents

A detailed evaluation of water treatment systems was not undertaken but it was understood that they comprise pH adjustment to reduce solubility of heavy metals and tank sedimentation. The action plan has involved replacement of a number of wet scrubbers by bag house units thus reducing effluent for discharge.

Slags after granulation are currently sold to the cement industry or for ballast in road/rail building. Any surplus is dumped in a landfill site located at a military base near to the plant. This was not visited.

The Haskoning report of 1992 has been used as the source for Table H.2.2 which shows emissions for 1991 from the lead plant. These figures exclude benefits from the recent action program.

Environmental strategy (future pollution control strategy)

With regard to lead pollution as discussed, KCM has already initiated a short-term action program to address the most critical sources of pollution. This short-term plan was nearing completion at the time of the visit, and appears to have made significant progress in addressing the priority pollution issue of dust emissions.

Tangible progress has also been made in reducing liquid effluent discharge (replacement of some wet scrubbers by bag houses).

As detailed in the preceding section these steps are on target to achieve dust emissions from cleaning devices below 10 mg/m^3 compared to previous values up to 50 mg/m^3.

The cost of these improvements (funded by KCM) was given as 26.5 million Leva broken down as follows:

	Leva
Bag house units	12 m
Reduction in blast furnace size and repairs	10 m
Monitoring/control system	4.5 m
Total	*26.5 m*

Further improvements have been made in other areas and are ongoing. Introduction of clean/dirty work area practices for the plant work force has been implemented.

Some 120 m Leva was stated to have been spent on education in the last one and one half years, some of this being related to addressing the historical lead pollution of the surrounding countryside. With regard to possible pollution control measures, their indicative

Table H.2.2 Total emissions from KCM-S.A. lead plant (1991)

Pollutant	*ton/annum*
Discharge to air	
Dust	58.7
Lead	25.9
Zinc	0.7
Cadmium	105 kg/annum
	18,406
Discharge to water	
Lead	6.9
Zinc	22.8
Cadmium	0.8

cost and their impact on emissions, the following priorities emerged for the lead plant:

- Possible modification of one line of acid plant to Matros technology to facilitate increased treatment of low-strength gases from lead plant sinter strand. A clear definition of this project was not obtained but an indicative cost of $1 million and an improvement in sinter plant gas treatment from 23 to 50 percent was indicated. Such an investment has, however, to be considered in relation to potential improvements on the zinc operation which will affect acid plant aspects. Modification of the sinter machine is also involved
- Design of a new water treatment system (closed circuit incorporating Lamellar thickeners for solids removal) has been initiated; the purchase and installation costs for this new system require funding (about $900,000) although design work is being self-funded.

In general the lead plant environmental investments to date are geared toward retention of the current technology and its improvement. There has been pressure (including earlier government decrees) for closure of the lead plant. However, this will not resolve the long-term problem of regional ground contamination.

Plant management consider (and had previously initiated but then suspended) a feasibility study is necessary to evaluate the options for the lead plant facility. The favored approach is to retain current conventional technology but continue to enhance the environmental and economic performance. (This is the approach adopted in mature lead operations such as MHO in Belgium.) The alternative approach involves consideration of newer technologies regarded as environmentally superior but suffering from the disadvantages of:

- Lack of substantial track record or proven nature
- High capital investment and consequent need to consider larger-scale operation to be economic
- Technologies to be considered include KIVCET, QSL, and ISAsmelt
- KCM has not obtained funding for this study (although self-funding is again being considered).

It is evident that such a study is necessary to compare technical and economic aspects of both the conventional and new technology options in order to facilitate decisions on medium-/long-term strategy. An order of cost estimate for such a study is $250,000. An early 1993 start for the study is intended with recommendations by year end.

Radical plant replacement investments are not considered appropriate without prior evaluation.

A number of more general investments relating to rehabilitation, repair, and enhancement of existing buildings and structures with a view to improved dust containment appear necessary.

Natural gas substitution for oil has been initiated. The major planned investments, however, relate to zinc operations as discussed below.

Investment plans of KCM

The major planned investment relates to modernization of the zinc plant at a cost estimated to be in the region of $100 million.

At present a short-term action program (similar to that for the lead plant) has been initiated on the zinc plant. An initial investment relating to installation of roof-mounted electrolyte coolers has been undertaken on the zinc tankhouse.

The main investment, however, relates to modernization and expansion by:

- Replacing the two fluosolids roasters by a single Lurgi unit
- Tankhouse modernization (increase to 3 m^2 "super-jumbo" cathodes with automated handling and stripping)
- Reconstruction of the acid plant.

Of the total $100 million estimated cost approximately 25 percent will be local. Zinc production will rise to around 85,000 t/y with lead production maintained at current levels around 32,000 t/y. The main environmental benefits in this investment would relate to improvements in zinc plant areas such as:

- Fugitive and untreated SO_2 gas
- In-plant hygiene (particularly acid plant and tankhouse)
- Improved operator working conditions
- Reduction in liquid effluent.

It is understood that the zinc expansion project has currently reached the stage of a draft financing package (backed by metal sales) but requires a government guarantee for contract completion. KCM has decided to self-finance design work for this project.

It was not possible to obtain further quantification of these improvements—these being related to the zinc plant area.

Some benefits from this investment would, however, accrue to the lead plant, including:

- Improved capability to treat more sinter strand offgases
- Consequential benefits from the improved overall revenues (lead revenues would fall to only 15 percent of total metal revenues at current prices).

Conclusions

Despite small capacity and old, conventional technology, the KCM lead plant represents a marginally viable operation in which substantial progress has been achieved in addressing severe environmental difficulties. The future is largely linked to investment decisions on the larger adjacent zinc operation.

Copsa Mica case study

Summary

The SOMETRA Metallurgical Plant at Copsa Mica was chosen to be a "benchmark" for the lead and zinc smelter industries.

The plant treated more than 100,000 tons of lead/zinc concentrates in 1989. With the closure of one process line, the plant now treats less than 30,000 tons per annum. Part of this reduction has been caused by factors associated with political change within Romania.

The plant is old and generally in poor condition. However, the plant technology is still employed successfully elsewhere in the world. There is no technical reason why, with the necessary work to bring the plant back to full operating condition plus regular maintenance and good plant management, it should not be run in a way which produces the least pollution.

SOMETRA is a major source of pollution in Copsa Mica, releasing large quantities of sulfur dioxide and lead-bearing dust to the general environment.

The major problem at the site is the acid plant, which is in very poor condition. It is the opinion of the consultant that the acid plant should be replaced with a new unit. Only a detailed examination of the acid plant and its function in the total process can confirm or deny this prognosis. A new acid plant is required if significant releases of sulfur dioxide are to be prevented.

The sinter plant is also in poor condition which gives rise to large fugitive releases of sulfur dioxide and dust. This plant can be repaired at significant cost and will then operate with limited emissions.

In the smelter area of the plant, dust and fume control systems are fitted to the major emission points. However, these systems are not functioning well and could be brought back to good operating condition with some repair and maintenance. There are other point emissions which require hoods and filters to clean the discharge. This could be best achieved by installing collection hoods ducted to suitable bag filter(s).

Much of the lead reaching the environment comes from the concentrate storage and handling and other windborne losses which have accumulated around the site over the years. The site is in need of thorough cleaning to remove deposits of concentrate that are spread all over it. To reduce concentrate losses the storage building should be totally enclosed and handling operations equipped with water sprays and suitable dust collection/filter systems. Various dust suppression and collection systems for concentrate handling and storage are estimated to cost \$0.5 million. Simply closing the side of the existing concentrate building would be a low-cost (<\$20,000) improvement.

The wastewater discharged from the plant is currently passed through a water treatment plant before discharge to the river. This plant is not functioning well and is in need of repair and maintenance. It was not clear whether all wastewater including run off water is treated in this plant. A new water treatment plant is estimated to cost \$10 million.

The plant in general is poorly instrumented and lacks a modern process control system. The installation of modern instrumentation and process control systems would better integrate the process operations so that the whole process is more efficient. This efficiency improvement would directly reduce the quantity of pollution produced by the plant. Cost estimates for replacement with modern instrumentation are estimated at \$0.5 million through to \$5.0 million for a full computer-based process control system.

The overall viability of the plant should be the subject of a detailed examination to decide the cost-effectiveness of new acid plant and other improvements.

History of SOMETRA

The name SOMETRA stands for Society Metallurgical Transylvania. The metallurgical operation, which was originally for the extraction of zinc only, and was started up in 1939 by Van der Velde (a Belgium-based holding company). At this stage of its history the plant was privately owned and used selected local concentrates to extract zinc using horizontal retorts.

At some stage in its history the plant became state owned. When suitable zinc concentrates became scarce they switched to other technologies that could utilize bulk concentrates. An Imperial Smelting Process-based plant was built in the 1960s. This process is used to smelt lead/zinc concentrates and to recover both lead and zinc. The original ISP[1] plant was built by Powergas (now Davy McKee) under license from Imperial Smelting. From this time until 1972 SOMETRA remained a member of the ISP Club and benefited from regular technical contact with other ISP plants worldwide. In 1972 they were forced to drop their membership by the Romanian government.

In the 1970s another ISP process line was built by Romanian contractors, this being a copy of the existing ISP plant. The existing plant is still running whereas the newer plant was closed down in 1990. The newer plant was closed due to its poor condition, the company being unable to maintain it in serviceable condition. The acid plant in particular was in very poor condition effectively putting the whole of the No. 2 plant into an inoperable condition.

Site details

The village of Copsa Mica is located in the Transylvania region of Romania. It is in the valley of the Tirnava Mare River which runs approximately east-west between the towns of Blaj and Sighisoara. The nearest large town is Medias, which lies some 10 km north-northeast of Copsa Mica with Blaj being 26 km to the west and Sighisoara 44 km to the east. This is shown on the sketch map in Figure H.3.1.

The Visa River runs north-south and joins the Tirnava Mare River at Copsa Mica. The Tirnava Mare River then flows westward to the town of Blaj. This river is polluted upstream by textile factories at Medias and Sighisoara.

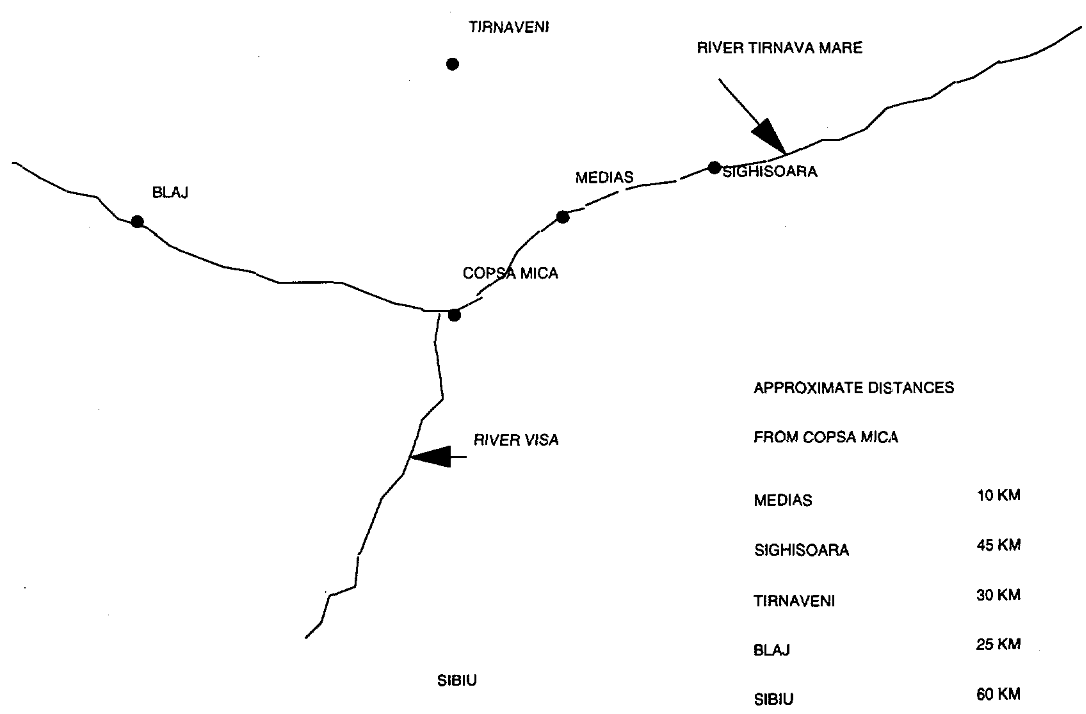
The village of Copsa Mica has a population of approximately 7,000 people. The population of the other towns in the region are approximately as follows:

- Medias – 80,000
- Tirnaveni – 30,000-40,000
- Sighisoara – 35,000-40,000
- Blaj – 30,000-35,000
- Sibiu – 140,000.

The main activity outside of the main towns is agriculture with cereal and other crops being grown in the region. Since the discovery of natural gas in the region in the 1930s various industrial activities have developed. At Copsa Mica two major industries were developed: a Carbon Black plant and the Lead Zinc Smelter currently under examination. Both plants are important to the general Romanian economy. The SOMETRA works employ some 3,000 plus people.

Both of the plants at Copsa Mica have given rise to very serious environmental pollution. Though of the

Figure H.3.1 Sketch map of area surrounding Copsa Mica



APPROXIMATE DISTANCES

FROM COPSA MICA

MEDIAS	10 KM
SIGHISOARA	45 KM
TIRNAVENI	30 KM
BLAJ	25 KM
SIBIU	60 KM

two plants the releases of sulfur dioxide and lead-bearing materials from the SOMETRA plant is probably the most harmful though the least visible.

A report in the National Geographic Magazine[2] has a series of photographs showing Copsa Mica that visually illustrate the pollution problems of the area.

A previous report[3] has estimated that some 200,000 people are affected by the pollution from Copsa Mica with some 75,000 living in an area where pollution levels are considered to be a serious threat to health.

The SOMETRA plant

The basic process flowsheet is shown in Figure H.3.2 and this can be used as the reference for following the process route.

The basic process encompasses a standard Imperial Smelting Process plant that can recover lead, zinc, and sulfuric acid from a lead/zinc sulfide concentrate.

Feed materials

The raw materials for the processes are all obtained internally within Romania. The major raw materials are as follows:

- Lead/zinc concentrates from Northern Romania (Baia Mare)
- Coke from various coke plants in Romania
- Scrap lead from various Romanian sources.

A figure of 50,000 tons of lead/zinc concentrates was quoted as the current annual consumption; this is most probably the approximate design capacity of the single ISP process line. This has dropped from a figure of 110,000 tons when both ISP lines were operating. (Only the No. 1 line is now operating, the No. 2 line was closed down in 1990.) Production figures quoted later indicated an actual concentrate consumption of some 26,000 tons. All the figures for production should be treated with care as the accuracy of the metallurgical accounting may be suspect.

The average analysis of the concentrate used is as follows:

- Zinc—32 percent
- Lead—24 percent
- Copper—1.6 percent
- Sulfur—25-30 percent.

The ore grade is quite acceptable for this type of operation and is amenable to treating by the Imperial Smelting Process. Obviously, higher-grade ores contain less gangue minerals and therefore produce less slag during the smelting operation. High-grade sulfide ores can produce a richer sulfur dioxide gas during the roasting process which improves the operation of associated sulfuric acid plants. There is, however, a balance to be struck between grade and recovery at the concentrator stage and the requirements of the roasting stage. The concentrates also contain small quantities of the following metals: cadmium, arsenic, gold, and silver.

