How Much Will Pollution Reduction in Krakow Cost?

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The region around Krakow in Southern Poland is one of the most heavily polluted areas in the world. In 1989, while visiting Poland, President George Bush made a commitment on behalf of the U.S. to assist in the reclamation of the Krakow environment; Congress in 1990 authorized $20 million to address pollutants from "low emissions sources," that is, from facilities with low stacks.

The low emission sources are responsible for 35 percent of SO_X emissions, significant NO_X emissions, and are the primary source of particulate and organic emissions. The Krakow Clean Fossil Fuels and Energy Efficiency Project, sponsored by the U.S. Agency for International Development and implemented by the U.S. Department of Energy, is designed to reduce these emissions by improving the efficiency of coal use in Krakow's 130,000 coal stoves and 1300 small coal-fired boilerhouses, by reducing demand for energy for space conditioning through thermal integrity improvements, and/or by switching to alternative fuels.

The project includes a comprehensive testing program, engineering analyses, and economic assessments to determine the most attractive strategy for reducing emissions from low emission sources in Krakow; this paper reports on the initial results of the project.

Situation Overview

The southern portion of Poland, around Krakow and Katowice, is one of the most heavily polluted areas in the world (PETC, 1990). Forty years of heavy industrialization, subsidized energy prices, and a general disregard for the environment has left a legacy of poisoned land, water, and air. The rapid collapse of the socialist governments of Eastern Europe was due in part to the recognition by the population of the unwillingness or inability of their governments to address environmental issues. "Concern about environmental degradation in a situation of powerlessness to act is mentioned as an early and powerful stimulus to mobilization" (Prins, ed.,1990).

The ancient Polish capital of Krakow is symbolic of both the environmental disregard of the old order and the commitment of the West to assist in improving the situation. One of the few Medieval Eastern European cities to escape destruction in World War II, Krakow has been designated an international treasure by the United Nations. The "faceless statues" of Krakow attest to the severity of the pollution problem. On a visit to Poland in 1989, U.S. President George Bush stated: "Today, Krakow is under siege by pollutants. Its priceless monuments are being destroyed. Krakow must be reclaimed, and the United States will help." (PETC, 1990) The project discussed in this paper is one part of that commitment.

Pollution Sources

In 1990, Congress authorized $20 million to address pollutants from "low emission sources" (facilities with low stacks) in Krakow. There are 130,000 coal burning stoves and about 1300 coal-fired boiler houses in Krakow. These sources are responsible for 35 percent of SO_X emissions, significant NO_X emissions, and are the primary source of particulates and organics. This project is designed to improve the efficiency of coal use, reduce the demand for space conditioning by improving the thermal integrity of buildings, and/or switch to alternative fuels.

The air quality in Krakow has improved during the past decade, due primarily to the economic recession and decreased production at the nearby Sendzimir steel works. However, pollution from vehicles and the low emission sources has increased. In 1990, Krakow was estimated to be the most polluted town in Poland (Main Statistical Office, 1992).

Effects of Pollution

Seven permanent continuous air monitoring stations have been operating around Krakow since August, 1991. Data from this equipment allowed observations on changes in air quality at the beginning of the heating season.

Pollutant concentrations increase drastically with the onset of the heating season, and far exceed Polish standards.

In particular, SO_2 concentrations show significant increases in downtown Krakow compared to areas of the city with district heating. Similar observations can be made about CO, particulates and organics, although concentrations of these pollutants are more affected by industrial sources. Overall, the prevalent sources of winter pollutants are the low sources of emission.

SO_2, NO_x, and particulates contribute to respiratory diseases and bronchitis. The frequency of bronchitis in children in Krakow is about 10 percent, compared to 2 to 3 percent in southern Poland. Respiratory diseases are more common in Krakow than in the rest of Poland; days absent from work (per hundred workers) due to respiratory problems average 25 to 33 percent more in Krakow than in the country as a whole.

