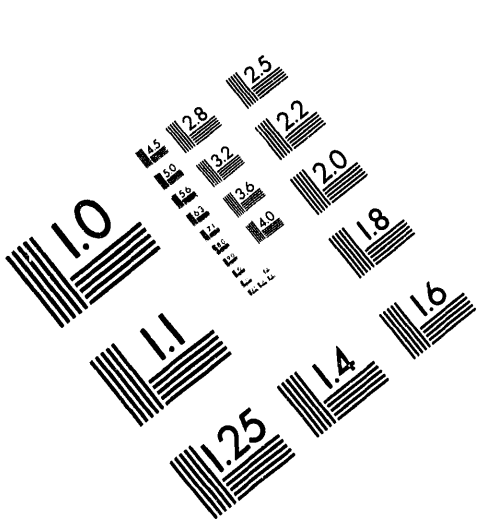

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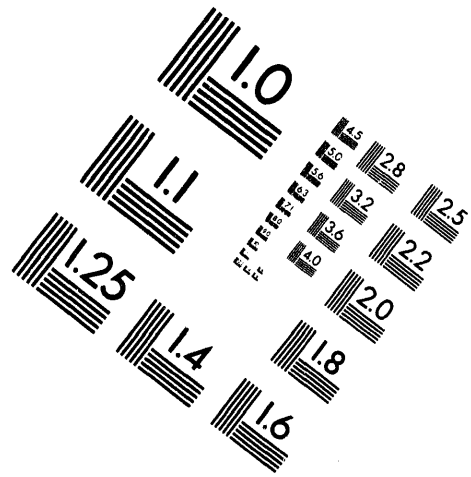

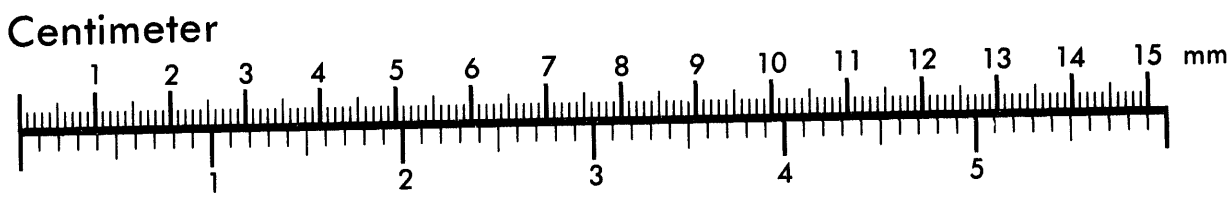

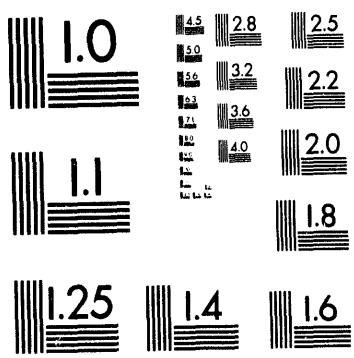

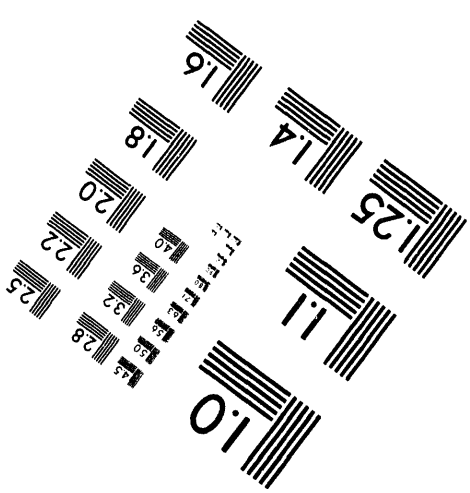

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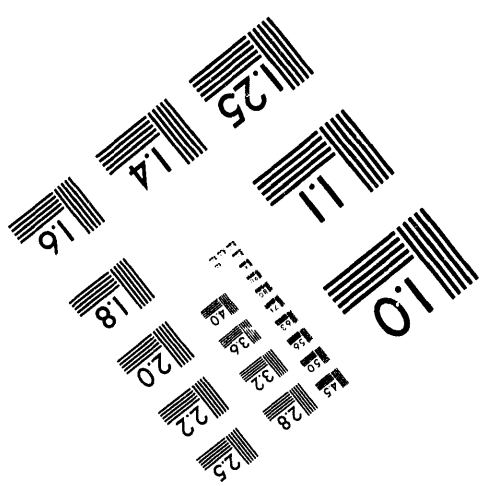

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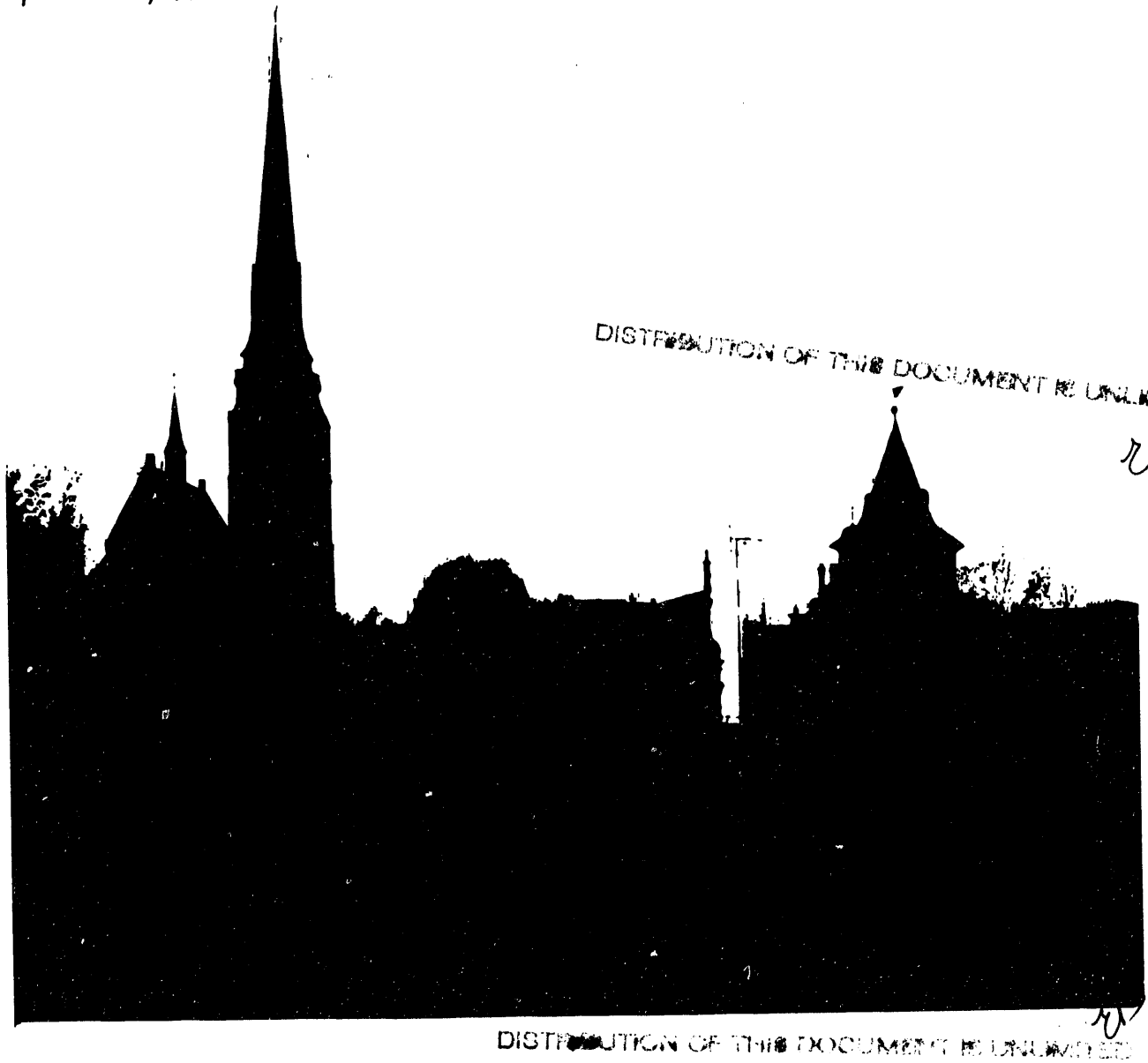
Plzeň Proceedings

Conference on Alternatives for Pollution Control from Coal-Fired Low Emission Sources Plzeň, Czech Republic

April 26-28, 1994



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FOREWORD

The Conference on Alternatives for Pollution Control from Coal-Fired Emission Sources presented cost-effective approaches for pollution control of low emission sources (LES). It also identified policies and strategies for implementation of pollution control measures at the local level. Plzen, Czech Republic, was chosen as the conference site to show participants first hand the LES problems facing Eastern Europe today.

Collectively, these Proceedings contain clear reports on:

a) methods for evaluating the cost effectiveness of alternative approaches to control pollution from small coal-fired boilers and furnaces;

b) cost-effective technologies for controlling pollution from coal-fired boilers and furnaces;

c) case studies of assessment of cost effective pollution control measures for selected cities in eastern Europe; and

d) approaches for actually implementing pollution control measures in cities in Eastern Europe.

It is intended that the eastern/central European reader will find in these Proceedings useful measures that can be applied to control emissions and clean the air in his city or region.

The conference was sponsored by the United States Agency for International Development (AID), the United States Department of Energy (DOE), and the Czech Ministry of Industry and Trade.

Howard Feibus
Co-Chairman
U.S. DOE

Printed with soy ink on recycled paper

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IN-COUNTRY OVERVIEW OF THE KRAKÓW PROJECTS

JAN FRIEBERG
Deputy Mayor
Kraków, Poland

INTRODUCTION

For several years we observe growing air pollution in Kraków. The city is located in the valley of Vistula river and together with climate conditions and industry concentration we have typical conditions for inversion phenomenon and smog generation. This situation brings damages to over 750 000 inhabitants, over 1.5 million visitors and unique buildings of our historic city. Fig. 1 shows some data on it.

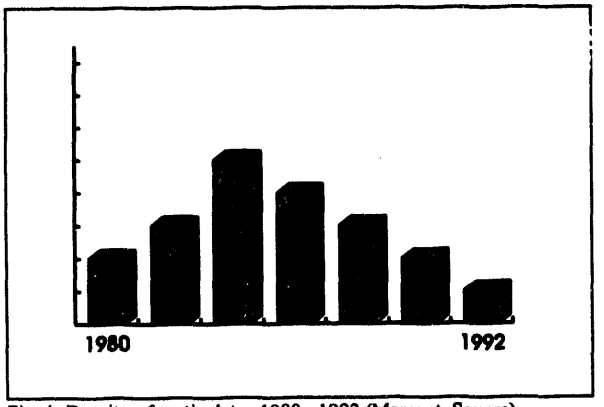


Fig. 1. Density of particulates 1980 - 1992 (Marquet Square)

Growing public concern on environment issues from one side and official research from another have lead to decisions for step - by - step elimination of low emissions sources in the city. At the end of eighties there were aprox. 100 000 traditional coal fired home stoves and over 1300 local boiler houses (coal and coke fired). Fig. 2 shows the main sources of air pollution. Therefore of this the main goal of local environment policy is to eliminate traditional stoves and boiler houses as the sources of heating energy.

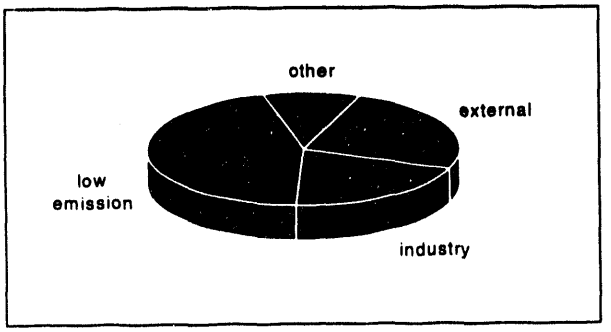


Fig.2 Sources of particulates in other Kraków's area

FORMER LOCAL POLICY AND ACTION

During the last 15 years the figures mentioned above are reduced by half. Regional and local authorities, environmental fund, district heating company and individual investors took action for significant reduction of low emission by connecting local boiler houses to the municipal network and by coal - to natural gas or electricity conversion. Figures 3 to 5 show detailed figures. These investments were mostly funded by budgetary means (governmental or municipal). No economic evaluations were used, environmental impact was the most concern.

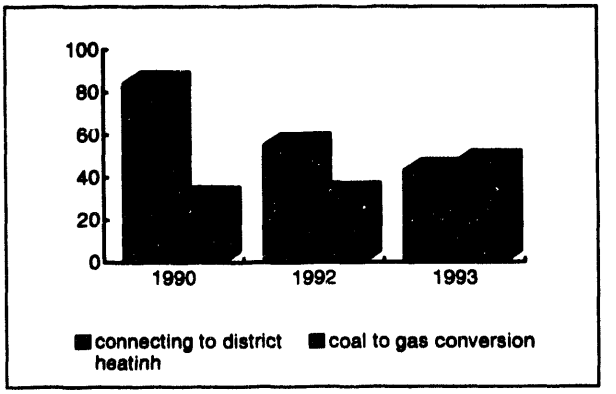


Fig. 3 Locla boiler houses elimination

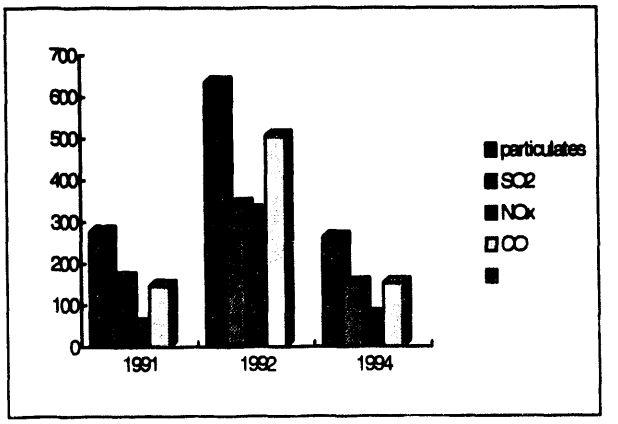


Fig. 4 Low emission sources climination results: reduction of emission (in tons)

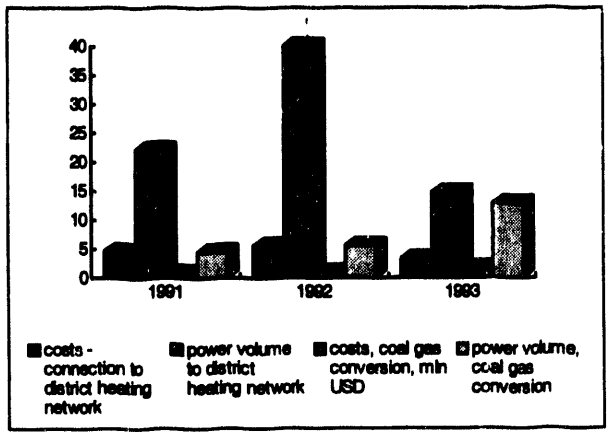


Fig. 5 Low emission sources elimination: Cost and power volume for local biler houses

POLISH - AMERICAN LOW EMISSION PROGRAMME

Thanks to the initiative of Mr. George Bush, the President of the United States, the City of Kraków was given a grand of 20 million USD for reducing air pollution. The programme was based on the US Congress SEED Act of 1989 (Support for Eastern European Democracy). The programme seeks to support introducing market economy practices into Poland, allows to transfer state-of-the-art-U.S. technology and gives expanding businesses and job opportunities for U.S. companies. Programme is dedicated to heavily polluted Kraków area but also projects are expected to
be models for other Polish cities and others.
The basic assumptions for the programme are as follows:

- the progamme is supporting market oriented projects in heating sector in Kraków,
- projects must lead to significant reduction of pollution with limited increase of heating costs,
- immediate results of emission reduction are expected.

During introductory studies five fields of possible activities were identified:

I. expanding and improving of the district heating system with local boiler houses connections and other efficiency upgrading;

II. coal-to-natural gas conversion of local boiler houses;

III. electric heating expanding;

IV. reduction of emissions and increase efficiency of local boiler houses;

V. introducing clean coal and smokeless fuels.

Using competitive project selection proposed by the U.S. companies (with Polish partners), nine project were selected. Economic feasibility was requested, although up to 50% of subsidy was available. The result of projects selection is so that 3 projects deal with field I (district heating expanding), and 5 with field IV (local boiler houses improvements, and 1 with field V (briquettes).

RESULTS

Assuming that this programme deals with economic efficiency of proposed projects this result means that local policy for expanding and improving district heating system is correct, while coal to gas conversion looks like not financially proven. This has been criticized by some environmental groups considering the use of natural gas as the most "clean" energy source. Detailed analyses show that the use of existing facilities (district heating) leads to least cost solutions. Also from the municipality standpoint it's important that the district heating system has some surplus in capacity and expanding this system means reduction of unit costs.

Another result of the programme shows that the City can speed up process of energy efficiency technology use by some legal and financial incentives. In today's Polish conditions it is rather difficult, but the City must work hard on the problem as one of possible ways to have better results in air protection.

As a political experience we see the need for good public relations campaign. Clean air means lot of work and spending money. In a rather poor country like Poland it is not politically easy to encourage individual people or businesses spend more money on heating. People Especially in post - communist countries are used to have all public services free or on low cost level. The market economy and deep economic crisis shows different approach and it is not easy to accept. However, the results we can expect to obtain in reduction of air pollution applying Polish - American programme gives us determination to go with the direction of market approach and technology progress.

PITTSBURGH ENERGY TECHNOLOGY CENTER'S OVERVIEW OF THE KRAKÓW PROJECTS

DOUGLAS F. GYORKE
U.S. Department of Energy
Pittsburgh Energy Technology Center

INTRODUCTION

Almost half of the energy used for heating in Kraków, Poland, is supplied by low emission sources, which are small, low-efficiency coal- and coke-fired boilers and coal-fired home stoves. These facilities are the primary sources of particulates and hydrocarbon air pollution in the city and major contributors of sulfur dioxide and carbon monoxide. Many of these facilities have no measures for limiting emissions. A major improvement in the air quality in the town can be realized by controlling these local low emission sources.

The U.S. Agency for International Development (USAID) and the U.S. Department of Energy (USDOE) are cooperating to undertake a program to reduce pollution from low emission sources in Kraków. The Program, called the "Kraków Clean Fossil Fuels and Energy Efficiency Program," is being implemented by the Pittsburgh Energy Technology Center (PETC) of the USDOE. During the last three years, the Program has sponsored testing and analyses to identify and quantify pollutant emissions and to identify alternative solutions. The USDOE issued a solicitation and selected eight companies for assistance to demonstrate and market energy efficiency and clean fossil fuel technologies in Kraków and elsewhere in Poland. Successful utilization of these technologies is expected to make a significant reduction in the pollution from low emission sources in the Kraków region.

BACKGROUND

As a center of Polish culture and the former royal capital of Poland, Kraków is important to all Poles and is recognized worldwide as a historical treasure. However, Kraków. its people, its environs, its art, and its monuments have been under siege for years by air pollution from power plants, small boilers and stoves with low stacks, and sources upwind in the Czech Republic and Upper Silesia.

The City of Kraków has more than 1,300 small boiler houses with a combined capacity of nearly 1,000 MW(t) and about 100,000 home heating stoves. The home stoves are fired with coal and many of the boilers are fired by coal or coke. The highest concentration of these boilers and stoves is in the center of the city. Due to the low stacks, the pollution remains close to ground level where it affects the health of the citizens and the integrity of the city's monuments.

The U.S. Support for the Eastern European Democracy (SEED) Act of 1989 directed USDOE to cooperate with U.S. and Polish experts to undertake an equipment assessment program in Poland to utilize fossil fuels cleanly in small-scale combustion equipment. This equipment assessment program became specifically directed toward the emission problems of low emission sources in Kraków. The U.S. government has allocated $20 million for the Kraków Program.

USAID and USDOE have worked with Polish officials to establish an eight-member Bilateral Steering Committee (BSC) to plan

and oversee the Program. In 1991, U.S. and Polish officials signed a Memorandum of Understanding formally initiating and directing the Kraków Clean Fossil Fuels and Energy Efficiency Program.

THE HEATING AND EMISSIONS SITUATION IN KRAKÓW

Before planning the Program, the BSC gathered information about sources of heating in Kraków. Information and data were obtained from Kraków's municipal and provincial authorities, public utilities, and several surveys of existing boilers and stoves. These facts helped the BSC determine initial pollution control approaches to address emissions from these specific heating sources.

District Heating:

Kraków is served by an extensive district heating system of over 630 kilometers of pipelines emanating from the combined heat and power plants, Łęg and Skawina. The district heating system serves much of the city, including numerous apartment complexes. The buildings in these apartment complexes are constructed of concrete slabs with little or no insulation. Residents often use their windows to control the temperature of their individual apartments. There is no incentive to conserve because heating bills are based on apartment floor area, not on the amount of heat used.

Boilers:

Because of the proximity to historical sites, existing pipes under narrow streets, or long distances to the district heating main lines, numerous sections of Kraków are not served by the central district heating system but are served by smaller local boiler houses. Approximately 20% of the heat supplied in Kraków is produced by local boiler houses, many of which are in the center city area. To obtain more information about these local heating systems, the BSC conducted a boiler survey to determine the make and model, location, age, ownership, utilization, and fuel used for every boiler in the city.

This survey found that 2,248 of the 2,927 boilers in Kraków are fired by coal and coke. Nearly half of these coal- and coke-fired boilers are less than ten years old. About 90% operate only during the heating season (October through April). These boilers supply either steam or hot water heat for apartments, businesses, and industries. Some boilers are owned by the district heating utility, while others are owned by businesses or private individuals.

Home Stoves:

Residences in Kraków are also heated by coal-fired home stoves. These stoves are of ceramic construction with an ornate glazed tile exterior. Kraków's residents fire a small (3.5-4.5 kg) charge of coal to heat the ceramic structure and use their windows to control the room temperature over the six to eight hour period required to radiate the stored heat to the room. Each stove typically heats one or two rooms in a home or apartment. The BSC has estimated that nearly 100,000 such stoves are in Kraków.

In the past, coal for home stove use could be purchased only from a state-operated coal supplier. This coal had high heating value and low sulfur content (about 0.6%). In today's market economy, residents are free to purchase coal from any supplier. As a result, cheaper coal higher in both sulfur and ash has been extensively used with a resulting increase in pollution, particularly sulfur dioxide, from home stove use.

Emissions/Air Quality:

Total emissions from the operation of coal- and coke-fired boilers and coal-fired stoves in Kraków were calculated from the boiler and stove population surveys and emissions indices from combustion tests in the Program. Annual emissions from these sources are estimated to be 5,000 metric tons of particulates, 11,000 metric tons of carbon monoxide, and 340 metric tons of semivolatile organics. The annual mean concentration of sulfur dioxide in the city is as high as 100 micrograms/cubic meter, over three times the permissible limit, and this peak concentration is located in the center of the city. Coal- and coke-fired boilers and stoves are concentrated in the city center where they contribute 40% of the peak concentration of sulfur dioxide.

KRAKÓW PROGRAM PLANNING

To analyze and compare the effectiveness and cost of alternatives for reducing air pollution from Kraków's low emission sources, the BSC developed a computer spreadsheet model. This model accounted for the existing sources in various categories (e.g., home stoves, boilers by size or fuel, etc.) and tallied the air pollutants, as well as the capital, operating, and maintenance costs associated with each category. Alternative methods of providing heat were identified and the pollutants and costs associated with these alternatives were compared with the existing sources. Grouping these pollution control alternatives resulted in five areas of interest (sometimes called "pilot projects" or "subprojects") for studies in the Program:

(1) Energy Conservation and Extension of Central Station District Heating. Energy conservation and the installation of energy efficiency measures would reduce the load and emissions from boiler houses or make more heat available for expansion of the district heating system. Extension of the central station district heating system would result in the elimination of local boiler houses in favor of heat supplied by more efficient, less-polluting cogeneration plants.

(2) Replacement of Coal- and Coke-Fired Boilers with Natural Gas-Fired Boilers. The feasibility of such replacements is limited to areas of the city where natural gas is available and the infrastructure is sufficient to handle the additional load. This is presently the case in the center city Old Town area, where low emission sources, boilers and home stoves, are concentrated.

(3) Replacement of Coal-Fired Home Stoves with Electric Heating Appliances. This involves the installation of electric thermal storage heaters or the retrofit of home stoves with heating coils. Such conversions are feasible in areas of the city where excess electrical capacity is available, but requires extensive rewiring of apartments and the use of both day and night electric rates. One area northwest of the city center has been identified as a potential site for conversion to electric heating appliances.

(4) Reduction of Emissions from Boiler Houses Firing Coal and Coke. Many local boilers are relatively new or are far from existing district heating lines. These boilers will not be replaced or eliminated, but there are numerous alternatives to increase

their efficiency and reduce their emissions. These boilers can be modernized by the addition of economizers or pulverized coal firing systems. Their efficiency can be improved by the installation of automatic combustion controls or by the use of coal that is properly sized for stoker firing. Emissions from these boilers can be reduced by the upgrade of existing cyclones, the installation of other particulate control devices, or the incorporation of other flue gas cleanup techniques.

(5) Reduction of Emissions from Coal-Fired Home Heating Stoves. Due to the historical significance and esthetics of the tile home stoves, it is doubtful that these stoves will be replaced by other stoves or significantly modified, while still firing coal. Emissions reductions from home stoves are possible through proper operation of these stoves and the use of smokeless fuels, such as certain briquettes.

A PHASED APPROACH

The BSC also identified three phases for the Program. Phase 1 was to gather more information, primarily on emissions and costs, to verify spreadsheet assumptions on existing heating methods and their identified alternatives. Phase 2 was to inform Polish and U.S. companies of the Program, the results of Phase 1, and the opportunities available in Phase 3. Phase 3 was to solicit U.S. firms for participation in cost-shared projects to demonstrate and market energy efficiency and clean fossil fuel technologies in the Kraków area to alleviate the air pollution problems caused by low emission sources.

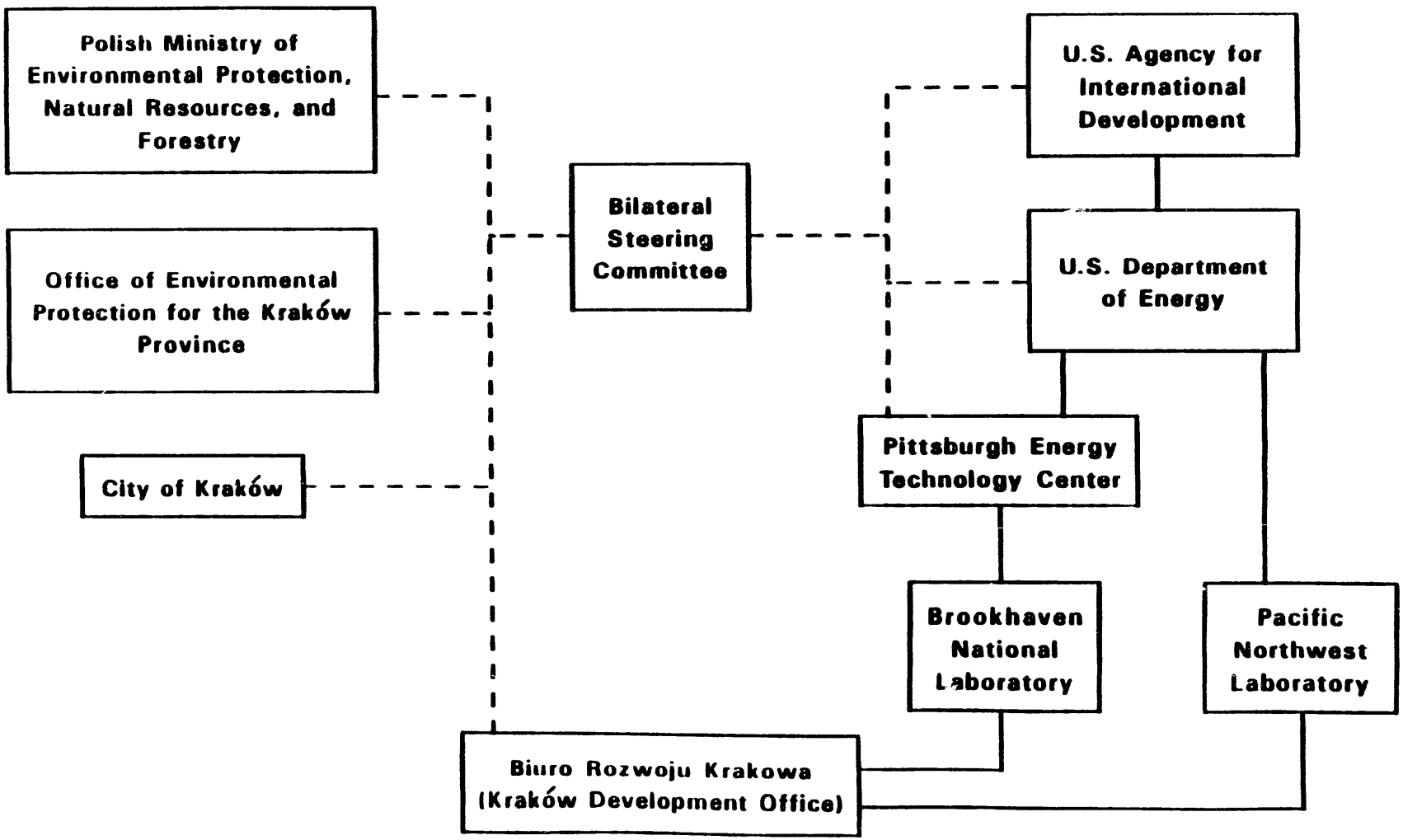
Phase 1: Organization

For the information gathering of Phase 1, funding was provided to Pacific Northwest Laboratories (PNL) to conduct studies for the first area of interest (energy efficiency and district heat extension) and to Brookhaven National Laboratory (BNL) for the remaining four areas of interest. The BSC designated PETC to manage all fossil energy-related work in the Program, including the BNL effort. The BSC also designated the Biuro Rozwoju Krakowa (BRK, the Kraków Development Office) to conduct all Phase 1 studies in Poland. PNL and BNL negotiated contracts with BRK to conduct their portions of the Phase 1 effort.

Figure 1 shows the organization of the Kraków Clean Fossil Fuels and Energy Efficiency Program for the Phase 1 effort and is indicative of the international cooperation at work in the Program. The eight-member BSC that directs the Program includes representatives of USAID; USDOE; the City of Kraków; the Office of Environmental Protection for the Kraków Province; and the Polish Ministry of Environmental Protection, Natural Resources, and Forestry.

The effort at BRK emphasized the performance, cost, and feasibility of heating methods in three major tasks: testing, engineering analysis, and incentives analysis. These tasks were conducted by BRK for each of the five areas of interest. Testing tasks measured emissions and performance results from equipment and fuels that are presently used, as well as alternative equipment and fuels considered as potential improvements. Engineering analysis tasks estimated costs for promising alternatives and conducted feasibility studies and conceptual designs for implementing these alternatives. The incentives analysis

Figure 1: Organization of Phase 1 of the Kraków Clean Fossil Fuels and Energy Efficiency Program



tasks recommended financial incentives or regulatory changes necessary to convince residents and boiler owners to invest in alternatives that will reduce emissions. Table 1 lists the major Phase 1 participants, including BRK subcontractors, and their areas of responsibility.

Phase 1: Testing

As part of its efforts related to conservation and district heating, BRK has coordinated studies of energy use in Kraków's apartment buildings. These studies, conducted over two heating seasons, showed the reduction in heat demand for buildings that incorporated weather stripping, insulation, apartment radiator controls, building heat exchangers, and automatic control of water circulation in comparison to a building with no changes. During the study, a special heat cost rebate was established to make residents responsible for their own heating costs. Other demonstrations are being done this heating season to examine the impact of external building insulation, and results are to be determined by summer 1994. These demonstrations have generated significant interest among building cooperatives in Kraków and other Polish cities.

BRK conducted boiler combustion tests to examine methods to reduce emissions from firing coal and coke and provide interim solutions to more expensive natural gas conversions. BNL scientists provided guidance to Polish engineers on test plans and data analysis procedures. Analytical equipment for emissions measurements was purchased by BNL and provided to the Kraków provincial government for use in the Program. Combustion tests were conducted at two sites with stoker boilers and two sites with hand-fired boilers. Tests utilized the baseline coal or coke and additional fuels such as several cleaned and graded coals, semi-coke, and smokeless briquettes. Measurements included boiler efficiency and emissions of particulates, SO_2, CO, and hydrocarbons at various load and excess air levels.

Test results showed that stoker boiler efficiency ranged from 50-70% depending on the excess air level and load level of the boiler. Measured excess air levels of 100-600% were extremely high due to the condition of the air control vanes and the leaky situation of the old boilers. Considerable improvement in performance and reduction in emissions could occur with greater control of excess air levels. Testing of overfire air for reduction of hydrocarbons and NO_x showed little effect due to the tremendous volume of air that passed through the grate or leaked into the boilers.

Results of testing in hand-fired boilers were similar in that thermal efficiencies were also in the range 50-70%. Briquette firing in these boilers showed little benefit on performance parameters or emissions. However, significant reductions in particulate emissions occurred by using coke as compared to coal in hand-fired boilers.

While the design of the ceramic tile home stove is over one thousand years old, the tests conducted in this Program gave the first known efficiency and emissions results for these stoves in Poland. Under the BRK contract, the Academy of Mining and Metallurgy in Kraków constructed a home stove test facility, including a completely instrumented home stove and gas analysis system. Academy and BNL scientists worked together to utilize BNL-supplied equipment and to develop stove operating and data analysis procedures for the test program. Combustion tests in home stoves utilized several coals, coke, and smokeless briquettes. Several stove operating

TABLE 1

Major Phase 1 Participants

Company	Responsibility
• Pacific Northwest Laboratories (PNL)	• Lead for Area of Interest #1
• Brookhaven National Laboratory (BNL)	• Lead for Areas of Interest #2 through #5
• Electrotek	• PNL contractor to direct BRK in tests conducted for energy efficiency/conservation
• Burns and Roe Services Corporation	• PETC Support Contractor
• Miejskie Przedsiębiorstwo Energetyki Cieplnej (MPEC)	• Host for boiler combustion testing
• Biuro Rozwoju Krakowa (BRK)	• Prime Contractor (to BNL and PNL) for all Phase 1 work
• BRK Subcontractors:	
- Ekopol	- Analysis of emissions, air quality, and associated fees and penalties
- Polinvest, Ltd.	- Legal and economic analysis of options and incentives
- Academy of Mining and Metallurgy	- Home stove combustion tests
- Energoekspert	- Boiler combustion tests
- NBS	- Public relations/public information
- FEWE - Kraków	- Installation of energy efficiency measures
- Kraków Design and Research Office of Industrial Construction	- Engineering analysis of options for boiler modernization

procedures were utilized to determine their effects on stove efficiency and emissions.

With proper operating procedures, the stoves were shown to be remarkably efficient and had measured thermal efficiencies as high as 70%. Efficiencies dropped by 10-20% with improper stove operating conditions, such as leaving both the fire and ash doors open for nearly all of the firing cycle. Firing briquettes in the home stoves reduced particulate emissions by an order of magnitude. This finding is significant because home stoves are the largest source of particulates among the low emission sources in Kraków.

Phase 1: Engineering Analysis

The engineering analysis tasks conducted in Phase 1 investigated the technical feasibility and costs associated with alternatives identified for emissions reductions. BRK determined which local boiler houses could feasibly be connected to the central station district heating system and the costs of each of these connections. Working with the Kraków gas utility, BRK identified the infrastructure upgrades and costs necessary to supply natural gas to all boilers in the Old Town area of Kraków. BRK developed engineering designs for the replacement of Old Town coal- and coke-fired boilers with natural gas-fired boilers and presented these designs to the boiler owners and city planners for their action. For one district of Kraków, BRK used a computer model to calculate the most efficient means of connecting apartment buildings to electrical substations and estimated the costs of additional transformers and new wiring in the apartments to handle the additional load.

Working with the Burns and Roe Company, BRK developed conceptual design and cost information for the replacement of old, stoker-fired boilers at a typical boiler house by modern combustion technologies, such as fluidized beds or modern stoker-fired boilers. BRK worked with coal mines and fuel suppliers to determine the availability and cost of various solid fuels and the feasibility of providing cleaned and graded coals for boiler applications and smokeless briquettes for home stoves. In every area of interest of the Program, the Phase 1 engineering analysis effort evaluated the emissions reductions and modeled the air quality improvements associated with the implementation of the pollution reduction alternatives under consideration.

Phase 1: Incentives Analysis

The incentives analysis efforts at BRK are not yet complete. BRK is investigating the legal possibilities of implementing local prices for district heat, gas, and electricity. BRK has conducted a study of the fees and fines for use of the environment that will be paid by a boiler owner who continues to fire with coal or coke. The incentives analysis effort has included a study comparing heating costs of several representative dwellings using various fuels and forms of heating. BRK is also assembling financial and regulatory incentives to recommend to municipal authorities to encourage the implementation of alternatives for pollution reduction. Financial incentives under consideration include: property or income tax rebates for those making conversions, reduced value added tax (VAT) rates for equipment suppliers and installers, increased permit fees and pollution fines, and grants or loans from the state environmental protection fund to finance a portion of each conversion. Regulations being considered include: licensing of coal distributors, requiring the use of briquettes or smokeless fuel in home stoves, strictly enforcing existing emissions regulations, prohibiting

the combustion of solid fuels in sensitive areas of the town, and liberalizing regulations of utility ownership and rate structure to encourage utilities to invest in the extension of their service area.

To provide inputs to the Program and to city policy making, the incentives analysis also included an evaluation of the attitudes of the public to the pollution problems in Kraków. Focus groups and public surveys established that residents support the idea of cleaner air, and a majority are willing to pay higher taxes to achieve this objective. Those firing coal would be willing to shift to cleaner sources of energy, primarily because of convenience. Some would like their landlords or the city to pay for new equipment. Of those surveyed, 25% were willing to pay for the higher costs of electricity or natural gas.

Phase 1: Other Activities

The BRK Phase 1 efforts are being extended to update data bases and communicate results of the Program to interested groups. A workshop is planned to present detailed results of Phase 1 to representatives of potential funding institutions, Kraków utilities, city and provincial governments, and other Program participants. BRK will assist the City of Kraków by providing details for the city's Master Plan for pollution control. BRK will update the survey information on the Kraków boiler population, its characteristics, and the fuels fired. This survey information will be linked to a geographical information system that will enable the preparation and comparison of detailed pollution control scenarios for the city. Through the extension of Phase 1, BRK will meet with representatives of other cities to share the information, tools (such as the spreadsheet model), and experiences of the Kraków Program.

STATUS OF PHASE 2 AND PHASE 3

Public meetings were held in June 1992, in Chicago, Illinois, and Washington, D.C., and in November 1992, in Kraków, Poland, to publicize the Program and its opportunities for U.S. and Polish businesses. The June meetings served to present details of the Program and the Phase 3 solicitation plans. Feedback from these meetings was used to revise the solicitation before it was issued. The November meeting included a formal pre-proposal conference at which the USDOE responded to questions on the solicitation asked by potential proposers. Time was allocated in November for presentations by U.S. and Polish firms on their capabilities, and the interaction of U.S. and Polish firms resulted in numerous teaming arrangements for the solicitation.

The solicitation, as revised by public input from the June 1992 meetings, was issued by USDOE/PETC in September 1992. The solicitation was a Program Opportunity Notice (PON) for proposals from U.S. firms for cost shared Cooperative Agreements. Minimum cost sharing was 50% from U.S. proposers, their team members, or third parties. Proposers were encouraged to include Polish firms as team members. All proposals were required to provide equipment, fuels, or services to address one or more of the five areas of interest identified by the BSC for the Program. The Cooperative Agreements were to establish businesses in the Kraków area for the proposed energy efficiency or clean fossil fuel technologies with the businesses continuing in Poland after the Cooperative Agreements were complete. Proposers were asked to discuss the performance and advantages of their technologies, the size of

the market and their approach to it, projected pollution reductions and associated costs, and the capabilities and experience of their teams. The U.S. government share allocated for funding of these Cooperative Agreements was $14.5 million.

Proposals were received by PETC in February 1993 and were evaluated by a USDOE Source Evaluation Board. The USDOE Board was advised by a group of Polish engineers and by the BSC. No acceptable proposals addressed the second and third areas of interest, the replacement by natural gas or electricity, respectively, probably because of Kraków's small market for these alternatives and the limits on the market imposed by heating and equipment costs, fuel availability, and state regulations. Final selections were made by USDOE and announced in September 1993.

The eight firms and brief descriptions of their proposed projects are the following:

Addressing energy efficiency or the district heating system:

- Shooshanian Engineering Associates, Inc., of Boston, Massachusetts, will team with two Polish firms, Miejskie Przedsiębiorstwo Energetyki Cieplnej [MPEC (the Kraków district heating utility)] and Polinvest, Ltd., to make two extensions of the central station district heating system and eliminate a total of ten coal- or coke-fired boilers. New sections of the district heating system will be designed and installed to incorporate state-of-the-art conservation features.

- Honeywell, Inc., of Minneapolis, Minnesota, will join with MPEC to demonstrate the use of controls and supervision for the district heating system to improve overall efficiency. A supervisory and data acquisition system will be installed at MPEC headquarters to monitor and supervise several functions of the central station district heating system. In one neighborhood district heating system, instrumentation will be installed to supervise the system, new plate heat exchangers will be installed in apartment buildings, and room comfort controls will be added to individual apartments. Revenue from the energy savings can be used to expand the district heating system, attract new customers, or shut down older boilers.

Addressing the reduction of emissions from boilers:

- Control Techtronics, Inc., of Harrisburg, Pennsylvania, will team with the Pennsylvania State University, MPEC, and Naftokrak-Naftobudowa of Kraków. The team will demonstrate and market the use of boiler combustion controls for increased boiler efficiency and reduced emissions. The project will include training in combustion techniques and automatic combustion controls and will recommend the use of clean, graded coal and boiler modifications to further reduce emissions. The first demonstration installation is planned at the district heating boiler house in the same neighborhood as the Honeywell project, and Control Techtronics combustion controls will be linked to the Honeywell supervisory system.

- Tecogen, Inc., of Waltham, Massachusetts, will join with Catholic University, the

Pennsylvania State University, and Naftokrak-Naftobudowa of Kraków to design and install various boiler system modifications to improve system performance and reduce emissions. The team will demonstrate the modifications at a local boiler house in Kraków. Modifications to be included at this demonstration site include: installation of boiler economizers, installation of automatic combustion controls, utilization of cleaned and graded coal, improvements to existing cyclones, and flue gas recirculation.

- LSR Technologies of Acton, Massachusetts, will team with Bradford Metal Works of the United Kingdom and a Polish marketing firm to develop LSR's novel particulate collection device called a "core separator." The device is more efficient than a cyclone, and its low cost, simplicity, reliability, and ease of maintenance make it ideal for the small boiler market. The team plans seven installations during the project and a manufacturing facility in Kraków to accommodate future sales.

- TCS, Inc., of Annapolis, Maryland, will work with Amerex, Inc., of Woodstock, Georgia, OPAM of Poland, and Polish Military Unit No. 1616 to demonstrate micronized coal combustion. TCS will provide its micronization mill and combustor together with an Amerex baghouse to perform a retrofit of the stoker boilers of the military base at the Kraków airport. The coal micronization system promises more complete combustion, lower emissions of nitrogen oxides, reduced boiler fouling, and lower sulfur dioxide emissions with co-micronization of limestone.

- EFH Coal Company of Wilkes Barre, Pennsylvania, will work with Pennsylvania State University, MPEC, and Naftokrak-Naftobudowa to build a coal preparation plant for Kraków to provide cleaned and graded coals for stoker-fired boilers. The project includes laboratory-scale combustion tests to determine plant design information and boiler combustion testing to confirm improved performance.

Addressing the reduction of emissions from home stoves:

- Acurex Environmental Corporation of Mountain View, California, and Planmar Consulting of Research Triangle Park, North Carolina, have teamed with the district heating company of Chrzanów, Poland, to introduce a novel briquetting technology to the Kraków market. Compared to coal firing, the briquettes promise to reduce emissions of particulates and carcinogenic hydrocarbons from home stoves. The project includes handling and laboratory-scale combustion tests to optimize briquette composition and extensive combustion tests to demonstrate emissions reductions.

These Cooperative Agreements are being awarded between February and May 1994 and will be completed in two to four years. After that time, it is expected that the teams will have established their technologies in the Kraków market and will begin branching

out into other areas of Poland. Modeling studies have shown that complete success of these eight Cooperative Agreements will result in 90% reduction in particulate emissions from low emission sources in Kraków at an 11% increase in heating costs.

CONCLUSION

The Kraków Program is one of the first of a growing number of programs initiated by USDOE and USAID to address pollution and energy concerns of developing and emerging countries. The approach to the Kraków Program is being used by USDOE as a model to plan these new programs.
The continued success of the Program will now depend on the incentives recommended by BRK and adopted by the City of Kraków, on the transfer of Phase 1 information and tools to other cities, and on the successful demonstration and marketing of the technologies of the eight U.S. firms selected from the solicitation. The market for these and other technologies is available in Kraków, and is duplicated in many other cities elsewhere in Poland and Eastern Europe.

DISCLAIMER

Reference in this report to any specific commercial product, process, or service is to facilitate understanding and does not necessarily imply its endorsement or favoring by the United States Department of Energy.

INCENTIVES FOR REDUCING EMISSIONS IN KRAKÓW

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INTRODUCTION

This paper describes the initial incentives analysis undertaken in the Kraków Clean Fossil Fuels and Energy Efficiency Program. It presents results for one of the alternatives for reducing emissions from low-stack sources - the conversion of solid fuel-fired boilers in the Old Town area of Kraków to gas.

The primary objective of incentives analysis is to define and evaluate incentives that the City could offer to encourage implementation of options under investigation in this project. Within each subproject, one or more options are selected for incentives analysis. Based on an economic analysis of each of these options, possible incentives are identified. The incentives are then evaluated in terms of their technical and legal feasibility, cost, and effectiveness.

The first step is to identify worthwhile options for reducing emissions from low-stack sources. The testing and engineering portions of the project have identified technically feasible options and their costs. Once the technical options are identified, the question of how to implement them becomes all-important.

Implementation barriers and issues must be identified. These can include infrastructure needs such as gas or electricity distribution system modernization or expansion of fuel supply or production activities. Ash disposal methods and costs may be important for some options. Consideration of these issues assists in defining those activities which must be included in economic analyses and helps in identifying targets and levels of possible incentives.

Legal and institutional barriers also need to be identified. These can include building and energy code requirements, as well as social issues which may affect residents' willingness or ability to change their behavior. Experience has shown that in most cases people do not adopt new technology quickly or easily. This may be due to lack of information, or because making a change is troublesome, or because it costs too much. Identification of these barriers helps identify possible incentives and may also be important to potential investors.

Economic analyses are performed from the fuel or equipment supplier point of view, from the fuel distributor point of view, and from the end-user point of view, as appropriate. Costs should be determined on a life-cycle basis, taking into consideration both investment and operating costs. Uncertainties need to be explicitly identified (for example, fuel price projections), and sensitivity analyses undertaken. Equity issues should be addressed. These economic analyses are not meant to substitute for the detailed analyses that would be undertaken by a potential investor, but rather to provide direction and assistance in identifying incentives.

The next step is to identify and design possible incentives to overcome barriers to implementing the option under consideration. There are three generic types of policies or incentives that can be used to encourage a particular action. These are regulation, financial incentives, and information programs. Each has unique advantages and costs which must be evaluated for specific situations. Combinations of different types of incentives are often the most effective; the way they are implemented, including the institutional framework, can often determine the success of a policy.

Regulation includes air quality standards, fuel quality standards, emission standards, equipment standards, and licensing and zoning regulations, along with enforcement mechanisms. Economic incentives include fees, taxes, subsidies, and market creation (for example, emission trading). Information policies include public relations and information campaigns, and may also include negotiated agreements with polluters and/or manufacturers.

Incentive identification and evaluation must also consider the feasibility of actual implementation. A legal evaluation identifies what kinds of regulation are possible, and which level of government has the authority to

impose them. The economic portion of the incentives analysis determines if economic incentives are necessary and how much they would cost. The results of the incentives analyses are a set of recommendations to local authorities.

APPROACH TAKEN IN KRAKÓW

The analysis presented here focuses on Old Town - the center of Kraków and it's most prestigious and precious part. About 20 years ago the City began to convert all coal-fired boiler houses located within the town walls into gas-fired ones. A central gas network for this project was built and then the project was interrupted. Natural gas was selected to be the right medium to replace coal fired boilers in local boiler-houses in part because the infrastructure under the Old Town does not permit extension of the district heating system into this area. Thirty-three solid fuel-fired boiler houses remain to be converted.

The following tasks were undertaken as part of the incentives analysis for gas conversion:

a) collection of data pertaining to existing coal and coke fired boiler houses using a questionnaire filled out by boiler house operators or direct interviews;
b) analysis of existing Kraków Development Bureau, EKOPOL, and ENERGOEKSPERT study data - these data regarded mostly engineering and environmental aspects of coke fired boiler house exploitation;
c) forecasting gas prices;
d) analysis of operating expenses for coal fired boiler houses for 1992-1996;
e) analysis of operating expenses for projected gas fired boiler houses for 1992-1996;
f) analysis of the return of investment for the ten sample boiler houses;
g) scheduling of an order of elimination of boiler houses based on the following criteria: existing environmental threat, possible extent of the reduction of emissions, emission reduction per US $1 in capital investment;
h) conversion program feasibility study under existing conditions with respect to the boiler house operators' legal and financial status;
i) study of the feasibility of the introduction of a new organizational structure and of local government participation;
j) study of selected incentives and stimuli required for the program implementation;
k) study of the feasibility of founding a non-profit organization to implement the program;
l) study of legal statutes in the following fields:
   - environmental protection and management statutes;
   - financial and tax statutes;
   - local government statutes;
   - rent controls; and
   - administrative law.

Economic analysis was performed in order to identify whether conversion of coal fired local boiler houses into gas fired ones can be carried out without incentives. A sample of 10 representative boiler houses were evaluated and the results generalized for all 33 boiler houses selected for conversion. The 10 representative boiler houses were selected on the basis of the following criteria:

- location of a proposed gas boiler house within host building;
- output of a proposed gas boiler house;
- cost of coal to gas conversion; and
- type of owner (i.e. conversion capital investor).

The following customer makeup has been determined for all 33 boiler houses:

For profit businesses	51.5 %,
Residents	36.4 %,
Non profit organizations	12.1 %.

The economic analysis performed by POLINVEST determined the required **Conversion Capital Cost Subsidy** for each boiler house. The Conversion Capital Cost Subsidy equals negative value of NPV calculated for the investments. The subsidy was calculated for two required Return of Investment periods: 10 years and 20 years.

Social and Legal Considerations

POLINVEST had to consider carefully the social environment of conversions. 45 years of central planned economy caused a wide spread reluctance towards any kind of administrative pressure. The only acceptable administrative activities are subsidies and tax exemptions. Inhabitants of Kraków try to avoid group activities, too. The above mentioned facts favored strongly individual sources of energy, e.g. coal fired boiler houses.

In the present legal environment there is no exclusive public institution responsible for environmental issues. The power in this area is distributed between governmental institutions (especially agencies of local governmental representative - *voivod)* and local

authorities (*Gmina*). Main prerogatives of *voivod* office and other governmental agencies, as far as environmental issues are concerned, are the following:

a. Exempting from income tax the expense of capital investment for business and environmental protection purposes and expenses for energy conservation measures, particularly the expenses for the purchase and installation of heat and water meters; and to determine procedures and conditions for qualifying these expenses for exemption from taxes (Article 18, paragraph 7 of the Corporate Income Tax Act).

b. Levying the following fines (pursuant to the January 31, 1980 Act *Regarding Environmental Protection and Management* (*Congressional Reports* #3, item 6, with subsequent amendments)):

   i) discharge of waste water non compliant with statutory requirements into water, onto land, or into state owned sewer systems;
   ii) exceeding of amounts or types of atmospheric emissions determined by the appropriate voivod;
   iii) exceeding of noise levels determined by the appropriate voivod;
   iv) destruction of landscaped areas, trees, and bushes by inappropriate earth work or use of heavy equipment, plant, or use of chemicals in a manner harmful to animal or plant life;
   v) unlicensed removal of trees and bushes;
   vi) collection or discharge of waste in areas not authorized for such use, or in violation of specified requirements.

Revenues from above listed fines constitute the National Fund (40 percent) and the Voivodship Fund (60 percent). Both funds are to be engaged in environmental projects.

c. Determining, after a motion from, and in consultation with, voivodship historical monument curators, requirements for the construction industry in their jurisdiction or ordering the removal, rearranging, or rebuilding of specific buildings, or issuing other appropriate orders related to historical urban areas and historical building complexes named in the national register of historical monuments. (Pursuant to article 20 of the February 15, 1962, Act *Regarding Museums and Protection of Cultural Objects*).

Main prerogatives of *Gmina* office, as far as environmental issues are concerned, are the following:

a. Imposing a real property tax (which is a local tax). Rates and exemptions related to this tax are set for the City of Kraków by City Council resolutions. Collected taxes are paid into the municipal budget. Maximum tax rates are set by the Minister of Finance, by executive order (The January 12, 1991 Act *Regarding Local Taxes and Fees* (*Congressional Reports* #9, item 31, with subsequent amendments: *Congr. Reports* 1991, #101 item 44, 1982 #21 item 86)).

b. Ordering a plant and/or equipment operator (including operators of coal fired boilers and other heat delivery systems) to perform, within a specified time, appropriate actions to limit the environmental burden of the plant and/or equipment. In case of non compliance the Gmina authority may order the closure of subject plant and/or equipment. (Pursuant to article 76 of the January 31, 1980 Bill *Regarding Environmental Protection and Management* (*Congressional Reports* #3, item 6, with subsequent amendments)). The above mentioned statutes apply to all entities whose actions pose environmental hazards (pursuant to article 64 of the above mentioned bill).

The possible fields of cooperation between *Gmina* Council on one side and the *voivod* and the State Environmental Inspector's office on the other may be the following: imposing fees and fines, promoting and supporting applications by boiler house owners who apply for environmental fee and fine extension and forgiveness on project completion contingent on the conversion of their boiler houses from solid fuel to gas firing. Unfortunately, up to now *Gmina* and governmental institutions have not been closely cooperating each with others.

PUBLIC RELATIONS

The scope of the public relations campaign was based on the results of a survey on Kraków citizens' attitudes to the low-emission problem. The main conclusions of the survey were as follows:

Citizens are aware of the importance of air pollution problems for their individual lives:

a. Almost 80% of Kraków citizens consider air pollution problem to be important.

b. Only 6.3% of Kraków citizens consider air pollution in the city area as not being hazardous for their health.

Citizens tend to blame industry rather than local boiler houses for the air pollution:

a. 70% of Kraków citizens consider either Huta im. Sendzimira (Metallurgical Factory) or traffic to be the main sources of air pollution.
b. Only 8.3% of them consider low-emission sources to be the most dangerous air polluters. This percentage is significantly higher in the Old Town where it reaches almost 20%.

Citizens stress that the Municipal authorities should feel responsible for the air pollution problem and are willing to accept any municipal activities leading to decreases in the emission levels:

a. 54% of Kraków citizens would agree to pay more taxes (or a special tax) to cover environmental expenses of *Gmina*.
b. More than half of them would accept to pay more than 5% average salary for the purpose at point a.

On the other side 44% of citizens maintain that, so far, municipal activities are non-effective.

Based on the survey results the following principal aims of the public relations campaign were defined:

a. to inform the Kraków residents on the consequences of low emission;
b. to inform the residents about the Polish-American Program, its assumptions, aims and consecutive results;
c. to create positive feeling towards the Program;
d. to inform the residents about the ways of energy saving;
e. to stimulate the Kraków Old Town residents to use suggested solutions.

NBS plans to use the following public relations tools for efficient implementation of the Program:

a. press releases reporting the achievements of the Program and important events connected with implementation of the American-Polish Program.
b. Briefings for the key local journalists and journalists from magazines dealing with energy issues and environmental protection.
c. Seminars devoted to air pollution problems and different methods to solve them as well as to presentation of the results of the Kraków Program.
d. Edition of educational materials - brochures explaining the Program and presenting what has been done so far.
e. Production of educational film focused on the Program's achievements.

TYPES OF INCENTIVES

POLINVEST had divided all possible incentives into three groups:

a. Incentives Resulting in Conversion Capital Cost Decrease

b. Incentives Resulting in Increased Profits for Boiler House Owners Following the Conversion

c. Non Financial Incentives

The two former groups consist of financial incentives. Incentives were classified according to their influence on different factors of investment analysis.

POLINVEST had to consider the following limitation on incentives:

a. a difficult financial position of *Gmina resulting with reluctance towards direct financial support of any investment projects and tax* exemptions,

b. uncertain local, legal environment: the ownership status of many real-estates in the Old Town had not been clarified, yet; many juridical entities were in process of ownership and organizational transformation,

c. limitations set by the Law:

The Local Government Act provides for a possibility of levying new taxes for public objectives **exclusively by a local referendum.** Current legislation makes it impossible to levy new taxes on Kraków's residents by the *Gmina* Council, even if the objective were to protect the region's natural environment.

The Rent Control Act, along with its accompanying specific regulations, preclude rent increases for municipal and employer provided building tenants, as these are set by executive order

of the Council of Ministers (the Cabinet) at about 30 percent of apartment maintenance cost. The remainder is subsidized in part by *Gminas* and in part by the State, through *the Gminas*.

Incentives Resulting in Conversion Capital Cost Decrease

a. Property Tax Deduction for Multi-Unit Property Owners for Replacement of Solid Fuel Fired Heating Systems with New Gas Fired Systems

b. Income Tax Deductions for Donations Made by Incorporated Entities for Implementation of Projects Related to the Program

c. VAT Sales Tax Exemption or Deduction for Project Implementation

d. Exemption from (or Deduction on) Import Tax and Customs Duty for Importers of Equipment Under the Program

e. Rent Reduction for Apartments (or Commercial Units) for Residents (Tenants) Who Replace Existing Heating Systems with Gas Fired Systems

f. Suspension (or Forgiveness) of Collection of Fines and Fees Levied for the Use of the Natural Environment In Exchange for Designating These Amounts on Capital Modernization Projects

g. Preferential Credit

h. Environmental Protection Fund Subsidies and Loans

i. Capital Cost Decrease Through Selection of Cost Effective Plant and Technology

j. Subsidies from Kraków's *Gmina* Environmental Protection Fund

Incentives Resulting in Increased Profits for Boiler House Owners Following the Conversion

a. Individual Income Tax Deduction for Capital Expense Related to Heating System Improvements

b. Property Tax Deduction for Multi-unit Property Owners for Replacement of Solid Fuel Fired Heating Systems with New Gas Fired Systems

c. *Gmina* Subsidies for Cost of Heating

Non-Financial Incentives

a. Building Permits for Remodelling Multi-Unit Buildings on the National Register of Historical Monuments and Other Multi-Unit Buildings

b. Administrative Orders to Limit Plant- and Equipment-Caused Environmental Hazard

c. Gas Fired Heating System Requirement for New Construction on Cleared Lots in the Old Town

SAMPLE RESULTS FOR KRAKÓW

Cash flow analysis for the 10 representative boiler houses showed that investment costs would not be recovered over the life of the equipment. Therefore, the amount of subsidy that would allow recovery of investment costs was calculated. The mean weighted conversion capital cost subsidy percent for the ten representative boiler houses is as follows:

a) 79.35 percent for a 10 year term of full return on investment;
b) 78.03 percent for a 20 year term of full return on investment.

Based on the above weighted means, subsidy amounts were calculated for the 33 boiler houses. The required subsidy as a percentage of total capital costs are presented in the Table 1.

Implications of increasing the cost of heat to residents were also examined. Taking an assumption that the conversions cannot cause any price increase for end users the cost increase had to be covered by a subsidy to the heat price. The amount of increase in heat price necessary for boiler-house owners to recover the investment costs was determined for the 33 boiler houses using as the index the weighted mean price subsidy for the ten selected boiler houses. This index was determined separately for subsidies ensuring full return on investment in 10 and in 20 years. This index was then multiplied by the number of GJ's of heat generated by the 33 boilerhouses. Mean subsidy to the price of heat in GJ's was determined in the following way:

a. a weighted mean heat price per GJ was determined for the ten selected boiler houses (at heat generation operating cost of a coke fired boiler house);
b. a weighted mean heat price per GJ was determined for the ten selected boiler houses (at a level ensuring full return on investment in ten years);

Table 1. Conversion Capital Cost Subsidy Amounts for 33 Boiler Houses

Data Obtained for 10 Boiler Houses from Economic Studies					
#	Capital expense per BRK [US $]	Subsidy Ensuring Full Return on Investment in 10 Years		Subsidy Ensuring Full Return on Investment in 20 Years	
		[Percent of Cap. Cost]	[US $]	[Percent of Cap. Cost]	[US $]
1	330,726	79.35	262,430	78.03	258,059
2	Mean Single Boiler House Subsidy	79.35	26,243	78.03	25,806
Results Generalized for 33 Boiler Houses Using Percentage Indices Calculated for 10 Boiler Houses					
3	1,341,593	79.35	1,064,554	78.03	1,046,845
4	Mean Single Boiler House Subsidy	79.35	32,259	78.03	31,723
Capital Cost Subsidy for 33 Boiler Houses as of 1.20.1994, Calculated at Mean Ntl. Bank of Poland of $1 = Zł. 21,655 (Table 14/94). Data in Zł.Million.					
5			23,052		22,669

Table 2. Weighted Mean Heat Price Per GJ for the 10 Selected Gas Boiler Houses Ensuring Full Return on Investment in 20 Years

#	Address	'91/'92 Season Heat Sales [GJ]	Price at Operating Cost for a Coke Boiler House in 1994 [US $/GJ]	Price Ensuring Full Return on Investment in 20 Years [US $/GJ]	Total Cost (Operating) of Heat Generation Col.4 x Col.5 [US $]
1	2	3	4	5	6
1	Rynek Główny 43	122	11.61	18.70	2,281.40
2	Sławkowska 12	694	11.07	12.18	8,452.92
3	Floriańska 45	1,111	8.41	12.36	13,731.96
4	Mikołajska 13	521	11.65	14.10	7,346.10
5	Św. Marka 17	694	11.86	11.98	8,314.12
6	Św. Marka 8	1,562	8.68	10.07	15,729.34
7	Św. Marka 34	1,840	8.88	10.30	18,952.00
8	Rynek Główny 47	1,042	7.64	13.04	13,587.68
9	Pijarska 1	1,302	7.62	10.90	14,191.80
10	Św. Krzyża 4	6,076	7.37	10.17	61,792.92
	Total (#1 through #10)	14,964			164,380.64
	Weighted Mean (Total Col.6/Total Col.3)			10.99	

c. a weighted mean heat price per GJ was determined for the ten selected boiler houses (at a level ensuring full return on investment in 20 years);
d. the subject weighted mean for a 10 year return on investment is the difference between the price defined at b. and a.;
e. the subject weighted mean for a 20 year return on investment is the difference between the price defined at c. and a. - results are shown in Table 2.

Heating fees will vary, depending on heat generation cost and building insulation. Discontinuing state subsidies will result in an approximately 30 percent heating cost rise for tenants and apartment owners. In Polinvest's opinion, the additional burden of an increased heating price may not possibly be borne by these customers. The remaining heat customers consist of businesses, who now pay for heating at coke fired boiler house generation cost plus a profit margin, and boiler house owners.

If the *Gmina* were to introduce price subsidies, the total cost to the *Gmina* would be much greater than the cost of capital investment subsidies.

Considering limited City Hall means, the need to allocate these means in a most effective manner, and the principal objective, i.e., reducing emissions, Polinvest suggests the following way to subsidize conversion capital cost:

a. 80 percent of conversion capital cost should be refunded for 10 boiler houses that meet the following conditions:
   - belong to the 20 top boiler houses with regard to emissions reduction;
   - emissions reduction per Zł. 1 million in capital cost is more than 10 kg.
b. 50 percent of conversion capital cost should be refunded for the remaining boiler houses.

The amount of subsidy (for all projects) was estimated to be US $759,858. The order (sequencing) of conversions and the amounts of individual subsidies should follow the criteria of subsidy amount. That means that the 10 conversions listed at a. should be subsidized in the first phase while remaining in the second one.

Subsidies were also calculated with fuel price projections provided by the U.S. Department of Energy. These prices were higher and increased more rapidly to Western-level prices; the Polish prices approach these prices near the end of the planning time-frame. Analysis with these fuel prices showed that a much higher subsidy would be required. The implication of these results is that the longer the *Gmina* waits to implement economic incentives, the more it will cost.

The use of incentives in the form of heat price subsidies, conversion capital cost subsidies, or property tax exemptions will result in all customers buying heat at generation cost (at cost of generating in a solid fuel fired boiler house).

An environmental effect of the conversions will be obtained through a significant reduction in low emission of such substances as: SO_2, CO, NO_x and CH_4. The expected reduction rate will vary from 76 to 97%, depending on the boiler house, in an especially calculated *Equivalent Emissions*. *Equivalent Emissions* represents a combined emission of the above mentioned hazardous substances.

As an indicator of reduction efficiency POLINVEST selected a ratio of *Equivalent Emissions* decrease per 1,000 USD. The Table 3 shows this ratio for 33 boiler houses.

In order to support the process of low emission elimination from the Old Town *Gmina* should undertake the following actions:

a. The *Gmina* may award financial assistance, extended from its funds to boiler house operators who commit to converting to gas firing. This may take the form of a property tax exemption not only in one fiscal year, but in a number of years, until all conversion capital cost is recovered. The City Council may enact such incentive by a resolution.

b. The *Gmina* Council may resolve to create a *Gmina* environmental protection fund pursuant to the Environmental Protection Act and allocate the majority of its monies in a given year to assist the program of solid fuel to gas boiler house conversion. The fund's revenues come from a portion of fees and fines for business use of the natural environment.

c. Kraków's City Council may lower commercial rents for space the *Gmina* rents and put a moratorium on future rent increases for a number of years for those commercial tenants who participate financially in boiler house conversion.

d. The *Gmina* Council should work more closely with the *voivod* (local governor) and the State Environmental Inspector's office with regard to fees

Table 3. Emissions Reduction per US $1 Thousand in Conversion Capital Cost

#	Address	Equivalent Emissions Decrease Relative to Pre-Conversion Conditions [kg/season]	Decrease per $ 1,000 in Capital Cost [kg]	#	Address	Equivalent Emissions Decrease Relative to Pre-Conversion Conditions [kg/season]	Decrease per $ 1,000 in Capital Cost [kg]
1	Rynek Główny 7	4,018	1,411	18	Pijarska 1	4,476	147
2	Rynek Główny 34	7,370	994	19	Wiślna 3	2,650	121
3	Grodzka 63	12,715	376	20	Pl. Szczepański 4	2,199	121
4	Św. Marka 34	11,568	359	21	Rynek Główny 44	1,950	120
5	Św. Tomasza 31	25,342	359	22	Rynek Główny 13	3,925	116
6	Pl. Mariacki 8	5,316	328	23	Pl. Szczepański 1	5,333	114
7	Pl. Szczepański 8	7,201	313	24	Św. Jana 2	10,296	107
8	Rynek Główny 8	6,556	300	25	Floriańska 32	2,357	96
9	Mikołajska 13	5,704	273	26	Bracka 1	1,546	89
10	Św.Krzyża 4	22,109	250	27	Rynek Główny 43	394	80
11	Św. Marka 8	5,242	226	28	Św. Tomasza 24	1,795	63
12	Rynek Główny 47	7,553	212	29	Sławkowska 20	570	57
13	Rynek Główny 6	4,119	201	30	Floriańska 28	1,018	54
14	Szpitalna 30-32	9,934	190	31	Rynek Główny 27	6,552	53
15	Sławkowska 12	2,722	156	32	Floriańska 45	1,222	46
16	Św. Marka 17	2,534	151	33	Szpitalna 38	1,409	45
17	Pijarska 17	8,173	147				

and fines and it should promote and support applications by boiler house owners who apply for environmental fee and fine extension and forgiveness on project completion contingent on the conversion of their boiler houses from solid fuel to gas firing.

e. The *Gmina* should make more frequent use of the following provisions of article 76:

"1. A *Gmina* agency may order an operator of a machine, plant, or other equipment to perform specified pro-environmental actions within a specified time.

2. In case of a failure of an operator of a machine, plant, or other equipment to comply with the order specified in paragraph 1 above, a *Gmina* agency may order that the use of the subject machine, plant, or other environmentally hazardous equipment be stopped."

CONCLUSIONS AND RECOMMENDATIONS

This effort is identifying specific incentives that may be used by Kraków city officials to encourage residents to change the way they heat their homes and businesses in order to reduce pollution. This paper describes the incentives study for converting small coal or coke-fired boilers to gas in the Old Town area. A similar study looked at incentives for expanding the district heating system and future analyses will be performed for home stove options.

This analysis shows that the conversion to gas requires an economic incentive for boiler owners. The study identifies the legal basis for possible City action and recommends the most cost-effective approach. Some of these incentives may be appropriate for others who have similar problems and wish to implement similar solutions.

Equally important for other cities and localities are the process we have developed and the general lessons learned during this project. We can recommend some guidelines to help guarantee successful identification and adoption of incentives. First, carefully select the options to evaluate. A solid technical analysis is crucial so that effort is not wasted on options that are ineffective, impractical, or too costly. In addition, the list of options should be developed with input from residents and local politicians.

Second, carefully select the data to use in the analysis. In Kraków, the economic portion of the incentive analysis used technical data from other parts of the project, such as boiler efficiencies determined in the testing program. These technical assumptions can dramatically affect the results, so it is important to examine these assumptions and document data sources. It is important that all project participants agree on these assumptions, so they will support the results.

Other assumptions, such as fuel prices and discount rates, are less certain in the time frame required for life-cycle costing and long-range planning. Therefore, alternative assumptions should be evaluated with sensitivity analyses. In this way, a range of possible futures can be identified and decision-makers will better understand the implications of their decisions. Defining alternative futures can be the most contentious part of the entire process.

All three generic types of incentives must be considered. To help guarantee that the recommended incentives will be adopted, it is important to understand the information needs of local officials and decision-makers. [1] It can be helpful to work with local officials early in the process to ensure that their concerns and questions are addressed. Equally important is to present a clear, concise summary of the analysis and its results. To be effective this summary should include the implications of choosing particular incentives, such as their cost.

Finally, a combination of incentives usually works best. Offering economic incentives will not be effective if residents are not aware of them, or if the process is complicated. Even if regulations are imposed, the public must be informed. Some options, such as improved operating procedures for home stoves, may not involve increased costs. For other options, costs to users may go up. It is important that the public understand why a particular policy is being adopted and what benefits may accrue. Public support is essential to the successful implementation of any policy.

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Session III
Completed Energy and Emissions Reduction Studies

Chairman: **William Fedarko**, U.S. DOE

Evaluation of Supply-Side Options for the Plzen District Heating System—Lynn N. Rubow, W. Franklin Seifert, David B. Stauffer, and Roman Zaharchuk, Gilbert/Commonwealth • Stanislav Kalous, EGU Prague • Josef Svoboda, Energoprojekt • Evzen Pribyl, RAEN, Ltd. • Ivan Benes, City Plan, s.r.o.

Emissions Reduction and Life Extension for Nova Hut and Trinec Steelworks Power Stations in North Moravia—Venanc Walder, Energo Steel • Miloslav Stanek, Nova Hut Ostrava • Bohuslav Bernatek, Energetika Trinec • Lynn N. Rubow, David B. Stauffer, and Roman Zaharchuk, Gilbert/Commonwealth.

Progress in Emission Reduction and Heating System Modernization in Cesky Krumlov—Robert Hershey, AEA O'Donnell • Edvard Barta, TEZA

Improving Energy Efficiency in Handlova, Slovak Republic—Peter Sestak, EGU Bratislava • Jaroslav Izak, Mayor of Handlova • Thomas Secrest, Pacific Northwest Laboratory • Andrew Popelka, Tecogen

EVALUATION OF SUPPLY-SIDE OPTIONS FOR THE PLZEN DISTRICT HEATING SYSTEM

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David B. Stauffer, and
Roman Zaharchuk, Gilbert/Commonwealth
Stanislav Kalous, EGU Prague
Josef Svoboda, Energoprojekt
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ABSTRACT

This work was sponsored by the U.S. Agency for International Development (AID), and under contract to the U.S. Department of Energy (DOE), and performed by Gilbert/Commonwealth (G/C). G/C was assisted by four Czech subcontractors: EGU Praha, Energoprojekt, RAEN, and CityPlan.

Several variants were investigated to satisfy emissions compliance requirements and two levels of future heating demands. Focus was on the Plzen district heating systems, but decentralized boilers were also considered. Future operating requirements and fuel use were determined, and an economic analysis was performed to select the least-cost variant. The results showed that variants involving gas turbines were less attractive than those employing FBC technology, primarily due to the projected price of natural gas. Sensitivity analyses covering commodity prices, varying demand, escalation, and centralization confirmed the initial findings. A financial analysis determined the price of hot water to be consistent with current trends.

Analysis of the environmental impact showed a significant reduction of particulate and SO_2 emissions in Plzen. A large contributor of particulate and CO emissions is the small decentralized boilers, for which significant reductions are possible.

INTRODUCTION

The primary objective of this study is to determine the most cost effective heat supply option(s) for the Plzen District Heating companies that meet the projected heat and steam demands, and new emission regulations. The G/C scope includes an analysis of the current supply-side situation of the district heating systems in Plzen, excluding Skoda, who independently supplies heat to the Skvrnany area.

The primary basis for the supply-side work is an excellent and comprehensive study performed previously by Energoprojekt (EGP). However, since the EGP report was completed, many conditions have changed in the Czech Republic, requiring this re-assessment. Additional tasks performed are intended to provide the City of Plzen with a stronger basis for decision making.