The ISP blast furnace uses around 25,000 tons of metallurgical coke per year. The coke used has an ash level of 12–18 percent and 1–1.5 percent sulfur. The plant management said that the coke was not of a good quality and adversely affected the blast furnace performance. A lower ash content (<12 percent) would be beneficial but the physical quality here is more of a limitation. Important physical characteristics here are correct size range and strength to maintain correct burden porosity. The coke used by SOMETRA is of inferior strength and hence suffers size degradation.

The other major input is scrap lead which is added at the kettle treatment stage and amounts to 5,000–9,000 tons/annum of lead. The analysis of this material is varied and was not declared.

Various internally recycled materials are used and these amount to approximately 10,000–14,000 tons/annum. Better controls will probably reduce these recycled materials and therefore improve the process energy efficiency.

Products

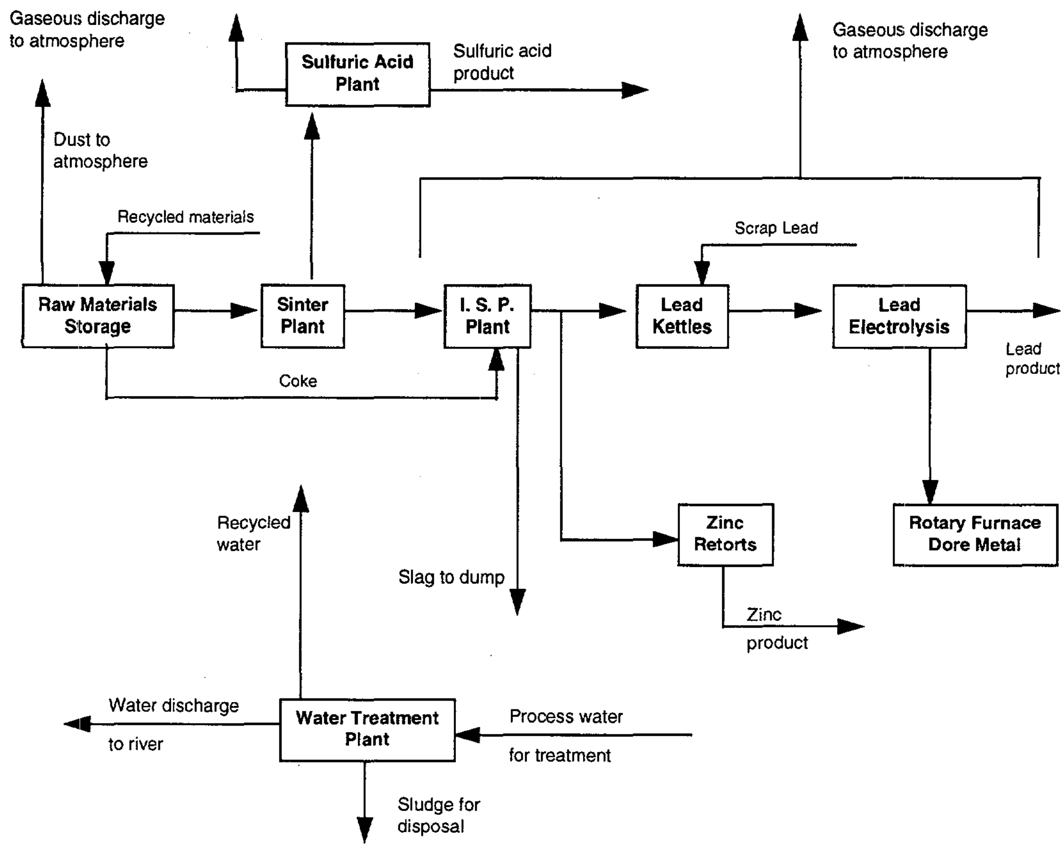
The major products produced by the plant are as follows:

- Lead at 99.99 percent purity to LME[4] standards, 8,000–10,000 tons/annum
- Zinc at 99.99 percent purity to LME standards, 15,000–18,000 tons/annum
- Sulfuric acid 90 to 98 percent concentration, 45,000 tons/annum
- Silver/gold dore sold to other Romanian companies
- Lead/copper dross sold to other Romanian companies.

Process description

The basic ISP process used at Copsa Mica is typical of many other ISP plants worldwide. The major differ-

Figure H.3.2 Simplified process flowsheet



ence is that this plant is in very poor condition and is in need of maintenance and replacement plant in certain areas, especially the sulfuric acid plant.

The various lead zinc concentrates are received into the works in railway trucks and are discharged into a covered stockyard area. During the discharge and reclaim activities in this building (it is open sided) there is obviously much dust created which blows around the site generally and into the surrounding countryside. The concentrates are reclaimed as required and are transferred by conveyor to the sinter plant feed bins.

The sinter plant bins have provision for storage of concentrates, fluxes, recycled materials, and return sinter. Sinter is recycled so that the total sulfur load to the sinter machine is around 6 percent sulfur. Recycled materials include such materials as sludge, blue powder, acid plant sludge, and ventilation sludge (from venturi scrubbers).

The lead zinc concentrates are blended with recycled products, sinter returns, limestone, and water in a mixing drum to provide to provide a consistent grade of feed to the sinter strand.

The sinter machine is an updraught machine that requires the provision of an ignition layer followed by the main sinter layer. The ignition layer is ignited by natural gas-fired burners; once ignited the updraught air blown through the sinter bed maintains combustion of the sulfur, forming sulfur dioxide, the heat of combustion sintering the bed together. The hoods and doors on the sinter machine were in a generally poor state of repair allowing large quantities of sulfur dioxide and dust to leak to atmosphere. This also allows ingress of air to the gas collection system, diluting the sulfur dioxide concentration and hence reducing the efficiency of the acid plant.

At the discharge end of the machine the sinter is fed to a breaker and then to a crushing and screening circuit. Sinter is either sent directly to the furnace, cooled and put into store, or sent back as sinter returns to the feed mixing drum of the sinter machine.

The sulfur dioxide and dust-laden gases from the sinter machine are collected and ducted to a washing tower and electrostatic precipitator system which removes the particulate matter. After this the gases are passed to the acid plant. The acid plant used is a single contact unit. The target sulfur dioxide content in the gas fed to the acid plant is 5.5 percent plus; this figure, however, has not been achieved since the early operating years of the plant. Average figures in recent years for the sulfur dioxide content of the gas stream have been less than 3 percent. The acid plant and associated gas cleaning equipment were in very poor condition. The ESP was not operational during the visit and obviously had not been so for sometime.

The sinter produced in the sinter plant is the main feed to the Imperial Smelting Furnace with coke and fluxes. The ISP furnace is similar to a lead blast furnace, the major addition being the lead splash condensers that are used to recover zinc.

Sinter, coke, and flux are charged to the furnace in the desired proportions. Preheated air at approximately 900° C is blown through the tuyeres at the bottom of the furnace. This burns the coke which generates a reducing gas that reduces the metal oxides in the sinter with the lead collecting in the bottom of the furnace and the zinc passing out of the top of the furnace, as a vapor to the lead splash condensers. At the top of the furnace hot air is added to partially burn the carbon monoxide which increases the temperature and prevents oxidation of the zinc vapor. The zinc vapor is collected in the lead splash condensers. The zinc is taken into solution in the molten lead and then by cooling the lead the zinc exceeds the saturation level and comes out of solution. The zinc is collected and passed to a casting machine.

The off-gases from the ISP furnace condensers are cleaned in Thiessen disintegrators to produce a clean low calorific value gas which is used as a fuel in the coke preheaters and the Cowper stoves (used to preheat the blast air). From an energy efficiency point of view the ISP furnace is relatively efficient in that the furnace off-gas is used as a fuel to preheat both the coke charged to the furnace and the blast air. Off-gases from the furnace top (at the charging point), the furnace forehearth, and other points are collected and ducted to venturi scrubbers for cleaning.

The slag tapped from the furnace is granulated in water and dumped on site. The slag was quoted as containing 0.7 to 1.5 percent lead; other analysis was not available. It is likely that the slag will also contain significant quantities of zinc. Without detailed operational information and slag analysis it is not possible to comment on the slag composition. The slag being water granulated will form a vitreous layer which will resist leaching by groundwater. The lead tapped from the forehearth of the furnace is passed to the lead kettles for further treatment.

The lead kettles are used for decoppering the lead. By cooling the lead to about 400° C and stirring the copper comes out of solution and forms a dross on the surface of the melt. The lead is cast into anodes for further refining by electrolytic means. There did not appear to be any fume extraction hoods in use over the operating lead kettles.

The final lead refining process is electrolytic refining which produces cathodes of 99.99 percent lead. The electrolytic technology used is supplied by an Italian company, Monteoni Montevecchio. The electrolyte used is imported hydrofluosilicic acid. This plant was not visited though it was claimed to be in reasonable condition.

Anode slimes from the electrolysis process are collected for further treatment as they contain the gold and silver. The slimes after washing are smelted in a short-bodied rotary furnace that produces a dore metal and slag containing other impurities.

The zinc is refined using New Jersey distillation columns to produce a refined zinc product of 99.99 percent purity. This plant was not visited and as such will not be commented on.

Water for use in the plant is drawn from the Tirnava Mare River at Copsa Mica. There is also an emergency reservoir at Baraj Ighis. The Tirnava River is already polluted by other industrial discharges into the river upstream at Medias and Sighisoara.

The plant is equipped with a water treatment plant which treats the various water streams from the plant before recycling them or discharging them to the river. The water is treated by settling, lime dosing, and flocculation before discharge to the river. This removes the solids and precipitates the dissolved metals. This plant, like many of the others, was in generally poor condition.

The water flows and analysis are as follows:

- Dirty water to settling tanks – 500-520 m^3/hour
- Recycled water – 220-270 m^3/hour
- Water discharged to river – 250-280 m^3/hour.

The discharge water analysis is as follows:

- Zinc – 2-12 mg/l
- Lead – 0.05-0.1 mg/l
- Cadmium – 0.001-0.01 mg/l.

On this basis the estimated annual metal discharge to the river can be calculated assuming that:

- The plant works 330 days/annum, 24 hours per day at 85 percent availability – this equates to 281 working days
- The total plant water discharge rate is 250 m^3/hour.

Therefore, metal discharge rates, based on average values, are:

- Zinc – 12 tons/annum
- Lead – 0.126 tons/annum
- Cadmium – 0.008 tons/annum.

These figures do not agree with the Government Commission figures reported in the Joint IAEI/UNIDO Report of December 1991. They reported 54 tons of lead being discharged annually to the river. Since these figures were reported, the plant is running at about one-quarter capacity which has produced consequent large decrease in discharges; however, the figures quoted by the plant still appear very low.

Pollution status

The general impression gained of the SOMETRA plant is a plant in a very run-down and poorly maintained state. The plant is in need of major investment to bring it up to a state where it can be safely operated without causing significant pollution. Lead and cadmium pollution can be significantly reduced by lower-cost pollution abatement techniques. To reduce sulfur dioxide emissions significantly will require much higher levels of expenditure.

The senior management of the plant were aware of the task ahead of them to return the plant to a viable operating unit. The various pollution problems were discussed and are reviewed below.

Government agencies have undertaken monitoring exercises in Copsa Mica and the surrounding regions. These surveys indicate the basic problems as being the release of sulfur dioxide, lead, and cadmium to the environment. From the examination of the plant made, measurements are not required for instance to determine the amount of sulfur dioxide released. A simple mass balance shows the quantity of sulfur dioxide being released (see Table H.3.1).

When examining the SOMETRA plant the major pollutants are those that would be expected, namely sulfur dioxide, lead, and cadmium.

Sulfurous emissions

The scale of the problem is shown by air monitoring tests which have reported high levels of sulfur dioxide in areas up to 10 km away in the town of Medias. Other sources of sulfur dioxide emission in the surrounding areas are likely to be from combustion boilers and are considered insignificant in comparison.

Table H.3.1 also illustrates the sulfur dioxide emission problem. Sulfur dioxide emissions were at a level over 50,000 tons/annum when the plant was running at full capacity. With the closure of the No. 2 ISP line the amount of concentrate processed has been reduced to 27,000 tons in 1991 with some 15,000 tons of sulfur dioxide being released to the atmosphere. This is approximately a 74 percent reduction in sulfur dioxide release.

The efficiency of the sulfuric acid plant in recovering sulfur should be over 90 percent (for a modern plant better than 98.5 percent); the SOMETRA sulfur recovery efficiency has been less than 10 percent in recent years. The decline in the efficiency of the acid plant can be ascribed to many factors, the predominant one being poor maintenance. Other factors are discussed in the following paragraphs.

For successful acid plant operation the feed gas stream needs to be of reasonably consistent flow and with a sulfur dioxide concentration above 5.5 percent (by volume).

When examining the situation at SOMETRA it is important to consider the sinter plant and acid plant as an integrated unit. The sinter plant is in poor condition with many leaks in the updraught and gas collection system. The ducting leading from the sinter hoods towards the acid plant were in very poor condition and leaking badly in many places. It was not possible to examine the sinter plant in any detail as the levels of sulfur dioxide around the machine made free access impossible.

Table H.3.1 Sulfur dioxide emissions

Year	Concentrate used	Sulfur in concentrate	Sulfur in concentrate	Sulfuric acid produced	SO_2 in sinter off-gas	Efficiency	Sulfur in acid	Sulfur lost	Sulfur as SO_2
	Tons	*Percent*	*Tons*	*Tons*	*Percent*		*Tons*	*Tons*	*Tons*
Standard	98,400	26.00	25,584	72,000	5.50	90.06	24,040	2,544	65,088
1970	104,625	30.10	31,492	58,195	5.34	59.13	18,622	12,870	25,750
1988	110,750	26.69	29,511	7,950	2.78	8.62	2,544	26,967	53,934
1989	107,985	27.96	30,193	7,510	2.26	7.96	2,403	27,790	55,579
1990	66,300	27.15	18,000	1,250	1.83	2.2	400	17,600	35,20
1991	26,954	28.28	7,623	802	1.89	3.37	257	7,366	14,731

The gas volume and concentration of sulfur dioxide produced from the sinter plant are variable due to the leaks in the system and poor sinter strand control (lack of modern instrumentation). The dirty gas (dust laden) is then passed to the gas cleaning system ahead of the acid plant. The gas cleaning consists of a washing tower and an electrostatic precipitator which removes the particulates and cools the gas before it enters the acid plant proper. This gas cleaning section has been functioning very poorly and the precipitator has not been working at all. The absence of efficient gas cleaning has allowed particulates to reach the catalyst in the acid plant which has poisoned the catalyst and therefore reduced the conversion efficiency.

High-efficiency operation of the acid plant relies upon consistent quality feed gas, i.e., correct sulfur dioxide concentration, no particulates, and relatively constant gas volume. This enables the plant to run at a stable temperature that maximizes conversion efficiency.

To summarize, the low acid plant efficiency is due in part to the poor condition of the plant and secondly to the variable quality and quantity of the gases received from the sinter plant.