Carbon monoxide reduces the amount of oxygen carried in the bloodstream, and has been linked to circulatory and heart diseases. Absence from work due to circulatory problems has been from 15 to 38 percent higher in Krakow than in Poland as a whole over the past decade. Figure 1 shows the frequency of several heart ailments, as well as chronic bronchitis, in Krakow compared to other areas of Poland.

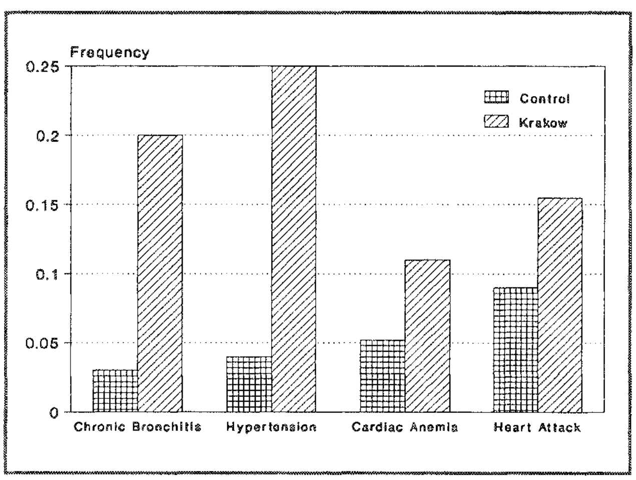

Figure 1. Effect of Air Pollution on Health

Organic pollutants are implicated in various cancers. The number of cancer diseases among men is 21 percent greater in Krakow than in Poland. For women, overall cancer cases are 50 percent higher in Krakow and the incidence of breast cancer is more than double the rate for Poland.

U.S. Involvement

In 1991, Polish and U.S. officials established an eight-member Bilateral Steering Committee to plan and guide the project. U.S. involvement in solving Krakow's air pollution problem will demonstrate the American commitment to improving the quality of life in Poland and expose to and train the Poles in the use of modern testing, analytical techniques, and technology in developing cost-effective solutions. It is hoped that the project will lead to joint ventures between U.S. and Polish firms, and serve as a useful model for solving similar problems elsewhere in Eastern Europe and the rest of the world.

Project Overview

The Krakow Clean Fossil Fuels and Energy Efficiency Project is being conducted in three phases. In Phase I, testing and analytical activities will establish the current level of emissions from existing equipment and operating practices, and will provide estimates of the costs and emission reductions of various options. Results from Phase I will provide information for Phase III (joint ventures) as well as provide input to the city of Krakow for the development of its Master Plan.

Phase II will consist of a series of public meetings in both Poland and the United States to present the results of Phase I activities. These meetings will serve to provide information to private firms who may be interested in forming joint ventures to implement recommendations from Phase I. In Phase III, DOE will issue a solicitation for Polish/U.S. joint ventures to perform commercial feasibility studies for the use of U.S. technology in one or more of the areas under consideration.

Low Emission Sources

Almost half of the energy used for heating in Krakow is supplied by low-efficiency boilerhouses and home coal stoves. Within the town, there are more than 1,300 boilerhouses with a total capacity of 1,071 MW, and about 130,000 home furnaces with a total capacity of about 300 MW. More than 600 boilerhouses and 60 percent of the home furnaces are situated near the city center. These facilities are referred to as "low emission sources." They are the primary sources of particulates and hydrocarbons in the city, and major contributors of sulfur dioxide and carbon monoxide. Poor natural ventilation of the Krakow area, situated in the Vistula valley, and the frequent occurrence of thermal inversions contribute to the air quality problems in the town.

It is estimated that the home coal stoves supply about 13 percent of the energy required for heating in the city. These are large masonry stoves, covered with ceramic tile, and are usually located in the main living space of an apartment. Most of these stoves are used for heating in the historic buildings in the center of town, and the emission of combustion gases from these sources adversely affects the air quality in the town.