Several key considerations influenced this study:

- the need to reassess energy use patterns;
- the future of many of the 595 small boilers in light of pending environmental regulations;
- competitiveness of current and projected DH operating costs;
- economic inputs to the study in the context of a changing Czech economy, including the future fuel prices, especially imported natural gas;
- the relative capital cost of foreign vs. domestic expenditures;
- the long-term cost of emissions compliance; and
- the potential to expand the present centralized DH system to include the town of Svetovar.

The heat supply sources in the Plzen area can be categorized into three groups, which were addressed in this study as follows:

- **Central heating plants**:
  The central heating plants are the focus of this study with special emphasis placed on CP Plzen, the cooperating sources, and the future of Heat Station Svetovar;
- **Decentralized 595 small boilers:**
  The decentralized 595 small boilers were considered for efficiency improvement, emissions reduction, and retirement (with consumer connection to DH system); and
- **Small home furnaces:**
  Small home furnace emissions estimates were made with less detailed consideration for improvement of efficiency or emissions.

CURRENT DISTRICT HEATING SUPPLY SYSTEM

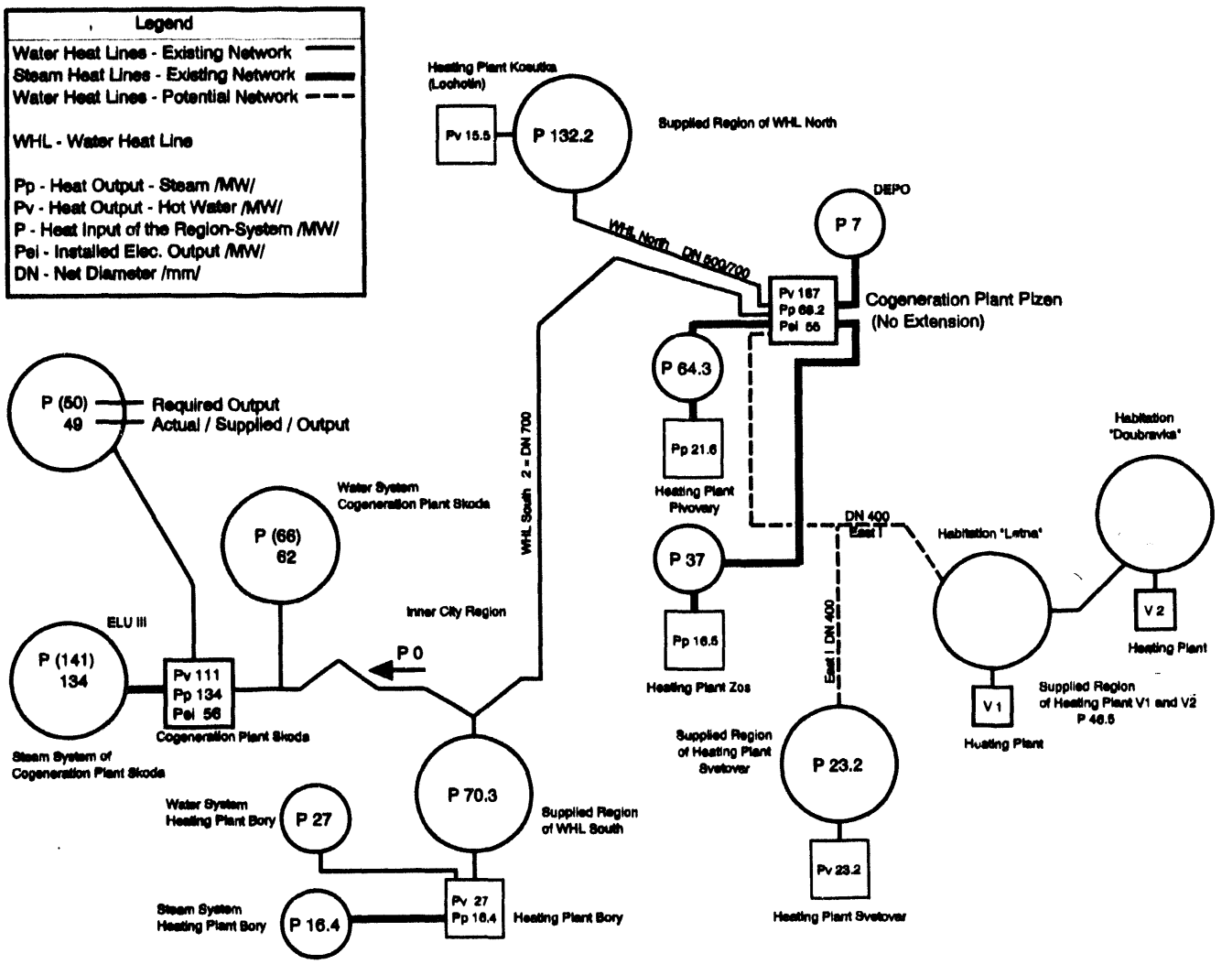
Centralized DH is presently supplied to the City of Plzen by the following sources:

- Cogeneration Plant (CP) Plzen, with collaborating sources Bory and peak source Kosutka;
- Cooperating (with CP Plzen) steam source, West Bohemian Brewery Boiler House (Zapadoceske Pivovary);
- Cooperating steam source (with CP Plzen), Railway Maintenance Company Boiler House (Zos);
- Independent hot water DH system Doubravka;
- Independent hot water DH system Svetovar; and
- On the west side, Skoda Works, supplying large quantities of heat and steam to its own production facilities, and heat to the habitation Skvrnany.

The Central DH system is the focus of this study. The relative location of these sources is shown schematically in Exhibit 1.

Several of the existing boiler units are near the end of their useful life, especially in the older independent DH systems (Doubravka and Svetovar). These boilers may soon need replacement, or significant upgrading. With the onset of environmental regulations, a decision to invest capital in the upgrade, or to invest in a higher efficiency replacement plant will soon be made. This study offers a basis for this decision.

Exhibit 1: EXISTING DISTRICT HEATING SYSTEM IN PLZEN



EVALUATION OF DECENTRALIZED SOURCES

There are 595 small boilers which provide a significant contribution to local pollution. The total capacity of these boilers is approximately the same as the central DH system, excluding Skoda. The potential of these boilers to improve efficiency and emissions, and potential to connect to the DH system was characterized.

A related study concluded that small cogeneration system retrofits are not economically viable for these boilers, unless some special circumstance exists. Further, small boilers which have the possibility to be connected to the DH system should do so, and the City of Plzen should strongly encourage compliance with environmental regulations among remaining small boiler owners and provide incentives to do so.

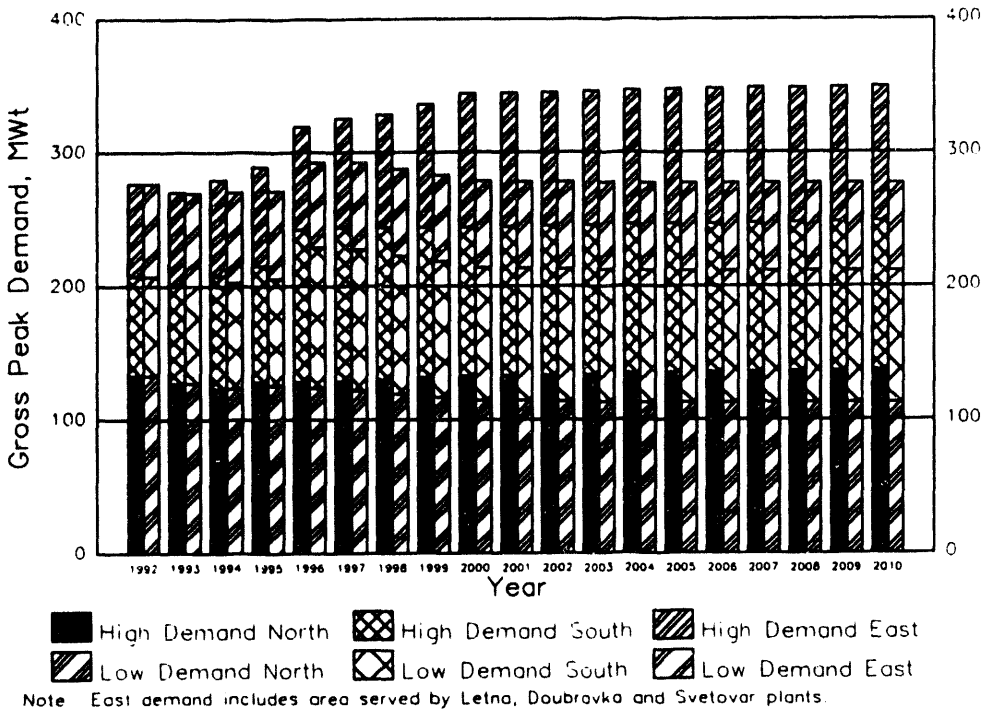
Finally, there are numerous small home furnaces which contribute significantly to pollution in Plzen. Some characterization was done in accounting for their emissions, but development of specific recommendations for the home furnaces was outside the project scope. The U.S. AID and DOE sponsored projects in Krakow provide good information on methods of reducing small furnace emissions.

THE REVISED DEMAND ASSESSMENT

The demand projection was reassessed to include additional parameters, including conservation by existing consumers, population growth (minimal), commercial/industrial growth, and new DH consumers from the pool of 595 small boilers. Resulting costs of operation, and therefore competitiveness of DH with other energy sources, will depend heavily on the realization of these forecasts. In turn, a reduction in the cost of energy supply will encourage new consumers to connect to the DH system. The resulting supply costs will also have an impact on the incentive to conserve energy.

The range of projected total demand through the year 2010, as used in this study, is presented in Exhibit 2. Variants were evaluated for both the high (expected) and low of this range. Note that in the high demand projection, about 25 percent increase in current overall demand is expected over the study period. Most of this increased demand is the result of the connection of Heat Lines South and East, and to anticipated connections of small boiler consumers. Demand from existing consumers is expected to decrease through conservation efforts.

Exhibit 2: TOTAL PLZEN DISTRICT HEATING DEMAND PROJECTION (excluding Skvrnany)



Note East demand includes area served by Letna, Doubravka and Svetovar plants.

TECHNOLOGY REVIEW / DEVELOPMENT OF VARIANTS

Based on the changes to the demand projections, and on other requirements, new/revised variants (options) were developed. Variants consider the operating method and economics included in a range of demand projections. Improvement in system efficiency, summer operation, and reliability are considered. The result is the expected "least cost" approach to meet the range of projected demands and the environmental regulations.

The variants (options) considered are mainly distinguished by the selection of the plant technology for CP Plzen IV. The basic plant technologies selected for analysis as Plzen IV are: (1) Gas-Fired Gas Turbine Combined Cycle and (2) Circulating Fluidized Bed (CFB) boiler. Not all of the variants were investigated by each company. The table below characterizes each variant by the Plzen IV technology selection and the investigating company.

Variant	Investigator	Description of Distinguishing Feature (Plzen IV)
A1	EGU	Combined Cycle plant with two 60.9 MWe (ISO) Gas Turbines
A2	EGU & G/C	Combined cycle plant with one 60.9 MWe (ISO) Gas Turbine.
A3	G/C	Combined cycle plant with one 47 MWe (ISO) Gas Turbine.
A4	EGP	Combined cycle plant with one 90 MWe (ISO) Gas Turbine.
B1	EGU & G/C	Cogeneration plant with one CFB boiler and a 32 MWe steam turbine.
C1	G/C	Life extension of existing units and introduction of a CFB boiler with a 32 MWe steam turbine in 2003.

Emissions reduction/system upgrade technologies were qualitatively considered and screened, while the selected options were analyzed quantitatively. Emissions reduction technologies considered for district heating boilers include the following:

- Integrated Gasification Combined Cycle,
- Fuel cells,
- Conventional Pulverized Coal Fired (PC-fired) with Flue Gas Desulfurization,
- Fluidized Bed Combustion (FBC),
- Gas Turbine Combined Cycle (GTCC),
- Flue Gas Desulfurization Retrofit,
- Duct Sorbent Injection (DSI),
- Gas Engine or Gas Turbine Repowering,
- Fuel Switching (incl. gas conversion), and
- Baghouse for particulate cleanup.

The primary technologies selected for the study variants included FBC, GTCC, Fuel Switching and the baghouse.

Two significant findings resulting from the technology evaluation are:

1. Pressurized Fluidized Bed Combustion (PFBC) is a promising technology to burn low grade, low cost indigenous fuels in district heating systems, and at a much higher electric to heat ratio than conventional cogeneration systems. Choosing Variant C1, which postpones a decision for increased capacity, could result in having this additional option.

2. Duct Sorbent Injection (DSI) technology uses a lime slurry to capture SO_2 within a flue gas duct, and is feasible for moderate levels of SO_2 removal. It provides a viable option to the fuel switch for CP Plzen II, in the case of potential problems caused by switching to black coal.

ECONOMIC ANALYSIS OF NEW/REVISED VARIANTS

Calculations of fuel use and other operating characteristics were carried out by EGU, Energoprojekt, and G/C for the variants introduced above. Basic assumptions for all three analyses were essentially the same. EGU and Energoprojekt carried out engineering calculations in a traditional manner of dividing the year into logical groups according to electric tarrifs, unit capacity ranges, and demand levels, and then calculating the operating hours of each unit according to dispatch logic aimed at minimizing operating costs. In the G/C analysis, a simplified approach is used to "model" the system. The performance of each studied plant is determined, and an annual stream of costs is developed for each variant through the year 2010 for two different levels of demand.

Capital and operating costs developed for each variant are based on vendor quotes, in-house experience, and

engineering judgement. Maintenance costs were estimated according to available ZCE information, and projections were prorated by the age of each unit. Fuel cost projections were based on current Czech prices, evaluation of remaining subsidies, and comparisons with world prices and trends.

Each variant is then structured to meet a demand and energy forecast of hot water and steam. The production of electricity is also considered. Calculations performed by EGU and EGP were compared for the common variants investigated.

The G/C model used in the analysis considers unit operation in a somewhat idealized state. In the actual operation of the district heating system, the existing cogeneration units probably operate less than would be predicted by the model. Possible reasons for this include a decision to shut down the large units as their minimum load is approached, instead of trying to extend the operation of these units as far into the summer as possible, thus maximizing electrical output and MWe sales. Minimum load of the PC units is quite high (in the range of 60 to 70 percent), and can impose a severe restriction on the annual number of hours of operation. Comparisons of G/C results made with the results of EGU for Variant A2 and B1 showed that the G/C approach yields results which are reasonably accurate in terms of fuel use, and are consistent in the choice of variant.

Determination of Plant Operating Characteristics

In the G/C model, fuel usage to meet hot water and steam demands is determined by characterizing the ability of each unit to meet a given thermal demand for both steam and hot water on a delivery of heat (MWt) basis. Generating units are dispatched in the model in a prioritized order until demand and minimum load criteria are met. The boiler duty is estimated as the sum of the steam duty, hot water duty, turbine power and heat rejected to the cooling tower. This boiler duty is augmented by an operating factor to capture operational influences like startup, shutdown, and equipment degradation.

Some simpifying assumptions were made to model each steam turbine to account for varying extractions and steam flows. Electric production of each turbine component is based upon the exhaust flow of the turbine. The performance data for the other turbines were based upon typical turbine efficiencies for the sizes of interest, a simple heat balance, and miscellaneous support calculations. Performance data for the gas turbines account for ambient temperature, elevation and operating load.

Economic Analysis

Several assumptions were made to support the economic analysis. The primary tool for investigating the economic merit of each proposed variant is a spreadsheet model designed to simulate plant operations. Available facilities are dispatched to meet steam and hot water demands in accordance with an established dispatching order.

Cost streams associated with fuel requirements to meet steam and hot water demands are developed along with revenue from electrical production in a step-by-step procedure. As the result of model simulations performed for each variant, the cumulative present worth of projected operating and capital expenditures is presented in Exhibit 3.

Exhibit 3: SUMMARY OF ECONOMIC ANALYSIS RESULTS

	CUMULATIVE PRESENT WORTH $(000)										
Variant	Capital	Natural Gas	Oil	Lignite	Black Coal	Net Power Interchange	Fixed & Variable Expenses	Sorbent, Ash Rem'l	Mainten -ance	Total Operating Expenses	Total Capital & Operating Expenses
C1	32,223	531	922	37,884	79,771	(95,511)	41,360	10,098	30,713	105,768	137,991
A2	58,825	97,495	4,732	23,695	68,641	(146,346)	38398	4,923	29,080	120,618	179,443
A3	51,667	90,072	5,376	23,695	69,622	(135,081)	38,283	4,968	28,835	125,771	177,438
B1	47,283	1,379	982	55,599	61,966	(112,526)	42,995	14,300	29,075	93,769	141,052

The economic analysis of variants investigated by EGU and Energoprojekt (A1, A2,A4 and B1) was developed using technical quantities developed by EGU and EGP, and economic assumptions consistent with the G/C economic analysis. Generally, the variant that would be selected based on these calculations is B1 (the one CFB boiler and steam turbine case), which is consistent G/C's results.

Sensitivity Analyses

Several sensitivity analyses were conducted, including the impact of lower demand, escalation, and then an "Indifference Analysis," which explores several parameters independently. The results of applying the lower demand or removing escalation did not change the conclusions.

In the "Indifference Analysis," we have represented, for each major component of cost, the unit cost adjustment that would be required for the overall present worth of each respective variant to be equivalent to that of the Base Case (C1). Exhibit 4 indicates the magnitude of adjustments required under the assumption that all other cost components remain unchanged. An indication of "NA" means that it is not possible to attain equilibrium through any logical adjustment of this factor in isolation.

An example of the use of this method is the adjustment of natural gas prices. The exhibit shows that a -43% adjustment to gas prices would be needed to make Variant A3 and C1 (Base) equivalent. A simliar exercise can be conducted for other numbers on this table. While negative adjustments of greater than 100% in total operating expenses would appear to be illogical, such expense totals include "expense credits" for excess power sales, which, if of sufficient magnitude could more than offset expenses otherwise incurred.

Svetovar DH System

The district heating system in Svetovar is not presently interconnected with the CP Plzen DH system. In order for the Svetovar DH system to meet the new emission requirements by 1997, they could either modify the present supply system for compliance, or connect to the Plzen district heating system. Three categories of plant modifications were considered: (1) a cogeneration retrofit, (2) a switch to coal, and (3) a switch to gas. Based on a break-even analysis and constant demand, connecting the Svetovar district heating system to the Plzen district heating system is more economical than the black coal or natural gas fuel switch option. The payback period for estimated costs incurred in connecting Svetovar should be two to three years. It is recommended that Svetovar be connected to the central district heating system through the proposed Heat Line East II.

Financial Analysis

While sufficient information is not available to make a complete review of the financial consequences of alternative decisions regarding future operations of CP Plzen, some additional perspective may be gained from even a somewhat limited analysis.

Exhibit 4: INDIFFERENCE ANALYSIS SUMMARY

	CUMULATIVE PRESENT WORTH $(000)										
Variant	Capital	Natural Gas	Oil	Lignite	Black Coal	Net Power Interchange	Fixed & Variable Expenses	Sorbent , Ash Rem'l	Mainten ance	Total Operating Expenses	Total Capital & Operating Expenses
C1	BASE	BASE	BASE	BASE	BASE	BASE	BASE	BASE	BASE	BASE	BASE
A2	-71%	-43%	NA	NA	372%	181%	NA	NA	NA	-279%	-23.1%
A3	-76%	-44%	NA	NA	389%	200%	NA	NA	NA	-197%	-22.2%
B1	-6.5%	NA	NA	-17.3%	17.2%	118%	-187%	-73%	187%	25.5%	-2.2%

No reliable data were available for the inclusion of debt service, if any, and remaining depreciation charges related to plants presently in service. In other respects, however, estimated hot water costs are derived by subtracting from total costs the costs directly attributable to, or allocated to steam deliveries. As a result of the financial analysis, the levelized cost of hot water as developed over the complete analysis period follows.

Variant	Levelized Cost of Hot Water	
	$ U.S./MWh	Kc/GJ
C1	$16.02	124.60
A2	$21.67	168.58
A3	$21.53	167.40
B1	$17.69	137.60

The relative level of costs is generally consistent with economic analysis results.

As a comparison to the "costs" above, it is of interest to note the historical and projected price of heat for dwellings in Plzen as summarized below:

Year	Cost of Hot Water for Dwellings	
	$ U.S./MWh	Kc/GJ
1992-93	$15.43	120
1993-94	$17.61	137
1994-95	$21.86	170
1995-96	$32.14	230-270

These values show a transition from pricing during the 1992-1993 heating season which was still subsidized/controlled, to actual market prices, expected to occur in 1995-96. For subsequent years the price of heat will reflect the escalation of the associated fuel costs.

Care must be taken when making comparisons of these annual projected costs with the levelized costs resulting from the financial analysis, and in recognizing that the developed costs are incomplete for the reasons previously stated. However, a comparison brings credibility to the costs which were independently developed by the G/C model.

Environmental Analysis

A primary assumption is that environmental requirements are satisfied for all variants. However, each variant results in a different quantity of pollutants produced by the system. The environmental analysis study area is larger than the one selected for the investigation of primary variants to capture a larger fraction of the emissions sources in Plzen and obtain a better representation of the relative changes in total emissions as changes are made to the central DH systems.

The present distribution of particulate, SO_2, NOx, and CO emissions for the city of Plzen is shown in Exhibit 5. All emissions source types share significant fractions of these emissions. Note the following:

- CP Plzen has a lower share of particulate since high efficiency ESPs are used for particulate removal on their large plants,
- CP Plzen has a higher share of NOx emissions because uncontrolled large boilers are generally higher in NOx,
- the CP Plzen share of SO_2 emissions is high because lower grade, higher sulfur fuels are generally burned in central stations and heating plants, and
- home furnaces have a disproportionate share of CO emissions, which is typical of these kinds of units.

Using Variant B1 as a basis, emissions improvement in the entire Plzen area is represented in Exhibit 6 for the years 1993 and 2010. Assumptions include:

- Skoda and Svetovar assume SO_2 emissions reduced by 70 percent.
- Decentralized small boilers assume 22 percent of capacity switches to district heating, 10 percent conservation through the study period, and other improvements are made as recommended in Section 4.0.
- Home furnaces assume 10 percent conservation (no other improvements).

Reductions in emissions, especially SO_2 and particulate, are significant.

Exhibit 5: 1993 DISTRIBUTION OF EMISSIONS FOR THE CITY OF PLZEN

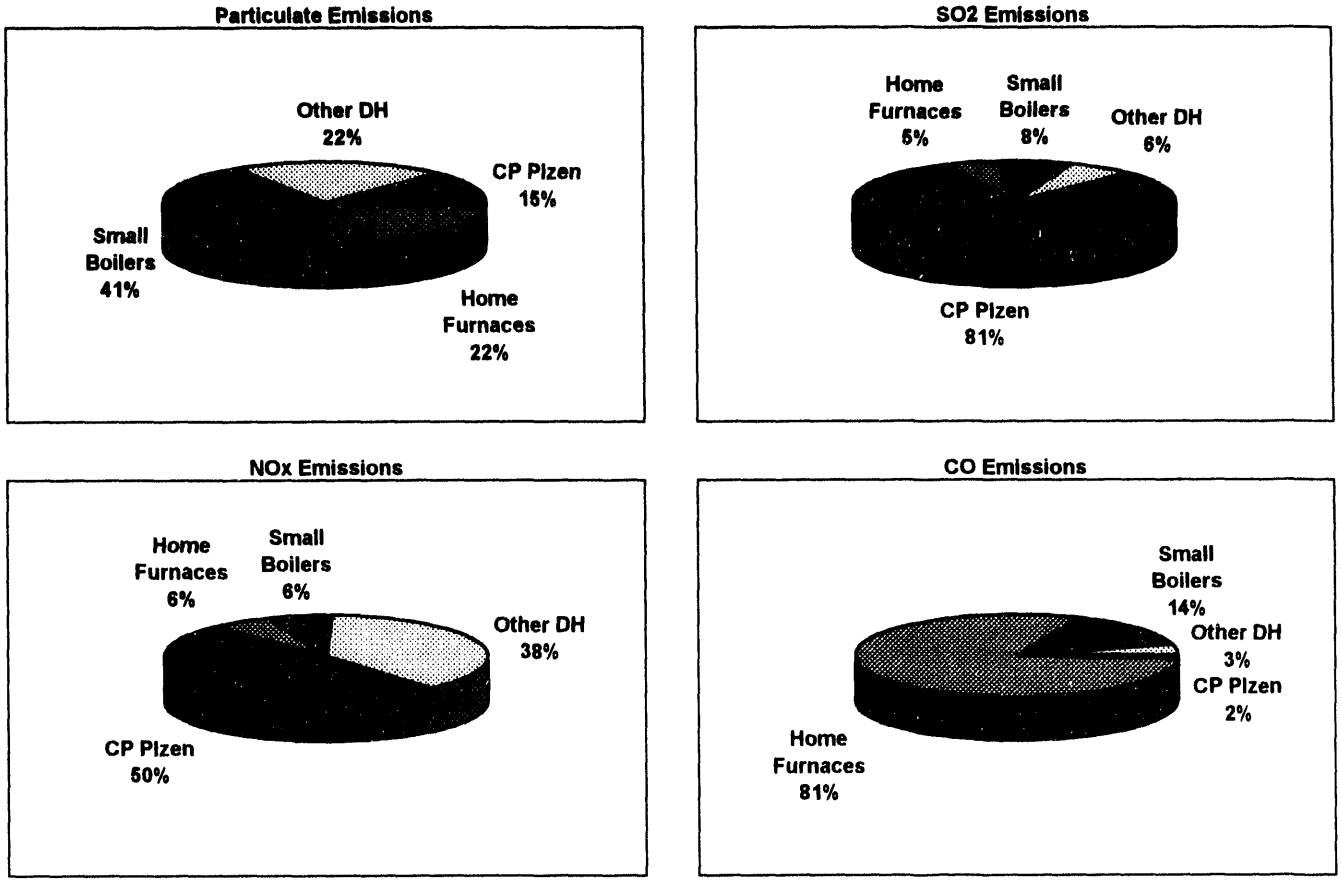
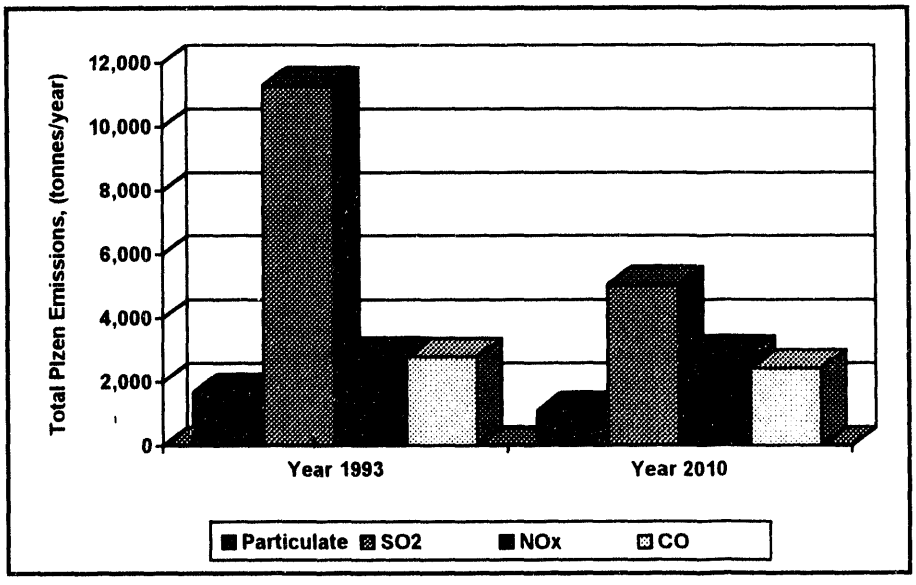


Exhibit 6: 1993 vs. 2010 EMISSIONS IN CITY OF PLZEN
WITH SMALL BOILER CHANGES IMPLEMENTED (Variant B1)



The changes planned for CP Plzen and cooperating district heat sources, combined with implementation of reasonable changes to many of the 595 small boilers, will produce dramatic changes to particulate and SO_2 emissions in the City of Plzen. Potential changes to small home furnaces should also be investigated due to the large fraction of emissions contributed by these sources. Wherever possible and economically justified, these sources should be connected to the district heating system. The programs being conducted in Krakow, Poland by U.S. AID and U.S. DOE will be useful to the City of Plzen in establishing policies to deal with these significant sources.

CONCLUSIONS AND RECOMMENDATIONS

1. The CFB boiler variants (B1 and C1) are recommended over the GTCC variants (A2, and A3) on the basis of the Cumulative Present Worth of Projected Costs resulting from the G/C economic analysis. The GTCC variants are clearly higher in cost (between 26 and 30%) than the CFB boiler variants. The selection of the CFB boiler variants over the GTCC variants are further supported by the following:

    - Sensitivity analyses show that in order for Variant A2 to be competitive with the C1 base case, significant changes in fuel or capital costs would be required.

    - The sensitivity analysis based on the low demand requirements did not alter the conclusions.

    - Economic analyses based on technical input from EGU and Energoprojekt are consistent with this conclusion.

    - The GTCC depends on imported natural gas, while the CFB boiler burns low price indigenous lignite.

2. The Cumulative Present Worth of Projected Costs for Variant B1and Variant C1 are virtually the same. Based on consideration of other factors, Variant C1 is recommended by Gilbert/Commonwealth. Some of these factors are:

    - Concern over future emission regulation changes.

    - Concern over the uncertain demand projections.

    - Desire to delay capital expenditures.

    - Desire to defer the decision to allow time for other technologies to become more viable. (e.g., PFBC will soon be viable and would allow a greater electric to heat ratio.)

3. Emissions compliance for all stoker (grate) boilers can be met most cost effectively by switching to low sulfur black (bituminous) coal and installing a baghouse.

4. It is recommended that Svetovar be connected to the central district heating system through the proposed Heat Line East II.

5. Without considering a switch to district heating, the potential exists to make significant improvements to many of the 595 small boilers, including switching to natural gas, installing new burners, boiler tuning, installing boiler controls, and boiler replacement with more efficient units. This can potentially result in reduced fuel use by more than 22 percent, reduced particulate and SO_2 emissions by 80 percent, reduced NOx emissions by 72 percent, reduced CO emissions by more than 80 percent, and reduced VOC emissions by more than 80 percent.

6. At least 64 MWt (representing 80 of the 595 boilers) of small boiler capacity should be retired and their consumers connected to the district heating system. More boilers may be suitable along Heat Line East II, if this project continues.

7. Small cogeneration alternatives should be considered only under special circumstances, and in isolated or remote areas of the City where the Central DH System cannot be extended. It is highly unlikely that small cogeneration systems will be able to compete with district heating as presently structured.

8. Regarding emissions, the changes planned for CP Plzen and cooperating district heat sources, combined with implementation of changes to many of the 595 small boilers, will produce dramatic reductions to particulate and SO_2 emissions in the City of Plzen of 35 and 55 percent respectively. Potential changes to home furnaces should be investigated due to the large fraction of emissions contributed by these sources. Wherever economically justified, these sources should be connected to the district heating system.

9. Several issues emerged during the study which were not directly compared between variants, but may be important for the future of centralized district heating (DH) in Plzen as follows:

   - A well maintained and managed CP Plzen central district heating system should prove to be economically superior to other competing heat or cogeneration sources.

   - Significant improvement in the operation of all plants is possible with addition of more sophisticated controls.

   - Reduction of system leakages can be improved through the gradual replacement of primary piping with corrosion resistant pipe with integrated leak detection and by the replacement of secondary systems with more modern two pipe systems, where possible. The future metering of heat and required measurements will also help to assess the true losses.

   - The management of Plzen district heating activities will best be consolidated into a single privatized company, and governed by a reguiatory body. Based on interviews with modern district heating companies, significantly greater efficiency in utilization of operations and maintenance personnel is possible.

ACKNOWLEDGEMENTS

This work has been sponsored by U.S. AID and funded through the U.S. DOE Contract AC01-88FE61657 awarded to Gilbert/Commonwealth. G/C is a Reading, PA based architect/Engineering firm experienced in power generation, emission compliance, economic analysis, and international projects. G/C subcontracted with four firms to support this effort: EGU Prague, Energoprojekt, RAEN, and CityPlan. Each firm made important contributions in the completion of this work.

EMISSIONS REDUCTION AND LIFE EXTENSION FOR NOVA HUT AND TRINEC STEELWORKS POWER STATIONS IN NORTH MORAVIA

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ABSTRACT

This work was sponsored by the U.S. Agency for International Development (AID), and under contract to the U.S. Department of Energy (DOE), and performed by Gilbert/Commonwealth (G/C). G/C was assisted by Energo Steel, a Czech subcontractor already familiar with the subject Steelworks and Power Stations.

The area of North Moravia in the Czech Republic is a highly polluted area. Two large steel works operate in this area and emit significant quanties of pollutants from the power house supplying energy to the steel works and district heating of the surrounding areas. Much of the major equipment is old and antiquated. The objective of this study is to identify the least cost energy supply options that will meet the new emission requlations and the projected energy requirements for the power stations within the two Steelworks.

The study investigated numerous emission reduction and energy supply options, including AFBCs, PFBCs, gas turbines, duct injection, new pulverized coal units, and fuel switching. The preliminary results of the combined technical and economic analysis favor the addition of a small gas turbine for both the Nova Hut and Trinec Power Stations.

INTRODUCTION

North Moravia is the home of more than 1.9 million inhabitants and the source of over 600,000 jobs in steel, chemicals, many other industries, and supporting businesses. Thirteen active coal mines are operated in the area. It is a highly polluted region of the Czech Republic, and a place where many industries are undergoing change to successfully comply with stringent emissions regulations.

A complicating factor is uncertainty. The uncertainty of future markets inhibits emissions compliance planning efforts, where large capital investments are necessary concurrent with a transition to privatization.

The Nova Hut and Trinec Power Stations function in a similar manner. They both serve the parent Steelworks company by providing energy in the form of steam, hot water, blast furnace air, compressed air, and electricity, and in turn, purchase byproducts blast furnace gas and coke oven gas from the Steelworks. In addition, both power stations deliver heat to the community through an independent distribution company. Although part of the parent company, they operate independently as a profit center. While the entire Steelworks is faced with emissions compliance decisions, this study focuses on the power stations.

The objectives of this study are as follows:

- determine projections of possible Power Station demands based on alternative Steelworks projections,
- determine the most cost effective emission reduction scheme, including an assessment of Clean Coal Technologies (a U.S. DOE sponsored program), to meet projected demands, and
- assist Nova Hut and Trinec Power Station management with decisions regarding emissions compliance and life extension.

A secondary objective is to organize operating data to facilitate the analysis of varying future operating scenarios.

This project involved close cooperation and exchange of information between G/C, Energo Steel and both Nova Hut and Trinec Power Station personnel. A visit to the United States was included in the project for training in new technologies, plant maintenance procedures, and engineering design; plant visits; and project working meetings. The results include a comprehensive final report for each power station.

The project work has been completed and the final reports are being internally reviewed. A final presentation to power station management is planned for June 1994.

TECHNICAL ANALYSIS: NOVA HUT

The powerhouse at Nova Hut (NH) will need to adjust its operation for the changing demand of steam, hot water, and electricity from the Steelworks and the district heating needs for the town. The new operations at Nova Hut will also have to accommodate the recent emission compliance requirements and account for the condition of the existing equipment. It is important to note that the emissions compliance requirements considered in this analysis are from the viewpoint of the Power Station only, and not from the viewpoint of the entire Steelworks, which has additional emission sources and compliance considerations. The objective of the technical analysis is to provide input to the economic analysis for the determination of the least cost technology option capable of meeting the projected demand and emission compliance requirements.

Projections of key operating parameters, such as the required blown air, compressed air, IP and LP technology steam, and heat were developed by Nova Hut. These projected demands along with the projected quantities of coke oven, blast furnace, converter, and firedamp gas available to the power house are principal inputs of the technical analysis. Since the projection of both these demands and supply considerations are a function of the uncertain steel production scenarios, three different scenarios were formulated by Nova Hut for the year 2000. The three year 2000 scenarios differ in the level of steel production and the number of blast furnaces in operation as summarized in Exhibit 1.

Exhibit 1: BLAST FURNACE OPERATION AND STEEL PRODUCTION

Year	Number of blast furnaces in operation	Steel Production (kt/year)
1995	3	2612
1997	3	2612
2000A	3	2612
2000B	2	2600
2000C	2	1915

The specific equipment utilized in the technical analysis was based upon the proposed equipment development plans provided by Nova Hut. These plans focused on the reconstruction, retirement, replacement or continued operation of the existing power equipment in both the boiler house and engine room. The Nova Hut plan was developed through the consideration of equipment conditions, projected demands and environmental compliance requirements.

Numerous technological options were qualitatively screened by G/C in order to select and analyze the most promising options. The screened options included the following:

- Gasification combined cycle,
- fuel cells,
- conventional PC with FGD,
- flue gas desulfurization (FGD) retrofit,
- circulating FBC (CFB),
- gas turbine combined cycle,
- gas turbine repowering,
- fuel switching,
- duct sorbent injection,
- various NOx control technologies, and
- baghouse/ESPs.

The five options selected for consideration are:

Case	Description
1. Base Case	Status quo, retain K2N as pulverized coal boiler
2. Circulating FBC	Circulating FBC as K2N
3. Small Waste Gas-Fired Gas Turbine,	Westinghouse W151 as K2N
4. Large Waste Gas-Fired Gas Turbine	Westinghouse W251 as K2N
5. Duct Sorbent Injection (DSI)	Applied to boilers K3, K5, K6, retain plans for pulverized coal boiler as K2N

These five options were evaluated technically through the development and use of two computer models. The first model, the steam demand model, determines the total high pressure (HP) steam demand, intermediate pressure (IP) and low pressure (LP) steam distribution and electricity generated as a function of required compressed air, blown air, IP and LP steam requirements, and heat demands. The second model determines fuel use, emissions and solid waste generation, lime/limestone feed requirements and, if applicable, electricity generated by a gas turbine, resulting from operation of the selected steam generators utilized to

meet the required HP steam demand. Both of these models are being made available for future evaluation of additional Nova Hut options.

A simplified version of the relationship of major equipment in these two models is presented in Exhibit 2. HP, IP and LP steam are manifolded for various purposes as shown. The system is quite efficient in that very little energy is wasted.

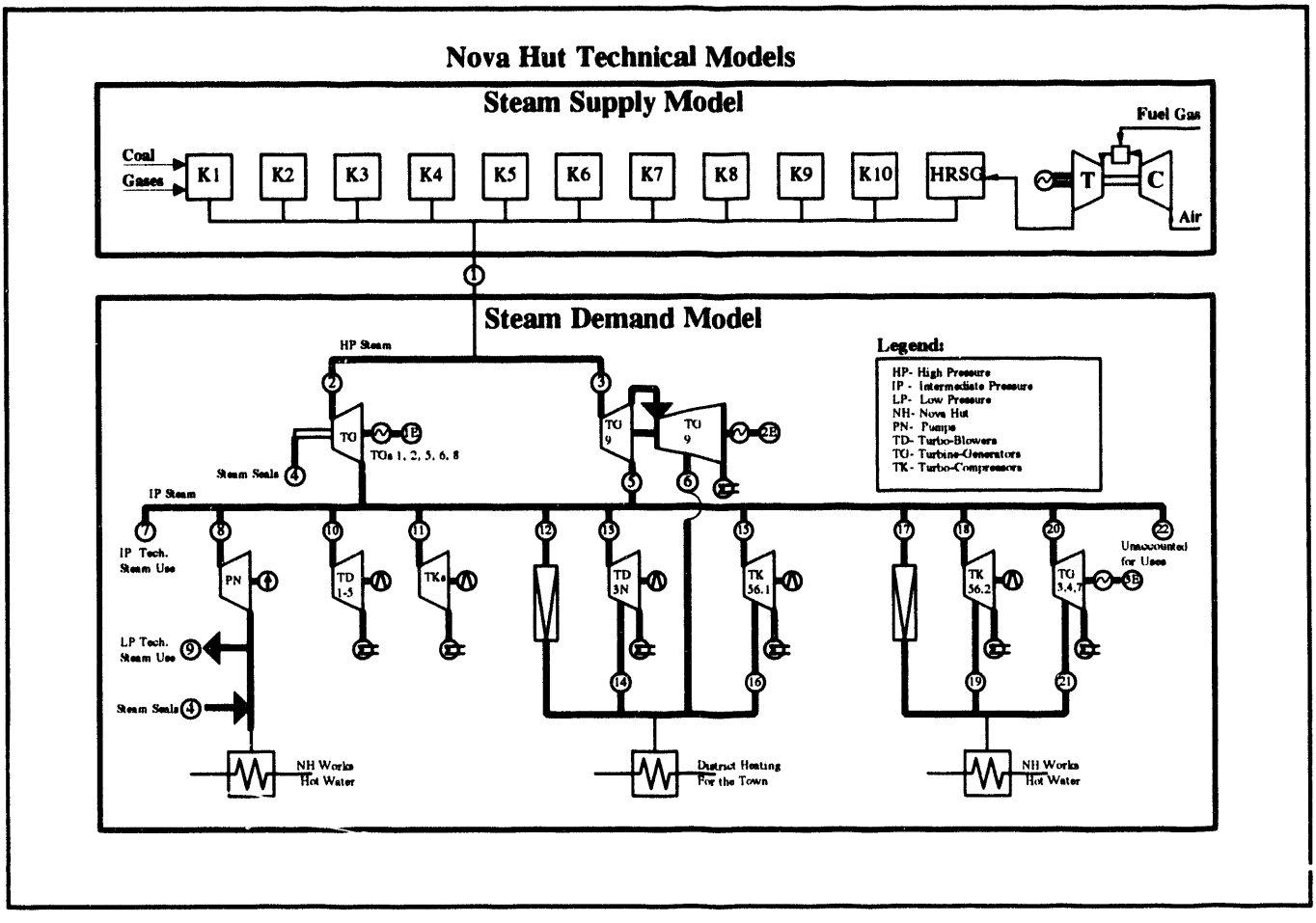
The initial modeling work involved the characterization of the existing power plant. This effort was substantial since heat and material balances for the plant had not previously been prepared. The reconciliation of data became an important and nontrivial task. The models were compared to 1992 historical data and found to be in good agreement.

Utilization of the provided input data and the developed models allowed for the analysis of the five selected options. Although the primary result of the technical analysis is the generation of input for use in the economic analysis, several technical results and conclusions have been made and are presented below in the conclusion section.

ECONOMIC ANALYSIS: NOVA HUT

An evaluation was performed through an economic analysis which utilized projected capital and operating costs through the year 2010 for each of five cases and three steelworks scenarios. Escalation factors are used to project the relative shift in expected prices for each relevant commodity, and a discount rate is used to establish a present value for future expenditures and revenues.

Exhibit 2: NOVA HUT STEAM DEMAND AND SUPPLY MODE'.S



For each of the cases, capital costs for new plants and modifications to existing plants as required were developed to meet the projected loads and comply with environmental regulations. Costs were derived from a number of U.S. and Czech sources.

A further breakdown between Czech costs and foreign costs are also provided by category. This is helpful in estimating the future price of foreign costs as a result of currency exchange considerations. The cases evaluated utilize differing amounts of equipment which is produced within the Czech Republic and imported from the United States.

A brief summary of the total capital costs (excluding inflation or escalation) associated with each case is presented in Exhibit 3. Costs are presented in Kc x 1000, and include a combination of in-country costs and foreign exchange costs. It can be noted that the magnitude of capital costs are significantly outweighed by the fuel costs in the economic analysis.

Exhibit 3: PRELIMINARY CAPITAL COSTS
(1993 Kcx10^6, without inflation or escalation)

Year	Case 1	Case 2	Case 3	Case 4	Case 5
1995	358	452	480	667	402
1996	498	600	480.4	667	542
1997	140	190			140
Total	996	1,242	960.8	1,334	1,084

The characteristics and initial prices assumed for this study, based on fuels currently used and fuels planned, are included as Exhibits 4 and 5.

There is a considerable supply of coal with a range of quality available in the Ostrava region. The use of higher quality coal is not viewed as a long term solution, since the quantity of reserves is more limited, and the price will escalate as demand for high quality coal increases.

Exhibit 4: SUMMARY OF ASSUMED SOLID FUEL CHARACTERISTICS

Parameter	Ostrava/ Russian	Polish	Parting	High Sulfur
LHV, MJ/kg	23.7	25.1	14.0	23.7
Sulfur	0.64%	0.66%	0.79%	1.09%
Ash	26.4%	6.6%	41.8%	26.4%
Cost, Kc/GJ	38.0	35.9	28.6	33.8

Exhibit 5: SUMMARY OF ASSUMED GASEOUS FUEL CHARACTERISTICS

Parameter	Blast Furnace Gas	Coke Oven Gas	Converter Gas	Fire-damp Gas	Natural Gas
LHV, MJ/Nm^3	3.1	16.8	8.3	22.0	33.5
Sulfur, g/Nm^3	0.001	3.05	0	0	0
Density, kg/Nm^3	1.27	0.45	1.305	0.996	0.790
Cost, Kc/GJ	26.0	51.2	33.0	50.0	93.7

Natural gas will be used sparingly at the Nova Hut power station, especially considering the availability of other "waste gas" fuels. The NH power station currently uses blast furnace gas and coke oven gas fuels which are purchased from the steelworks at an agreed price based on heating value, previous trends, and other factors. Blast furnace gas can be burned in all of the boilers, including Boiler K4 which is dedicated exclusively to gas burning. Coke oven gas is used for flame stabilization in the coal boilers, and while higher in heating value, contains disagreeable tars. The converter gas and firedamp gas (obtained from the coal mines), which will soon be available to the power station should be priced on a similar basis.

Oil is currently used in standby units and for startup of the larger plants. Since not much oil use is anticipated compared to the use of other fuels, this price will not substantially affect the comparison of cases, and is not considered in detail.

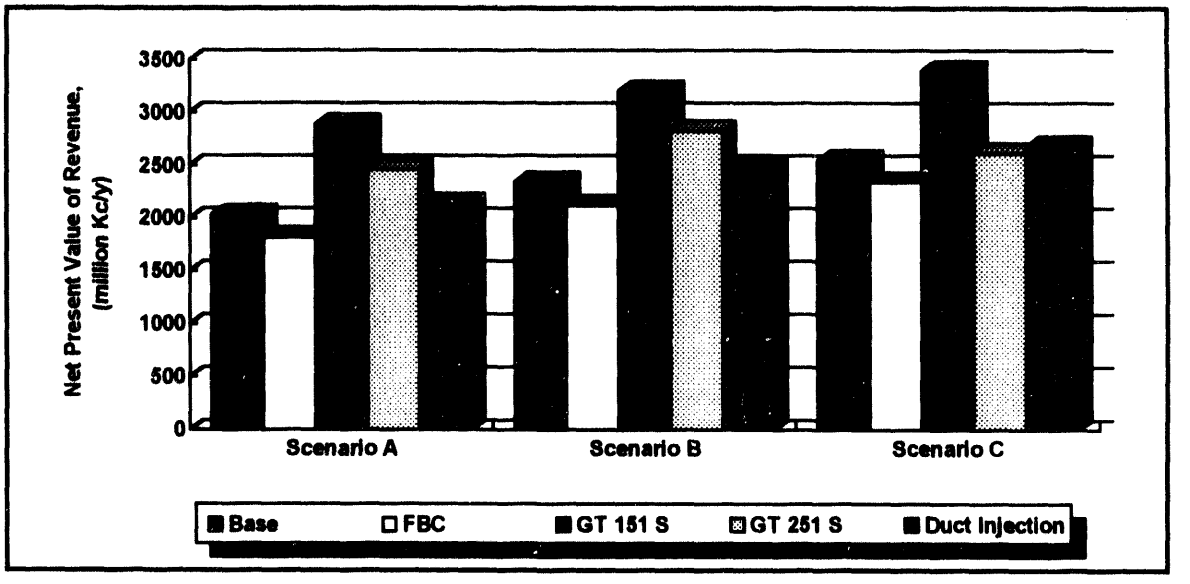
Other operating and maintenance costs were based on good historical data, and projected into the future through the use of escalation factors. A unit age factor was applied to equipment maintenance values. Labor costs are not currently a significant fraction of the operating costs, due to the lower wage rates in the Czech Republic. While wages are expected to rise as the economy strengthens, worker efficiency will also increase, somewhat offsetting the total labor cost. Ash disposal costs were escalated to reflect increasing difficulty of opening new ash disposal sites in the Czech Republic.

A computer spreadsheet was specifically created as a vehicle for interpreting the results of the technical analysis in economic terms over the projected period through the year 2010. Several assumptions were made regarding commodity purchase and sale terms, currency exchange rates, discount rates, and other conditions of the study.

The economic spreadsheet is separated into two parts: (1) quantity information and (2) economic results. Purchased quantities consist of fuel, other feedstocks, ash disposal, labor, fixed and variable operation and maintenance, and capital cost. Sales quantities include several commodities sold to the steelworks and district heat to the town. Most quantities are imported directly from a spreadsheet created by the technical model described earlier. Scenarios A, B and C of each case are addressed in the same spreadsheet.

A graphical depiction of results for all three scenarios, and for each of the cases, is shown in Exhibit 6. While each of the resulting cumulative projection of revenue streams is different, the smaller gas turbine, Case 3, is the clear winner, and is the appropriate size considering the quantities of gas fuels available for use in the power station. The larger gas turbine represented in Case 4 must use natural gas to fulfill its fuel requirement, and thus has a lower projected revenue.

Exhibit 6: COMPARISON OF ECONOMIC ANALYSIS RESULTS SUMMARY FOR SCENARIOS A, B AND C, AND CASES 1 THROUGH 5



A sensitivity analysis was performed to evaluate the impact of escalation on the ranking of cases. It is apparent that even with the removal of escalation, the gas turbine cases (Cases 2 and 3) remain superior to other cases.

Finally, an "indifference analysis" was performed to determine the unit cost adjustment of each significant variable or group of variables, that would be required in order for the overall present worth of each respective case to be equivalent to that of the Base Case. The table in the lower portion of Exhibit 7 (Scenario A) indicates the magnitude of adjustments required under the assumption that all other cost components for that case and the Base Case remain unchanged. For example, in order for the net present worth for Case 2 to equal that of the Base Case, the capital cost of Case 2 would have to be reduced by 21 percent. Similarly, in order for the net present worth for Case 3 to be equal to the Base Case, the price of electricity as sold to the steelworks would have to be reduced by 75 percent, or the capital cost would have to be increased by 100 percent.

Exhibit 7: INDIFFERENCE ANALYSIS SUMMARY FOR SCENARIO A

RESULTS FOR SCENARIO A	Percent Adjustment Required to Individual Cost or Revenue Element to Equate Cumulative Present Worth of the Specified Case with the Base Case							Net Present Worth (Kc x10^6)
		Gas and Solid Fuel Costs					Sales	
	Capital Cost	Waste Gas	Natural Gas	Pol/Ostr/ Russian Coal	Parting Waste Coal	High Sulfur Coal	Electric	
Case 1: Base	**Base**	**Base**	**Base**	**Base**	**Base**	**Base**	**Base**	
Case 2: FBC	-21%	NA	NA	38%	-50%	NA	NA	-11%
Case 3: GT 151S	102%	2633%	NA	472%	17600%	NA	-75%	42%
Case 4: GT 251S	37%	1330%	103%	112%	4205%	NA	-25%	21%
Case 5: Duct Injection	12%	330%	NA	-8%	NA	10%	NA	5%

EMISSIONS REDUCTION: NOVA HUT

Czech emisson regulations are being evaluated by most organizations who must comply. Currently, the regulations allow for the co-firing of different fuels, and specify that the regulation is determined by the fuel which is burned in the majority. Thus, under current regulations, gas burning can effectively be used as an "emissions control" strategy. This is an advantage for the Power Stations because a large amount of waste gas fuels are available from the Steelworks, as well as other sources. While emission regulations may someday change in this regard, and compliance will probably be determined on a case-to-case basis, the regulations were assumed to remain as presently constituted for study purposes.

Another aspect of the regulation concerns multiple boilers which together make up a complete "station." Often, these boilers are tied to a single stack. Current interpretation of the regulations call for each boiler to be classified by its individual size and to be brought into compliance, and monitored, on an individual basis. Again this may change. If it is in the state's best interest to adopt an alternate compliance scenario (with fewer tonnes/y for the station), it is possible that this scenario would be accepted. Again, for study purposes, the present interpretation of the regulation was adopted.

Emissions are reduced through implementation of each alternative. The results vary according to the technology in which the available fuels are burned, their respective efficiencies, and their associated cleanup systems.

Emissions results are less startling than expected because measures are already being taken to reduce emissions to comply with existing environmental regulations. Coals burned in Nova Hut are already low in sulfur, with reasonable heating values. The addition of new available gases to provide energy naturally reduces emissions.

An anomoly occurs with the production of additional electric energy. If this energy were not provided by the Power Station, it would be provided by the grid, which produces this energy primarily by coal-fired plants, which must also undergo changes to comply with emissions requirements. No attempt was made to reconcile emissions between Power Station sources and outside sources, since the goal was to bring the Power Station into compliance.

TECHNICAL ANALYSIS: TRINEC

A similar analysis was conducted for Trinec. There are some physical differences in the arrangement of plants in that there are two Power Stations instead of one. There are three coal-fired boilers in EIII and four gas-fired boilers in EII. The analysis differs because the changeout of one boiler (K11) has already been committed to a CFB Boiler, and this installation is almost complete. A second CFB Boiler may soon be committed. It was decided that a pressurized FBC would be included in the cases evaluated at the Trinec Power Station. A similar process of elimination of potential alternatives occurred with Trinec, with the selected cases depicted according to the associated plant/boilerhouse as shown in Exhibit 8.

A pressurized FBC (PFBC) was added to the Trinec options. An advantage of the PFBC is that a much higher electricity to heat ratio is a characteristic of the cycle. It is comparable to a gas turbine combined cycle, except that coal is the fuel.

Exhibit 8: OPTIONS CHOSEN FOR TRINEC ANALYSIS

Case	Title	Boiler K11	Boiler K12	Boiler K13	Boiler House EII
1	Base Case	Circulating FBC in 1995	Circulating FBC in 1997	Reconstruct in 1997	Cupola gas to EII in 1997
2	Fuel Switch	Base	PC-Fired in 1997	Base	Base
3	Duct Sorbent Injection (DSI)	Base	DSI (to PC-Fired) in 1997	DSI (to PC-Fired) in 1997	Base
4	Pressurized FBC	Base	Base	PFBC in 1997	Base
5	Small Waste Gas-Fired Gas Turbine,	Base	Base	Base	

A steam supply model unique to Trinec was created and used to evaluate fuel requirements and emissions for three different Steelworks scenarios. The results were transported to an economic model where net present worth of revenue calculations were made.

A steam demand model was not required for the Trinec analysis, since Trinec supplied the steam demand projections directly, and in a form that did not necessitate the creation of an additional model.

ECONOMIC ANALYSIS: TRINEC

An analysis similar to Nova Hut is being conducted for Trinec. The same basic assumptions were made. Fuels unique to Trinec are used in the economic analysis. While similar results are expected, the introduction of the PFBC case to Trinec should yield interesting results, considering the high electrical output, derived from less expensive, indigenous fuels.

CONCLUSIONS AND RECOMMENDATIONS: NOVA HUT

Conclusions and recommendations were developed for Nova Hut and divided into three areas: Economic Analysis results, Technical Analysis results, and General Recommendations. Conclusions for Trinec are forthcoming, and will be published in the Trinec final report.

Economic Analysis

1. A customized economic model has been developed, which provides the capability to analyze a variety of economic factors such as individual commodity escalation, currency exchange differences. This model, along with the technical model, will be handed over to the Czech people to allow the further refinement of the scenarios and different assumptions.

2. Assuming the three proposed steelworks scenarios investigated encompass the most probable range of outcomes, the smaller Waste Fuel-Fired Gas Turbine Case (Case 3) is superior to all other cases evaluated. The primary reason is that electric sales are significantly higher than non-gas turbine cases, and natural gas fuel is not required to meet fuel requirements of the gas turbine, as with Case 4 (W251 Waste Fuel-Fired Gas Turbine).

3. Duct Sorbent Injection (DSI), (Case 5) while second to the gas turbine-based cases, provides a good degree of flexibility in allowing the purchase of lower quality coals. DSI is particularly suitable to Boilers 3, 5 and 6 which have long duct lengths between the boiler and newly installed baghouses.

4. The effect of capital cost associated with each case was diminished by the comparatively large cost of operation.

5. The impact of escalation was evaluated for each case by removing all escalation factors and it was determined that escalation of purchased and sold commodity prices does not alter the relative position of the cases.

6. Pricing of commodities which cross the boundary between the Power Station and the Steelworks needs to be re-evaluated in light of rapidly changing economics and needs to be associated with the true cost to produce the commodity, as well as the market price of alternative sources.

Technical Analysis

1. Two computer models have been developed in order to assist in the technical analysis of the energy supply alternatives. The first model, the steam demand model, determines the high pressure steam requirement by modeling the primary equipment and the required steam, air and heat commodities. The second model, the steam supply model, determines the specific fuel usage, quantities of feed stock and waste streams, total plant emissions, unit emission levels over the regulation limits, gas turbine electric generation, for use in the economic model. Both models will be given to Nova Hut to assist them in future work.

A gas surplus is possible for all technology options except the large gas turbine case.

2. Gas turbines offer the ability to generate additional electricity with the increased supply of gas. Gas turbines also either reduce or eliminate the potential to have unutilized or surplus gas. Nevertheless, it is prudent to retain the ability to use the firedamp and converter gas in the existing boilers for periods when the gas turbine is out of service.

3. The use of high sulfur coke oven gas in boiler K4 results in exceeding the current regulation limit. It may be necessary to add gas cleanup equipment, to use some other clean fuel for stabilization in K4, or to evaluate/propose an emissions averaging scheme across all Nova Hut units..

4. Although an FBC boiler is not required in order to meet the current emission limits with the current fuel, the utilization of an FBC adds to the fuel flexibility, and is more likely to remain in compliance should the emission regulations become more restrictive or are interpreted differently in the future.

5. Since meeting an increased demand of district heat will result in the generation of additional electrical energy by causing an additional quantity of steam to flow through the steam turbines, it is recommended that the potential to supply district heating to the following areas be pursued further:

   - The town Vratimov and the coal mine Paskov.
   - Radvanice and Silesian Ostrava.
   - The town of Havírov.

6. It is recommended that more a detailed analysis should be performed to assess the effects of the following operational areas:

   - Boiler and gas turbine outages,
   - Daily load fluctuations,
   - Control upgrade requirements,
   - Utilization /blending of waste gas, and
   - The potential of long term fuel contracts to insure an adequate supply of coal and gases.

7. Numerous meetings were held with Nova Hut plant personnel, independent analysis was conducted, and several discussions were held with a U.S. steel plant, of a size similar to Trinec, which utilizes major equipment from 50 to more than 80 years old. Some observations were made which led to conclusions appropriate for the Nova Hut plant as follows:

   - Decisions to refurbish or replace equipment must be made on an economic basis, based on the true physical condition of the equipment rather than the current pre-set guidelines for refurbishment/replacement.
   - The large amount of data that is collected and stored must be systematically analyzed to determine cost effective maintenance procedures.
   - Spare parts inventory decisions need to be integrated with the entire maintenance program, employing techniques such as failure modes and effects analysis (FMEA).
   - Plant energy audits, including heat and mass balances should be conducted every year. Boiler efficiencies should be regularly checked.

- State of the art diagnostic equipment should be used routinely including infrared cameras, vibration meters, x-ray analyzers, chemical analyzers, hardness and thickness gauges, combustion analyzers, gas chromatograph, spectrograph, grain boundary check equipment, thermography, etc.

General Conclusions/Recommendations

1. Nova Hut power station personnel are aware of many of their needs, but just now, under the second "wave" of privatization, are they squarely faced with the prospect of becoming a truly market oriented entity. Near-term decisions related to expansion of the facility are now very important and will directly impact the viability of the power station as a "profit center." Even the decision to add capacity in any form needs to be carefully evaluated.

2. Favorable long-term commodity contracts should be negotiated where possible to reduce the risk inherent in the changing economy.

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PROGRESS IN EMISSION REDUCTION AND HEATING SYSTEM MODERNIZATION IN CESKY KRUMLOV

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A computer spreadsheet model has been developed for analyzing the costs and emissions of a city's boiler houses and home stoves. Through the use of the model, city officials are able to analyze their energy situation in an effective manner and make decisions on fuel choices. The model has been used by the town of Cesky Krumlov in the Czech Republic and the city of Krakow, Poland.

The model requires data on a city's boilers, particularly their sizes and annual fuel consumption. This information is obtained from a survey of the boilers by municipal officials. The numbers and types of home stoves are also estimated. From these data, the model estimates the capital cost and annual cost of heating the city in the present situation. It also estimates the emissions of particulate, SO_2, NO_x, CO, and volatile organic compounds. The model can then be used for analyzing the potential effects on costs and emissions of various scenarios, such as changes of fuel, installing new boilers, and adding pollution control equipment.

INTRODUCTION

Cesky Krumlov is a town with important historic structures which is located approximately 150 km south of Prague. The town of Cesky Krumlov depends on tourism for its economic well being. There is no heavy industry near the center of the historic town and no power plants nearby. Energy for heating is provided mainly by coal and natural gas. About one third of the town's heating energy comes from the Energoblok coal-fired fluidized bed district heating facility. Another third comes from natural gas. The remaining third is mainly from coal-fired boiler houses and home furnaces. Since this coal combustion at the boiler houses and home furnaces is generally done without pollution control equipment, there are problems with emissions of organics and particulate.

Hundreds of thousands of tourists come to the town each year, and it is essential to keep the buildings clean and beautiful. This will require reducing particulate emissions from coal combustion, which causes soiling problems.

DOE has been working with local officials since 1992, helping to analyze the various heating options and evaluate their costs and emissions. The DOE Cesky Krumlov project is under the direction of Mr. Peter Muchunas, Deputy Director of the Coal Combustion, Coal Preparation and Control Systems Division. He has traveled to the Czech Republic several times and met with the Cesky Krumlov officials to arrange for the program. Dr. Jerry Shang, a fluidized bed combustion expert in the Division has also visited Cesky Krumlov as part of the program and arranged for technical visits to U.S. facilities.

AEA O'Donnell Inc. has assisted DOE in the analysis of the Cesky Krumlov situation. Dr. Robert Hershey, the AEA O'Donnell project manager, has traveled to Cesky Krumlov and worked with local people in analyzing their energy options.

Mr. Edvard Barta managed the Cesky Krumlov boiler survey and analyzed local heating options. Dr. Milan Marko, an engineer and attorney, has visited U.S. fluidized bed combustion facilities and arranged for emissions testing at the Energoblok fluidized bed in Cesky Krumlov.

Cesky Krumlov conducted a comprehensive study of the trade-offs of costs and emissions for the town. The study included extensive analysis of coal usage by boiler houses and home furnaces. At the beginning of the project, in January 1992, a DOE team went to Cesky Krumlov and observed the combustion equipment in operation. With DOE assistance, the local project team looked at the possible introduction of various modern technologies, including fluidized bed combustion and advanced particulate control equipment. The study also compared the costs and emissions to other alternatives, such as substituting natural gas for coal.

SPREADSHEET MODEL

Under DOE sponsorship, a computer spreadsheet model has been developed for analyzing the costs and emissions of Cesky Krumlov's boiler houses and home heating units. Through the use of the model, town officials are able to analyze their energy situation in an effective manner and make decisions on fuel choices. This type of spreadsheet model had also been used by the city of Krakow, Poland in a previous DOE study.

The structure of the spreadsheet model is shown in Table 1. The model can be used for analyzing the potential effects on costs and emissions of various scenarios, such as changes of fuel, installing new boilers, and adding pollution control equipment. The model calculates annual costs, capital costs, and emission levels for the boiler houses and home furnaces in the city. It also calculates the costs for utility support of any augmentation to the use of natural gas.

The model requires data about the town's boilers, particularly their sizes and annual fuel consumption. For Cesky Krumlov, this information was obtained from a survey of the boilers by Mr. Barta's group at the local district heating company. They also estimated the numbers of home heating units of various types. The project team analyzed the boiler house survey data and constructed the model, based on the observed boiler characteristics. This included spreadsheet modeling of the economics of coal, district heating, and natural gas usage.

An important feature of the model is the use of free market energy pricing. In the past four years the countries of Eastern Europe have been trying to reduce their household energy subsidies and bring prices into line with the rest of Europe. This is helping to stimulate investment and encourage more efficient use of energy resources. It is expected that in the next several years the consumer prices of electricity and natural gas will rise to the levels in Western Europe. Any investment in new equipment should be based on these free market prices, since they will be in effect for most of the equipment life.

The model includes estimates of the capital cost and annual costs of all combustion equipment and home heating equipment. When no local capital cost data are available, the estimates are derived from the capital costs of similar U.S. equipment. This is done by multiplying the U.S. capital cost by a "domestic fabrication factor" of 0.4. This accounts for the fact that labor rates are lower in Eastern Europe, and a unit which costs $100,000 to build in the U.S. might cost only $40,000 in Eastern Europe.

The annual operation and maintenance cost (O&M) is generally estimated at 5% of the capital cost in the model unless some better data are available.

For Cesky Krumlov, the model estimated the capital cost and annual cost of heating the town, based on the equipment and fuels used. It also estimated the emissions of particulate, SO_2, NO_x, CO, and volatile organic compounds. The analyses pointed out that particulate and organics emissions are the main problems. The model showed how these problems can be solved and how much it would cost. In particular, the analysis showed that substantial particulate reduction could be achieved by adding an electrostatic precipitator (ESP) or a baghouse at the Energoblok fluidized bed combustion facility.

SURVEY OF HEATING EQUIPMENT

The boiler houses of Cesky Krumlov were surveyed as part of the project. This survey was performed in 1992 by the Cesky Krumlov district heating company. The results of the survey are shown in Table 2, along with the resulting estimates of the emissions at that time. The main coal combustion is at the Energoblok facility, which has 3 fluidized bed combustion units. There are also 62 boiler houses in Cesky Krumlov. Most boilers use natural gas, but 44 are coal or coke boilers. Of these, 8 are traveling grate coal units. The other 36 coal and coke boilers are hand-fired units. There are also 14 oil boilers and 7 wood waste boilers. Almost all the wood waste is scrap burned at the Lira Domoradice frame factory.

The data surveyed for each boiler included:

- Description
- Survey Number
- Boiler Number
- Type (Trade Name or Model Number)
- Stoker or Hand-Fired
- Design Capacity in kW
- Efficiency (%)
- Fuel (annual tonnes)

On the basis of the fuel usage and the boiler type, we were able to estimate the emissions of SO_2, particulate, CO, organics, and NO_x for each boiler category. Emissions factors were based on DOE's testing program in Krakow, Poland. The resulting emissions estimates are shown in the five columns on the right of Table 2.

TABLE 1. STRUCTURE OF THE SPREADSHEET MODEL

	Million Btu/yr Input	Fuel Cost	Capital Cost in Czech Republic	Annual O & M Cost	Annual Fuel tons	Annual tons SO_2	Annual tons Particulate	Annual tons CO	Annual tons Organics	Annual tons NO_x
COAL BOILERS *COKE BOILERS* *WOOD WASTE BOILERS* *NATURAL GAS BOILERS* *OIL BOILERS*	Energy Input	$	$	$	Fuel	Emissions Tonnage				
HOME COAL HEATING *HOME GAS HEATING* *HOME ELECTRIC HEATING* **TOTALS: BOILER HOUSES AND HOMES**	Energy Input	$	$	$	Fuel	Emissions Tonnage				
NATURAL GAS SUPPLIED BY UTILITY **TOTALS: UTILITY**		$	$	$	Fuel					

TABLE 2. CESKY KRUMLOV FUEL USE AND EMISSIONS ESTIMATES

	Number	Total Design MW	Million Btu/yr Input	Annual tons SO2	Annual tons Particulate	Annual tons CO	Annual tons Organics	Annual tons NOx
Boiler Houses								
Energoblok	3	55.800	344,535	988	1,012	220	1	34
Stoker Coal Boilers	7	8.330	32,928	86	123	13	0	7
Hand–Fired Soft Coal Boilers	28	7.390	32,151	60	113	112	1	6
Hand–Fired Black Coal Boilers	3	3.360	1,977	4	7	0	0	0
Stoker Coal Boilers with PCEs	1	2.900	13,952	37	2	6	0	3
Hand–Fired Coke Boilers	5	1.091	13,613	9	11	25	0	1
Wood Waste Boilers	7	6.830	47,624	0	12	295	4	10
Natural Gas Boilers	380	62.265	307,817					31
Distillate Oil Boilers	14	6.018	18,648	17	1	0		2
Total for all B.H.	448	153.984	813,246	1,199	1,280	672	7	94
Home Heating								
Present Coal Stoves	533	1.066	13,340	25	22	47	1	1
Natural Gas Stoves	93	0.186	1,995					0
Electric Heating	200	0.800	6,007					
Coal Boiler for Building	371	9.275	116,070	216	189	405	5	9
Oil Boilers for Flats	55	0.605	6,057	5	0	0		
Gas Boilers for Flats	83	0.913	9,793					1
Total for all Homes	1,335	12.845	153,263	246	211	451	6	11
Total for all B.H. and Homes		**166.829**	**966,509**	**1,445**	**1,491**	**1,123**	**13**	**105**

BOILER HOUSES AND HOME STOVES

The project team visited all three boiler houses in Cesky Krumlov which have coal stokers. These boiler houses have a total of 8 boilers with traveling grate stokers similar to those used in Krakow.

Plesivec 1st

This is the largest coal boiler house in Cesky Krumlov. It is currently owned and operated by the town government. Its four boilers have a combined capacity of 5.6 MW. One of the boilers - a 2.9 MW unit is equipped with a cyclone. The other three units, totalling 2.7 MW have no particulate control. In 1992, Cesky Krumlov officials were considering whether to replace these three units with a fluidized bed coal boiler or with natural gas. They decided on natural gas, and the new unit is expected to be in operation in November 1994.

Cheese Production Plant

The boiler house at this plant had two 1.86 MW traveling grate stokers in 1992, when our study was done. In 1993, the operators of the plant acquired natural gas boilers and scrapped the coal boilers.

Otavan Clothing Factory

This boiler house at the Otavan clothing factory has two boilers with a combined capacity of 1.91 MW. Besides coal, they burn scrap cloth from the factory.

Hand-Fired Boiler

We also visited the Tavirna 108 boiler house, which is located in the basement of the boarding house it serves. In 1992, it had a typical hand-fired coal boiler with 200 kW of capacity. The boiler room was modified to burn natural gas in the beginning of 1994.

Home Furnaces

On the basis of their heating data, Mr. Barta and his associates made estimates of the population of home heating units. The boiler house survey and home heating estimates provided sufficient data for development of the spreadsheet model of Cesky Krumlov energy costs and emissions.

The composition of the population of coal home furnaces in Cesky Krumlov is much different from that in Krakow. Our 1992 study estimated that there were only 533 home stoves in Cesky Krumlov, with a combined capacity of about 1 MW. Almost all of these are made of iron or steel, rather than ceramic material.

We estimated there were 371 metal home furnaces, each one used for the hot water radiator system of an entire flat, as well as the hot water heater. These metal furnaces probably have a combined capacity of about 9 MW. We visited two homes that had these furnaces and obtained copies of the manufacturers' specifications.

Our 1992 study estimated there were about 200 electric heaters in Cesky Krumlov with an average capacity of 4 kW each. Some of them are storage-type electric heaters. They store the heat and release it into the room at an increased rate when their fan is turned on.

FLUIDIZED BED BOILER FACILITY

The Energoblok facility located north of Cesky Krumlov has three fluidized bed boilers of 18.6 MW each. Energoblok also has a 6.5 MW gas boiler. The facility burns lignite with a heating value of 9,100 kJ/kg (3,900 Btu/lb), an ash content of 43%, a sulfur content of 1.4% and a moisture content of 34%. The facility is owned by Jihostroj, a machinery company, which has recently been privatized. They sell heat to TEZA, who in turn sells it to the district heating customers.

The Energoblok facility has the steam production capability to make much more steam than can be sold to district heating customers. In 1992, it was estimated that Energoblok produced approximately 264,000 GJ (250,000 million Btu) of heat, of which about 24,000 GJ (23,000 million Btu) went directly to the Jihostroj machinery factory. The remaining 240,000 GJ (228,000 million Btu) was sent to the heat exchangers.

In 1992, we estimated that the steam suffered about 25% losses, which amounted to 60,000 GJ (57,000 million Btu), in going from Energoblok to the heat exchangers. Since that time Cesky Krumlov has succeeded in reducing these thermal losses to 18%.

After the heat exchangers there was 180,000 GJ (171,000 million Btu) left, which was sold to the customers. The sales were split approximately equally between high-rise apartment buildings and other customers. About 90,000 GJ (85,000 million Btu) was sold to high-rise apartment buildings and 90,000 GJ (85,000 million Btu) was sold to other users, such as schools, factories, and small apartment buildings. Since our 1992 study, the charges for district heating have been reformed. In 1992, customers had been charged on the basis of their square meters of floor area, but

now they are charged on the basis of heat actually consumed. The price of heat now includes a surcharge of 5% for the heat losses in reaching the customer's radiator.

When we did this study in 1992, Energoblok was burning about 40,000 tonnes (44,000 tons) of lignite per year which had a heating value of 3,907 Btu/lb. Thus the input energy was 363,000 GJ (335,000 million Btu). At that time. the efficiency was approximately 73%. In 1993, Cesky Krumlov began building a central heating plant control system. This system will have a control system from Allen Bradley, a unit of the American firm Rockwell International. The system is expected to be completed in 1994.