A 250 meter high chimney stack was installed on the site approximately five years ago. This height of stack was chosen to provide good dispersion for sulfur dioxide and dust being discharged from the plant. Originally this stack was connected to the acid plant and other locations on the plant. In case of an acid plant breakdown the sinter plant discharged through a short stack to atmosphere. Following a recommendation of the IAEA/UNIDO report the sinter gas outlet has been linked directly to this stack so that in the event of acid plant failure the sulfur dioxide can be discharged via the tall stack. This should ensure better dispersion and lower ground-level concentrations of sulfur dioxide.

Lead emissions

The other major pollutant from the plant is lead, which comes from many sources. Lead levels in the atmosphere in the works are high, being above the 0.15 mg/m^3 TLV (Threshold Limit Value) occupational exposure limit applicable in the United Kingdom. Lead reaching the environment can be from two basic sources either by dust from the raw materials used or losses from the process, for instance lead fume from the lead kettles.

The site generally, roadways and yards, and so forth, are covered in a layer of black dust which is probably concentrate that has blown about the site. This dust will be high in lead and other metals and will either be windborne around the site and surrounding districts or washed by rain water into the nearby river. It is likely that there are high levels of the metals accumulated over the years in the ground. These will be leached by rain water into the groundwater and will find their way into underground aquifers and hence into the river. This has been identified in the IAEI/UNIDO report as a potential source of pollution of drinking waters.

At present the largest single source of lead pollution on site comes from the layer of concentrates that have been blown around the site over the years. Serious attempts must be made to clean up as much of this material as possible. In tandem with this the concentrate store and handling facilities should be modified to prevent concentrate being lost during handling. Simple water sprays installed at strategic points would have a big effect. A system of water sprays, dust extraction/filter systems, and suitable enclosures at various points would significantly reduce dust emissions. Dust losses from stockpiles are typically 0.5 to 1 percent of the quantity of concentrate handled. The system mentioned above would reduce stockpile losses and those during handling to less than 0.1 percent. Such a system is estimated to cost $0.5 million. This cost, however, depends very much on the exact circumstances and plant layout. Simply closing in the side of the existing building would be a low-cost (<$20,000) improvement.

Most of the plants appear to be fitted with fume collecting and dedusting equipment. For instance the ISP furnace has four separate fume collection and dedusting venturi scrubber units. These ISP dust and fume collection systems appeared to be working though it is difficult without detailed examination and measurements to assess the overall effectiveness. The major difference here would be that a modern Western plant would be fitted with additional dust and fume collection equipment to control more of the releases. The sinter plant off-gas collection system is equipped with washing towers and electrostatic precipitators. The pollution control equipment fitted to the sinter plant and associated off-gas system was not working effectively.

The lead kettle operation was fitted with hoods which could be swung into position over the kettles. There was, however, no sign of these being used.

The plant was built in the 1960s and as such was not fitted with the hygiene air systems that would be fitted to a modern plant. There is therefore a need to fit additional hoods in various points around the plant to control emissions. In particular the use of bag filters and suitable collection systems to control point emissions need to be fitted.

The plant in general is poorly instrumented, the controls dating from the 1960s and 1970s. Modern instrumentation and process control systems would greatly benefit certain areas of the plant and help to reduce emissions. In particular the controls for the sinter and acid plants are in need of modernization.

Wastewater

The wastewater from the plant contains various quantities of the metals from the process. The main ones of concern are lead, cadmium, zinc, and iron. All these can be reduced to relatively low levels by treatment in a suitable water treatment plant.

This involves settling, pH adjustment, lime precipitation, flocculation, and further settling. This will produce a sludge for disposal in which the metals are in a relatively stable form. However, in the West this type of residue has now to be sent to licensed landfill sites.

The water treatment plant at SOMETRA is a basic settling and lime-based precipitation plant. The plant is, however, in poor condition and in need of repair and modernization. With only one ISP plant running at reduced throughput this has probably helped to produce a cleaner water discharge.

Solid wastes

The major solid waste produced from the process is the slag from the ISP furnace. This slag is granulated in water at the furnace and then transported to a dump on the main site. This slag will have significant quantities of lead and zinc (cadmium will have been volatilized either at the sinter plant or in the ISP furnace) in a silicate-based slag. The rapid cooling of the slag during granulation will form a vitreous layer on the outside of the granules which will tend to prevent the lead and zinc from being leached from the slag by groundwater when dumped.

It may be worth treating old slag stockpiles to recover some valuable metals if present in sufficient quantities.

The other major solid wastes produced by the plant are from the venturi scrubbers which are used to dedust various gas streams. The sludges from these units are collected and recycled back to the process at the sinter plant. This is the same for many other wastes, though some such as dross are saleable to other plants for further treatment.

Occupational health

The occupational exposure information for the plant was discussed in some detail. Workers at the plant work a six-hour day and are medically examined at six-month intervals with lead levels in blood and urine being checked. (This compares with monthly blood and urine tests for U.K. plants.) If levels are found to be high (85 mg/l of blood) the worker is moved out to a spa town for two weeks. Workers can request examination if they are unwell. There are hospitals at Sibiu and Cluj with specialist occupational health centers.

The short working day (six hours) helps to reduce the workers' exposure to the various pollutants found in the plant. However it means the company has to have five full shifts of workers and hence this lowers the plant's productivity even further.

The basic hygiene requirements normally common to a lead plant do not appear to be present or enforced at the plant. It is normal that workers change their clothes on arriving and departing from work, there being a compulsory shower on leaving work. Smoking is not normally allowed in a lead plant nor for that matter is eating in the workplace.

Staff are each issued with a dust mask plus in certain areas a pair of goggles. On the visit to the plant there was no particular evidence of the use of safety equipment by plant personnel.

The basic results for lead tests on workers for the last three years are shown below:

Year	*Professional saturnism*[5]	*Early retirements due to lead disease*
1990	129	2
1991	84	4
1992	106	4

No special provisions are made for testing people from high-risk areas.

The plant monitors the concentration of lead in the air in the workplace. No results were presented for this monitoring though a IAEI/UNIDO report indicated that these values are above the Threshold Limit Value for lead (0.150 mg/m^3 in Romania).

One of the problems the plant has at the moment is the high turnover of staff. This has been caused by the changes in government that has allowed free movement of people (many people of German origin have left the area). The replacement staff have no experience of the industry and therefore require basic training. However it will take them some time to become fully familiar with their job such that they minimize the health and safety risk to themselves. New employees currently receive two days' induction training plus on plant instruction. Once a month there is "hazard factor" training.

Public health

Public health monitoring, with regard to the emissions from the SOMETRA plant, is carried out by the Ministry of the Environment. The Ministry laboratories at Sibiu carry out air monitoring tests in Copsa Mica and the surrounding districts. There are five locations where sampling of the air has been undertaken. These are as follows:

- Copsa Mica, at the Hospital, approximately 500 meters from the plant
- Copsa Mica, in the new quarter
- Baraj Ighis, site of the emergency reservoir
- Tirnasoara
- Medias, approximately 10 kilometers away.

The results for the air sampling tests taken at the above locations generally all exceed the limits quoted. However, insufficient information was presented to draw meaningful conclusions about the trends in this data. What effect has the drop in plant output had on pollution in the surrounding districts?

The monthly averages and maximum results for sulfur dioxide air monitoring were quoted by the plant management with the figures being shown below:

- Monthly average—280-600 mg/m^3
- Monthly maximum—700-2,000 mg/m^3.

Apparently the higher figures are normally found in the winter months.

The plant management quoted the government-imposed Public Health regulatory limits as the following:

- Sulfur dioxide – 250 mg/m^3/24-hour period
- Dust:
  - 500 mg/m^3/ ½ hour
  - 150 mg/m^3/day
  - 25 mg/m^3/year average
- Lead:
  - 0.7 mg/m^3/24-hour period
  - 0.05 mg/m^3 average
  - 0.1 mg/m^3 maximum.

The last two values for lead are the current legislation as of 15/07/91.

Capital expenditure plans

Currently any future investment plans are dependent on the availability of finance from the government. There are plans to privatize SOMETRA but presently any investment plans have to be approved and financed by the government.

Various paid studies have been undertaken by local specialized institutes but these have largely been stopped due to lack of money.

There was some discussion on project financing for small projects that the plant management believe they probably could finance out of revenue. Tests have been carried out utilizing cyclones and venturi tubes for dedusting hygiene air on the sinter plant. Small projects have been aimed at reducing point source emissions. No evidence was seen of actual setting up of any of these small projects.

The current plans for larger projects include the two following possibilities:

- New water treatment plant for line No. 1 – this project has been approved and finance is available and is due to be started in 1993. The Non-Ferrous Metal Institute from Baia Mare will design the plant which has an estimated capital cost of 1.5 billion Lei (approximately £3.5 million). The project has been conceived by the plant management and it is planned that the plant personnel will have a large participation in the project design and implementation
- Updating sulfur dioxide recovery – a feasibility study for a new sulfuric acid plant has apparently been carried out. It was not possible to learn what was included in this study. The financing of the project is uncertain but it is hoped that some work will start in May 1993. This assumes that the project will be financed by the state.

Diversification into other products was discussed with the aim of increasing revenue and utilizing empty buildings. Other potential products included those shown below:

- Chemicals
- Alloys
- Sheeting (requiring rolling mill)
- Oxides
- Salts
- Pigments
- Dyes
- Cadmium sulfate.

Recommendations

The plant is old and generally in poor condition. However, the plant technology is still employed successfully elsewhere in the world. There is no technical reason why, with the necessary work to bring the plant back to full operating condition plus regular maintenance and good plant management, it should not be run in a way which produces least pollution.

The major exception to the above is the acid plant and possibly the sinter plant. Considering the sinter plant, first it could be repaired so that releases of sulfur dioxide are minimized. Other repairs should be undertaken to reduce fugitive dust emissions from the sinter plant, particularly the sinter breaker and screening area. This in turn would prevent ingress of air to the off-gas system which would assist in producing a consistent level of sulfur dioxide in the sinter plant off-gas. The gas cleaning system ahead of the acid plant (electrostatic precipitator and washing tower) is not working. This has allowed particulate matter to reach the catalyst section of the acid plant and has poisoned the catalyst. It is therefore essential that the gas cleaning system be repaired or replaced. It is most likely that the gas cleaning system will be very badly corroded and should be replaced totally (only a detailed examination will confirm or deny this). The catalyst in the acid plant could be replaced at a capital cost of approximately $60,000. However, the acid plant is in such poor condition that total replacement of the unit is the only viable alternative. The acid plant is very badly corroded, leaking at numerous points with little or no working instrumentation.

A new acid plant is required if significant releases of sulfur dioxide are to be prevented. A minimum cost of $50 million (acid plant alone) is envisaged here rising to around $100 million for an acid plant and sinter plant. The plant cannot continue to operate without a new acid plant and major expenditure on the sinter plant.

The addition of a modern PLC[6]/computer-based process control system would significantly improve operations of the plant. In particular the operations of the sinter plant and acid plant would benefit from improved process control so that the operations of the units are better integrated. At a more basic level provision of good instrumentation would help the operators to run the plant in a more effective manner. Provisions of modern instrumentation and control systems would be estimated to cost $0.5 million (conventional instrumentation) to $5.0 million for a full computer-based process control system.

At present the largest single source of lead pollution on site comes from the layer of concentrates which has been blown around the site over the years. Serious attempts must be made to clean up as much of this material as possible. In tandem with this the concentrate store and handling facilities should be modified to prevent concentrate being lost during handling. Simple water sprays installed at strategic points would have a big effect. A system of water sprays, dust extraction/filter systems and suitable enclosures at various points would significantly reduce dust emissions. Dust losses from stockpiles are typically 0.5 to 1 percent of the quantity of concentrate handled. The system mentioned above would reduce stockpile losses and those during handling to less than 0.1 percent. Such a system is estimated to cost $0.5 million. This cost, however, depends very much on the exact circumstances and plant layout. Simply closing in the side of the existing building would be a low-cost (<$20,000) improvement.

The general dust and fume control systems on the plant are in need of repair and modernization. The SOMETRA plant has dust and fume control systems installed at the major emission points, which is typical for a plant of its age. The existing dust and fume control plant does not have any spare capacity to enable the installation of extra hoods and collection points. In modern Western plants most of point emission sources are fitted with fume and dust control systems. Bag filters are preferred for many of these installations as they can reliably clean the discharge gas down to less than 50 mg/m^3 of dust and where required to 10 mg/m^3. Installation of bag filters and suitable collection hoods at the more serious point source emissions would reduce lead releases. These would range in cost from £50,000 for a unit to handle 10,000 Nm^3 to £500,000 for a unit of 250,000 Nm^3.

The water treatment plant is in need of modernization, the cost of this being difficult to estimate without detailed examination. However, a new water treatment plant could probably be installed for a cost of approximately $10 million.

The plant was treating in excess of 100,000 tons/annum of lead/zinc concentrates in 1989. With the closure of one of the process lines the plant is now treating less than 30,000 tons/annum. Part of this reduction is due to other factors that have been caused by political change within Romania. This level of production with a work force of 3,000 plus cannot be economic (equivalent Western plant has less than 1,000 employees), therefore a decision has to be made about what is a viable size for the operation. The overall viability of the plant should be the subject of a detailed feasibility study to determine the cost-effectiveness of a new acid plant and other improvements.

Endnotes

1 Imperial Smelting Process.
2 August 1991 issue.
3 Joint IAEI/UNIDO Report on Copsa Mica, dated Dec. 1991.
4 London Metal Exchange.
5 Lead poisoning.
6 Programmable Logic Controller.

Annex I

Pulp and Paper

Introduction

In this annex we summarize the key issues arising from our analysis of the technical and economic aspects of environmental protection in the pulp and paper industry of Central and Eastern Europe. We focus our analysis on the pulp industry which has more extensive air pollution problems than the paper industry. The analysis is based on both desk research and a case study of the Sloka Pulp Mill in Latvia. This annex provides details of the case study, and a separate working paper provides an economic profile of the sectors and an analysis of the air pollution problems in the pulp sector and their possible solutions.

Structure of the sector

Table I.1 summarizes the structure of the pulp and paper industry in Central and Eastern Europe, and makes comparison within the industry in Western Europe. Overall, the industry in Central and Eastern Europe is small in comparison with that in Western Europe (WE). But the industry in Central and Eastern Europe (excluding the former Soviet Union) has almost half the number of employees as the industry in Western Europe, despite being in order of magnitude smaller in size.

Table I.2 compares data on the production, trade, and consumption of pulp and paper in Central and Eastern Europe in 1991 with data for Western Europe. Only the former Czechoslovakia and the former Soviet Union are major exporters of pulp; and only the former Czechoslovakia and Poland are major exporters of paper products. Production and consumption of both pulp and paper declined by about 25-30 percent in Central and Eastern Europe as a whole over the period 1989 to 1991. In Bulgaria and Romania pulp production fell by more than half over the same period. As a result of these trends, operating rates are considerably lower in Central and Eastern Europe than those in Western Europe, as shown in Table I.3. The low utilization of capacity in all countries of CEE reflects strategy of fuel and raw materials as well as inherent problems with production technology.

Table I.4 shows pulp production by major grades in 1991. A notable feature of the industry in Central and Eastern Europe is its relatively greater production of chemical pulps, particularly sulfite and semi-chemical pulps, than the industry in Western Europe, which produces relatively more mechanical pulps.