A survey of the boilerhouses was conducted in 1990 by Krakow municipal authorities (Kirchstetter, 1992). There are 2,929 boilers in Krakow's boilerhouses. Most of these boilers supply heat to more than one building; altogether they provide about 35 percent of the heating needs of the city. About 77 percent of the boilers, representing 86 percent of the capacity and almost 90 percent of the fuel use, are solid-fuel fired. More than 387,000 tons of coal and coke are consumed annually in the boilers.

Most of the boilers, more than 2,600, are small hand-fired units. These boilers primarily use coke. Hand-fired boilers account for about half of the total capacity and almost 40 percent of the fuel use. There are 227 traveling grate (mechanical) boilers, which use coal and represent 48 percent of the total capacity and almost 60 percent of the fuel use. The remaining boilers (3 percent) are fluidized bed boilers. At the time of the survey, small gas-fired boilers represented about 7 percent of total boiler capacity.

The only pollution control equipment (PCE) used at Krakow boilerhouses are cyclones for particulate removal. Fewer than 10 percent of the boilers are equipped with PCE's; most of these are larger mechanical boilers. Slightly less than 60 percent of the annual solid-fuel consumption is in boilers with PCE's.

At the end of 1990, about 86 solid fuel boilers were operating within the Old Town area of Krakow. These are mainly small boilers with a total capacity of 18.6 MW and annual fuel consumption of 4562 tons. During 1991, 12 of these were converted to gas or eliminated.

Options Considered

Phase I of the project is designed to identify the most efficient ways to reduce emissions from the low emission sources in Krakow. The Bilateral Steering Committee approved five subproject areas for study, as described below. Each focuses on specific alternatives to eliminate boilers or stoves, or to improve their performance.

District Heating. About half of the heat demand in Krakow is supplied by the municipal district heating system. The distribution system serves most parts of the city, except the center. A large portion of the heat supplied to the system comes from cogeneration plants, but these are currently underutilized. Expanding the district heating system in six areas of the city and improving its efficiency could eliminate approximately 290 local boilerhouses with a total capacity of about 250 MW. Further, the large multi-family buildings served by the district heating system are inefficient. This subproject includes a demonstration of efficiency improvements to four of these buildings, including shell measures and installation of individual apartment meters. The district heating portion of Phase I is being managed by Pacific Northwest Laboratory and is not included in the discussion that follows.

Converting Old Town Solid Fuel-Fired Boilerhouses to Natural Gas. As mentioned above, there is practically no district heating alternative to elimination of low sources of air pollution in the Old Town because the area cannot be accessed by the urban district heating system. Some Old Town boilers have already been converted to gas; this subproject will examine the possibility of using the excess capacity of the natural gas distribution system for further conversions. The pricing of natural gas will be examined, along with possible incentives to those consumers who would consider converting to natural gas as a fuel because it will be more expensive than using solid fuel. Other areas of the city are also being considered for conversion to natural gas.

Because some of the existing coal- or coke-fired units are relatively new and not likely to be replaced, this subproject also includes testing of a typical Old Town fixed grate boiler to establish if use of different fuels or different operating procedures would result in decreased atmospheric emission levels.

Selected Conversion of Home Stoves to Electric Heat. A one square kilometer area immediately adjacent to the historic Old Town quarter is also inaccessible to the heat distribution network due to its dense character, including narrow streets with extensive underground infrastructure. Heating is based on solid fuel, mostly home stoves. In the center of this area there is an electric substation with a reserve output in the range of 50 MW that could be used for heating purposes. To use this reserve, some coal stoves would be retrofitted with electric inserts or replaced by electric thermal storage heaters.

Costs include upgrading the distribution system and modifications to individual buildings, as well as equipment and electricity costs to consumers. As with natural gas, other areas of the city are being considered for electric heating.

Modernization of Boilerhouses. At present, there are more than a dozen larger boilerhouses (10-40 MW capacity) operating in Krakow. Because of their role in the town's heating system, they will not be eliminated even in the distant future. This subproject considers options to modernize these boilerhouses.