Under our 1992 project, DOE also worked with the officials of Cesky Krumlov to arrange for combustion testing at Energoblok. The testing was conducted by INPEK, a Prague consulting firm. The work was led by Dr. V. Hepnerova. Messrs. Petr Heppner, Vojtech Trs, P. Kostal, and Jiri Vanek performed the testing. The tests at Energoblok showed that SO_2 emissions can be reduced if limestone is added to the coal burned in the fluidized bed.

These test data were useful when Energoblok added pollution control equipment in 1993. They put in an ESP and installed new equipment for SO_2 reduction through adding limestone to the fluidized bed. The recent construction at Energoblok included limestone storage areas and transport lines.

The construction of the ESP and the SO_2 control equipment resulted in dramatic emissions reductions. The annual particulate emissions were reduced from 1,012 tons in 1991 to 10 tons in 1994. The SO_2 emissions went from 988 tons in 1991 to 325 tons in 1994.

COMPARISON OF SCENARIOS

On the basis of the survey data, the spreadsheet model was used to analyze various scenarios. A summary of the results is presented in Table 3, which is entitled "Comparison of Various Cesky Krumlov Scenarios." For each of the five scenarios, the table presents estimates of capital costs and annual costs, as well as emission levels for SO_2 and particulate. Note that the costs are rounded to the nearest $100,000.

The scenarios show a wide range of choices. They vary in cost and in their degree of particulate reduction. Switching to natural gas is expensive when users buy gas at free market prices, such as prevail in Western Europe. The current natural gas prices in the Czech Republic are artificially low because of subsidies. We analyzed technologies for burning coal more cleanly and found that they will cost less in the future than switching to natural gas.

Scenario #0 Present Situation

Scenario #0 presents the "Present Situation," of the Cesky Krumlov heating configuration as it was in 1992. There were 1,445 tons of SO_2 and 1,491 tons of particulate emitted each year in the Cesky Krumlov area. Most of these emissions came from Energoblok, which gave off 988 tons of SO_2 and 1,012 tons of particulate. However, these emission tonnage numbers overstate the pollution contribution of Energoblok, because it is more than a mile away and the wind usually blows the pollution away from Cesky Krumlov. Nevertheless, the figures showed that the energy usage and emissions of Energoblok are a big part of the picture. The spreadsheet also showed the importance of the emissions of the eight stoker-fired coal boilers, which are estimated to contribute 123 tons of SO_2 and 125 tons of particulate annually.

In terms of costs, the spreadsheet shows how expensive natural gas is likely to be when Cesky Krumlov's prices rise to the levels of Western Europe. Of the $4.3 million that would be paid annually by users for fuel at free market prices, $2.9 million would be for natural gas, even though gas provides only one third of the energy.

Scenario #1 Baghouse at Energoblok

Scenario #1 involves adding a baghouse or ESP to Energoblok, which would increase particulate removal efficiency to 99.9%. This is estimated to increase the capital cost of Energoblok by about $0.5 million. Note that this would have a major effect on the area's particulate emissions, reducing them by 1,008 tons. Cesky Krumlov would see some benefit from this reduction, even though much of the particulate is currently blown elsewhere.

Scenario #2 Gas Replacement

Scenario #2 envisions replacing some coal-fired boilers in flats with natural gas boilers. This would be expensive to the users in the capital cost of buying gas furnaces. They would also have high annual costs to buy the gas, when Czech gas prices rise to free market levels. Particulate and SO_2 are reduced, but at a very

TABLE 3. COMPARISON OF VARIOUS CESKY KRUMLOV SCENARIOS

Project	Capital Cost $ million	Annual Outlay $ million	Total SO_2 tons	Total Particulate tons	SO_2 tons Removed	Particulate tons Removed
#0 Present Situation	4.3	5.2	1,445	1,491	0	0
#1 Baghouse at Energoblok	4.9	5.3	1,445	483	0	1,008
#2 Gas Replacement	4.7	6.0	1,230	1,303	215	188
#3 Electric Power Production	11.6	4.4	1,939	485	(494)	1,006
#4 Fluidized Bed at Plesivec 1st	4.4	5.2	1,432	1,447	13	44
#5 Improved Efficiency at Energoblok	4.4	5.2	1,359	1,402	86	89

TABLE 4. EMISSION REDUCTION COSTS UNDER CESKY KRUMLOV SCENARIOS

Project	Interest & Depreciation Cost/yr $ million	Annual Outlay $ million	Combined Cost/yr $ million	Added Cost/yr $ million	$/ton SO_2 Removed	$/ton Particulate Removed
#0 Present Situation	0.8	5.2	6.0	0.0	---	---
#1 Baghouse at Energoblok	0.9	5.3	6.2	0.2	---	225
#2 Gas Replacement	0.9	6.0	6.8	0.9	3,992	4,563
#3 Electric Power Production	2.1	4.4	6.6	0.6	---	593
#4 Fluidized Bed at Plesivec 1st	0.8	5.2	6.0	0.0	324	96
#5 Improved Efficiency at Energoblok	0.8	5.2	6.0	0.0	61	59

high cost per ton. There would also be a slight increase in NO_x, approximately 1 ton per year.

Scenario #3 Electric Power Production

Scenario #3 involves adding electric generating equipment and an ESP or baghouse to Energoblok. This could produce $2.6 million in revenue for Energoblok each year if the electricity can be sold for $0.07 per kWh. The capital cost investment is estimated to be about $7.2 million. In this scenario, an ESP or baghouse is added to Energoblok along with the steam turbines and generators. As a result, particulate is reduced by 1,006 tons per year even though coal consumption at Energoblok is increased by 50%.

Scenario #4 Fluidized Bed at Plesivec 1st

The fourth Scenario involves replacing 2.7 MW of boiler capacity at the Plesivec 1st boiler house with fluidized bed combustion. By present cost estimates, advanced combustion boilers have high capital costs, but they reduce SO_2 and particulate.

Scenario #5 Improved Efficiency at Energoblok

The fifth scenario involves modification of the combustion system at Energoblok and improving its efficiency from the present level of 73% to a new level of 80%. It is assumed that the capital cost to accomplish this would be about $100,000. Our observations at Energoblok indicated that better instrumentation and controls for the air-to-fuel ratio might contribute to efficiency improvement.

Our analyses of these five scenarios calculated the annual costs, capital costs, and emission levels for the boiler houses and home furnaces in the town. We also calculated the costs for utility support of any augmentation to the use of natural gas.

EMISSION REDUCTION COSTS

In Cesky Krumlov the main emission problem is particulate from coal combustion. Particulate causes health problems and it also soils buildings and other structures. Coatings of particulate make structures look dingy and can eventually cause surface erosion. In an area like Cesky Krumlov, whose economy depends on tourists visiting historic structures, this becomes a major problem. Clearly, particulate must be reduced in an economical manner.

Table 4 compares the costs of the five scenarios and their emissions reductions. The first column of figures is titled "Interest and Depreciation Cost/yr." Its entries are computed from the corresponding capital cost entries in Table 3. In this computation, the real interest rate in the Czech Republic is assumed to be 15%. Then, the annual interest is 0.15 times the User Capital Cost. The depreciation comes from assuming a 30-year life and straight line depreciation. Thus, the annual depreciation is the capital cost divided by 30. This is equivalent to multiplying it by 0.0333. Adding together the 0.15 factor and the 0.0333 factor gives a combined factor for interest and depreciation of 0.1833. This is the factor to annualize the capital cost and come up with an annual fixed cost for interest and depreciation.

The second column of figures is "Annual Outlay." It simply repeats the "Annual Outlay" figure from Table 3 for each scenario. The third column is "Combined Cost/yr." It is the sum of the first and second columns. This adds the fixed cost and the outlay to come up with a combined annual cost for each scenario.

The fourth column is the "Added Cost/yr." This is the cost above the User Combined Cost for Scenario #0, which is the Present Situation.

The fifth column of figures is "$/ton SO_2 Removed." This compares the cost and SO_2 level to the present situation. The figure shown is the User Added Cost from the fourth column divided by the SO_2 tons removed. The last column does the same $/ton computation for particulate removal.

In comparing of the cost and the SO_2 and particulate emission estimates for the scenarios, it is apparent that there is a wide range of $/ton values. These cost/ton figures vary by orders of magnitude.

CONCLUSIONS

Use of the DOE spreadsheet model has provided insights into the costs and emissions of various energy options. It has pointed out the importance of Energoblok to Cesky Krumlov's energy future and the emissions in the area. DOE assisted Cesky Krumlov in arranging combustion tests at their Energoblok fluidized bed combustion plant. On the basis of this study, Cesky Krumlov moved forward to install an ESP, SO_2 reduction equipment, and a control system at Energoblok. The town leaders of Cesky Krumlov have taken appropriate steps to provide energy more cleanly and more economically.

IMPROVING ENERGY EFFICIENCY IN HANDLOVA, SLOVAK REPUBLIC

Peter Sestak, EGU Bratislava, Andrew Popelka, Tecogen, Thomas Secrest, Pacific Northwest Laboratory, Jaroslav Izak, Mayor of Handlova.

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Introduction

The Town of Handlova in the Slovak Republic is considering options for providing energy services to its citizens. The existing Central Heating Plant is at the end of its useful life and must be replaced. The Town is evaluating alternative solutions to providing its citizens with thermal energy at the lowest possible cost and at the lowest pollution level from available energy sources.

This report documents the assessment of the buildings sector efficiency resource and performs analyses of alternative solutions of heat supply available for the Town of Handlova, and evaluates their technical, economic, and environmental merits. It analyzes the alternatives with respect to the cost of delivered thermal energy to the user.

This project was made possible by the US Agency for International Development (US AID). US AID provided funding through the Department of Energy, Office of Energy Efficiency and Renewable Energy, which contracted Battelle, Pacific Northwest Laboratories (PNL) to manage and technically direct the project. The analyses of the demand side and the supply side were performed by the Energy Research Institute (EGU), Bratislava and by the US-based company, Tecogen.

PART 1 – AN ASSESSMENT OF THE BUILDING SECTOR EFFICIENCY RESOURCE

The baseline energy use characterization segments the residential and non-residential building stock into individual building types and estimates the space and water heat energy consumption by each building type, fuel type, and equipment type. The efficiency potential is then estimated for each building, fuel, and equipment type based upon cost-effectiveness criteria.

Residential Sector

The residential sector was then divided into the following seven representative residential building types:

Res-1	Apartment Buildings 2 to 3 floors (1951-1952)
Res-2	Apartment Buildings 3 to 7 floors (1954-1957)
Res-3	Pre-fab Buildings T 06 B (1968-1984)
Res-4	Pre-fab Buildings (1962-1965)
Res-5	Pre-fab Buildings P1-15-NKS (1982-1991)
Res-6	Two family detached houses
Res-7	Single family detached houses

The survey indicates that the town of Handlova has 336,975 m^2 of residential heated area, out of which approximately 27% of floor space is in brick apartment buildings from the 1950's (Res-1&2), 49% in the pre-fab multi-family housing (Res-3-5), and the remaining 24% in detached single and two family houses.

Non-Residential Sector

The seven building types identified in the non-residential sector are as follows:

NonRes-1	Education (primary schools, dormitory)
NonRes-2	Culture
NonRes-3	Health Facilities (including nursery schools)
NonRes-4	Sport facilities
NonRes-5	Office/Administration
NonRes-6	Services and Retail
NonRes-7	Accommodation, Hotels

Data limitations coupled with time and budget limitations did not permit a comparable characterization of the non-residential building stock.

In addition, each of the non-residential building types alone represent a very small fraction of the total energy consumption (maximum 3.5%) and all types of buildings in this sector combined represent less than 20% of the total energy consumption.

Industrial Sector

The industrial sector in Handlova is represented by the following firms: Coal Mine Handlova, including garages, Slovenka, Lahke Universalne Konstrukcie, AMK, Chemika,

CSD station and State Agricultural Farm. The thermal energy is used only for space and water heating. Technological use of thermal energy is negligible. Except for the Coal Mine Industry, this energy demand sector is relatively small and was not characterized in detail because of the time and budget limitations of the project.

ENERGY CONSUMPTION BY SECTORS

Nearly 62% of the net delivered energy (fuel input less losses in conversion and transit) is consumed by the residential sector. More detailed energy consumption data are presented in the following subsections. Industrial consumption represents about 19% and the non-residential sector also about 19%. District Heat is the major energy source for space and water heating, representing 79.6% of total energy consumption (see Table 1).

DEMAND FORECAST

This section develops the three variants for energy demand growth used for the study. Assuming a 25 year life for the heat supply equipment to be built by 1997, the energy demand was projected to the year 2022. Forecast scenarios are summarized in Table 2.

FUEL	SECTORS			TOTAL	
	Residential GJ/year	Non-Residential	Industrial GJ/year	GJ/year	%
LOCAL					
Coal	29,599	0	0	29,599	5.2
Gas	66,950	50	0	67,000	11.9
Electric	1,200	1,684	0	2,884	0.5
BOILER HOU.					
Coal	0	11,080	0	11,080	2.0
Gas	0	4,737	0	4,737	0.8
DISTRICT HEAT	251,033	92,054	107,671	450,758	79.6
TOTAL	348,782	109,605	107,671	566,058	100
%	61.6	19.4	19.0	100	100

Table 1. Energy End Use by Sectors and Fuels

GJ/yr	Load Variant 1		Load Variant 2		Load Variant 3	
	MWt	GJ/yr	MWt	GJ/yr	MWt	GJ/yr
Residential Sector	30.32	251,033	30.32	251,033	30.32	251,033
Population Growth	---	---	1.58	11,268	3.40	24,247
Non-Residential Sector	11.12	92,054	11.12	92,054	11.12	92,054
New Customers (Residential and Non-Residential)	---	---	8.2	68,024	8.20	68,024
Industry	---	---	12.80	107,671	12.8	107,671
Industrial Growth	---	---	---	---	2.56	23,287
TOTAL	41.44	343,087	64.02	530,050	68.40	566,316

Table 2. Demand Forecast Scenarios, Year 2022

Variant 1:

This variant assumes no change in thermal energy demand in both the residential and non-residential sectors and assumes detachment of the industrial sector from the District Heating system.

Under this variant, energy demand will, for space heating and water heating in both the residential and non-residential sectors, remain on the 1992 level of 458,387 GJ/Year. This variant represents the lowest possible energy demand.

Variant 2:

This variant was based on the Urban Development Plan for the Town of Handlova performed by AGS Atelier for the Town Hall in 1993. This study predicted the town population would increase from 18,332 in 1992 to 19,500 in year 2010. By extrapolating the growth curve at a somewhat cautious rate, the town population was predicted to be 19,750 in 2022. This is a population increase of approximately 1400 persons, or 5.22%. Industrial activity in this variant was assumed to stay at the 1992 level with no increase in thermal energy demand. Under these assumptions, energy demand for space heating and water heating would increase by 18,206 GJ, or 3.22% of the town energy demand in 1992. Increase in District Heating Demand is assumed 11,268 GJ, or 4.5%.

Variant 3:

This variant assumed greater population growth and increased industrial activity. Population growth was assumed to be 6% greater than predicted in Variant 1, for a total increase of 11.22%, or 2057 persons. Industrial thermal energy demand was assumed to grow by 20% from the 1992 level. For this variant, energy demand for residential space heating and water heating would increase by 39,133 GJ, or 6.91%, and industrial thermal energy demand would increase by 21,534 GJ, or 3.80%. Total energy demand would increase by 60,667 GJ, or 10.71% of the total demand in 1992. The District Heating Demand would increase by 24,247 GJ (4.28%) due to population growth, and 23,287 GJ (4.11%) due to industrial growth.

BUILDING SECTOR EFFICIENCY ASSESSMENT

Fifty energy conservation opportunities (ECOs) were considered for evaluation for the residential and non-residential building stock in Handlova. Of these, 24 ECOs were determined to be applicable to more than one building group and were analyzed with respect to energy efficiency potential, cost, and availability on the Slovak market.

Table 3 summarizes the 24 efficiency measures considered by cost-per-unit of application and measure lifetime.

Number	Energy Saving Option Description	Unit	Cost (SK/Unit)	Lifetime (Years)
	Building Envelope			
1	Insulate Exterior Side Walls	m^2	700 - 800	30
2	Insulate Top Floor Ceiling	m^2	700	30
3	Insulate Attic	m^2	385	30
4	Insulate Floor Above Basement	m^2	120	30
5	Weatherstrip Elevator Penthouse, Stairway, Doors and Windows	m	40	10
6	Weatherstrip Doors and Windows	m	40	10
7	Install Revolving or Double Door in Building Vestibule	Unit	30,000	30
8	Install Triple Pane Windows	m^2	5409	30
9	Install Storm Windows	m^2	600	30
10	Install Heat Reflectors Behind Each Radiator or Heater	m^2	148	5
11	Remove Draperies from Radiator		0	
	Domestic Water Heating			
12	Install Low-Flow Water Heads	Unit	250	10
13	Install Flow Restrictors in Faucets	Unit	70	5
14	Insulate Hot Water Pipes in Unconditioned Spaces	m	158	15
15	Install Hot Water Flow Meters	Unit	900	30
	Heating System			
16	Balance Heating System Using Existing Valves	Flat	400	5
17	Install Balancing Valves on Each Radiator	Unit	350	15
18	a. Install Thermostatic Radiator Valves	Unit	650	15
	b. Install Heat Allocators/Meters	Unit	100	1
	c. Install Building Level GJ Meter	Unit	10-40000	30
19	a. Install Zone Valves on Each Radiator	Unit	330	15
	b. Install Central Thermostats with On-Time Counter in Each Flat	Unit	2300	15
	c. Install Building Level GJ Meter	Unit	24-46000	30
20	a. Install Zone Valves on Each Radiator	Unit	330	15
	b. Install Central Programmable Thermostats with On-Time Counter in Each Flat	Unit	6120	15
	c. Install Building Level GJ Meter	Unit	24-46000	30
21	Install Building Energy Management System (EMS)	Unit-Rad.	7000	30
	Ventilation and Heat Recovery			
22	a. Install Heat Recovery Vent System in Basements	Unit	7600	10
	b. Weatherstrip Basement Windows and Doors	m	40	10
23	Install Waste Water Heat Recovery Heat Exchanger	Unit	10200-126000	15
24	a. Install Bath/Kitchen Vent Heat Recovery Heat Exchanger	Unit	9050	10
	b. Install Back-Flow Damper in Kitchen/Bath Vent Duct	Unit	350	15

Table 3. Efficiency Measures Considered and Estimated Per Unit Cost and Lifetime

Analyses of Building Envelope Measures

The ASEAM3 (A Simplified Energy Analysis Method, Version 3.0) computer program for simulating heat losses in buildings based on procedures recommended by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Fundamentals was used for the analysis. The program provides prediction of maximum heat loads, annual energy consumption, and the effect of other factors on building heat loads (occupancy, lighting, appliances usage, insulation, etc.).
Baseline and post-measure installation heat loss was calculated for each measure. The difference between the two heat loss values is the energy savings.

Analyses of Water Heating Measures

Energy saving calculations for low flow shower heads and faucet flow restrictors are based on statistical information regarding the use of hot water in the Czech Republic, statistical information on hot water use by purpose (dish-washing, shower, laundry, etc.), and manufacturers' performance information.

Analyses of Building Heating System

All ECOs analyzed in this category provide improved energy management in the building. The computerized calculations used for the building heating system energy saving measures were also derived from the products recommended by the (ASHRAE) Fundamentals. For each measure, both the baseline and post-measure installation heat loss was calculated. The difference between the two heat loss values is then the energy use reduction.

Analyses of Ventilation and Heat Recovery Measures

The energy saving calculations developed for the heat recovery applications were again derived from procedures recommended by the ASHRAE Fundamentals. Inputs to the calculations include properties and mass flow of media from which the waste heat is recovered, and manufacturers' performance characteristics for the heat recovery equipment.

The ECOs described in the previous section were analyzed in a number of ways, with the intent of presenting a variety of what are called "analyses matrix" for measuring the attractiveness of an ECO as an investment. A number of economic matrices commonly used to evaluate measure effectiveness are present value, net present value, simple payback, and levelized energy cost.

BASE ECONOMIC ASSUMPTIONS FOR ANALYSIS OF EFFICIENCY MEASURES

Nominal Discount Rate	17.5%
Expected Inflation	.0%
Real Discount Rate	.5%
Analysis Period	0 years

ALTERNATE FUEL PRICES

Energy prices are currently subject to some form of regulation and/or subsidy, both of which will be modified in the near future. In addition, district heating systems will either have to be upgraded or replaced by the decentralized system. Each of these alternatives will result in different energy prices. Therefore, the four fuel price levels were developed for investigation of the impact of likely changes in near term energy prices on the energy efficiency resources. This was done in conjunction with staff from the Town, Heating Plant, EGU, ZPZ and SEP. The prices are shown in Table 4.

	FUEL PRICE LEVEL (Sk/GJ)			
FUEL TYPE	Level 1	Level 2	Level 3	Level 4
On-Side Gas	80.00	108.00	150.00	270.00
On-Side Coal	55.00	80.00	100.00	150.00
Electricity	222.00	250.00	300.00	350.00
District Heat	165.00	210.00	270.00	300.00

Table 4. Fuel Price Levels Used to Drive Analysis of Efficiency Resource and Sensitivity Analysis, by Fuel Type

Level 1 represents the current, still subsidized fuel prices. Level 2 corresponds to the removal of subsidies, Level 3 corresponds to a more aggressive and most likely fuel price increase, and Level 4 roughly corresponds to West European absolute and relative fuel prices. At all four levels, the price increases are assumed to happen at the time

of implementing energy conservation technologies. The price of coal is assumed to increase by 2.7% annually over the general inflation rate, the price of gas is assumed to increase by 2.85% over the general inflation rate to the year 2005, and 1.4% annually after that year. The price of electricity is assumed to increase by 6% over the general inflation. Level 3 prices were used for the analysis in this report.

BASELINE EFFICIENCY ASSESSMENT

Table 5 provides the cost-effective space and water heat efficiency resource by residential sector building and fuel type for 1993 using the base economic assumptions and the Level 3 fuel prices.

Bldg Group	Fuel	Baseline Use (GJ)	Percent of Total Use	Cost Effective Savings Potential (GJ)	Cost Effective Savings as Percent of Use	Percent of Total Cost Effective Savings	Levelized Energy Cost ($/GJ)
1	On-Site Gas	13330	3.82%	5789	43.43%	3.93%	100.61
1	On-Site Coal	0	0.00%	0	0.00%	0.00%	0
1	Electricity	0	0.00%	0	0.00%	0.00%	0
1	District Heat	0	0.00%	0	0.00%	0.00%	0
1	Total	13330	3.82%	5789	43.43%	3.93%	100.61
2	On-Site Gas	7260	2.19%	2553	33.51%	1.73%	81.70
2	On-Site Coal	659	0.19%	216	32.78%	0.15%	76.83
2	Electricity	0	0.00%	0	0.00%	0.00%	0
2	District Heat	69819	20.02%	24034	34.42%	16.31%	132.75
2	Total	78098	23.40%	26803	34.32%	18.19%	127.44
3	On-Site Gas	0	0.00%	0	0.00%	0.00%	0
3	On-Site Coal	0	0.00%	0	0.00%	0.00%	0
3	Electricity	0	0.00%	0	0.00%	0.00%	0
3	District Heat	98405	28.22%	49150	49.59%	33.35%	155.97
3	Total	98405	28.22%	49150	49.59%	33.35%	155.97
4	On-Site Gas	0	0.00%	0	0.00%	0.00%	0
4	On-Site Coal	0	0.00%	0	0.00%	0.00%	0
4	Electricity	0	0.00%	0	0.00%	0.00%	0
4	District Heat	23618	6.77%	12146	51.43%	8.24%	132.95
4	Total	23618	6.77%	12146	51.43%	8.24%	132.95
5	On-Site Gas	0	0.00%	0	0.00%	0.00%	0
5	On-Site Coal	0	0.00%	0	0.00%	0.00%	0
5	Electricity	0	0.00%	0	0.00%	0.00%	0
5	District Heat	59191	16.97%	30857	52.13%	20.94%	140.29
5	Total	59191	16.97%	30857	52.13%	20.94%	140.29
6	On-Site Gas	15420	4.42%	3392	22.00%	2.30%	172.17
6	On-Site Coal	400	0.11%	108	27.06%	0.07%	175.30
6	Electricity	0	0.00%	0	0.00%	0.00%	0
6	District Heat	0	0.00%	0	0.00%	0.00%	0
6	Total	15820	4.54%	3500	22.13%	2.38%	172.27
7	On-Site Gas	30580	8.77%	9895	32.36%	6.71%	112.08
7	On-Site Coal	28440	8.16%	9198	32.34%	6.24%	74.07
7	Electricity	1200	0.34%	40	3.33%	0.03%	168.28
7	District Heat	0	0.00%	0	0.00%	0.00%	0
7	Total	60220	17.27%	19133	31.77%	12.98%	93.93
All	On-Site Gas	66950	19.20%	21630	32.31%	14.68%	114.85
All	On-Site Coal	29599	8.46%	9522	32.28%	6.46%	75.29
All	Electricity	1200	0.34%	40	3.33%	0.03%	168.28
All	District Heat	251033	71.99%	116187	46.28%	78.83%	144.60
All	Total	348682	100.00%	147381	42.27%	100.00%	135.76

Table 5. Residential Sector Cost-Effective Space and Water Heat Efficiency Resource by Building, Fuel, and Equipment Type, Using Base Assumptions and Level 3 Fuel Prices

The 147,381 GJ of cost-effective savings represents a 42% reduction in current residential sector energy consumption. This ranges from 3.33% to 43.43% of current use for building groups 1, 6, and 7, and 32.7% to 52.13% of current use for building groups 2 through 5. Residential district heating energy use can be cost-effectively reduced by about 46%, which represents over 78.8% of all of the cost-effective savings. Residential natural gas consumption can be reduced by almost 32%, accounting for almost 15% of the efficiency potential, and coal consumption can be reduced by about 32%, which represents about 6% of the efficiency potential. Residential electricity use can be cost-effectively reduced by 3%, although this represents only .03% of total cost effective savings.

Table 6 provides the economic analysis of the residential sector efficiency resource presented in Table 5.

Full Price Scenario	All Fuels All Building Groups 1993	District Heating Building Groups 2 to 5
Economic Assumptions	Default	Default
Annual Energy Use Reduction [GJ]	147.381	112.411 116.187
Value of Annual [million Sk]	35.6	31.4
Present Value of Energy [million Sk]	529.1	480.2
Total Installed [million Sk]	131.8	114.2
PV of Installed [million Sk]	198.3	166.5
Simple Payback [years]	4	4
Net Present [million Sk]	330.8	313.7
Annualized Cost [million Sk]	20.0	16.8 83.92
Cost of Conserved [Sk/GJ]	135.8	144.6

Table 6. Cost Effective Economic Results of Residential Sector

The residential sector cost-effective efficiency resource of 147,381 GJ annually, is expected to cost about 131.8 (k) million SK and have a net present value of 198.3 (k) million SK. The cost of conserved energy (the annualized cost divided by the annual energy use reduction) works out to an average of 136 SK/GJ for all fuels. While high rise apartment buildings (building types 2-5) supplied by district heat account for about 77.8% of residential sector heat and hot water energy consumption, they account for over 80% of the cost-effective efficiency resource. This 135 SK/GJ estimated cost of this resource appears to be very cost-effective when compared to the current price of 210 SK/GJ for district heat.

SENSITIVITY ANALYSIS

The sensitivity of the energy savings potential and the cost of energy saved in the residential sector were analyzed for all four levels of fuel prices presented in Table 4. Level 1 represents the current energy prices, Level 2 and 3 represent an optimistic estimate of moderate fuel price increases, while Level 4 represents a pessimistic scenario of fuel prices development. The selection of fuel price levels is not intended to be an accurate estimate for the price of each fuel. Instead, a wide range of fuel price development scenarios was selected to analyze the relation between the expected energy savings potential and the fuel price. The impact of fuel prices on the levelized cost of heat and on the energy saving potential in the Town of Handlova is presented in Table 7.

Fuel Price Level	1	2	3	4
All Fuels Saving Potential [GJ/yr]	125.168 35.9%	140.825 40.4%	147.381 42.2%	154.238 44.2%
Levelized Cost [Sk/GJ]	132.47	133.79	135.76	140.14
District Head Saving Potential [GJ/yr]	112.556 44.8%	112.556 44.8%	116.187 46.3%	117.416 46.8%
Levelized Cost [Sk/GJ]	135.85	141.87	144.60	149.66

Table 7. Sensitivity of the Energy Savings Potential and the Cost of Delivered Heat to Fuel Prices

The energy savings potential in the residential building stock was calculated using methods recommended by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). However, inherent to this process is that many assumptions have to be made based on experience and results from previous studies and demonstrations. A certain level of inaccuracy depends on the quality of workmanship, materials and equipment used, and other factors which are difficult to predict.

The reason for analyzing the sensitivity of the economically effective energy savings potential and the levelized cost of saved energy to the savings actually achieved is not to raise skepticism about the calculated results, but to make an assessment of consequences due to the above mentioned factors. Lower-than-expected energy savings will increase the levelized cost of saved energy and reduce savings potential.

For the purpose of this analysis, the calculated savings for each ECO was reduced to 50% of the calculated value, which means that only 50% of calculated savings would be achieved. Fuel Case 3 was selected for the calculation.

In the unlikely scenario where only 50% of expected energy savings would be actually achieved, the cost effective savings potential for all the fuel groups would be reduced to 58,940 GJ/year, or by 60%. In the district heating system, the savings potential would be lowered by approximately 53%. The levelized energy cost for all fuel groups and for the district heating system only would increase to 267.75 SK/GJ and 274.60 SK/GJ, respectively. The results of the analysis of the three supply side alternatives shows that the cost of delivered thermal energy would be in a range from 180 SK/GJ to 350 SK/GJ, depending on selected alternatives, cost of fuel, and economic environment.

PART 2 - THE SUPPLY SIDE ANALYSES

This chapter develops and evaluates the supply side alternatives for production and distribution of thermal energy for space heating and water heating. The investment effectiveness and the sensitivity analysis are performed for each of the three developed alternatives. Variables in the sensitivity study are demand side energy consumption levels, real interest on borrowed money and cost of fuels.

The purpose of the work presented in this chapter is to provide information on technical, economic, and environmental parameters for each of the thermal energy supply alternatives.

HISTORY AND CURRENT STATE OF THE THERMAL ENERGY SUPPLY AND DEMAND

The central heating system covers 80% of the current energy demand for space heating and water heating in the town of Handlova. The Heating Plant was built from 1937 to 1940 and was originally designed as a cogeneration plant with a condensing steam turbine, which supplied the electricity for the coal mine Handlova. Operation of the plant began in 1938. The last major investment to the plant was in 1954, when the boiler K6 (45 t/h, 432°C, 3.8 MPa) was built.

The steam distribution system was built in 1965 and the central heating system was started in 1968. Steam was supplied through the non-regulated heat transfer station TG2 at 3.0/0.9 MPa and 250°C.

Currently, the distribution network consists of 29 heat exchanger stations, 5,300 meters of pipes installed in non-accessible channels and 2,735 meters of pipes on the surface. Maximum pipe dimension is DN 400 for the steam distribution lines and DN 150 for the condensate return lines.

Due to the equipment's age and the economically ineffective production of electricity, the cogeneration plant was converted to heat production only. Boiler K2 was retrofitted in 1982 and boiler K5 was retrofitted and equipped with a pre-combustion reactor in 1990. Boiler K6, which was installed in 1954, was upgraded in 1989 and was converted to gas operation.

The heat generating plant uses industrial grade coal (brown coal dust) with a heating value of 8.5 - 12.54 MJ/kg and natural gas with a heating value of 33.4 MJ/m3. Boilers with natural circulation are equipped with closed-loop coal feed and electrostatic filters. Boiler K1 is equipped with a pre-combustion reactor, boilers K5 and K6 are equipped with gas burners with capacity equal to 50% of the boiler total output. Total output of all boilers is 100 ton/hr (600 MWt). The plant employs 120 workers and 24 administration staff members.

The next, 115 meter concrete stack was built in 1983; in 1984 and 1985, the flue exhaust was equipped with electrostatic filters. The old generators were removed from the building. Ash produced by the heating plant is either used by the coal mine to fill old coal mine cavities or partially deposited to an ash and coal mine refuse depository outside of town.

In general, the central heating system, including the heat generating plant, distribution and the heat exchanging stations, is old and inefficient.

BASELINE PARAMETERS

Energy consumption in Handlova for space heating, water heating, and for industrial processes in 1992 was summarized back in Table 1.

Demand Forecast

This section develops the three variants for energy demand growth used for the study. Assuming a 25 year life for the heat supply equipment to be built by 1997, the energy demand was projected to the year 2022.

The summary of parameters in each variant was presented in Table 2.

Fuel Availability

The State Upper Nitra Coal Mines (Hornonitrianske Bane) with headquarters in Prievidza, Slovakia have, in their letter from August 14, 1993 to SEP Bratislava, guaranteed supply of standard quality coal up to year 2020.

The following coal quality was guaranteed:

Heating value	Qa = 10.5 MJ/kg
Ash content	A = 36.38%
Water	W = 21.46%
Sulfur	S = 1.55%
Carbon	C = 66.51%
Hydrogen	H = 5.4%
Nitrogen	N = 1.28%
Oxygen	O = 25.49%

The Slovak Gas Company (Slovensky Plynarensky Podnik), the local gas utility, with headquarters in Prievidza, Slovakia, is capable and willing to provide a sufficient gas supply to satisfy the needs of the Town of Handlova. Currently, the low pressure gas distribution network in Handlova is in use and serves only small users (residences). The decentralized heating system would require installation of new pipes with a gas pressure of 0.3 MP to serve new, distributed boilers.

CENTRAL DISTRICT HEATING SYSTEM

This section presents a technical and economic evaluation of the central district heating system alternatives considered for the thermal energy supply for the town of Handlova.

Distribution System Analysis

The replacement of the old steam distribution system with new, hot water distribution system must be performed without service interruption. Therefore, the new system will be installed parallel to the existing one, as recommended by the study "Transition from Steam to Hot Water Distribution System in the Town of Handlova," which was performed by Energoprojekt Kosice in March 1992. The replacement of heat exchangers in all stations is assumed to be performed in the summer season.

Quotes for delivery of the materials listed were requested and received from PIPECO, Ltd., Podbrezova and the ASEA Brown Boveri, Bratislava. Pricing information from BTV STAV-ISOLAR, Bratislava was also used for comparison. This company is offering pre-insulated pipes, type Fotav-Isoplus, and also type KE Rohrsystem und Umwelttechnik GmbH. For the purpose of this study, an average price was calculated for each component from all received quotes.

The cost of installation was calculated based on information provided by the company ALDY, s.r.o. and on information included in the previously mentioned study "Transition from Steam to Hot Water Distribution System in Town of Handlova."

The cost of material and installation of pre-insulated pipes buried in-ground:

Material	45,000,000 SK
Installation	21,000,000 SK
Total	66,000,000 SK

Heat Exchanger Station

The new heat exchangers and other required equipment will be installed in existing buildings. The domestic water heating equipment is assumed to be installed at the consumption sites, in the building basements. A secondary side distribution will be utilized for providing the heat source for water heating purposes.

The installed cost of compact water-to-water heat exchangers from company Tlakove Nadoby, Zilina, should be expected to be 80,000 SK. The installed cost of plate heat exchangers from company ALFA LAVAL can be expected to be 54,000 SK. This lower price was used for the economic evaluation calculations.

Heating Plant

ALTERNATIVE 1: Central District Heating System with Cogeneration and Coal/Gas Fuels

This alternative assumes reconstruction of existing boilers K5 and K6, fuel supply equipment, ash removal equipment and hot water manifolds, completion of a new chemical plant for water treatment, installation of new gas-fired hot water boilers including gas piping, new 6.2 kW electrical distribution center, new mechanical room, new hot water heat exchanger station, and limestone preparation equipment, and a new ash dump site. General schematic of the system is shown in Figure 1.

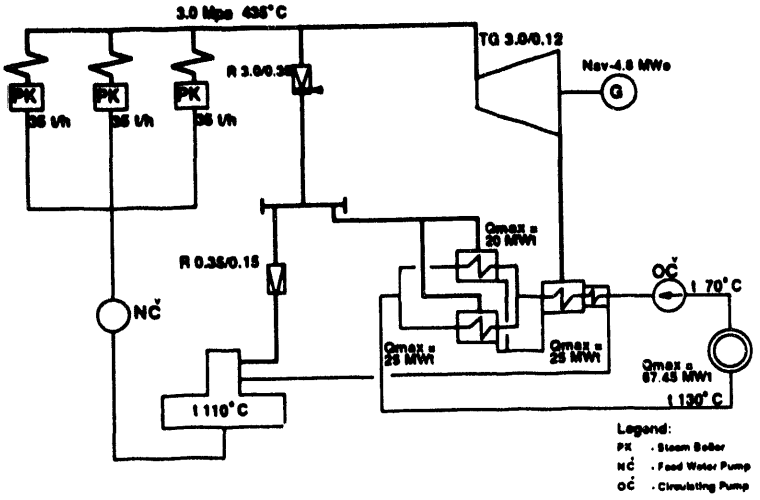


Figure 1. Equipment Diagram for Alternative 1

Investment for Heating Plant Reconstruction

Total Investment Required: 180.5 Million SK

Analysis of Operation

Thermodynamic calculations were performed for several alternative loads. The internal and distribution losses in the primary and secondary circuits were included. Please see Table 8.

	Unit	Var. 1	Var. 2	Var. 3
Heat Production by the Plant	GJ/yr	363,710	561,856	600,295
Fuel Consumption				
Coal (10,5 MJ/kg)	t/yr	50,297	69,307	71,908
Gas (33,4 MJ/m^3)	10^6m^3	1,947	3,947	4,254
Limestone Consumption	t/yr	5,029	6,931	7,191
Internal Consumption				
Thermal Energy	GJ/yr	75,597	110,234	114,188
Electricity	MWh/yr	1,280	1,790	1,890
Production of Thermal Energy	GJ/yr	418,720	640,320	680,540
Production of Electricity	MWh/yr	16,030	22,400	23,620
Heat Losses in Distribution	GJ/yr	20,623	31,806	33,979
Thermal Energy Delivered	GJ/yr	343,087	530,050	566,316
Electricity Delivered	MWh/yr	14,750	20,610	21,730
Ash Production	t/yr	18,298	25,218	26,160

Table 8. Analyses of Operation - Alternative 1

ALTERNATIVE 2: Central District Heating System with Cogeneration, Coal Fired

This alternative assumes reconstruction of existing boilers K5 and K6, coal supply equipment, ash removal equipment and hot water manifolds, completion of a new chemical plant for water treatment, installation of a new 6.2 kW electrical distribution center, new mechanical room, new hot water heat exchanger station, and a new ash dump site. A general schematic of the system is shown in Figure 2.

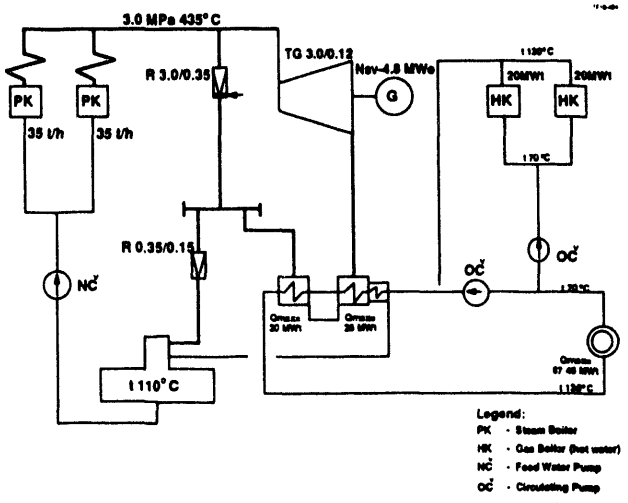


Figure 2. Equipment Diagram for Alternative 2

Investment for Heating Plant Reconstruction

Total Investment Required: 141.5 Million SK

Analysis of Operation

Thermodynamic calculations were performed for several alternative loads. The internal and distribution losses in the primary and secondary circuits were included. The same method was used as for Alternative 1. Please see Table 9.

	Unit	Var. 1	Var. 2	Var. 3
Heat Production by the Plant	GJ/yr	363,710	561,865	600,295
Fuel Consumption Coal (10,5 MJ/kg)	t/yr	64,059	93,013	106,327
Limestone Consumption	t/yr	5,030	9,301	10,633
Internal Consumption Thermal Energy Electricity	 GJ/yr MWh/yr	 64,070 1,490	 94,2094 2,180	 100,406 2,300
Production of Thermal Energy Production of Electricity	GJ/yr MWh/yr	427,780 18,610	656,100 27,200	700,740 28,740
Heat Losses in Distribution	GJ/yr	20,623	31,806	33,979
Thermal Energy Delivered Electricity Delivered	GJ/yr MWh/yr	343,087 17,210	530,050 25,020	566,316 26,440
Ash Production	t/yr	32,599	47,334	38,681

Table 9. Analyses of Operation - Alternative 2

ALTERNATIVE 3: Decentralized Heat Supply System

The analysis of the decentralized heat supply were performed for gas fuel only, since previous studies have shown that coal-fired environmentally friendly small heat sources (small boilers) cannot compete with gas-fired boilers due to the high cost of flue cleaning equipment. Electric boilers were also not considered due to the high cost of electric energy. It is expected that the cost of electricity will increase from 1.67 SL/kWh to approximately 3.0 SK/kWh in 1997, and up to 3.4 SK/kWh in 2000.

The analysis assumes that the decentralized heat supply system will provide heat only to residential and non-residential sectors, and will not provide heat to industrial customers. The total installed capacity of all boilers amounts to 42.2 MWt with annual delivery of 377.28 TJ.

The assumed total delivered thermal energy is smaller than in previous alternatives, however this should not have any impact on cost of delivered energy. In the case of this system, an increase in the required capacity will equally increase the investment.

The specifications for each boiler and other boiler room equipment were based on the required heat delivery in a given location with respect to code CSN 06 0310, Section 58b. A duplication of equipment in as many locations as possible was also a consideration to simplify maintenance and reduce spare parts inventory. The installation of boilers was assumed (where possible) to be in existing heat exchanger station buildings and existing old boiler houses to minimize the installation cost. The boiler rooms were designed to comply with the code CSN 07 0703. Results are presented in Table 10.

Total Production of Heat by all Boiler Rooms	GJ/year	377,280
Gas Consumption (33,4 MJ/m³)	$10^6 m^3$	11074,3
Internal Consumption		
Thermal Energy	GJ/year	---
Electricity	MWh/year	500
Thermal Energy Production	GJ/year	386,712
Delivered Thermal Energy	GJ/year	377,280

Table 10. Operation - Alternative 3

Distribution System

The distribution system external to the boiler rooms will utilize the existing secondary distribution system. Hot water will be distributed at 110/70°C in the winter and at 70/40°C during the summer. Domestic hot water heating and space heating water temperature control will be done in individual residential buildings based on outside air temperature. Buildings wiil be equipped with GJ meters and water flow meters.

Water Heating

The domestic water heating system (DWHS) will be designed in two alternatives, depending on the building:

1. Buildings with the boiler room inside (basement) will have a DWHS with the storage tank installed in the boiler room. The water heating system will utilize the boiler flue gas condensing heat for preheating the cold water.

2. Buildings supplied with heat from an external boiler room (old heat exchanger station) will have the DWHS installed in the external boiler room.

Required Investment

Total installed cost of all listed equipment, including gas piping, and new building structures as required by specification: 203,014 Million SK.

Total installed cost for Energy Management System EY 2 400, from Sauter, Switzerland (662,303 SF): 14,570 Million SK.

Installation of gas distribution system for all boiler rooms: 11,970 Million SK.

Total Installed Cost of this Alternative: 229,554 Million SK.

Analysis of Operation

Table 11 summarizes heat production, consumption of the fuel and electric energy.

KEY FINANCIAL ASSUMPTION FOR EVALUATION OF ALTERNATIVES

COMPARISON OF ALTERNATIVES

This chapter summarizes the results and offers a comparison of the results obtained for all three alternatives. The results are shown in Table 12. The economic parameters for the central district heat system shown in this table were, for the purpose of comparison, calculated for load Variant 2 and a coal cost of 680 SK/ton, which is the most likely cost of coal in year 1997.

As it can be seen from the presented results, the lowest delivered energy cost (205.80 SK/GJ) is for Alternative 2. Alternative 2 also creates approximately 55 job opportunities and helps to maintain 1,000 to 1,400 jobs in the Handlova Coal Mine (Note that the central heating system may not be the only user of the industrial grade coal produced by the coal mine, and the coal mine can maintain employment by finding other customers, should the heating system be converted to natural gas). The delivered energy cost for Alternative 1 is slightly higher - 228.35 Sk/GJ; however, this Alternative offers more reliable operations, lower emissions, and less solid waste production due to a bi-fuel (coal/gas) base.

In order to compare the town's central and decentralized energy supply system options on an equal platform, the economic calculations were performed for selected technical and economic assumptions which were the same for both systems. Internal Rate of Return on investment was set at 14%, financing of the project was assumed to be 90%, electricity price sold to distribution was assumed to be 1,389 SK/MWh and cost of electricity purchased was assumed at 1,894 SK/MWh. The central system is represented by Alternative 1. The delivered thermal energy cost was selected as the comparison parameter. The results are graphically presented in Figure 3. The five fields shown in Figure 3 represent delivered energy cost ranges calculated for Alternative 1 and 3.

	Alt 1 / Alt 2	Alt 3
Construction duration	2 years	2 years
Time of start up/base year	1997	1997
Term of Projected Sales (life)	25 years	25 years
Cost of Natural Gas in 1997	3.350 SK/m^3	3.350 SK/m^3
Cost of Coal in 1997 (four alternatives)	467.3 SK/ton 380.0 SK/ton 850.0 SK/ton 1,275 SK/ton	
Fuel Cost Escalation		
Natural Gas from year 1997 to 2005 after year 2005	2.85% 1.4%	2.85% annually 1.4% annually
Coal	2.7%	
Rate of Return Investment	14%	14%
Nominal Interest Rate	5% to 30%	5% to 30%
Real Interest Rate	2%, 5%, 9.5% and 12%	2%, 5%, 9.5% and 12%
Investment Repayment Term	10 years	10 years
Investment Financed	90%	90%
Net Effective Tax Rate	45%	45%
Labor Rate	8,750 mil.SK/yr	1.8 mil.SK/yr
Labor Escalation to year 2005 after 2005	12.4% annually 6.0% annually	14.4% annually 6% annually
Overhead	3,000 mil.SK/yr	2.3 mil.SK/yr
Overhead Escalation to year 2005 after 2005	6.0% annually 3.0% annually	7.5% annually 3.5% annually
Repairs and Maintenance	5,000 mil.SK/yr	2.3 mil.SK/yr
R&M Escalation to year 2005 after 2005	7.5% annually 3.5% annually	7.5% annually 3.5% annually
Material, energy		
Water		10.0 SK/m^3
Water cost escalation to year 2005 after 2005		2.85% annually 1.4% annually
Electricity a) b)		3230.0 SK/MWh 1894.0 SK/MWh
Electricity cost escalation a) b)		2.0% 6.0%
Material Supplies	3,500 mil.SK/yr	
Material Escalation to year 2005 after 2005	7.5% annually 3.5% annually	
Other Expenses, emissions		0.0346 mil.SK/yr
Other Expenses, Escalation	1.0% annually	1.0% annually
Depreciation of Existing Equipment (steam distr., electrostatic filters) In Year 1997 In Year 2000 In Year 2003	 1.566 mil.SK/yr 0.690 mil.SK/yr 0.690 mil.SK/yr	
Price of electricity sold	1.389 SK/MWh	
Escalation	6% annually	
TOTAL PROJECT COST	300.5 / 261.5 mil.SK	229,554 mil.SK

Table 11. Project Economic Analysis, Key Financial Assumptions

Parameter	Unit	Alt.1	Alt.2	Alt.3
Technical Parameters				
Boiler Output	MWt	60	90	1,5
Steam	MWt	40	---	55.5
Hot Water	MWe	4.8	4.8	(.2-.3)
Source Installed Output	MWt	70	70	42.5
System Peak Thermal Output Requirements				
Operational Parameters				
Fuel Consumption				
Coal	t/year	69,307	93,013	---
Gas	mil.m³/yr	3,947	---	11,074
Internal Consumption				
Electricity	MWh/yr	1,790	2,180	500
Thermal Energy	GJ/yr	110,234	94,209	---
Delivered Energy				
Thermal Energy	GJ/yr	530,050	530,050	377,280
Electricity	MWh/yr	20,610	25,020	---
Emissions Produced				
SO_2	ton/yr	1,073	1,518	---
NO_x	ton/yr	266	344	14.58
Particulate	ton/yr	25,212	47,334	---
Economic Parameters				
Total Investment (IN)	thous.SK	300,500	261,500	229,554
Average Annual Net Profit	thous.SK	23,366	20,448	18,787
Discounted Total Profit	thous.SK	220,522	192,975	172,232
Discounted Total Cash Flow	thous.SK	96,245	85,954	70,662
Simple Payback	years	16	16	15
Cost of Delivered Energy	SK/GJ	228.35	205.80	245.30
Number of Jobs	---	55	55	7

Table 12. Technical and Economical Evaluation of Alternatives

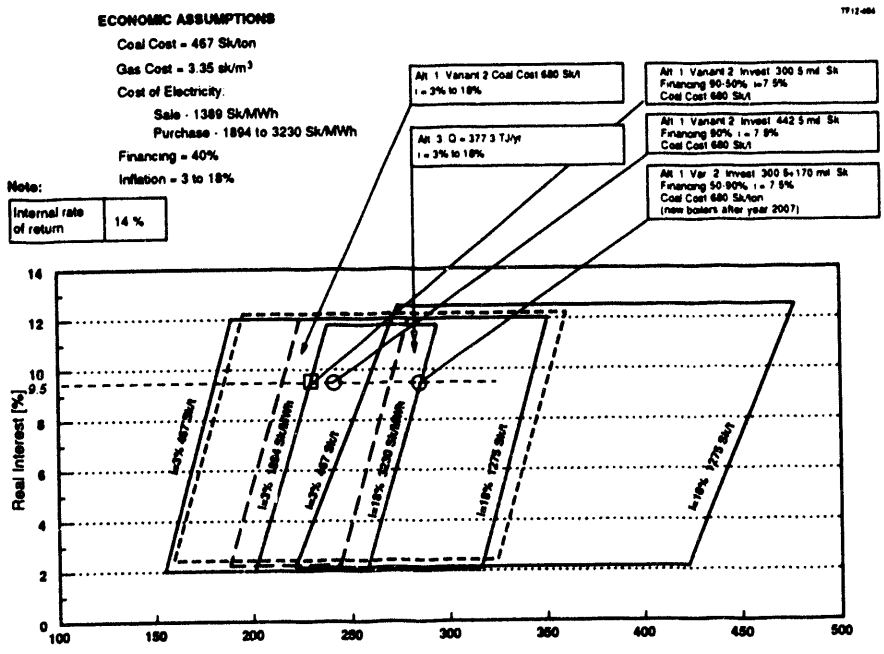


Figure 3. Economic Analysis and Sensitivity of Results for Decentralized (Alt. 3) and Central (Alt. 1) Production of Thermal Energy for Space and Water Heating in the town of Handlova, Slovakia

Each field is defined by the minimum assumed fuel price (467 SK/ton for coal) and minimum inflation (3%) on the left side and the maximum assumed fuel price (1,275 SK/ton for coal) and maximum inflation (18%) on the right side. The price of natural gas is assumed to be 3,350 Sk/m3. The real interest rate of 2% and 12% defined the low and high of the range, respectively.

The following conclusions can be drawn from the presented results of comparison of the central and the decentralized heating systems, providing that the fuel prices and the prices of electricity purchased and sold will be developing as assumed in the calculation:

* The delivered energy cost will be lower for the decentralized system when the coal price is higher than 800 SK/ton and the thermal energy demand is lower than 350 TJ/year. Increased demand and lower coal price will make the centralized system more attractive.

* The delivered energy cost will be lower for the central heating system when the coal price is less than 700 SK/ton and the thermal energy demand is over 500 TJ/year.

The absolute energy cost will depend on the actual economic parameters, such as general inflation, real interest rate, purchasing and selling prices of electricity, and on actual thermal energy demand. The thermal delivered energy cost fields shown in Figure 4 are overlapping and suggest the thermal delivered energy price could fall in broad range from approximately 150 to 430 SK/GJ. A more realistic range is more likely to be between 200 and 250 SK/GJ.

In the US, it is common practice to perform the economic analysis on a real basis, thus excluding general inflation. Such analysis can be performed under the assumption that the inflation has the same impact on general prices and income of citizens. This is currently not the case in Slovakia, where prices are inflating at a substantially higher rate than income. For this reason, the general inflation can be removed by setting the inflation rate equal to zero. In this case, the delivered energy cost would in general be lower.

The decision on whether to implement the decentralized or the central heat supply system will depend on actual negotiated prices of coal from the Handlova Coal Mine, the latest development in world gas prices, and the latest estimates for the purchase and selling prices of electricity.

The economic calculations were performed with the following assumptions: 90% financing, real interest rate 9.5%, normal interest rate 17%, coal price (1st year of operation) 680 SK/ton, gas price 3.25 SK/m3, electricity price (selling to distribution) 1,894 SK/MWh, electricity purchase price (buy from distribution) 1,389 SK/MWh, and required return on investment 14%.

The presented results show that the delivered energy cost is substantially influenced by investment approach, pricing policy, and by quantity of delivered energy (sales). For example, 50% financing (compared to 90%) will reduce the cost of delivered energy by 15 SK/GJ, a 200 SK/MWh increase in the price of electricity sold will reduce the cost of delivered heat by approximately 10 SK/GJ.

Session IV
Ongoing Energy Emissions Reduction Studies

Chairman: **Barry Worthington**, United States Energy Agency

Usti-nad-Labem Emission Reduction and Energy Supply Alternatives—Zdenek Krivsky, Pavel Horak, Jiri Sykora, North Bohemia Economic Association • Jiri Bavor, Usti-nad-Labem City Hall • Lynn N. Rubow, Richard E. Weinstein, and David B. Stauffer, Gilbert/Commonwealth

Ziar-nad-Hronum Emission Reduction and Energy Supply Alternatives—Karol Dvorak and Ol'ga Murinova, EGU Bratislava • Ivan Knapco, ZSNP • David B. Stauffer, Lynn N. Rubow, and Roman Zaharchuk, Gilbert/Commonwealth

Evaluating Programs to Reduce Building Sector Energy Consumption: Bulgaria's First Steps—Lawrence F. Sutkowski, Robert V. Russo, Electrotek Concepts, Inc. • Zdravko Genchev, Bulgarian Energy Efficiency Foundation (EnEffect)

USTI-NAD-LABEM EMISSION REDUCTION AND ENERGY SUPPLY ALTERNATIVES

Zdenek Krivsky, North Bohemia Economic Association
Pavel Horak, North Bohemia Economic Association
Jiri Sykora, North Bohemia Economic Association
Jiri Bavor, Usti nad Labem City Hall
Lynn Rubow, Gilbert/Commonwealth
Richard Weinstein, Gilbert/Commonwealth
David Stauffer, Gilbert/Commonwealth

ABSTRACT

As part of the overall effort in support of a Presidential Initiative, the U.S. Department of Energy (DOE) / Fossil Energy (FE) Office of Coal Research and Development has been conducting, under the U.S. Agency for International Development (AID) sponsorship, a number of studies to assist the Eastern European countries in the transition to more efficient energy utilization with reduced pollution. The primary objective of this study is the reduction of emissions for the city of Usti-nad-Labem of the Czech Republic, through the development of emission reduction alternatives for the district heating system and other stationary sources. At the time of this writing, the study is in the data gathering phase. The study will be conducted in conjunction with EERC (Energy & Environmental Research Center) who will perform tests on a local coal to determine the potential of pre-combustion treatment. Emission reduction alternatives will be examined to determine which set of options provide the least cost solution while meeting the emission and energy requirements. This paper addresses the task objective, current situation (equipment, fuels, emissions, and energy demands), projected energy and emission requirements, anticipated emission reduction options, and the technical and economic analysis to be performed.

INTRODUCTION

The city of Usti-nad-Labem is located in Northern Bohemia of the Czech Republic, and is included, along with bordering industrial cities in east Germany and Poland, in an area known as the "Black Triangle" because of its high pollution levels. Sources of pollution include electric utilities, coal mines, district heating systems and the chemical industry.

The U.S. AID has channeled funds through the U.S. DOE for the purpose of assisting Eastern European countries by providing economically based study projects. DOE has contracted Gilbert/Commonwealth, Inc., (G/C) to study emission reduction alternatives for the city of Usti-nad-Labem.

Within the city of Usti-nad-Labem, a major source of pollution comes from three large district heating plants that supply 80 percent of the heating energy demand. All three plants are cogenerators and currently use low rank coal that, for the most part, is supplied from the nearby Chabarovice mine. It is relatively low in sulfur and heating content, but high in ash. The largest of the three plants is Trmice, which receives all of its coal from the Chabarovice mine. Its largest heat customer is a chemical plant. STZ, a chemical processing company, represents the second largest DH company, and primarily uses coal from a mine located near Most, and only 15 percent from the Chabarovice mine. The smallest DH facility is Tonaso whose current plans are to switch to natural gas. Other identified sources of pollution are small residential coal-fired stoves.

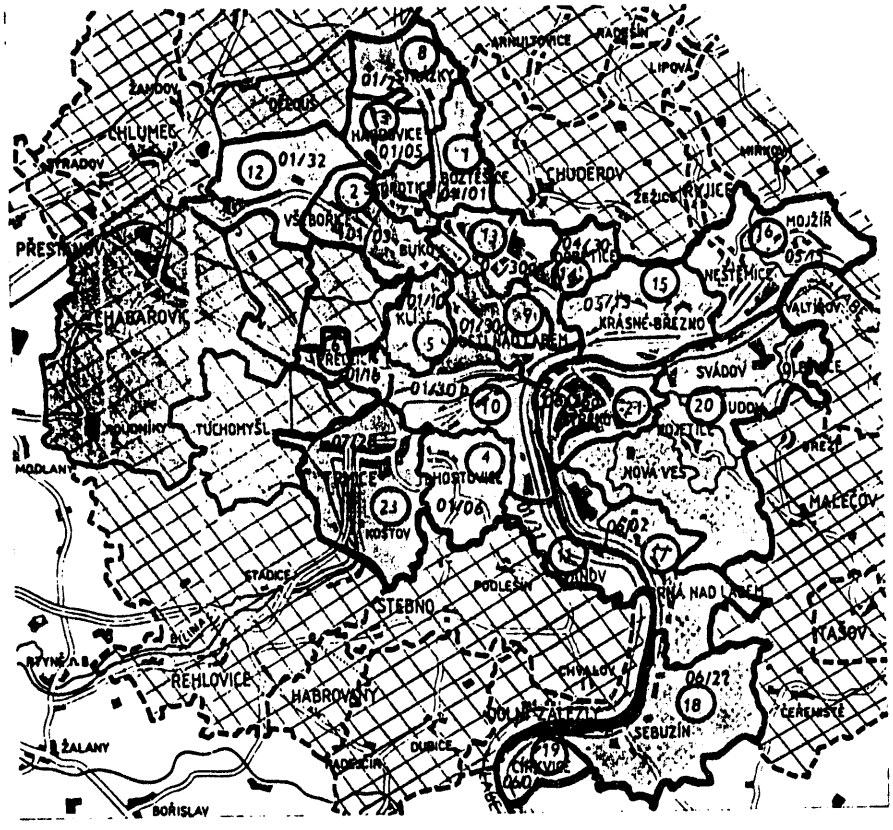
As a result of the pollution in the Black Triangle, the closure of the Chabarovice mine, and the one large town gas facilities using this indigenous coal is anticipated. Natural gas will be substituted for the town gas. Lower ash coals and natural gas will be available for use in the district heating plants as part of the emission reduction options.

The City of Usti-nad-Labem has a population of approximately 121,000. The Usti-nad-Labem region is shown in Exhibit 1 along with the population of the given districts. Most of the region's population is centrally located and, as such, is well suited for centralized district heating. The regions shown in Exhibit 1 will be conveniently used in the study for evaluation of alternatives.

Project Objectives

The primary objective of the project is to determine the most cost-effective energy production alternative capable of meeting the required emission limits, while satisfying the steam, hot water and electric demands. Emphasis will be placed on the three district heating systems within the city. A simplified, least cost economic analysis will be performed on a net present worth basis and will be analyzed from the perspective of the city. This means that the needs of the city will be considered as a whole.

Exhibit 1
Usti-nad-Labem City and Surrounding Area



Map Seq. No.	Town District Name	District Population
1	Boztesice	428
2	Bukov	10,489
3	Habrovice	200
4	Hostovice	214
5	Klise	7,468
6	Predlice	1,285
7	Skorotice	651
8	Strazky	103
9	Usti n.l. Centrum-a	14,456
10	Usti n.l. Centrum-b	1,129
11	Vanov	713
12	Vseborice	2
13	Severni Terasa-a	16,653
14	Severni Terasa-b	6,555
15	Krasne Brezno	14,867
16	Nestemice	10,510
17	Brna	1,551
18	Sebuzin	378
19	Cirkvice	51
20	Kojetice	1,342
21	Strekov- a	10,886
22	Trmice	2,213
23	Strizovice	140
24	Ostatni Casti Mesta	18,625
	TOTAL Population	120,909

Specifically, the following objectives have been established for this project:

- Characterize the current status of the energy supply facilities, consumers, and emissions in Usti-nad-Labem;
- Assist the city of Usti-nad-Labem in developing cost-effective alternatives for reducing emissions from the district heating systems and other polluting stationary sources; and
- Provide recommendations for cost effective improvement of the existing situation.

The analysis will consider the following factors:

- The current status of the generation units, distribution system, demand and emission levels. (This information, along with the minimum changes required to meet future emission limits will define the base case.)
- The impact of emissions legislation on both new and existing generation units.
- A steam and hot water demand projection which reflects projected growth, conservation and control measures, and natural market forces.
- A spectrum of alternate supply side options which can potentially be part of the total picture in meeting both the demand and emission levels. One alternative to be analyzed will include the upgrading of low rank coal.

PRESENT SITUATION

Energy Supply Facilities

The total installed thermal output of all boilers in the Usti-nad-Labem area is 1243 MWt. This total output is split into the component sources of large central sources, block boiler houses, small boilers and local sources in Exhibit 2.

Exhibit 2
Total Heat Sources in Usti-nad-Labem

Heat Source	No. of Units	Installed Capacity (MWt)
Large Central Sources	8	928
Block Boiler Houses	about 100	127
Small Boilers	about 200	71
Local Sources (flats)	about 7400	117
Total Installed Output	about 7700	1243

The eight large central heat sources represent approximately 80 percent of the installed thermal capacity of the boilers in Usti. These eight heat sources are shown in more detail in Exhibit 3.

Exhibit 3
Eight Large Central Heat Sources

Boiler House	No. of boilers	Installed Capacity
1. Trmice	8	570
2. Setuza (STZ)	4	144
3. Tonaso-Eson	2	40
4. PK Gas Works	2	98
5. PK Gas Works (DH)	-	27
6. Prefa Prestanov	3	19
7. Kunz Bukov	2	12
8. KB Liker	2	18
Total		928

The four largest Central heat sources are Trmice, Setuza, Tonaso-Eson, and the PK Gas Works. These facilities are described below.

Trmice

The Trmice plant has a total of eight operating boilers. Four boilers, K101 to K104, are traveling grate stokers originally placed in service between 1948 to 1956. Each grate boiler has a capacity of 50 tph. The next two boilers, K105 and K106, are pulverized coal boilers built in the 1970s, each with an associated 16 MWe back pressure steam turbine generator. The last two boilers, K107 and K108, are low pressure boilers installed in 1987. With the addition of these boilers, the plant took its present configuration. [A 14 t/h FBC boiler of Czech manufacture was added in 1988, but is no longer in service because of operational difficulties.] The total Trmice output has stabilized at steam output of 426 MWt and 42.5 MWe. The major equipment information for Trmice is summarized by Exhibit 4.

The Trmice station is situated at the Chabarovice mine mouth and has historically utilized the Chabarovice brown coal almost exclusively. The Chabarovice coal is segregated into two types of coal, industrial heating mixture, and a heating mixture coal. The heating values for these coals are 11.9 and 10.6 MJ/kg respectively. The average composite heating value is 11.37 MJ/kg. The Trmice station has historically produced SO_2 emission level that are under the 389/91 regulation because of the low 0.5 percent sulfur content of the Chabarovice fuel.

Exhibit 4
Trmice Plant Major Equipment Summary

Parameters	Units	K101 -104	K105-106	K107-108
Boiler Type	-	Grate	Pulverized	Pulverized
Boiler In-Service Year	Year	1948 - 1956	1975 + 1981	1987 + 1988
Boiler Output, Thermal	MWt	42	121	80
Boiler Output, Flow	t/h	50	160	115
Steam Pressure	MPa	12.5	13.9	1.8
Steam Temperature	°C	500	540	260
Reheater Pressure	MPa	1.7	NA	NA
Reheater Temperature	°C	370	NA	NA
Design Fuel LHV	MJ/kg	11.9	10.6	10.6
Boiler Efficiency[a]	%	[tbd][a]	[tbd][a]	[tbd][a]
Particulate Removal	-	Bags (2 Units)/ ESP[b]	ESP	ESP
Particulate Removal Eff.	%	99.5%/Out of service	98.2/99.7	99.6
Achievable TG Output	MWe	-	14	-

Note a. The boiler efficiencies will be determined in the near future. ["tbd" stands for "to be determined."]
b. The remaining 2 units with ESPs will be replaced with baghouses in the near future.

However, public opinion and recent decisions by the Czech government, (Nos. 33/91 and 444/910) will result in the future reduction of mining activity at the Chabarovice mine. Therefore the Trmice plant will begin to utilize coal from the mines of Bilina, Vrsany and Komarany. The coal from these mines will on average exceed a one percent sulfur content. This will require sulfur mitigation in order to meet the SO_2 emission regulations.

Setuza a.s.

The Setuza company produces edible oils, margarine, soaps and cosmetics. Additionally, its heating plant delivers heat into a central heating system on the Strekov side of town. The plant operates four boilers and burns pulverized coal taken from the Lednice coal mine. SO_2 emissions are 1400-2800 mg/Nm^3. NOx emissions are below the 650 mg/Nm^3 limit. The plant's efficient ESP and one baghouse keep particulate emissions below 50 and 5 mg/Nm^3 respectively. The company will retrofit all boilers with wet-dry lime FGD units.

Tonaso-Eson

The main function of the Tonaso facility was the production of caustic soda, however the facility is no longer competitive because of the increased cost of raw materials.

The Tonaso-Eson power plant has four old boilers burning local lignite. The smallest boiler's output is 35 tph while the three larger boilers each are capable of 50 tph. Currently these boilers are not heavily utilized and will be replaced by two new 25 tph gas-fired boilers. The new boilers apparently have sufficient capacity to meet the required load. The Tonaso plant also has a 6 MWe steam turbine generator.

The cost of district heat produced by Tonaso is subsidized and their decisions have not been made on a least cost basis.

PK Gas Works

The PK Gas Works is a large town gas facility that will be closed in 1995. Town gas will be replaced with natural gas. The future of the plant has not been determined, although both methanol manufacturing and combined cycle power generation are being considered by plant management.

District Heat Distribution and Utilization

The are approximately 9,417 heated objects (customers) in the city of Usti. Approximately 1,997 objects are heated by the central heating systems (CZT), 2,150 objects are heated by block house boilers, and 5,270 objects are heated by local heat boilers (flats). This data is summarized in Exhibit 5.

Exhibit 5
Heat Source of Heated Objects

Heat Source	No. of Heated Objects	Percentage of Heated Objects
Central Heating System	1997	21 %
Block and House Boilers	2150	23 %
Local Boilers (Flats)	5270	56 %
Total Heated Objects	9417	100 %

The distribution system of these large central heating systems provide approximately 320 MWt to the flats and 340 MWt for organizations and industry. The distribution systems consist of 102 km of primary piping, and 74 km of secondary piping. These large systems embody 103 Heat exchange stations over 1 MWt and 126 under 1 MWt. These systems now supply to objects once served by 33 former sources.

Typical heat consumers of these large district heating systems consist of residential flats, houses, industrial plants and factories.

The percentage of heated objects (by heated area) resulting from each type of heat source is presented in Exhibit 6.

Exhibit 6
Percentage of Heated Objects by Heat Source

Heated Source	Percentage of Total Heated Area
Central Heating System	51%
Block Boiler Houses	7%
House Boilers	3%
Local Heating	27%
Organization (not specified)	12%
Total of Heated Objects	100%

The total thermal losses for both a central heating and local heating system are summarized in Exhibit 7 as a fraction of the fuel heating value.

Exhibit 7
Heat Losses for Central Heating and Local Heating Systems

Loss Area (% of fuel input)	Loss for Local Heating Systems	Loss for Central Heating Systems
Manipulation of Fuel	4%	4%
Boiler House Inefficiencies	16%	15%
Primary Distribution and Condensate	22%	18%
H.E.S. and Secondary Distribution	12%	8%
Poor Building Insulation & Overheating	15%	8%
Total Heat Loss	69%	53%

Available Fuels

Historically, the most important fuel in the Usti-nad-Labem area has been the indigenous low rank brown coal from the Chabarovice mine. Other primary fuels include brown coal from other sources, hard coal from Ostrava and natural gas. Secondary fuels used in the area include both heavy and light fuel oils. The major characteristics of the primary fuels are presented in Exhibit 8. The hard coal most come to Usti via either the river or rail and is much more expensive than the local brown coal. The study will be conducted in conjunction with EERC (Energy & Environmental Research Center) who will perform tests on a local coal to determine the potential of pre-combustion treatment.

Current Emission Levels

The emission levels for the two largest district heating companies, Trmice and Setuza are presented in Exhibits 9 and 10 respectively. The 1992 emission levels for the Trmice plant are shown in Exhibit 9 while the current emission levels for Setuza are presented in Exhibit 10.

Exhibit 9
Trmice Plant 1992 Emission Levels

Parameters	Boiler No. Units	K101 - 104	K105-106	K107-108
Particulate	mg/Nm^3	880	350	125
SO_2	mg/Nm^3	660	950	450
NOx	mg/Nm^3	280	560	320
CO	mg/Nm^3	NA	NA	NA

Exhibit 10
Setuza Current Emission Levels

Parameters	Units	All Boilers
Particulate	mg/Nm^3-	<50 & <5
SO_2	mg/Nm^3	1400-2800
NOx	mg/Nm^3	<650
CO	mg/Nm^3	NA

Waste Disposal

Ash and clinker disposal is a serious problem in densely populated areas such as the city of Usti. The Trmice and Setuza plants each have their own waste sites, but the transportation of the ash and desulphurization by-products and the leachate from by-products will certainly generate problems in the future.

Exhibit 8
Typical Fuel Characteristics

Parameter	Units	Brown Coal from the Chabarovice Mine	Brown Coal from the Ledvice Mine	Coking Coal from the Ostrava Region	Town Gas from the local town gas facilities	Natural Gas
Lower Heating Value	MJ/kg	~16.0	~17.0	~28.0		
	MJ/Nm^3				16.8	35.9
Water Content	%	~33	~30	~9		
Ash Content	%	~12	~11	~12		
Sulfur Content, dry	%	~0.5	~0.8	~0.7		
	mg/Nm^3				17.8	0.2-0.8

FUTURE REQUIREMENTS/ PROJECTIONS

Emission Regulations

Starting in January 1998, the boilers will be required to meet the stringent emission limits based on the execution rulings of Act No. 309, 1991. The emission limits depend upon the primary fuel being combusted as well as the boiler thermal output. These emission limits are summarized in Exhibit 11

There are no local regulations that augment the state regulations. Although some changes to the state regulations are anticipated in the near future.

PAST STUDIES

All companies operating heating plants in Usti-nad-Labem are currently evaluating options for improving their environmental and economic performance. Recent studies have been selectively conducted on specific plants or areas, and include topics such as FBC repowering, fuel substitution, SO_2, NOx and particulate control. These studies will be used to assist in the preparation of this current study.

OPTION ANALYSIS

Potential Emission Reduction Alternatives to be Considered

The emission reduction alternatives cover a variety of options. Some of the potential reduction alternatives that may be considered in this study are presented in the following list:

- Emissions Control of Central Heating Sources
- Fuel Switching at Central or Local Heating Sources
- Fuel Upgrading of the Low Rank Brown Coal
- Connection of Local Consumers to Central Sources
- Conversion of Distribution System to Hot Water
- Distribution of Gas to New Users
- Improved Control Systems for Distribution
- Addition of Heat Meters
- Addition of Local Regulations
- Improved Insulation of Buildings
- Improved Insulation of Distribution System.

Exhibit 11
Emission Regulations by Boiler Output and Fuel

Fuel	Boiler Output	Emission Limit (mg/Nm^3)[a]			
		0.2-5 MWt	5-50 MWt	50-300 MWt	over 300 MWt
Solid Fuels	Solid	250	150	100	100
	SOx	2500	2500	1700	500
	NOx	650	650	650	650
	CO	250	250	250	250
Liquid Fuels	Solid	100	100	100	50
	SOx	Fuel S <=1%	1750	1750	500
	NOx	500	450	450	450
	CO	175	175	175	175
Gaseous Fuels	Solid	10	10	10	10
	SOx	35	35	35	35
	NOx	200	200	200	200
	CO	100	100	100	100
All Fuels in an FBC	Solid		50	50	50
	SOx		500	500	500
	NOx		400	400	400
	CO		NA	NA	NA
All Fuels in a Gas turbine[b]	Solid		NA	NA	
	SOx		1700	1700	
	NOx		350	300	
	CO		100	NA	

Notes: a. All standards in mg/Nm^3 are related to dry flue gas at 101.32 kPa, 0°C, and 3% O_2 for liquid and gaseous fuels and 6% O_2 for solid fuels.

b. Special regulations exist for gas turbines and are a function of the volumetric flue gas flow. The "smaller" and "larger" sizes listed above correspond to gas turbines having an actual volumetric flue gas flow of either less or more than 60,000 m3/h respectively.