Pollution problems in the pulp industry

Pulping processes generate potentially polluting emissions to all environmental media, especially water. The type and significance of any pollution problems will be process and site specific. Sulfite pulping in particular, causes appreciable water pollution problems and its use has declined in WE countries because of the high cost of addressing these problems. As noted above, sulfite pulping is still widely used in CEE countries. The basic pulping technology used in CEE countries is similar to that used in WE countries, but the equipment tends to be older and comparatively less sophis-

Table I.1 The pulp and paper industry in Central and Eastern Europe in 1991

Country	Population (millions)	Number of mills		Capacity (th t/y)		Number of employees (thousands)
		Pulp[1]	P & B[2]	Pulp	P & B	
Bulgaria	8.8	3	11	150	380	14.0
Former Czechoslovakia	15.7	19	37	1,105	1,520	47.0
Czech Republic	10.4	..	..	..	..	31.5
Slovakia	5.3	..	..	..	..	15.5
Hungary	10.6	10	31	130	600	8.9
Poland	38.2	13	50	985	1,670	41.0
Romania	22.8	12	18	780	845	34.5
Former Soviet Union	288.8	53	174	11,000	11,500	..
C.I.S. and Georgia	280.7	50	161	10,780	11,065	..
Belarus	10.3	1	..	35	..	..
Moldova	4.3	0	..	0	..	..
Western Russia	115.1	25	..	6,150	..	..
Ukraine	51.7	5	..	360	..	..
Estonia	1.6	2	4	100	85	..
Latvia	2.7	1	4	65	145	..
Lithuania	3.8	1	5	55	202	..
Total CEE (excl. former Soviet Union)	**96.1**	**57**	**147**	**3,150**	**5,015**	**145.4**
Total CEE (incl. former Soviet Union)	**385.0**	**110**	**321**	**14,150**	**16,515**	**..**
Total Western Europe	**378.0**	**267**	**1,303**	**36,170**	**70,905**	**296.1**

[1] Including integrated mills.
[2] Paper and board.

Table I.2 Production, trade, and consumption of pulp and paper products in Central and Eastern Europe in 1991 (*thousand tons*)

	Pulp				*Paper and board*			
Country	*prod'n*	*exp's*	*imp's*	*cons'n*	*prod'n*	*exp's*	*imp's*	*cons'n*
Bulgaria	96	8	59	147	269	29	53	293
Former Czechoslovakia	978	172	<1	806	1,050	140	47	957
Czech Republic	624	95	<1	529	647	0	45	695
Slovakia	354	77	<1	277	403	140	2	262
Hungary	46	..	102	148	364	61	233	536
Poland	632	8	46	670	1,066	256	26	836
Romania	289	0	18	307	359	27	6	338
Former Soviet Union	7,700	200	40	7,540	8,030	200	210	8,148
C.I.S. and Georgia	7,580	200	40	7,420	7,910	200	210	7,920
Belarus	..	..	..	..	..	..	..	..
Moldova	..	..	..	..	..	..	..	..
Western Russia	..	..	..	..	..	..	..	..
Ukraine	..	..	..	..	..	..	..	..
Estonia	45	..	..	45	40	..	..	40
Latvia	50	..	..	50	78	..	..	78
Lithuania	25	..	..	25	110	..	..	110
Total CEE (excl. former Soviet Union)	2,041	..	..	2,078	3,108	..	..	2,960
Total CEE	9,741	..	..	9,619	11,246	..	..	11,108
Total Western Europe	31,372	..	..	36,598	58,160	..	..	57,510

Table I.3 Operating rates of pulp and paper mills in Central and Eastern Europe in 1991

Country	*Operating rates (percentage)* Pulp	*Operating rates (percentage)* P & B
Bulgaria	64	71
Former Czechoslovakia	88	69
Czech Republic	..	..
Slovakia	..	..
Hungary	36	61
Poland	64	64
Romania	37	42
Former Soviet Union	70	70
C.I.S. and Georgia	70	71
Belarus	..	..
Moldova	..	..
Western Russia	..	..
Ukraine	..	..
Estonia	44	46
Latvia	76	55
Lithuania	47	54
Total CEE (excl. former Soviet Union)	**65**	**62**
Total CEE (incl. former Soviet Union)	**69**	**67**
Total Western Europe	**86**	**89**

ticated than in WE countries. The industry in CEE countries therefore lags behind that in WE countries in reducing environmental emissions.

Air emissions

Table 1.5 summarizes the air pollution problems which typically arise in each of the main pulping processes.

Chemical processes typically cause more air pollution problems than mechanical processes. Hazardous airborne emissions from chemical pulping operations are dominated by sulfur dioxide and reduced sulfur compounds formed during digestion and recovery processes. Volatile organic compounds are emitted with digester gases, from multi-stage evaporation dryers and any other treatments involving heat. The Kraft mill at Razlog in Bulgaria, for example, emits high levels of H_2S and mercaptans, which have been linked to high incidence of asthma, skin diseases, and conjunctivitis in the local population.

Water emissions

Pulp and paper mills in CEE countries are associated with excessive water consumption and gross pollution of watercourses; just as mills in WE countries were until the 1970s when pollution control became a serious consideration. Public concerns about water pollution have resulted in the closure of several mills in Russia including two sulfate mills that have polluted Lake Ladoga for decades. Similarly, operation of the Sloka mill in Latvia is constrained because it cannot find an acceptable disposal route for lignosulfonates. Closure of the Tallinn pulp mill in Estonia on environmental grounds is being discussed.

Table I.4 Production of paper making pulp grades in Central and Eastern Europe in 1991

Country	*Total*	*Kraft*	*Sulfite and semi-chemical*	*Mechanical*	*Other grades*	*Kraft*	*Sulfite and semi-chemical*	*Mechanical*	*Other grades*
	Thousand tons					*As percentage of total*			
Bulgaria	96	58	20	8	10	60	21	8	10
Former Czechoslovakia	978	516	378	83	1	53	39	8	-
Czech Republic	624	285	260	78	1	46	42	13	-
Slovakia	534	231	118	5	-	65	33	1	-
Hungary	46	..	29	3	14	..	63	7	30
Poland	632	423	128	81	..	67	20	13	..
Romania	289	134	86	51	18	46	30	18	6
Former Soviet Union	7,920	3,770	2,330	1,600	-	48	29	20	-
C.I.S. and Georgia	7,700	3,770	2,330	1,600	..	60	20	21	..
Belarus	..	..	..	..	..	..	..	..	..
Moldova	..	..	..	..	..	..	..	..	..
Western Russia	..	..	..	..	..	..	..	..	..
Ukraine	..	..	..	..	..	..	..	..	..
Estonia	101	..	101	..	..	..	100	..	..
Latvia	66	..	66	..	..	..	100	..	..
Lithuania	53	..	53	..	..	..	100	..	..
Total CEE (excl. former Soviet Union)	2,042	1,131	641	226	44	55	31	11	2
Total CEE (incl. former Soviet Union)	9,962	4,901	2,971	1,826	44	49	30	18	<1
Total Western Europe	31,109	15,835	3,816	11,357	101	51	12	37	<1

Table I.6 shows typical wastewater characteristics of the main pulping processes. The least polluting processes are the mechanical processes, and the most polluting are the chemical processes. The most polluting process is the sodium-based sulfite process in which the yield is low and the economics of the process do not justify liquor recovery; therefore, all of the spent liquor is discharged. These trends reflect the fact that the major source of BOD and COD is escape of spent liquor, which contains all of the organic matter dissolved during the pulping process. The lower the yield the more material present in the liquor and the less pulp produced from a given amount of wood. Although not included in Table I.6, the paper making process represents the largest volume of discharge and is also a major source of potential pollution—particularly suspended solids.

The major sources of suspended solids and organic compounds from chemical pulping are the pulp washing operations and general material losses.

Chlorine bleaching, particularly of Kraft pulps, generates significant amounts of AOXs (Absorbable organic halogen compounds) such as dioxins, chloroforms, chlorophenols and furans. Up to 8 kg of AOX per ton of pulp were found in wastewaters from Swedish bleaching plants in the 1970s. Concerns about the hazard to health from these compounds has recently led to the introduction of stringent regulations for their control in WE countries.

Solid wastes

Significant quantities of solid wastes are produced from all pulp mills. Major sources include:

- Bark from debarking
- Woody residues from pulping processes
- Sludges from wastewater treatment plants
- Ash from boilers burning coal.

These materials can generally be safely disposed of to landfills provided they do not contain hazardous materials such as AOXs and landfill sites are constructed to standards adequate to prevent groundwater and surface water contamination.

It is unlikely that altering existing practices for disposal of solid wastes from pulp mills would represent short- to medium-term priorities.

Pollution control options in the pulp industry

Table I.7 shows indicative capital costs of different possible methods of controlling air and water emissions from pulp mills where no controls currently exist. Installation of these control measures may also have significant operating costs associated with items such as labor, energy, and chemicals and waste disposal. For example, the annual energy costs for a wastewater treatment plant for a 50,000 tons per year pulp mill would be approximately $90,000.[1]

Air emissions

Boilers and furnaces represent the only significant source of NO_x emissions from pulp mill, while boilers and furnaces burning coal, fuel oil, or mill residues are likely to represent the largest source of SO_2 emissions

Table I.5 Typical air pollution problems arising from pulping processes

Process	*Source*	*Pollutants*
Kraft	Boilers (fossil fuel)	Particulates, SO_2, NO_x
	Recovery	Reduced sulfur compounds
	Condensate	SO_2 and reduced sulfur compounds
	Post-digestion pulp handling	VOCs
	Evaporator vent gas	SO_2 and reduced sulfur compounds
	Lime kilns	Particulates
Sulfite	Boilers (fossil fuel)	Particulates, SO_2, NO_x
	Condensate	VOCs
	Evaporator vent gas	SO_2
	Cooking liquor preparation	SO_2
	Wastewater treatment plant	Reduced sulfur compounds
Mechanical	Boilers (fossil fuel)	Particulates, SO_2, NO_x
	Waste burning	Particulates
	Heated processes	VOCs

and boilers and furnaces burning coal or mill residues are likely to represent the largest source of dust emissions. Control of dust emissions is generally cheaper than control of either SO_x or NO_x emissions.

Considerable scope is likely to exist at mills in CEE countries for CHP and energy efficiency improvements to improve both economic and environmental performance. However, substantial investments will generally be required to realize the potential savings.

Fuel switching is likely to represent the lowest cost option for reducing boiler and furnace emissions where it is feasible. For example, the case study at the Sloka mill in Latvia identified that an investment of approximately $30,000 would be needed to convert yeast sulfur dioxide emissions from the mill by approximately 70 percent.

The usual means of controlling sulfurous emissions from chemical pulping processes is to collect from emission points associated with or immediately after the digestion process and subsequently treat by scrubbing or incineration.

Electrostatic precipitators are typically used to control particulates contained in the waste gases from recovery boilers and lime kilns.

The case study at the Sloka mill revealed that there were no chemical recovery processes, and that there were significant fugitive emissions of sulfur dioxide and VOCs from the digestion plant. There were no air extraction arrangements at key emission sources. Finally, there were sulfur dioxide emissions from leaking utilities.

We believe that modern mills located in CEE countries are likely to be equipped with fugitive emission control to mitigate the malodorous and toxic effects of reduced sulfur compounds. However, the older chemical pulp mills will have little or no control equipment installed – as was the case with the Sloka mill in Latvia. Furthermore, inadequate levels of mechanical maintenance on the chemical preparation and sulfurous chemical handling will result in high levels of accidental emissions.

A common problem in mills located in CEE countries is inadequate process monitoring, which results in poor operation and a lack of knowledge about potential pollution problems. The provision of monitoring equipment, together with appropriate training, is likely to represent a highly cost-effective route to improving environmental performance. The cost of simple equipment for monitor boiler and fugitive emissions would be about $40,000 for a mill capable of producing 50,000 tons of pulp per year.

Wastewater

There is likely to be considerable scope for reducing the overall volume of wastewater discharged from pulp mills in CEE countries by recycling water within the pulping process or by using wastewater from other mill processes. In the Sloka mill, for example, inefficient operation of the pulp washing equipment together with only limited recycling of wastewater meant that overall water consumption was more than twice that of a typical mill in WE.

The introduction of high levels of internal process water recycling requires the introduction of destruction, separation, and disinfection measures within the process loops, which is expensive and is unlikely to represent a short- to medium-term priority. In the short term, however, there may be significant improvements to be made by better process monitoring and control requiring minor modifications and operator training.

Most mills in CEE countries already have wastewater treatment facilities on site and many have biological treatment. In come cases, existing equipment is not functioning as designed due to poor operational and maintenance practices, shortages of chemical in-

Table I.6 Typical untreated wastewater characteristics for different pulping processes

	Flow	*BOD*	*COD*	*TSS*
Process	*m^3/ADt*		*kg/ADt*	
Unbleached Kraft	100	20	65	15
Kraft bleaching	100	30	90	20
Unbleached sulfite	125	275	850	15
Sulfite bleaching	200	300	900	20
Semi-chemical	50	200	550	65
Mechanical (groundwood)	20	10	45	30

ADt—Air-dried ton of pulp produced.
BOD—Bio-chemical oxygen demand.
COD—Chemical oxygen demand.
TSS—Total suspended solids.

Table I.7 Summary of pollution control costs—pulp mills

Source	*Pollutant*	*Mass emission kg/ADt*[1]	*Control technology*	*Capital cost $/ADt*
Boiler fuel combustion	SO_x	-	Change to lower sulfur fuel	-
			Flue gas desulfurisation	140 - 180
	NO_x	-	Low-NO_x burners	8 - 14
Boiler fuel/incinerator	Dust	-	Electrostatic precipitators	8 - 18
Chemical pulp processes	Fugitive SO_x	0.5	Collection and scrubbing	8 - 12
Chemical pulp processes	Fugitive VOC/odor	-	Collection and burning or scrubbing	2 - 4
Wasterwater treatment	Fugitive H_2S	0.1	Collection and scrubbing	3 - 8
Pulping processes	Wastewater	50 - 250[2]	Waste minimization (recycling)	Site specific
Pulping processes	Suspended solids	15 - 300	Sedimentation	12 - 18
Pulping processes	Soluble BOD/COD	10 - 300	Full treatment incl. biological stage	210 - 280
Process condensates	Soluble BOD/COD	20	Anaerobic biological treatment	30 - 55
Solids removal processes	Sludges	10 - 250		
Biological treatment		10 - 250	Dewatering - e.g., centrifugation	5 - 10

Note: The reference values used for this table are based on a nominal mill of 50,00 ADt pulp production/year.

[1] ADt—air-dried tonne of pulp produced.

[2] m^3/ADt.

puts, or insufficient capacity. For example, major constraints on the performance of the wastewater treatment at Sloka included:

- Presence of lignosulfonates and other complex organic materials which are not readily biodegradable and therefore pass through the treatment plant
- Sludge accumulation in the sedimentation lagoons due to the inadequate performance of the dewatering centrifuges resulting in more sludge solids being pumped to the lagoons, which are not then removed effectively
- Inefficient activated sludge plant aeration system
- Insufficient treatment plant performance monitoring.

Overall, wastewater treatment plant efficiency at Sloka, and elsewhere, could be improved significantly through better monitoring and control. Simple systems may be most appropriate since sophisticated systems require skilled technicians to monitor and maintain the component units, especially the sensing equipment in contract with the wastewater.

The installation of state-of-the-art technology for water management and wastewater treatment would be very expensive.