The Municipal Heating Authority (MPEC) at Krakow suggested that the boilerhouse at Krzeslawice be used for testing and demonstration. The boilerhouse consists of four traveling grate boilers and several smaller boilers for a total output of 23 tonnes of steam per hour. Preliminary evaluation of expected future demand in the area has indicated that the capacity of this boilerhouse should be increased to about 50 tonnes of steam per hour. The modernization combined with extension would allow 9 nearby boilerhouses (with a total of about 10 MW capacity) to be eliminated.

As an alternative to replacing the boilerhouses, the possibility of using different fuels is being examined in a boiler test program. Changes in emissions, air quality, and costs will be calculated, and the results will be evaluated to determine the applicability of this approach for pollution reduction in other Krakow boilerhouses.

Replacement of Existing Coal Stoves. The improvement of stove-based heating by simple replacement of existing low-efficiency stoves by modern units could give considerable savings in coal consumption, and would lead to reductions of pollution by coal combustion products. The combination of more efficient stoves with application of improved fuel, such as washed, briquetted coal, may translate into substantial emission reductions.

This subproject includes testing of modern stoves and conducting air quality analyses. As an alternative to replacing the present home heating stoves, the work under this subtask also includes testing to evaluate pollution reduction achievable by use of alternate fuels and operating procedures.

Approach

Each of the areas described above includes testing, engineering analysis, and incentive analysis components, as appropriate. Boiler and stove testing is establishing baseline performance and emissions using current fuels and operating conditions. Additional tests utilize alternative fuels such as washed and graded coal and briquettes, and alternative operating conditions. Particulates and condensable organics are being measured.

The engineering analyses include evaluation of local and regional air quality improvements due to the various alternatives considered, as well as cost estimates for conversions or replacements. The incentive analyses include fuel price projections, examination of any legal or regulatory impediments to the various alternatives, and suggested activities for the local government to encourage implementation of those alternatives found to be worthwhile.

In addition, a public relations effort has been defined to inform the citizens of Krakow about the project and provide the means for public attitudes to be measured and incorporated into project decision-making. Surveys will measure the relative importance of issues as well as price elasticities.

Finally, an integrative analysis will incorporate results from all the above activities into a common framework which will allow a comparison of the alternatives under consideration.

Results to Date

Current Emissions

Figure 2 shows estimated current emissions from the boilers and stoves. These emissions are based on fuel use from the boilerhouse survey and emission factors from the testing activity of this project. EPA emission factors are used where test results were not available.

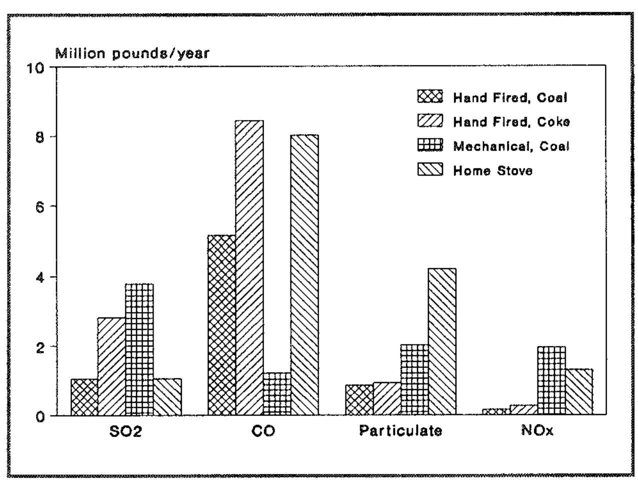

Figure 2. Estimated Current Emissions

The figure shows that the home stoves are responsible for about half of the particulate emissions and slightly more than one-third of the CO and NO_x emissions from the low emission sources. Hand-fired boilers contribute almost 60 percent of the CO and almost half of the SO_2. It should be noted that the home stoves were tested with a low-sulfur coal; SO_2 emissions would be significantly larger with a higher sulfur coal. Mechanical boilers are important SO_2 and NO_x sources. These results will be updated as more testing results become available.