Technical and Economic/Financial Analysis

The technical and economic analysis to be performed will be based upon the selected options, meeting the required energy demands, and emission requirements. The analysis will most likely be performed on an existing calculational spreadsheet model developed by Gilbert/Commonwealth. The model evaluates changes to selected emissions source groups in terms of capital costs and economics by exploring a number of alternatives such as FBC, expansion or connection of district heating systems, gas conversion, or other fuel switching options. Improvements to the system in terms of reducing energy distribution loss, or end-use conservation, will also be considered in the model, and a recommendation will be made based on the best solution for the Usti-nad-Labem region. These calculated values will be utilized to perform the economic and financial analysis for the determination of the least cost alternative capable of meeting the power house requirements. A study period of 1995 through the year 2010 has been proposed.

IMPLEMENTATION PLANS / NEXT STEPS

The results of this study are anticipated to provide input to the City's Zone Plan, the Development Plan for the Year 2005. This plan is schedule for completion in December 1994.

In addition, upon the completion of this study, it is likely that the next steps to implementing the study recommendations will involve the detailed design and financing of the several of the recommended solutions. Although it is possible that concerns and considerations uncovered during the study may need to be addressed by subsequent studies, ultimately the question of financing will become prominent.

Financing

In general the ability of the city and the local enterprises to finance any of the emission reduction projects will depend on the economic health of the Czech economy and that of the individual enterprises. Financing is most likely to come from international lending agencies and equipment vendors. Three of the most prominent international lending agencies are listed and described below:

- World Bank
- European Bank for Reconstruction and Development (EBRD)
- European Investment Bank.

The World bank investment in Eastern Europe has increased substantially in recent years. Recent World Bank lending levels have totaled $543 million, 1.8 billion, $2.7 billion, and $2.2 billion for 1989, 1990, 1991, and 1992 respectively. The expected lending level for 1993 is estimated to be excess of $3 billion.

The European Bank for Reconstruction and Development (EBRD) is a multilateral financial institution established in 1991 to provide loans and equity investment to qualified applicants in Central and Eastern Europe. EBRD has an authorized capitalization of approximately $14 billion, of which 30 percent is currently paid up by its 50 country members. In 1992, the EBRD disbursed ECU 126 million out of ECU 1.2 billion in approved loans and equity injections for projects in Eastern Europe and the former Soviet Union. In most cases, EBRD seeks to share risks though co-financing programs with other international financial institutions and commercial banks.

EBRD's funding is not concessionary. It requires commercial returns on its investments and loans, but is prepared to extend debt repayment periods beyond those available from commercial banks. In addition to its commercial requirements, the EBRD has a strong commitment to improving the environment as a part of its operations. Consequently, rehabilitation projects are required to meet the current European Community (EC) standards and to provide the necessary technology to meet such standards.

The European Investment Bank (EIB) is an autonomous financial institution of the EC established by the Treaty of Rome. The EIB was established to promote greater economic and social cohesion though loans that facilitate capital projects contributing to balanced development of the EC. EIB loans can be granted to public- or private- sector borrowers for financing infrastructure, energy, industry, services, and agriculture with special attention paid to environmental protection.

Lending by the EIB to Eastern Europe has increased steadily, with commitments of ECU 215 million in 1990, ECU 285 million in 1991, and ECU 925 million in 1992. The 1993 lending level is anticipated to reach ECU 1.7 billion in 1993. The EIB will usually finance less than 50 percent of a project's total investment costs, supplementing the borrower's own funds and other sources of finance.

In general, it is likely that these lending agencies would want the City of Usti and/or the individual enterprises to meet the following requirements for the proposed projects:

- Demonstration of the technological soundness of the proposed project;
- Funding of new capital investments is at least partially from the involved party funds (approximately 30 percent or more);
- Elimination of state subsidies in related commodities (e.g. natural gas, district heating,); and
- Compliance with the lending agencies guidelines for environmental sound projects.

The information gathered and the analyses to be performed for this study will be structured in a manner to provide a first step in the satisfaction of these requirements.

ACKNOWLEDGMENTS

This work has been sponsored by AID and has been funded through the DOE Contract AC01-94FE62747, Task 2, awarded to Gilbert/Commonwealth on October 4, 1993. Gilbert/Commonwealth is a Reading Pennsylvania based Architect/Engineering firm experienced in power generation, emission compliance, economic analysis and international projects. Gilbert/Commonwealth has subcontracted The North Bohemia Economic Association (NBEA) to assist in the characterization of the present situation, selection of the potential options, development of capital cost values, and engineering support. NBEA is a non-government, non-profit voluntary membership organization composed primarily of local heavy industries involved in energy use and pollution. The two primary goals of the NBEA are to assist these industries/companies in the transition to a free market economy and to clean the environment.

ZIAR-NAD-HRONOM EMISSION REDUCTION AND ENERGY SUPPLY ALTERNATIVES

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ABSTRACT

As part of the overall effort in support of a Presidential Initiative, the U.S. Department of Energy (DOE)/ Fossil Energy (FE) Office of Coal Research and Development has been conducting, under U.S. Agency for International Development (AID) sponsorship, a number of studies to assist the Eastern European countries in the transition to more efficient energy utilization with reduced pollution. The primary objective of this study is the reduction of emissions in the power plant within the Zavod Energeticke Hospodarstvo (ZSNP) aluminum plant near the city of Ziar-nad-Hronom, Slovakia. The power plant supplies steam, hot water and electricity to the aluminum plant, and also heat to the city of Ziar-nad-Hronom and local industry. At the time of this writing, the study was in the data gathering phase. Emission reduction options will be examined to determine which option provides the least cost solution while meeting the emission and energy requirements. A conceptual design will then be developed for the option that proves to be the most cost effective. This paper addresses the task objective, current situation (equipment, fuels, emissions, and energy demands), projected energy and emission requirements, anticipated emission reduction options, and the technical and economic analysis to be performed.

INTRODUCTION

The U.S. AID has channeled funds through the U.S. DOE for the purpose of assisting Eastern European countries by providing economically based study projects. DOE has contracted Gilbert/Commonwealth, Inc., (G/C) to study emission reduction alternatives for the "Energy Unit", or power plant, within the ZSNP aluminum plant in the city of Ziar-nad-Hronom. The objective of the project is to determine the most cost effective energy production alternative capable of meeting the required emission limits, and satisfying the steam, hot water and electric demands. A least cost economic analysis will be performed on a cumulative present worth of costs basis and will be analyzed from the perspective of the ZSNP power plant entity.

Project Objectives

Specifically, the following objectives have been established for this project:

- Characterize the current status of the energy supply facilities, consumers, and emissions at the ZSNP Aluminum plant in Ziar-nad-Hronom;
- Develop cost-effective alternatives for reducing emissions from the power plant entity;
- Provide recommendations for cost effective improvement of the existing situation; and
- Develop a conceptual design of the recommended option.

The analysis will consider the following factors:

- The current status of the generation units, distribution system, demand and emission levels. (This information, along with the minimum changes required to meet future emission limits will define the base case.)
- The impact of emissions legislation on both new and existing generation units.
- A steam and hot water demand projection which reflects projected growth, conservation and control measures, and natural market forces.
- A spectrum of alternate supply side options which can be part of the total picture in meeting both the demand and emission levels. The most likely alternatives include (1) a fluidized bed combustor (new or repowered), (2) a gas turbine combined cycle, (3) a gas turbine repowering of an existing boiler, (4) flue gas desulphurization, and/or (5) fuel switching.

PRESENT SITUATION

The ZSNP power house is expected to become a daughter plant of the aluminum plant some time in 1994 but will continue to fulfill its current role of supplying heat, electricity, and water treatment to the aluminum plant and heat to the city and local industry. The power house also supplies a limited amount of maintenance work. The major function of the Energy Unit is the generation of both thermal and electric power. The installed thermal capacity of the steam generator is 269.5 MWt. The installed electric capacity of the steam turbines is 28.0 MWe. The existing facilities are described more fully on the next page.

Energy Supply Facilities

The power house is comprised of seven boilers, three turbine generators, and several district heating heat exchangers. A schematic of the major power house equipment is presented in Exhibit 1.

The first five boilers (nos. 1 through 5) are grate boilers that are antiquated, inefficient and serious polluters. All five boilers were produced by CKD-Dukla in 1956. These boilers primarily fire coal. Natural gas is used for stabilization.

Boiler nos. 6 and 7 are pulverized coal units that were built by SES in 1992 and 1985 respectively. The units have the ability to utilize gas firing up to 33 percent and 100 percent load for boiler nos. 6 and 7 respectively. The major parameters of these seven boilers are summarized in Exhibit 2.

Exhibit 1
ZSNP Power Plant Cogeneration Schematic

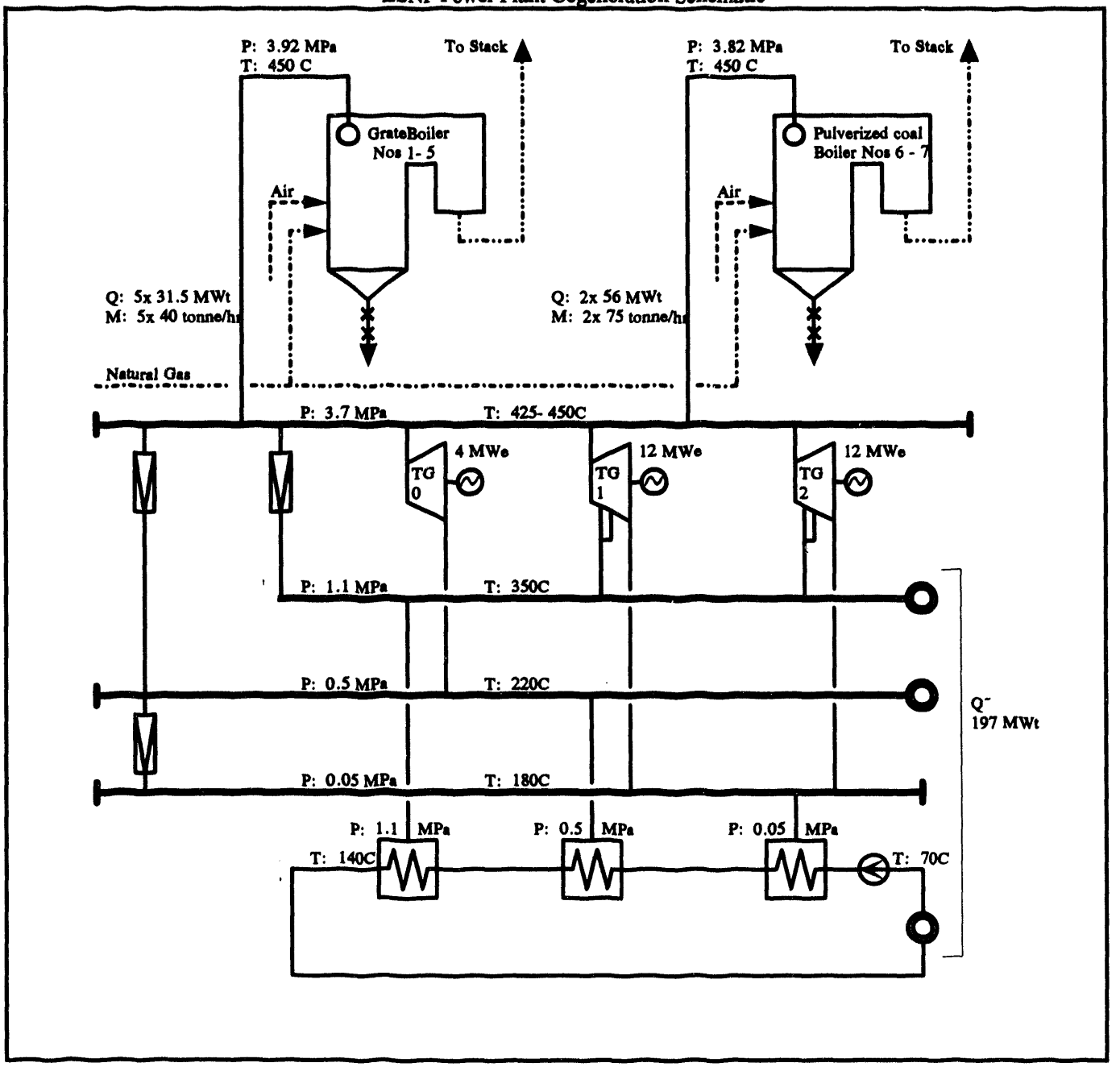


Exhibit 2
Major Boiler Parameters

Parameter	Units	Boiler nos. 1-5	Boiler no. 6	Boiler no. 7
Nominal Output, Thermal	MWt	31.5	56.0	56.0
Nominal Output, Steam Flow	tonne/hour	40	75	75
Working Pressure	MPa	3.92	3.82	3.82
Working Temperature	°C	450	450	450
Boiler Efficiency	%	69	83.5	84.5

The remaining life of the five grate boilers has been estimated to be approximately 12 years. The drum and evaporator tubes are original equipment from 1956. The drum corrosion is typical of its age with corrosion depths of 0.5 to 1.0 mm. The steam superheaters and air and water preheaters have historically been replaced quite regularly. This situation was improved when the water treatment system was upgraded in 1983. The most significant problem is the poor condition of the brickwork, which is causing the degradation of the structural steel via local overheating. In spite of the remaining life, these boilers are currently considered to be obsolete. These grate boilers have such a poor efficiency that they are utilized only to meet peak requirements and to provide backup capacity.

Boiler no. 1 was partly modernized in 1993 by the introduction of automatically controlled gas burners that can provide up to 60 percent of the total thermal input. Boiler no. 2 will receive the same modernization in 1994. Nevertheless, even after these modifications, the Energy Unit managers still recommend either substantial reconstruction or replacement of these five grate boilers.

Each of the seven boilers are connected to an ESP, which were added in 1986.

The turbine hall contains three steam turbines which are designated as TG0, TG1, and TG2. All three turbines were produced by First Brno Engineering (PBS) in 1956. TG0 is a single casing back pressure unit. TG1 and TG2 are double casing condensing/extraction units with two regulated extractions. The major parameters for these turbines are presented in Exhibit 3

Exhibit 3
Major Turbine Generator Parameters

Parameter	Units	TG 0	TG 1 & 2
Gross Electrical Output	MWe	4.0	12.0
Throttle Steam Pressure	MPa	3.7	3.7
Throttle Steam Temperature	°C	425-450	425-450
No. Regulated Extractions	#	0	2
1st Extrac. Pressure	MPa	NA	1.1
1st Extrac Flow, nominal	tonne/hr	NA	50
2nd Extrac./ Outlet Pres.	MPa	.58	0.05
2nd Extrac / Outlet Flow	tonne/hr	NA	40

In the 1970s, PBS modified TG1 and TG2 to be capable of being converted back and forth between extraction/condensing operation in the summer and back pressure operation in the winter. This conversion takes approximately two weeks. However, since 1988 the turbines have operated in the back pressure mode year round.

The technical condition of these turbines are generally consistent with their age. TG0 has approximately 300,000 hours of operation, while TG1 and TG2 both have approximately 200,000 hours. All three turbines are considered to be obsolete by the Energy Unit managers, and possess an antiquated control system that is no longer appropriate nor able to fulfill the current operational requirements.

District Heat Distribution and Utilization

The City of Ziar has approximately 25,000 inhabitants. High-rise apartments buildings utilize the district heating supplied by ZSNP. Individual homes usually have their own source of heat. The local hospital also has its own heat supply. As an aggregate, approximately 80 percent of the city is supplied by heat from the plant. The district heating portion of the power house has essentially no direct competition in the city of Ziar.

The district heating system operates with a 140°C hot water supply and a return leg of 70°C. The hot water is distributed through a main pipeline (a feeder line) and a primary side network leading to 43 heat exchange stations scattered throughout the city.

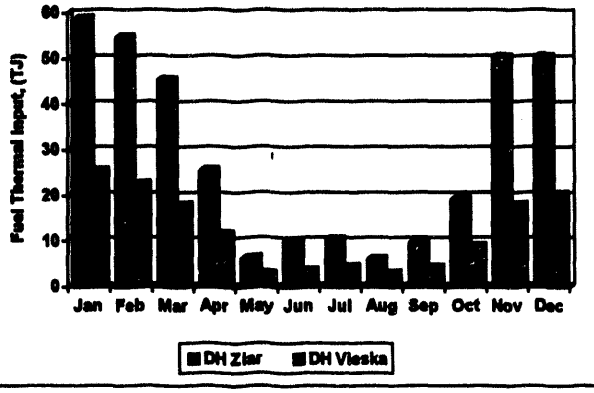
The general condition of the distribution system is best characterized by the age of its various segments. The main pipeline is in good condition. The primary lines going to the heat exchangers are 30 years old and are no longer in good condition. The maintenance of the main and primary lines are the responsibility of ZSNP. The heat exchangers and secondary lines after the heat exchangers are not owned nor maintained by ZSNP.

Besides supplying heat to the district heating system for the city of Ziar, heat from the ZSNP Energy unit is also used to

supply the Vieska settlement located next to the ZSNP factory. The heat transportation medium is hot water at 100°C/80°C. The distribution system is not in good condition. Heat consumption of this settlement is lower than that of the district heating system to the city of Ziar by approximately 60 percent.

The 1993 heat delivery to the district heating systems for both the city of Ziar and for the Vieska settlement are displayed in Exhibit 4.

Exhibit 4
Annual Heat Delivery in The Ziar and Vieska DHS



Historical Consumption

The 1993 power house output was 3.032 x 10^6 GJ thermal. This output is distributed among several different thermal media as summarized in Exhibit 5.

Exhibit 5
Heat Consumption Applications and Media

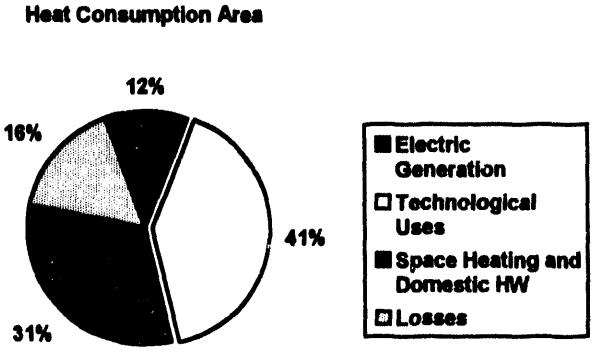
Thermal Media	Pressure	Temperature	Application
Steam	3.7 MPa	425-450°C	Electric Generation
Steam	1.1 MPa	350°C	Technology Purposes
Steam	0.58MPa	220°C	Technology Purposes and Space Heating
Steam	0.05MPa	180°C	Steam to HW Exchangers
Hot Water		110/80°C	Space Heating • ZSNP • Nearby Industry • Vieska
Hot Water		140/70°C	Space Heating for City

The distribution of this heat consumption is presented in Exhibit 6.

Exhibit 6
Heat Consumption Applications and Media

Heat Consumption Area	Heat Consumption Percentage
Electric Generation	11.6%
Technological Uses	40.6%
Space Heating & Domestic HW	31.5%
Losses[a]	16.3%

Note: a. The high "losses" percentage results from the inclusion of feedwater preparation in this losses term. This preparation is estimated to be approximately 9.5% of the power plant heat production.

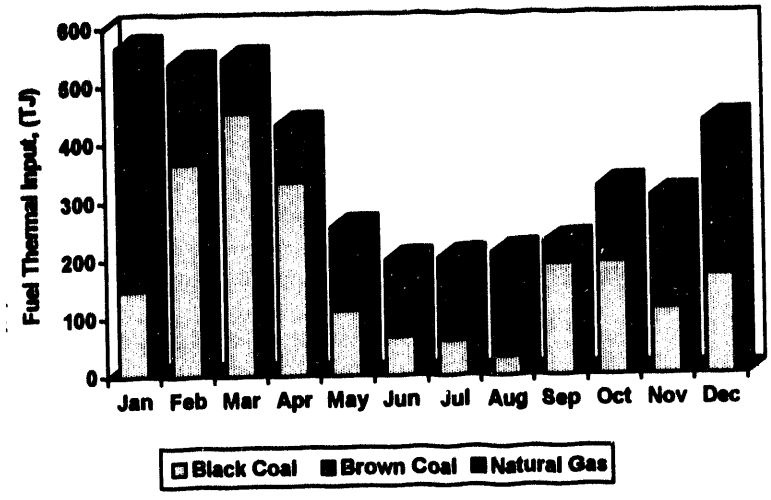


The consumption of electricity at the ZSNP aluminum plant is much greater than what is produced in the power house. The electricity generated by the power house supplies less than 5 percent of the required electricity. After a new electrolysis unit goes into operation in 1994, the purchases from the national grid are expected to rise to approximately 1600 GWh in 1995. The electric generation for 1993 was only 71 GWh. In order to meet the new demands of the electrolysis unit, a high voltage interconnection to the national grid has recently been built with a capacity of 220 MW.

Available Fuels

Recently the only fuels utilized in the Energy Unit are: black Polish coal, brown coal from the Sokolov region and natural gas. The specific monthly fuel usage for the year 1993 is presented in Exhibit 7. The utilized fuels are purchased without long term contracts and result in the purchase of coal from many different sources and suppliers.

Exhibit 7
Fuel Heat Input to ZSNP Energy Unit



Based on Monthly Fuel Consumption and an Annual LHV

The major characteristics of these fuels are presented in Exhibit 8. Sample ultimate analyses for these coals and natural gas are found in Exhibits 9 and 10 respectively.

Exhibit 8
Typical Fuel Characteristics

Parameter	Units	Black Polish Coal	Brown Sokolov Coal	Natural Gas
Lower Heating Value	MJ/kg	17.0	12.5	
	MJ/Nm^3			35.9
Water Content	%	10-20	35	
Ash Content	%	20-30	25	
Sulfur Content	%	1.2-1.8	1.1	
	mg/Nm^3			0.2-0.8

Exhibit 9
Typical Ultimate Analyses for the Utilized Coals

Parameter	Units	Black Polish Coal	Brown Coal from Sokolov
Carbon	%	41.40	35.59
Hydrogen	%	2.70	2.98
Nitrogen	%	0.56	0.42
Oxygen	%	9.51	10.06
Sulfur	%	1.08	0.84
Water	%	22.85	36.11
Ash	%	21.45	14.00
Total	%	99.55	100.00
LHV	MJ/kg	17.0	12.5

Exhibit 10
Typical Ultimate Analyses for the Utilized Natural Gas

Parameter	Units	Natural Gas
CH_4	%	97.40
C_2H_6	%	1.05
C_3H_8	%	0.34
C_4H_{10}	%	0.13
C_5H_{12}	%	0.04
C_6H_{14}	%	0.03
CO_2	%	0.18
N_2	%	0.83
Total	%	100.00
Sulfur	mg/m^3	0.491
LHV	MJ/m^3	33.26

The proportion of coal and natural gas presently utilized in the power plant is presented in Exhibit 11.

Exhibit 11
Present Fuel Utilization by Boiler and Fuel

Boiler	Units	Coal	Natural Gas
Boiler 1 to 5	%	75	25
Boiler 6	%	85	15
Boiler 7	%	82	18

A major natural gas pipeline is very close to the ZSNP power house. The design capacity of the gas interconnection to the power house is 20,000 Nm^3/h. Currently the unutilized pipeline capacity is sufficient to supply a small 30 MW natural gas fired gas turbine, or up to a 50 MW gas turbine should the current gas consumption of boilers be reduced. The pressure in the pipeline, however, is lower than that required. Instead of boosting the pressure, the most cost effective solution is likely to be the construction a new 2 km interconnection designed to supply a suitable gas pressure level. ZSNP is likely to be willing to pay for the 2 km pipeline in exchange for an appropriate long term gas contract.

ZSNP, like all large gas users, has been and still is receiving a natural gas price subsidy. This subsidy will be removed as the prices move to a market based economy. Currently the subsidy is stated in terms of US dollars, so as the crown devalues, the subsidy is decreased. The natural gas pricing projections will be evaluated as part of this study.

Compliance coal: Low sulfur coal is not readily available in Slovakia. Historically, coal has only been sold on a heating value basis. However, even if 0.9 percent S coal were available, the boilers would still require natural gas co-firing of approximately 30-40 percent (on a thermal basis) in order to meet the current emission requirements for 1999. The specific source of this low sulfur coal is not clear. Although it would certainly cost more than the $50-55/ton of the imported black coal.

Current Emission Levels

Emission levels are measured for all seven boilers by the Department of Environment Protection for dust, SO_2, NOx and CO. These measurements are usually performed two or more times each year. In addition, the power plant has purchased a portable flue gas analyzer in order to augment the measurements of SO_2 and CO.

Actual average emission levels recorded in 1992 are presented in Exhibit 12. These values have been adjusted to the standard basis of 6 percent O_2 in the flue gas and standard conditions (101.32 kPa, and 0°C). These emissions correspond to combustion with brown coal and natural gas. For a point of reference, the corresponding emission limits are presented. These emission limits are the combination of the legal limit and more restrictive limits imposed by an EBRD loan agreement. (Additional information on these limits can be found under the Emission Regulation subheading.) The emission levels in excess of these limits are italicized.

Exhibit 12
Typical Boiler Emission Levels as measured in 1992

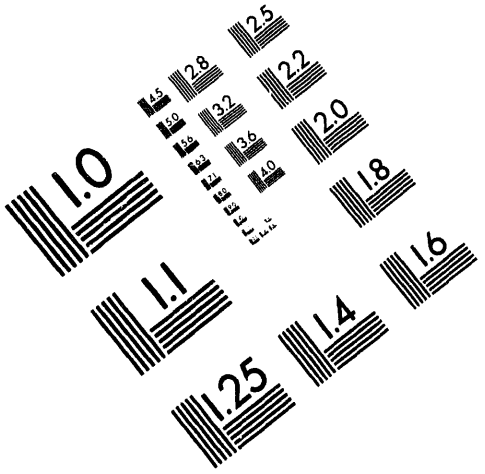
Boiler	Flue Gas Flow (m^3/hr)	Dust (mg/m^3)	SO_2 (mg/m^3)	NOx (mg/m^3)	CO (mg/m^3)
Boiler no. 1	42,273	*169*	*1,781*	183	*846*
Boiler no. 2	38,713	*547*	*2,363*	281	*666*
Boiler no. 3	35,754	70	*1,814*	235	*884*
Boiler no. 4	44,032	*171*	1,044	218	*728*
Boiler no. 5	32,848	29	*2,330*	210	196
Boilers 1-5 Limit[a]		**100**	**1,700**	**650**	**250**
Boiler no. 6	82,432	*445*	*3,121*	360	71
Boiler no. 7	67,356	*320*	1,598	496	70
Boilers 6-7 Limit[a]		**100**	**1,700**	**550**	**250**

Note a. The reported limits are a combination of the legal limit and more restrictive limits imposed by an EBRD bank loan. Additional discussion can be found in the Emission Regulation subheading.

The 1992 dust emission levels exceed the future limits for all of the boilers except boiler nos. 3 and 5. All seven boilers utilize ESP particulate control constructed in 1986. Examination of the ESP design and the current fuel reveals that the ESPs should be capable of meeting the 100 mg/Nm^3 limit in all of the boilers. That is, the emission violations are a result of the ESP being in poor repair, and should be correctable by proper maintenance. This assertion was confirmed after maintenance on boiler no. 7 reduced the emission level from 320 to 36 mg/Nm^3. Therefore, keeping the ESPs in good technical condition should eliminate the current dust emission problem. Significant fuel changes, however, can upset the ESP collection efficiency and need to be accounted for whenever fuel switching is considered for meeting the SO_2 emission limit.

The task of meeting the proposed SO_2 emission limit is the must significant problem which most be addressed by the power house. The 1992 emission levels exceeded the limits for all but boiler nos. 4 and 7. The reason boiler nos. 4 and 7 meet the limit is most likely the utilization of unusually low fuel sulfur levels during the test measurement period. Since the boilers are currently uncontrolled with respect to SO_2, emission levels are primarily a function of the fuel sulfur only. Unlike the dust problem, maintenance will not solve this problem. Technological solutions or fuel switching options will be required. The temporary solution of switching to a mixture of low sulfur coal and an increased use of natural gas will be implemented until an economical long term solution can be determined. This temporary solution will need to be implemented by January 1995 or earlier.

The 1992 NOx emission levels currently meet the anticipated emission limits for all seven boilers. These emissions can not be dismissed from concern however, since an increase in gas utilization to alleviate the SO_2 problem can raise the NOx levels.



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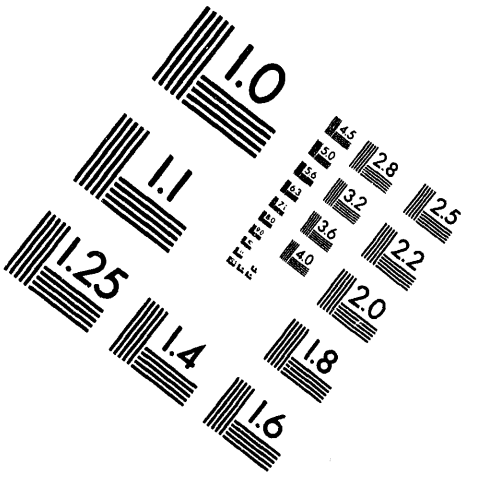

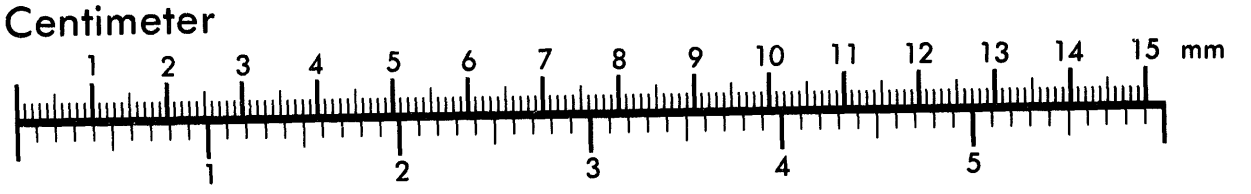

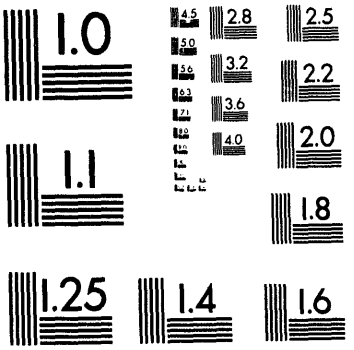

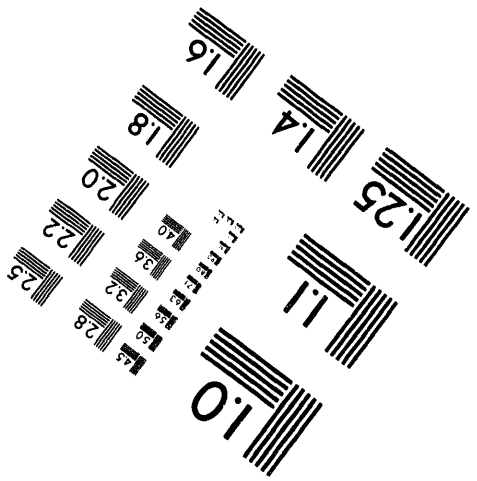

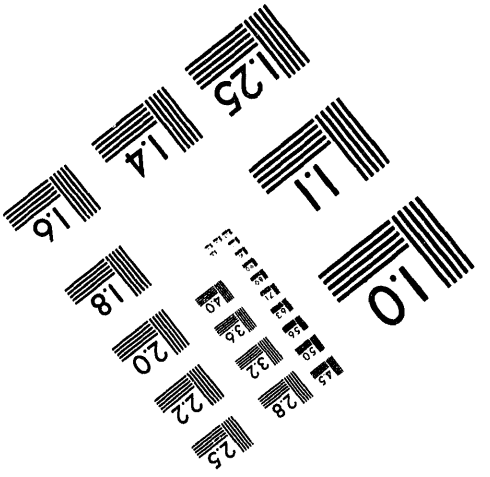

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The flue gas CO levels significantly exceeded the regulation limit of 250 mg/Nm^3 for boiler nos. 1-4, with 1992 level ranging from approximately 700 to 900 mg/Nm^3. Boiler nos. 5-7 are in compliance. Some reduction should be possible through boiler tune-up.

Waste Disposal

ZSNP has an ash storage site which is capable of another two or three more years of disposal at the current disposal rate without any further development. After this time period, ZSNP will either need to reconstruct the current site, develop an additional storage site or find a significant ash utilization option. Currently no ash utilization is implemented. ZSNP owns land for a future disposal, although the costs associated with opening up and maintaining this disposal site are expected to be quite high as the environmental regulations continue to tighten. As of March 1994, ZSNP favored the option of reconstructing the existing site. The reconstruction would be performed in phases, in order not to disturb the operation of the power plant. The ash disposal site capacity after reconstruction would be 1.6 million m^3, or roughly 20 years of projected ash storage. Should an FBC unit be the recommended option, the projected ash disposal site lifetime would be somewhat shorter.

FUTURE REQUIREMENTS/ PROJECTIONS

Emission Regulations

Starting January 1999, the boilers will be required to meet stringent emission limits based on Act Nos. 309/1991 and 134/1992 Coll. issued by Slovak National Council (Parliment). Besides this, ZSNP will agree to an additional emission level reductions in conjunction with the loan agreement with EBRD. These additional emission limits are expected to be effective starting January 1, 1995. Both of these limits are presented in Exhibit 13, and a composite limit is presented for the boiler groupings 1-5, and 6-7. The composite limit was also presented in Exhibit 12, the typical 1992 emissions level table, and shows that the largest problem is the SO_2 emissions.

The Slovak Republic is now in the process of re-evaluating the emission limits for single and multiple plant sites of various sizes. One of the changes proposed is the specification of so called "composition (mixture) limits." When multiple types of fuel (e.g., coal and gas) are fired in one combustor, a composite limit is applicable, which is calculated as the weighted average of the fuel types being used. This composite limit is appropriate whenever the proportions of the heat input from the primary fuel type is less than 80 percent. When the primary fuel type supplies more than 80 percent of the thermal input, the emission limit of this single fuel type is applicable. Until the re-evaluation is complete, combustors firing multiple fuel types at the same time must meet the applicable emission limit for the fuel supplying the majority (more than 50 percent) of the thermal input.

Demand Projections

No major change is expected in the heat demand of the city's district heating system. Growth in the consumer base is assumed to be roughly offset by anticipated conservation measures over the next five to 10 years. Specifically, the heat consumption of the Ziar district heating system is expected to remain at approximately 361x10^3 GJ, while the consumption of the Vieska settlement is expected to remain at approximately 125x10^3 GJ.

Exhibit 13
Emission Limits

Boiler	Dust (mg/m^3)	SO_2 (mg/m^3)	NOx (mg/m^3)	CO (mg/m^3)
Boiler no. 1-5 Limit, per Act No. 309, 1991[a]	150	2,500	650	250
Boiler no. 1-5 Limit, per EBRD loan agreement	100	1,700	650	Not Specified
Boiler nos. 1-5 Composite Limit	**100**	**1,700**	**650**	**250**
Boiler no. 6-7 Limit, per Act No. 309, 1991[a]	100	1,700	550	250
Boiler no. 6-7 Limit, per EBRD loan agreement	100	1,700	550	Not Specified
Boiler nos. 6-7 Composite Limit	**100**	**1,700**	**550**	**250**

Note a. The Slovak Republic is now in the process of re-evaluating these limits for single and multiple plant sites of various sizes.

Changes are, however, expected in the area of the technological heat consumption. The largest technological heat consumer is the alumina production line. Its consumption represented about 84 percent of the total heat consumption for technological uses in 1993. This 1993 heat demand value corresponds to an alumina production level of about 150,000 tonnes/year. To date, alumina has been produced by two separate technologies: a sintering process and the Bayer process. After performance of a market analysis and the completion of the new electrolysis process, the ZSNP Board has decided, in March 1994, to terminate the alumina production by the sintering method upon the depletion of the existing bauxite reserves (expected in July, 1994) and to continue with the Bayer method operation. After that time, a realistic alumina production level will be approximately 60,000 tonnes/year. This will have a significant impact on the power stations technological heat consumption. The heat consumption of the alumina production line will be lowered by more than 60 percent compared to the current level, while the total heat consumption supplied by the ZSNP power station will be reduced by about one third, down to the level of about 1.472×10^6 GJ.

From this total heat demand of 1.472×10^6 GJ, the proportion of technological heat is estimated to be approximately 34.5 percent. Fifty-seven percent (57%) of this technological heat use is supplied by 1.1 MPa steam with the remainder being supplied by 0.58 MPa pressure steam. The 0.58 MPa steam is also used for space heating purposes both within the ZSNP factory and by external heat users. (13% of the total space heating demand is from 0.58 MPa steam.) Some external customers utilize the 1.1 MPa pressure steam for space heating (5.8%). Otherwise, the prevailing medium for heating purposes is hot water (81.2% of the total heat demand for space heating.)

Electrical Rate Agreements

Preliminary discussions with the World Bank on financing a gas turbine option have resulted in the requirement of establishing of a long-term electric contract with an electric supplier. The specific price negotiated in the contract would, of course, be of central importance. The negotiated electric price structure should be available in the near future as several discussions have already taken place. It is anticipated that the electric price structure will be known by June 1994.

PAST STUDIES

Several past energy supply option studies can be utilized to help guide the analysis options in this study. One study looked at the reconstruction of boiler no. 5 to an FBC. Other studies/proposals have analyzed 10 different FGD technologies for boiler nos. 6 and 7 since 1991. In addition, two separate gas turbine combined cycle studies have been performed. All of these past studies can be utilized to provide guidance, lessons learned, capital costs, etc. for the technical and economic analysis to be performed in the latest study.

The 1990 FBC study analyzed the replacement of boiler no. 5 with a 56 MWt (75 tonne/hour) FBC. The FBC was assumed to utilized low quality coal (8.57 MJ/kg, 34% H_2O, 41% Ash, and 1.8% S) and achieved a sulfur removal efficiency of 90 percent. The new boiler would have an increased efficiency, decreased use of natural gas, cheaper primary fuel and a reduction in SO_2 emissions. The estimated 1990 investment cost was Ks 214 million.

Although extensively studied, the FGD options for boiler nos. 6 and 7 have largely been dismissed as unattractive in light of the high investment costs. There may however, be one or two promising options.

The first gas turbine combined cycle study, completed in 1992, assumed the reconstruction of boiler nos. 1 and 3 and use of the existing steam turbines. Two separate gas turbines, placed at the current location of boiler no. 2, would tie into reconstructed waste heat boiler nos. 1 and 3. The output of boiler nos. 1 and 3 is maintained by supplemental firing. Existing boiler nos. 4 and 5 are assumed not to operate. The combined cycle would serve as the base load units, while boiler nos. 6 and 7 would provide additional steam as required. The study considered both the addition of two 9 MWe (ABB MARS) and two 13 MWe (GTE 16) gas turbines. An increase in annual electricity production has been estimated as 140 to 210 GWh, depending upon the gas turbine selected. The total investment cost (in 1992 currency) has been estimated as Ks 418.5 million (ABB MARS) and Ks 533.5 million (GTE 16). ZSNP has already received an offer to reconstruct the boilers. First Brno Engineering has submitted a proposal for the gas turbines.

The second gas turbine study assumed the repowering of reconstructed boiler no. 6, and utilize a single 25 MWe gas turbine (ABB GT 10). The output of the reconstructed boiler would remain unchanged; Only the feedwater temperature to the boiler would change. Supplemental firing would be required to maintain the existing steam conditions. The reconstructed boiler efficiency is estimated at 77.1 percent with a total fuel conversion efficiency of 82.6 percent. The configuration would provide an increase in electricity production of 197 GWh/yr. The study was performed with collaboration with Brno, and developed as a turnkey plant. The proposal was priced at Ks 571 million,

(1993 currency, complete, including the 25 percent VAT, but excluding the cost of financing, and legal services.)

OPTION ANALYSIS

The alternatives to be analyzed will be required to meet the imposed emission limits and energy requirements of the city and the ZSNP alumimum plant. This requirement includes the decreased total heat demand and increased electricity requirement resulting from the anticipated changes in the aluminum production processes and levels.

Potential Emission Reduction Alternatives to be Analyzed

A number of alternatives can be utilized to meet the energy and emission requirements. The most likely alternatives include:

1. A fluidized bed combustor
2. A gas turbine combined cycle
3. A gas turbine repowering of an existing boiler
4. Flue gas desulphurization
5. Fuel switching.

The final selection of which alternatives to analyze will be performed in a joint meeting between ZSNP power house representatives, EGU Bratislava and Gilbert/Commonwealth representatives, tentatively planned for May 1994.

Technical and Economic/Financial Analysis

The technical analysis to be performed will be based upon the selected options, meeting the required energy demands, and emission requirements. The analysis will most likely be performed on an existing calculational spreadsheet developed by Gilbert/Commonwealth. The model predicts the fuel consumption, emission levels, electricity produced by the gas and steam turbines, sorbent feed and waste generation levels resulting from the develivery of the required steam generation. These calculated values will be utilized to perform the economic and financial analysis for the determination of the least cost alternative capable of meeting the power house requirements. A study period of 1995 through the year 2010 has been proposed.

Economic analysis will be based on a spreadsheet approach which assigns prices, escalation, and discounted costs/revenues to commodities and other expenses as developed in the technical model. The figure of merit is the "Cumulative Present Worth of Projected Costs/Revenues" for the study period.

Conceptual Design

Once the most cost-effective solution to the emissions/efficiency problem at ZSNP power house has been determined, a preliminary conceptual design will be performed to assist the powerhouse in the implementation of the selected option. The conceptual design will include items such as:

- Plant design criteria
- Plant description
- Process flow diagrams
- Heat and mass balance
- Electrical one-line drawings
- Equipment layout
- Major equipment list.

IMPLEMENTATION PLANS / NEXT STEPS

Once this project has completed, it is likely that the next steps to implementing the solution will involve the detailed design and financing of the selected option. Although it is possible that concerns and considerations uncovered during the study may need to be addressed by subsequent studies, ultimately the question of financing will become prominent.

Financing

In general, the ability of ZSNP to finance any of the emission reduction projects will depend on the economic health of the Slovakian economy and that of ZSNP. Financing is most likely to come from international lending agencies and equipment vendors. Three of the most prominent international lending agencies are listed and described below:

- World Bank
- European Bank for Reconstruction and Development (EBRD)
- European Investment Bank.

The World bank investment in Eastern Europe has increased substantially in recent years. Recent World Bank lending levels have totaled $543 million, $1.8 billion, $2.7 billion, and $2.2 billion for 1989, 1990, 1991, and 1992 respectively. The expected lending level for 1993 is estimated to be excess of $ 3 billion.

The European Bank for Reconstruction and Development (EBRD) is a multilateral financial institution established in 1991 to provide loans and equity investment to qualified applicants in Central and Eastern Europe. EBRD has an authorized capitalization of approximately $14 billion, of which 30 percent is currently paid up by its 50 country members. In 1992, the EBRD disbursed ECU 126 million out of ECU 1.2 billion in approved loans and equity

injections for projects in Eastern Europe and the former Soviet Union. In most cases, EBRD seeks to share risks though co-financing programs with other international financial institutions and commercial banks.

EBRD's funding is not concessionary. It requires commercial returns on its investments and loans, but is prepared to extend debt repayment periods beyond those available from commercial banks. In addition to its commercial requirements, the EBRD has a strong commitment to improving the environment as a part of its operations. Consequently, rehabilitation projects are required to meet the current European Community (EC) standards and to provide the necessary technology to meet such standards.

The European Investment Bank (EIB) is an autonomous financial institution of the EC established by the Treaty of Rome. The EIB was established to promote greater economic and social cohesion though loans that facilitate capital projects contributing to balanced development of the EC. EIB loans can be granted to public- or private- sector borrowers for financing infrastructure, energy, industry, services, and agriculture with special attention paid to environmental protection.

Lending by the EIB to Eastern Europe has increased steadily, with commitments of ECU 215 million in 1990, ECU 285 million in 1991, and ECU 925 million in 1992. The 1993 lending level is anticipated to reach ECU 1.7 billion in 1993. The EIB will usually finance less than 50 percent of a project's total investment costs, supplementing the borrower's own funds and other sources of finance.

In general, it is likely that these lending agencies would want ZSNP and the proposed project to meet the following requirements:

- Demonstration of the technological soundness of the proposed project;
- Funding of new capital investments is at least partially from ZSNP funds (approximately 30% or more);
- Elimination of state subsidies in the cost of natural gas, and district heating;
- Compliance with the lending agencies guidelines for environmental sound projects; and
- Establishment of a long-term electricity pricing structure contract.

The information gathered and the analyses to be performed for this study will be structured in a manner to assist in the satisfaction of these requirements.

ACKNOWLEDGMENTS

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EVALUATING PROGRAMS TO REDUCE BUILDING SECTOR ENERGY CONSUMPTION: BULGARIA'S FIRST STEPS

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ABSTRACT

Bulgaria, like other East European nations, is making the difficult transition from a centrally planned to a market economy. This economic transformation requires policy, institutional, and market reforms. The objectives of this project are to promote and support the development of indigenous capabilities in Bulgaria to formulate, evaluate and implement policies and programs to reduce energy consumption in the building sector. Electrotek is working with the recently established Bulgarian Energy Efficiency Foundation (EnEffect), and their subcontractors, to understand and develop policy/program evaluation capabilities and methodologies, and to evaluate a number of selected programs in the municipality of Gabrovo. This paper presents the progress to date, and identifies the significant issues that have been addressed during the course of the work.

INTRODUCTION AND BACKGROUND

The Bulgarian government is striving to increase the energy efficiency of residential and public buildings to help offset higher energy costs to consumers resulting from energy price decontrol. The United States Agency for International Development (USAID) is providing the technical assistance required to identify and evaluate programs and policies which will encourage energy efficiency in the buildings sector. The U.S. Department of Energy (USDOE) is cooperating with USAID in providing this assistance. Electrotek is the contractor providing technical assistance, and is working closely with the Bulgarian Energy Efficiency Foundation toward this end. Within the Bulgarian government, the Committee on Energy (COE) and the Ministry of Regional Development and Construction are participating in the project's activities. The project began in March 1993, and is scheduled for completion in June 1994.

The objectives of this project are to promote and support an understanding of the framework for program and policy formulation and evaluation in Bulgaria directed toward reducing energy consumption in the building sector. These objectives have been achieved by working closely with representatives from one municipality (Gabrovo), the Bulgarian Energy Efficiency Foundation and other Bulgarian energy and building experts. It should be noted that the objectives of the project are not to identify the most suitable policies/programs for the building sector in Bulgaria, nor to provide analytical tools for policy evaluation - there is insufficient data and budget for such an extensive activity. Rather, the objective is to work with Bulgarian experts in formulating and evaluating example programs and policies, including potential delivery mechanisms, using readily available data.

PROJECT APPROACH

From the outset of the project, it was agreed that the project team's efforts should focus on developing the tools, methodologies and capabilities in Bulgaria to evaluate energy programs and policies that will improve the energy efficiency of the residential and commercial building stock in country. As opposed to a conventional program/policy evaluation, it was felt that the chosen approach is the best way to build the necessary capabilities in Bulgaria. To accomplish this, the project team selected the municipality of Gabrovo as the "host" for the project. Gabrovo was jointly selected by EnEffect, COE, USAID and Electrotek, from an initial list of five municipalities - Aitos, Devin, Gabrovo, Etropole

and Strajitza - based on capabilities within the municipality to participate in the project, on data availability, and on the commitment of the municipal governments to energy policy reform.

The project team has worked with representatives of Gabrovo to characterize the existing energy supply and demand situation, and to identify and select candidate program/policy options for evaluation. The specific steps in the project are detailed below.

Identify & Characterize Municipalities for Project Participation

In order to demonstrate the value of program/policy evaluation in terms that were appropriate to the candidate municipalities, it was fundamental that the municipalities help to define the framework for evaluation. This consisted of helping both EnEffect and Electrotek to understand the building sector energy situation, and to identify strategies that might be feasible for improving energy efficiency in each of the five municipality's building sectors. EnEffect and Electrotek met representatives from each of the municipalities to discuss their current energy and building sector profile. Particular attention was paid to efforts or initiatives that the municipalities have undertaken in these areas.

With these efforts, EnEffect and its contractors collected considerable information about each of the municipalities, and also developed an understanding of the issues and problems concerning energy consumption and the building sector. Furthermore, these efforts also provided a clearer understanding of what data resources were available, as well as other additional data that would be required.

In order to make the selection of the municipality, a decision analysis approach was used. Based on the information obtained during the meetings, as well as additional information received during site visits to several of the municipalities, Gabrovo was selected.

Select Program/Policy Options

The definition of the program/policy options addressed the specific profile of the participating municipality - Gabrovo - including the building stock, climate, energy end-use patterns, and specific municipal and institutional issues. Once this information was collected and compiled, a list of potential programs and strategies was developed by EnEffect and Electrotek, and subsequently presented to Gabrovo for consideration.

Define Building Sector

To perform a program/policy evaluation, properly defining the context of the analysis domain is essential. Representatives of EnEffect and Gabrovo characterized the municipality in terms of its specific elements of definition (e.g. building sector profile, building sector population, energy prices, energy technologies). With a high resolution municipal-specific characterization, a more accurate evaluation could be conducted.

Define Building Sector Data Requirements

The building sector data requirements are those data that are necessary to support the program/policy evaluations. These requirements are used to define "building types" in the analysis. A building type data set is a profile of each of the significant building types in Bulgaria. A significant building type is one which, in this case, on a municipal level consumes significant energy resources. The data necessary to define the building types reflect both the building stock in Gabrovo as well as its availability. Among the data collected are: building construction type and population, disaggregated by size and function; space and water heating fuel for each building type, disaggregated by fuel type and source (i.e. local/individual boiler versus district heat); and energy consumption profiles disaggregated by end use, building type and fuel source.

Collect Building Sector Data

Once the data requirements were agreed upon, the matter of data collection was addressed. First, it was necessary to identify potential sources of data. Next, data availability, accessibility and quality were addressed. In some instances, there were multiple sources for data, and in those cases it was necessary to objectively evaluate each of the potential data sources and select those that most accurately and efficiently provided the information needed for the analysis.

Once the sources of data were identified, the collection process commenced. The data were organized by EnEffect, according to formatting requirements proposed by Electrotek. The assistance of Gabrovo was timely and essential, ensuring effective data collection and compilation. This was critical given the quantity of data involved. Gabrovo also had a key role in reviewing these data.

Develop Evaluation Methodology

In this task, a framework was produced for the analysis of program/policy evaluation. This task was undertaken primarily by Electrotek, and consisted of developing an analytical procedure to be used in evaluating energy program/policy options for the building sector. The objective of this effort, using data researched or developed for this project, was a methodology that allowed for a systematic assessment of program and policy options that are designed to promote energy efficiency in the building sector.

Apply Evaluation Methodology to Municipality Program/Policy Options

Prototypical building characteristics were used to develop energy consumption profiles for each of the building types. These profiles were developed based on the building envelope of each of the building types along with the annual energy consumption of the residential and public building sectors. The energy program/policy options were evaluated in terms of how these options would alter the energy consumption of each of the prototypical building types. These total costs of these energy reductions were evaluated based on three different fuel cost scenarios (low, medium and high), along with the costs of program development and implementation. Additional scenarios were run based on alternative penetration rates for the policy options, as well as different levels of energy conservation effectiveness.

DATA SUMMARY

Building sector and energy data were collected by the Bulgarian Energy Efficiency Foundation and its subcontractors, with the assistance of representatives of the Municipality of Gabrovo. These data were used to characterize energy consumption in residential and public buildings in Gabrovo, and have provided the basis for defining and evaluating program/policy options to improve the building sector energy efficiency. In addition, they give a broad understanding of the types of buildings (size, construction type and function) in Gabrovo, along with the fuels that are used for space and water heating.

Construction Characteristics

Brick/block buildings represent the majority of the residential and public buildings sector construction in Gabrovo. In the residential sector, brick/block buildings account for over 70% of the building stock (See Figure 1). Adobe accounts for about 26% of the residential construction. In the public buildings sector, brick/block buildings account for almost 90%, with cast-in-place concrete accounting for most of the balance (See Figure 2). Hence, it appears that programs/policies targeted at these dominant building types are appropriate.

Heating System Characterization

Nearly 80 percent (23,790 out of 30,310) of the residential dwellings in Gabrovo are heated with individual boilers or local space heaters (Figure 3). Of these dwellings, about 40% are heated with individual electric heaters, 40% with coal or wood stoves and 20% with coal boilers. Given the predominance of electricity (approximately 9,500 residences) for primary and supplemental

space heating, there are ample opportunities to reduce the electric space heating load. In addition, there is extensive use of electric water heaters.

About 5% of the residential dwellings are connected to regional district heating plants. In these dwellings, supplemental space and water heating, primarily with electricity, is often used. The need for this supplemental heating is driven by the district heating plants delivery schedules, which provide thermal energy for only a few hours during each day. This supplemental electric space and water heat is an area that could be targeted with energy policies/programs.

Finally, the remaining 17% of residential dwellings receive space and water heat from the local electric-heat generating plant. Little supplemental space or water heat seems to be required at these buildings. These residential flats, however, lack thermal regulating devices such as valves or thermostats, resulting in poor control. Frequently, the occupants of these buildings resort to venting excess heat through open windows for regulation.

A problem common to nearly all of the residential dwellings is excessive heat loss resulting from poor thermal integrity of the brick/block buildings. This presents a significant opportunity to encourage and promote building energy conservation.

Approximately 86 percent of the 104 public buildings in Gabrovo are heated with individual boilers, primarily diesel or fuel oil-fired (Figure 4). Generally speaking, the thermal integrity of these buildings is poor, and can be targeted with energy programs/policies. In addition, boiler maintenance programs provide an additional opportunity to reduce fuel consumption given the total amount of space heat provided by these boilers in the public buildings sector.

Seven public buildings are connected to regional district heating plants, while nine are connected to the local electric heat plant. The thermal integrity of these buildings is poor and could be targeted with programs/policies. In addition, programs/policies could also be directed at improving the heat exchange between the local heating network and the buildings.

ENERGY POLICY/PROGRAM OPTIONS

The following policy/program options were selected by EnEffect, Electrotek and representatives of Gabrovo based on their applicability in Gabrovo, their potential impact on building sector energy consumption, and their ease of implementation.

Reduce Building Heat Loss

Promote weatherization and insulation of building envelope. A major factor in the volume of energy consumed is the energy efficiency of the building shell or envelope. The efficiency of the building envelope is a function of the interior and exterior temperature differences and the rate of energy loss or gain due to conduction, convection and infiltration. Several measures that can be undertaken to improve the building envelope efficiency are:

- Attic insulation
- Insulation of hollow cores
- Exterior insulation
- Caulking/Weatherstripping

There may be several delivery mechanisms for promoting the improvement of building envelope characteristics. Broadly speaking, these can include increasing the incentives for building owners, residents or third parties to undertake these measures. Among the kinds of delivery mechanisms that can be used are:

- Tax incentives for investments in energy conservation measures.
- Third party financing, where the cost of the measures is borne by a party other than the building owner who stands to benefit from the investment.
- Information campaigns to increase public awareness and promote public participation.

Improve Heat Regulation/Control

Install Building Level Heat Meters, and Apartment Level Thermostatic Radiator Valves and Heat Allocation Devices. In multi-family residences and public buildings served by district heat, there are two fundamental problems that make the process of promoting energy efficiency more difficult. These are: 1) the inability to control the amount of heat provided to individual residential flats; and 2) the lack of heat metering at the building level and in individual flats. Collectively, these two problems discourage energy conservation, since customers have no means of directly controlling their energy consumption, nor do they have a good understanding of how much energy they are consuming.

The installation of thermostatic control valves on radiators would provide consumers with a direct means of controlling their energy consumption. Through the use of these valves, consumers can reduce waste heat by controlling how much thermal energy is supplied. With such an ability, consumers would not have to resort to venting excess thermal energy through open windows, and could thus reduce district heating loads. In addition, consumer comfort levels could be expected to improve with better temperature control.

Typically, because of the lack of metering and heat allocation devices, heating costs have been allocated based on floor space or volume. Such an allocation scheme does not account for differences in energy consumption among individual flats. By installing building level heat meters and heat allocators, individual heat customers can be made accountable for the energy they consume. This accountability, coupled with more efficient heat tariffs based on actual usage, can reduce heat consumption in buildings connected to the district heating system.

The direct participants in a program of installing building level heat meters, thermostatic control valves and heat allocators are the district heating company, the building owners/occupants, and service contractors (mainly plumbers). The responsibility for installing and maintaining this equipment would be that of these participants. While these costs cannot be considered insignificant, there are several possibilities for covering these expenses:

- A cooperative building management structure in residential multi-family buildings to coordinate system installation and operation. The cooperative management could also have the authority to allocate funds from energy savings to building improvements.

- Financing through a district heating company lease or sales arrangement. Lease or equipment purchase payments can be collected through monthly heating bills. The revenue losses of the district heating company can be offset by sales or lease payment revenues for this equipment.

Reduce Fuel Consumption in Local Boilers

Boiler tune-up programs. The amount of space heating provided by liquid-fuel local boilers in Gabrovo is significant. In both residential and public buildings, local boilers account for the majority of the heating systems in use (See Figures 3 & 4). In the residential sector, local boilers are used in over 75% of the residences, while in the public sector local boilers account for more than 85% of the heating systems. Clearly, with such magnitudes, there are opportunities for energy conservation.

By properly maintaining boilers, fuel consumption will be reduced. Simple measures such as routine adjustments to fuel/air ratios and firing rate are important for minimizing fuel consumption. In addition, routine cleaning of heat exchanger surfaces, through blowdown or chemical cleaning, is also required.

Potential delivery mechanisms for boiler tune-ups include:

- Information campaigns, which can be conducted by the municipal government,

utilities, and/or boiler dealer/repair organizations

- Subsidization programs administered by the municipal and federal government

- Shared savings arrangements with public or private third party organizations.

General Institutional Reforms

There are many processes and reforms that will promote building energy efficiency that have significant potential, but are not easily quantifiable. In a general sense, these measures foster an improvement in the institutional structures that will encourage more long-term energy efficiency. Such institutional changes can establish a more direct relationship between energy consumers and energy suppliers, and provide consumers with more information and options for energy services.

An example of an infrastructural investment to reduce building energy consumption is the installation of metering and thermostatic control systems for hot water or steam systems in individual flats at multi-family residences. Such a measure would create in each residence a direct relationship between energy consumption and energy cost. Hence, energy consumers would have a direct incentive to reduce their energy consumption through strategies of their own choosing.

Additional benefits to be derived f:om such a program would be the ability to e:nploy more innovative pricing to influence energy consumption patterns. Such pricing, which can include more broadly based time-of-use rates, would provide customers with an incentive to alter their energy consumption patterns and allow the utilities to more effectively and efficiently recover their costs.

The participants in institutional reform include federal and municipal governments, utilities, and building occupants and owners. In the case of federal and municipal governments, measures that can be undertaken include legal and regulatory mandates, such as regulations requiring utilities to install more meters, mandates for the use of time-differentiated pricing for certain customer classes, regulatory measures requiring the development and implementation of conservation programs by utilities for the building sector, and high efficiency appliance standards and building codes. Another means of promoting building sector energy efficiency would be through the use of financial incentives such as tax deductions, tax credits, or government assisted financing (e.g. low-interest loans, loan guarantees, research & development grants).

The role of utilities as active participants in institutional reform measures can also be critical to the process of improving building sector energy efficiency. Utility initiated programs can, as previously noted, be mandated, or may be voluntarily undertaken to further develop building sector energy efficiency. Such utility-initiated measures can be further promoted with the introduction of cost-recovery mechanisms for direct expenses incurred or for lost revenue due to lower energy sales.

The role of institutional reform is to provide a favorable policy and regulatory framework, and to remove barriers to conservation investment. In addition, there are ancillary benefits to institutional reform, including innovation, and the development of information and technical assistance infrastructure to consumers. In a general sense, institutional reform can be used to promote the development of infrastructure through investment.

There are a number of measures that can be considered institutional reforms can be promoted. These include:

- The acceleration of market pricing for energy

- More progressive regulation of electric and district heating utilities

- The passage of national energy legislation to promote energy conservation and efficiency

- The provision of education programs for decision-makers and planners.

POLICY/PROGRAM ANALYSIS MODEL

The principal objective of our effort in Bulgaria was to promote an understanding of the program and policy evaluation process. After a series of meetings with members of EnEffect and with representatives from Gabrovo, and with a review of the data resources available, it was decided that the most effective approach would be one which provides an analytical framework, a starting point, from which more rigorous analytical methods and more extensive data development could evolve. Our purpose was not to provide a state of the art technical analysis or to perform an extensive analytical exercise, but to engage and involve our Bulgarian partners in constructing an analytical approach, and using it for the evaluation of three program options.

For this effort, the period of analysis is eleven years, 1995 - 2005. There are three options that have been evaluated for the residential and public building sectors. For the residential sector the three programs are: 1) Attic insulation; 2) Weatherization; and 3) The installation of heat meters and thermostatic valves. For the public and commercial buildings the three programs are: 1) Weatherization; 2) Boiler tune-ups; and 3) The installation of heat meters and thermostatic valves.

The analytical approach used begins with an inventory of the building stock for both the residential and public/commercial sectors. These building types are differentiated by construction type, size/function, and primary heating source. In the residential sector, there are 20 building types, while in the public/commercial building sector there are 40 building types. Figure 5 presents a flowchart of the analytical approach used.

For the base case, in which no conservation measures are taken, each building type has a calculated average annual heating load, which reflects its particular thermal characteristics and function, based on data provided by the municipality and EnEffect. For each of the program/policy options, the annual heating load is calculated based on the conservation potential of the option along with its penetration rate for the period of analysis by building type. Fuel costs are then calculated for the base case and each program/policy option using low, medium and high fuel price scenarios.

Emissions are also estimated for the base case and each program/policy option for each building type. Three types of emissions are considered: sulfur dioxide (SO_2); carbon dioxide (CO_2); and particulates (PM-10). Each residential and public sector building type has an emissions rate (kg/GCAL), based on its heating fuel type, for each of these three pollutants. These rates are applied to the respective residential and public sector heating loads, by building type, scenario and year.

The next element in the analysis is the calculation of program/policy implementation costs. These costs consider both fixed and variable elements, including administration, direct labor and material costs associated with the establishment and administration of each of the program/policy options. The variable costs are based on the penetration rates of each option over time and considers both labor and material costs.

PROJECT RESULTS

Based on the analysis conducted for the residential sector, several conclusions can be drawn. First, all of the program/policy options, based on the participation rates evaluated, can make significant contributions to energy conservation. Table 1 presents a summary of these energy savings for each of the scenarios evaluated for the residential building sector. In all cases, maximum energy savings were achieved with the weatherization program.

Cost savings and cost-benefit ratios, which must consider total implementation costs, are strongly influenced by the energy prices used. Implementation costs, which include material, labor and administrative expenses, can be estimated with a fairly high degree of confidence. Energy price projections, however, are typically very speculative in market based economies, and even more uncertain in transitional economies,

given the historical role of the political system in energy pricing.

For our analysis, three fuel cost scenarios were used, reflecting different time periods for the equilibration of Bulgarian energy prices to world market energy prices, as well as different rates of world fuel price escalation. Table 2 presents the residential building sector cost-benefit ratios of the weatherization program, attic insulation program, and heat meter and thermostatic valve installation program for the low, medium and high energy price projections.

CONCLUSIONS

There are many difficulties and challenges facing all of the East European economies in their transition from a centrally planned to a more market based foundation. The challenges to assuring a smooth transition, particularly in regards to the energy sector, are daunting. In making this transition, Bulgaria is faced with many decisions that will have a significant bearing on how effectively and efficiently energy is used. In terms of building sector energy efficiency, there are many program and policy options available. To effectively promote energy efficiency, it is necessary to evaluate these options to determine which ones are most cost-effective.

This process is one which, if it is to be successful, must have ownership in Bulgaria. Given that, Electrotek has worked very closely with EnEffect and other agencies in Bulgaria to first assess the building sector energy situation in the host municipality, Gabrovo, to identify candidate programs, and finally to develop an analytical framework to evaluate these programs.

What this effort represents is not a computer model or an analysis, but a framework. This framework is a starting point which integrates the elements necessary to conduct a program evaluation. What will determine the ultimate success of this effort is not the accuracy of the forecasts, but the level of understanding imparted to our Bulgarian partners. For it is ultimately their efforts in improving, enhancing and further developing this framework that will determine its technical merits.

In the new democratic state of Bulgaria, as in any democracy, ideas need advocates and proponents. The effectiveness of these proponents is determined in large part by the quality of their information, both for formulation and dissemination. From a policy formulation perspective, the success of any program is dependent on the efforts at promoting an understanding of what these programs are, and how they can succeed.

ACKNOWLEDGEMENTS

We have had the privilege of working closely with the very capable and diligent members of EnEffect, and wish to acknowledge their significant efforts and contributions to this effort. In particular we would like to acknowledge the contributions and efforts of Zdravko Genchev, Peter Kambourov, and Maria Dyankova of EnEffect. In addition, we would like to express our sincerest appreciation to the Ministry of Regional Development and Construction and the Committee on Energy for their cooperation and assistance, especially Maria Diamandieva. In addition, we would like to acknowledge the generous support and assistance provided by Mr. Tom Secrest of Pacific Northwest Labs, for his assistance in this effort.

Based on our experience in Bulgaria, we have tremendous confidence in the capabilities of our Bulgarian colleagues in successfully taking this first step, and in following it with continued progress, improvement and refinement.

TABLE 1
GABROVO RESIDENTIAL BUILDING SECTOR
PROJECTED ENERGY SAVINGS (GCAL)
1995 - 2005

Scenario	Weatherization	Attic Insulation	Heat Meters
Base Case	47,214	26,964	16,184
Low Program Penetration	42,494	24,463	14,562
High Program Penetration	51,938	29,907	17,798
Low Conservation Potential	42,493	24,467	14,566
High Conservation Potential	51,936	21,904	15,222

TABLE 2
GABROVO RESIDENTIAL BUILDING SECTOR
PROJECTED COST - BENEFIT RATIOS
(LOW / MEDIUM / HIGH FUEL PRICES)

Scenario	Weatherization	Attic Insulation	Heat Meters
Base Case	0.65 / 0.55 / 0.51	0.64 / 0.54 / 0.50	10.27 / 9.99 / 9.52
Low Program Penetration	0.69 / 0.58 / 0.54	0.71 / 0.60 / 0.56	10.37 / 10.08 / 9.61
High Program Penetration	0.62 / 0.53 / 0.49	0.58 / 0.49 / 0.46	10.19 / 9.92 / 9.45
Low Conservation Potential	0.72 / 0.61 / 0.57	0.71 / 0.60 / 0.56	11.41 / 11.10 / 10.58
High Conservation Potential	0.59 / 0.50 / 0.47	0.58 / 0.49 / 0.46	10.90 / 10.58 / 10.08

FIGURE 1
GABROVO RESIDENTIAL BUILDING
CONSTRUCTION PROFILE

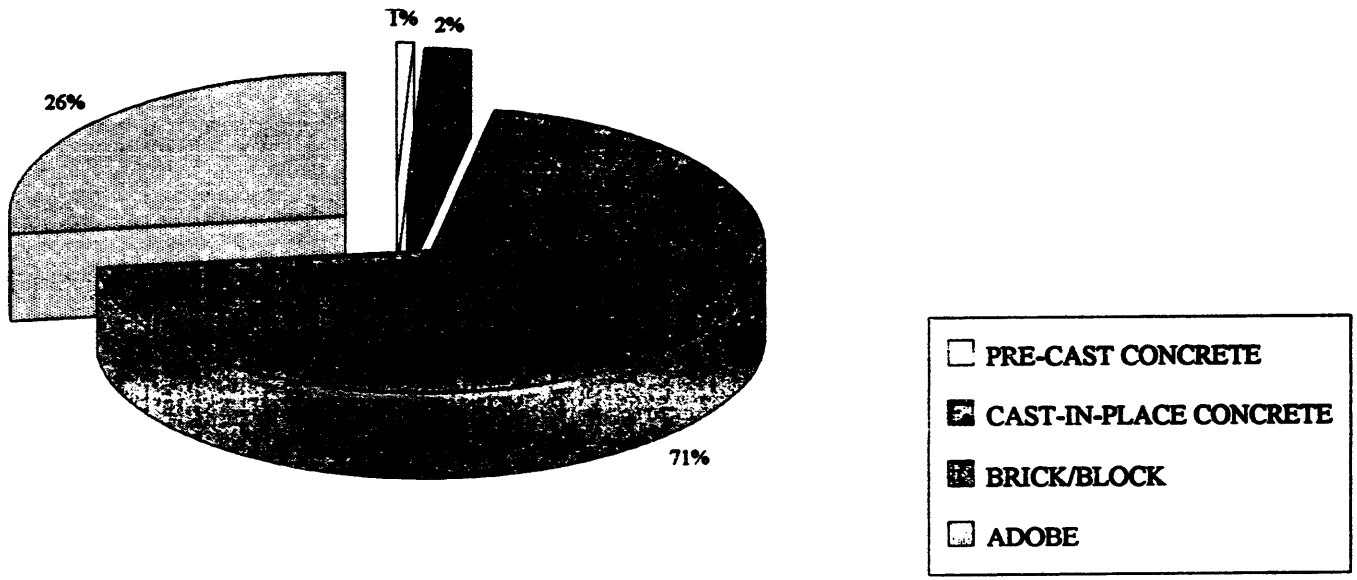


FIGURE 2
GABROVO PUBLIC BUILDING
CONSTRUCTION PROFILE

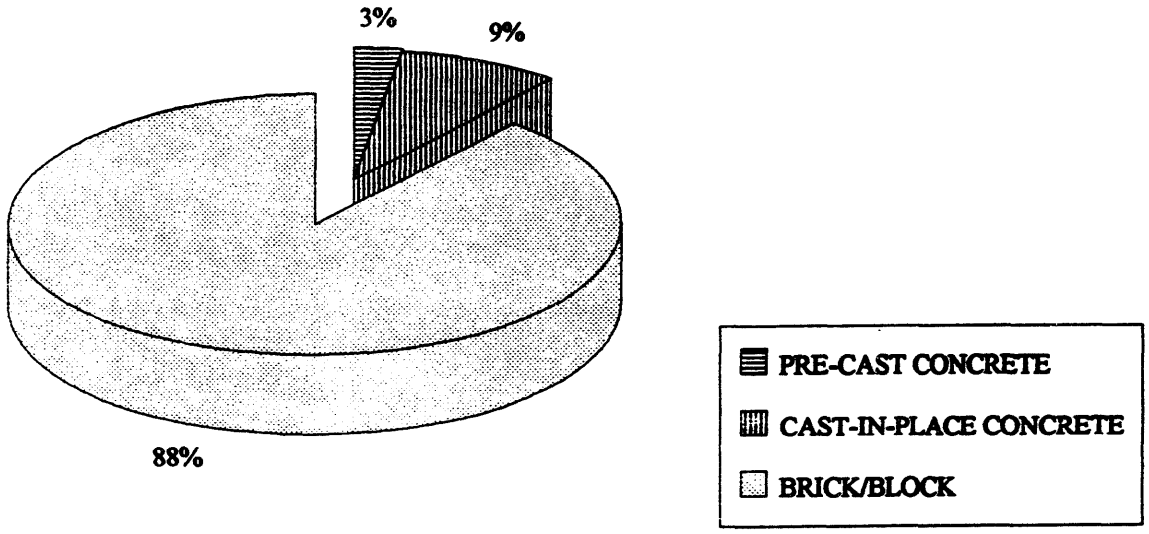


FIGURE 3
RESIDENTIAL SECTOR
HEATING SYSTEM PROFILE

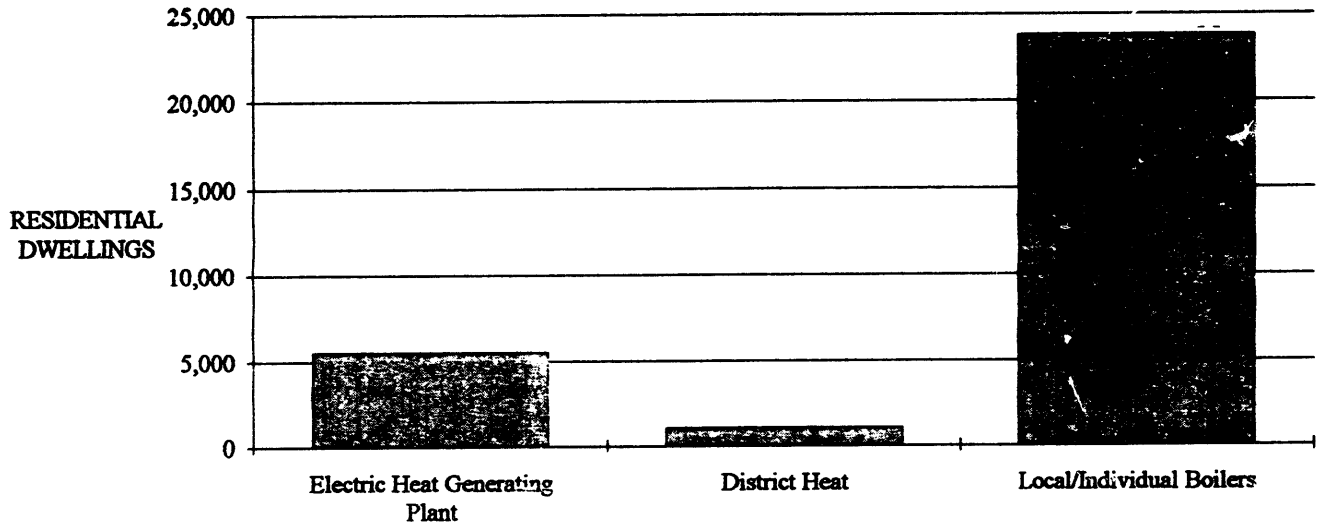


FIGURE 4
PUBLIC SECTOR
HEATING SYSTEM PROFILE

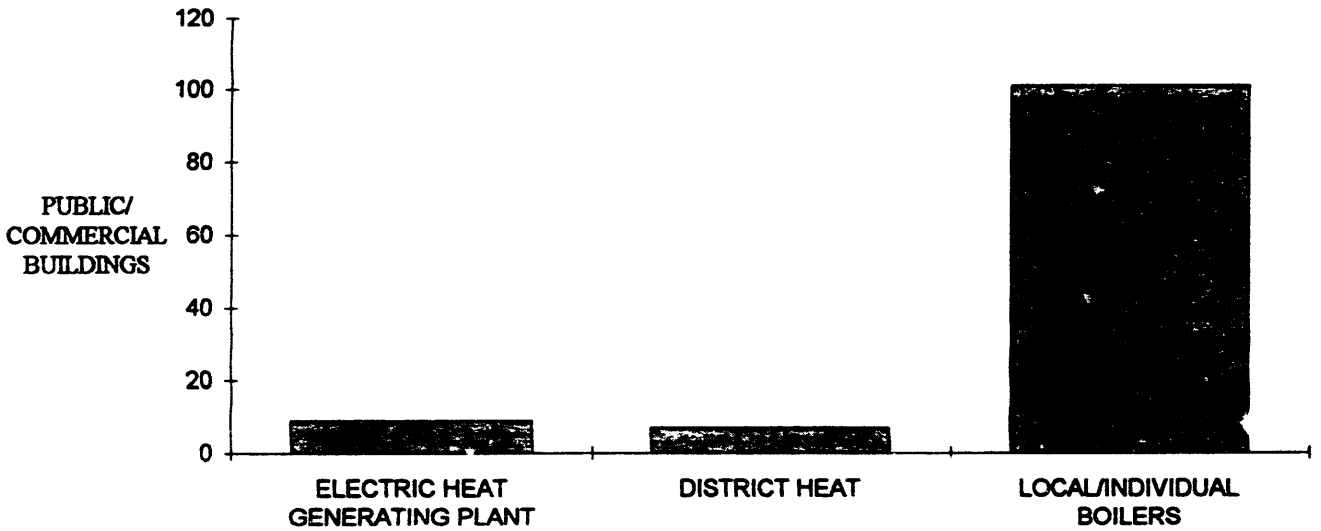
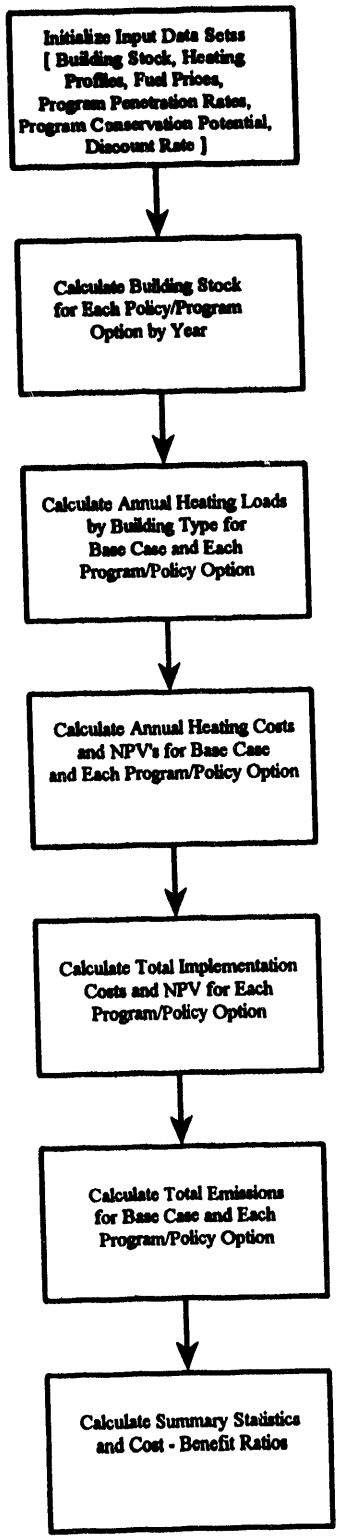


FIGURE 5
ANALYSIS FLOWCHART



Session V
Market Oriented Approaches to Emissions Reduction and Efficiency Improvement: Characterization and Testing

Chairman: Lawrence Markel, Electrotek Concepts, Inc.