Industry prospects

Table I.8 compares per capita consumption of paper and board in CEE countries with the Western European average. The relatively low levels of consumption in CEE countries suggest that there is a large unserved demand. This together with the fact that the region has considerable pulpwood resources indicates that the industry is currently underdeveloped and may have considerable long-term growth potential. In the short to medium term, however, raw material supply problems, the adverse impact of rising energy prices on profitability of existing mills, and the general recessionary effects of the transition to market economics will limit the scope for growth.

Table I.9 compares levels of production per employee in CEE countries with the Western European average. The low levels reflect gross overmanning as well as widespread use of inefficient plant. In the short to medium term low wage rates may allow mills in CEE countries to compete effectively in international markets despite rising prices of other inputs, notably energy prices. In the longer term, major restructuring and rationalization of the pulp and paper industry in CEE countries will be required if it is to remain viable and attract investment for modernization and growth.

Table I.8 Per capita consumption of all paper and board products, newsprint, and printings and writings in CEE countries in 1991

	Per capita consumption (kg/year)		
Country	*All paper and board*	*Newsprint*	*Printings and writings*
Bulgaria	33	4	5
Former Czechoslovakia	61	2	17
Hungary	52	5	9
Poland	22	1	6
Romania	15	2	2
Former Soviet Union	28	5	4
Average CEE:			
excl. former Soviet Union	31	2	7
incl. former Soviet Union	29	4	5
Average Western Europe	161	21	57

Table I.9 Production of pulp and paper per employee in CEE countries in 1991

Country	*Production of pulp and paper per employee*
Bulgaria	26
Former Czechoslovakia	43
Hungary	46
Poland	41
Romania	19
Former Soviet Union	..
Average CEE (excl. former Soviet Union)	35
Average Western Europe	319

Endnote

1 Assumes energy prices are at average Western European levels.

Sloka case study

Summary

The Sloka integrated pulp and paper mill is a state-owned enterprise located near Jurmala in Latvia, approximately 28 kilometers from Riga. The mill employs over 1,200 people and manufactures a range of paper products from pulp produced at the mill by a chemical sulfite process and mechanical groundwood process. The mill's capacity is equivalent to around half of the republic's total paper and board production.

Currently paper production and plant investment is severely constrained by the economic situation in Latvia and its trading nations. Paper production costs are substantially higher than competing mills in other countries and production has decreased in the last three years to below half of the quoted mill capacity. Lack of investment has resulted in little or no progress to resolve environmental factors, even those restricting production.

Closure of the mill was considered three years ago, but was not implemented on political grounds due to the local employment situation.

Overall the mechanical condition of the pulping plant is reported as satisfactory with performance figures typical of equivalent Scandinavian sulfite mills.

Environmental emissions from industry in the Jurmala area are regulated by the Riga-Jurmala Environmental Protection Committee (RJEPC). The RJEPC imposes annual permits for emissions to water and atmosphere based on either mass or concentration units. The Sloka mill pays for discharging effluent to water and is penalized financially if it exceeds permit levels.

The mill does not comply with the permit levels for aqueous effluent discharge particularly with respect to lignosulfonate and phenol concentrations, but also suspended solids, oil products, and methanol. The mill may comply with the permit conditions in terms of pollutant masses discharged, but not in concentration terms. This is due to the reduced mill production.

The mill exceeds its permitted emission levels to atmosphere with respect to sulfur dioxide, nitrous oxides, and hydrogen sulfide.

No action on the permit violations has been taken in 1992 by the republic's environmental agencies.

This study identified nine measures which will reduce the environmental impact of the mill:

- Optimization of the existing centrifuge sludge dewatering plant
- Finding a viable means of disposing of the lignosulfonate production from the chemical pulping plant
- Provision of portable air monitoring equipment
- Provision of wastewater treatment plant monitoring equipment
- Conversion of the yeast dryer burner to gas firing from oil fuel
- Installation of low-NO_x burners in the main mill boilers
- Collection and scrubbing of hydrogen sulfide emissions from the wastewater treatment plant
- Installation of fume extraction, collection, and disposal at key points in the chemical pulp mill
- Installation of separate treatment for the condensate liquors currently sent to the wastewater treatment plant.

In addition, replacement or refurbishment of the chemical pulp washing equipment will improve the performance of the wastewater treatment plant, and installation of monitoring equipment at key points in the pulping mill will improve the process efficiencies.

The mill management are investigating various means of reducing environmental impacts from lignosulfonate disposal. However, any project involving investment is unlikely to proceed at present on financial grounds.

The measures most likely to represent the best environmental improvement value for the money in descending order of efficacy are:

- Conversion of the yeast dryer plant to gas firing
- Provision of air monitoring equipment
- Provision of water monitoring equipment
- Installation of process fume collection and disposal.

There is considerable uncertainty regarding the future of paper and pulp manufacturing at the Sloka site. The mill management have submitted proposals for a $90 million upgrading of the Sloka plant. Four potential greenfield sites for such capacity have been identified. However, this proposal has not progressed through the republic Parliament. The need for Latvia to have an increased production capacity is not clear.

All environmental improvement measures proposed must be considered with respect to the uncertain future of the mill.

Introduction

This annex reviews the environmental pollution problems and options for abatement at the Sloka pulp and paper mill in Latvia. It appraises the costs and effectiveness of each option identified.

The Sloka integrated pulp and paper mill is a state-owned enterprise situated in the village of Sloka, near Jurmala, approximately 28 kilometers southwest of Riga in the Latvian Republic. The mill is the only pulping plant in Latvia although a further three paper mills exist in the republic.

The Sloka mill produces unbleached sulfite and groundwood pulp from local wood and manufactures low-grade products including wallpaper, wrapping paper, boxboard, punched card, and surface-sized paper. The mill employs around 1,200 personnel.

Site details

The Sloka mill site is some 80 hectares in area and occupies a bankside position on the river Lielupe in the village of Sloka near to the Jurmala resort area which it has occupied since 1898. The site is approximately 28 kilometers upstream from the entry of the river into the Gulf of Riga. The site is enclosed by residential areas to the north, east, and west and by the river to the south. The Gulf of Riga is approximately two kilometers to the north of the site.

Generally, the area topography is flat, slightly wooded and semi-rural, dominated by holiday residential accommodation. Jurmala is a tourist health resort with a resident population of around 60,000 which increased to over 600,000 during holiday periods in the past. The tourist trade has decreased drastically in the last two years due to the currency situation. The village of Sloka has a population of approximately 15,000.

Other industrial units in the vicinity include wallpaper production and computer paper manufacture on or immediately adjacent to the mill site, together with wood preparation and asphalt production industries in the Jurmala area.

The mill has imposed a "sanitary" zone for 500 meters around the mill since 1975 and has moved its workers to new flats elsewhere. Some private residents chose to remain within the zone. Plans to increase the sanitary zone radius to 1,000 meters have been considered, but not implemented.

Pulp mill process description

The pulp mill consists of two process streams; a chemical sulfite pulping process and a mechanical groundwood pulping process.

The pulp feedstocks for 1990 are given in Table I.1.1 together with the productions for the mill. The production figures for 1990 are approximately 60 percent of the quoted mill capacity of 110,000 tons per year. Production data for 1991 and 1992 were not available, but are known to be significantly less than 1990 figures; no pulp has been purchased in 1992.

The mill consumed around 185,000 cubic meters of unbarked wood in 1990 equivalent to a consumption of 4.84 cubic meters unbarked wood per dry ton unbleached sulfite pulp and 2.54 cubic meters unbarked wood per dry ton for unbleached groundwood pulp; these figures are typical for Scandinavian sulfite pulping operations.

The mill's primary raw material is Latvian spruce roundwood supplemented with up to 10 percent aspen. The wood is received by rail and consists of 2, 4, and 6 meter logs of between 10 and 35 centimeter diameter. Wood for pulping is slashed to 2 meter lengths and hydraulically debarked consuming an estimated 3 cubic meters of water per meter roundwood. Debarking process water is derived from the paper machines, surplus white waters. It is mostly recirculated after screening and partly discharged to the wastewater system. After press dewatering, the bark is burnt in two small boilers. The debarked wood is chipped and stored prior to digestion, or removed to the groundwood grinding plant.

Three 320 cubic meter batch digesters are installed and up to five "cooks" per day may be performed using a two stage cooking process. In the first cooking stage sodium bisulfite ($NaHSO_3$) liquor is used, and the second stage uses sulfurous acid (H_2SO_3). The sodium bisulfite pulp produced has a kappa number (brightness) of 34.38 and digester yield is reported as 54 percent.

Process chemicals recovery is reported as being 70 percent, but Swedish consultants believed this figure to be an underestimate and they assumed a 92 per-

Table I.1.1 Mill feedstocks and production, 1990

	*Ton/year**
Chemical pulp (incl. knot pulp)	35,600
Waste paper pulp	3,200
Mechanical groundwood pulp	4,900
Purchased bleached sulfite pulp	18,300
Purchased mechanical pulp	4,000
Paper	62,000
Board	2,000
Lignosulfonates	48,000
Dried yeast solids	1,500

Note: *Ton: assumed to be metric ton.

cent recovery allowing for accidental losses. Recovered chemicals leave the site either as lignosulfonates, in thick liquor, or via dried yeast solids grown on the lignosulfonate liquors. Therefore, the digestion chemicals are not recycled to repeat the cooking process. After chemical digestion, the pulp is screened, washed, and thickened prior to being stored for the paper machines. The thick liquor is concentrated to 50 percent dry solids content in a six stage forced circulation evaporator. The concentrated liquor was sold to a variety of market outlets principally in Russia.

Sodium bisulfite liquor is prepared by liquifying and burning elemental sulfur and then reacting this with sodium carbonate solution to yield sodium bisulfite plus carbon dioxide. Sulfurous acid water is made by dissolving sulfur dioxide into water. The sulfur consumption of the plant is reported as around 90 kilograms per ton of pulp. This is typical of a process without chemical recovery. Sulfur dioxide from the digester degassing is recovered in two acid pressure tanks.

The liquor flow from pulp processing and washing is divided; 400 cubic meters per day is sent to the evaporating plant and the balance of 1,000 cubic meters is neutralized with ammonium hydroxide and then fermented for yeast production. The yeast produced is dried and sold in sacks equivalent to around 1,500 tons per year. The yeast drying furnace is fuelled by oil containing 2 percent sulfur and therefore is a significant sulfur emission to atmosphere.

The groundwood plant has two grinders although only one is used at a time. White water from the paper machines is used by the process, but an additional make-up of 10 cubic meters clean water per ton of pulp is consumed.

Waste paper and purchased pulp are processed in separate pulpers and added to the pulp storage.

The process flow schematic in Figure I.1.1 identifies the significant emissions to air and water.

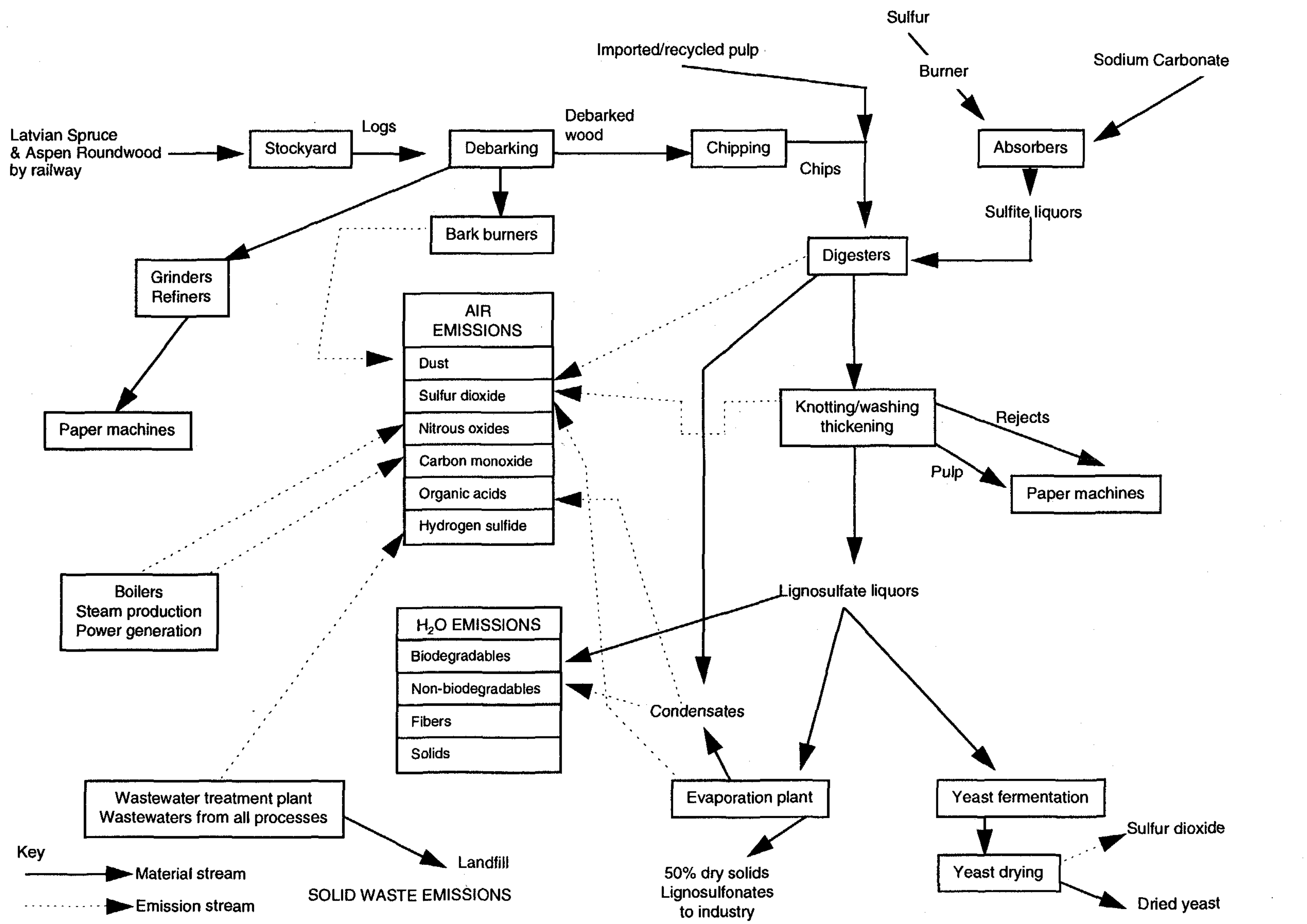
Around 200 tons of steam per hour are raised by gas-fired boilers for process use and for electricity generation. Some 11 MW of electricity is generated on site and 12 MW is purchased from the grid.

The chemical pulping plant was installed in 1965 together with paper machine 8 (PM8). The mill is geared for production seven days per week, 24 hours per day, but currently plant operation has become intermittent due to the constraining factors.

The paper machines are excluded from this case study, but for information a summary of paper machine technical details is given in Table I.1.2. The paper machines were stated as having a conventional technical standard for their age, but with a low degree of instrumentation. Fibre loss from the machines was reported as high and in need of improvement. The paper products include wrapping paper, wallpaper, one- and two-layer boxboard, punched card, and surfaced-sized paper.

Waters for process use are abstracted from the river Lielupe or from boreholes if the river quality is poor. Around 1,500 cubic meters of process water are required per hour with the sulfite pulping operations consuming around 570 cubic meters per hour. There is no treatment of process waters prior to use in the mill.