Testing

Tests have been completed for one of the four boilers scheduled for testing, a mechanical stoker-fired boiler with cyclone dust collectors at the Balicka boilerhouse. Baseline tests were done with coal from the Ziemowit mine in Silesia, which has a total sulfur content of 0.8 percent and an ash content of about 23 percent. At 50 percent load, the emission factors, in pounds per ton of coal, were: CO, 3.4; NO_x, 7.6; SO_2, 10.4; and particulates, about 4. These factors are quite similar to EPA emission factors. Test results using a different coal, both run-of-mine and washed, are currently being analyzed, as are emission factors for organics.

Testing at the Krzeslawice boiler, which is connected to the municipal district heating system, will be conducted in June. Tests at two hand-fired units will be done in the fall, at the beginning of the next heating season.

Stove testing is being carried out at a facility built at the Academy of Mining and Metallurgy (AGH) in Krakow, under the direction of BNL. The system uses a dilution tunnel method to determine gaseous pollutant emission rates and flue gas energy loss on a continuous basis. Particulate emissions are averaged over firing cycles. Test results are available for a typical run-of-mine coal with 0.28 percent combustible sulfur and 3.34 percent ash (ultimate analysis).

The stoves are typically fired at 12 or 24 hour intervals, heating the masonry structure. The firing cycle lasts for about 1 1/2 hours, after which the room continues to be warmed by the heat stored in the masonry. Data are taken during a 24 hour test to provide continuous measurement of the emission rate of gaseous pollutants and combustion products, as well as the stack gas losses.

Analysis of the data shows that the CO emission rate is very high during the first 0.3 hours (about 200 grams per hour), then decreases to about 50 grams per hour. At the 1 hour point, the top door of the stove is closed, leading to a gradual reduction in the combustion rate but a dramatic increase in the CO emission rate (again up to 200 grams per hour). A significant part of the total CO emissions occurs after the top door is closed. NO_x emissions are high at the beginning of the firing cycle, while the SO_2 emission rate increases throughout. At 1.3 hours, the bottom ash pit door is closed and the combustion process stops (Butcher et al., 1992).

Emission rates from the stove tests in pounds per ton of coal are: CO, 80; NO_x, 13; SO_2, 10.6; and particulates, about 40. These rates roughly compare with prior published data for stoves. Test results to date indicate that the stove efficiencies are about 65 percent, significantly higher than previous estimates of 30 to 40 percent.

Tests have been completed with a coal with higher sulfur and ash content and with briquettes, and results are currently being analyzed. Briquettes have the potential to significantly reduce particulate and organics emissions. Emissions and stove efficiency are dependent on the operating procedures as well as the coal characteristics, and tests are underway to measure these effects.

Costs

Fuel Prices. Increasing fuel prices will be a significant determinant of the relative costs and benefits of the options under consideration. Prices in Poland have risen rapidly in the recent past and are now close to world levels, but further increases are expected. Fuel price projections have been prepared by Polish analysts for natural gas, coal, and electricity (Polinvest, 1992).

Subsidies for coal will be eliminated this year, and thereafter coal prices are expected to grow at an annual rate of approximately 2.3 percent to 1995, and between 1 and 2 percent per year through 2010. Coke prices are about 1 1/2 times the price of coal, and industry pays about 30 to 60 percent less than other customers.

Electricity prices are directly related to coal prices, because all electricity is produced in coal-fired power stations. Residential electricity prices are forecast to reach about \$0.05/kWh by 1996, with time-of-day pricing of \$0.065 for peak use and slightly over \$0.01/kWh for nighttime use. Such a rate structure should help provide an incentive to switch from coal to electric heat.

Non-industry natural gas prices have risen dramatically from less than $\$30/10^3m^3$ in 1990 to \$139 now. An agreement with the World Bank stipulates that this will rise to $\$216/10^3m^3$ by 1996; a slightly lower price may be acceptable.