Characteristics of Krakow's Boiler Population—Dr. Piotr Cyklis, Politechnika Krakowska • Dr. Jerzy Kowalski, Jerzy Kroll, and Andrzej Wodkowski, Energoekspert • Andrzej Zaczkowski, Biuro Rozwoju Krakowa • Jacek Boron, Miekskie Przedsiebiorstwo Energetyki Cieplnej • Dr. Thomas Butcher, Brookhaven National Laboratory

Performance of Polish Home Stoves—Dr. Tadeusz Jaszczur, Dr. Maciej Lewandowski, Dr. Witold Szewczyk, Academy of Mining and Metallurgy Krakow • Andrzej Zaczkowski, Biuro Rozwoju Krakowa • Dr. Thomas Butcher, Brookhaven National Laboratory

Energy Savings Potential in Multi-Family Residences in Krakow—Lawrence C. Markel, Electrotek Concepts • Adam Gula, Marek Ciechanowski, Jacek Markiewicz, Fundacja na Rzecz Efektywnego Wykorzystania Energii w Krakowie • Richard Szydlowski, Pacific Northwest Laboratories • George Reeves, G. Reeves Associates

Alternative Methods for Reducing Air Pollution from Low Emissions Sources in Krakow—Jan Bieda, Janusz Bardel, Biuro Rozwoju Krakowa • Janusz Nedoma, Ekopol • Barbara Pierce, Brookhaven National Laboratory

CHARACTERISTICS OF KRAKÓW'S BOILER POPULATION

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INTRODUCTION

About 70% of the population of the city of Kraków is provided heat through the district heating system. The combined heat and power plant at Łeg supplies about 50% of the heat to the system and the Skawina power plant supplies another 10%. The balance is provided to the system from a wide variety of smaller, local boiler houses. Many of these are owned and operated by the heat distribution utility - Miejskie Przedsiębiorstwo Energetyki Cieplnej (MPEC). For those residents not connected to the district heating system three types of heating are most common - coal-fired home stoves, direct electric heating, and single building boilers (coal- or gas-fired). In this paper the characteristics of the local boiler houses and the single-building boilers which are coal-fired are discussed. These sources are seen as particularly important for air quality in Kraków for two reasons. First, these sources have very high emission factors. Unlike the large power plants at Łeg and Skawina these smaller boilers do not have high efficiency dust collectors. Also, because of the nature of the boilers they often have high emissions of volatile organics and CO. The second factor which makes these sources so important is their location - very close to residents.

BOILER SURVEY

Information presented here on this population of smaller boilers comes from a variety of sources. The City of Kraków, through Biuro Rozwoju Krakowa (BRK), conducted a detailed survey on these boilers between 1990 and 1992. The survey was done in two parts. The first survey covered boilers which supply heat to more than one building. This includes large boiler houses which provide a combination of steam to local industries and hot water for either the central or local district heating systems. This first survey also includes smaller boiler "rooms" which may be located in the basements of buildings and supply heat to a few neighboring buildings. The survey included the type, size, make and model, location, age, ownership, utilization and fuel consumption for every district heating boiler in the city.

Based on this first survey there are about 2,900 boilers in Krakow's 1,344 boilerhouses, providing about 35% of the heating needs of the city. About 77% of the boilers, representing about 86% of the capacity and almost 90% of the fuel use, are solid-fuel fired. More than 370,000 metric tons of coal and coke are consumed annually in these boilers. Eighty-eight percent of the boilers operate only during the heating season. Nearly half of the solid fuel-fired boilers are less than 10 years old.

The solid fueled boilers included in the first survey include two primary types: gravity feed, travelling grate ("stoker-fired") boilers and hand-fired boilers. Most of the boilers, more than 2000, are small, hand-fired units, and these account for about half of the total capacity and almost 40% of the fuel use. There are 227 traveling grate boilers which use coal and represent 48% of the total capacity and almost 60% of the fuel use. Table 1 provides a summary of the population of the district heating boilers which are included in the first Kraków survey. The only pollution control devices used are cyclones for particulate removal. About 10% of the district heating boilers are equipped with the cyclones and most of these are larger, stoker-fired units. Approximately 60% of the annual solid-fuel consumption is in boilers with cyclones. Eighty-five percent of the coal consumption in traveling grate units is in boilers which have cyclones. Only nine percent of the fuel consumed in hand-fired boilers is in units with cyclones.

The second survey which was conducted by the city covered stoves and boilers (all fuels) which heat only one room, one flat, or one building. This provides much less detail than the district heating boiler survey. The most useful information is the area of living space and commercial space for each heating system type. From this survey the number of heating units and fuel consumption can only be estimated. Table 2 lists the distribution of these smaller heating units, based on the second survey.

For the purposes of assessing their relative importance it is currently estimated that there are 2930 of the smaller boilers listed in Table 2 in Kraków with a total installed capacity of 34.2 MW. Annual coal consumption in these units is estimated to be 22,900 metric tons.

Table 1. Solid Fuel-Fired District Heating Boilers in Kraków, 1990 survey

Boiler Type	Number	Design Capacity (MW)	Coal Use (metric tons/year)	Coke Use (metric tons/year)
Overfeed, traveling grate stoker	227	518	233,224	1250
Hand-fired	2021	452	52,023	85,119

Table 2. Distribution of Smaller, Single Room, Flat, or Building Heating Systems

	Area Heated (square meters)		
	Living Area	Non-Living Area	Total
Coal Stoves	1,822,000	150,000	1,972,000
Coal Boilers	299,000	61,000	360,000
Gas	1,427,000	53,000	1,480,000
Electric	458,000	118,000	576,000

The population of hand-fired boilers includes both cast iron boilers, nominally designed for coke use, and steel boilers designed for coal or coal/coke mixtures. The cast iron units are sectional boilers with design capacity adjusted by adding or removing standard sections. Model KZ-5 (manufactured by FAKORA -Łódź), is particularly common, with design capacities from 60 to 172 kW. For smaller units model KWD-K is common, with capacities from 9.8 to 23.7 kW. For larger sizes model ECA-IV (made by DOZAMET -Nowa Sol) is used with capacities from 158 to 493 kW. Firing controls on all of the hand-fired boilers are typically air inlet doors regulated by either water temperature or steam pressure. Hand-fired boilers are normally natural draft, although for those few hand-fired boilers which have cyclones induced draft fans have, of course, been added.

For the hand-fired boilers, cast iron with coke firing is the preferred and most popular arrangement. Relative to coal, coke produces less smoke and requires less boiler system maintenance. However, in the 1980's there was a severe shortage of coke in Poland due to high industrial demand. This led to regulations which prohibited or limited coke use, resulting in use of coal in cast iron boilers as well as the installation of some hand-fired steel boilers specifically designed for coal. Currently there is no coke shortage and its use in hand-fired boilers is encouraged.

Since the completion of the surveys some of the fuel use patterns have changed. It is expected there has been some shift from coal to coke use in the hand- fired boilers. MPEC now uses coke only in all of its hand-fired boiler houses. In steel boilers which cannot burn coke without having problems with overheating, use may have shifted to coal/coke mixtures. In addition, some of the smaller boiler houses included in the first survey have converted to natural gas (new boilers). A new survey is currently being planned.

In the case of the larger, mechanical grate-fired boilers the designs are very typical and common models are the WR series (made by SEFAKO-Sedziszow) and PLM/WLM series (anufactured by RAFAKO -Raciborz). These are all gravity feed stokers with flat, horizontal grates. As discussed above the first survey has shown that most of these have cyclone particulate collectors. It is expected that since the time of completion of this survey the remainder have added cyclone collectors in response to environmental regulations. Some of these boilers have overfire air ports installed. Operation is fully manual.
Table 3 provides a comparison of the current prices paid for fuels commonly used in the boilers (tax included). For the hand-fired boilers coal is clearly less expensive and for this reason its use persists in smaller, privately owned boiler houses and boiler rooms. The coal used in the stoker-fired boiler houses is unwashed duf, typically - 20 mm, from the nearby Silesian mines. This fuel typically contains more fines than is normally considered proper for boilers of this type. The very low relative cost of this, essentially unprocessed, fuel makes its use very attractive.

Table 3. Typical Current Prices of Fuels for Kraków Boilers

	$/ton
duf for stoker-fired boilers	27
graded coal for hand-fired boilers	42
coke for hand-fired boilers	94

Another important source of information about the smaller boilers in Kraków is the results of a testing program recently completed as part of the Kraków Clean Fossil Fuels and Energy Efficiency Program sponsored by the U.S. government through the Agency for International Development (AID) and the Department of Energy (DOE). The objectives of this testing program were to obtain information on the baseline performance characteristics and also to provide a preliminary evaluation of some selected approaches towards improving performance. These studies, done during Phase I of the Krakow program, were planned to provide data for U.S. companies involved later and also to help identify emission sources which should receive the most attention from the City. The following sections of this paper provide descriptions of the organization of the test program and the results.

TEST PROGRAM ORGANIZATION

All boiler tests were done by the consulting firm Energoekspert, under contract to BRK. Brookhaven National Laboratory (BNL), under contract to the U.S. Department of Energy (DOE), provided technical assistance and all test equipment. This equipment has been permanently transferred to Kraków for future use. Most testing was done at boiler houses or boiler rooms owned and operated by MPEC, and MPEC staff assisted in the completion of the planned tests. Testing was done at four sites - two with larger, mechanical stoker-fired boilers and two with hand-fired boilers. One of the stoker tests sites, "Krzeslawice," is in poor technical condition and was selected to be representative of boilers which may be retired in the near future. The other stoker-fired boiler, "Balicka," is more typical of boilers which are expected to remain in service. The hand-fired boilers tested include one site with cast iron boilers designed for coke firing, "Rydla Street," and one site with steel boilers, "Ulanów Street."

At all of the test sites efficiency and emissions studies were done following both U.S. and Polish standards as closely as possible. At the sites which have stoker-fired boilers efficiency measurements were made using the standard heat loss method.[1] It was not practical to use this method at the sites which have hand-fired boilers because of the cyclic nature of normal operations. Instead, efficiency was determined using the direct input-output method which required the addition of instrumentation for accurate measurement of fuel input and heat output.

Particulate emissions were measured using a U.S. EPA method 5 train.[2] This involves capturing particulates on a filter maintained at 120 C. Downstream of this filter is an ice trap from which "semi-volatile" organics are extracted and measured. The most volatile organics were measured downstream of an ice trap using a flame-ionization detector. Other flue gas compounds (O_2, CO, NO_x, SO_2) were measured using an analyzer with electrochemical cells. This analyzer was carefully maintained and frequently calibrated during the test program.

HAND-FIRED BOILER TEST PROGRAM

Rydla Street

The MPEC boiler house on Rydla Street contains three cast iron type hand-fired boilers, model ECA IV. The boiler house delivers hot water to three multi-story buildings and was built between 1975 and 1976. Two of the boilers have rated output capacities of 352 kW each and were manufactured in 1992. The third is rated at 383 kW and was manufactured in 1976. These three natural draft boilers exhaust flue gas into a common breaching ("setting chamber") and chimney. Because of this arrangement it was not possible to test boilers individually but rather they were tested as a boiler system.[3] During the testing program boiler house load, which is essentially determined by outdoor temperature, was constant. Load on individual boilers was varied by changing the number of boilers operating. With 3 boilers at the site this gave three possibilities for load: high (1 boiler operating), medium (2 operating), and low (3 operating).

In normal operation these boilers are stoked about every 6 hours with fuel shoveled onto a cast iron grate through the front door. Firing rate is modulated to maintain desired outlet water temperature by manually changing the position of a damper which admits combustion air under the grate. The door over the fire has an integral air shutter which can be used to provide "overfire" air, which is often used (sometimes with blowers) to promote complete combustion of CO and hydrocarbons over the fire bed. At this site normal practice is to leave this damper closed.

The normal fuel used at the Rydla boiler house is coke. Testing was, in addition, done with a coal/coke mixture and smokeless briquettes produced by the Institute for the Chemical Processing of Coal, Zabrze, Poland. To produce these, hot char from a circulating fluid bed gasifier is pressed together with a preheated coking coal.[4] Fuel properties are listed in Table 4. In addition to different fuels, some different operating procedures were also evaluated. These include the introduction of overfire air and stoking the fuel in thinner layers at the grate. This last procedure obviously requires more frequent stoking.

Table 4. Test Fuels : Hand-Fired Boilers at Rydla Street

fuel properties as-fired		Coke	1:1 Coal and Coke Mixture	Zabrze Briquettes
Water	%	3.13	10.2	3.34
Ash	%	11.1	8.42	11.2
Volatiles	%	2	18.1	8.8
Sulfur	%	0.91	1.02	0.55
Lower Heating Value	kJ/kg	27490	25224	27498

With boilers of this type flue gas emissions are always greatest immediately following fuel additions, as the fresh fuel is being devolatilized. The magnitude of these transient emissions is dependent upon the volatiles content of the fuel. For example, Figure 1 shows the results of measurement of CO in the chimney over two fueling cycles firing coal/coke mixtures. These show that flue gas CO levels were at 3000 ppm just after fueling. In fact CO was really overrange for the analyzer used and was greater than 3000 ppm. Similar transients could be shown for gaseous hydrocarbons and smoke. Because of these strong transients, averaging of emissions over firing cycles was necessary to develop useful emission factors.

Table 5 shows the effect of fuel type on system efficiency and emissions for the normal operating procedures at mid-load. The low volatile coke clearly produces the lowest particulate emissions, indicating that soot- or condensed-organics are primary contributors to the measured particulate emissions. Coke also gives lowest emissions factors for CO, semi-volatile organics and volatile organics. It should be noted that the boiler efficiency in Table 5 is based on the fuel lower heating value as is the customary method in Europe. Using the customary U.S. method of calculating boiler efficiency would produce efficiency values which are lower by 3-4%. This applies to all efficiency numbers in this paper.

Table 6 again compares performance with different fuels at mid-load, but in this case the overfire air port is open for all tests. Opening this port clearly leads to reduced CO with all fuels and reduced volatile organics at least for the briquettes and the mixture. Particulates and semivolatile organic emissions, however, are increased with the overfire air.

For the purpose of combining effects of different pollutants, emissions can be converted to a single "equivalent emission" using a formula which has been issued by the Polish Ministry for Environmental Protection.

$$E_e = \text{particulates} \times 2.9 + CO \times 0.5 + NO_x \times 2.9 + SO_2 \times 1$$

Equivalent emissions both under normal operating procedures and with overfire air are compared in Table 7. The equivalent emissions results confirm the better performance of coke and also show a net benefit with the use of overfire air.

In tests which were done with thinner fuel layers the overfire air port was always open. These tests produced lower efficiency, higher particulate emissions, CO and volatile organics emissions similar to those with overfire air, lower NO_x emissions, and generally higher emissions of semivolatile organics. Overall performance with the thinner layers might have been better if the overfire air ports were closed.

Ulanów Street

For the second site for the hand-fired boiler tests, a steel boiler with coal as the normal fuel, was sought. Since MPEC does not operate such boiler houses, a boiler house inside an office building belonging to the army base at Ulanów Street in Kraków was selected for testing. In the boiler room there are two, identical, steel, hot water boilers, type ES-ZET, which operate only during the heating season. Total installed capacity is 240 kW. Normal operations and the testing methodology are the same as for the hand-fired boiler at Rydla Street. The test

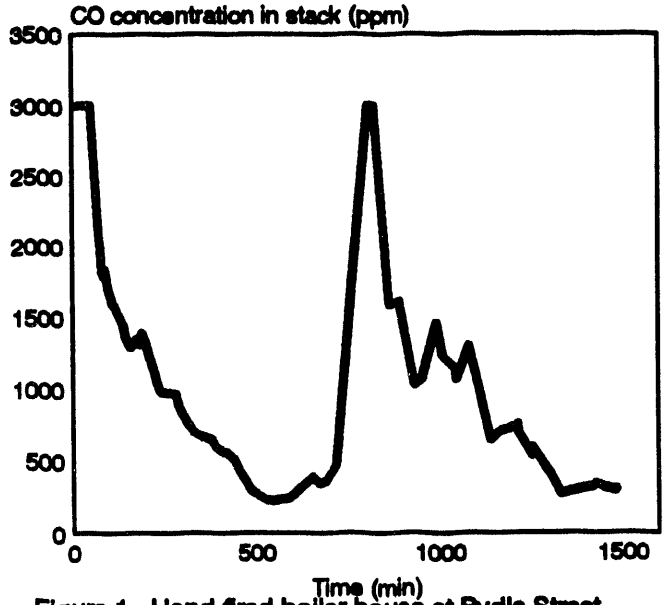

Figure 1. Hand-fired boiler house at Rydla Street. Illustration of CO transient over two firing cycles

Table 5. Results: Hand-Fired Boilers at Rydla Street
Fuel Effects at Midload with Normal Operating Procedures

		Coke	1:1 Coal and Coke Mixture	Zabrze Briquettes
Efficiency	%	72	71	65
Particulates	g/kg	1.5	5.4	4.1
CO	g/kg	70.0	74.4	102.8
Semivolatile Organics	g/kg	0.1	1.1	0.3
Volatile Organics	g/kg	0.5	6.3	3.7
NOx	g/kg	1.4	1.2	1.1
SO2	g/kg	12.0	10.4	7.9

Table 6. Results: Rydla Hand Fired Boilers
Fuel Effects at Midload with Overfire Air Port Open

		Coke	1:1 Coal and Coke Mixture	Zabrze Briquettes
Efficiency	%	73	71	65
Particulates	g/kg	2.1	11.5	17.5
CO	g/kg	46.3	41.3	43.3
Semivolatile Organics	g/kg	0.2	2.2	0.4
Volatile Organics	g/kg	0.5	2.1	0.9
NOx	g/kg	1.4	1.1	1.1
SO2	g/kg	12.3	10.9	7.9

Table 7. Results: Hand-Fired Boiler Tests at Rydla
Equivalent Emissions at Midload

		Coke	1:1 Coal and Coke Mixture	Zabrze Briquettes
Equivalent Emissions with normal operation	g/kg	55.5	66.7	74.5
Equivalent Emissions with overfire air	g/kg	45.4	67.9	83.4

program included effects of fuel type, load, and fuel bed layering. Effects of overfire air which were evaluated at the Rydla Street site, were not evaluated at Ulanów. As at Rydla Street, the load was varied by changing the number of boilers operating to meet the heat demand. This gave roughly two loads--high and medium.

Properties of the test fuels are listed in Table 8. The 70% coke/30% coal blend tested is a typical alternative (to coal) used in boilers of this type. The briquettes tested are from the same source as for the Rydla Street tests.

Table 9 shows the effect of fuel type on system efficiency and emissions for the normal operating procedure at high load (one boiler operating). Table 10 shows these results for the medium load (two boilers operating). Comparison of these Tables with Table 5 shows that the emissions factors for particulates are by far the greatest with 100% coal firing, and reduced particulates are the most significant benefit which can be realized by using fuel alternatives.

Tests with thinner fuel loads, or layering, were done with all fuels at both high and low loads. Results were mixed and differences generally small. Table 11 provides a summary of these results at high load.

As for the Rydla Street results, different pollutants can be combined using the equivalent emissions formula. Table 12 provides this for all tested conditions at Ulanów.

STOKER-FIRED BOILER TEST PROGRAM

Krzeslawice

The Kreslawice boiler house is owned and operated by MPEC and contains four identical PLM-2.51 boilers with a total thermal

Table 8. Test Fuels: Hand-Fired Boiler at Ulanow Street

fuel properties as-fired		Coal	70% Coke / 30% Coal	Zabrze Briquettes
Water	%	2.2	3.3	4.4
Ash	%	9.2	9.6	13.1
Volatiles	%	31.5	10.4	10
Sulfur	%	0.93	0.72	0.62
Lower Heating Value	kJ/kg	28993	27803	26787

Table 9. Results: Hand-Fired Boilers at Ulanow Street
Fuel Effects at High Load with Normal Operating Procedures

		Coal	70% Coke / 30% Coal	Zabrze Briquettes
Efficiency	%	53	63	67
Particulates	g/kg	20.5	12.6	7.6
CO	g/kg	34.2	56.7	39.1
Semivolatile Organics	g/kg	0.72	1.82	0.67
Volatile Organics	g/kg	1.25	2.68	2.38
NOx	g/kg	2.46	1.34	0.54
SO2	g/kg	8.6	7.2	3.6

Table 10. Results: Hand-Fired Boilers at Ulanow Street
Fuel Effects at Mid Load with Normal Operation

		Coal	70% Coke / 30% Coal	Zabrze Briquettes
Efficiency	%	60	65	71
Particulates	g/kg	18.9	6.5	1.9
CO	g/kg	52.3	56.2	43.2
Semivolatile Organics	g/kg	2.5	7	0.3
Volatile Organics	g/kg	4.1	0.8	2
NOx	g/kg	2.2	1.6	1
SO2	g/kg	5.7	5.3	2.6

Table 11. Results: Hand-Fired Boilers at Ulanow Street
Fuel Effects at High Load with Thin Fuel Bed "Layered Operation"

		Coal	70% Coke / 30% Coal	Zabrze Briquettes
Efficiency	%	56	61	67
Particulates	g/kg	26.9	6.5	9.5
CO	g/kg	34.8	32.1	22
Semivolatile Organics	g/kg	1	1.1	0.48
Volatile Organics	g/kg	0.7	0.6	1
NOx	g/kg	2.8	0.7	0.6
SO2	g/kg	11.3	6.7	3.7

Table 12. Results: Hand-Fired Boiler Tests at Ulanow
Equivalent Emissions at High Load

		Coal	70% Coke / 30% Coal	Zabrze Briquettes
Equivalent Emissions with normal operation	g/kg	192.9	195	207.8
Equivalent Emissions with Layered Operation	g/kg	382.5	264.0	179.6

capacity of 11.63 MW. One of these was tested during this program. The boilers are used to produce steam for nearby industries and operate all year. These boilers cannot, practically, be connected to the district heating system and are considered to be excellent candidates for modernization or replacement. Each boiler is equipped with a bank of six cyclones and an induced draft fan. During tests at this site, measurements were made before and after the cyclones to allow cyclone particulate removal efficiency to be determined.

Combustion air can be controlled in three ways: 1) by adjusting radial inlet dampers on each of the fans which feed air under the fuel bed (forced-draft fans), 2) by changing the position of a slide damper located at the boiler exit and 3) by changing the position of inlet dampers on the induced draft fan downstream of the cyclones.

The basic test plan was to first measure baseline performance with the normal fuel and procedures and then to conduct tests over a range of excess air levels and loads with the baseline and other selected fuels. In normal operation, only the forced draft fan inlet dampers are adjusted and, since the operators at this site do not currently have flue gas monitoring equipment available, overall excess air levels are normally very high, leading to low efficiency. Completing the planned test matrix was difficult because of imbalances between the two grates and mechanical condition of the dampers. With some of the test fuels, good performance was only achieved after the testing crew and operators made a great effort to balance the system. In making conclusions about small differences in results between tests, the importance of this factor should be considered.

Properties of all fuels tested at Krzeslawice are listed in Table 13. The normal, baseline fuel is Ziemowit. It is generally agreed that the Ziemowit coal contains more fines than is considered correct for boilers of this type, and one objective during the test was to evaluate benefits of a graded coal. Considerable effort was put into obtaining better fuel both from a size distribution perspective as well as with reduced ash content. The fuels listed as Staszic I and Staszic III were obtained for this purpose. Staszic III coal is a sample of the run-of-mine coal from the Staszic mine in Silesia (Staszic I) which has been washed and graded. Measurements of as-fired size distributions during the test program, however, indicated that Staszic III still contained more fines than is considered optimal. The final coal, listed as "pea coal", was considerably coarser.

Table 14 provides a comparison of the sizing of the as-fired test fuels with sizing recommended by the American Boiler Manufacturers Association for boilers of this type.[5] Lower rank coals should be near the ABMA upper limit and higher rank coals should approach the lower limit. The fuel normally used at Krzeslawice and both of the Staszic fuels are near or above the upper limit. The pea coal represents an extreme case - one in which essentially everything below 5 mm has been removed.

Tests at Krzeslawice were done in two series. The first series which included the Ziemowit and Staszic fuels was done at three loads with three excess air levels. For the other fuels, tests were done only at a single excess air level that was considered to be optimal. This was defined as the lowest excess air consistent with good combustion, based on visual inspection of the burning fuel bed.

In baseline tests with Ziemowit coal excess air could not be reduced below about 150% at high load without leading to clearly excessive unburned carbon losses. As load is reduced, even higher excess air levels (200 - 300%) are required. Most of this excess air is simply uncontrolled casing leaks - even though an effort was made to seal the casing prior to the start of the test program. In addition, flue gas exit temperature was higher than specified in the design. Together, the high excess air and high gas temperature lead to very low efficiency for this boiler - from 56 to 72%. Boilers of this type should be capable of operating with excess air levels less than 100 percent and with thermal efficiencies from 77 to 87%. Under optimal operating conditions, the ash carbon content was about 10% - leading to thermal efficiency loss due to unburned carbon of about 4%. The cyclone dust collector efficiency ranged from 70 to 95% during the test program.

Table 15 provides a summary of the efficiency and emissions results obtained at Krzeslawice with each of the four test fuels at their "optimal" excess air setting and three load levels. Relative to the fuel normally used at this site -Ziemowit - the Staszic coals and especially the washed Staszic III coal, gave reduced emissions and marked improvements in efficiency. In contrast, performance with the "pea coal" was very disappointing. During operation, this coal burned vigorously very close to the point at which it first fell on the grate. This led to poor distribution of heat release on the bed and high flue gas exit temperatures. Considerable effort was put into improving performance with

Table 13. Test Fuels: Stoker-Fired Boiler at Krzesiawice

fuel properties as-fired		Ziemowit Coal	Staszic I Coal	Staszic III Coal	Pea Coal
Water	%	17.4	17.4	7.6	10.9
Ash	%	22.9	23.1	6.1	4.6
Volatiles	%	27.2	26.9	30.9	33.7
Sulfur	%	1.5	0.73	0.72	0.52
Lower Heating Value	kJ/kg	19014	21918	26840	28823

Table 14. Size Distribution of Test Fuels and Comparison with Recommended Distribution: Stoker-Fired Boiler at Krzesiawice

	Percent by weight of sample less than size					
size (mm)	ABMA recommended lower limit	ABMA recommended upper limit	Ziemowit Coal	Staszic I Coal	Staszic III Coal	Pea Coal
12	52	82	73.2	82.0	87.7	10.1
5	16	53	45.1	54.3	63.1	0.6
1	3	17	17.7	22.2	14.7	0

this fuel. Increasing grate speed was not possible without leading to obvious increases in the carbon content of the bottom ash.

Boilers of this type are subjected to regulations regarding the maximum allowed level of pollutant emissions as well as standard fees per kg of emitted pollutant. In essentially every test case, the maximum emission levels were not exceeded. For particulates, the maximum emission level in Table 15 is only 16% of the current limit of 800 g/GJ. Current fees for pollutant emission are: 1100 ZLP/kg of sulfur dioxide and nitrogen oxides, 600 ZLP/kg of particulates, and 300 ZLP/kg of carbon monoxide (ZLP = Polish Zloty). Using these, it is possible to develop a cost-based criterion for comparing fuel alternatives. These results are shown in Table 16 and clearly demonstrate the benefits of the improved fuel. This is a cost-per-unit heat input.

Balicka

The Balicka boiler house is also owned and operated by MPEC and provides hot water to a local part of the district heating system. The boiler tested was built in 1972 and is one of seven at Balicka. It has a maximum continuous rating of 11.6 MW thermal and is the largest of the "low emission sources" in Krakow. A battery of six cyclones are installed for particulates control and the unit is of the balanced draft type. An overfire air fan is installed, although it is not normally used. Such overfire air fans can provide significant performance improvements in boilers of this type, and they are commonly used on new units. The air from these high pressure fans provides mixing in the over bed region, reducing emissions of unburned products and/or allowing operation at lower excess air levels.

Test fuels at Balicka included the normal fuel, Ziemowit, and again unwashed and washed coals from the Staszic mine. During the test program, it was attempted to vary overall excess air by changing the supply of air under the grate. This was not successful because reduced combustion air supplied in this way was simply replaced by increased leakage elsewhere. It was not possible to reduce this leakage by reducing furnace draft because the dampers at the induced draft fan inlet were not operational. Normal practice at this site calls for all air dampers to remain fixed for the entire operating season, a practice which leads to very high excess air (to 500%) at low loads and low thermal efficiency (52%).

Emission factors were generally similar to the baseline conditions at Krzesiawice. No significant improvements were realized with the use of alternative fuels, such as the washed Staszic coal or with the use of the overfire air. This somewhat surprising result may be largely due to the limited ability to control air flows at this site.

DISCUSSION

Based upon the test results at all of the sites, average emission factors have been developed which can be used to compare different emission sources. These are considered to be typical for normal operations at these sites. Estimated emission factors for boilers of these types are also compiled by the U. S. EPA. [6] Table 17 provides a comparison of the emission factors developed during this testing program with the other published factors.

Table 15. Comparison of Efficiency and Emissions
Stoker-Fired Boiler at Krzeslawice

Thermal Efficiency		Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
minimum load	(%)	54.1	62	68.4	58.4
medium load	(%)	53.3	61.3	73.3	62.1
maximum load	(%)	69.1	70.1	66.2	65.8
Particulates		Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
minimum load	g/kg	1.79	1.82	1.4	2.77
medium load	g/kg	2.11	2.76	1.53	1.42
maximum load	g/kg	2.4	1.32	1.34	3.13
Carbon Monoxide		Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
minimum load	g/kg	12.82	9.36	7.52	11.8
medium load	g/kg	20.25	8.18	17.23	7.71
maximum load	g/kg	13.77	4.01	18.06	23.1
Semivolatile Organics		Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
minimum load	g/kg	0.02	0.12	0.17	0.14
medium load	g/kg	0.08	0.09	0.03	0.13
maximum load	g/kg	0.08	0.04	0.05	0.13
NOx		Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
minimum load	g/kg	2.93	2.92	4.32	3.82
medium load	g/kg	3.54	3.02	3.36	3.76
maximum load	g/kg	1.86	1.97	4.16	3.73
SO2		Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
minimum load	g/kg	11.14	4.6	4.56	7.51
medium load	g/kg	12.68	6.03	4.29	6.99
maximum load	g/kg	12.55	6.58	4.72	6.91
Equivalent Emission		Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
minimum load	g/kg	31.2	23.0	24.9	32.6
medium load	g/kg	39.2	26.9	27.1	25.8
maximum load	g/kg	31.8	18.1	29.7	38.3

Table 16. Tests of Stoker-Fired Boiler at Krzeslawice
Cost-Based Criteria for Comparing Fuel Alternatives

	Ziemowit	Staszic I Coal	Staszic III Coal	Pea Coal
Use Cost Based on Environmental Fees (Polish Zloties)	3524	1717	1616	1614

This table does not include a factor for SO_2, which is dependent on fuel sulfur content. Currently, we are using the U.S. EPA formula of 19.5 x %S for the SO_2 emission factor in g/kg. Generally, the results in Table 17 show that emissions from the Kraków boilers are somewhat higher than would be expected for each boiler type. The EPA values can be used to make estimates of the magnitude of emission reductions which might be realized by improving operations, fuels, or physical conditions at the Kraków boiler houses.

Using the emission factors developed from the testing program and available data on fuel consumption, the total contribution of each boiler type to the total emissions inventory in Kraków can be determined. This is presented in Table 18. Several important assumptions were used in developing this, including: 1) all cyclones are assumed to have efficiencies of 85% and 2) it is assumed that half of the coal consumed in hand-fired boilers is used as part of a coal/coke mixture and the remainder as straight coal. Table 18 can be used to make some important conclusions about the population. The stoker-fired boilers with cyclones clearly consume the most fuel, but this category is not always responsible for most of the emissions. Stokers without cyclones emit more particulates than those with cyclones. As discussed earlier, the data used in this paper is based on a survey

Table 17. Recommended Emission Factors and Comparison with U.S. EPA Published Factors [6]

Stoker-Fired Boiler, Coal		Based on Kraków Tests	U.S. EPA
Particulates (before cyclone)	g/kg	14.1	8
CO	g/kg	8.3	3
Semivolatile Organics	g/kg	0.03	-
Volatile Organics	g/kg	0	-
NOx	g/kg	3.5	3.8
Hand-Fired Boiler, Coal			
Particulates (before cyclone)	g/kg	18.8	7.5
CO	g/kg	52.3	45
Semivolatile Organics	g/kg	1.6	-
Volatile Organics	g/kg	4.1	-
NOx	g/kg	2.2	1.5
Hand-Fired Boiler, Coke			
Particulates (before cyclone)	g/kg	2	5
CO	g/kg	70	45
Semivolatile Organics	g/kg	0.07	-
Volatile Organics	g/kg	0.54	-
NOx	g/kg	1.4	1.5
Hand-Fired Boiler, Coal/Coke Mixture			
Particulates (before cyclone)	g/kg	5.4	-
CO	g/kg	74.4	-
Semivolatile Organics	g/kg	1.1	-
Volatile Organics	g/kg	6.3	-

conducted by BRK in 1990-91; some changes have occurred since that time. It may be that now all stoker-fired boilers have cyclones. A new survey to update all of this information is currently being planned. Clearly cyclones, at a minimum, should be required on all such boilers. Hand-fired boilers which use coal are also a very important source of particulate emissions, and wherever possible these units should change to coke or coal/coke mixtures. The hand-fired boilers are the dominant sources of CO and the organics. Changing from coal toward coke use in these boilers will reduce emissions of the organics but not CO. Based on experience gained during the testing program, it may be useful to explore the use of forced, distributed secondary air injection over the fire bed to reduce CO production in these boilers.

All of the results of this testing program lead to some conclusions about approaches which could, at least from a technical perspective, have the most immediate impact on emission of pollutants from Kraków's boilers. In the case of the hand-fired boilers, clearly coke use should be promoted. Also, all stokers should have particulate controls. The efficiency of the stoker-fired boilers is low. Improvements in instrumentation, controls, and mechanical conditions would allow operators to gain about 15% in efficiency with corresponding reductions in

Table 18. Comparison of Contribution of Each Boiler Category to Krakow Emissions

	fuel use	Annual Emissions (metric tons per year)					
	(metric tons per year)	particulates	CO	Semivolatile Organics	Volatile Organics	NOx	SO2
Stokers without cyclones	34984	493.3	290.4	1.0	0.0	122.4	1025.0
Stokers with cyclones	198240	391.3	1645.4	5.9	0.0	436.1	5808.4
Hand-Fired Boilers - coke	59107	118.2	4137.5	4.1	31.9	82.7	1046.0
Hand-Fired Boilers - coal/coke mixtures	52023	280.9	3870.5	57.2	327.7	62.4	931.2
Hand-Fired Boilers - coal	26012	489.0	1360.4	41.6	106.6	57.2	470.8

pollution. The use of improved fuels at the stoker would be beneficial but only if the fuel switch is combined with an effort to optimize performance. An effort of this type must include adequate instrumentation to accurately detemine performance changes.

CONCLUSIONS

The testing program reported on in this paper provides important information on the performance of the varied types of boilers in Kraków and lends to suggestions for improvements. Primary conclusions are:

- The current stoker-fired boilers have unusually low efficiency due to limited instrumentation and controls and poor mechanical condition. Improvements in efficiency of about 15% could be obtained through a combination of improved fuels in combination with an optimization program. These boilers would benefit greatly from the addition of automatic controls.

- For the stoker-fired boilers: the substitution of Staszic coal for Ziemowit coal makes it possible to reduce operating costs through higher efficiency. However, this is possible only when improved instrumentation and/or controls can be added. This cost reduction is estimated to be about $15,000 per year per boiler. Overall emission reductions on the order of 50% are possible.

- Some of the hand-fired boilers in Kraków use coal. These are important sources of pollution and, wherever possible, these should be converted to coke or coal/coke mixtures. For steel boilers which cannot burn coke briquettes should be considered. In all cases overfire air should be used at the beginning of the firing cycle to minimize CO and volatile organics emissions.

- For the stoker fired boilers: optimal operating procedures should be developed for the specific fuel used. This optimal procedure can then be the basis for future automatic control routines.

- Recommendations have been made for emission factors which should be used for all categories in normal operation.

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PERFORMANCE OF POLISH HOME STOVES

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INTRODUCTION

Most of the city of Kraków, Poland is heated by either the central district heating system or single-building boilers, gas or coal-fired. In addition, concentrated in the older, central part of the city, there are many traditional, coal-fired tile stoves. It is currently estimated that there are 100,000 such stoves in Kraków with an annual coal consumption of 130,000 metric tons. These are felt to be important contributors to Kraków's air quality problems. It has been estimated that there are about 7 million of these stoves throughout the country of Poland.[1]

These are very large masonry stoves with ornate tile exterior. They are built in place by specialized craftsmen and often two or more stoves will be used to heat a single flat. During the heating season these stoves are fired once or twice each day. For each firing the owner will carry a bucket of coal up from a basement storage area, light a new fire, and then tend it occasionally for about one hour. During this time the masonry is heated and this stored heat keeps the flat warm for the next 12 hours.

A testing effort on these tile stoves has been conducted as part of the Kraków Clean Fossil Fuels and Energy Efficiency Program, sponsored by the U.S. Government through the Agency for International Development (AID) and the U.S. Department of Energy (DOE). One of the objectives of this testing program was to provide baseline thermal efficiency and emissions data as input to evaluations of costs and benefits of alternative options for heating these flats. The second primary objective was to provide at least a preliminary assessment of the possibility of reducing emissions by using improved fuels in these stoves.

TEST PROGRAM

Description of the Stove Tested

The masonry tile stove tested during this program is very typical of those used in Kraków. It was built specifically for these tests by local craftsmen in a laboratory at the Academy of Mining and Metallurgy. During construction great care was taken to record dimensions and the types of materials used. A series of thermocouples were installed in selected locations within the stove mass to monitor heat storage during the firing cycle. Vertical cross-section drawings of the tile stove tested are shown in Figures 1 and 2. The stove has three flue gas passes. The first and largest vertical pass acts as the combustion chamber, and is full width across the front of the stove. The second (down) and third (up) passes are half width across the back. There is an ash clean-out port at the bottom of the second pass. The section in Figure 1 is through the center of the second pass and the left side of the first pass. The section in Figure 2 is through the center of the third pass and the right side of the first pass. Figure 3 shows several horizontal cross-sections at planes defined in Figure 1. Figure 4 shows the locations of the internal thermocouples.

Test Arrangement

A facility for studying the emissions and efficiency of the home coal stoves has been built at the Academy of Mining and Metallurgy (AGH) in Kraków with guidance from Brookhaven National Laboratory (BNL) and equipment provided from the U.S. under this program. The system uses a dilution tunnel method [2,3] to determine gaseous pollutant emission rates and flue gas energy loss on a continuous basis. Particulate emissions are averaged over firing cycles.

The dilution tunnel system is illustrated in Figure 5. All of the combustion products leaving the stove enter the dilution tunnel along with air from the room. The flue gas flow at the stove exit varies greatly during a firing cycle and is often too low to measure practically. The flow in the dilution tunnel, in contrast, is steady and can be easily measured. The emission rate of any gaseous pollutant is simply the product of the dilution tunnel concentration and the dilution tunnel flow rate.

Particulates are measured by sampling from the dilution tunnel using a heated filter. Beyond the filter semi-volatile organics are condensed in the icebath impingers. These organics are later extracted and total mass determined. Stove thermal efficiency is determined by integrating the rate of energy loss from the stove over the firing cycle.

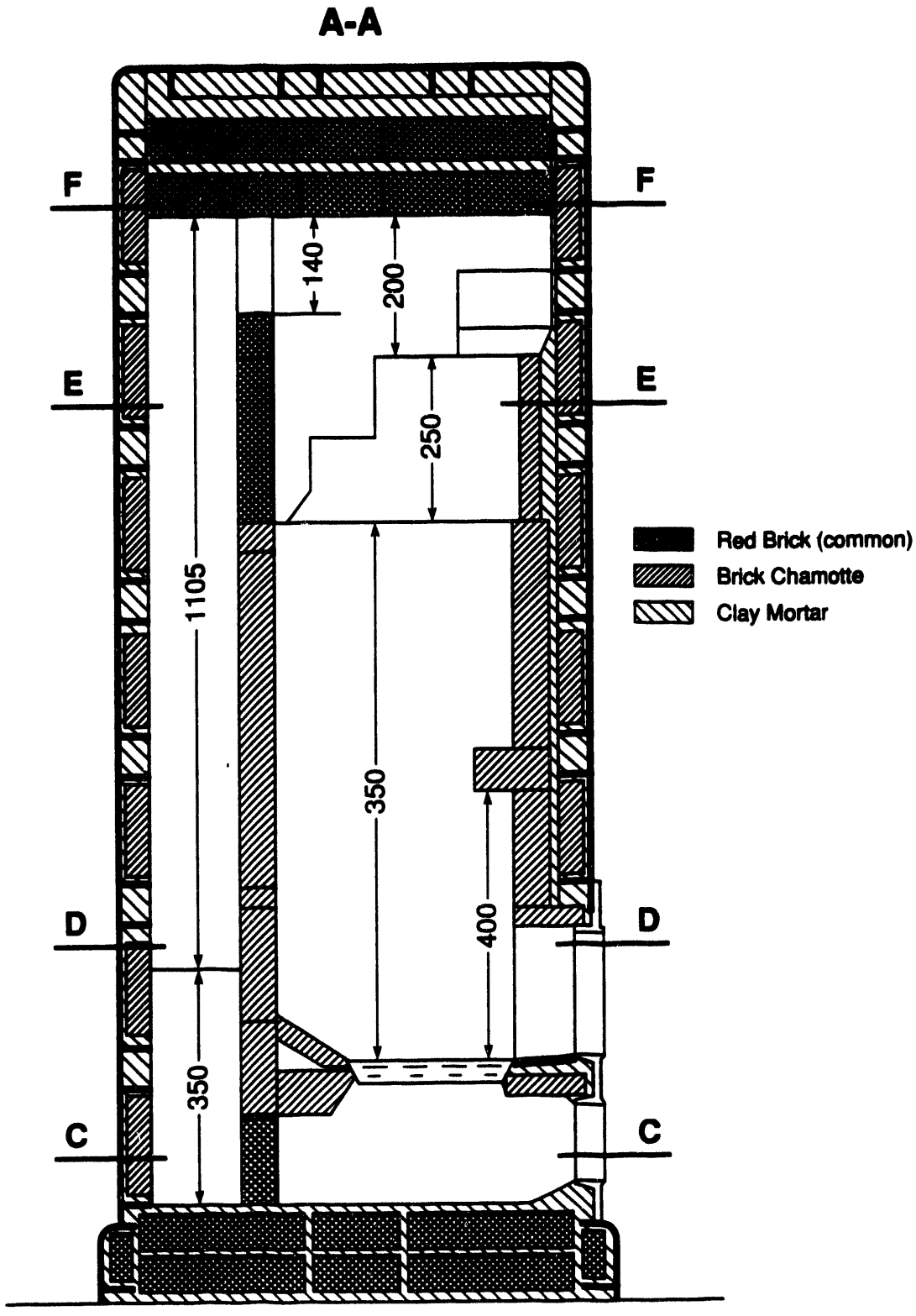


Figure 1. Vertical Cross-Section of Polish Tile Stove Showing First and Second Passes. (dimensions in millimeters)

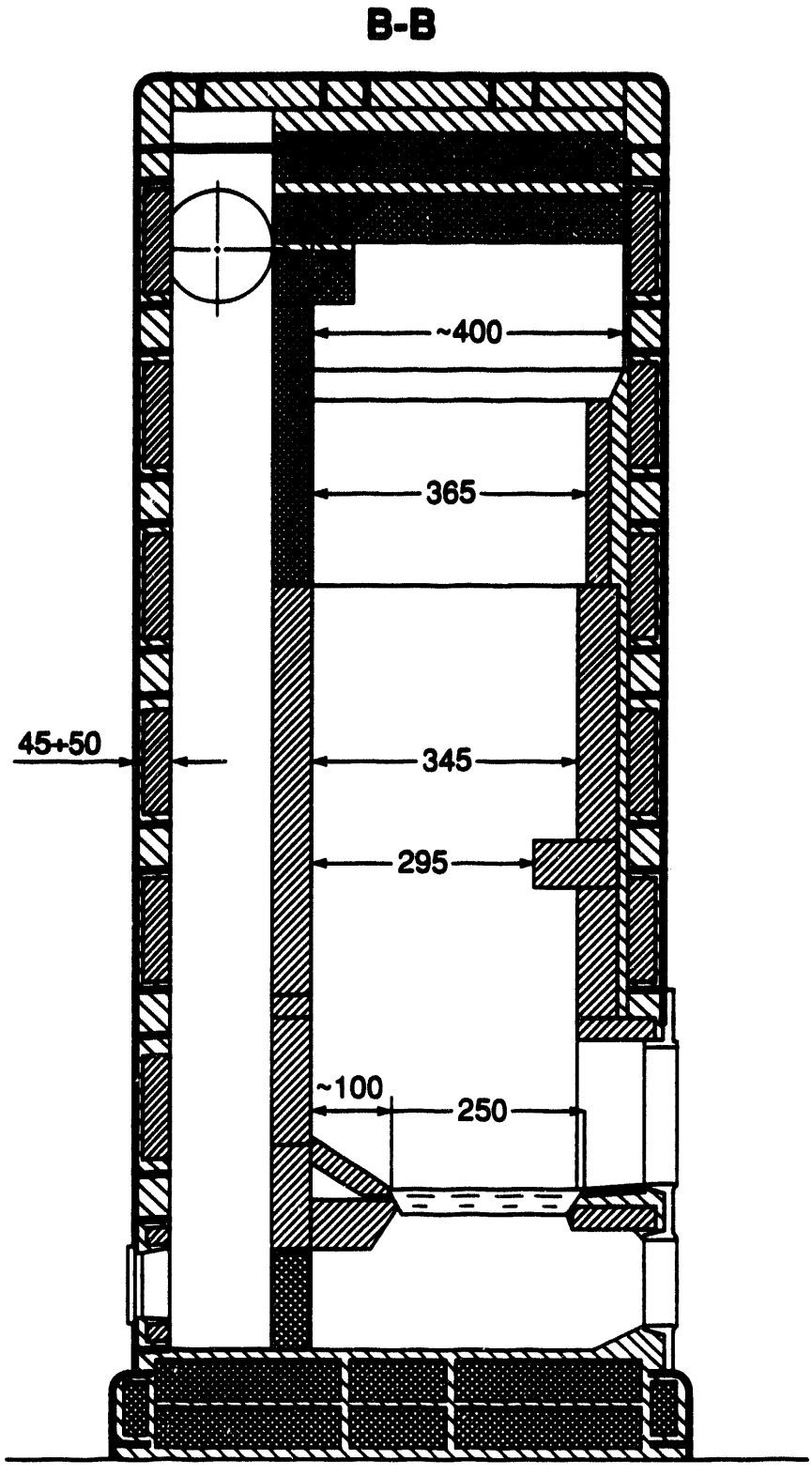
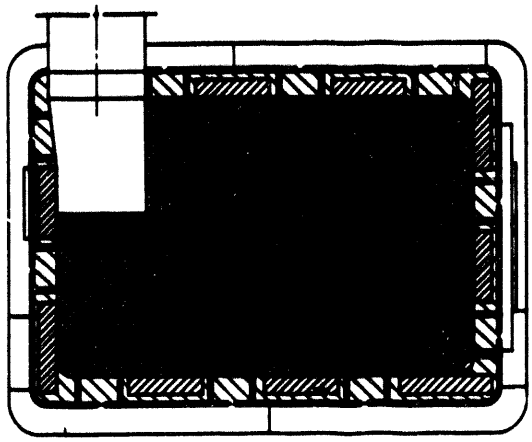


Figure 2. Vertical Cross-Section of Polish Tile Stove Showing First and Third Passes. (dimensions in millimeters)



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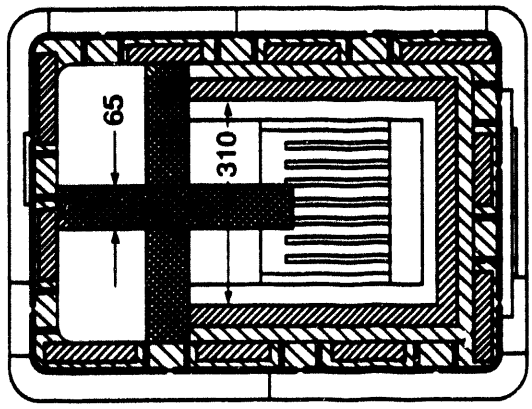

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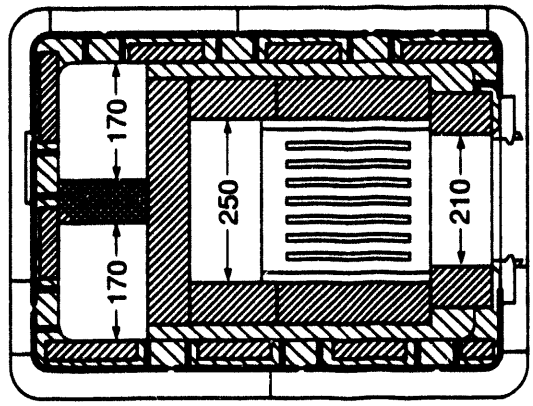

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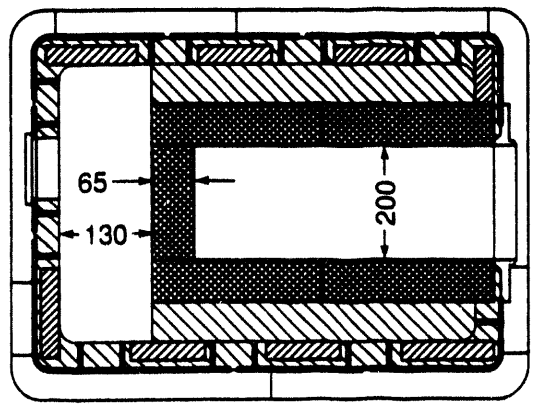

C-C

Figure 3. Horizontal Cross Sections

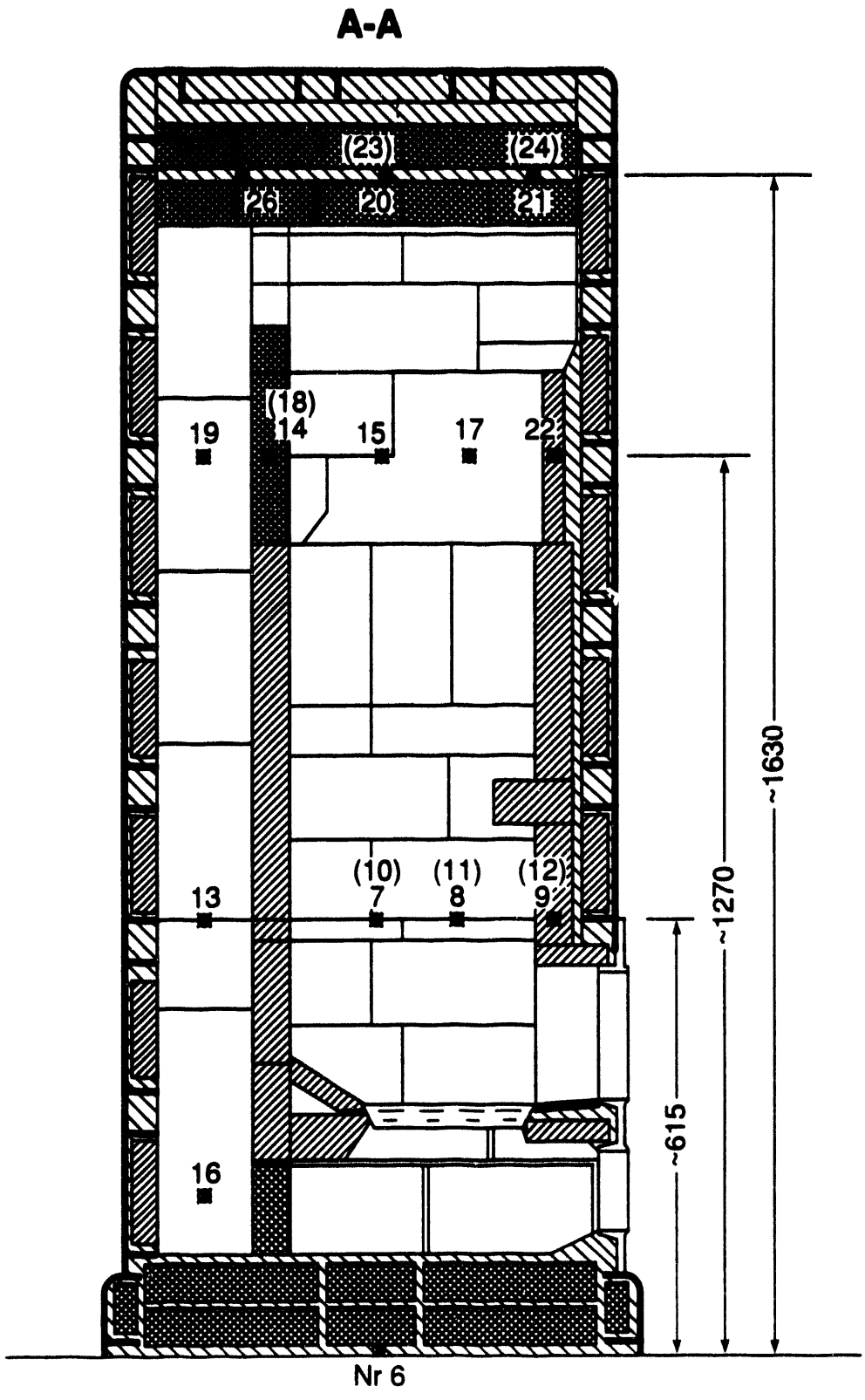

Figure 4. Location of Internal Thermocouples.
(dimensions in millimeters)

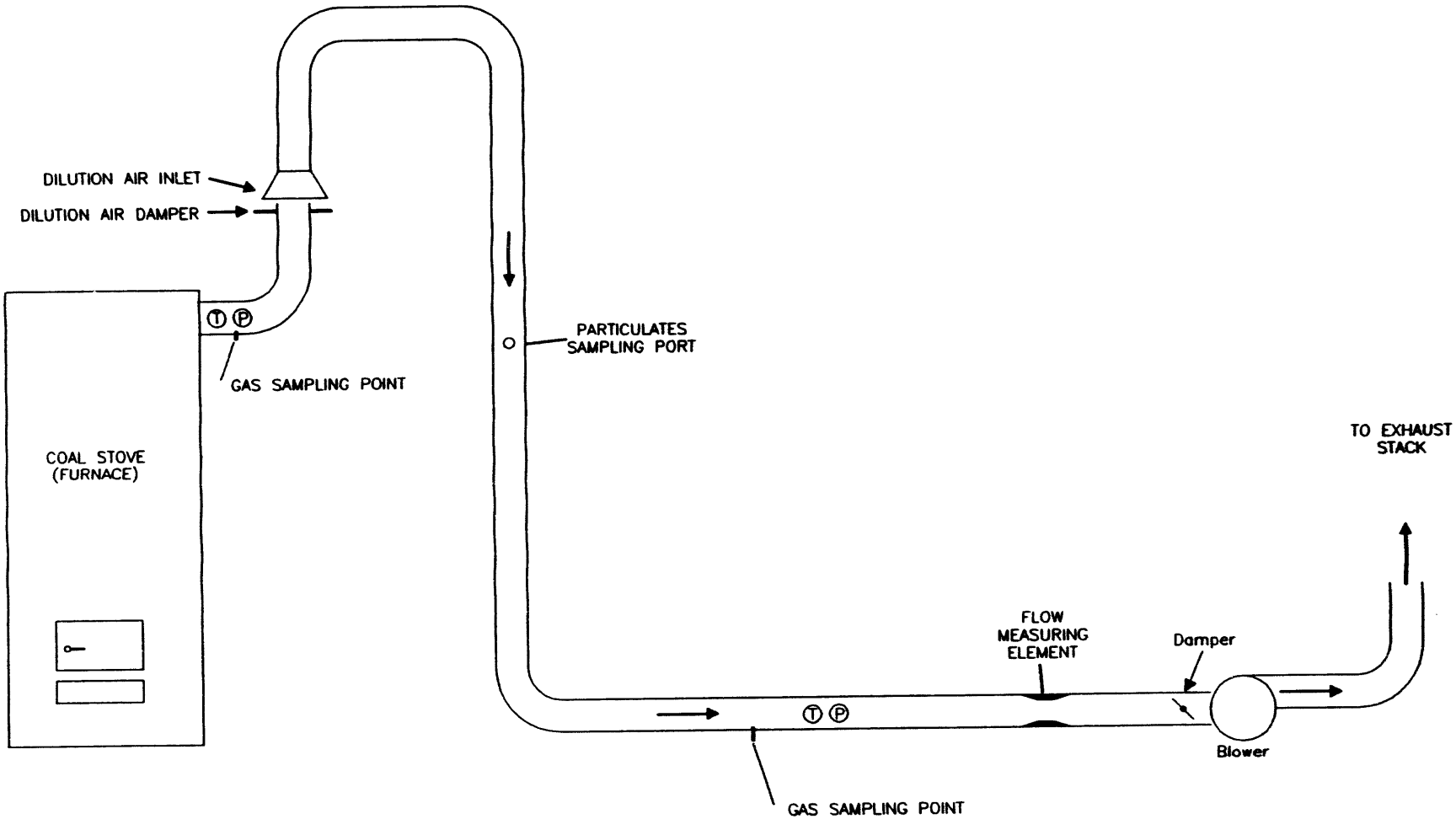

Figure 5. Illustration of Dilution Tunnel System for Emissions and Efficiency Measurements in Stove Tests.

This requires measurement of the mass flow rate of flue gas from the stove. Infrared analyzers are used to monitor CO_2 in both the stove exhaust and the dilution tunnel continuously. These measurements, along with dilution tunnel flow, allow calculation of the stove mass flow.

Test Plan

Test procedures were planned so that the stoves would operate in a manner as close to typical as possible. In the case of the tile stoves each "firing" cycle lasted about 24 hours and a total of 5 cycles was used to evaluate each fuel. Before each such test series the combustion chamber, ash pit and dilution tunnel were carefully cleaned to remove the remains of the previous series. After each firing cycle ash on the grate and from the ash pit was removed for analysis but the char was left for the next run. The mass of fuel, char, kindling and ash were all carefully measured for each run.

In lighting the fire in the tile stoves the fuel charge was added in two stages, following normal practice. The first part (1/3 of total) was added initially with the kindling. The remainder was added 15 minutes later.

During the main part of the combustion in the tile stove the top door and the bottom (ash pit) door are both partially ajar. The top door is normally closed after "degasification" is complete ("long flame disappears"), about 1 hour. The ash pit door is closed completely when the "glow is dark red", about 1/2 hour later.

In baseline tests the doors were closed tightly after combustion ended. In this case measurements showed the total stove flow to be zero and there were no "off-cycle" flue energy losses.

In typical home installations stoves from different floors are common-vented. Stove draft varies considerably over a firing cycle and will depend upon the number of stoves firing into the chimney at a given time. To develop a typical draft/time profile, field measurements were made before the test program started. Based on these, a target profile was developed and implemented by adjusting the dilution air damper position during the firing. After the firing part of the cycle the dilution air damper was closed completely and the tunnel blower was turned off. Natural draft from the fan exhaust stack provided the desired draft level for the remainder of the test period.

It is interesting to note that the past practice of common venting (common chimneys) floors has led to building codes which prohibit use of stoves with fan-assisted combustion air flow. This could impede the replacement of existing tile stoves with some advanced designs. Changes very recently made in the building codes prohibit common venting.

Test Fuels

Properties of the fuels evaluated during this testing program are listed in Table 1. The two coals listed represent the best and worst fuels currently used in Kraków. Coal from the Bolesłow Smialy mine is high in ash content and low in heating value and currently sells for about $60/metric ton. Wujek coal is much better in quality and higher in price--about $80/ton. The "Zabrze" briquettes have been produced by the Institute for the Chemical Processing of Coal in Zabrze, Poland in a pilot-scale facility. In this process, hot char from a fluid bed gasifier is combined with a preheated coking coal. The mixture feeds into a roll press, forming the egg-shaped briquettes.[4] These briquettes are termed "smokeless" because of their reduced volatiles content.

The wood briquettes listed in Table 1 have been made from wood waste and have recently been proposed as an option for the tile stoves. A principle advantage of these is price--currently about half the price of coal (per-ton basis). Even considering the low heating value of these briquettes, they may be attractive to apartment owners. The final fuel listed is a coke which has also been recently offered as a possible option for the home stoves. This fuel was supplied by the Przyjaźń cokery.

TEST PROGRAM RESULTS

Normal Operating Procedures

The general nature of the operation of the tile stove and the dilution tunnel system is shown in Figure 6. All of these data were obtained using Wujek coal and the normal stove operating procedures described earlier. The emission rate of CO_2 shown in Figure 6 can be used as a measure of the combustion rate. Initially the coal volatiles burn giving high combustion rates as well as high emission rates of CO. After about 0.3 hours much of the volatiles are burned off, the combustion rate remains fairly high but the CO emission rate decreases. In addition to the lost volatiles it is likely that the higher temperatures of the combustion chamber and the masonry flue passages also help keep the CO down from about 0.4 to 0.9 hours. At the 1 hour point the top door of the stove was closed, leading to a gradual reduction in the combustion rate but a dramatic increase in the CO emission rate. A very significant part of the total CO emission rate clearly occurs after this top door has been closed. When the lower, ash pit door is finally closed at about 1.3 hours the combustion process clearly stops. Figure 7 shows the heating and cooling of the stove mass during a typical 24 hour cycle.

Performance of the tile stove with the fuels tested using the normal operating procedure is summarized in Table 2. Generally, the efficiency of the tile stove was found to be higher than expected. Both efficiency and emissions with the coals tested are roughly similar to results which has

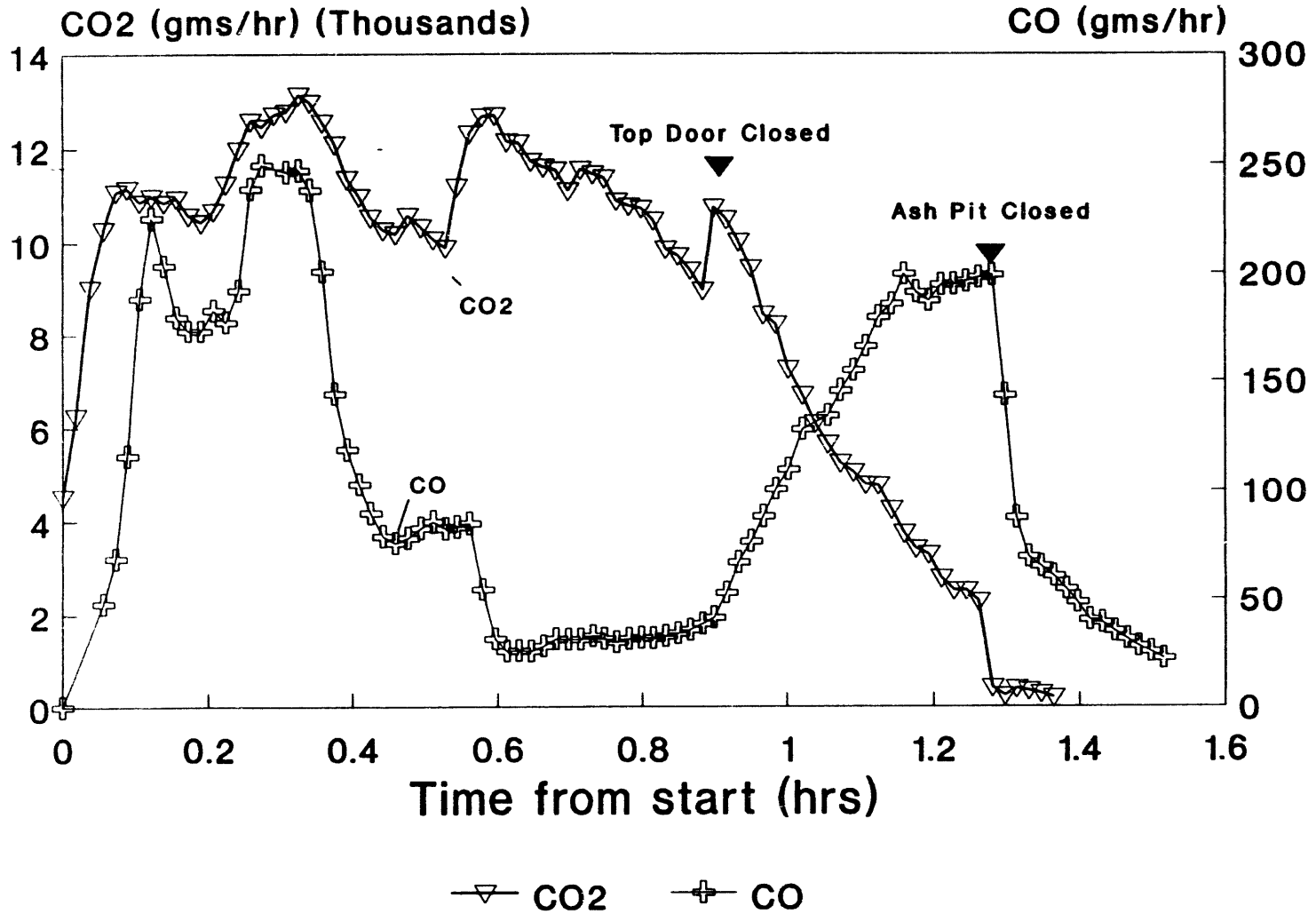

Figure 6. Emission of CO_2 and CO from Tile Stove During a Typical Firing Cycle.

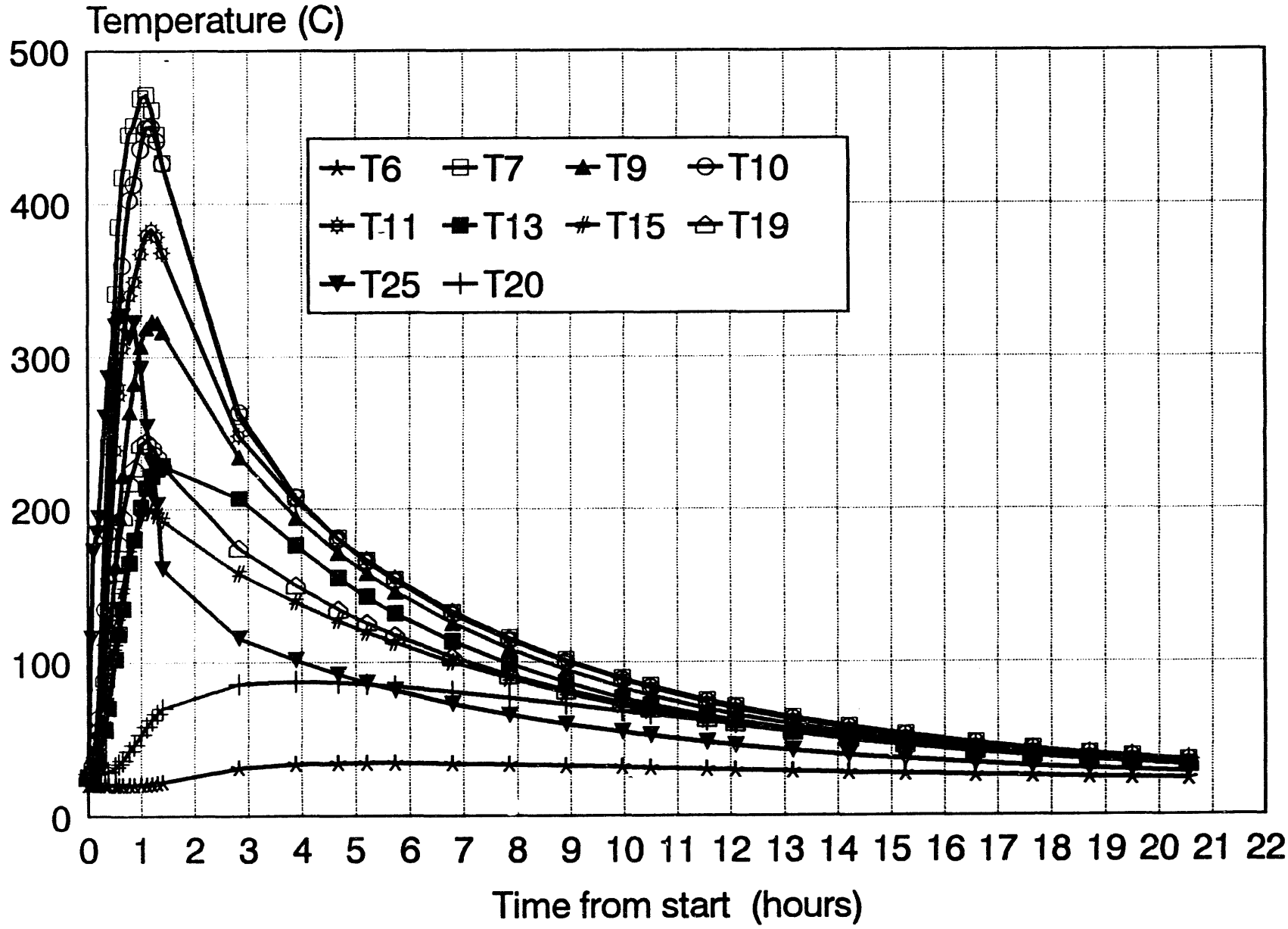

Figure 7. Tile Stove - Trends in Internal Temperature During a Typical 20 Hour Cycle.