Figure I.1.1 Process flow schematic—major emissions



It was reported that the water consumption of the combined paper and pulping operation was 160 cubic meters per ton.

If the 1990 data set is used, wastewater production was approximately 214 cubic meters per ton product with approximately 44.5 kilograms BOD produced per ton product in the unsettled wastewater. The wastewater volume is high by Western standards; an average wastewater production from an integrated mill is around 105 cubic meters per ton. The BOD generated is broadly equivalent to Western mills where a typical BOD production is around 27 kilograms BOD produced per ton product after primary settlement. This is consistent with the view that water consumption by the pulping process is high due to inefficient operation of the pulp washing equipment which leads to excessive dilution of the black liquors.

The mill management are aware of this problem and have carried out operator training to reduce the volume of water used for washing. The management claim that this has been successful in reducing the volume of water used to around 120 cubic meters per ton although this was not substantiated.

The entire waterborne waste from the mill is received at the wastewater treatment plant located within the mill boundaries. This wastewater treatment plant also treats domestic sewage from the local community although only a portion of the total community is connected to a sewerage system. Operation and performance of the wastewater treatment plant are the responsibility of the mill management.

The loading on the wastewater treatment plant from the various mill process sources is summarized in Table I.1.3.

The solids contribution for 1990 was 6,600 tons.

Pulp-related operations, such as condensate production and pulp washing, contribute the majority of the BOD and COD load to the wastewater treatment plant.

The wastewaters from the mill are treated together with the municipal sewage in a conventional diffused air-activated sludge plant. Primary treatment of the mill wastewater is separate from the domestic sewage, but the flows are combined for biological treatment. A process flow schematic for the treatment plant is given in Figure I.1.2 and the performance of the treatment plant is discussed below. Nitrogen and phosphorus nutrients are dosed to the wastewater although this was believed to be unnecessary.

Several aspects of the wastewater treatment plant operation were subject to comment, particularly the sedimentation lagoons. These are operated as two streams of two lagoons in series with floating aerators installed in the final lagoon to raise the effluent dissolved oxygen concentration in excess of 4 milligrams dissolved oxygen per liter prior to discharge to the river. The sedimentation lagoons receive all the treated effluent from the activated sludge plant together with sludge solids from the sludge treatment processes. Half of the combined domestic and surplus activated sludge is pumped into the sedimentation lagoons without treatment with the remainder being thickened by two centrifuges prior to sludge disposal to landfill. The sedimentation lagoons are alleged to contain 20 years worth of accumulated sludge solids.

Sludge from the mill wastewater stream sedimentation tanks is dewatered by rotary vacuum filters prior to landfill although some filter cake is sold for filler

Table I.1.2 Paper machine technical details

	PM1	*PM5*	*PM6*	*PM7*	*PM8*
Year	1921	1930	1952	1964	1965
Width meters	1.8	2.4	2.7	2.4	4.2
Speed meters/min	30-60	70-110	30-110	130-180	50-250
Basic weight gram/m^2	65-90	80	90-200	90	150-200
Production capacity ADt/year	3,000	8,000	14,000	17,000	50,000
Water consumption m^3/ADt	60	34	28	58	39

Note: ADt—Air-dried ton.

Table I.1.3 Mill process discharges to wastewater treatment plant for 1990

	*COD**		*BOD***		*Flow*
Source	*kg/ADt*	*ton/year*	*kg/ADt*	*ton/year*	*m^3/year x 1,000*
Debarking sulfite	7		2.5	90	
Debarking groundwood	3	10	1	0	
Washing loss	66	250	17	610	
Condensates from pulping	40	1,400	22	780	
Accidental loss	40	1,400	10	360	
Groundwood	30	150	15	70	
Waste paper	15	50	7	20	
Paper mill dissolved	6	390	2	130	
Total dissolved		5,950		2,060	
Total fibre loss		4,300		790	
Total to treatment		10,300		2,850	13,700

Notes:
* COD—Chemical Oxygen Demand (dichromate value).
** BOD—Biochemical Oxygen Demand measured over 7 days; the BOD7 figures are equivalent to approximately 1.15 x BOD 5 day value.
ADt—Air-dried ton.

material; for example in cement products. Sludge from the domestic sewage is anaerobically digested prior to thickening and dewatering. The methane produced by the digestion process is burnt in the mill.

Major constraints on the performance of the wastewater treatment plant were reported as:

- Presence of lignosulfonates and other complex organic materials which are not readily biodegradable and therefore pass through the treatment plant resulting in an effluent COD of around 150 mg COD/l equivalent to around a 50 percent removal of the inlet load
- Sludge accumulation in the sedimentation lagoons due to the inadequate performance of the dewatering centrifuges resulting in more sludge solids being pumped to the lagoons and then little or no removal of the sedimented solids from the lagoons. The operation of the centrifuges has not been optimized with respect to chemical conditioning as only one grade of polyelectrolyte is available in Latvia
- The activated sludge plant aeration system has a low aeration efficiency
- Insufficient treatment plant performance monitoring
- The variations in domestic sewage flow; the mill wastewater flow is relatively constant under operating conditions, but the domestic sewage loading depends on the population contributing to the sewerage system at a particular time.

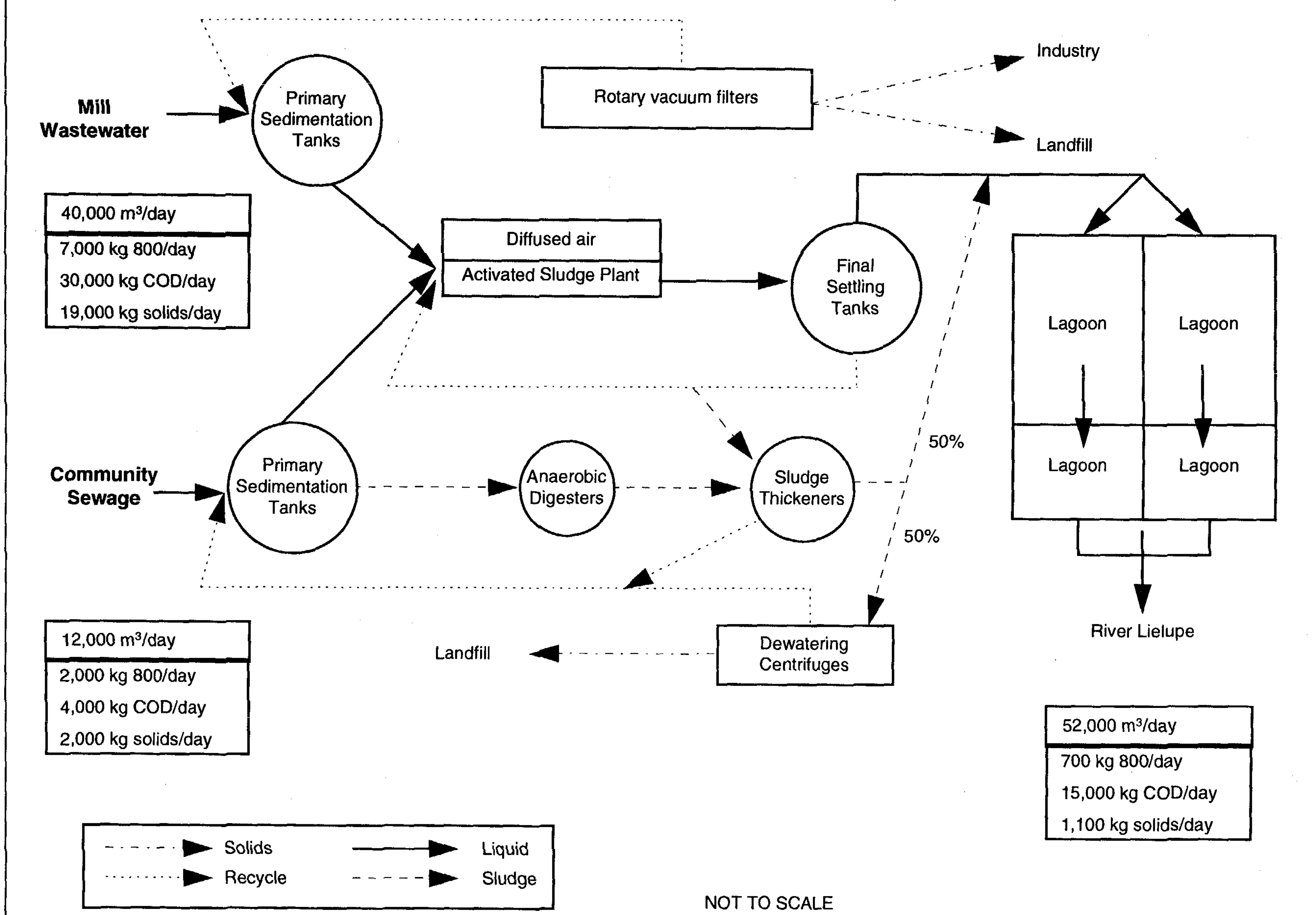
Current status of the Sloka mill

Environmental position

The Sloka mill has invested heavily in environmental protection measures since 1955. The bulk of this investment is probably represented by the wastewater treatment plant although other measures such as conversion of the boilers to gas firing are significant.

The RJEPC imposes annually reviewed permits for the abstraction of river water from, and the dis-

Figure I.1.2 Process schematic—wastewater treatment plant



charge of treated effluent to, the river Lielupe. The 1992 permit conditions for discharge of effluent to the river Lielupe are summarized in Table I.1.4.

In 1993 the permit will be adjusted to increase the flow condition to 23,124,000 cubic meters per year, with a corresponding increase in the tons per year mass figures, to accommodate domestic sewage treatment in the permit conditions.

Permit compliance is based on daily analysis of effluent samples by the mill laboratory together with approximately four samples per year analyzed by the RJEPC. In 1992, compliance with the permit conditions was said to be good with the exception of phenol concentrations which are consistently 5 times the permitted concentration and lignosulfonates which are 10 times higher than the permitted concentration. This has not been the case in the past and therefore may reflect the reduced mill operations in 1992 together with the diminished domestic sewage contribution. The performance of the wastewater treatment plant is summarized in Tables I.1.5, I.1.6, and I.1.7.

The quantity of wastewater discharged in 1990 is reduced from previous years as shown by Table I.1.5. This reverses the overall rising trend of the previous nine years and could be due to reduced mill production, improved water conservation, or volume measurement by a different agency.

The BOD removal reported for 1990 was reduced to 81percent due to various reasons including low activated sludge plant aeration efficiency (although Table I.1.6 does not show this).

A detailed breakdown of effluent parameters with respect to discharge permit conditions for 1989 is given in Table I.1.7.

There are inconsistencies between the data given in Tables I.1.5 and I.1.7. Table I.1.5 gives the flow as 82,000 cubic meters per day compared to around 41,000 cubic meters per day in Table I.1.7 and the concentrations of BOD and suspended solids also differ.

Table I.1.7 shows that compliance with the 1992 permit conditions on an annual basis would not have been achieved in 1989 for the following determinants: suspended solids, oil products, phenols, lignosulfonates, and methanol. This situation is expected to be unchanged as no significant modifications or changes have been made to the mill operation since 1989, except for the reduction in production. Therefore, the mill continues to exceed the effluent discharge permit conditions on some chemical determinants in concentration units, but is likely to comply with the mass-based permit conditions due to the reduced mill production in 1992.

The measurement of the lignosulfonate concentration has been found to be subject to chemical interferences from humic acids and algae present in the river water. A more specific chemical test is to be introduced which will report true concentrations that may be lower than the value currently reported.

Sloka mill pays a monthly charge to the republic to discharge treated effluent to the river. An additional charge is payable to a special fund for environmental improvements if the permit conditions are violated in a month period. This additional charge was three times the monthly payment, but this has been increased to five times from October 1992. Previously, with the mill production at normal levels, the increased charges for permit violation were not a problem, but now the mill cannot pay these charges.

The mill management thought new standards might be imposed on the treated effluent discharge on the order of 3 mg BOD/l and 3 mg solids/l together with a limit of 10 mg COD/l when lignosulfonates are excluded from the wastewater. They also think that they have to comply with more stringent standards than competitors; for example in Finland.

The mill intends to appeal to change the permit conditions to mass-based units rather than concentration-based units which can encourage the use of clean water to dilute effluent concentrations. The RJEPC did not seem to be aware of these proposed changes in the permit conditions.

Overall, the presence of lignosulfonates and complex organic compounds in the wastewater is restricting the mill's paper production until an acceptable disposal route is found for the lignosulfonates. This is a typical problem for sulfite mills.

The impact of the continued discharge of lignosulfonates, phenols, and methanol in excess of the permit limits on the river quality is difficult to assess without a more detailed analysis of the constituent chemicals present and the dilution in the river.

Phenol, methanol, cresols, and guaiacol are biodegradable although bacterial acclimatization may be required. Therefore, these materials will not persist in the environment. In general terms, toxicity of the materials is not significant below 5 mg/l concentrations.

Table I.1.4 Sloka mill treated effluent permit conditions

Parameter		Concentration mg/l	Mass ton/year	Flow m^3/year
Flow		-	-	20,600,000
BOD	—21 day	28	576.8	-
	—7 day	13	267.8	-
COD		200	4,120	-
Solids		12	247.2	-
pH		-	-	-
Temperature (°C)		-	-	-
Phenols		0.02	0.4	-
Ammonia nitrogen		4.0	83.7	-
Nitrite nitrogen		0.1	2.1	-
Nitrate nitrogen		10	206	-
Phosphorus		2.5	51.5	-
Lignosulfonate		4.0	82.4	-
Oils		0.4	8.2	-
Surfactants	—ionic	0.5	10.3	-
	—nonionic	2.0	41.2	-
Chloride		300	6,180	-
Sulfate		500	10,300	-
Methanol and formaldehyde*		3.0	61.8	-
Sulfide*		0.03	0.618	-

Note: *Imposed from 1 October 1992.

Table I.1.5 Volume of suspended solids and BOD discharges to river Lielupe from 1980 to 1990

		Suspended solids		BOD (5 day)	
Year	Flow	mg/l	ton/day	mg/l	ton/day
1980	64,400	44	2.84	25	1.61
1981	66,700	26	1.73	19	1.27
1982	68,900	15	1.03	13	0.90
1983	72,900	34	2.48	53	3.86
1984	75,300	39	2.94	30	2.26
1985	72,300	90	6.50	34	2.46
1986	70,000	28	1.98	14	0.99
1989	82,000	12	0.99	9	0.74
1990	52,000	21	1.1	13.5	0.70

Note: Flow includes community sewage contribution.

Table I.1.6 Wastewater treatment plant performance (1990)

Source	Flow m³/day	BOD ton/day	COD ton/day	Solids ton/day
Mill	40,000	7	30	19
Municipal*	12,000	2	4	2
Total before treatment	52,000	9	34	21
Total after treatment	52,000	0.7	15	1.1
% inlet load removed**		92	56	95

Notes:
* Municipal data 1989.
** Derived from table data.

However, phenols in particular and possibly cresols and guaiacol are associated with taste, therefore tainting of fish flesh and shellfish would be possible.

It must be noted, however, that the river Lielupe is already substantially polluted upstream of the mill discharge by domestic sewage at Jelgard and by the chemical plant at Olaine. Also, prior to commissioning of the new wastewater treatment plant for Riga in 1992, domestic sewage pollution from Riga was washed back into the river Lielupe from the Gulf of Riga and contributed to the pollution load of the river.