In the transition to a free-market economy, a significant restructuring of energy industries is necessary to achieve world energy prices and local control of pricing policies. Legislative activity in this area has begun. It is likely that the Polish Oil Drilling and Gas Engineering Company (PGNiG) will be split into one company for extracting and processing natural gas, and another for transmission and distribution. The monopoly of PGNiG over extraction of natural gas is expected to be eliminated this year, and negotiations for licensing foreign companies are being completed. Joint venture companies for distribution will be possible around the end of 1993 and the beginning of 1994. Similar restructuring and privatization activities are planned for the electric company in Krakow.

Rapidly rising fuel prices lead to concerns about their economic impact on individuals. Although average expenditures on fuels and electricity represent only about 5 percent of home budgets compared to about 18 percent in Western Europe, doubling or more of prices will have a severe impact. Industry restructuring and privatization may help lower production costs, especially for natural gas. Other forms of relief and assistance are likely to be necessary, however.

Gas Conversion. Cost estimates for converting Old Town boilers to natural gas have been prepared (Krakow Development Office, 1992). Costs include boiler-specific replacement costs for the 36 remaining Old Town boilerhouses (total capacity 16,252 kW) and costs to upgrade and expand the gas distribution network. Boiler costs are based on actual costs incurred in replacing or eliminating 12 boilerhouses in 1991 and detailed estimates for the rest.

Necessary improvements to the distribution system include the reconstruction of 4 sections of low-pressure pipelines totalling 585 meters, the reconstruction of 15 connections, and increasing the capacity at 2 reduction stations. Total cost is estimated at 1 billion zlotys, or $90,810 using the 1991 exchange rate. It is unclear whether these costs would be applicable to other areas of the city.

Total boiler replacement costs are estimated to be $1,907,010. Individual boiler costs depend on the capacity as well as the building characteristics. Costs can be significantly higher in buildings designated as having historic value. Capacity related costs range from $90 per kWh for large boilers to $272 per kWh for small boilers. Total investment costs for the Old Town boilers and distribution system are $123 per kW, or approximately $2 million.

Using EPA emission factors for hand-fired boilers as in the estimation of total current emissions, elimination of the original 48 Old Town solid-fuel boilerhouses will reduce SO_2 emissions by 1.4 percent, CO emissions by 1.8 percent, and particulate and NO_x emissions by less than 1 percent. As discussed below in the Analysis section, total emission reduction is not an adequate measure of benefit. To provide a full measure of benefit, emission reductions must be linked to pollutant concentration levels.

Air Pollution Fees and Penalties. The Poles currently have in place a system of fees and penalties for polluting the air (Ekopol, 1991). The fees may also be called an environmental tax, which may be incorporated in the price of the product. Permits are granted on the basis that ambient air quality standards will not be exceeded, and penalties are levied when a firm exceeds permitted levels of emissions. Home stove owners are not subject to standards or fees.

If a plant has received a permit, but exceeds the allowed emissions, the fee is assessed for emissions up to the limit of the permit. Above this limit, the penalty is 10 times the fee and is accounted for as an extraordinary loss and deducted from after-tax profit. If a plant has no permit, the plant pays a small penalty (fee times 2) which is treated as a regular cost. All fees and penalties are directed to a fund for environmental improvement.

Enforcement is difficult. Violations are determined by measuring stack gas concentrations, and there are only three teams engaged in doing this for the entire province. Rulings can also be appealed in court, and penalties are suspended during the period of appeal. Continuous monitoring is required only for plants emitting more than 100 tons/hour of SO_2. Better enforcement options are currently being considered.

Fees in the Krakow and Katowice provinces are double the national rates because these regions are considered to be ecologically endangered. The total annual fee which could be collected in Krakow from low emission sources is about 23 billion zlotys (around $2 million); most of this is from the municipal district heating company. Fees are from 7 to 19 percent of the price of coal, depending on the type of boiler, and about 3 percent of the cost of coke. Fees are negligible for natural gas.