Table 1. Coal Stove Test Fuels						
fuel properties as-fired		Bolesław Smiały Coal	Wujek Coal	Zabrze Briquettes	Wood Briquettes	Coke
Water	%	2.5	2.72	3.3	5.6	0.1
Ash	%	21.6	3.32	10.9	1.8	8.7
Volatiles	%	30.3	32.1	8.1	71.6	1.0
Combustible Sulfur	%	.3	0.3	0.2	0.0	0.5
Lower Heating Value	kJ/kg	24505	31324	27619	17916	30280

been obtained by others with more modern stove designs.[5] A dramatic reduction in particulate emissions is obtained by substituting the smokeless briquettes for the coal. Carbon monoxide emissions, however, were found to increase sharply with this fuel and this result is unacceptable.

With the smokeless briquettes combustion was very slow--leading to the low values of NO_x emissions with this fuel. Also the stove mass temperature rise during firing was considerably lower with the briquettes. This is consistent with the lower stove efficiency listed in Table 2.

Table 2. Baseline Test Results					
		Bolesław Smiały Coal	Wujek Coal	Zabrze Briquettes	Wood Briquettes
Efficiency	%	62	68	57	74
Emissions per mass of fuel:					
Particulates	g/kg	13.8	16.6	0.8	6.4
CO	g/kg	20	27.1	49.3	48.4
Semivolatile Organics	g/kg	0.9	0.9	0.4	2.05
Volatile Organics	g/kg	3.4	1.8	2.4	6.0
NOx	g/kg	3.3	6.9	2.4	0.5
SO2	g/kg	5.6	5.1	3.3	0.07
Emissions per GJ of heat input:					
Particulates	g/GJ	563.	530.	29.	357
CO	g/GJ	816.	865.	1785.	2701.
Semivolatile Organics	g/GJ	37.	29.	14.	114.
Volatile Organics	g/GJ	139.	54.	87.	335.
NOx	g/GJ	135.	221.	87.	28.
SO2	g/GJ	229.	163.	119.	4.

Tests Under Poor Operating Conditions

All of the tests for which results are reported in Table 2 were done under really ideal operating conditions. In many cases, however, stoves are not operated correctly and, in addition, many stoves have cracks and other flaws that lead to air leaks. These air leaks could lead to efficiency loss as room air is heated and then discarded out the chimney. Additional tests were carried out to quantify the influence of incorrect operating procedures commonly used and the effects of leaks. In this program the following two "incorrect" procedures were evaluated:

- o leaving the two doors fully, rather than partially open during the active part of the combustion process
- o shutting the doors one hour later than in the normal case

To evaluate the effects of air leaks the doors were left open a very small and carefully set amount after the end of the normal combustion process. The door opening to be used in this case was determined through a set of field tests in which actual leakage rates with older stoves were measured. In these field measurements a metal flow hood was constructed and sealed to the stove front face, completely covering the doors. All air flow leaking into the stove, through and around the door set passed through a duct at the opposite end of the flow hood. A hot wire anemometer was used to measure this flow rate. During the lab tests of leakage rates the door opening after the end of the active combustion process was set to give the same leakage rates.

Table 3 summarizes the results of all of the tests done under poor conditions with the Wujek coal. In all cases the efficiency was lower than with normal operating procedures (Table 2) and the worst case was when the door was left open for an extra hour. The efficiency penalty due to leaks

Table 3. Results of Tests With Poor Operating Conditions With Wujek Coal

		Doors Fully Open for Entire Firing Cycle	Doors Open Extra Hour	Simulated Leaky Stove	Doors Open Fully for Firing Cycle and Leaky Stove
Efficiency	%	55.	47.	54.	53.
Emissions per mass of fuel					
Particulates	g/kg	17.1	20.	16.9	14.5
CO	g/kg	19.7	24.5	28.7	26.7
Semivolatile Organics	g/kg	0.7	0.6	0.5	0.7
Volatile Organics	g/kg	2.6	3.1	2.7	2.8
NOx	g/kg	4.2	4.1	4.4	5.0
SO2	g/kg	5.1	5.5	4.4	4.9
Emissions per GJ of heat input					
Particulates	g/GJ	545.	638.	539.	462.
CO	g/GJ	628.	781.	915.	852.
Semivolatile Organics	g/GJ	22.	20.	17.	2.
Volatile Organics	g/GJ	83.	100.	85.	91.
NOx	g/GJ	133.	132.	141.	159.
SO2	g/GJ	161.	175.	141.	155.

was found to be fairly small. Stove temperature measurements made with and without leaks showed that the rate of cooling of the bricks after the end of the combustion process was about the same in both cases. This confirms that the rate of energy loss due to the leaks is not significant. When the doors were fully open for the entire combustion process CO was reduced. Volatile organics, however, increased. In all other cases effects on emissions could be considered rather small.

Tests With Modified Operating Procedures

In the baseline tests the results with the smokeless briquettes were very encouraging for the possibility of reducing particulate emissions. The increased CO emissions with this fuel, however, is not acceptable even considering the order of magnitude reduction in particulates. Based on the long burning time and the low stove mass temperatures observed with the smokeless briquettes it was felt that the high CO was primarily due to the low temperature of the combustion zone. Several methods of increasing the burning zone temperature were then evaluated including: 1) the use of two types of metal inserts designed to increase air flow through and reduce heat loss from the fuel bed and, 2) packaging the briquettes in combustible containers. These efforts were essentially not successful. During the course of the investigations, however, an improved operating procedure was developed which was successful in improving performance. This new procedure involved the following:

- feeding the fuel onto the grate in 3 equal parts - one was used during the ignition and the other two were added during the process of combustion
- reducing the overall excess air and, at the same time, supplying all of the combustion air through the lower, ash pit, door (obviously except when adding fuel or grooming the bed)
- more frequent poking of the bed
- closing the bottom door, effectively ending combustion, earlier. Specifically, the bottom door was closed just after the flue gas leaving the stove reached it peak temperature

The last part of the procedure is an important one because CO emissions always increase dramatically at the end of the normal operating procedure. Closing the door earlier may lead to higher amounts of unburned coke remaining on the grate. However, this coke is burned during the next firing cycle and does not lead to an efficiency loss. It should be noted that as part of the test procedures used during this program efficiency was evaluated during multiple cycles, not just a single firing.

Testing with the improved operating procedure was done with three selected fuels - Wujek coal, the smokeless briquettes, and coke. Results are listed in Table 4. Relative to the baseline tests the new procedure gave dramatic improvements in thermal efficiency and reductions in CO with the low volatile content briquettes. Using this procedure with smokeless fuels leads to clear reductions in emissions.

DISCUSSION

In the preceding paper at this conference [6] standard emission factors for Kraków's boiler population were presented and these were used to compare total emissions from different sources. With the stove test results in the present paper this can be extended to include the home stoves. For this purpose the emissions factor developed for Wujek coal with normal operating procedures (Table 2) were adopted. Results are shown in Table 5. Among the categories listed, the home stoves do not consume the most coal. They are, however, by far the most important single source of particulates and semivolatile organics. They are, in addition, important sources of both volatile organics and CO. Changing the fuel to briquettes or coke and using the improved operating procedures developed here would reduce stove particulate emissions by 90%, CO emissions by 13%, and semivolatile organics emissions by 31%. This would clearly have a great impact on Kraków's air quality.

CONCLUSIONS

As part of the Kraków Clean Fossil Fuels and Energy Efficiency Program a coal stove testing laboratory has been established in Kraków and some very important data on the behavior of these stoves has been produced. Properly CO. operated these stoves have fairly high thermal efficiency. They also have, however, very high emission factors for particulates, CO, and organics. These stoves are clearly a very important source of particulate pollution in the city. Changing the fuel used from current coal to coke or briquettes combined with the use of improved operating procedures developed during this work would have a great impact on total particulate emissions in Kraków. This change would require no capital investment by Kraków residents.

Table 4. Results of Tests with Modified Operating Procedure				
		Wujek	Zabrze Briquettes	Coke
Efficiency	%	75.1	73.6	73.1
Emissions per mass of fuel:				
Particulates	g/kg	15.	1.2	1.8
CO	g/kg	32.	21.	28.
Semivolatile Organics	g/kg	1.9	0.54	0.55
Volatile Organics	g/kg	3.9	1.4	1.8
NOx	g/kg	2.8	1.8	1.6
SO2	g/kg	2.7	4.1	2.8
Emissions per GJ of heat input				
Particulates	g/GJ	478	43	58
CO	g/GJ	1027	752	928
Semivolatile Organics	g/GJ	61	20	18.
Volatile Organics	g/GJ	123	50	58
NOx	g/GJ	89	65	52
SO2	g/GJ	87	149	94

Table 5. Comparison of Contribution of Boilers and Home Stove to Kraków Emissions							
	fuel use (metric tons per year)	Annual Emissons (metric tons per year)					
		Particulates	CO	Semivolatile Organics	Volatile Organics	NOx	SO2
Stoker without cyclones	34984	539	290	1	0	77	1025
Stokers with cyclones	198240	427	1645	6	0	436	5808
Hand-Fired Boilers-coke	59107	118	5467	4	41	112	1046
Hand-Fired Boilers-coal/coke mixtures	52023	281	3871	57	328	62	931
Hand-Fired Boilers - coal	26012	520	1171	42	75	60	471
Home Stoves - coal fired	130000	2158	3523	117	221	455	663

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ENERGY SAVINGS POTENTIAL IN MULTI-FAMILY RESIDENCES IN KRAKÓW

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INTRODUCTION

The primary objective of the Kraków Clean Fossil Fuels and Energy Efficiency Program is to reduce air pollution in Kraków. The main sources of space heat in Kraków are:

- The municipal district heat network, served by centrally-located coal-fired combined heat and power plants.
- Local coal-fired boiler houses, that supply hot water to buildings for space heat and process heat or steam to industrial customers.
- Individual coal- or coke-fired boilers in residential buildings, which supply hot water for space heat.
- Coal stoves, used to heat some of the older buildings in the city's center.
- Gas-fired boilers, used to heat water for space heat for individual buildings.
- Electric resistance heaters, both those designed to heat single rooms (often with a heat storage capacity) and electric element inserts that fit into a coal stove's fire box, and replace coal as the stove's fuel.

The coal-fired boilers and stoves are the so called "low emissions sources;" they are significant sources of airborne pollutants in Kraków, and throughout Central and Eastern Europe.

The City of Kraków has a comprehensive program to reduce air pollution from low emissions sources. This includes an ongoing effort to eliminate local coal-fired boiler houses and coal stoves, replacing them with municipal district heat, gas-fired boilers, or electric heat sources. The City has also attempted to improve the characteristics of the coal burned in Kraków and to rehabilitate and/or add emission control equipment to local boiler houses that cannot be eliminated. These efforts have intensified under the Polish-American Kraków Clean Fossil Fuels and Energy Efficiency Program. Improved energy efficiency at the point of use will help in all aspects of the City's programs:

- Those buildings served by coal boilers and stoves can burn less coal.
- The municipal district heat utility will be able to serve more customers with its existing network and heat sources, eliminating local boiler houses.
- The economic consequences to the residents of higher prices of alternative fuels (i.e., gas and electricity) can be mitigated by energy efficiency measures that reduce their demand for space heat.
- Electric heat connections are now constrained by limits to installed transformer capacity. Additional gas heat connections in some areas are now constrained by limited pipeline sizes and pressures. Reducing individual demands through end use efficiency measures may allow more gas and electric conversions under present distribution supply constraints.

The motivations for energy efficiency are environmental, economic, and social; efficiency improvements enhance all pollution reduction strategies the City is promoting. A conservation experiment was incorporated in the Kraków Project in order to identify the amount of achievable energy conservation in Kraków's buildings, and the technologies and costs associated with an appropriate building energy efficiency strategy. The project team designed the conservation demonstration to identify cost-effective energy efficiency techniques that could be applied to the building stock of Kraków, Poland, and other countries in Central and Eastern Europe. We decided to look at retrofit measures for existing concrete element construction, which comprises the majority of large multi-family buildings. Candidate energy efficiency measures had to be suitable for the Kraków building stock, affordable, use materials available (or that could be made available) to the Kraków residents, and be compatible with the residents' lifestyles. A variety of building energy efficiency measures were considered, and the Polish-American team selected those of most relevance

to conditions in Poland. Energy use of the buildings was measured before and after a series of energy efficiency actions were implemented. Measurements were taken over two heating seasons: 1992-93 and 1993-94. Preliminary results from the 1992-93 heating season are presented in this paper.

BACKGROUND

Concrete buildings are ubiquitous throughout Central and Eastern Europe. They consist of massive concrete elements, usually prefabricated at a factory and shipped to the building site for assembly. There have been many design changes and improvements in the concrete element construction, but most such buildings remain uninsulated or poorly insulated. Three types of factors affect building energy efficiency:

- building thermal performance characteristics,
- heat delivery methods and controls, and
- incentives motivating efficiency improvements.

The buildings' thermal characteristics are an energy efficiency "nightmare." The walls are uninsulated concrete with a heat transfer coefficient of 1.15 $W/m^2 \cdot K$. This is equal to a U.S. R-value of just over 1.5 (about equal to double glazed windows). The windows are wood framed casement type. They are double glazed, with the outside pane set in its own wooden frame, separable for cleaning. The glass panes are about 2-3 cm apart. There is usually a small window above the main windows that is opened for ventilation. Most apartments have balconies, with a wood-framed doorway. There is much infiltration around the window and door frames. The window frames warp; we have observed air gaps as large as 2 cm. Also, the concrete slabs often settle unevenly after construction, leading to distortion of the frames and, frequently, cracks in the concrete. As a result, many of the windows and doors have large visible air gaps and/or cannot be closed tightly.

Ventilation in the apartments is by natural convection, using internal ventilation chimneys. This works poorly in mild weather. Most cooking stoves are gas-fired, and hot water is supplied by gas-fired instantaneous water heaters mounted on the wall above the faucets and in the bathroom. Some kitchens have exhaust fans, but these are not very effective. Additional ventilation is often needed because many of the residents smoke, and the small upper windows are used for this purpose. In pre-demonstration inspections, we found a number of apartments with high levels of CO_2 and CO, especially during cooking.

Many of the apartments have moisture problems. The uninsulated walls are cold, and water vapor condenses on the interior surface. In some apartments (on the first two floors), the walls have been so cold that the condensation froze, resulting in ice on the inside surface of the exterior walls.

Radiators in the rooms are located under the windows, usually with a stone or concrete shelf over the radiator. Furniture is often placed in front of the radiator, and most apartments have floor to ceiling curtains which cover the radiator. The result is that the heat from the radiator is often impeded from warming the room; instead the radiator warms the exterior concrete wall.

Heat is supplied to the building by pressurized hot water from the municipal district heat utility, Miejskie Przedsiębioriorstwo Energetyki Cieplnej w Krakowie (MPEC). Hot water at 150°C is provided to the building by MPEC through a hydroelevator. The hydroelevator is designed to mix the MPEC supply water with the water already circulating in the building, so water entering the building piping system will be at approximately 90°C (on design cold days), and water returned to the MPEC network will be about 70°C.

Most buildings have no controls. Instead, MPEC regulates the temperature it sends out from the heat source, varying the temperature of water in the network from 150°C to about 75°C. The water temperature in the buildings' radiators will vary in proportion. The radiators are often warmer than necessary on mild days.

Most radiators do not have thermostats. There are on/off valves, but if these are not used regularly they become inoperable, due to mineral deposits, within a few months. If they are used, they leak; consequently almost everyone sets them fully open and leaves them alone. If the room is too warm, the residents will open a window to cool off.

Just as the heat delivery system does not permit residents to control the amount of heat transferred to the building, the price and tariff infrastructure doesn't provide an incentive to use energy more efficiently. The price apartment residents pay for district heat is set by the national government (the "official price"), based upon the floor area of the living space. In the past, district heat has been highly subsidized, with residents paying less than 20% of the actual estimated cost of hot water. These subsidies are being phased out. As a result, payments for district heat average about 15% of a typical resident's salary. There is no individual metering, so the resident pays a monthly charge, per square meter, each month of the year. This charge is included in the rent the resident pays the housing cooperative or building owners. MPEC charges the housing cooperative for heat supplied, both a capacity and an energy charge. The difference between what the Cooperative receives from the residents

and what it must pay MPEC is made up by the municipal or national government (depending upon who owns the apartment building); this is the heat subsidy.

Most apartment buildings in Poland do not have heat meters. MPEC calculates the heating bill for the Cooperative by estimating the design heat loss of the building and factoring in actual weather conditions. Where a heat meter has been installed, MPEC charges for the actual energy used. While recent Polish legislation requires heat meters on all new buildings, meter installations on existing buildings are few and are growing in number only slowly. However, some Cooperatives that have more energy-efficient buildings or implement conservation measures have purchased and installed meters themselves, when they believe the metered energy (i.e., actual energy used) will be less than the MPEC-calculated energy use.

In summary, the multi-family housing stock constructed of concrete elements is uninsulated or underinsulated, with large infiltration of outside air. The buildings tend to be cold, drafty, and have internal moisture/condensation problems. In buildings served by the district heat system or local hot water boilers, residents cannot control the amount of heat delivered to their apartments. They are cold on the coldest days and must open windows to alleviate overheating on mild days.

Residents pay a monthly charge for district heat energy that is independent of the amount of energy they use, or need. District heat prices are rising rapidly as subsidies are withdrawn. However, there is no mechanism for residents to reduce the amount of heat they pay for (i.e., to pocket the energy savings resulting from conservation measures). Since most Housing Cooperatives pay for district heat energy based on calculated, not metered, usage, they also have little incentive to implement efficiency measures that will reduce their actual heat consumption.

THE CONSERVATION EXPERIMENT

Weatherization measures may reduce the amount of heat needed in a building, but without accompanying controls, MPEC will deliver the same amount of heat; residents will just overheat and have to open their windows more often; no energy will be saved. Better controls will reduce energy used on mild days, but without weatherization, the capacity requirements for heat will not change, and the buildings will still be uncomfortable on cold days. In addition to technological "fixes," any efficiency program must include the economic incentives to motivate its implementation. Therefore, the Kraków Conservation experiment has three major aspects:

- Building envelope improvements, to reduce the demand for heat and improve comfort.
- Building-level control, to reduce the amount of heat delivered to the building during mild weather.
- Thermostatic controls of individual radiators, and incentives for the residents to use them.

Four adjacent "identical" buildings were selected for the project. The buildings are eleven stories high, with six apartments per floor, and have a basement storage area. The buildings have the same orientations and are located at numbers 4, 6, 8, and 10 Wolasa Street in the ho ısing cooperative Spółdzielnia Mieszkaniowa "Krowodrza." Figure 1 shows the building floor plan. All floors in each building are identical. The building heating system consists of hot water radiators, generally piped vertically, with added heating supplied by pipe loops in bathrooms and foyers. Radiator sizing is adjusted for the calculated heat loss of each room, giving consideration to orientation, roof or floor heat loss, etc. The building heating energy source is the Kraków municipal district heat utility (MPEC). Before our improvements, all four buildings used about 15 GJ of energy per day. (All four buildings' baseline energy use was within 5% of each other.)

A heat meter and data collection system were installed in each building to monitor conditions during the 1992-93 and 1993-94 heating seasons. The primary quantities measured were:

- building heat energy use
- building electricity use
- water flows, temperatures, and pressures (supply and return)
- outdoor air temperature
- indoor air temperatures at selected locations.

It is not possible to meter each apartment's energy use with one meter because the heating system uses vertical risers, with each riser supplying hot water to 11 different apartments. Each apartment is supplied by four to five risers. Instead, energy use by each radiator was estimated by using a "cost allocator" device with a digital readout. These devices measure the temperature difference between the radiator and the indoor air and, based upon radiator size and shape, estimate the energy transfer from the radiator. FEWE-Kraków staff read and recorded these values monthly.

The two heating seasons were each divided into two parts:

Period I: October - December, 1992
Period II: January - April, 1993

Period III: October - December, 1993
Period IV: January - April, 1994

Different sets of efficiency measures were demonstrated in each building in each period. The building's energy use and sample indoor temperatures were monitored.

CONSERVATION MEASURES DEMONSTRATED

This section describes the energy efficiency measures demonstrated. The complete list is given, but only the results from Periods I and II are available now, as the data from the 1993-94 heating season are still being collected and validated. Until all the data are analyzed, the results here must be viewed as preliminary.

Base Case – Hydroelevator with no Control

All four buildings originally used a hydroelevator with no temperature reset control. Baseline monitoring was done for Wolasa 4, 6, 8, and 10 during Period I and for Wolasa 4 and 6 during alternate 2-week intervals of Period III. We also alternated weatherized (Wolasa 4 and 6) and insulated (Wolasa 8 and 10) buildings for two weeks with the hydroelevator and two weeks with the regulated heat exchanger during Periods III and IV.

Hydroelevator with Temperature-Reset Control

An outside temperature-based controller was installed on the hydroelevator in Wolasa 4. The controller regulated the amount of heat extracted from the MPEC supply, based upon outside air temperature. The objective was to reduce overheating the apartments on mild days. This controller was activated in January 1993 for Period II. It was also activated and deactivated for alternating 2-week periods for Period III. (In this way, Period III gave us two weeks of baseline data alternated with two weeks of regulated hydroelevator data for Wolasa 4.)

Heat Exchanger with Temperature-Reset Control

Flat-plate heat exchangers with outside air temperature-based controls were installed in Wolasa 6, 8, and 10 in parallel with the existing hydroelevators. The piping and valves were configured so that the building could be switched between hydroelevator and heat exchanger operation. The temperature-based regulation system was designed to vary the heat input to the building water loop, based upon outside air temperature, thus reducing overheating on mild days. Use of the heat exchanger and an in-building pump gave us better control of water flows and temperatures, and also isolated the building water from the MPEC supply water. Since some of MPEC's water losses appear to be the result of diversion, this is a feature that MPEC finds particularly attractive. The heat exchangers were activated in Wolasa 6, 8, and 10 at the start of Period II. The heat exchanger in Wolasa 6 was switched every two weeks (alternating heat exchanger and hydroelevator) for Periods III and IV. The heat exchanger and hydroelevator were also switched every two weeks during Period III in Wolasa buildings 8 and 10.

Weatherization Measures

All four buildings were weatherized, as follows:

- Caulking of window and door frames, and cracks in walls.
- Weatherstripping of windows and doors.
- Door sweeps and thresholds installed on entry and balcony doors.
- Insulated reflective barriers installed between each radiator and the wall, and also on the bottom of the window shelf above the radiator.
- Approximately 20 cm of fiberglass insulation was blown into the space between the top apartment's ceiling and the building's roof.
- Fiberglass insulation was blown into air channels in the basement ceiling, for the entire basement of Wolasa 8 and 10 and the basement perimeter of Wolasa 6.
- Infiltration bypasses caused by pipe and electrical conduit openings in the basement ceiling were sealed.

The basement sealing was done to reduce the significant stack effect observed. No internal insulation (beyond the use of the radiator shields) was tried because of the buildings' moisture problems. CO and CO_2 levels in each apartment were measured before and after weatherization. When doing apartment weatherization work, FEWE-Kraków staff also described to the residents the need to keep the air flow over the radiator unobstructed (i.e., don't block radiator with curtains or furniture). The weatherization of each building was done as follows: Wolasa 10–January 1993; Wolasa 8–August 1993; Wolasa 4 and 6–January 1994.

Thermostats and Conservation Incentives

Thermostats were installed on each radiator (except common area staircases and hallways) in Wolasa 8 and 10 in August-September of 1992. These were set "full open" and the heads removed (i.e., they were disabled) during Periods I and III.

In order to give residents an incentive to use their thermostats, a usage-based rebate was implemented during Period II. The rebate consisted of two parts:

- A "solidarity" rebate given to every apartment, based on building-level energy use.
- An apartment-level rebate, given to individual apartments, based upon the sum of the apartment's cost allocator readings.

The amount of rebate was determined by the amount, if any, the building or apartment was below a pre-determined energy use target. The target was set based upon calculated building heat loss and observed weather.

Pipe Cleaning

The heating system pipes of Wolasa 8 and 10 were chemically cleaned, with an acid solution, in August 1992. This was done to prevent the thermostats from becoming fouled by scale deposits from the district heat system water. An alternative chemical cleaning method using a non-acidic American process, which can be done while the heating system is operating, was demonstrated on Wolasa 6 during the summer of 1993.

External Insulation

External styrofoam insulation has traditionally been the means of insulating buildings in Poland. This was done for Wolasa 10 (all exterior walls) and Wolasa 8 (only those wall surfaces without windows or loggias) during the summer of 1993.

Table 1 summarizes the conservation measures demonstrated.

PRELIMINARY RESULTS

This section gives preliminary results from the first heating season. The additional baseline data and combinations of weatherization measures observed during the second heating season will give us more precise estimates of the effect of each of the individual measures taken. However, the overall savings from weatherization and control observed during the first heating season are not expected to decrease.

The analysis methodology used is to extrapolate the measured building energy use to a typical Kraków winter using a linear regression model. During the base period, no control was exercised other than MPEC's varying the supply temperature. The variation in energy use in any building is thus a function only of the temperature of the MPEC-supplied water and of the weather conditions. In essence, the entire building can be viewed as a radiator providing a resistance to heat flow from MPEC to outdoors. The outdoor temperature is included as a separate term, rather than using temperature difference, to test whether the response to weather is different from the response to the supply temperature. Note that the MPEC supply temperature is controlled in response to outdoor air temperature, and so the separate outdoor air term will only pick up building response that is independent of the MPEC supply temperature. Tests of power fits were made, since radiators in heated rooms transfer energy in proportion to T^K, where K ranges from 1.1 to about 1.5. These regressions gave no significant improvement over the linear model.

The model used was simple multiple linear regression of daily energy use against MPEC daily system average temperature and daily average outdoor temperature:

$$\begin{aligned} \text{EnergyUse} &= F_1(T_{\text{OutdoorAir}}) + F_2(T_{\text{MPEC Supply}}) \\ &= a_0 + a_1 T_{OA} + a_2 T_{MPEC} \end{aligned}$$

Regression results are shown in Table 2. Values in parenthesis are standard errors. *Italics* indicate that the standard error of the coefficient's estimate is larger than the value of the estimate, and thus the probable range for the coefficient includes zero. These coefficients are not reliable. Coefficients that are at least double the size of the standard error are indicated by **boldface**. These values are the most reliable.

Note that the outdoor air temperature coefficient is extremely small in all of the b[illegible]e case (Period I) regressions and not significant in any. For example, the largest value, for building #4, is a result of only 0.648 GJ per day for a 10°C drop in outdoor temperature. In addition, the standard error on that value is ±1.088 GJ per day. It is apparent that the buildings are responding only to the MPEC supply temperature control. The outdoor air temperature can thus be dropped from the Period I regression, yielding the results shown in Table 3. Note that the estimate of annual use will be essentially unchanged, since the outdoor air coefficient was very small, and the average winter outdoor air temperature is close to zero.

For Period II, the energy use is dependent both on the MPEC supply temperature and on outdoor temperature. This is an expected: local control in the buildings allowed a better match of energy use with energy needs (i.e., current weather conditions).

Since the model is linear, the winter average energy use per day will equal the model result evaluated at the winter average outdoor air temperature of 1.55 C and MPEC supply temperature of 80.8°C. The energy savings for the Period II measures are shown in Table 4.

DISCUSSION

Wolasa 4, with the addition of the regulated hydroelevator, allowing outdoor air reset, showed no savings. The Wolasa buildings are near the end of the MPEC supply lines, and thus may have less overheating than in average buildings. More significantly, the control on the regulated hydroelevator was set too high in 1993, continuing the previous levels of overheating. Further monitoring during the 1993-94 heating season will more precisely determine the benefits of regulated hydroelevator control.

Wolasa 6 had a heat exchanger and outdoor air temperature reset installed as a test of an alternate to the regulated hydroelevator. The results were expected to be similar to Wolasa 4, with possible improvement due to elimination of any diversions of system water. As with #4, the local control was evident in the significant values for dependance on outdoor air and reduced dependance on the MPEC supply temperature. Unfortunately, also as with Wolasa 4, the base and post usage are essentially the same, and no significant savings were found. The coefficient on the outdoor air temperature is much lower in this building, leading to speculation that the controller was not functioning correctly in 1993. Again, re-calibration of the controller and further monitoring in 1993-94 will clarify these results.

Wolasa 8 was retrofit with a heat exchanger and outdoor temperature air reset controls, thermostats on almost all radiators, and cost allocators. In addition, as an incentive to use the thermostats, rebates were paid to the occupants of the building based on their apartment's energy use and on the building's total energy use. This building did not always maintain comfort conditions throughout the post retrofit period. Thus, a direct comparison is not possible. We can set an upper limit on the savings due to pricing and thermostatic control of about 9%, the difference between the reductions at Wolasa 8 and Wolasa 6. Temperature data collected show clear evidence of occupant thermostat use, and of thermostat control of flow and energy use. However, some time periods show full open thermostats operation with cold interior temperatures. We can speculate that half (4-5%) of the apparent savings are actually due to the combination of pricing and thermostatic control. The remainder could be the result of low (uncomfortable) indoor temperatures. It is not possible to estimate the effect of thermostats alone, without a price incentive. (Pricing without thermostats would have no effect.)

Wolasa 10 was treated the same as Wolasa 8. In addition, the building was weatherized following methods found successful in the United States and adapted to Polish construction and materials. The treatment included infiltration reduction methods, improvement of glazing, and attic insulation. The 21% savings are apparently real and due to the project. Based on comparison with the other buildings, we can conclude the weatherization saved a minimum of 9%. The actual value is higher than that for two reasons. First, Wolasa 8 had much lower indoor temperatures during several time periods (below the comfort level), so the pricing-thermostat savings are less than 9% (we estimated 4-5%). Second, the weatherization and insulation were not all completed before the beginning of the post period (Period II). In fact, the analysis includes a significant number of days where the building was partially unweatherized. Note that weatherization has no effect if occupants open windows due to overheating in mild periods, so some control is necessary to achieve maximum savings. This control, however, could be at the building level (i.e., outdoor air temperature regulation of a heat exchanger); thermostats may not be necessary.

Interviews with the residents showed they were overwhelmingly positive about the weatherization improvements. People were warmer on the cold days. The thermostats and heat exchanger controllers reduced overheating on mild days, when they were set properly. (Analysis of the data from Period II suggests the Wolasa 4 and 6 controllers were not set properly. This has been remedied, and additional data were obtained during Period III.)

Teaching the residents how to use thermostats, and overcoming their initial reluctance to reduce the amount of heat in their apartments, required significant personal interaction from the FEWE-Kraków staff. For example, once during the project we were called to an apartment with a complaint of "no heat." On arrival we found the apartment temperature was well above 20°C. Upon being asked about the complaint, the resident went to the radiator and said that it was cold. This reaction was not unusual, since in the past the radiators were normally hot all winter: a cold radiator was a sign of trouble. In this case though, the radiator had been shut off by the thermostat.

The rebates accomplished their purpose, as they helped motivate the residents to use the thermostats. Indeed, when the thermostats were temporarily disabled during Period III, so we could observe the effects on insulated buildings of building-level control only, most of the residents objected, and between 1/3 to 1/2 re-installed their thermostat heads, complaining that they were overheating.

Building-level control (temperature-regulated heat exchanger) in a well-balanced building may be able to achieve significant energy savings without the cost of thermostats (the Period III and IV data should tell us this), but there is no denying the psychological and comfort

benefits of giving residents control over their own heat. Indeed, until the infrastructure changes so residents have a direct economic incentive to save energy, conservation measures may be "sold" on "comfort" rather than energy savings.

For district heat-served customers, the building-level heat exchanger and controller are expensive on a per-apartment basis (about $250 per apartment). MPEC feels that substation-level heat exchangers and controls (a single installation would serve 5 to 25 buildings), with simple auxiliary controls in each building, could achieve almost the same benefits at a cost of about $80 per apartment.

The economics of the conservation and control measures provide some interesting numbers:

- The cost of the weatherization measures (excluding controls) is about the same as the first year's savings.
- Adding the cost of substation-level control leads to a 2-3 year simple payback.
- The cost of substation-level control and building weatherization is comparable to the annual per-apartment subsidy the national government paid for district heat in 1992-93.
- The conservation rebates we paid to the Wolasa 8 and 10 residents for Period II totalled about 55 million Polish zlotys. In the summer of 1993, the Cooperative received a rebate from MPEC of about 70 million Polish zlotys for using less (metered) heat than the calculated heat demand for these buildings. Thus, the rebates were consistent with the magnitude of actual energy savings.

CONCLUSIONS

The weatherization and control measures implemented in Wolasa 10 showed it is possible to save over 20% of a building's space heat energy. These are demonstrated, not theoretical savings. Actual savings will almost always be less than engineering calculations, as people open windows for ventilation; building settling means that some windows can't be weatherstripped, or they won't close; some people will opt for higher indoor temperatures—comfort—instead of using less energy; etc.

Again, we must stress that controls and weatherization are both necessary to save significant energy. Weatherization can reduce the amount of heat a building needs. Controls are needed to reduce the amount of heat a building takes. In buildings heated by district heat or individual boilers, a conservation program must include installation of appropriate controls. Where there is already a thermostat-controlled heat source (e.g., electric heat or thermostat-controlled gas furnaces), then the controls are already in place. For hand-stoked boilers or coal stoves, the operator must be trained to reduce the amount of fuel used.

The first season's data, while preliminary, do suggest which energy efficiency measures are cost-effective for the large concrete buildings:

- Caulking, wetherstripping, and radiator shields
- Attic/roof insulation
- Control of energy supply at the building or substation level.

Individual radiator thermostats do not appear to be cost-effective, but the individual control they afford is a major "selling point" for an energy efficiency program.

Total cost of the weatherization package approximated first year energy savings. Cost of all improvements, including the building-level control, was about equal to the annual state subsidy paid to heat the apartments. Cost of controls and weatherization will yield a simple payback of two to three years. The costs of the measures demonstrated, while not onerous, still requires a rationalization of the payment structure for heat, in order to provide an economic incentive to conserve and financial feedback to the resident.

Kraków's plans to eliminate 633 local solid-fuel boilers and connect their buildings to the district heat system will increase the demand for the MPEC network to about 2060 MW (see paper "Comparing Alternatives for Reducing Air Pollution for Low Emission Sources in Kraków" by Bieda, et. al., in this session), compared to an existing central heat and power plant capacity of 1730 MW. Obviously, a comprehensive conservation program that can reduce district heat demand by 20% will eliminate, or defer significantly, the need for construction of new central heating sources. Thus, conservation must be a key element to the City's strategy for eliminating local boilers.

While the analysis shown relates to the large multi-family buildings, smaller scale demonstrations in the Old Town during this project have shown comparable energy savings in gas-heated apartments in smaller, 400-500-year-old masonry and brick structures.

In summary, the project team has identified and demonstrated affordable and effective conservation technologies that can be applied to Kraków's existing concrete-element residential housing. The results suggest that conservation strategies will be key to many alternatives in the City of Kraków's plan to eliminate low-emissions sources:

- Connecting more customers to the MPEC network and eliminating local boilers without requiring construction of new combined heat and power plants.
- Reducing heat costs for customers converting from solid fuel heat sources to less polluting sources.
- Reducing heat demand so more customers can be served by existing gas and electric distribution systems.

To fully encourage energy efficiency and exploit the demonstrated savings, the existing system of tariffs, subsidies and payments must be revised so the people who use heat 1) can control their usage, and 2) have an economic incentive to reduce their usage. The project has shown that this is indeed possible without putting a heavy financial burden on the residents. The national and city governments are actively designing and evaluating programs to implement such incentives.

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TABLE 1: CONSERVATION MEASURES DEMONSTRATED

PERIOD	Wolasa 4				Wolasa 6				Wolasa 8				Wolasa 10			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
CONSERVATION MEASURES																
Base Case-Hydroelevator	X		X[1]	X[1]	X		X[1]	X[1]	X		X[1]		X		X[1]	
Regulated Hydroelevator		X	X[1]	X[1]												
Regulated Heat Exchanger						X	X[1]	X[1]		X	X[1]	X		X	X[1]	X
Weatherization and Attic Insulation				X				X			X	X		X	X	X
Thermostats										X	X[4]	X		X	X[5]	X
Conservation Incentives										X				X		
Pipe Cleaning							X	X	X	X	X	X	X	X	X	X
External Insulation											X[2]	X[2]			X[3]	X[3]

[1] Alternating 2-week period between base case hydroelevator and temperature-controlled heat exchanger (Wolasa 6, 8, and 10) or controlled hydroelevator (Wolasa 4)
[2] External insulation on windowless walls only
[3] Full external insulation
[4] Residents reinstalled 36% of the thermostat heads during this period.
[5] Residents reinstalled 48% of the thermostat heads during this period.

Period I: October-December 1992
Period II: January-April 1993
Period III: October-December 1993
Period IV: January-April 1994

TABLE 2: REGRESSION RESULTS

Test Building	Period	R^2	Constant a_0 (GJ)	Outdoor Temp, a_1 (GJ/°C)	MPEC Temp, a_2 (GJ/°C)
#4	Base (I)	0.747	-8.03 (4.52)	*-0.0648* *(0.1088)*	**0.2892** **(0.0527)**
#6	Base (I)	0.822	**-8.36** **(3.50)**	*-0.0053* *(0.0792)*	**0.2848** **(0.0404)**
#8	Base (I)	0.584	-7.89 (5.57)	*-0.0197* *(0.1292)*	**0.2837** **(0.0645)**
#10	Base (I)	0.853	**-9.29** **(3.12)**	*-0.0531* *(0.0731)*	**0.3052** **(0.0361)**
#4	Post (II)	0.962	1.28 (1.46)	**-0.4398** **(0.0491)**	**0.1819** **(0.0168)**
#6	Post (II)	0.972	**-3.65** **(1.11)**	**-0.1878** **(0.0367)**	**0.2237** **(0.0127)**
#8	Post (II)	0.848	4.62 (2.88)	**-0.5039** **(0.0975)**	**0.1180** **(0.0326)**
#10	Post (II)	0.955	**4.96** **(1.39)**	**-0.4616** **(0.0468)**	**0.0967** **(0.0157)**

(Standard errors are in parentheses)

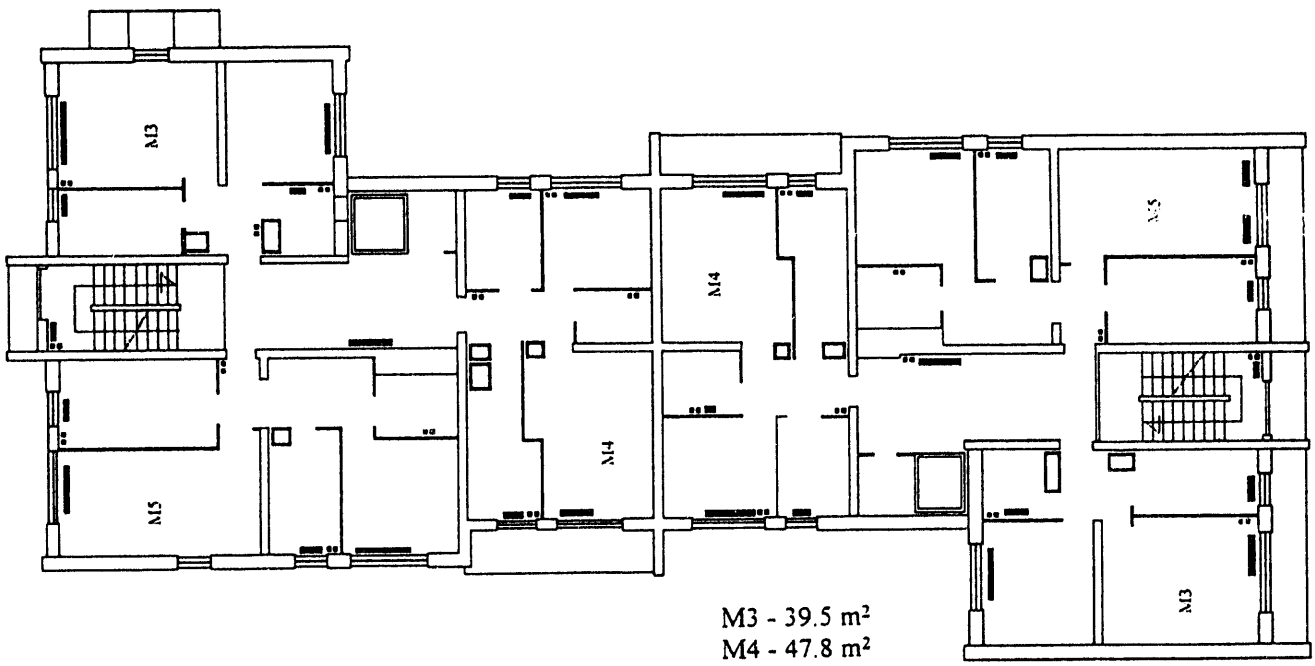
TABLE 3: PERIOD I REGRESSION RESULTS WITHOUT OUTSIDE AIR TEMPERATURE TERM

Test Building	Period	R^2	Constant (GJ)	MPEC Temp (GJ/°C)
#4	Base (I)	0.759	-10.160	0.315
#6	Base (I)	0.832	-8.5547	0.287
#8	Base (I)	0.601	-8.592	0.292
#10	Base (I)	0.857	-11.164	0.327

TABLE 4. ENERGY SAVINGS ESTIMATES FOR PERIOD II

Building	(Period I) Baseline Annual Average Use per Day, GJ	(Period II) Post Annual Average Use per Day, GJ	Energy Savings
#4 Regulated Hydroelevator	15.29	15.29	0.0%
#6 Regulated Heat Exchanger	14.64	14.13	3.5%
#8 Regulated Heat Exchanger + Thermostats	14.99	13.13	12.4%
#10 Regulated Heat Exchanger + Thermostats + Building Weatherization	15.28	12.02	21.3%

FIGURE 1: FLOOR PLAN OF WOLASA STREET BUILDINGS



ALTERNATIVE METHODS OF REDUCING AIR POLLUTION FROM LOW-EMISSIONS SOURCES IN KRAKÓW

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INTRODUCTION

Kraków is one of the largest and oldest cities in Poland. It is situated in the south of the country on the banks of the Vistula River. From the 11th till the 17th century it was the capital of Poland. Today, Kraków is a city of 750,000 residents, one of the largest centers of higher education, and an important industrial center.

Many centuries of town development, with a rapid acceleration in housing construction after WW II (threefold increase in city resident population) brought in many different heating systems, from primitive coal-fired stoves in the old part of the city, boiler rooms in buildings, boiler houses serving multi-family housing and whole housing estates - mostly using solid fuel (coke, coal) - up to the district heating systems supplied from a central combined heat and power (CHP) plant.

Because of the nature of its resources, more than 90% of the heating in Poland is based on firing solid fuels, with natural gas and electricity used only exceptionally for heating purposes. In recent years natural gas and electricity have been increasingly used, and this tendency will continue in the central parts of the city.

A study on air quality monitoring carried out in the 1980s indicated that around 40% of the high concentrations of air pollutants adversely affecting residents and the natural environment were contributed by coal-fired home stoves and boiler houses using solid fuels. These heat sources discharging particulate matters at low heights, basically lacking any pollution control devices, are called the "low emission sources."

The American-Polish Program on Clean Fossil Fuels and Energy Efficiency in Kraków, which began in 1992, was preceded by a detailed inventory of low emissions sources completed in 1991. The inventory lists the following sources in Kraków:

- 1,134 boiler houses using solid fuel with design output of 977 MW,
- 100,000 coal-fired home stoves,
- plus 17,000 rooms, mostly in single-family houses, heated by individual small boilers using solid fuel.

A significant portion of these boiler houses and buildings heated by stoves are in the central part of the city. The boiler houses consume around 375,000 Mg of solid fuels, the furnaces a further 120,000 Mg, giving combined consumption of around 500,000 Mg of coal and coke.

Moreover, the city has a district heating network supplied from two main CHP plants with a combined output of around 1,700 MW, which ensures heat supply to about 50% of the buildings in town. There are also 202 natural gas-fired boiler houses with a combined output of 76 MW, 73,000 rooms heated by gas-fired systems, and 25,000 more by electric heating systems individually installed.

In the American-Polish program mentioned earlier it has been accepted that all possible technical means would be used to reduce pollution, mainly those which enable utilization of reserves present in the existing networks of:

- district heating;
- gas distribution; and
- power distribution.

The analysis indicated that the following activities can bring about realistic progress in reducing air pollution:

- elimination of the existing solid fuel boiler houses by connecting the buildings they serve to the municipal district heating network;

- elimination of solid fuel boiler houses by converting them to natural gas (mainly in the old parts of the city);

- elimination of solid fuel-fired home stoves by replacing them with electric heating;

- modernization of those solid fuel boiler houses which cannot be eliminated because of their function (such as industrial boiler houses operated year round) by better control of the combustion process, introducing environmentally sound combustion methods, installing air pollution control equipment, etc.

- reducing the adverse environmental effects of home stove use throughout the city by changes in the combustion process, eliminating coal and replacing it with natural gas or electricity, and/or looking for combustion devices that can burn coal without producing air pollutants.

The above methods of eliminating or reducing low emissions have been studied in detail in engineering analyses.

As alternative or transitional measures, testing of existing heating systems has been carried out to show the environmental benefits (reduction of air pollution) of using cleaner fuels, such as:

- smokeless briquettes for stoves and small boilers;

- coke for small boilers; and

- washed and graded coal fines for larger boilers (above 1 MW) with a traveling grate.

The results of testing have facilitated various kinds of environmental analyses, which allowed assessment of the extent to which reduction in pollution loads and concentrations of dust, SO_2, CO, NO_x and CH_4 can be achieved by introducing different technical approaches in various parts of the city.

Engineering analyses, including the capital costs of the various technical options, and environmental assessment, showing the reductions in pollutant loads, allow evaluation of the unit cost of reducing pollution and comparison of various options on this basis.

MAIN RESULTS OF ENGINEERING ANALYSES

Each technical solution adopted for elimination or reduction of low emissions was given an engineering analysis. The aim of the analysis was:

- to determine the part of the city where the action can be undertaken, and the conditions for such action;

- to determine the technical scope of the suggested work; and

- to determine the capital project costs to implement the suggested scope of technical activities.

The major findings in the engineering analysis can be summarised as follows.

Elimination of the Existing Solid Fuel Boiler Houses by Connecting Them to the Municipal District Heating System

The technical prospects and economic sense of connecting to the municipal district system were assessed for all solid fuel-fired boiler houses covered by the inventory (1,134 boiler houses of 977 MW combined output). 633 boiler houses of more than 630 MW output were qualified as suitable for such connection.

To extend the district heating systems to these boiler houses and thus to eliminate them will require:

- laying more than 94 km of new heat pipelines with diameters ranging from 40 to 400 mm

- building more than 20 heating nodes for direct connections for about 150 MW output

- installing more than 560 heat exchangers of around 300 MW combined output.

The investment cost associated directly with connecting these boiler houses to the municipal district heating network was estimated to be:

- connection network	approx. USD 34 million
- heating nodes	approx. USD 8 million
TOTAL	approx. USD 42 million

The elimination of 630 boiler houses by connecting them to the municipal district heating network requires 83 new extensions (total length of more than 94 km). Of course, some extensions would have a large effect at a moderate cost, by eliminating a high-output boiler house.

For each extension an index of effectiveness was calculated, expressed as the cost per 1 KW of eliminated boiler output. The range of these indexes is:
- minimum, USD 22 per KW
- maximum, USD 598 per KW

The average index is around USD 90 per KW.

Determining these indexes allows the potential order to be set for implementing individual extensions, starting from the most effective ones.

Nevertheless, to make a full engineering analysis, the municipal district heating system has to be checked from the point of view of:

- the capacity of the existing CHP plants at Łęg and Skawina; and
- the flow capacities of the existing main heat pipelines.

The above tasks required preparation of a heat demand forecast for the period up to the year 2005, with consideration given not only to the demand created by the elimination of low emissions sources but also to heat demand from new construction which will be completed in the next 15 years and which will take heat from the municipal network.

A detailed heat demand and supply study completed in 1993 gave estimated demand from the municipal heating network at around 2,060 MW. The existing capacity of the CHP plants supplying the system is 1,730 MW. Hence there is a theoretical future shortage in the capacity of central heat sources of around 330 MW.

For heat supply and demand forecast, the capacity of the existing network was assessed. The expected load on it requires upgrade work at a cost of between USD 21 and 53 million, depending on the extent of work envisaged.

As seen from the above, extreme-case costs of upgrading the main pipelines in the municipal heating network exceed the capital cost of connecting all selected solid fuel-fired boiler houses. There is a widespread belief that connecting selected boiler houses will not require expansion of either the central sources or the network for a long time to come. The necessity of such expansion can be avoided by broadly introducing all possible energy conservation measures both by end-users and by the heat distribution network itself.

The results obtained from the energy efficiency demonstration project carried out under American-Polish program in Kraków as well as practical steps recently taken by the Kraków Heat Distribution Company (MPEC Kraków) indicate clearly that there is a fairly realistic prospect of obtaining the required energy savings on the order of 20% during periods with the lowest temperatures.

Conversion of Solid Fuel-Fired Boiler Houses to Natural Gas-Firing

The conversion of solid fuel-fired boiler houses to natural gas-fired ones has proceeded in Kraków for more than 20 years. This regards mainly the Old Town and, to a lesser extent, the surrounding quarters. In order to meet the increased demand, the distribution system was adapted to supply more natural gas.

The increase in capacity was also boosted by conversion of the entire system from coke-gas to natural gas less than twenty years ago. Up to 1992, 73 Old Town boiler houses with output of 36 MW have been converted to gas, and 36 more representing a further 13 MW have switched to gas in the areas surrounding the center of the city.

For conversion of boilers to gas, the American-Polish program was to include analysis of the Old Town, where 41 solid fuel boiler houses of 16 MW output still operated, consuming about 4,000 Mg of fuel (coal, coke). The engineering analysis was to produce a technical concept for each boiler house conversion, with a capital cost estimate and a check on whether the existing gas supply network and its pressure-reducing stations are capable of meeting the increased demand for gas, indicating the cost of modernizing the network.

The analysis showed that from a technical standpoint all the boiler houses but one (suitable for conversion to fuel oil) can be converted to gas-firing, with only minor modifications required in the gas distribution system.

The capital costs of the above work were estimated to be:

- conversion of boiler houses to gas
  approx. USD 1.9 million
- extension of gas supply system
  approx. USD 0.1 million

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TOTAL approx. USD 2.0 million

The average capital cost index for conversion of solid fuel boiler houses to natural gas in the Old Town is about USD 125 per KW.

An additional engineering analysis was completed to show the necessary scope of gas supply upgrade if boiler houses from adjacent areas also were to convert to gas fuel. This is an area within a second ring of development, mostly inaccessible to the district heating network. There are 195 boiler houses operating there, of around 95 MW combined output.

The analysis indicated that to supply gas to these boiler houses would require the following extensions of the gas network, regarding only medium- and low-pressure systems:

- construction of 5 new pressure-reduction and metering stations and modernization of 2 existing stations;
- laying more than 3 kilometers of medium-pressure pipelines; and
- laying 10 kilometers of low-pressure pipelines.

The capital cost of these was estimated to be USD 2.0 million.

The cost of converting boiler houses in this area to gas is estimated to be USD 10.5 million.

Thus the average index of capital cost for gas conversion of solid fuel boiler houses in the areas adjacent to the Old Town (within the second ring) is USD 132 per KW. As mentioned above, this estimate does not include the possible cost of extending the high-pressure part of gas supply system, i.e. the main pipelines, as this analysis is being prepared now.

When the assumption is made that all boiler houses in the areas adjacent to the Old Town that cannot be reached by the municipal district heating network are converted to gas together with some reserve towards gas heating for buildings now using home stoves, there is a huge increase in the hourly demand for gas. The increase is on the order of 100%.

Elimination of Coal-Fired Stove Heating in a Selected Area of the City, Replacing It With Electric Heating

Both in the past and at present, a significant number of residents would be willing to cover the cost of changing from heating by coal-fired stoves to electric space-heating. The obstacle to more widespread adoption of this conversion is the lack of transformer stations and cable networks distributing power from the main power supply points (MPSPs) and supplying each building with heating stoves.

Within the American-Polish program one area has been selected, immediately adjacent to the Old Town. It has many buildings heated by stoves, and the newly-erected ŁOBZÓW MPSP with reserve capacity of about 50 MW which can be used for heating.

The objective of the engineering analysis was to determine the scope of capital projects enabling supply of this power for conversion of stove-based heating to electric heating in each building with stoves.

A dedicated piece of software was developed to optimize possible technical solutions.

In the selected part of town, around 8,500 coal stoves can be converted to electric heating provided the following work is done:

- 78 transformer stations, 15/0.4 kV
- 19.4 kilometers of medium-voltage cable network
- 19.0 kilometers of low-voltage cable network

The total cost of these capital projects is around USD 2.4 million.

The above cost estimate for the outside network should be increased by the cost of converting the coal stoves, i.e. modification of the internal electrical installations in buildings with stoves and installation of electric resistance heating inserts in ceramic stoves. The total cost of converting one stove was estimated to be USD 200 per stove.

For all 8,500 stoves this amounts to a total of USD 1.7 million. The installed capacity in these stoves will be 18.1 MW.

The average index of capital cost in the case of coal to electricity conversion of heating in the ŁOBZÓW MPSP is USD 227 per KW.

Here again the analysis was extended to survey the necessary scope of capital projects needed to convert the remaining 3,100 coal stoves in the Old Town to electricity. Broadening the scope of the analysis was justified by the fact that the demand for power in the Łobzów area will not use all the reserve capacity of this station.

To eliminate coal stove heating and replace it with electric heating in the Old Town area would require:

- 18 transformer stations
- 7.2 kilometers of medium-voltage cable network
- 4.0 kilometers of low-voltage cable network.

The total cost of this project would be around USD 0.58 million. The total cost of converting 3,100 coal stoves to electricity is USD 0.62 million. The power output installed in these stoves would be 8.7 MW.

The average index of capital cost for coal to electricity conversion of stoves in the Old Town will be USD 138 per KW.

Modernization of the existing solid fuel boiler houses

Not all the solid fuel boiler houses in Kraków could be eliminated by connecting them to the district heating network, nor improved in terms of emissions by conversion to natural gas. The town has more than 100 solid fuel boilerhouses of a combined output of around 250 MW, operated throughout the year, producing either process steam or domestic hot water. These boiler houses should continue on solid fuels, with necessary upgrades to lessen the impact of the combustion process on the environment.

Within the American-Polish program one boiler house of this type was selected where a demonstration modernization project might possibly provide a pattern to follow in other boiler houses that will continue to use coal.

The selected boiler house, called Baza Zaopatrzenia and situated in Krzesławice, produces process steam for nearby industries. It has four PLM-2.5 boilers with designed capacity of 11.6 MW.

The engineering analysis was carried out by two teams - American and Polish. Three American designs were prepared by Burns and Roe Services Corporation of Pittsburgh, under Morton Blinn, and by Burns and Roe Company, under Peter Kemeny. Polish designs were prepared by the Kraków Industrial Construction Design Office (KBP-BBP), under Jerzy Sadowski.

The American team adopted American technology and equipment; the domestic team adopted Polish technology and equipment. The American concept includes three options for modernizing the boiler house, using the following equipment:

a) two stoker boilers with traveling grates, CP type, steam output 9 Mg/h, manufacturer: Tampella-Keller;

b) four fluidized bed combustion boilers, rotating bed, CFB type, steam output 4.5 Mg/h each, or, alternatively, two CFB type boilers, steam output 9.0 Mg/h each, manufacturer: Donlee - York; and

c) chamber boilers, IRIS type - for preheating of feed water, manufacturer: Tecogen - USA.

The Polish concept of KBP-BBP includes options for modernizing the boiler house with the following equipment:

d) three Polish-made rotating fluidized bed boilers, RPF type, steam output 7 Mg/h;

e) two or four perforated-bottom fluidized pre-furnaces, KF type, with various steam boilers of steam capacities from 4 Mg/h to 8 Mg/h; and

f) four Polish or imported oil-fired boilers, various types, steam capacities from 4 Mg/h to 5 Mg/h.

Description of Design Options

Re.a. 2 CP boilers - modern, efficient, with stoker furnace, working for peak steam demand. The boilers will have installations for flue gas desulphurization, semi-dry type, with rotating jets.

Re.b. 4 CFB boilers. Highly efficient, may burn fuel of lower grade. Combustion with sorbent addition.

Re.c. economizer (feed water heater) in IRIS chamber. The flue gas from the chamber will require a semi-dry type of desulphurization installation with bag filters.

Re.d. 3 Polish-made boilers, e.g. of PLM type reconstructed by a Kraków-based firm, RENER, as fluidized bed boilers with rotating bed. PLM-boiler with additional tube heating surfaces. Traveling grates replaced by fluidized beds with coils and rotating grate. Burning lower-quality fuel with sorbent, flue gas purified in cyclones (adaptation of the existing ones) and bag filters.

Re.e. KF-type pre-furnaces with perforated bottom, cooled - built in PLM-2.5 boilers, and additional superheaters. Coal of lower quality with sorbent. Flue gas purified in cyclones and bag filters.

Re.f. In this option the entire boiler house is converted to liquid fuel. Options with EOG-4.5 manufactured by SEFAKO or VX vertical steel boilers manufactured by HENSCHEL of Germany.

All concepts of modernization of the boiler house were subjected to comparative analysis of purchase costs, construction and assembly costs and annual operating costs.

After comparing investment costs for various types of boilers it can be said that the least costs are those associated with fuel oil boilers (about 40% the cost of

purchasing Polish-made coal-fired boilers). High capital costs for the options involving imported equipment stem from the high exchange rate between Polish zloty and USD, and the severalfold difference in labor costs.

These high costs can be moderated by using the maximum contribution of Polish labor in implementing the design according to American technical documentation. An adverse factor in this case may be the prototype nature of the installation, limited to only several units.

The annual cost of operation was determined on the basis of analysis of variable costs in the plants operated. In all modernization options involving coal-fired boilers there is a drop in fuel consumption following better efficiency. This allows savings in fuel cost as well as in labor and environmental fees.

In Polish options based on fluidized bed boilers this enables the operating cost to be kept at a level similar to the present one, in spite of considerable sums paid for depreciation. The opposite occurs in options based on import of equipment. High investment costs will affect the total cost by considerable deductions for depreciation.

Calculating the annual cost of an oil-fired boiler house shows that it will not be competitive with coal-fired boiler houses because of the high price for heating oil in Poland (oil costs about USD 300 per Mg; coal costs USD 20-60 per Mg).

Indexes and comparative features of various options for modernization of a boiler house is given in Attachment 2.

The basic prerequisite for implementation of any of the options has been to secure financing. Regarding the activities of American firms, TECOGEN is in the process of finalizing an agreement with the owner of the boiler house in question, e.g. the Municipal District Heating Company (MPEC Kraków), to undertake a joint action financed under the American assistance project.

AIR QUALITY ANALYSES

Air quality analyses in the Kraków project are being carried out following the completion of engineering analyses. These regard environmental effects e.g.:

- quantitative reduction in pollution loads
- reduction in ambient concentrations of basic pollutants which could be obtained by implementation of specified technical activities.

Hence assessments were obtained for air quality improvements which can be brought about by:

- conversion of solid fuel-fired boiler houses in the Old Town to natural gas;
- connecting all selected local boiler houses to the municipal district heating network;
- conversion of all coal stoves to electricity heating within "ŁOBZÓW" MPSP; and
- elimination of all coal stoves in the city, replacing them with electric and gas-fired stoves, and in a parallel study, replacing coal with smokeless briquettes as fuel.

Air quality modeling follows Pasquille's formula in the version adopted in Poland according to the guidelines of the Ministry of Environmental Protection.

Calculations are based on emissions of particulates, SO_2, NO_X, CO and so-called equivalent emissions according to the formula:

$$Er = 2.9\ (Ep + ENOx) + 0.5\ ECO + ESO2$$

The amount of emissions (concentrations of pollutants) are related to annual standard values, i.e. 32 $\mu g/m^3$ for SO_2 and 50 $\mu g/m^3$ for particulates. In the city center these values are exceeded threefold and more.

The tables presented below have been taken from a report entitled "An assessment of air quality improvement that can be obtained in the city by replacing coal stove heating with natural gas-fired or electric heating systems", done by Ekopol Kraków.

SCENARIO 1 presents the overall environmental effects when coal stoves in the city are replaced with natural gas-fired or electric heating.

SCENARIO 2 presents the overall environmental effects when smokeless briquettes are burnt in stoves instead of coal.

It should be noted how great the environmental advantage is obtained when coal fuel for stoves is replaced with smokeless briquettes. This is an effect which does not involve any investment on the part of the consumer. The concentrations of particulates and SO_2 drop within the city center by an amount equal to the standard permissible load. The results of analyses confirm the paramount importance of using "clean" coal, even if only in a transitional period when the ultimate solutions are still distant in time.

Table 1. Effect of Replacing Coal Stoves With Natural Gas or Electric Heating					
	total particulates	sulphur dioxide	nitrogen oxides	carbon monoxide	equivalent emissions
	Mg/year				
present state	3502	1144	895	4587	16188
remaining low emissions	22	0	196	22	643
increase in high emissions	12	605	170	7	1136
NET EFFECT	3458	539	529	4558	14409

Table 2. Effect of Replacing Coal in Home Stoves With Briquettes					
	total particulates	sulphur dioxide	nitrogen oxides	carbon monoxide	equivalent emissions
	Mg/year				
present state	3502	1144	895	4587	16188
remaining low emissions	368	514	325	2591	3819
increase in high emissions	1	68	19	1	127
NET EFFECT	3133	562	551	1995	12243

COMPARING ALTERNATIVES

Once the engineering data are developed, the relative costs and effectiveness of alternative options need to be examined. One platform for this comparison is the screening model developed by the U.S. Department of Energy (DOE) for Eastern Europe. This section presents preliminary model results for two of the options under consideration in Kraków.

The model was originally developed as a screening tool for use in Kraków. It was then modified by Gilbert/Commonwealth, Inc. and applied to other locations. Brookhaven National Laboratory then adapted the modified version of the model to Kraków for this conference; further modifications are expected. The model is more fully described in other sessions of the conference.

DOE's model is a static model. That is, it calculates annual costs and emission levels for one year rather than calculating costs and benefits over the lifetime of the project. Investment costs and fuel prices are entered for the selected year. For this analysis, projected fuel prices for 1996 are used.

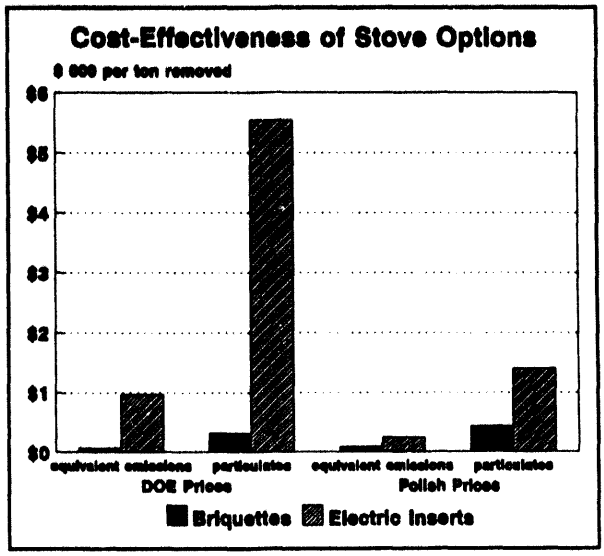
In this analysis subsidies are not included; full conversion costs are assigned to the user. Conversion costs are taken from the engineering studies described above. Emission factors are from the boiler and stove testing activities described in an earlier session.

The two options evaluated with the model are the use of briquettes in home stoves instead of coal, and conversion of home stoves to electric heat using electric inserts. Two sets of fuel price projections are used, one developed in Poland and one developed by DOE. The DOE prices

represent a more rapid transition to Western European price levels, and are higher than the price projections developed in Poland.

Based on model results, the cost-effectiveness of the two options has been calculated. Costs include the increase in operating costs associated with each option as well as the annualized investment cost. Cost-effectiveness is calculated per ton of particulate emissions reduced and per ton of equivalent emissions reduced. The figure shows the results for both sets of fuel price projections.

In both cases, switching to briquettes is more cost-effective than converting to electricity. This is because no capital investment is required to use briquettes in the home stoves. The difference between the two options is less with the Polish fuel prices, however, because the projected price of electricity is less. In the future, the model will be used to compare all the options under consideration for Kraków.



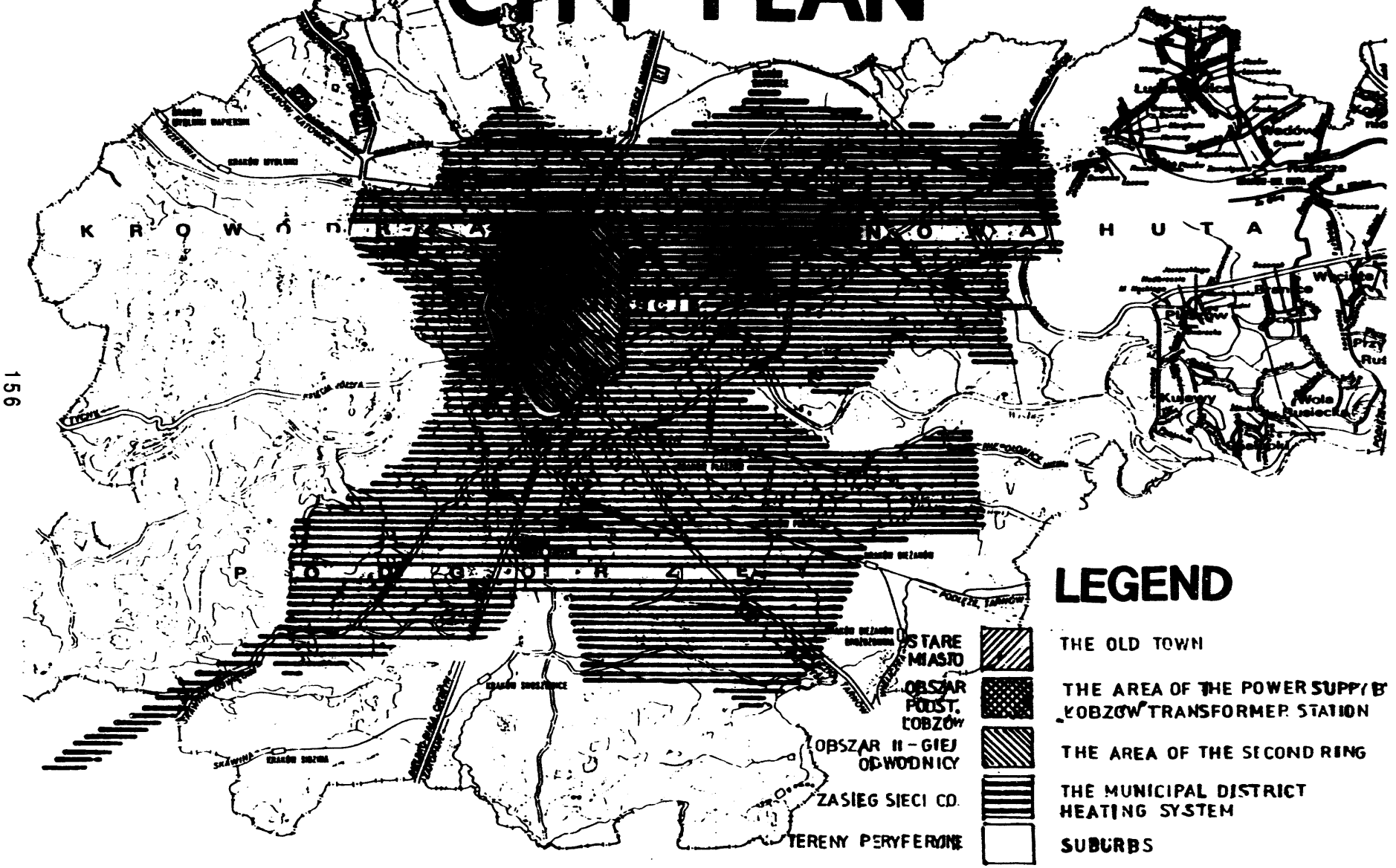
Comparative indexes for modernization options for the Krzeslawice boiler house.
Indexes and characteristics

Attachment 2

No.		Units	Modernization options								
			"a"		"b"		"c"		"d"	"e"	"f"
1	2	3	4	5	6	7	8	9	10	11	12
1	Option	-	CP	CP	CFB	CFB	IRIS	IRIS	RPF	KF/VX	E OG- 4.5-VX
2	Equipment supplies from	-	USA	USA/PL	USA	USA/PL	USA	USA/PL	PL	PL	PL
3	Furnace	-	stoker traveling grate		fluidized bed		fluidized bed		fluidized bed	fluidized bed	oil-fired
4	Number of boilers units	items	2	2	4	4	1	1	3	4	4
5	Boiler house steam output	Mg/h	18	18	18	18	-	-	18	18	18
6	Boiler house capacity (comparative)	MW	11	11	11	11	0.65	0.65	11	11	11
7	Boiler efficiency	%			up to 87.7		from 87.7 to 86		80	80	80
8	Fuel consumption (estimate)	Mt/year	9.0	9.0	8.7	8.7	about 0.5		9.4	9.7	4.8
9	Cost of boilers with auxiliary equipment	USD thousands	2135.3	1400	4664.7	2635.3	435.3	300	947	729.4	529.4
10	Total capital cost of the project	USD thousands	3211.7	2400	6158.8	3929.4	582.3	435.3	2688.2	2482.3	1082.3
11	Index of capital costs	USD thousands/MW	292.0	218.2	559.9	357.2	895.8	669.7	244.4	225.7	98.4
12	Operating costs	USD thousands	723.5	682.3	894.1	782.3	-	-	729.4	717.6	1858.8
13	Index of operating cost	USD thousands/MW	65.8	62.0	81.3	71.1	-	-	66.3	65.2	169.0

ATTACHMENT 1

CITY PLAN



Session VI
Market-oriented Approaches to Emissions Reduction and Efficiency Improvement Commercial Projects

Co-Chairman: Krzysztof Gorlich, Krakow City Council
Co-Chairman: Douglas F. Gyorke, U.S. DOE

Participation of MPEC SA in Polish-American Projects Aimed for Liquidation of Low Emission in Krakow—Jacek Boron, Janusz Mazur, Adam Swierz, Municipal District Heating Enterprise Joint Stock Company in Krakow

Extension of the Central District Heating System—Michael A. Selig, Shooshanian Engineering

Emissions Reduction through District Heating Controls and Supervision in Krakow—Benoit Bô, Honeywell Inc.

Combustion Improvements in Stoker Fired Boilers — James R. Myers, Pennsylvania State University

Modernization of Coal-Fired Boilerhouses for Emissions Reduction in Krakow—Dr. Ronald W. Breault, Tecogen

Inertial Particulate Separator for Reduction of LES Emissions in Krakow—S. Ronald Wysk, LSR Technologies•Jan Surowka, Polish Foundation for Energy Efficiency

Micronized Coal Firing Applied to Plants in the Czech Republic and Krakow—Rick Sheahan, TCS Inc.

Graded/Cleaned Coals for Stoker Plants in Krakow, Poland Peter Rozelle, Robert Eggleston, Jr., EFH Coal Co.

Clean Burning Briquettes for Pollution Control from Low Emission Sources—Wojciech Jozewicz, David F. Natschke, Acurex Environmental Corp. • J.A. Jack Steer, Planmar Consulting, Inc. • Andrzej Smolka, Przedsiebiorstwo Energetyki Cieplnej

PARTICIPATION OF MPEC SA IN POLISH-AMERICAN PROJECTS AIMED FOR LIQUIDATION OF LOW EMISSION IN KRAKOW

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JANUSZ MAZUR
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Municipal District Heating Enterprise
Joint Stock Co. in Kraków

SHORT PRESENTATION OF THE PROJECTS IN WHICH MPEC SA PARTICIPATES AND ESTIMATION OF BENEFITS FROM THEIR IMPLEMENTATION

The Municipal District Heating Enterprise (MPEC) in Cracow was established in 1953. At that time it took 12 district heating and industrial boiler houses and about 30 km of the heating network in the newly established industrial district of Cracow, Nowa Huta. Growth, the construction of a cogeneration plant at Leg, and structural change in the district heating system have contributed much the enterprise's development. Currently, acting as a stock company owned by the City of Cracow since December 31, 1993, it administers assets which include almost 700 km of the heating network (including 1,000 mm diameter pipes), over 200 buildings and other structures, several thousand heating nodes, 4 large industrial boiler houses and more than 100 small and medium-size boiler houses. Almost 2,000 MW (1,800) of power is at the disposal of the enterprise, of which 70% is bought from the Cracow-Leg Cogeneration Plant S.A. and 15% from the Skawina Cogeneration Plant; the rest consists of purchases from the Sendzimir Steelworks power plant and the enterprise's own production. This accounts for annual sales in the range of 12,000 TJ and covers over 50% of the heat demand of Cracow and Skawina. Since the dynamic development in the 1970's and 1980's was not always matched by the quality of the pipes, equipment and fittings, the enterprise faced the need for a major retrofit at the beginning of the 1990's. Considerable depreciation of the assets has also significantly affected that. For these reasons, in September 1991, after negotiations with the World Bank and the Government of the Republic of Poland, a new loan agreement was signed for the project entitled "Rehabilitation of the Cracow District Heating System," in amount of USD 25 million. The money was to be spent on the following: completion of the Master Plan for Cracow District Heating SWECO, a Swedish consulting company, in cooperation with MPEC specialists; all works connected with improving leak tightness and insulation of the heating network, including separation of the return heat exchanger station from the consumers' installation: as well as the system automation, retrofitting, teletechnology and telemetries. By the end of 1994, 40% of the loan is expected to be spent, and there are already visible results from the first stages of the program.