Emissions to atmosphere

Emissions to atmosphere from the mill are regulated by RJEPC issuing a conditional permit. The major chimney stacks noted for the pulp mill were two for the bark burners (36 meters high) and two for the boilers (73 and 85 meters high). There was one stack for the new fodder yeast department which is still to be used. The evaporator plant is also likely to have a stack, but this was not seen.

Sloka mill measures its own emissions to the atmosphere and reports these results to RJEPC. In addition, RJEPC carries out atmospheric monitoring using a local inspector. The reported emissions to atmosphere for 1990 and 1991 are summarized in Table I.1.8. In 1990 and 1991 the mill did not comply with the permit limits with respect to nitrous oxide, sulfur dioxide, and hydrogen sulfide emissions.

The emission figures support the RJEPC view that the mill is a major contributor to air pollution in the Jurmala region particularly with respect to sulfur dioxide emissions, which are alleged to have damaged local pine trees. The sources of sulfur dioxide emissions from the mill have been further resolved and limit values imposed as given by Table I.1.9.

On the basis of these results, the mill is complying with the limits imposed for process emissions. There are no significant sulfur dioxide emissions from the gas-fired boilers. The yeast dryer is contributing the bulk of the sulfur dioxide emission from the mill.

The mill management made various comments on local emissions to atmosphere; it is estimated that the mill produces around 18 tons per year of sulfur dioxide excluding yeast drying operations. This figure should be compared to local emissions from around 318 domestic water boilers burning approximately 48,000 tons per year of fuel oil or wood equivalent resulting in sulfur dioxide emissions of around 1,800 tons per year.

Table I.1.7 Total discharge to river of other materials (1989) with derived comparison to 1992 permit concentrations

Parameter	Discharged 1989		1992 permit
Flow	14,830,000 m³	-	20,600,000 m³
	tons	mg/l	mg/l
Suspended solids	294.9	19.9	12
BOD total	203.3*	13.7	28
Oil products	10.33	0.7	0.4
Total phosphorus	10.39	0.7	2.5
Total nitrogen	152.5	10.2	14.1
Phenols	0.771	0.8	0.02
Methanols	180.0	12.1	3.0
Lignosulfonates	763.0	51.4	4.0

Note: * This figure was reported as 2,032.6 tons, however this is not consistent with the other data and therefore has been reduced by a factor of 10.

Table I.1.8 Mill emissions to atmosphere

Parameter	Permit limit ton/year	Measured emission ton/year 1990	ton/year 1991
Particulates	11.4	13.34*	9.94
Wood	9.764		7.067
Nitrous oxides	69.96	180.47	192.845
Sulfur dioxide	23.53	63.92	69.21
Carbon monoxide	984.1	692.22	733.264
Acetic acid	0.006	0.003**	0.003
Ammonia	0.1300	0.122	0.110
Hydrogen sulfide	0.4700	4.505	4.25

Notes:

* Combined figure to be compared with 20.9 ton/year total permit level.

** Actual permit level was 0.004 t/y in 1990.

The mill is thought to contribute 55 percent of the area's total atmospheric emissions, but only 1 percent of the total sulfur dioxide emission. The basis for this statement is assumed to be that the mill's emissions amount to some 18 tons sulfur dioxide per year plus around 45 tons per year from the yeast dryer. Other local industries also emit sulfur dioxide to atmosphere, for example a wood preparation plant.

The mill management would like to eliminate the sulfur dioxide emissions from the yeast drying plant by converting the boiler to gas firing from oil firing. This burner is reported as releasing approximately 45 tons of sulfur dioxide per year.

The mill management also pointed out that hydrogen sulfide emissions were solely derived from the domestic sewage contribution to the wastewater treatment plant. This is likely to be associated with the anaerobic digester and the sludge handling and storage units. Hydrogen sulfide emissions can be effectively reduced by operational changes, local containment, or chemical dosing, or alternatively fully removed by a collection system and bioscrubbing plant.

Solid waste emissions

There are two major solid material disposals to landfill.

Dewatered fibre cake from the vacuum filters is partially sold as cement filler material and the remainder is landfilled via road transport. The solids content of this material is acceptable for landfilling at around 20 percent dry solids content. The annual tonnage going to landfill was not given, but is estimated to be up to 20 tons dry solids per day.

Sludge from the community sewage stream is anaerobically digested (generating methane gas for the

Table I.1.9 Sources of sulfur dioxide emissions and limit values

	Measured SO_2 emission gram/second*	ton/year**	Limit value gram/second
Pulp cooking area:	0.135-0.146	4.0-4.3	0.33
- Rear absorber			
- Washing & Knot collection	0.069-1.09	2.0-32.0	1.14
- Liquor tanks	0.003-0.034	0.09-1.0	0.05
- low tanks	0.557-0.746	16.4-21.9	1.12
Evaporators	0.002-0.089	0.06-2.6	0.68
Yeast drying (oil burning)	1.8	52.9	-

Notes:

* Value range; not related to any specific year.

** Derived data based on range of values and 340 working days per year. In reality these emissions will be intermittent and consequently the actual mass of pollutant discharged may be less than the figures estimated.

mill), and then is mixed and thickened with the surplus biological sludge from the aeration plant. Half of the combined sludge is centrifuged by decanting centrifuges, and the balance is sent to the first of the two duty sedimentation lagoons in series. The centrifuge operation is inadequate to treat the sludge due to a suitable polyelectrolyte being unavailable. Also there is inadequate capacity to treat any sedimented sludge removed from the sedimentation lagoons (which need to be emptied to enable concrete lining).

Environmental accidents

It was reported that major environmental incidents were rare at the mill and that the last reported major accident was over five years ago when there was an excessive ammonia discharge to the river.

Contaminated land

There is no polluted or contaminated land on the mill site.

Economic position

In 1990, Latvia imported half of its pulp requirement and exported 40,000 tons of paper and board from total production of 150,000 tons. This situation has changed significantly in 1992. No pulp has been imported and paper production has been curtailed due to low domestic demand and the high cost of Latvian paper and board.

The mill is severely constrained by the following economic factors:

- Energy costs—energy and fuel must be imported from CIS
- Latvian currency situation
- External competition; the competitive costs of paper from other sources, for example, CIS cannot be matched by the Latvian mills. The Russian paper market price is around 35,000–40,000 roubles per ton compared to the relative Latvian paper market price of 120,000 roubles per ton
- Latvian paper quality is not suitable to sell to Western markets
- The loss of market opportunities in other CEE (Central and Eastern European) countries to sell particularly the lignosulfonates has resulted in retardation of pulp production and an increased cost penalty.

These factors have resulted in lack of investment and reductions in production at the Sloka mill.

The internal market in the republic is expected to increase slowly as consumption rises in printing and writing grades together with packing grades. In 1990 the republic had an annual per capita paper and board consumption of 41 kilograms. This can be compared to other Western countries where consumption is in excess of 200 kilograms per head.

At present the domestic market for Latvian-produced paper is nearly zero due to the cheaper paper available from Russia.

The Sloka mill was to be closed three years ago, but has been kept open on political grounds due to the local employment situation.

Mechanical plant appraisal

Various processes were seen during the site visit. However, no pulping machinery was operational due to a boiler breakdown.

The plant visit was limited to the following process areas:

- Woodyard
- Paper machine 8
- Digester floor
- Sulfur burners and associated absorbers
- Wastewater treatment plant
- Pulp washing and preparation room.

There was insufficient time for a detailed machinery appraisal and the comments made refer only to the plant seen in a stationary state.

Generally the mechanical plant seen was said to be functional. Externally equipment condition was poor, with surface damage and corrosion. Floors and walkways were uneven and corroded. There was substantial surface corrosion associated with steel work around the bisulfite preparation area although this was not examined in detail.

Access to the digester floor area was not possible due to high sulfur dioxide concentrations in the area. This was due to mechanical leakage.

Paper machine 8 was in good condition and appeared well maintained.

The wastewater treatment plant was fully functional with respect to the air compressors, rotary vacuum filters, aeration tanks, and sedimentation tanks seen. The efficiency of the treatment plant was not assessed although the process loadings for 1990 were within conventional criteria.

Health and safety measures seen were few or nonexistent in the areas visited. For example, there was no breathing apparatus evident in the digester floor area for personnel to deal with the alleged sulfur dioxide leak. However, mill personnel are educated and tested for two weeks per year with respect to workplace hazards. It was not clear if personnel health records are maintained by the mill.

The pulp washing machine was functional, but is known to be inefficient and in need of replacement. There was no air emission control equipment evident in the post-digester pulp processing area or the digester floor area.

The bark-burning boilers were operational and producing a dirty brown smoke plume.

Except in the vicinity of the bisulfite preparation area and the digester floor area, there were no discernable odors detected during the visit although conditions were not conducive to odor detection; i.e., the weather was cold and damp with a light breeze.

Overall, no specific measures for reduction of process atmospheric emissions were seen within the pulp mill except those recovery features incorporated into the basic process design.

Retrofitting of air collection and scrubbing equipment to eliminate point emissions, especially sulfur dioxide, in the post-digester processes is feasible, but the cost and practicality of installing such equipment would need detailed investigation.

A more detailed examination of the mill by Swedish consultants concluded that the overall condition of the pulping plant was good for its age although the following comments were made:

- Liquor recovery from pulp washing could be more efficient with respect to reducing the dilution of the cooking liquors prior to further treatment
- Refurbishment of the evaporation plant was needed due to one stage being inoperative leading to excessive scaling and steam consumption
- Improved training of operators particularly regarding the pulp washing operation was required (this has been carried out to an unknown extent)
- Separate treatment of condensate liquors.

In general the pulping operation and pulp produced were of an acceptable quality. The mill's process control instrumentation was very limited and crude, but improving this is unlikely to reduce environmental impacts significantly in most cases, although product quality would be improved.

Environmental emission abatement measures

Environmental status of mill

The Sloka mill pulp production and chemical use data were stated to be typical for a sulfite mill despite the age of the equipment installed. It was assumed that significant improvements were not to be found in minor pulping process changes (except for operator training regarding water use in the pulp washing operation).

When asked to prioritize measures to reduce environmental impact, the mill management gave the following six-point list.

First, improved dewatering of the accumulated sludge retrieved from the sedimentation lagoons is needed to allow a sufficient percentage of dry solids to enable efficient transport to landfill. This refers to the existing centrifuge operation being optimized or uprated to handle the existing sludge production and enable processing of the sedimented sludge accumulated in the lagoons.

Experiments into the use of different polyelectrolytes for the centrifugation would be beneficial. However, the mill can only obtain supplies of one proprietary polyelectrolyte grade at present.

The removal and dewatering of 20 years' accumulated sludge would improve the sedimentation lagoon performance and enable the lagoon capacity to be taken offstream for concrete lining. An increased centrifuge efficiency should reduce the mass of sludge pumped to the lagoon.

The treated effluent quality discharged to the river should improve with both the suspended solids and BOD being reduced.

The mill is also experimenting with alternative technology such as vermiculture to address sludge disposal problems. However, such technology is unlikely to prove an effective enhancement to sludge disposal based on experience in West European domestic sludge treatment.

Sludge disposal to landfill was not identified as an environmental hazard or as a constraint on mill operation although there are costs associated with transport and maybe landfill.

Second, an environmentally sound route for disposal or utilization of lignosulfonate is needed. Lignosulfonate production limits pulp production due to the lack of a suitable environmentally sound disposal route. The material is not degraded efficiently by the wastewater treatment plant and would be better excluded from the mill wastewater. In previous years, the total lignosulfonate production was evaporated to 50 percent dry solids content and sold to Russia for inclusion in asphalt materials, for example. However, the Russian market is now cash limited and this outlet is now effectively closed.

Currently the mill can produce three to five marketable modified lignosulfonate products.

Some 5,000 tons of lignosulfonate per year could be dried to greater than 50 percent dry solids and sold for animal fodder. A suitable dryer already exists at Sloka but there is insufficient investment to install it. Another local plant may be able to dry a limited amount of product. However, none of these methods would account for the current lignosulfonate production.

Another project under consideration is to return the current fodder yeast production back to alcohol fermentation and recovery; the environmental benefit of this is not clear. It was also noted that AMP (adenosine monophosphate) could be extracted from yeast biomass and used for medicinal purposes. This would reduce the RiboNucleic Acid content of the yeast to 3 percent from 10 percent, which is claimed to be beneficial with respect to the ultimate yeast product.

The major current initiative is to implement lignosulfonate processing to give up to 300 modified products for sale.

A Norwegian company (Karlsruhr Lignotech) has been identified as being suitable for carrying out the reprocessing operation. The mill has investigated the feasibility of transporting all the Sloka mill lignosulfonates production to the Norway plant for reprocessing (without profit). However, this is not economic and therefore the mill management are hoping to initiate a joint venture with the Norwegian company to carry out lignosulfonate reprocessing on the Sloka site. Negotiations are scheduled for January 1993.

The viability of building a reprocessing plant on the Sloka site is uncertain given the present financial situation and the apparent lack of a significant market in Latvia.

If the initiative to reprocess the lignosulfonates is not successful, the mill management must find an environmentally sound disposal route for the bulk of the lignosulfonates to continue chemical pulping operations. The materials will not be fully removed by the existing wastewater treatment plant and incineration or equivalent would be very expensive in capital and operating costs.

Third, provision of portable air emission monitoring equipment to enable the mill to monitor emissions at source would improve overall emission control.

Fourth, provision of water quality monitoring equipment could lead to improved performance of the wastewater treatment plant. This may be self-financing in terms of avoiding payment of permit violation costs.

Fifth, the improved instrumentation in some areas of the mill, for example the pulp washing operation, would have a minor environmental impact and also improve product quality.

Finally, conversion of the yeast dryer to gas firing would reduce total sulfur dioxide emissions from the mill. The existing dryer burns oil fuel at approximately 2 percent sulfur content which amounts to some 45 tons of sulfur dioxide per year. This would be virtually eliminated by installing gas-fired burners in the dryer. Based on the data obtained, the mill would then comply with the permit conditions for sulfur dioxide.

The mill management are aware of the inefficiencies associated with the pulp washing equipment. However, there are no plans to replace the machinery although improved manual operation is alleged to have reduced water consumption.

In addition to the environmental priorities identified by the mill management, there are further measures which can be taken to reduce environmental emissions (subject to detailed feasibility studies). The Swedish consultants' report identified improved fibre recovery from the paper machines, pulp washing, and separate digester condensate treatment as other environmentally oriented improvements.

From the discussions with the mill management and by reference to the environmental data obtained, additional improvements in the mill's environmental emissions to atmosphere can be achieved by:

- Retrofitting low-NO_x burners and a management system to reduce nitrous oxide emissions in the boilers, flue gas by up to 50 percent (in most cases)
- Biological scrubbing to reduce sulfurous emissions such as hydrogen sulfide from key emission points in the water treatment plant. Depending on the rela-

tive positions of the major hydrogen sulfide emission points (almost certainly associated with the sludge digestion and treatment plant), either scrubbing from several compost filters, or a centralized collection and scrubber system would be applicable
- Introducing of fume collection and scrubbing equipment in the digester blowdown pits and the pulp washing and screening machines to reduce process sulfur emissions from the mill (see Table I.1.9). This will require a detailed feasibility study, however the installation of fume collecting hoods with interconnecting ductwork and fans to a external scrubber unit or to the sulfur burner is suggested.