It should be noted that estimates of environmental externality costs compiled for the U.S. for several pollutants (Pace, 1990) are higher than the Polish penalties by as much as a factor of 20; the Polish system is now under review and will probably be revised.

Integrative Analysis

The projects under consideration for the Krakow Clean Coal and Energy-Efficiency Project will be evaluated within the context of Poland's transition to a free-market economy, including a transition to world prices for fuels, and the urgent need to alleviate the damage caused by energy-related pollution. This will require analyzing each proposed action from two perspectives:

- that of the individuals affected by the measure (private perspective); and
- that of society as a whole (public, or social perspective).

Both classes of analysis require technical information on the attributes of the individual options (costs, efficiencies, emissions characteristics), their interactions with other options (e.g., energy-saving measures reducing the savings associated with efficiency improvements), and "macro" factors which affect the economics of the options (energy prices, elasticities, discount rates). Care must be taken to evaluate all options on a common basis; that is, using common economic parameters and a methodology that forces comparisons to be made on an internally-consistent basis.

The problem of selecting the "best" measures for reducing pollution in Krakow is complex. Both the type of pollutant (e.g., particulates, SO_X, organics) and the location of its source will have measurable and significant (order/orders of magnitude) impacts on the benefits of reduction. The benefits of reducing emissions are the avoided costs of the health and physical damage effects associated with ambient (ground level) pollution. Aggregate quantities of emissions reduced may not provide the best measure of benefit.

Actions taken by governments on behalf of their citizens are expected to generate benefits which exceed the costs of the actions. Estimates of the costs of the pollution reduction measures considered in this study are subject to uncertainties, some of which have been reduced through testing and study (e.g., efficiency of energy use, investment cost). Benefit estimation is also subject to considerable uncertainties, ranging from estimates of the distribution of pollutants to estimates of the health effects of various levels of pollution. Damage functions which relate physical damage due to the level of pollution to monetary damage are notoriously difficult to estimate. However, if the public is to be persuaded of the merits of actions to reduce pollution (which will involve tangible monetary costs), understandable and believable estimates of the benefits must be supplied as well.

Methodology. The approach taken was to:

- develop a set of specifications for the methodology to be used in evaluation of the options considered in the project;
- review existing methodologies for their suitability with respect to meeting these specifications; and
- select an existing methodology for adaptation or create a new methodology.

The methodology selected had to be capable of quantifying the costs and benefits of each option under consideration, providing the information needed to evaluate the economic viability of potential joint ventures, and of analyzing the tradeoffs among options under a variety of future scenarios.

Three criteria were applied in the evaluation of candidate methodologies:

- Appropriateness - the ability of the methodology to address relevant information needs;
- Transparency - ease of understanding; and
- Resource requirements - level of effort required to implement the methodology for Krakow.

The evaluation was undertaken jointly by the American and Polish project participants. Methodologies considered ranged from a simple spreadsheet model to an optimization framework constrained by ambient air quality standards.

The spreadsheet model (U.S. DOE 1992) was developed for screening candidate options for pollution reduction for Krakow on the basis of cost; while the model required the lowest commitment of resources and was the easiest to understand of the alternatives considered, it was weak in providing estimates of the benefits of alternative courses of action and in accounting for the interactions among options.

Linear programming models applied to city or regional level problems similar to those in Krakow (Johnson et al. 1992) overcame the problem of accounting for interactions, but did not provide estimates of benefits other than in terms of aggregate quantities of pollutant reduction.

The methodology found to be strongest in terms of providing useful measures of benefit (changes in ambient [ground-level] concentrations of pollutants) involved the linkage of an optimization (linear programming) framework with a matrix of source-receptor relationships which allowed for the use of air quality standards as constraints (Balandynowicz, Cofala). The model was developed for an earlier study of another region in Poland; while resource requirements were greater than those for the other alternatives, the ability of the model to provide estimates of benefit which could be understood by the inhabitants (changes in ambient concentrations can be translated into improvements in health) and to optimize benefits subject to a variety of constraints were considered important.