Almost simultaneously with the signing of the Loan Agreement, the Program for Elimination of Low

Emission Sources began to be developed in Cracow, supported by a grant for USD 20 million from the US Congress, following a visit to Cracow by George Bush, who was the Vice-President of the United States at that time. Thanks to coordinated efforts, the guidelines of the Program for Elimination of Low Emission Sources, presently called the Cracow Program for Clean Fossil Fuel and Energy Efficiency, have been defined in a way that supplements the Master Plan of the World Bank and fills in the gap not covered by the World Bank loan due to the meagerness of funds (USD 25 million) compared to the enormous needs of the system.

This especially concerns the modernization of boiler houses,which, because of their productive function (steam or process water) or because of their location, are not planned to be liquidated. Another constructive contribution of the program lies in extending the areas heated by the district heating network, of no small importance for the enterprise, considering the growing competition between various energy sources.

In view of the competence, needs and the current share of MPEC S.A. in satisfying the heat demand of Cracow and Skawina, six proposed Polish-American joint ventures will be implemented, in cooperation with our enterprise. The US Department of Energy (DOE) has positively evaluated the following proposals in competitive bidding:

to improve and extend the existing district heating system in Cracow, in order to eliminate old low-efficiency, environmentally unsound boiler houses:

- a joint venture project of **Shooshanion Engineering Associates Inc.** of Boston, MPEC S.A. and Polinvest Cracow, which consists in extending the heating network and in liquidating 5 large and more than a dozen small boiler houses all over the city, and connecting new customers to the central network. 100% of the new network area would use heat exchanger stations, fully automated and metered heating nodes with quantitative and qualitative controls. It is estimated that full implementation of this project would reduce the emission in the area by the following amounts:
  - CO - 39 Tons per Year
  - SO - 14 Tons per Year
  - Particulates 54 Tons per Year

  The newly created firm would offer similar services not only to Cracow but to other towns in Poland and in Central and Eastern Europe as well.

- **Hart Associates Inc.**, of Washington, intends to create a joint venture company with MPEC S.A., to carry out a Customer Assistance Program to encourage the owners of local boiler houses to liquidate them and to connect to the district heating network. The company to be created would also promote a set of recommendations to the representatives of local and central government authorities concerning policy for creating and implementing financial and legal incentives for using the heating network. It would also offer comprehensive services to customers who liquidate boiler house: negotiations, City Study tests, assistance in getting credit and credit guarantees, investment implementation, start-up etc.

- The last project in this field will be carried out by **Honeywell Inc.** of Minneapolis and MPEC S.A. on the buildings of the Widok Housing Cooperative in Cracow. It will consist of controlling and supervising the heating system of the housing estate, including installation of energy-saving equipment in customer apartments. This is the typical range of activities of Demand Side Management (DSM), as with the two projects mentioned above. It is expected that most of the expenses will be covered by the "avoided costs," that is, the project cost will be reimbursed from the savings, which are estimated as a 20% decrease of energy consumption by the residents.

For emissions reduction and increased boiler efficiency the following projects are planned:

- **Control Techtronics International, Inc,.** supported by Penn State University, together with MPEC S.A. and Naftokrak-Naftobudowa Construction and Assembly Company, will carry out a project to increase efficiency and to modernize a boiler house on Lindego Street in Cracow.This is a large industrial boiler house owned by MPEC, using 3 steam boilers and two process water boilers which supply heat to, among other customers, a large diary and the Widok housing estate, included in the modernization project with the Honeywell company. The scope of increasing boiler house efficiency provides for - rarely applied in Poland - reduction of emissions through an automatically controlled combustion process in the boiler and the use of processed and graded coal (the Company described below, created as a result of the program, would be the producer of this coal). In this way, instead of cleaning enormous amounts of flue gases, the reduction of emissions will occur through appropriate preparation of the fuel and control over the combustion process. It is estimated that there should be an increase in efficiency by 15 - 25% (in the case of that boiler house this means about 5,000 t annually), a reduction of particulates emissions by 75% and of CO by 20%. Training courses for operators and Polish engineers will be given, to enable the new company to operate the boiler house properly and to sell the applied technologies in Poland and throughout Europe.

- The second project in this field concerns retrofitting another industrial boiler house owned by MPEC and located in the Nowa Huta District. In this instance, **Tecogen Inc.** of Waldham, using the equipment of the aforementioned Control Techtronics Inc., together with MPEC S.A. and a Japanese financial institution named JAIDO (Japan Development Organization International) and with Naftokrak-Naftobudowa, will carry out a comprehensive modernization of a boiler house. The scope of work in this instance is slightly broader than that of the boiler house on Lindego Street. The major difference, however, is not technological but organizational, as MPEC S.A., being at the same

time a shareholder and the primary customer of the Company, as in all the other cases, will pay for the installed equipment exclusively from the savings compared to current consumption. A similar rule will be applied to all successive customers of the Company in Poland and in Europe. The benefits from such a project can be compared to those achieved from the modernization of the boiler house on Lindego Street.

- The last project in which MPEC is involved is being carried out by the **EFH Coal Company** of Wilkes Barry, with the participation of Naftokrak-Naftobudowa. The company to be created will build a coal processing plant for stoker boilers, which will produce graded, purified, washed and processed fuel for stoker boilers, including the boilers on Lindego Street and in Krzeslawice. In addition to the production of environmentally sound coal, the company will sell similar plants, which draw much interest not only in Poland but also in Germany. Polish employees will be trained in the methods used for burning coal in stoker boilers in the USA.

It is easy to see that all the above-described proposals have a common goal - to improve air quality through liquidation of low emissions sources, to reduce emissions from the remaining boilers, and to save energy among customers and suppliers, as it is obvious that protecting the air from emissions from the energy sector consists not only in catching particulates and other substances in cyclones, filters, electrostatic precipitators and desulfurization installations, but also in economizing every GJ and every kilogram of unburned fuel.

It is clear that the implementation of such a wide program was preceded by much research work and studies dedicated to the energy sector in the city of Cracow. All boiler houses were listed and described, and the needs and possible actions for specific energy sectors and town districts were identified. It is worthy of note that most of the tests of heating facilities were carried out on MPEC structures.

The investigation was done on boiler houses - large industrial and small heating boilers - and on the distribution system; an experiment on energy efficiency carried out on four blocks heated by the MPEC heating network has shown the potential for proper fuel selection and the use of energy-saving equipment and a system of incentives. The results of the experiments drew much interest from the participants in the 2nd Polish District Heating Conference in Miedzyzdroje in September 1993.

The present phase is a continuation of those activities according to new commercial rules. Finally, MPEC's participation in the program complements steps taken individually by our enterprise to reconstruct the energy system in Cracow, financed from MPEC's own funds and from the World Bank loan.

Thus , the main effects expected from participation in the program are as follows:

- improvement of the efficiency of fuel and energy use by the city; - the reduction of particulates and gas emissions;
- expansion of the market by winning new customers;
- modernization and improved operation of the facilities owned by MPEC S.A.

Apart from these, there will be benefits difficult to measure, such as exchange of experience between American and Polish specialists, and the resulting knowledge of advanced technologies, management methods in free-market conditions and methods of organizing that market through paying more attention to marketing issues, diversification of services provided, spreadsheet billing and the resulting tariff system.

SPECIFIC ROLE OF THE MPEC SA IN THESE PROJECTS

MPEC SA as a partner in these joint - venture partnership

As already said, MPEC S.A. has a very special role in all the projects, that of a shareholder and at the same time customer. The enterprise began its participation in the life of the 6 above-described in November 1992, right after the conference at which representatives of the Polish and American firms met. In 1993, in the course of initial negotiations and exchanges of letters of intent, draft projects were developed and presented to a committee to have their environmental and economic effectiveness assessed.

Joint efforts by MPEC and its American partners were crowned with the positive evaluation of all 6 contracts.

The year 1993 was a period of working contacts, aimed at in-depth specification of the technical and financial details and development of draft agreements. Because of the fact that the negotiations have continued up to the present day (March 23, 1994) more details are not provided here. It can be guessed that the dual role of MPEC S.A. in the projects causes an obvious conflict of interest which affects each of the projects to various extents. Such a situation, though significantly affecting and somewhat hampering the negotiations, makes it possible to develop a formula for the new company's activities that will facilitate cooperation with new customers. Obviously, all the activities involve a compromise between what is required from the company which provides the services and the expectations of the shareholders. The fact that MPEC -- an enterprise with many years of experience in administering and operating boiler houses and heating networks -- is participating in the company will be significant to the company's future. It will allow the projects to be planned in such a way that they will fully respond to the market demand and customer requirements. The participation of MPEC S.A., Cracow, an enterprise which is recognized and renowned in the Polish heating sector, raises the new company's prestige and perceived reliability. It is a guarantee of the quality of services and the proficiency and experience of the staff.

Thus, although MPEC's participation in the projects may undoubtedly tend to create temporary difficulties in the initial phase, it will have a positive effect on the results achieved by the companies.

MPEC SA as a first client of the joint venture partnership

Another aspect is MPEC's participation in the projects as a primary customer of the companies to be created. The companies are investment/operational companies, and the scope of their activity is specified precisely enough, consisting of specific work on the objects structures. By definition, the primary customer of the companies will be MPEC, which will buy specific technologies and programs and contract for their implementation and operation. The basic incentive for such a way of proceeding is the economic results of implementing new technologies. The results are in the fuel economized, reduced fees for the use of the natural environment for economic purposes, and the reduced operational costs within a certain group of specified costs which can be defined as non-incurred or avoided costs. According to preliminary economic simulations, for specific programs the current costs will be decreased by even 20 - 30%. Thus it seems beneficial to us, as a customer, to execute the proposed contracts.

Another less tangible but no less important element of the program, to be achieved through training courses and cooperation within the program, is knowledge of project and work management, programming and planning skills, investment project evaluation, new operational experience, and especially skills in using the new technologies that will become MPEC property.

These are only some some of the benefits MPEC will have from participating in the program. It is also necessary to pay attention to problems related to MPEC's participation as a shareholder in the companies. As already stated, the purchase of technologies by an enterprise which is so experienced and renowned all over the country will strengthen the companies' perceived reliability to customers and confirm the soundness of similar modernization projects.

Of course, that is not all the customer will get for the price he pays, as the major benefit will be clean air, that is, public health.

BENEFITS FOR CITY KRAKOW FROM IMPLEMENTATION OF PROJECTS AT THE BASE OF COMMERCIALISATION OF MPEC SA

The benefits of the Program must not be considered on the micro-scale only, at the level of the enterprise as customer or shareholder, as its customer is the city and society as a whole. Implementation of the projects will bring evident benefits in the form of studies and technical documentation which permit activities to improve the natural environment, based on technical and economic calculations that use reliable and true data. Moreover, a reduction of atmospheric air pollution indices can be observed already, which undoubtedly will become more visible after all the projects are implemented, including

those in which MPEC is not participating. In addition, the city's technical infrastructure will be strengthened by the use of a USD 20 million gift from the US Congress to the residents of Cracow, matched by the same amount from investors participating in the program.

The programs that have begun will be continued in our city when the best organizational and legal solutions are formulated and applied to other structures on strictly commercial basis. Since the beginning of 1994, thanks to privatization, MPEC has become a legal entity under the Commercial Code, a stock company with the City of Cracow as sole shareholder. This fact has a significant impact on the work in progress, considering the new character of our enterprise. Apart from its role as a public utility, which will remain an indispensable element of its functioning, a new, strictly economic function arises, producing the necessity to generate profit, so that the activities mentioned need to be conducted with great economic efficiency. The possibility of commercial activities will be especially important to the development of the projects in the program. If the intentions are fulfilled and the joint ventures bring the profits expected, the newly created entities will extend their activities to other Polish cities, and perhaps to other countries in our region.

Such a thesis is based on the fact that Cracow's problems with the technologies used here are almost the same as in other district heating enterprises in Poland and in Central and Eastern Europe, so the development of these issues will be similar, and our experience in this area may prove very valuable to many new partners.

Access to other energy markets will be extremely beneficial to both the city and MPEC, since, in addition to the expected financial results we expect an increase in the firm's prestige and promotional benefits for our home town.

The challenge of the program forces us to change the organizational structure of the Enterprise, to make it more modern and more flexible. This regards the accounting system especially, which was not compatible with DOE requirements. The new requirements have made MPEC an organizationally efficient company, attractive in the free market which is being created. At present,several months after the transformation we are in the restructurization phase. The DOE and American contractors have imposed specific models a operational schemes which have proven effective in the USA. Within the next few years the enterprise is sure to be fully commercialized, i.e., privatized through the sale of stock.

An efficient company, well organized and managed, which, besides its function as a public utility offers a range of activities as described, will certainly be highly appreciated and will find serious investors ready to engage their funds in its further development, to the benefit of the city, the enterprise itself and to its employees.

EXTENSION OF THE CENTRAL DISTRICT HEATING SYSTEM

KRAKOW, POLAND
KRAKOW CLEAN FOSSIL FUELS AND ENERGY EFFICIENCY PROGRAM

MICHAEL A. SELIG, P.E.
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Summary

It is generally agreed that centralized district heating systems, when coupled with electricity generation (cogeneration), represent one of the most energy efficient approaches to providing space and process heat in urban areas. Centralization in turn affords the opportunity to cost-effectively limit emissions. Minimized primary fuel consumption and maximized pollution control makes expanding the use of district heat a very desirable approach toward urban air quality improvement.

The planned DOE-supported project addresses Pilot Project 1 of the Krakow Clean Fossil Fuels and Energy Efficient Program - extension of the central station district heating system, to eliminate local boiler houses. This Project Area is considered by most to be the most cost-effective area within the DOE/Krakow program. The project will be particularly effective because the large boilers to be eliminated are antiquated, with very low-quality particulate removal systems.

Our scope of work is to design and construct new portions of the heating system network, to enable the abandonment of existing local boilers. Prior to final design, we shall perform exhaustive engineering evaluations of alternative pipe types, burial techniques, and energy conservation and control features, such as variable speed pumping and controls. Our goal is to achieve, in a pilot project sense, a piece of heating system network expansion that is state-of-the-art in its energy efficiency and cost-effectiveness.

At the same time, the project team will carefully develop the economic and legal framework knowledge necessary for the development of a commercially-viable business entity in Krakow. This entity, which presumably will be started as a joint venture, will ultimately perform district heating system expansion and upgrade work elsewhere in Krakow and Poland. It will be formed of project team members, and others as applicable, and will offer engineering and contracting services throughout the region.

Background on Shooshanian Engineering

Shooshanian Engineering Associates, Inc., located in Boston, Massachusetts, is a mechanical and electrical engineering firm specializing in study, design, and construction services for the following systems for commercial, industrial, and institutional clients:

- Heating Systems
- Piping Systems
- Ventilating Systems
- Air Conditioning Systems
- Electrical Systems
- Telecommunications Wiring
- Security Systems
- Energy Conservation Systems
- Fire Protection Systems
- Sanitary Systems
- Refrigeration Systems

Founded in 1961, Shooshanian Engineering Associates is one of New England's largest mechanical and electrical engineering firms. Shooshanian employs a staff of 90 which includes professional engineers, designers, draftspersons, construction administrators, computer applications specialists, and energy conservation and management experts.

Shooshanian Engineering Associates has been involved in the international arena since the early 1970s, providing mechanical and electrical engineering consulting services to governments, corporations, and architects worldwide.

We are committed to the project for the following reasons:

- We are active in the international marketplace and have been pursuing work in central Europe for three years. We are pursuing other projects in Krakow also.

- We are committed, as a firm, to develop cost-effective applications of environmentally friendly technologies. Energy conservation is an area of significant concentration for us.

Other Team Members

Our partners, POLINVEST and MPEC, are ideally suited for this project. POLINVEST will perform financial and legal analysis, while MPEC, as owner of the system, will be intimately involved with the planning of its extension. POLINVEST and MPEC have a strong pre-existing business relationship. POLINVEST is a small but growing entrepreneurial enterprise and is very eager to develop this component of their business. MPEC would like to increase their market share in Krakow, and would thus like to continue its expansion.

The Project

Scope

Our planned project addresses Pilot Project No. 1 - Extend Central Station District Heating. In conjunction with our partners, MPEC and POLINVEST, Ltd., we will extend the existing district heating and piping network. This scope also includes finding methods to increase the efficiency of heat distribution and methods to incorporate conservation measures in the district heating system. As a pilot project, this work will serve as the basis for future heating network expansions, both in Krakow and elsewhere in Poland and in central and eastern Europe. If successful, the project team will create a formal joint venture in Poland for the pursuit of this work.

Emissions reductions are achieved by eliminating local coal- and coke-fired boiler houses, providing the heat instead by far less polluting and more efficient cogeneration plants. Ample excess heat capacity exists in these cogeneration plants, and they are also equipped with pollution control equipment. Moreover, our work will include optimization of all components of the network expansion (pipe insulation, heat exchangers, variable flow, instrumentation and automation), to further reduce coal consumption and associated emissions. The objective is a major improvement in the air quality of Krakow, needed to protect the health of its inhabitants and visitors. Once complete, the process can be repeated in other parts of the city, country, and region.

Local boilers will be demolished, removed, or abandoned in place. The largest of the boilers might be left on-line for peaking service, but this will be avoided. Existing independent hot water circuits will be connected to the network through new heat exchangers, to prevent network water from coming in contact with individual building piping and to improve overall control. A Polish contracting firm will do the construction work.

Our technical approach comprises very comprehensive analyses of the existing system and circumstances in Krakow. Shooshanian Engineering brings substantial experience with underground piping, hydronic systems and controls, and historical renovation work. POLINVEST is extremely well qualified in the evaluation of local legal and economic conditions, for the development of our partnership into a long-term viable commercial enterprise. MPEC, as a system owner/operator, brings the experience of decades of work with the system. Its highly qualified engineers will bring great knowledge and insight to the project.

The project is to be carried out in two phases. The first phase will consist of detailed technical and economic feasibility studies to determine optimum system design, and to identify the most appropriate investment strategy. At this time, it is anticipated that the conclusion of Phase I will involve the retirement of 4 large boilers with a combined capacity of 13.0 MW. The second phase will involve the retirement of 5 boilers with a combined power output of 5.5 MW. The feasibility studies may modify these plans, however, depending on the results.

The commercial entity anticipated as a result of this pilot project will be either a design firm (consulting) or a design/build firm (engineering and construction). It will be comprised of both American and Polish partners, and will be occupied primarily with the expansion and modernization of district heating systems in Poland and throughout central and eastern Europe. Revenues will be generated by charging for the labor and materials expended in each project. Funds will be supplied by a combination of the district heating companies, consumers (residential and commercial) brought onto the networks, and third party investors.

Detailed definition of the commercial approach will develop as the project progresses. Initially, costs will be shared by the project team and DOE. It is desired, however, that other investors eventually become involved. A detailed economic feasibility study will be carried out early in the project. The results of this study will form the basis of organizing third party investors, such as equipment suppliers, construction firms, or banks. In addition, MPEC will try to involve the owners of the boilers being liquidated in the financing of the project.

One of the crucial components of this pilot phase of the work is to develop the financial and legal framework necessary to cost-effectively expand the network. At present, by order of the President of Krakow, the owners of local coal-fired boilers must either install environmental regulatory equipment or eliminate the boilers by the year 1997. Hook-up to MPEC's system represents one of the possible solutions for these owners, and at this time it appears that the costs per individual participation in the network extension are comparable to those of installing pollution control equipment or converting to gas.

However, most individual boiler owners do not have the financial means for any of the above.

The activities supported by DOE funds consist of the technical and economic study, design, and installation of a pilot state-of-the-art system extension project in Krakow, for the purposes of reducing pollution and increasing the efficiency with which primary energy (coal) is consumed. When complete, the work will enable the project team to continue system extensions elsewhere in Krakow and throughout Poland and Europe. Construction techniques, energy efficient system features, implementation costs, and funding strategies will have been identified and optimized to ensure financially viable future ventures.

Rationale

There are ten large coal-fired boilers in the planned construction area, as well as a large number of buildings heated by unitary local coal furnaces. The boilers to be eliminated are generally old and without pollution control equipment, thereby greatly enhancing the potential for pollution reduction in the area. Future heat will be generated by efficient cogeneration plants that are fully equipped with pollution control equipment. The stated objective of the program - to reduce pollution in the Krakow area - will clearly be attained.

Based on the measurements taken and results presented during earlier phases of work associated with the Krakow Clean Fossil Fuels and Energy Efficiency Program, we estimate a total pollution reduction potential of roughly 130,000 pounds per year in the subject region associated only with the 18.5 MW of large boilers to be eliminated, with that amount again attributable to smaller residential stoves to be rendered obsolete. Our projection of total reductions in particulates, CO, NO_x, and organics connected with this proposed project therefore total 260,000 pounds per year.

Alternative approaches would include converting the existing boilers to gas or electric heat. The pollution reduction objective would be achieved in both cases, but neither would make as efficient use of primary fuel as the project proposed herein, so in the long run neither would be as cost-effective.

Heating network extension is by far the most effective and cost-efficient strategy for reducing pollution in Krakow. The cost per unit of pollution reduction is over an order of magnitude lower than that of the other options. This is because the main sources of low emissions - unitary coal-fired boilers and furnaces without pollution control - are eliminated, while the new sources of heat energy are very energy efficient and are equipped with substantial pollution control equipment. As part of our scope of work, we intend to calculate in detail what the reduction will be in Krakow of each affected pollutant.

We anticipate, again on a preliminary basis, the following individual pollutant reductions:

	Tons per Year
Particulates	54
CO	39
NO_x	22
SO_2	14
Hydrocarbons	1
TOTAL	130

As for heating costs, in the future the heat will be generated by efficient cogeneration plants, having the net effect of reducing the coal required to heat the water. In theory, therefore, the cost of heat could go down or stay the same. However, the price of heat is already below what it should be based on the cost of producing it. The price must go up, regardless, and our analysis will include the determination of market-based heating price increases. By extending the district heating network, cleaner air and greater efficiency will be achieved at the lowest overall life cycle cost.

It is our full intent to maintain the highest standards of environmental protection, health, and safety throughout the course of this work, and we will do our utmost to comply with all applicable regulations.

Strategy

Our strategy in this project is multi-faceted, but it all centers around one key objective - to build a state-of-the-art network segment that is well-received by customers and highly cost-effective. To achieve this, we will begin with exhaustive analysis of technical and economic issues that will impact the final form of the work. Technical studies will include, but are not limited to, the following:

- Develop design criteria including distribution temperature, pressure, velocity, maximum allowable pressure drops, etc.
- Compare alternative pipe types, minimum wall thicknesses, insulation types, insulation thickness, covering type, burial method (tunnels, conduit, direct buried, above-ground), etc. Establish optimum piping system type for use in this project.
- Establish optimum expansion absorption strategies for this application, considering heat pre-stressing, expansion loops, and various mechanical compensator types (bellows, slip, ball joint, etc.).

- Develop criteria for maximum allowable pipe stress values and other stress limits for piping components (including pressure, temperature, ambient influences, dynamic effects, weight effects, thermal expansion and contraction loads).

- Develop criteria for placement of manholes, isolation valves, anchors, pipe and component supports, guides, drain points, air venting points, natural and mechanical expansion devices, etc., building on experience gained elsewhere in the system and on modern design practices.

- Determine feasibility and technical requirements for variable speed pumping applications in the new piping segment(s). Consider where secondary/tertiary loops would be appropriate and what would be required within pumping stations.

- Establish desired control parameters (e.g. flow, valve position, temperature, temperature differential, monitoring points, etc.). Determine if new controls will stand alone or be integrated into existing control system. Establish communications medium (radio, powerline carrier, twisted pair, fiber optic cable, etc.)

- Evaluate options for building interfaces, including metering strategies, heat exchanger types, valving schemes, electrical isolation flanges, and locations for each of the above.

- Provide test and operational data as available regarding emissions from existing boilers and power plants (e.g. Łęg, Skawina), so that Shooshanian can calculate and document changes in emissions resulting from this project on a boiler-by-boiler basis.

- Identify environmental impacts of construction activities, permitting needs, and safety requirements.

- Define soil environment for buried pipe systems including maximum soil loading, assessment of soil pH, electrical conductivity and chemical content.

- Determine appropriate cathodic protection schemes for underground piping system (pipe, fittings, anchors, electrical isolation flanges) to lengthen their useful lives in corrosive underground environments. Consider photovoltaics if lengthy grid extensions represent significant costs.

  The following schemes shall be examined at a minimum:

  a) Sacrificial anode systems

  b) Rectifier systems, both grid and photovoltaically powered.

- Perform ongoing economic analysis, developing cost-effectiveness criteria throughout. Establish projections for future returns on investment.

Economic studies will include, but are not limited to, the following:

- Cost of Delivering Heat

  Provide report detailing the full current and anticipated cost of delivering heat via MPEC's system. Cost items include:

  a) Fuel
  b) Electricity (pumping power)
  c) Depreciation
  d) Maintenance
  e) Labor
  f) Other (taxes, capital improvements, etc.)

- System Ownership Issues

  Provide report describing the lines of ownership of system components. Hot water is generated primarily from waste heat at Łęg, Skawina, Solway and Nova Huta power plants. Do the large heat exchangers and pumps belong to MPEC? Does MPEC buy the heat and/or participate in power plant coal purchases?

  Similarly, does MPEC own smaller boilers not directly connected to the central system, or participate in the fuel purchases and maintenance of these boilers? Does MPEC own piping and heat exchangers in end users' facilities? What ownership issues arise when MPEC hooks into a new building?

- Pricing Regulations

  As a public utility, MPEC is undoubtedly subject to public regulations pertaining to pricing. How does this process work? What is the procedure for MPEC to raise rates? Are billings done monthly? Who designs the rate structure, and how would a potential system of incentives (for hookup to the system) be decided upon?

- 1997 Environmental Regulations and Cost Implications

  Provide a complete description of the emissions reduction regulations, going into effect in 1997, that affect the boiler owners we will be dealing with. Describe what they must do to comply, what it will cost, what will happen if they do not comply, and how likely it is the regulations will be enforced.

- Boiler Ownership Issues

  Who owns the boilers that we are planning to eliminate? Is anyone making money through their operation? Who buys the fuel, and who does the operation and maintenance? Do the boilers have any salvage value, and if so, who would receive the proceeds if they were sold?

- Easement Issues

  As the piping system is expanded, will any special permit requirements or other legalities arise before excavation can take place for pipe burial?

- Public Bidding Requirements

  To ensure fair contractor pricing, DOE has strongly requested that all construction work be competitively bid. Are there regulations governing public bidding, as there are in the United States, such as advertising requirements, a period for public comment, prevailing wage laws, equal opportunity, etc? If so, we would like them summarized, along with their economic and procedural impact on the project.

- Long-Term Pricing Strategies

  In order for MPEC to be economically viable as it expands while providing ongoing service, its rates must cover capital and operating costs. A long-term plan for how to establish and structure rates that ensure cost recovery is necessary not only for planning purposes, but also to attract potential investors.

  Reasonable strategies are those that will meet no significant opposition from regulators, will be accepted by customers, will attract new customers to the system, and will generate profits. Structure can be either demand-oriented or consumption-oriented, depending on the nature of the operation, and on what is acceptable to customers and regulators. Consideration should also be given to interest rates, inflation, and equipment depreciation in the determination of long-term pricing strategies.

- Environmental Costs

  Although this project will greatly reduce air pollution in Krakow, there may still be environment-related costs associated with it that should be considered in the economic analysis and planning. Examples include additional pollution control equipment at Łęg, boiler water treatment, disposal of additional boiler blowdown, disposal of additional cooling tower blowdown, etc., all made necessary by the added system load.

- Cash Flow Options

  Expansion of the system, now and in the future, will require cash to pay for materials and installation labor (and possibly incentives as well). Without a large savings account, this needed cash may not always be available. Options for financing include local private lenders, public grants, and foreign grants and lenders. Discuss the applicability and desirability, along with likely repayment terms, of each reasonable option.

- Insurance Needs

  Describe the insurance climate in Krakow, and the types and costs of insurance that MPEC needs to carry as they pertain to this project. This again is a cost that needs to be figured in the overall picture.

- Taxes

  Is MPEC required to pay taxes on fuel purchases and/or its revenues? Are its customers (private residential, private commercial, public) required to pay taxes on purchased energy? If so, how much?

- Funding Sources

  How can we inform potential investors, both domestic and foreign, of the opportunity that this project and future related projects have to offer? Shall we do a mailing, develop media advertising, or prepare listings for EBRD, World Bank, or related agency publications? How do we present the relevant information?

- Future Customers

  Present day boiler owners and independent heat consumers are going to have to be convinced of the benefits and advantages of connecting to the district heating system. This is particularly true if purchased heat is more expensive (by the kilowatthour or kilocalorie, as it is likely to be) than self-generated heat.

  It will be necessary to market the benefits of maintenance, space, cleanliness, and pollution reduction to the future system users. A user survey will be helpful, and a media campaign may be appropriate. Coordination with the Hart Industries project is essential.

The purpose of this study is to develop a marketing strategy of maximum effectiveness directed towards future customers.

- Investment Analysis

When individuals and organizations consider investing in the future Krakow heating system, they will compare the investment with others available to them in terms of likely return, potential return, liquidity, guarantees/insurance, and so forth. This study aims to develop and present a range of feasible scenarios for these investors to evaluate, in order to prepare for the eventual true offering.

- Structure of the Offering

There are many ways that investors can provide financing. They can provide direct loans with fixed or variable interest rates, or they can purchase shares of stock, becoming owners and participating directly in the operation and return. The many structuring options need to be developed and evaluated, so that an approach can be decided upon that will be both very effective and in MPEC's best interest.

- Carrot Versus Stick Options

Discussions with boiler owners have thus far centered around the issue of compliance with air pollution reduction regulations. More specifically, potential heat customers are informed that if they do not hook into the district heating system, they will have to implement costly modifications to their boiler plants in order to be in compliance with the law. This argument (the "stick" approach) has been used to try to convince boiler owners to participate financially in the expansion of the heating system. While the argument is sound, most boiler owners do not have the financial strength to come up with the necessary capital to proceed in either direction.

Rather than a disincentive to do nothing, MPEC could offer an incentive to hook up ("carrot" approach). This incentive could take the form of up-front cash credit, reduced rates for an initial period of time, and/or conservation products and services (e.g. insulation, clock thermostats, etc.) that will help control consumption and thus reduce costs. Shooshanian will provide general information about various types of incentive programs that have been used in the United States. POLINVEST will provide input regarding which types of incentives would be applicable in Krakow, how they would be structured, how the approval process would work, and how the system would be publicized and implemented. We will also investigate any incentivization procedure(s) that has been considered that would apply uniquely to Krakow.

- Cash Flow

The only way that any business can function is with a positive cash flow, or a negative cash flow that is limited to a relatively short period of time. In any analysis of incentive structures, any present-day disbursement of MPEC funds would have to be justified by expected future revenues and profits. The magnitude of any incentives would be a function of the expected return. The same would hold true for any third-party investors.

This study will prepare a cash flow analysis for any reasonable options developed in the previous study.

- Existing Rates and Costs

Boiler owners will be faced with a number of options in the years ahead. They can continue their present operation, maintaining and modifying equipment as needed to keep it operational and legal. They can convert to oil, gas or electricity, which presumably would drive up fuel costs but reduce maintenance and emissions. Finally, they can join the MPEC system.

A key factor in the decision-making process is the relative costs, and effective negotiations by MPEC and POLINVEST will require a complete understanding of the financial aspects of each option.

This phase of work asks that POLINVEST study and report upon existing energy pricing structures for different customer types (e.g. residential, commercial, industrial). In other words, what does it currently costs to heat an apartment building with coal, gas, electricity and MPEC heat? How easy is it to switch over to gas or to electricity, and who pays? Are there other incentives?

This is essentially a study of the competition, necessary to strengthen, as much as possible, our own negotiating position.

- Future Rates

Forecasting has never been an exact science, but it is necessary nonetheless to make educated decisions. In the case of negotiations, forecasts can be used to strengthen a position.

This study asks POLINVEST to research trends in energy costs in Poland, and develop a position for MPEC, particularly regarding the nature and magnitude of future rates.

An argument could be made that increased cogeneration as well as economies of scale could make MPEC heat less expensive in the long run than self-generated heat. We will investigate the validity of this argument.

Projected Outcome

The outcome of this work will have three components:

- Heating network expansion
- Pollution reduction
- Joint venture

Network Expansion - the new, state-of-the-art network segments will conserve energy by making greater use of power plant waste heat, and by eliminating old, inefficient local boilers. It will also deliver heat to the new customers in a highly efficient manner, minimizing pumping costs, friction loss, and heat loss. Instrumentation, controls, and metering will be state-of-the-art also, allowing MPEC to deliver only as much heat as is needed, and allowing customers to pay for only as much heat as is used.

The new customers will enlarge MPEC's customer base, allowing them to spread fixed costs over a larger number of individual users. It will also increase MPEC's revenues, and ultimately its profits.

Pollution Reduction - Several factors conspire to render this project particularly attractive from the standpoint of pollution abatement.

a) The existing power generation equipment is outfitted with high exhaust stacks and pollution control equipment, while the boilers to be retired have neither. This leads to lower, less densely concentrated levels of pollution.

b) Waste heat is currently created at the generating station during periods of imbalanced demand for electricity and heat, while remote boilers are simultaneously being operated to deliver heat to buildings not connected to the network. Tying them into the district hot water system will eliminate many of these "unbalanced capacity" pollutants at the generating station.

c) Although yet to be verified, the power plant boiler system almost certainly enjoys higher combustion efficiency than the remote stations. Even taking into account distribution losses, central heating is likely to be the more efficient consumer of source energy.

d) The retirement of local boiler plants will also eliminate the need for coal delivery to these sites, leading to reduced traffic and, admittedly relatively small, automotive emissions.

Joint Venture - The successful development of this joint venture will require careful strategic planning, detailed financial and operational analysis, and ongoing management commitment. A detailed business plan will be needed to bring all these matters together.

Usually a feasibility study precedes the business plan because it collects the information needed. Since the feasibility study has yet to be carried out, we can only provide a preliminary draft of a business plan. Discussion is provided below.

a) Type of Business - At a minimum, we will provide technical, economic, and legal consulting services to district heating utilities in Poland who are contemplating expanding their network and/or making it more efficient. At a maximum, we will also provide labor, materials, and funding to achieve the same, and expand to areas outside of Poland. The business would be a private, for-profit joint venture with minority U.S. ownership.

b) Market Assesment - The heating network in Krakow, while it spans a good portion of the city, leaves many sections unserved. The same holds true for other cities in Poland. Expanding networks into those currently unserved areas should represent a great deal of potential work for the joint venture. In Krakow alone we anticipate over $100 million in construction costs for network expansion. In Poland, this number probably exceeds $1 billion.

c) Demand - Demand should be high, because heating utilities want to expand market share and conserve energy (boosting profitability), and local governments want to improve air quality. Individuals would like to eliminate the headaches associated with coal stoves. All of these factors point to a strong demand for our work.

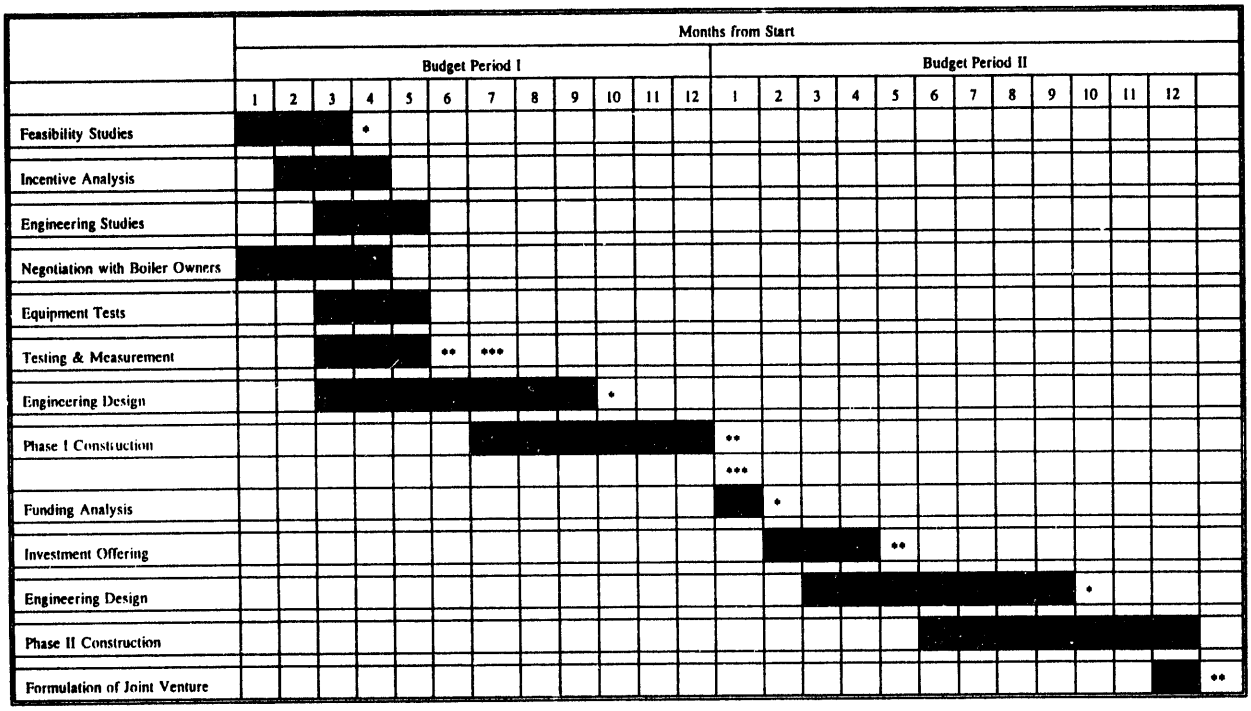
Our competitors will most likely be Western Europeans also well versed in district heating networks. We believe, however, that U.S. goods and services are very competitive today, and that Poles are generally interested in American alternatives to what is often German. Our labor rates are also substantially lower than those of our competitors.

d) Financial - The joint venture could develop in a number of different directions, depending on the results of the pilot phase. For the purposes of this discussion, we will make the following assumptions:

i) Heating rates are deregulated to the point where MPEC, and other utilities, are allowed a reasonable return on their investments in the system.

The financial plan will consist of enlarging the work scope each year, while at the same time developing procedures and agreements with suppliers that lower unit costs. With effective planning and management, we would hope to see the venture's income and profit grow each year. Note also that the amount of engineering and other consulting needs will drop each year, since successful strategies employed previously will be reused in subsequent work.

MILESTONE CHART



* Progress Report
** Progress Presentation
*** Decision Point for Proceeding with Project

ii) The economy in Poland continues to improve, allowing MPEC to collect reliably on its billings and repay its investors.

iii) The joint venture provides design/build services to heating utilities - MPEC initially. Fixed fees are negotiated for each network segment before work commences.

iv) Invoices are rendered monthly to cover our costs of materials, labor and profit.

A possible financial plan would consist of initially borrowing $500,000 to cover startup costs, to be repaid over three to four years. Initially, we would use office space at either POLINVEST's or the contractor's offices to control costs. Administrative support functions (e.g. receptionist, telephone, accounting, etc.) could also be shared. Once the venture was self-supporting (Year 3), it would rent or lease its own facilities.

From a personnel perspective, we expect that full-time assignment of individuals would be made upon the execution of the joint venture agreement. Initially, we would anticipate four or five full-time personnel, to cover management, engineering, legal, and economic roles. Part-time and contracting personnel would be added as needed. Full-time personnel would presumable be former employees of Shooshanian, POLINVEST, and the contracting firm.

e) Legal and Regulatory - The joint venture would conform to all applicable laws and regulations in Poland. POLINVEST has the in-house expertise to structure the venture accordingly.

f) Marketing - Initially most of our work would be for MPEC, so minimal marketing would be required. Eventually we would develop brochures and a marketing strategy to penetrate other district heating systems in Poland and elsewhere. A full-time marketing manager is anticipated, one who is very familiar with the Polish marketplace and who also could employ some U.S. marketing strategies.

We are sending teams of engineers to Krakow regularly to gather information and data for our studies and pre-design activities. We are very excited about the work, and are doing our utmost to ensure a successful outcome.

EMISSIONS REDUCTION THROUGH DISTRICT HEATING CONTROLS AND SUPERVISION IN KRAKOW

Benoit Bô
Honeywell Inc.

Opening remarks on the Clean Fossil Fuel Program

In case that not all of you are familiar with this kind of program sponsored by the United States Government, let me briefly draw your attention to the specifics of the Program. Instead of inviting specialised companies in bidding for one given project with well defined specifications, DoE has adopted a quite open approach, which consisted in inviting companies from any technological field to propose a solution to the issue of pollution. This is why you have such a diversity of projects and technologies represented here today. This is also what makes such a program and today's seminar so interesting.

Another important feature of the Clean Fossil Fuel program which I want to mention in these opening remarks is that proposed projects had to make economical sense and therefore be replicable on a pure commercial basis i.e., without any governmental support or subsidies.

As explained by the representatives from the Department of Energy, the funding mechanism of the project is the following :

- DoE covers up to 50% of the total cost of the project, with some costs being identified as non allowable (e.g., profit, advertising...).
- The contractors to DoE - i.e., the US participating companies, including Honeywell - have to finance the remaining 50%. In our case, we have concluded a cost sharing arrangement with our partner, the local district heating company : MPEC.

Analysis of the Situation

In the City of Krakow as in many cities in Central and Eastern Europe, Honeywell has identified the district heating systems as being a major source of air pollution. This is even more serious in cities which use coal as a primary fuel to produce heat and electricity. Krakow is one unfortunate but famous example, the Northern Bohemian Region in the Czech Republic is another one. In its preliminary study, DoE had also earmarked the district heating system as a key focus area for its program.

Let us now further analyse the situation. For those of you who may not be quite familiar with district heating systems, let me just remind the key elements of this concept. District Heating is a centralised approach to heating of residential buildings, apartment buildings and commercial or industrial buildings. Fig. 1 describes the general architecture of such a system. A heating plant produces steam or hot water, which is then distributed to the buildings via a piping network running through the city. Often we also find intermediate substations - also called heat exchangers - whose purpose it is to dispatch the heat to the various parts of the city and also to lower the temperature level from about 130-150 degrees Celsius at the output of the plant to less than 100 degrees in the buildings.

At a first glance, we may think that the responsibility for generating all this pollution falls on the power plant. Technically speaking, this is correct. But what happens if the distribution system of the heat is inefficient? What happens if the pipes leak? What happens if the heat in the buildings is either excessive or poorly balanced? (By the way the consequence of this last default is well known and obvious if you look up in the street : in Siberian-like temperature conditions, you will still see some open windows, signalling an overheated room or apartment).

In reality, what happens is that for a given need of energy at the consumption level - often referred to as the **energy demand** - there is more than an optimal quantity of energy produced - often we speak about **energy supply**. In brief, too much energy is produced compared to what would normally be produced for a given level of comfort in the buildings. To come back to our most favourite subject - pollution - this means that the power plant will have to produce more energy than would optimally be needed and therefore burn more fuel and generate more low emissions than required (if I may say so).

This whole analysis may seem very theoretical but the reality is not different. The whole issue with district heating systems is their overall inefficiency, not just a problem of power generation. This general discussion will be useful to understand the Honeywell response to Low Emissions Reduction in Krakow.

Honeywell objectives

By participating in the Krakow Clean Fossil Fuel program, Honeywell wants to demonstrate on a large scale that there are huge potential energy savings in East European district heating systems, which, if the proper investments are made, will not only prove the economic rationale of these investments but also bring a significant contribution to environmental clean up.

To reach this global objective, we have determined secondary objectives :

1. Adopt a demand driven approach : the City of Krakow, through MPEC, would have to select the scope of work to be done and the priorities.

2. Run the project as a venture between Honeywell and his local partner, which means sharing costs, risks and benefits.

3. Take advantage of such a co-operation to transfer as much technology and know-how as possible to the Krakow area.

4. Involve outside partners as widely as possible : consultants, engineers, manufacturers, contractors.

Honeywell experience in District Heating

This Krakow project will in fact take advantage of Honeywell extensive experience in the optimization of district heating systems in Western and in Eastern Europe. We have recently completed projects in the Netherlands, Italy, France, Germany but also in Poland, Russia, Ukraine, Armenia, Uzbekistan, the Czech Republic etc. (see enclosed map).

The Eastern European experience will be particularly useful and relevant. We have indeed implemented a number of

small scale projects covering various aspects of a district heating system - from the power plant to the individual apartments. We also now have feed back and savings results from those installations, which tell us where and how the optimal savings were achieved, depending on the configuration and status of the district heating system in place. In Krakow for example, we implemented last year a comparative energy efficiency improvement in four buildings with varying levels of energy conservation measures. One building was left in its original condition and will serve as a benchmark. The other three, comparable in size, have different control or insulation systems in place so that actual savings comparisons can be made.

But the most significant experience to date is the project Honeywell did in Moscow, in a district called Tushino. 100,000 people live in this district. The four boilers - delivering a combined heat power of 400 Megawatts - and 19 substations were equipped with state-of-the art control and communication systems. This will allow to optimise the supply of heat coming from the boilers as a function of demand as measured at the substations level. A total of 3 million dollars were invested in this upgrade program. The installation is now complete and two out of four boilers are in full automatic control. Although no result is available yet, we expect that the current gas consumption of the four boilers (90 million cubic meters annually) will be reduced by at least 20%.

Scope of the project in Krakow

Given the objective of the Clean Fossil Fuel Program (i.e., to assess the feasibility of an environmental and energy conservation venture in Poland) Honeywell proposed a project that would cover the entire scope of a district heating system. It is meant to serve as a case study that can then be used for other Polish cities and - why not ? - in other countries faced with similar problems.
Fig. 3 describes the Krakow district heating system. It is composed of a "main" network and a number of "local" networks. The primary energy source for the main network is the Leg power plant. A widespread piping network distributes the heat to a major part of the city. Pumping stations in several places ensure an adequate pressure throughout the network. A few small coal/coke fired boilers are also connected to this main piping network.

Two heat exchange stations, one in Czerwony, one on Olsza distribute the heat to the various apartment blocks.

Some parts of the city could not be connected to the main network. One of them is the Balicka area : a group of seven coal-fired boilers generate a combined heat power of 46 Megawatts. 177 buildings directly receive their heat and domestic hot water from the boiler house. Another group of buildings are connected to the network through a group heat exchanger with an installed capacity of 4.7 Megawatts (see Fig. 4).

After discussions with the municipal district heating company - MPEC - it was decided to implement the following upgrade program.

Main Network

- Install a Supervision and Data Acquisition System (SCADA) in MPEC main office, which will allow to centrally monitor and

supervise the overall functioning of the system.

- Upgrade and control the pumping station and the two group heat exchangers and increase their own performance. These three subsystems will be connected to the SCADA system via modems.

Balicka Network

- In co-operation with the Company Controltechtronics, install a boiler control and optimisation system. This system will be supervised by a Honeywell supervisor, which in turn will be connected by modem to the SCADA system.

- Remove the existing hydroelevators in approximately 50 buildings connected to the Balicka plant and install new compact plate heat exchangers from the Finnish company LPM. These heat exchangers will be equipped with a control system allowing outside temperature compensation.

- In these same buildings, install thermostatic radiator valves on each radiator.

The Balicka local network will therefore be fully automated and the energy supply should be optimised in real time as a function of cumulated demand from the end users.

Project schedule

Most of the work is expected to be carried out in 1994. Only the installation of radiator valves will be done in 1995. The preliminary feasibility study is already completed.

Task breakdown

The following tasks have to be performed to meet the technical and business objectives of the project.

- Feasibility study : a project of such technical complexity and wide scope has to start with a detailed feasibility study to assess the status of the equipment in place, their level of performance and establish the detailed control strategy.

- Technical work : this represents the major effort in the project and includes : engineering, delivery of equipment, installation and commissioning, start up of the system.

- Project management and reporting : the coordination of the project and the numerous partners involved, reporting to the Department of Energy of progress and budgets will require almost a full time experienced project manager. Also a tight project schedule management is essential because the beginning and end of the heating season determines when the installation work can be done.

- Training : this is a critical task because the system will be operated and maintained mainly by MPEC crew after commissioning. Transfer of technology and know-how is one of the key objectives of the project.

- Business activities : a post project evaluation will be carried out to determine on which basis this experience can be replicated and

applied to others cities in Poland as well as other East European countries.

- Performance monitoring : it is essential that the energy savings and emissions reduction be well assessed so that the return on investment can be measured.

Technology

The essence of the technology used in this project is control technology. Modern analogue and digital control equipment, computerised supervision systems and state of the art software's will be installed to optimise on line the functioning of the district heating system. Modem communication technology will also be used to allow central monitoring and control of the remote sites : pumping stations, heat exchangers.

Co-operation with other companies

Right from the beginning, Honeywell decided to widen the scope of the project and to cooperate with other American, West European and of course Polish firms. The actual Honeywell content in the project is less than 50 % - both on the equipment and the labour portions. A few examples of some partners involved are described below.

- Consultants : Honeywell has called on the expertise of three companies to help on the feasibility study and the business evaluation of the project. The Krakow company Polinvest - a close adviser of MPEC - will provide assistance on the legal and economical aspects of the venture formation and possible future development of the activities beyond the Clean Fossil Fuel Program. Another Krakow based company - BRK, Krakow planning office - will bring its expertise in technical issues and its knowledge of the Krakow district heating system. The American consulting firm RMA will supervise the feasibility study and make sure it is conducted in the most professional and objective way. RMA has an impressive record of energy efficiency and environmental feasibility studies in Central and Eastern Europe.

- Equipment suppliers : a close co-operation was initiated with another American company participating in the program - Controltechtronics. Controltechtronics will be providing an boiler optimization package for the Balicka boiler, comprising hardware and software systems. This boiler optimization package will then be supervised and monitored from the SCADA system. Another co-operation with a Finnish heat exchanger manufacturer - LPM - is a key part of the project, both technically and economically.

- Service companies : Honeywell will cooperate with many local firms in the course of the project. In particular, local companies will be responsible for the erection and installation of the equipment (up to 15,000 radiator valves will have to be installed with subsequent modifications on the radiator piping system). The assembly of the heat exchangers including the piping, valves and controls may also be done locally.

- The main partnership will however be with the district heating company itself. MPEC will be

playing an important role in the overall project management, the engineering and the commissioning of the system.

Energy savings potential and emission reduction

Overall, we expect to be able to save 10% to 20% from the demand side and an additional 15% to 20% from the supply side.

Emissions reduction due to the proposed efficiency improvements will come primarily from reduced operations of Leg heat only boilers, heat output at higher combustion efficiency and reduction from MPEC-operated local boiler houses.

System efficiency improvements will reduce the amount of fuel burned in district heating plants. Emissions will be directly reduced as a result of burning less fuel. The target would be to shut down 3 of the 7 boilers in Balicka.

A reasonable estimate of coal burned by the Balicka boiler house is approximately 16,500 tons per year at current system efficiency. Estimated emissions from this plant include 110 tons of SO_2 and 135 tons of particulate annually. A 30 % reduction of coal consumption will result in reducing SO_2 emissions by 33 tons and particulate emissions by 40 tons per year.

For the Krakow area, assuming 380,000 tons of coal are burned in similar boiler houses serving the district heating system, reductions of 744 tons of SO_2 and 936 tons of particulate can be achieved annually with a 30 % global efficiency improvement of the network. In addition, pollution can be reduced as a consequence of a more complete burning cycle.

Additional benefits

As a side but significant benefit, we also expect positive impact on the heating costs to the Krakow inhabitants. The district heating company will indeed be able to operate in a more cost efficient way thanks to :

- a lower fuel bill;
- more modern equipment requiring less maintenance;
- an extended life of the boilers and heat exchangers thanks to a more rationale use.

Finally, transfer of technology into Poland and particularly in the Krakow area is of utmost importance for the local industry.

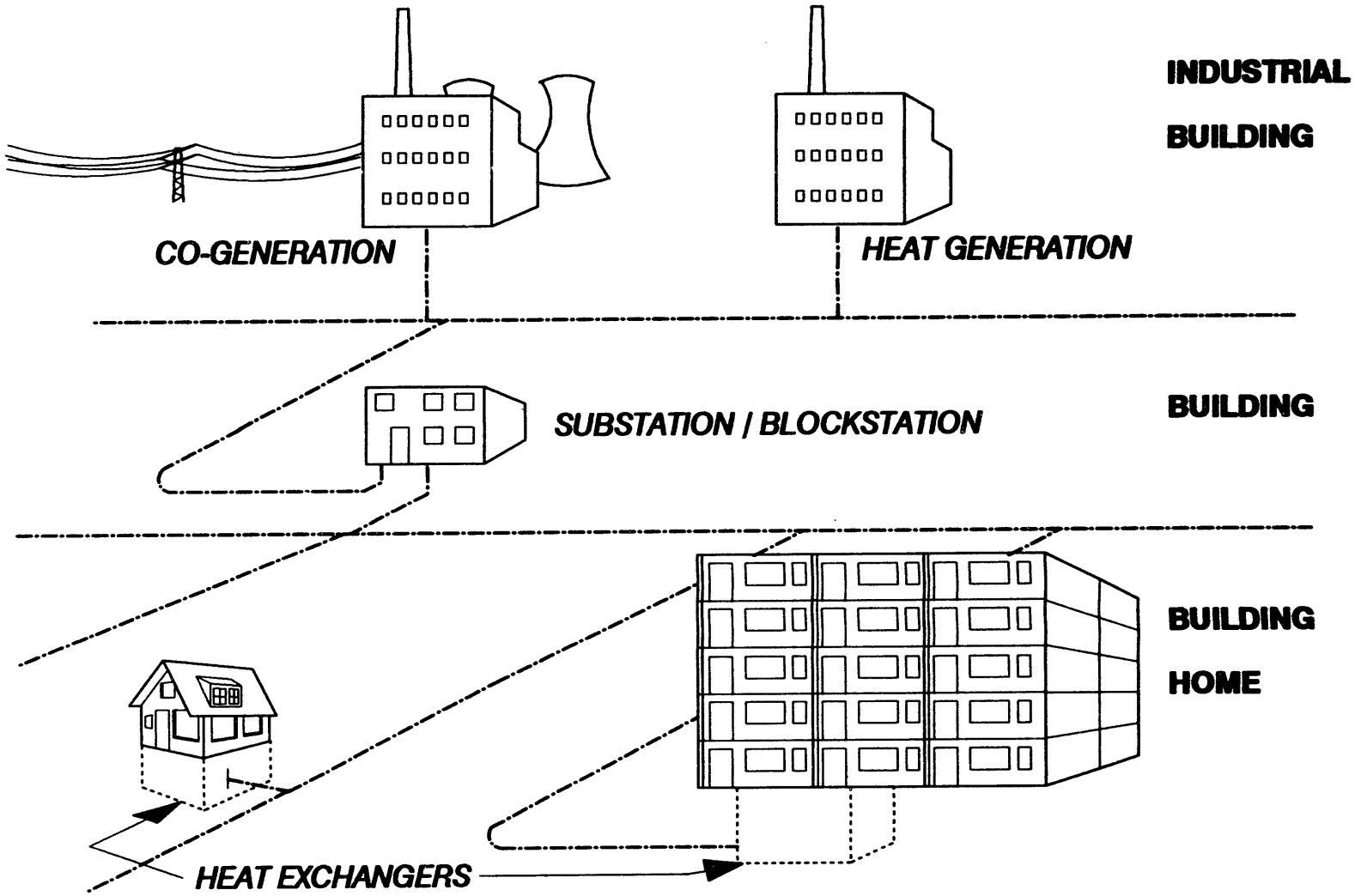


Figure 1

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Honeywell In Russia

Figure 2

CITY OF KRAKOW

DISTRICT HEATING NETWORK

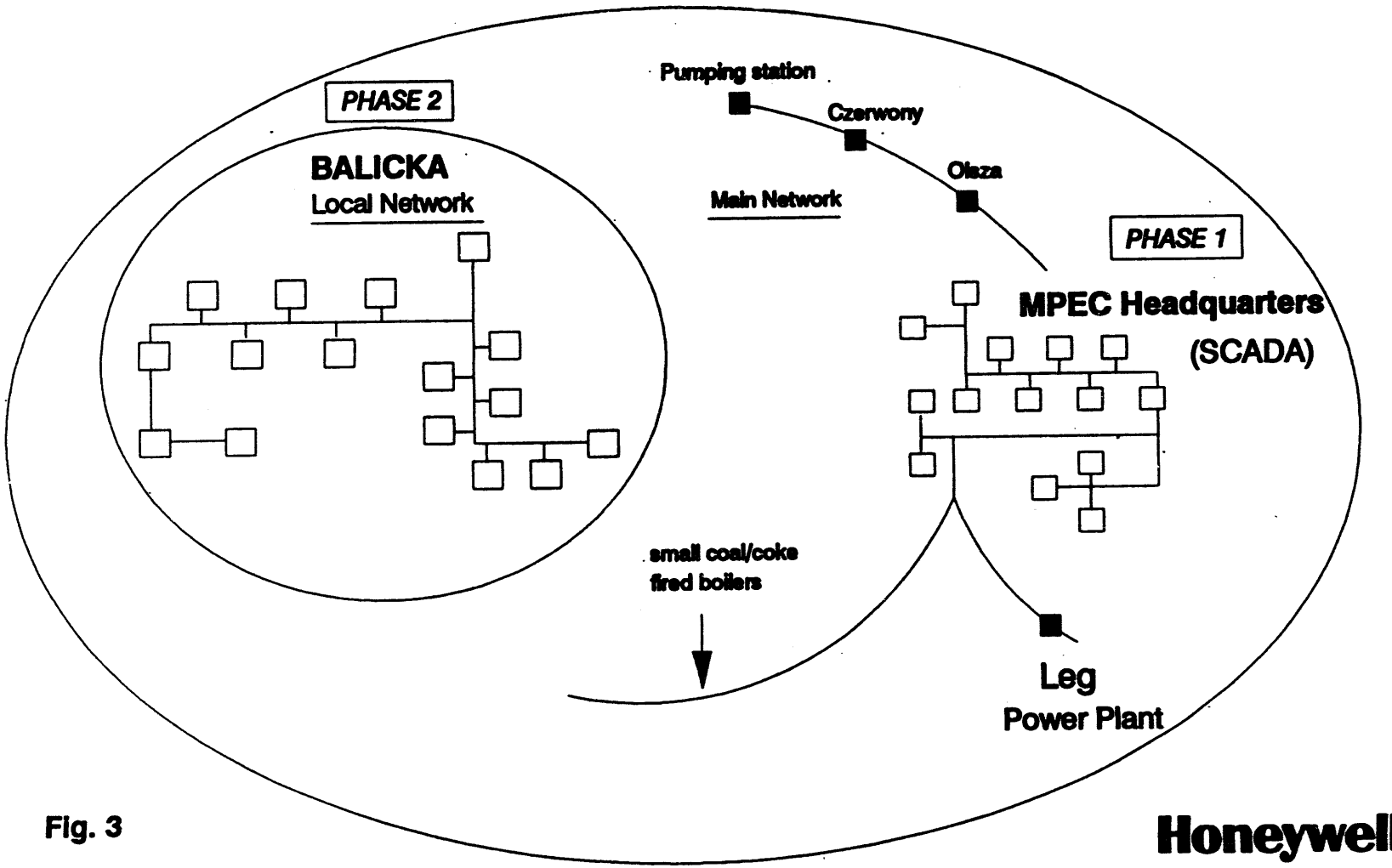

Fig. 3

Honeywell

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DOE KRAKOW CLEAN FOSSIL FUEL PROGRAM

PROJECT SCOPE : BALICKA LOCAL D.H. NETWORK

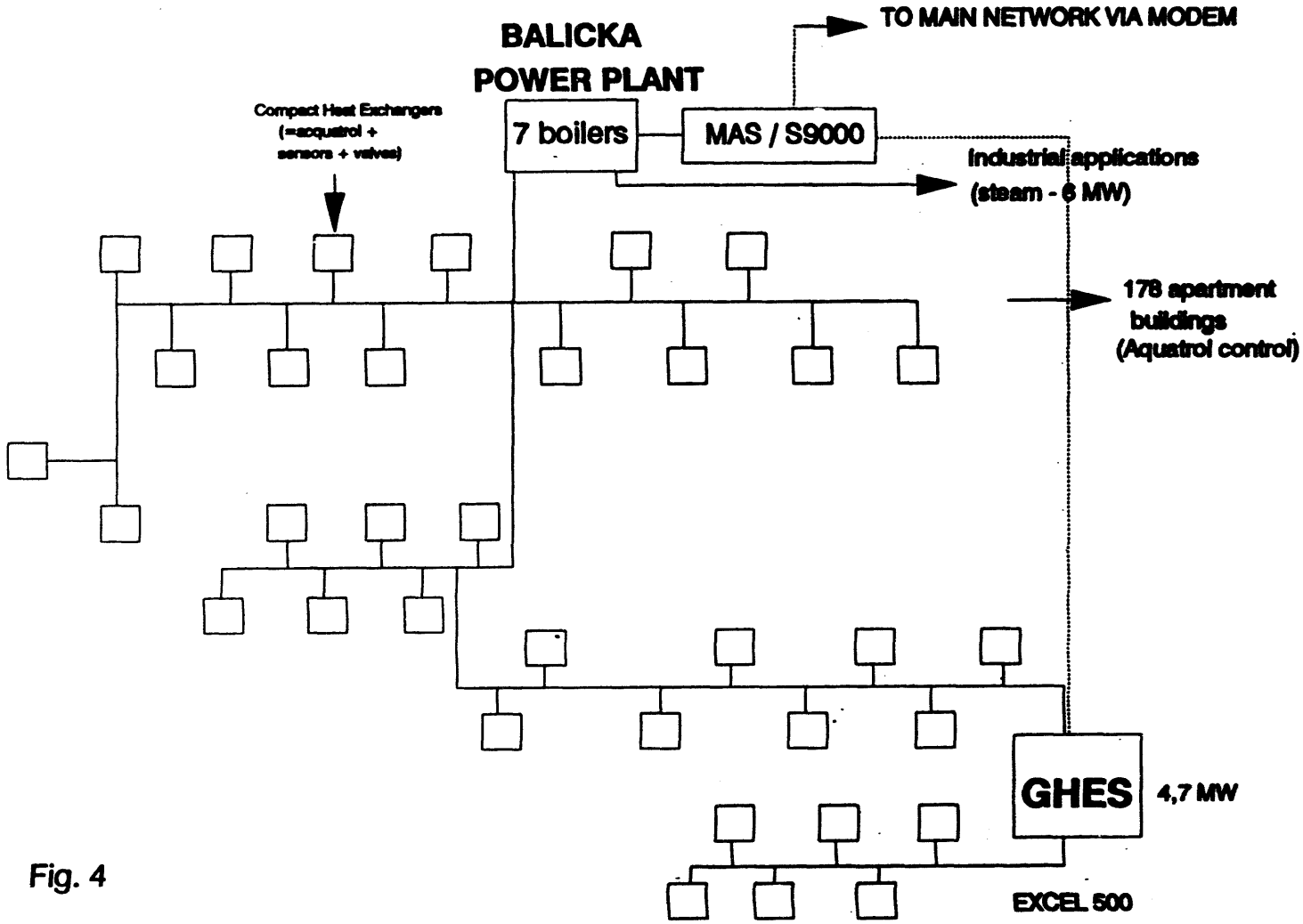

Fig. 4

COMBUSTION IMPROVEMENTS IN STOKER FIRED BOILERS

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Introduction

Today, stoker fired boiler plants are common throughout Eastern Europe. The small and mid-sized coal combustion plants utilize travelling grate stokers to produce steam or hot water that is used by district heating companies and industries. When these plants were first designed 25 to 50 years ago, reliability was the key concern. Now, the 1990's, there is considerable attention being paid to increasing efficiency and reducing emissions.

It is because of the environmental concerns and age of the plants that some believe that stoker plants should simply be replaced. This may be true in certain cases for very small plants or where it is economically feasible to replace or eliminate a plant. For example it might be more economical to eliminate a small district heating plant if it is close to the distribution lines of a large system. The smaller distribution system could be connected to the larger system. However, there are some points in favor of keeping an existing stoker plant. First the equipment and the infrastructure are already in place in an existing system. Second, although the equipment may be old, some older equipment was built to last longer and to be more durable than newer equipment. This reinforces the fact that the plants were origanally built for reliability. Third, dramatic improvements can be made to the efficiency and emissions level of these plants for significantly less money than replacement cost. The application of upgrading plants and improving efficiency has been documented in the United States. These proven methods along with new technological advancements can be applied in Eastern Europe to make significant improvements to the performance and emissions from existing stoker plants.

In Krakow, Poland, Control Techtronics of Harrisburg, PA has teamed with The Pennsylvania State University (Penn State) to provide an economical solution to the problem of improving efficiency and reducing emissions from stoker fired boiler plants in the Polish/American DOE Krakow Clean Fossil Fuels and Energy Efficiency Program. A multi-disciplinary approach to improving the stoker operations can be classified into three areas as follows:

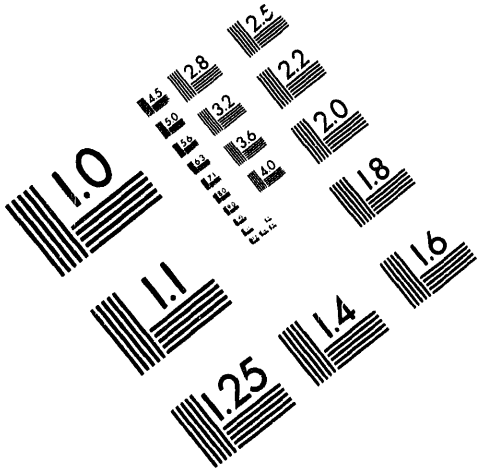
1. Fuel Characteristics.
2. Automatic Control of Equipment.
3. Operator Training.

Work conducted under Phase I of the DOE program in Krakow recognizes these areas of need[1]. Although, these areas are inter-related, they are addressed individually in this paper for the sake of clarity.

Fuel Characteristics

For stoker applications, combustion is governed primarily by the physical properties of the fuel bed and air distribution throughout the bed and not by the inherent reactivity of the coal or even by the percentage of ash in the coal. The physical properties of the coal bed are particle size, particle size distribution, caking properties and ash fusion temperature of the coal which govern the flow of air through the fuel bed.

For proper combustion, the air must rise up through the grate and diffuse through the bed of coal. The combustion air must have intimate contact with the coal particles throughout the combustion process. This principle of securing proper distribution of air through a stoker fuel bed is fundamental; most of the difficulties that arise in burning solid fuel are the result of poor distribution of combustion air. Coal particle size and size distribution affect the air distribution within the bed, the void ratio and the pressure drop. Void ratio and pressure drop can then be correlated to carbon burnout of the coal during combustion. Research conducted on a series of low volatile coals helps to illustrate these principles. Figure 1 shows a plot of initial pressure drop across the fuel bed versus carbon burnout of the fuel, which is a measure of combustion efficiency[2]. A higher initial pressure drop across the bed results in lower burnout of the fuel. This result can be explained qualitatively by considering a coal that has a wide particle



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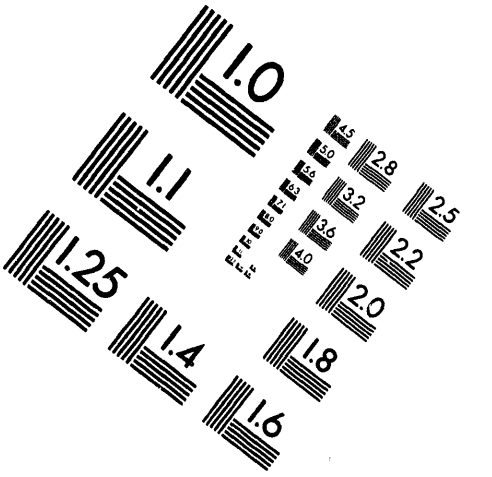

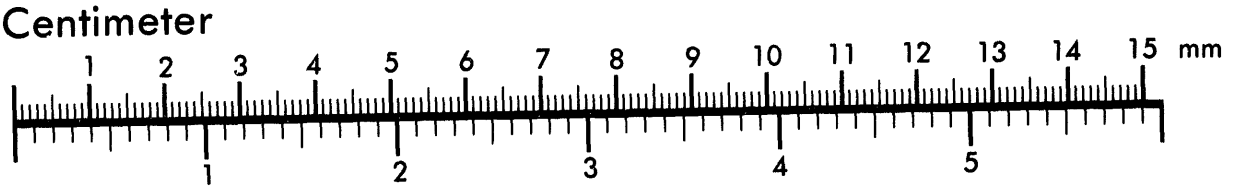

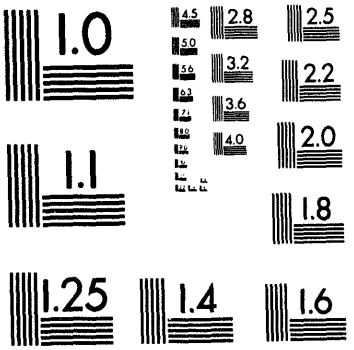

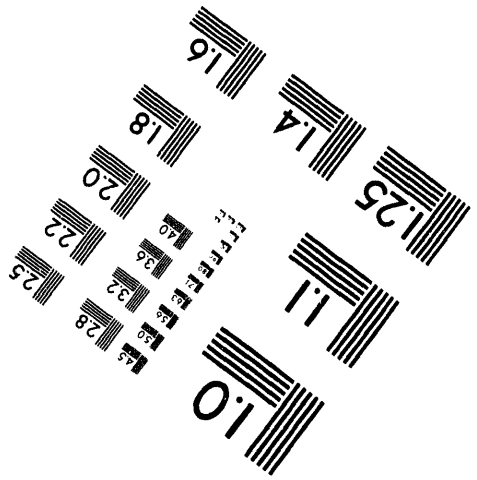

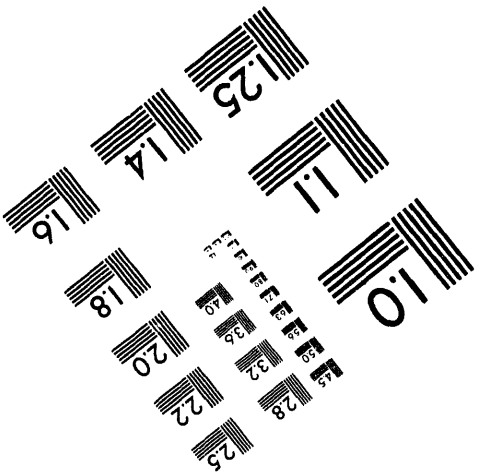

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Figure 1
Burnout on LV Coals vs. Initial dP

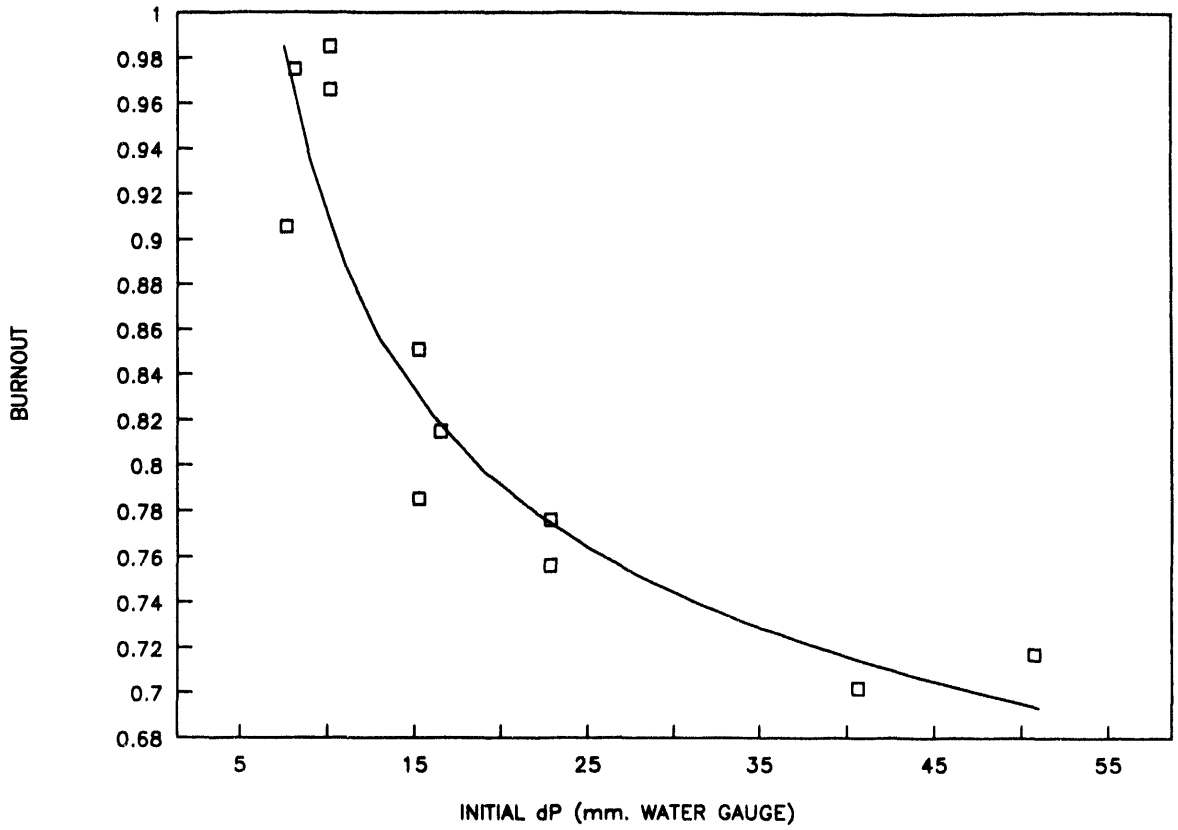
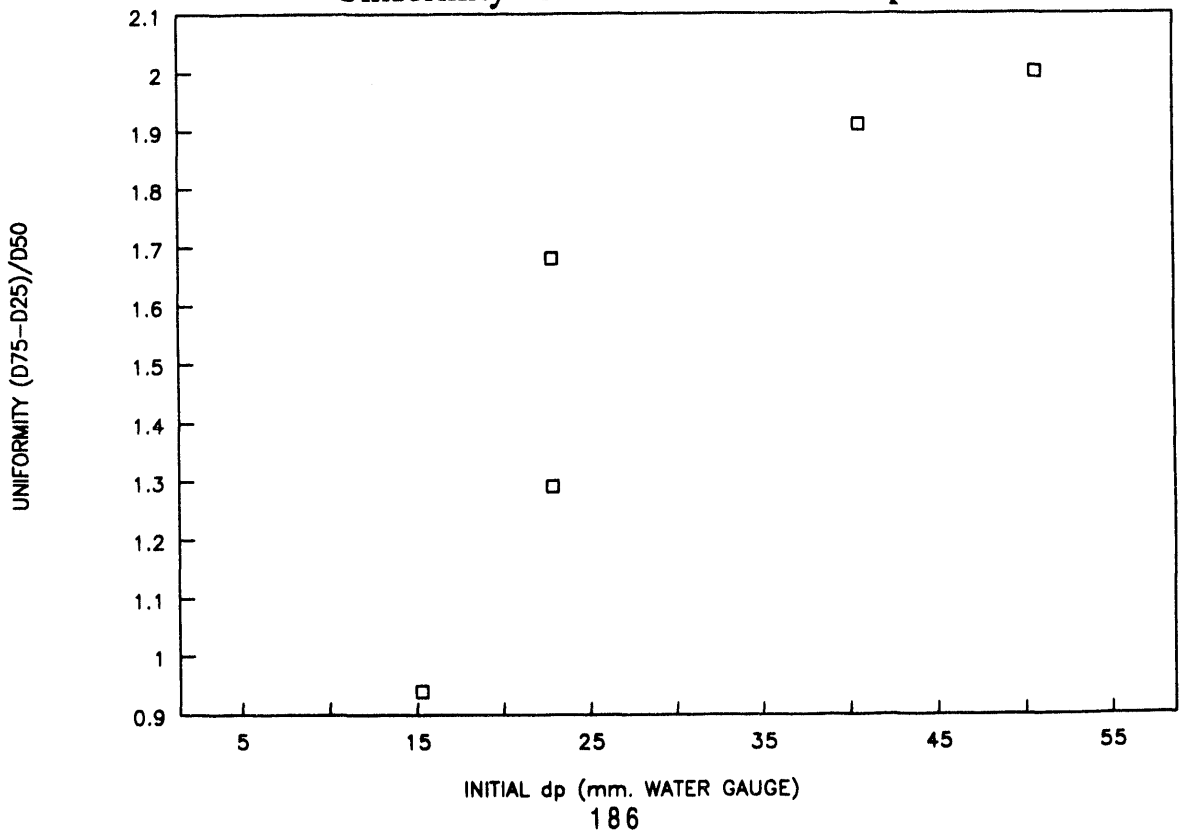


Figure 2
Uniformity vs. Initial Pressure Drop



size distribution. The finer particles fall into and take up the voids between the larger particles. They tend to pack and clog the bed, increasing the bed density, increasing the pressure drop and causing poor distribution of air throughout the bed. When air does not reach the coal particle or have intimate contact, it will not burn completely. Therefore, coals with wide particle size distribution or a high percentage of fines create combustion problems. Figure 2 is a plot of initial pressure drop versus uniformity coefficient for the same coals[2]. A low uniformity coefficient indicates a narrow particle size distribution. This plot shows that the more uniform the size, the lower the pressure drop. Therefore, coals with more uniform particle size distribution burn more efficiently in stoker boilers than those with a wide particle size distribution and a high percentage of fines.