As is common with most wastewater treatment plants at pulp and paper mills, there are likely to be performance problems associated with biological aspects of the activated sludge process although the mill management made no reference to such. Therefore, there are likely to be operational improvements in the wastewater treatment plant performance achievable by minor modifications to the processes. Provision of contact zones to reduce microbiological-related bulking and foaming problems is an example. Costs for these problems were not formally identified in this area.

This study has identified nine major environmentally related improvements which could be made to the existing Sloka mill. These improvements and budget costs associated are summarized in Table I.1.10. In addition, the cost of separate condensate treatment to reduce the BOD loading on the wastewater treatment plant is given.

Excluded from this table are refurbishment or replacement of the pulp screening and washing equipment which requires a detailed feasibility study, and also provision of pulp process monitoring devices which require discussions with the mill operational staff.

In terms of best environmental improvement value for money, the following four improvements are given priority:

- Conversion of the yeast dryer plant to gas firing
- Provision of air pollution monitoring equipment
- Water treatment plant monitoring (simple monitors will cost less than the cost given which includes far more sophisticated apparatus)
- Installation of a sulfur dioxide collection and removal/scrubbing system will reduce sulfur emissions to atmosphere and may also improve working conditions in the mill. This option requires further detailed feasibility studies.

The other options are of major environmental significance, but the abatement measures may be expensive, not feasible, or may not give value for money in relative terms to the other measures proposed.

The investigation and optimization of the centrifuge operation is a priority, however if a reliable source of the optimal polyelectrolyte needed for efficient operation cannot be guaranteed, this effort would be futile.

The lignosulfonate disposal/reprocessing route cannot be costed in the terms of this study (although this aspect is crucial to the future operation of the chemical pulp mill).

Separate condensate treatment would be justified if the existing wastewater treatment plant was shown to be organically overloaded. The methanol concentrations recorded in the treated effluent are said to be derived from the condensate liquors; however methanol is biodegradable and ought to be removed by the existing wastewater treatment plant.

The hydrogen sulphide emission sources from the wastewater treatment plant need to be identified prior to considering abatement measures. The major reason for hydrogen sulphide removal treatment is usually odor complaints and these were not mentioned by the mill management or the RJEPC as problems associated with the mill operations.

Nitrous oxide removal by installation of low-NO_x burners is feasible assuming the boiler design is suitable. The degree of NO_x reduction is variable depending on the boiler design and therefore this measure requires detailed technical feasibility studies.

It must be stressed that all the measures proposed should be preceded by a detailed feasibility and impact studies the cost of which are not included in the costs quoted in Table I.1.10.

Long-term development plans

Sloka mill management have presented plans to the republic's Parliament for a $90 million investment in a new pressurized groundwood plant at the existing mill site plus non-chlorine-based bleaching and modifications to Paper Machine 8 to produce box board. There has been no decision so far on this project which would increase emissions to water and is also likely to increase emissions to atmosphere without modifications to the existing mill processes.

It was a generally held view that a new paper mill was required in Latvia and there were four potential greenfield sites.

The options for the Sloka site discussed include:

- Redevelop the Sloka mill by installing new equipment as detailed above. This option retained substantial portions of the existing mill and would therefore not reduce emissions to the environment unless abatement technology was installed. Also this option assumes an environmentally sound means of disposal can be found for the lignosulfonates produced during sulfite pulping
- Build a new Magnefite pulping mill which would recover the digestion chemicals for reuse in the process. This could be at the Sloka site or elsewhere in Latvia. The environmental impact of such a development would depend on the plant capacity and technology employed in the mill construction
- Continue as at present assuming an environmentally sound disposal route for the lignosulfonates. (It is not known whether this can be sustained economically)
- Shut the mill and accept the socioeconomic impact on the population of the region.

At the time of the visit, it was unclear which strategy (if any) will be followed by the republic given the current economic situation.

Conclusions

The existing Sloka paper and pulp mill is severely constrained by environmental, financial, and market factors. 1992 production is expected to be less than half the quoted capacity for the mill.

The mill has violated its permit conditions for emissions to water and atmosphere in the last two years. No action has been taken on the consent violations in 1992.

The major factor in the violation of the permit conditions for treated effluent discharge to the river is the presence of recalcitrant organic compounds derived from the pulping operation, such as lignosulfonates, phenols, and methanol.

The mill management are actively investigating new routes for disposal or utilization of the lignosulfonate production as this is crucial for continued pulp production.

The overall technology and performance of the pulping plant is comparable with Scandinavian sulfite plants. Improvements in process efficiency could be made by a variety of means such as installation of improved pulp washing equipment.

The future of paper and pulp production on the Sloka site is uncertain. The facility would have closed three years ago except for the local employment penalty. Plans for substantial investment in new pulping process plant and non-chlorine bleaching plant at Sloka have been submitted to the republic's government.

A need for increased paper production in Latvia was identified for the longer term, but no progress has been made on isolating a site for this development.

The financial situation prevents the implementation of measures already identified to reduce environmental impacts.

The future viability of the existing chemical pulping operations at Sloka is subject to finding an environmentally sound route for lignosulfonate disposal. The future of pulping and paper making at the Sloka site is dependent on reducing the high cost of the paper and board produced to be competitive with external suppliers. The mill also needs to establish a market for its products or change its products to accommodate the markets available.

The pulping plant equipment installed was considered to be technically viable subject to the comments made in this case study.

Generally the level of automation, monitoring, and control for all mill processes was low by Western standards. Operations are thought to be labor intensive. Health and safety aspects of the mill's operations are thought to be minimal compared to Western work practices although this was not confirmed.

Table I.1.10 Pollution abatement technology and cost estimate

Problem	*Measure remedial*	*Capital cost*	*Operating cost*	*Comments*
Inadequate sludge dewatering operations	Investigate/optimize centrifuge operation	-	$10,000	Requires identification of an optimal polyelectrolyte chemical and a means of supply
Lignosulfonate disposal	Investigate reprocessing option at Sloka site	?		Co-venture with Norwegian company being investigated
Inadequate air emission monitoring	Purchase portable air emission monitors	$20,000	$1,000	Permanent monitors would be beneficial but are more expensive; cost for a mixture of instruments
Inadequate WWTP* monitoring	Purchase portable & permanent WWTP monitors	$100,000	$1,000	Includes COD monitor & assorted portable monitors + datalogging
Emissions of SO_2 from chemical pulping plant	Install collection & disposal system at key sources	$45,000 - $525,000	-	Installation of fume extraction and ducting to scrubber or to sulfur burner
Yeast dryer sulfur emissions	Conversion of yeast dryer to gas firing	$30,000	-	Cost assumes burner replacement only is required
Separate condensate treatment	Install anaerobic treatment or reverse osmosis	$2,250,000	$375,000	Subject to feasibility trials. Methane generation could offset operating costs
Hydrogen sulfide emissions from WWTP	Install gas collection and bioscrubbing equipment	$300,000	$45,000	Assumes emission sources are close and amenable to collection
Nitrous oxide emission from boilers	Install low-NO_x burners	$330,000	-	Assumes boiler design is suitable for burner installation

Annex J

Small Boilers and Households

Introduction

This annex summarizes the material available to us from a literature review and visits to Katowice in Poland and Ostrava in the Czech Republic, on pollution problems and remedies in the small boilers[1] and household sectors.

Small boilers and households represent major sources of pollution in many urban centers—in some locations emissions from small boilers and households account for in excess of 50 percent of the observed pollution levels including areas in Katowice and Ostrava. There is a clear consensus among decisionmakers and experts that the control of emissions from these sources is a high priority on health grounds. The underlying causes of the pollution problems—lack of energy markets, inadequate regulatory frameworks, and irrational pricing practices—are well understood. There is, however, only limited information on the characteristics of the possible technical measures for controlling pollution from the sectors. We have synthesized the information that is available.

Pollution problems

These sectors are characterized by a heavy reliance on coal, often poor-quality coal such as coal sludge and lignite briquettes, used in inefficient and poorly maintained equipment. Coal sludge, for example, contains 50-60 percent ash and is high in sulfur. Few, if any, small boilers are fitted with partuculate emission control devices. Coal stoves and open fires in individual homes tend to be very inefficient and highly polluting so that those urban areas where a substantial proportion of households relies upon individual coal burning tend to be grossly polluted. Domestic waste is also commonly burned in small boilers, which may contribute PCB and dioxin emissions as well as lead and other metals.

Consumers do not have the choice to switch to more convenient and less polluting fuels, such as gas, since there has been a lack of investment in the necessary infrastructure. They also have less incentive to improve energy efficiency, due to pricing practices which do not reflect the true costs of supply. Individual apartments supplied from a central heating system do not have any thermal control or metering. The boiler houses themselves may have no thermal control.

Most studies agree that the pattern of energy use in the small boilers and household sectors will have to be reorganized drastically to ensure both better energy efficiency and environmental improvement. A rational pricing system that incorporates individual metering is undoubtedly a cornerstone of the required changes, but the encouragement of a market in fuels and technologies will also be needed. Regulation, such as the creation of smokeless zones and/or fuel quality standards, may also have a role to play.

Pollution control

There is a diverse range of technical options for reducing emissions from small boilers and households. The most important, in broad terms, are:

- Energy efficiency so that less fuel is used to obtain a given output
- Fuel quality improvements, including fuel switching
- Equipment modernization or replacement
- Installation of pollution abatement equipment (boiler houses only).

Energy efficiency

There is significant theoretical potential for improving energy efficiency. In the residential sector, for example, the average energy intensity is approximately 1.5 $GJ/m^2/yr$ in Central and Eastern Europe compared with approximately 0.9 $GJ/m^2/yr$ in Western Europe. Better insulation, individual metering, and thermal controls are some basic measures that could be taken. Certain measures, such as better insulation of pipes in boiler houses, energy control in boiler houses, secondary windows, and roof insulation could save between 5 and 15 percent of current energy use, be implemented quickly and at relatively low cost. Other measures would, however, require significant investment. For example, the ubiquitous prefabricated "panel" type blocks of apartments—of which between 1.2 million and 1.3 million were built between 1960 and the mid-1980s in Hungary and the former Czechoslovakia alone—are noted for their poor thermal insulation characteristics. Insulating such buildings is an expensive proposition. Central heating is usually supplied to these apartments by single pipe systems, where radiators have no bypass piping and cannot be shut off without cutting the flow of hot water to all the radiators; in these circumstances the only means of "regulating" temperature is in open windows. These systems require substantial modification for installation of individual temperature regulation valves.

In practice there are significant constraints on the take up to energy efficiency measures. For example, there is little or no energy-efficient equipment indigenously available now or in prospect. Similarly, traditional public attitudes on energy use will, in the short term, limit the scope for improvement through behavioral changes.

Fuel switching

Emissions could be reduced by switching to a better-quality hard coal where technically feasible. Better-quality coal will command a higher price, although the effect on overall expenditure will be offset to a considerable extent by improved efficiency. An analysis using data provided by the U.S. Department of Energy from a joint U.S.-Polish study suggests that in Krakow switching from the unwashed coal currently widely used to a washed and graded coal would reduce particulate emissions from specific applications by as much as 80 percent at a cost of around $80 per ton of particulates abated.[2] The situation in Krakow may not be typical of the region as a whole, but represents an attractive option wherever poor-quality coal is currently used.

Switching to smokeless solid fuel (i.e., domestic coke) could reduce particulate emissions from specific applications by over 90 percent. However, many existing boilers and furnaces may not be able to use smokeless fuels. It is also an expensive option—in Western Europe, the price of coke typically exceeds that of house coal by around 40–60 percent. The cost of achieving a reduction in particulate emissions through switching to smokeless fuel works out at about $4,000 per ton of particulates abated.[3]

Another possibility would be to switch from burning coal to burning gas. A substantial level of investment would be required to make gas more widely available. Work carried out as part of the World Bank's Gas Development Plan for Poland concluded that conversion of small boilers to use gas would be financially viable assuming economic energy prices, and indicated that some 50 percent of the boilers surveyed would be suitable for conversion (proximity of gas supply, age, and so forth). Conversion of a typical boiler would cost about $3,000, and would avoid the generation of about 30 tonnes per year of particulates and about 15 tons per year of SO_2.

Existing coal stoves could also be replaced by gas stoves. Although gas stoves are less efficient than modern individual gas boilers or central heating systems, they are far less polluting and more convenient than coal stoves. The cost of retrofitting an existing dwelling would be typically about $1,500, more than half of which is the cost of retrofitting the building and connecting to the gas supply. When a household already uses gas for cooking, but a coal stove for heating, the conversion cost would be halved. Even then, the conversion would not be financially attractive to the individual consumer. But, in terms of achieving reductions in pollution, it would represent a cheaper option than switching to smokeless fuel (if that were feasible).

Equipment modernization or replacement

In addition to switching to gas it may be possible to replace existing equipment with modern coal-burning equipment with better pollution control characteristics. In the United Kingdom, British Coal has suggested that modifying existing equipment or installing new modern equipment can reduce particulate emissions to the same extent and at a lower cost than switching to smokeless fuel. Underfeed stokers, in which coal is fed mechanically to the bottom of a firebed, have been developed for small- and medium-size applications and can provide virtually smokeless combustion. A second approach, used for household coal stoves, is to pass the combustion products down through the heated firebed where the combustible component of the smoke (soot and volatile organics) is burnt before reaching the chimney. However, the opportunity for using such equipment will not necessarily be the same in Central and Eastern Europe and should be examined specifically for coal-burning boilers and stoves used in the region. In any case, the potential for reducing SO_2 emissions using either smokeless fuel or smokeless appliances is limited, whereas switching to gas eliminates SO_2 as well as particulates.

Pollution abatement equipment

Household boilers and furnaces cannot, realistically, be fitted with pollution control devices. Similarly, in many cases, it may not be possible to fit particulate control devices to small boilers because of space limitations or ash handling problems. In some cases, however, bag filters could be used to control particulate emissions effectively, at an investment cost of something like $25–40 per annual ton of emission avoided. This represents a cheaper option than switching to gas, but it would not, of course, control SO_2 emissions.

Conclusions

The small boilers and households sectors are important sources of urban air pollution. The ultimate solutions to pollution problems in these sectors are closely bound up with the economic and market reforms, perhaps more so than in any other sectors. For example, price liberalization is required to stimulate investments in gas supply infrastructure and encourage the use of better-quality coals. Regulations may be needed to create clean air zones.

Meanwhile, potential remedial measures could include:

- Basic energy efficiency measures
- Switching to higher quality coal
- Switching to gas
- Switching to modern clean coal technology
- Retrofitting particulate control equipment to boiler houses.

Producers and consumers do not have the incentives to make these expenditures and, therefore, public policy mechanisms are needed to provide them. In the short to medium term such mechanisms may include directing pubic funding towards priority areas.

Endnotes

1. Small boilers (typically less than 200 kW_{th}) are used in small industrial and commercial enterprises, public buildings, and residential apartment blocks.
2. This figure assumes that all incremental costs are ascribed to particulate emissions reduction and, therefore, does not reflect the benefit associated with any simultaneous reduction in gaseous emissions.
3. This figure assumes that all incremental costs are ascribed to particulate emissions reduction and, therefore, does not reflect the benefit with associated any simultaneous reduction in gaseous emissions.

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