At present, the level of resources available is sufficient only to support enhancement of the spreadsheet approach used in the earlier scoping analysis. However, alternatives that go beyond the spreadsheet approach are still being explored. As the data required by the spreadsheet model are a subset of those required by the optimization/air quality approach, it may be possible to exercise this methodology as well, so that the utility of the different approaches can be compared.

Another methodology (Sinyak 1992) having many of the attributes of the optimization/air quality approach was considered, but rejected due to its early stage of development.

Summary/Next Steps

Joint Ventures

Based on the results of Phase I, DOE will issue a solicitation for promising Polish/American joint ventures designed to provide equipment to lead to air quality improvement in Krakow. The solicitation may be issued as early as the Fall of 1992 (Gyorke et al. 1992). Selection of joint ventures will be based on an evaluation of the equipment or technology proposed, including performance, commercial readiness, potential for improvement of the air quality in Krakow, anticipated market penetration, and applicability for utilization beyond Krakow. Joint venture activities could include studies of the legal, regulatory, and financial aspects of setting up business, and could include demonstration-scale tests of equipment. At least 50 percent cost-sharing will be required.

References

Balandynowicz, H.W. et al. November, 1990. "Modeling of Air Pollution Control Strategies In Industrial Region: Case Study for Tarnobrzeg Region (Stage 1)". Polish Academy of Sciences, Warsaw, Poland.

Butcher, Thomas A. et al. July 1992. "Krakow Clean Fossil Fuels and Energy Efficiency Project". Presented at the Eighth Annual Coal Preparation, Utilization, and Environmental Control Contractors Conference, Pittsburgh, PA.

Cofala, J., and Lis, T. August, 1991. "Modeling of Air Pollution Control Strategies in Industrial Region: Case Study for Tarnobrzeg" Region (Stage II - Benefit Estimates). Polish Academy of Sciences, Warsaw, Poland.

Cracow Development Office. "Proposal of the Cracow Development Office To Perform Selected Tasks Under the Project of Low Emission Elimination in Cracow".

Ekopol 1991. "Low Emission - Subject I/2.3". Krakow, Poland.

ERG Inc. Fall, 1991. *Energy Issues*, "Gaining a Perspective on the Issue of Environmental Externalities."

Gyorke, D.F., Blinn, M.B., and T.A. Butcher. 1992. "The Krakow Clean Fossil Fuels and Energy Efficiency Project." Presented at Air & Waste Management Association 1992 Annual Meeting, Kansas City, MO.

Johnson, J. et. al. January, 1992. "Integrated Energy-Emissions Control Planning in the Community of Uppsala". Chalmers University of Technology, Goteborg, Sweden.

Kirchstetter, Thomas. 1992. "Krakow Boilerhouse Survey Analysis." Brookhaven National Laboratory, Upton, NY.

Krakow Development Office. April 1992. "Replacing Solid Fuel Fired Boiler Houses with Gas Fired Ones Within the Old City Area; Investment Costs Estimate Summary." Krakow, Poland.

Main Statistical Office. "Environmental Protection 1992".

Pace University Center for Environmental Legal Studies 1990. *Environmental Costs of Electricity*. Oceana Publications, Inc., Dobbs Ferry, New York.

PETC Review. September, 1990.

Polinvest Ltd. March, 1992. "American-Polish Program of Elimination of Low-Emission Sources in Krakow". Krakow Development Office, Krakow, Poland.

Prins, Gwyn, ed. 1990. *Spring in Winter: The 1989 Revolutions*. Manchester University Press, Manchester and New York.

Sinyak, Y. January, 1992. "Environmental Decision Support System CLAIR." International Institute for Applied Systems Analysis, Laxenberg, Austria.

U.S. DOE. January, 1992. "Low Emissions Sources of Krakow: Analysis of Cost Effective Approaches to Cleanup."