Although initial particle sizes of a coal can be determined by a sieve analysis, the sizes of the particles in the bed change during combustion. They decrease in size due to a loss of mass during the combustion process. They may also increase in size by agglomerating or fusing due to clinkering and swelling. A caking coal or a coal with a high free swelling index (FSI) will expand when heated. This tends to close off the voids between coal particles causing poor air distribution within the bed. A coal with a low fusion temperature (below 1350°C) will melt into a mass on the stoker grate. This mass does not easily allow air to penetrate, and will also cause poor air distribution, and incomplete combustion. The various problems described above can compound upon one another. When air distribution is poor, local holes develop in the bed and allow relatively large quantities of air to pass. Excess temperatures or "hot spots" are then created which increases the possibility of fusion of the coal. In turn new or larger blow holes are created in the bed.

A primary task in improving boiler efficiency and reducing emissions in the Krakow region, is to analyze the quality and characteristics of the coal. Boiler plants in Krakow receive their coal from the Upper Silesian Basin. The run of mine coal from this region may go through various coal preparation processes that include crushing, screening, heavy media mineral separation or differential density separation. The most common coal that is used in the stoker plants of Krakow is 20 x 0 m.m. coal that is not cleaned by any mineral separation process. An analysis of one such coal is shown on Table 1. Several properties shown in the analysis are highly desirable for stoker coal. The caking indicated by the free swelling index is zero meaning that the coal does not swell upon heating. The ash softening temperature is 1400°C which is acceptable and means that the coal does not have a tendency to fuse together during combustion. The Hardgrove Grindability index of 53 is relatively low indicating that the coal is hard and particles do not easily degrade. This is important because extremely soft coal that is initially sized properly will degrade during transport and handling, thus creating a high percentage of fines in the coal. As stated earlier, the high percentage of fines results in poor air distribution in the stoker fuel bed and reduced combustion efficiency. The volatile content of the coal shown on Table 1 is 23.5 - 25.5%. This is relatively low and no overfire combustion air is required for efficient combustion. However coals with higher volatile content may require overfire air and coals with a volatility greater than or equal to 30% require properly controlled overfire air for efficient combustion.

Although the ash content is relative high 18%-25%, it is acceptable because stokers are capable of burning such material. Results of testing conducted by Brookhaven National Laboratory under Phase I of the U.S. DOE Krakow Clean Fossil Fuel and Energy Efficiency Program showed that cleaning coal does not significantly improve combustion[1].

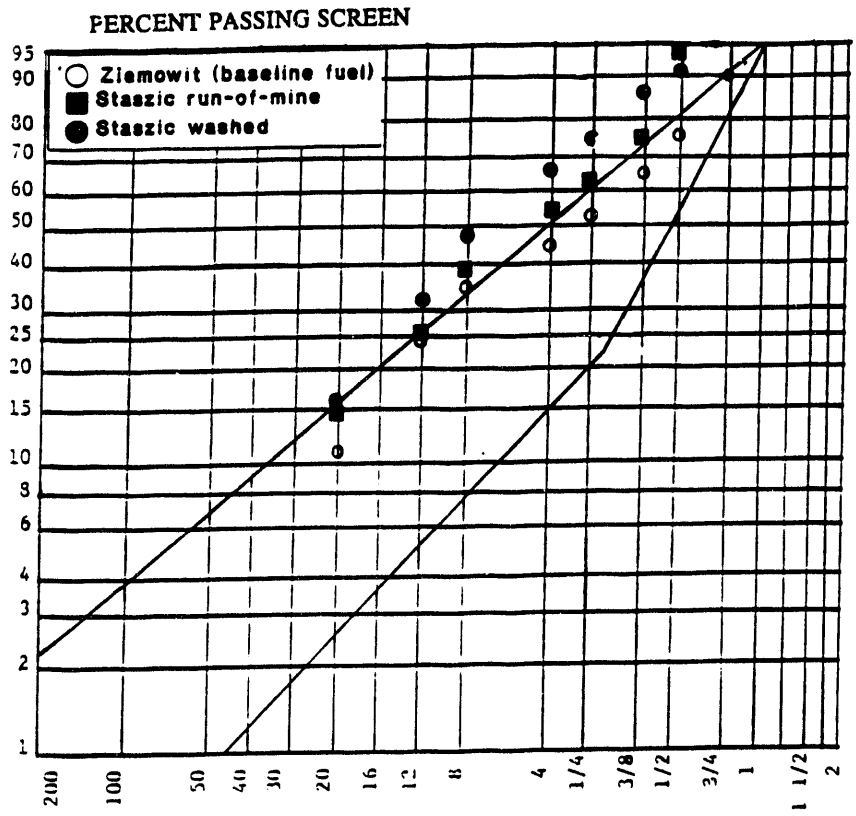
Figure 3 shows a particle size distribution of the coals used in the tests by Brookhaven. The washed and unwashed coals have similar particle size distributions with the washed coal having a slightly higher percentage of fine particles. The high percentage of fines (over 50% smaller than 5 mm) causes packing of the bed and disrupts the flow of air through the fuel bed which hinders combustion. This demonstrates that cleaning improperly sized coal does little to improve combustion and further confirms that sizing and not ash content is the key for gaining combustion improvements for this application. It should be noted that although ash content is not the main parameter governing stoker combustion, reduced ash content does have some benefits. The higher calorific valve means less coal must be purchased and there is less ash to be disposed.

In developing a program to improve efficiency in stoker boilers in Krakow, it was necessary to analyze how to improve the characteristic of the fuel bed. During this investigation, we performed the following:

a) observed the combustion of the coal presently used
b) studied results of combustion tests conducted under earlier phases of the project
c) visited a mine and cleaning plant which is a source of coal for Krakow
d) obtained samples of coal
e) analyzed our results along with results from other's testing
f) obtained cost information on various grades of coal

TABLE 1 Analysis of 20 x 0 mm. coal from Upper Silesia	
Ash Content	18-25%
Total moisture	7-11%
Calorific value	23000-21000 kw/kg
Volatile content	23.5%-25.5%
Sulfur content	0.7%-0.8%
Ash softening temperature	1400°C
Free Swelling Index	0
Hardgrove Grindability	53

Figure 3
Particle Size Distribution of Test Coals[1].



As a result, we found that the most economical solution is to properly size the coal without cleaning. Screening the coal to obtain the proper sizing increases the price only 10% to 20% and will allow for more significant improvements when used with automatic controls. As part of preliminary work for this project, we found existing production facilities in Upper Silesia that will provide a variety of specified sizes for a price moderately higher than the current fuel. In addition many of these coals have other characteristics which make them an excellent stoker coal. The result is that a graded unwashed coal 20 x 8 mm. will be utilized on the stokers included in our work.

Automatic Control of Equipment

With the proper fuel in place, the next step is to automatically match the fuel and air inputs to the boiler with the output required. It is fundamental to boiler plant engineering that if you take a piece of coal, you can calculate how much air is required to burn it. The same is true regardless of the amount of coal. For a certain quantity of fuel, there is an optimum amount of air that should be utilized to efficiently and cleanly burn the fuel.

Too much air results in an excessive discharge of hot gases from the stack with a correspondingly high heat loss. For example, at optimum conditions, stokers can be operated down to 40% excess air. At various loads and conditions that are less than optimum, a properly controlled stoker fired boiler can operate between 40% and 100% excess air. Results from the Phase I DOE work at the MPEC Balicka Plant in Krakow show that excess air ranging from 107% at the best testing point to over 500% in tests with the most inefficient results.[1] The excess air rates averaged about 240% which translates to an efficiency loss of about 15%. However, at some conditions efficiency loss was over 20%. These losses are in excess of what would be expected with an efficient automatic combustion control system. Increasing the efficiency by properly controlling combustion with an automatic combustion control system will reduce the cost of fuel significantly. Since emissions can be calculated as a function of the quantity of fuel used, increasing combustion efficiency not only saves fuel costs but also reduces emissions. Reduction in emissions have an economic benefit to the plant owner because emission fees have been imposed and have an environmental benefit to the community.

While an excess of air in the boiler is inefficient, a deficiency of air is also inefficient. When insufficient air is supplied to the boiler, some of the fuel passes through the furnace on the grate as unburned coal or partially burned coal with the ash or as volatile hydrocarbons in the flue gas. Incomplete combustion also represents an unsafe operating condition. Combustion gases that are not completely oxidized will explode if exposed to oxygen at high enough temperatures.

The function of the automatic combustion control system is to properly match the air flow rate to fuel input so that there is enough air to extract all the energy from the fuel while maintaining a minimum of excess air. The control systems measure the steam pressure or hot water temperature for a hot water boiler and modulates the air and fuel input accordingly. If the steam pressure begins to drop, the air and fuel are increased and if the steam pressure increases, air and fuel decrease. There are many ways to accomplish this based on the equipment and fuel used. It is also important to a have proper level of sophistication in the control system that matches the design to the response time of a stoker. Some engineers believe that stokers can be controlled just like pulverized coal boilers in utilities or like gas and oil burners. This is not true, so it is important to understand what can be done with a stoker system.

There are three basic types of modulating combustion control systems. They are:

* Single point positioning
* Parallel Positioning
* Metering

The simplest type of modulating combustion control system is a single point positioning type. A pressure transmitter measures the steam pressure and sends a signal to a controller which in turn sends a reverse proportional output signal to an actuator. The actuator is modulated in response to output of the controller to move a jackshaft. This movement of the jackshaft changes the input of air and fuel. The air changes by changing the position of a fan damper. The fuel flow changes by movement of the position of a fuel valve. Since the fuel valve and forced draft damper are linked together, the system will not compensate for any variations in the fuel. To do so, would require adjustment of mechanical components in the system that are normally fixed during system start-up or when making calibration adjustments to the controls. For this reason, a single point positioning system is normally only used in natural gas and fuel oil fired applications.

A parallel positioning system utilizes the signal from a pressure transmitter to regulate the fuel and the forced draft air inputs in parallel. A pressure transmitter in the steam header generates a signal that responds to changes in the boiler output steam pressure. It is a reverse proportional signal that increases as the boiler output pressure decreases to provide more fuel and air. For a hot

water boiler the signal would be generated by the output hot water temperature. Separate control actuators are installed to automatically regulate a damper on a constant speed forced draft fan and the speed of the stoker drive. This provides for automatic control of the air and the fuel independently so that the air/fuel ratio can be characterized for each boiler. This is the most effective and economical type of system for small and medium sized stoker fired boiler plants since it usually matches the physical equipment layout of such plants. It can also be supplied with the components to make it flexible for changing conditions.

A metered system is similar to a parallel positioning system except that it has an additional level of sophistication. Fuel flow and air flow are metered and a signal is fed back into the controllers to correct air/fuel ratios that may change due to variation in the fuel quality, variations in the temperature and humidity of the air, and mechanical linkage of the control system over time. A feature known as cross-limiting can also be incorporated into metered controls to assure that there is always sufficient air for complete combustion. This is a very good type of control system, but is usually not applicable to stoker systems because very precise fuel feed is required. In most stoker plants, fuel is batch weighed to the boiler or not metered at all. Although changes could be made to accommodate metering, they would be expensive. Therefore metered systems are most applicable for large electrical generating plants and very large industrial boilers.

On first appearances, small stoker boiler plants in Poland look similar to ones in the United States. Three to six boilers are coal fed by an overhead bunker to a traveling grate stoker. Some other features are also similar such as location and arrangement of fans, pumps, deaereator and basic flue gas cleaning devices. Some key specifications relative to combustion control of the Balicka Plant owned by the MPEC in Krakow are shown on Table 2. It should be noted that it is missing some significant components that are critical to efficient operation of the plants. Very little was built into the Balicka plant to monitor or control plant efficiency. Most stoker boiler plants in Poland contain no measurement of the input of fuel or the output of the steam or hot water. There is no automatic control of the combustion process. The forced draft fan and induced draft fan are usually maintained at a maximum rate while fuel may be changed manually with load conditions. This means that there is high excess air, fuel feed probably does not match the load conditions and certainly there is no optimization of the air/fuel ratio at any given fuel feed rate or load condition.

Figure 4 schematically shows the type of systems that Control Techtronics is installing in Poland on stoker fired steam boilers. It is a parallel positioning system with bias and manual override capability. It automatically controls the air and the fuel independently so that the air/fuel ratio can be characterized for each boiler. The controls have the ability to be switched to a manual mode for start-up and shut down operations or for other occasions when manual operation may be required. The bias function adds to or subtracts from the output signal of the controller while it is still in automatic operation. This gives the operator more flexibility by allowing him to make minor control changes while maintaining the system in the automatic mode. Such changes may be desired due to changes in the fuel supply or an anticipated load change. Sometimes the operators know that the load will increase or decrease by a drastic amount at a certain time each day. This is an example of an anticipated load change.

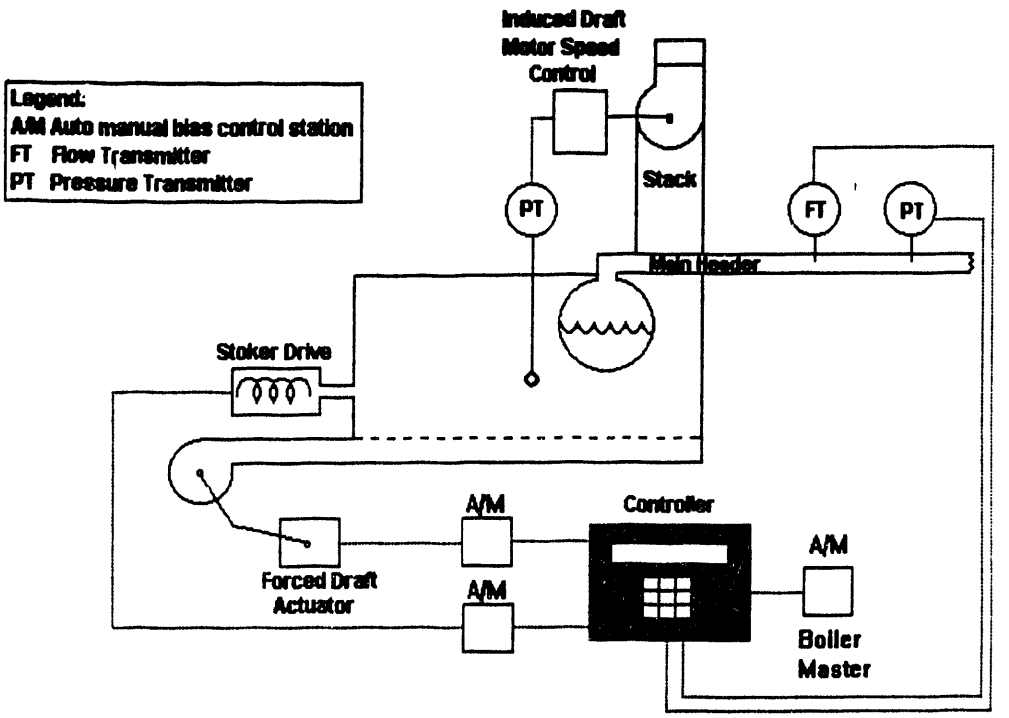
In the stoker systems, control of furnace pressure is an additional independent control loop that is critical to safe, efficient operation. Stoker furnaces cannot operate under a positive pressure without causing damage to equipment and safety hazards to operating personnel. Therefore, a negative pressure must be maintained. In boilers without automatic controls, the induced draft fan operates at full speed with dampers that are fully open. The fan and dampers are maintained in this manner to assure safe operation. The high negative draft draws ambient air into furnace openings causing extremely high excess air. Under automatic operation, the furnace pressure can be set at a slightly negative pressure of about 2mm water gauge by the controller. Traditionally, for boilers of this size, the furnace is controlled by modulating a boiler outlet damper or induced draft fan damper. With the availability of reliable, affordable variable frequency controllers, the draft in the Control Techtronics system will be controlled by modulating the speed of induced draft fan motor. A pressure transmitter will measure the furnace pressure and send a signal to the controller. The controller will then signal the variable frequency controller to increase the speed when more draft is required and to reduce the speed if the draft increases. Thus a properly controlled draft system safely evacuates combustion gases from the boiler without drawing excessive ambient air.

Since cyclone dust collectors are most commonly used in stoker plants, there is concern that the reduction in excess air will reduce the velocity through the collectors thus reducing the collection efficiency of the cyclones[3]. This concern is addressed in two ways. First, high excess air also increases the velocity through the fuel bed and boiler causing a higher carryover of particulate matter out of the boiler. By reducing excess air, particulate exiting the

TABLE 2 SELECTED BOILER PLANT INFORMATION ON THE MPEC BALICKA PLANT IN KRAKOW	
Stoker Type	Travelling Grate
Overfire Air	[1]Yes
Emission Control Devices	Mechanical Collectors
Air/Fuel Ratio Control	Manual
Control of Firing Rate	Manual
Control of Furnace Pressure	Manual
Measurement of Plant Output	Estimated
Measurement of Coal Input	[2]Estimated
Plant Input-Output Efficiency	62.6%

1. Not normally used
2. Estimated by the speed of the stoker, depth of the bed and bulk density of the coal.

Figure 4
Parallel Positioning Combustion Control.



boiler will decrease. Second, improvements to the cyclone collectors will offset the efficiency reductions or actually improve the collection efficiency of the cyclones.

The Control Techtronics controller is a multi-loop microprocessor based controller that accepts 32 analog inputs and has up to 8 analog outputs. A digital input/output board includes up to 24 relays that can be selected for either inputs or outputs. The controller as well as all of the displays used in Poland will be in metric units and in the Polish language. The Control Techtronics controllers are functioning successfully on stoker fired boilers as well as natural gas, fuel oil, and refuse boilers in the pollution sensitive areas of the northeast United States, southern California, and Mexico. With this experience, the application of these controls to stoker fired boilers in Poland will not be an experiment but a matter of applying proven engineering solutions to solving these problems.

Operator Training

The third aspect of the program that is integral part of improving efficiency and reducing emissions is operator training. Even with the proper fuel and automatic controls, many aspects of plant operation require good operating techniques to insure safety, reliability and efficiency. Boiler operators also need to be trained to recognize the early signals of emissions or plant equipment problems, and must be able to determine the quality of the coal they are going to burn. This aspect of boiler operations might seem obvious, but it is often ignored or undervalued.

One example of the importance of operator knowledge relates to regulating fuel feed to the stoker. There are two ways to regulate the amount of coal supplied to the furnace: by controlling the speed of the stoker and by controlling depth of the coal in the bed. Most manually operated plants control fuel feed by changing the depth of the bed. On the other hand, with an automatic control system, the fuel feed rate is controlled automatically by the speed of the stoker drive. Under automatic operation, the bed depth is set at one level and may be changed only occasionally by plant personnel to account for seasonal load changes or changes in the fuel. However, the operator must be aware of initial settings and how much and when to change the bed depth.

A second example of how an operator must use good judgement relates to distribution of air in the stoker. The automatic combustion controls will modulate the total quantity of air to the boiler, but there are manual adjustments to determine the distribution of the air to various zones in the stoker. These adjustments are also made infrequently, but when required, judgement must be used in such matters. In addition, the supervising operator should frequently observe the combustion and values of instrument readouts to see if adjustments to the automatic controls are required. Such observations include flue gas temperature, flue gas oxygen readings and burnout of the coal as it discharges to the ash pit.

In the Control Techtronics, Penn State project, each boiler operator will be trained not only on the operation of new controls but also on proper stoker boiler plant operation. This includes topics on combustion of fuels, operation of stokers, boiler control systems, boiler water treatment and plant safety. The Penn State Facilities Engineering Institute works primarily with district heating and small industrial type boilers, the majority of which are stoker fired boilers. Training material developed by personnel at Penn State for this application and currently used for operator training by hundreds of operators in the United States will be the basis of the training curriculum. The material will be modified and translated using the Polish language and copyrighted.

To overcome cultural and language barriers, we will be working with the Polytechnika Krakowska to translate and modify the training material. Native Poles will conduct the actual training sessions with boiler operators. We will then work with the Polytechnika in the second period of this work to establish a training center in Krakow as a long term resource. As part of the training center, a boiler control simulator will be built for classroom training.

The individuals who will install, start-up and service future control systems in Poland will also require training. Initial training will take place at Penn State University with subsequent field training in the United States by Control Techtronics.

Predicted Results

Table 3 shows current estimated emissions, fuel usage and efficiency from the MPEC Balicka Plant in Krakow and compares it to predicted results after implementation of the program described herein. The average annual efficiency is currently about 62.5%. With properly graded fuel and automatic combustion controls an average efficiency of 72.5% is achievable. Currently, the plant uses 19,000 tonnes/year of coal. The predicted fuel consumption can then be calculated based on the efficiency, the calorific value of the fuel, and the annual production as follows:

TABLE 3 A COMPARISON CURRENT ESTIMATED EMISSION AND PREDICTED EMISSION WITH PROPOSED ENHANCEMENTS AT THE BALICKA PLANT		
	Current Estimated	Predicted
Plant Input-Output Efficiency	62.5%	72.5%
Annual Fuel Usage	19,000 tonnes	14,100 tonnes
Annual Heat Production	225,580 GJ	225,580 GJ
Particulate Emissions	220 Mg/year	53.6 Mg/year
SO_2 Emissions	215 Mg/year	160 Mg/year
CO Emissions	19.0 Mg/year	14.1 Mg/year

$$\text{Fuel Used} = \frac{225{,}580 \times 10^9 \text{ J.}}{(.725 \text{ eff.})(1000\text{kg/tonne})(22{,}000{,}000\text{J/kg})}$$

$$= 14{,}100 \text{ tonnes}$$

A particulate emissions limit of 0.40#/MMBtu is required for older stoker plants in the United States. Stoker plants meet or exceed this requirement by using mechanical collectors, automatic combustion controls and properly sized fuel. Using this experience as a model, a maximum of 0.40#/MMBtu is the projected particulate emissions for our program. The 0.40#/MMBtu is equivalent to 172g/GJ. Based on the calorific value of the fuel, a predicted 53.6Mg/year of particulate will be emitted. This is a 75% reduction in particulates from the current 220Mg/year. Predicted reductions in SO_2 and CO are a function of the increased efficiency and reduced coal consumption. The SO_2 emissions will reduce from 215Mg/year to 160Mg/year while CO should reduce from 19.0Mg/year to 14.1Mg/year.

The savings in fuel costs realized from the predicted gain in efficiency is estimated at $55,700/year by the following:

(19,000T)($20/T)-(14,100T)($23/T)=$55,700/year

Current fees for emissions are: 600 zl/kg for particulates, 1100 zl/kg for SO_2, and 300 zl/kg for CO.[4] Based on the projected reduction of emissions shown in Table 3, the annual savings in emissions fees would be $8,090/year.

Other savings not quantified here are reduced ash disposal costs, reduced power consumption by plant equipment, and reduced plant maintenance costs. Based on an implementation cost of $125,000 to $175,000, the savings quantified above will provide a simple payback of two to three years.

Conclusions

Existing stoker fired boiler plants in Eastern Europe need to reduce air emissions and increase operating efficiency. The cost to eliminate or replace many of these plants is too great. Therefore an economical means of achieving these goals is necessary. Control Techtronics and Penn State have examined and analyzed the needs of these plants and then developed a multi-disciplinary approach to reducing emission and operating costs. The approach outlined in this paper provides sound solutions to the problems encountered in stoker fired boiler plants based on the analysis and proven field experience. It is anticipated that the analysis used here and similar solutions can be applied throughout Poland and Eastern Europe.

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MODERNIZATION OF COAL-FIRED BOILERHOUSES FOR EMISSION REDUCTION IN KRAKOW

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Abstract

Over the past decade the world has become increasingly aware of catastrophic air, land and ground water pollution over much of eastern and central Europe. Areas in Poland, Czechoslovakia, Hungary, and what use to be East Germany have unprecedented pollution levels, far worse than anything in the West. Per-capita SO_2 emissions in East Germany are over 15 times greater than in western Germany. In particular, in southwest Poland, air pollution is among the worst in central Europe. Additionally, because heavy industry in central and eastern Europe tends to be clumped together, concentrations of particulate and gaseous emissions in these areas are often extremely high. For example 40 percent of Poland's total emissions are found in the Katowice district, Jelenia Goria, Krakow, and Warsaw. Adding to this problem is pollution from the use of coal furnaces used to heat commercial and residential buildings.

Compounding the problems created by the political atmosphere are the high use of "unclean" coal and the decentralized energy structure. Poland uses approximately 100 million tons annually of low grade highly polluting coal for industrial/commercial and residential purposes. Very little of this coal is cleaned, less than thirty percent, and essentially non of the electric generating coal is cleaned. Since, coal is the primary energy source of Poland, it is mined at a rate of approximately 190 million tons per year. This compares to the U.S. production of about 1000 million tons per year or that the Poland produces nearly one fifth of the coal the U.S. does. Over fifty percent of the coal mined is used for small scale industrial and residential purposes. Only about thirty percent of this coal is cleaned.

Despite the severity of the air pollution, this environmental problem is most readily solvable. As a first step, retrofitting emissions control equipment to old coal fired systems along with installing new, more efficient boilers would be an important start. Furthermore, such projects could be the start of a new market opportunities in technology sales or joint ventures for U.S. firms.

The work presented in this paper is an overview of the design of a retrofit system for such a joint venture. Specific issues discussed in the paper are requirements for systems of this scale, potential slagging and fouling of heat transfer surfaces, combustor system design for high carbon conversion and low NO_x emissions, post combustion cleanup of SO_2 and particulate and system controls. The components have been integrated and optimized to provide a district heating boiler house system with 4 to 1 turndown, 85 percent thermal efficiency and high carbon conversion. Emissions of NO_x, SO_2 and particulate will be controlled to values approaching 0.22, 0.16 and 0.087 lb/10^6 Btu, respectively. Operational considerations are also addressed in the design. These are rapid startup, operating labor, dust-free ash removal and bi-annual maintenance. In addition, the methodology used in establishing this joint venture and obtaining the finances to initate this work as well as the payback are provided.

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The Problem

The underlying principal to the Polish and generally speaking the Eastern European environmental problems is that the communist regimes emphasized production quotas at the expense of the environment. Additionally, because heavy industry in central and eastern Europe tends to be clumped together, concentrations of particulate and gaseous emissions in these areas are often extremely high. This has made this region to be one of the most heavily polluted areas of the world. Areas in Poland, Czechoslovakia, Hungary, and what use to be East Germany have unprecedented pollution levels, far worse than anything in the West. Per-capita SO_2 emissions in East Germany are over 15 times greater than in western Germany. In particular, in southwest Poland, air pollution is among the worst in central Europe. For example, 40% of Poland's total emissions are found in the Katowice district, Jelenia Goria, Krakow, and Warsaw. In Poland, faceless statues and crumbling buildings in the city of Krakow demonstrate how the high levels of air pollution caused by forty years of neglect have destroyed these monuments that had previously lasted hundreds of years with no deterioration. The Poles not only face this enemy that they can visually see what it is doing, they also have extensive soil and water pollution damage. For example, the Vistula river is so polluted from human, industrial, and coal mining wastes that it is not even fit for industrial use and certainly is not potable.

Compounding the problems created by the political atmosphere are the high use of "un-clean" coal and the decentralized energy structure. Poland uses approximately 100 million tons annually of low grade highly polluting coal for industrial/commercial and residential purposes. Very little of this coal is cleaned, less than 30%, and essentially none of the electric generating coal is cleaned. Since coal is the primary energy source of Poland, it is mined at a rate of approximately 190 million tons per year. This compares to the U.S. production of about 1000 million tons per year or that Poland produces nearly 20% of the coal the U.S. does. Over 50% of the coal mined is used for small scale industrial and residential purposes and only about 30% of this coal is cleaned.

Despite the severity of the air pollution, this environmental problem is most readily solvable. As a first step, retrofitting emissions control equipment to old coal-fired systems along with installing new, more efficient boilers would be an important start. Unfortunately, the technology and capital necessary to do so, especially on small-industrial levels is severely lacking in these countries. However, with U.S. foreign aid, transfer of "clean coal" technologies developed in the U.S. to these countries could be achieved, and act to encourage the continued development of such advanced technologies. Furthermore, such projects could be the start of new market opportunities in technology sales or joint ventures for U.S. firms.

Specific Problems at Krzesiawice

Existing Design. The facility was put into operation in 1958. The facility consists of a brick building with no external plaster on a very small building lot (Figure 1). The coal and bottom ash bins were made of reinforced concrete construction. Low chimneys were erected with steel pipes for each boiler. Railway supply of coal was foreseen, accompanied with wagon tipper, coal chute to provide coal to the sunken bins which are made of reinforced concrete. Further horizontal transportation with manually driven trucks was planned.

Bottom ash transport (after dumping with water spray) using jubilee wagons to transport the ash to the elevator was proposed. Ash was poured into the bin made of reinforced concrete and then released onto the truck platform. During the construction and operation of the boiler house, changes were introduced in the area of coal transportation. The railway transport was replaced with road transport. One shaft of the elevator was used for assembling a bucket elevator. Belt conveyors were used for horizontal transport.

The bottom ash is transported with an elevator and poured into the bin. The ash is not stored in the bin. It is especially important for the winter season since the bin is not heated. The manual ash transport is very inconvenient. During the operation, several modifications were put into force:

- Four chimneys over the boilers were replaced with two external chimneys h=15 m. and cyclone fuel gas dedusting devices were installed (see Figure 2);
- The traveling grates, initially driven with a discrete multi-speed regulation, are now provided with infinitely variable speed drives (see Figure 3);
- Two additional pipe-lines transporting steam and condensate have been assembled on high supports made of reinforced concrete:
  - To the Dairy
  - To the SPOLEM company plant

Present Condition. The technical state of the building is satisfactory. However, serious erosion of external wall mortar is visible. Refilling of wall defects and laying the external plaster is required and would improve the appearance. There is some corrosion of the reinforcement in the point of contact of the reinforced concrete bins and coal feed chute (onto the grate). The external chimneys are made of low-grade steel. They show signs of corrosion and may need to be replaced with new chimneys made of high-quality steel. Their height should correspond with ecological requirements. Finally, the external corrosion of flue gas dedusting cyclones is visible.

Both the chimney and the cyclones have been in operation for two years. If a proper anticorrosion protection will be applied, they should still operate for several more years. The technical condition of the exhaust fan is good. Dust is taken from the cyclone tanks into the open trucks using rotary valves. The external ash tank does not fulfill the proposed function and ash is poured through the tank outside onto the ground.

Since the beginning of operation, i.e., since 1958, the boilers were repaired many times. The accompanying devices, i.e., grate with drive, blast air fans are currently repaired and are technically efficient.

Steam passes from the boiler house into the external network laid partially underground and partially over the ground surface. Steam for the Laundry Company is supplied using a special network with pressure 8 bar. All the other plants obtain steam 4 bar of input pressure. Boilers are partially (approximately 60%) supplied with reversed condensate and processed water. Water supplied is processed in a thermal degassing process. In steam boilers type PLM-2.5, forced circulation of water is utilized.

Coal is fed with a self-propelled loader onto the belt conveyor (horizontal), which transports the coal to the bucket elevator and then with a horizontal belt conveyor into the storage bin near the boilers and onto the boiler grate.

Bottom ash from the grate leaves through a chute and flows into the hand trucks. The dust generated from this activity is suppressed with water spray. The trucks are pushed manually into an elevator which transports ash from the basement to the silo. Then, the ash is manually poured into silo by overturning the truck. Dedusting occurs individually for each separate boiler using a battery consisting of 6 cyclones.

Specifications. There are four type PMS-2.5 boilers at the facility. These are water-tube, single-draught boilers. The specifications for the units are provided in the Table 1.

Existing Performance. To document the existing performance of the boiler at the Krzeslawice boiler house, tests were conducted using several coals. A summary of the results are

provided in Table 2. Generally, the unit operated from 54 to 70% thermal efficiency on a higher heating value basis. The excess air ranged from 200 to 400%, well in excess of the 45% design value. SO_2 emissions ranged from 0.34 to 1.47 lb/10^6 Btu, while NO_x emissions ranged from 0.14 to 0.44 lb/10^6 Btu. The particulate emissions ranged from 0.09 to 0.47 lb/10^6 Btu. Also provided in the table is the data that was reported using a clean and slightly graded coal, similar to what can be expected to be used in the future.

Emission Regulations and Goals

The system performance goals for boiler house requirements of commercial buildings are listed below. The project will focus on advanced systems capable of achieving the following performance goals:

Turndown Ratio:	4:1
Thermal Efficiency:	>85%
Combustion Efficiency:	>96%
Ash Removal:	semiautomatic
Scheduled Maintenance:	once a year
Emissions:	0.16 lb SO_2/10^6 Btu
	0.22 lb NO_x/10^6 Btu
	0.087 lb particulates/10^6 Btu

The Solution

Several modifications will be made to the combustion/boiler system to increase the efficiency of the unit and reduce the emissions. First, an automatic control system manufactured by Control Techtronics will be installed by NAFTOKRAK. This effort alone will improve the efficiency of the unit and reduce emissions by controlling the air-fuel ratio. Second, the exit gas temperature will be reduced by installing an economizer. This unit will reduce the exit gas temperature by approximately 100°F, which will account for an increase in efficiency of about 2%. Properly sized coal will be used, which will maintain the carbon loss at approximately 3.5%. The use of properly sized coal coupled with the automatic controls can add as much as 17% to the thermal efficiency of the unit. The NO_x emissions will be controlled through the use of low excess air levels provided by the forced draft fan and adding secondary air for volatile burnout above the bed. Also, flue gas recirculation will be utilized to control the temperature of the grate and the bed of fuel. There is a possibility that limestone can be added to the fuel to provide reasonable SO_2 removal efficiencies due to the low temperatures in the bed and above the bed. Finally, modifications to the exit gas ductwork and the cyclones will be provided to reduce the particulate emissions. The specifics of each of these modifications will be discussed below in much greater detail.

Automatic System Controls. Control Techtronics offers a full array of products, including the Model 2000 multi-loop controller, Windows-compatible data acquisition software, Model O2-1000, -2000, -3000, and -4000 oxygen trim systems, and the Model 300 oxygen sensor. Control Techtronics also provides complete boiler control systems, including free-standing or wall-mounted enclosures that can accept opacity monitors, draft gauges, flame supervision, communication equipment, and recorders. Other field components can also be provided, such as orifice plates, flow and pressure transmitters, thermocouples, flow meters, annubars, and more.

The Model 2000 is the main component in a Control Techtronics' system. The Model 2000 has a powerful 32-bit, 16 Mhz microprocessor and is programmed in high level C software. Thus, the Model 2000 is the most powerful and versatile controller on the market. It has an easy operator interface and a modular design to provide their customers with the most cost-effective boiler controller.

Economizer. An economizer will be added to reduce the stack losses. The economizer will recover approximately 816,000 Btu/hr of heat. This corresponds to about 8% of the thermal input at full load.

Sized Coal. It is expected that graded coal will be available for use in Krakow in the near term. Therefore, improvements that can be realized through the use of sized or graded coal is included. To estimate the effect of using graded coal, a comparison of test data taken on the Krzeslawice boiler through a Brookhaven National Laboratory program will be utilized. In those tests, many operating variables were changing throughout the test which makes it difficult to make direct comparisons. However, two tests have the same boiler load of 1.96 Mw. For these two tests, the test with the graded coal had a carbon loss of 2.8% versus a carbon loss from the ungraded coal of 12.4%. This is a 9.6% improvement in the efficiency according to the carbon loss. However, other factors enter into the efficiency which reduced that to 8.8%. A second set of data at a much lower load, approximately 1.18 Mw, does not show such a great difference. This is completely expected since the velocity is much lower and the loss due to the entrained coal fines is significantly lower. In this set of data, the improvement from using graded coal is only 1.5%.

NO_x Control. Overbed stoker systems have a number of advantages over spreader stoker or pulverized coal systems in controlling NO_x emissions (NO and NO_2). Lower operating temperatures significantly reduce the amount of NO_x produced by oxidation of the nitrogen in the combustion air (often referred to as "thermal NO_x").

However, in coal-fired systems as much as 75% of the NO_x results from the oxidation of fuel-bound nitrogen (or "fuel-NO_x"). Fuel-NO_x formation appears to depend on the local availability of oxygen during combustion, the complex evolution of intermediate nitrogenous radical species, and coal properties such as volatility. Meeting stringent NO_x emissions limits without relying on post combustion controls will require effective control on chemistry of fuel-bound nitrogen.

Overbed stoker fired combustion processes operate at low temperature 1100-1700°K (1500-2000°F). These low temperatures have an important effect on NO_x production by the virtual elimination of thermal NO_x. Sufficient energy is not available to break the triple bond of the atmospheric N_2 molecule. The low temperatures also have the added effect of reducing the rate of NO formation from fuel nitrogen.

One method of obtaining low NO_x emissions is through staged combustion. This is achieved in the overbed feed stoker system by operating the combustor under stoichiometric conditions. This is easily obtained since the inventory of carbon in the bed at any time greatly exceeds the need of oxygen. The four most important variables influencing NO_x control in low temperature, staged combustion systems are (Breault, 1987[1]):

- Primary zone stoichiometry
- Primary zone residence time
- Primary zone temperature
- Fuel nitrogen content

The importance of primary or first stage stoichiometry is shown in Figure 4 where the NO_x emission rate is plotted against the primary air to stoichiometric air ratio. The width of the curve indicates that the effect of temperature, residence time, and fuel nitrogen could not be separated. Stoichiometric ratios less that 1 are required to provide NO_x emissions less than $0.22/10^6$ Btu.

[1]Breault, R.W., "NO_x Emissions from a Staged Circulating Fluidized Bed Process: The Multi-Solids Fluidized Bed Combustor," ASME Winter Annual Meeting, Boston, 1987.

The effect of the staged line residence time on the same date is shown in Figure 5. The fuel nitrogen content falls out clearly in this presentation of the data. Increased residence time is required for high nitrogen fuels. A low percent nitrogen fuel requires 0.3 seconds while a fuel with a nitrogen content 40% greater, requires 0.85 seconds to reduce NO_x emissions below 0.1 lb/10_6 Btu. The Polish coals are approximately 1% nitrogen.

The influence of the temperature is shown in Figure 6. As in the plot of primary air to stoichiometric air ratio, fuel nitrogen, temperature, and residence time are not clear parameters. The plot does show that lower temperatures are required to produce lower NO_x emissions. The lowest NO_x emissions were obtained at temperatures less than 1520°F. Temperatures less than 1700°F will be required to achieve the NO_x control.

SO_2 Control. The control of SO_2 emissions in furnaces has received considerable attention during the past twenty years. Two approaches have been used. The first is for high temperature systems, that is typically referred to as either LIM for limestone injection/multistage or as furnace injection. In this process, the limestone is injected into the furnace flame zone where it is often exposed to temperatures that are high enough to sinter the lime. This is referred to as dead burning. The second and more successful approach to the control of SO_2 emissions during the combustion process takes place in fluidized bed systems. The primary reason for this is that the temperatures in a fluidized bed are high enough to promote the rapid decomposition of the limestone into lime and not be sufficiently high to cause dead burning. For this to occur, the temperature needs to be between 1500 to 2000°F. The units at Krzeslawice are interesting in that the zone above the grate and below the steam generator is within this temperature window. The amount of sulfur that is captured is dependent upon many parameters (Breault, 1987[2,3]). Generally, this can be expressed as the product of the reaction rate constant corrected for mass transfer, the surface area for reaction, the residence time for the gas in the removal zone and the concentration driving force. The zone above the grate is not significantly different from the lean phase region of the MSFB. In that regard, application of the published MSFB data could provide some predicted performance estimates for SO_2 removal for the Krzeslawice boilers.

Fine ground lime will be injected into the zone above the grate. The lime will be sized to fall to the grate for removal as bottom ash, approximately 300 microns. At full load, the residence time of the flue gas in the removal zone is approximately 1.7 seconds. With these conditions and assuming that a comparable stone is found, SO_2 removals of 75 to 85% can be achieved. It should be noted that not all boilers in Krakow and Poland will perform in this same fashion. For example, stoker boilers with waterwalls will have a lower temperature and correspondingly, a lower removal.

Particulate Control. The cyclones that are in place at the boiler house are designed for only a 90% particulate removal efficiency. Without making significant changes, i.e., replacing the cyclones, modifications to the inlet ductwork can be done to ensure that fully developed flows are entering the cyclone. Also, performance is related to the highest velocity, either inlet or outlet. In this regard, decreasing the inlet or outlet area will improve the performance.

Specifically, using the test data from the graded coal tests that were conducted, the average cyclone efficiency was about 75%. Since the performance is related to the dimensions of

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[2]Breault, R.W., "Sulfur Removal Modeling in a Circulating Fluidized Bed: The Multisolids Fluidized Bed Combustor," 1987 AIChE Presented at the National Meeting, Houston, TX, March 1987.

[3]Breault, R.W., "Theoretical Modeling of the Multisolids Fluidized Bed Combustor: Hydrodynamics, Combustion, and Desulfurization," Proceedings of the Ninth International Conference on Fluidized Bed Combustion, Boston, MA, May 1987.

the cyclone, the velocities and the physical properties of the gas, a simplistic ratio can be developed to determine the improvement that would be expected from changes to the base performance which has been documented. The performance of the cyclone can be related to the ratio of the particle size to the theoretical particle size. For the performance to increase from 75% to 92%, the theoretical particle size needs to be reduced by about 60%. Otherwise stated, the new theoretical particle size needs to be about 2.5 times smaller than the exiting size. If the entrance width to the cyclone is cut in half and the corresponding velocity doubled, the theoretical particle size is reduced by 2.5 times. Therefore, the new efficiency to the cyclone would be 92%. Modifications to the outlet tube might be needed also to ensure that no slippage, bypassing, is occurring. A site inspection will identify the specifics of the modifications.

Predicted Performance

The predicted performance of the system will be discussed as outlined in the list of goals.

- Turndown - 4 to 1
- Thermal Efficiency - 85%
- Combustion Efficiency - 96.5%
- Emissions - Primary emission concerns are for SO_2, NO_x, and particulates. The predicted emissions for each of these are listed below:

	lb/10^6 Btu (g/GJ)
SO_2	0.16 (66)
NO_x	0.22 (95)
Particulates	0.087 (36)

Emissions Reduction Potential and Estimated Impact on Heating Costs

An estimate as to the total emissions reduction from the joint venture will be made using the projections developed for the demonstration at Krzeslawice. These estimates are based on the incorporation of all the modifications discussed above. The emissions from the Krzeslawice boiler house are summarized in Table 2. If it can be assumed that the cost of reducing all the emissions is approximately the same, then the total emissions reduced at Krzeslawice is 115.06 tons/year. This corresponds to an emissions control cost of $9213/ton per year. This is within the range presented in the PON for control of units greater than 2 Mw using mechanical collectors.

Estimating how the joint venture effects the emissions in Krakow and throughout Poland is much more difficult, since it requires that the sales defined in the pro-forma cash flow estimate be further defined. In that regard, if we assume that the sales during the first three years are all within Krakow, then the total emissions reduced in Krakow at the end of the third year will be 441.83 tons per year.

Joint Venture

A three stage cooperative joint venture program illustrated in Figure 7 is planned. The program brings together from each country expertise from technology-based organizations, equipment manufacturers and universities. The first stage, BUSINESS DEVELOPMENT, focuses on developing market and technical information from which specific projects will be identified and agreements obtained to do business together in the form of shared savings and equity financing of the capital equipment. This stage is not a DOE-funded task.

In this stage, the commercial market segments presently utilizing or capable of utilizing coal will be evaluated. Problems associated with coal utilization in these markets and proposed solutions utilizing advanced technologies will be addressed. If the application base is very broad,

the best approach may be a modular, highly flexible system. On the other hand, if the applications are well defined, a truly "packaged" concept approach may be best.

Based upon the design criteria and performance specifications, a preliminary design of a full-scale system is made. Utilizing scaling principles developed under previous programs, this design will form the foundation for preliminary manufacturing cost analyses and the following Stage II development activities.

Upon completion of the Stage I effort, the work will proceed to Stage II. This stage is divided into four parts - Advanced Technology Engineering and Design, Components Fabrication, Components Installation, and Site demonstration. The deliverable from Stage II will be a modified system that meets the design criteria and performance goals set forth in Stage I, which, when operated, will provide the return on the investment to the joint venture.

The third stage of the program is Site Operation. It is in this stage that the shared savings obtained from operating the modified systems will flow to the joint venture and provide a return on the investment.

The joint venture is a group of U.S. and Polish companies with the objective of conducting shared savings programs for energy efficiency programs. These programs will have several parts. First, the joint venture will discuss with the owner of a boiler facility the goals of the program which is to make modifications to the facility that will significantly cut the operating cost and that the savings would go to the joint venture for a period of time such that any incurred debt can be repaid and income generated by the joint venture. Once a general agreement has been reached that both parties, the site owner, and the joint venture are interested in conducting the program, a review of the operation and condition of a particular boiler would be conducted to determine if a program could be conducted which would be profitable for both parties. After determining that the site holds significant promise, negotiations between the owner and the joint venture will be undertaken to establish the length of the shared savings program and the fraction of the savings that the joint venture would receive during this demonstration. Once these issues have been completed, especially, early in the joint venture, financing of the conversion will be obtained. This procedure will occur for the first few years until the joint venture can finance its own programs. For this program, third party financing is required and Tecogen Inc., the joint venture, has received a letter of intent. After these agreements are finalized, design of the conversion subsystems will be initiated. This step will be followed by fabrication and installation of the conversion modifications. Finally, performance tests will be conducted such that the predicted performance can be verified. Income for the joint venture will be received from the operation of the facility under the agreement between the owner and the joint venture.

Market

In the Krakow area, there are 222 boilers with a size greater than 2 Mw. These have an installed capacity of 965 Mw and an average capacity of 4.346 Mw. In all of Poland, the commercial and small industrial boilers ranging in size from 2 Mw to 35 Mw number 20,000. Using the average for the city of Krakow, there is an installed capacity throughout Poland of 86,929 Mw. At the smaller scale of 200 kW to 2 Mw, it is estimated, based on interviews with manufacturers, that there are approximately 40,000 units in operation. One particular company that was interviewed, the largest producer of boilers in this size range, estimated the average capacity based on their sales to be 350 kW. Therefore, in this size range, there is an additional 14,000 Mw which will need to be brought into compliance and provide a market for the joint venture. Thus, the total market is approximately 101,000 Mw.

The joint venture is assuming only that it has a very small market penetration. If we assume that 50% of these units will be replaced with alternate energy, new boilers, electricity, or added into larger district heating systems, there would still be a market of approximately 50,000 Mw. Examining the pro-forma cash flow analysis shows that only a fraction of 1% of the boilers is taken as the joint venture market size. If anything, the market penetration can be significantly increased especially in the outer years.

Income

The project focuses on improving the efficiency of the boilers through the use of automatic controls and additional modifications to the boiler combustion zone for NO_x control and potentially SO_2 control. For this concept, third party funding in the form of equity financing would be required. This would have a payback period of two years and two months at an interest rate of 10%. In essence, income will result from the sale of steam which is produced at a lower cost due to the improved efficiency of the new boiler house. In this regard, the sales for this project will remain constant. However, due to escalation of fuel and labor costs and the devaluation of the currency, the annual income form this project decreases with time.

Furthermore, the joint venture has an agreement with the district heating company to receive payments which are equal to the operating cost savings and continue the payback payments in a shared savings plan for an additional five years beyond the repayment of the debt. The joint venture must repay the debt with a portion of these additional payments for your participation in the program. The details of this shared savings program will provide the investor group with a 43.09% rate of return. The investor will receive 95% of the savings during the first four years and will the receive 90, 90, 80, 80, and 750%, respectively, for each of the remaining years to the agreement. The balance of the payments will go to the joint venture for funding additional programs in the future years.

Future system sales are based upon continuing to obtain third party funding for the next several years until sufficient funds have been recovered for the joint venture to finance its own system installations. Utilizing the same fraction of the income to make the payments on the future loans, it can be estimated that it will take approximately five years before the joint venture has received sufficient funds to finance a project itself. After this time, the income grows rapidly for the joint venture.

Figure 1 Krzeslawice Boiler House

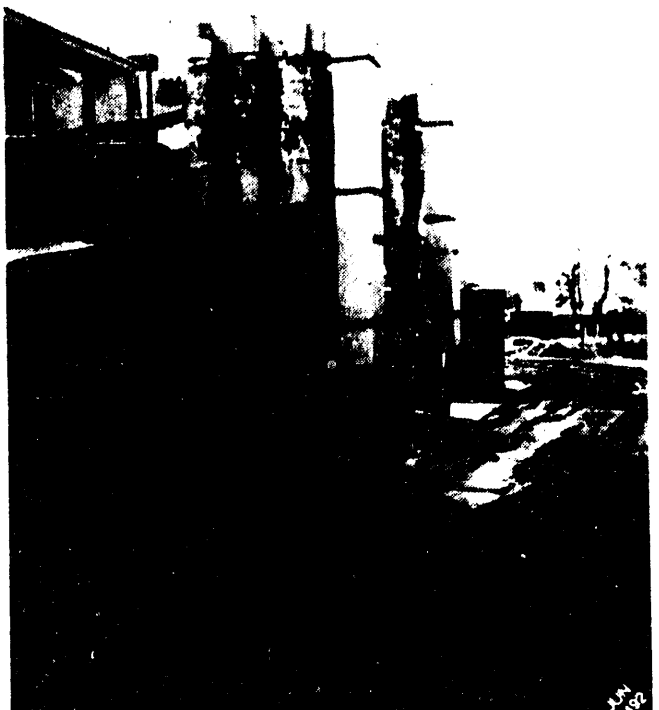

Figure 2 Cyclones at Krzeslawice

Figure 3 Photo of Grate Drives at Krzeslawice

Table 1

TECHNICAL DATA OF PLM-2.5/1 BOILERS

Steaming Capacity of the Boiler	**2.5 x 10^6 kcal/h = 10.5 GJ/h**
Power	**2.9 MW**
Pressure	**10 bar (saturated steam)**
Intake Water Temperature	**105°C**
Boiler Efficiency	**70.75%**
Total Volume of the Boiler	**3,923 liter**
Required Flow	**Minimum: 28 t/h** **Maximum: 35 t/h**
Grate:	**Two grates per boiler**
Surface	**6.24 sq. m**
Width	**2*1.2 = 2.4 m**
Length	**2.6 m**
Grate Drive	**Type NS-250-1**
Extreme Rotation	**Maximum: 1,918 rpm** **Minimum: 266 rpm**
Electrical Engine	**Power 0.75 kW; 960 rpm**
Variable Gear for Revolutions	**Maximum: 0.446 rpm** **Minimum: 0.066 rpm**
Combustion:	
Fuel	**Boiler bituminous coal, type 31.2 class 50/21**
Assortment MI/M – Characteristics as follows:	
Grain Size	**0.20 mm**
Volatiles in Combustible Mass	**28%**
Ash Content	**21%**
Moisture Content	**15%**
Net Calorific Value	**4400 kcal/kg = 18.4 MJ/kg**
Amount of Coal Burned	**760 kg/hour**
Flue Gases and Air:	
Air Excess	**1.45**
Air Demand	**95 Nm^3/minute**
CO_2 Content After Boiler	**10%**
Temperature of Flue Gases After Boiler	**200.220°C**
Quantity of Flue Gases After Boiler	**131 Nm^3/minute**
Required Draught After Boiler	**7 mm H_2O**
Forced Draught Fans - two per each boiler	
Type: WPPD-40A+K:	
Capacity	**80 m^3/minute**
Compression	**60 mm H_2O**
Motor Power	**5.5 kW**
Revolutions	**1,450 rpm**
Air quantity regulated with throttles.	
Cyclones:	
Battery of Cyclone Deducters	
(6 Cyclones Combined)	**4 units**
Dimensions of the First Cyclone	**6*0 630**
Nominal Range of Flue Gas Rate	**3.38..6.33 m^3/s**
Average Pressure Decrease	**1400 Pa**
Deducting Efficiency	**90%**
Velocity at Cyclone Inlet	**8.15 m/s**
Induced Draft Fans:	
Type WPWS-60 With Regulated Guide Vane	**2 units**
Type WWGax-63 With No Regulation	**2 units**
Capacity	**2.5 m^3/s**
Swelling (at y = 1.2 kg/cub.m)	**2500.1700 Pa**
Power	**22 kW**
Revolutions	**1460 rpm**

TABLE 2

EXAMPLE TEST RESULTS

Staszic III				
Gate Height	(cm)	9	8	6.5
Load (output)	(MW)	2.59	1.71	1.21
Flue Gas Temp.	(C)	268	271	209
Flue Gas Oxygen	(%)	10.8	14.1	16.9
Flue Gas CO	(ppm)	1400	1394	238
Flue Gas NO_x	(ppm)	132	105	69
Flue Gas SO_2	(ppm)	115	80	50
Excess Air	(%)	102	196	400
Efficiency	(%)	72.7	63.9	58.6
Carbon in Ash	(%)	30.1	32.9	36.0
Carbon Loss	(%)	3.8	3.8	4.4
Particulates	(lbs/MMBtu)	0.47	0.17	0.29
CO	(lbs/MMBtu)	1.98	2.86	0.83
NO_x	(lbs/MMBtu)	0.31	0.35	0.40
Semi-Vol Organics	(lbs/MMBtu)	0.016	0.012	0.017
Emission Indices				
Particulates	(g/kg Coal)	5.61	2.07	3.50
CO	(g/kg Coal)	23.80	34.36	9.97
NO_x	(g/kg Coal)	3.69	4.25	4.75
SO_2	(g/kg Coal)	4.47	4.51	4.79
Semi-Vol Organics	(g/kg Coal)	0.19	0.14	0.20
Cyclone Efficiency	(%)	70	76	76

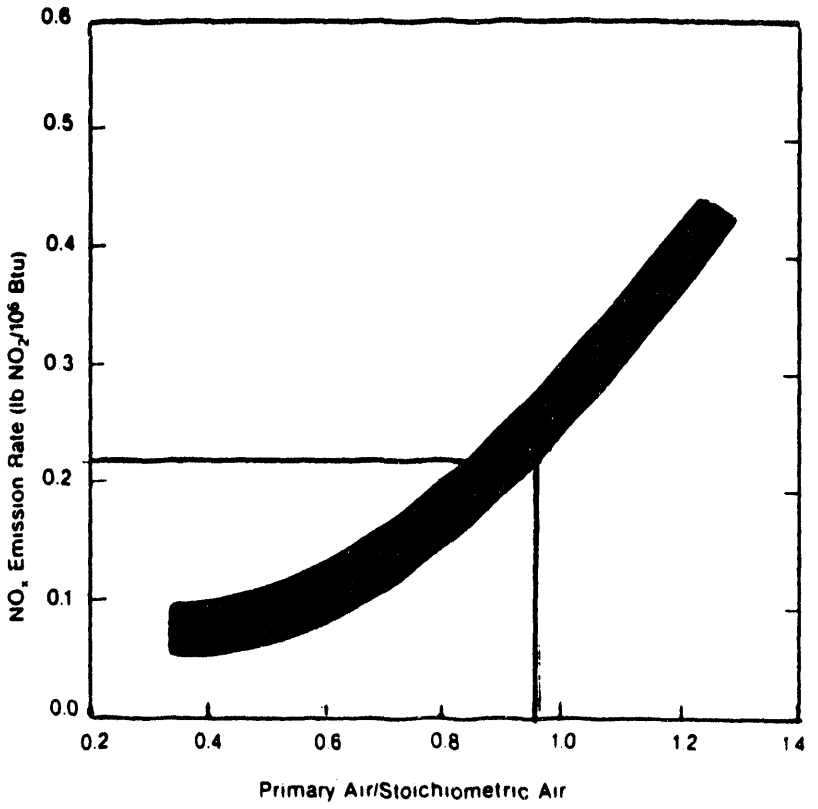

Figure 4 Effect of Stoichiometry on NO_x Emission Rate

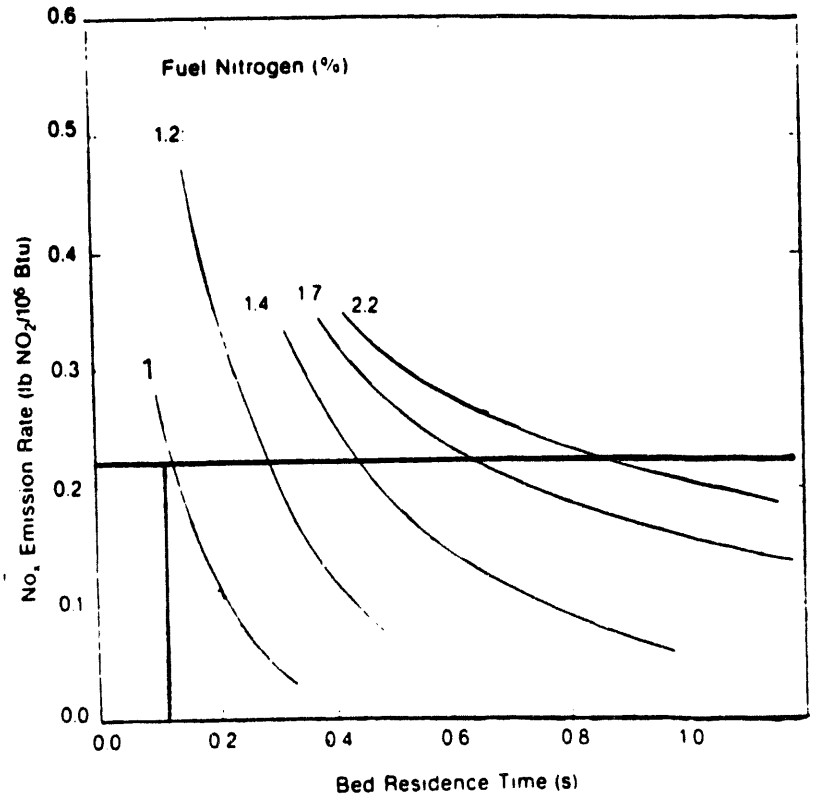

Figure 5 Effect of Bed Residence Time on NO_x Emissions Rate

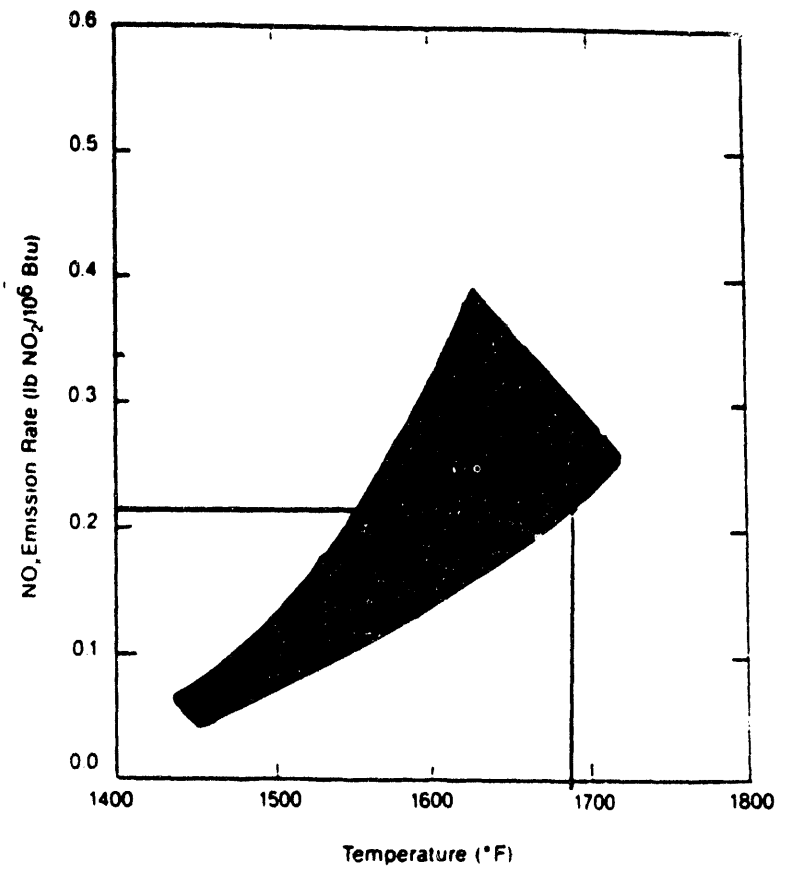

Figure 6 Effect of Bed Temperature on NO_x Emissions Rate

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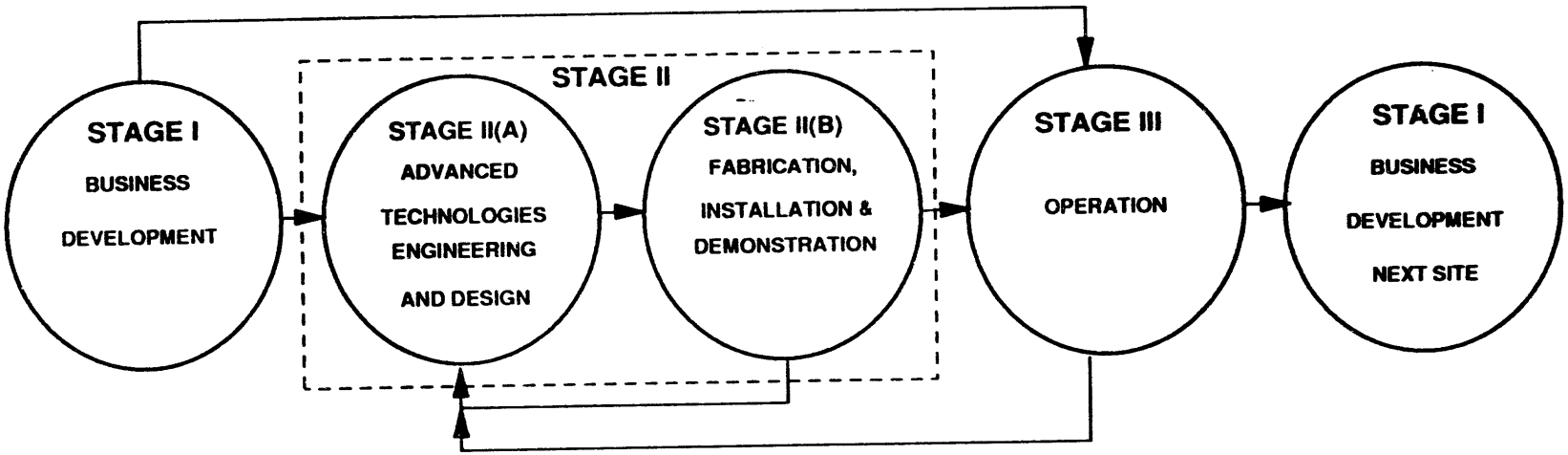

Figure 7 Relationship of Major Program Elements

INERTIAL PARTICULATE SEPARATOR FOR REDUCTION OF LES EMISSIONS IN KRAKOW

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Introduction

Environmental clean-up and pollution control are considered foremost national priorities in Poland. More than four decades of centralized planning has produced serious contamination of air, water, and soil throughout the country and a resulting deterioration of public health. As a result, life expectancy is lower today than it was 20 years ago. Also, incidents of serious disease in adults and young children there have been on the rise. It is therefore, imperative that corrective action be taken.

The government of Poland has begun to implement strong environmental controls to reverse this condition. The target of these controls is the Polish coal industry, which currently comprises over 78% of primary energy production (65% hard coal and 13% lignite). The coal utilization, especially in low grade coals, is highly inefficient. For example, Poland uses almost three times as much energy as Western Europe per unit of gross domestic product (GDP). In many cases, coal combustors have no pollution controls. Moreover, most have relatively low stacks and release emissions relatively close to the ground, further aggravating the problem. The result is that concentrations of airborne dust have been found to be many times higher than the maximum safe level.

The City of Krakow, one of the world's great cultural centers, has a serious problem with airborne pollutants. These emissions are discharged from stacks burning coal, mainly unwashed. This paper discusses one of the projects initiated by the U.S.Department of Energy for environmental cleanup in Krakow. This particular project involves an efficient control technology for mitigation of particulate emissions. The technology is referred to as the *Core Separator*, and it has been under development by LSR Technologies, Inc. in the U.S.A.

Environmental Conditions in Krakow

During a visit to Poland a few years ago, former President Bush stated, "Today Krakow is under siege by pollutants. Its priceless monuments are being destroyed."

The destruction is caused primarily by airborne pollutants emanating from the combustion of hard coal and coke in so called Low Emission Sources(LES). Fossil fuels are used heavily for heating purposes during the winter season. The 750000 population in Krakow relies heavily on hard coal as the heating source. About 35% of the heating needs is provided by some 2900 local boilers, often with low efficiency cyclones for particulate removal and no sulfur abatement technologies. These boilers consume yearly an estimated 370000 tonnes of coal and coke. As a result, the combination of coal combustion and the city's location in a valley having a temperature inversion, quite often a heavy suspended smog is visible over Krakow.

A major portion of heating needs is provided by district heating supplied with heat from local power plants, Leg and Skawina. These plants have high stacks that dilute and distribute pollutants over large areas. The primary cause of low ambient air quality in Krakow is from suspended particles and SO_2 emissions. SO_2 pollution is generated to a large extent (some 47%) from the neighboring Upper Silesian Industrial Region, while the balance comes from Krakow industry and power sectors (some 18%) and Low Emission Sources (35%). The picture is, however, quite different with particulate matter. Low Emission Sources are almost entirely responsible for suspended particulate matter in the ambient air in Krakow.

By definition "suspended particles" are referred to as particles of dust with a size less than 10 μm in diameter that do not fall to the ground from the force of gravity. These particles are in the respirable range, i.e., they have potential for accumulating in the lungs of humans causing respiratory disease.

Krakow air is continuously measured by a network of Automatic Ambient Air Monitoring Stations. The instantaneous/real time concentrations of SO_2, CO, suspended dust, and NO_2 in the ambient air are monitored continuously. The 30-minute (D_{30}) and daily (D_{24}) average concentrations for each pollutant are plotted and tabulated. From this, the actual pollutant measurements can be compared with permissible values. According to Polish Law, Krakow is located in a "protected area." For designated protected areas, the permissible concentrations of the main air pollutants are given in Table 1.

Table 1 Allowable Concentrations- Pollutants in Ambient Air Protected Areas of Poland

Pollutant	30-Minute Concentration D_{30} µg/m^3	Daily Average Concentration D_{24} µg/m^3
SO_2	600	200
NO_2	500	150
CO	5000	1000
Suspended Particles	**250**	**120**
O_3	100	30

It is of particular interest to compare measurements of suspended particulate concentrations in both the winter and summer seasons. Figures 1 and 2 show measurements taken at one monitoring station in February 1993 and in July/August 1993. In these figures, it is immediately apparent that: (1) concentrations are significantly higher in winter during the heating season, and (2) concentrations in wintertime very often exceed the permissible values from Table 1.

The same correlation can be observed in other air pollutants from coal combustion such as sulphur dioxide and carbon monoxide. The conclusion in each case is unmistakable, that Low Emission Sources used during the heating season are responsible for this situation.

Abatement Options for Dust Emissions

In order to improve ambient air quality in Krakow, the discharge of emissions during the heating season must be reduced. There are several ways to limit particulate emissions from LES. Conversion of coal/coke boilers to natural gas and connection of some heated areas to the district heating network are a couple of examples. Also in this category are improvements in energy saving measures in buildings, which would reduce fuel consumption. In the long run though, it is unlikely that coal combustion in local boilerhouses in Krakow will be entirely eliminated. The Ordinance of the Polish Ministry of Environmental Protection of February 12, 1990 on Protection of Air Against Pollution gives allowable emissions for combustion sources. The values are more stringent than earlier Polish standards, but not yet as demanding as those in Western Europe. The deadline to comply with these limits was set for the beginning of 1998. In addition, the local voivod environmental standards will likely go beyond that of the Polish Ministry. Existing pollution control equipment (mainly cyclones) is not likely to meet future regulations for dust mitigation in Krakow. Utilization of smokeless fuel or bag filters are possible options, but both are rather costly. The novel *Core Separator* technology developed by LSR Technologies can meet these regulations for either new or existing boilers. This technology will be described in more detail in the following section.

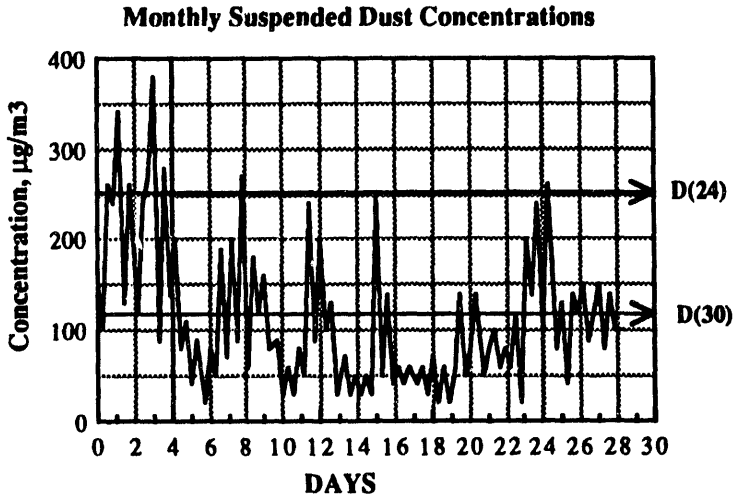


Fig.1 Transient Concentrations - Suspended Air, µg/m3 Krakow February 1993

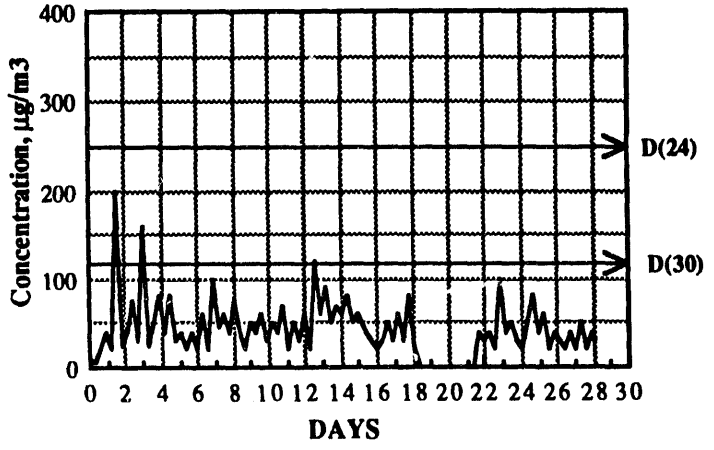


Fig.2 Transient Concentrations - Suspended Air, µg/m3 Krakow July/August 1993

Principle of Operation

The *Core Separator* is one of very few advances made in the field of particulate control in recent years. The technology was developed through research sponsored by the U.S. Department of Energy and Environmental Protection Agency. A number of these units have been placed in operation in the U.S. All of the units now in service are performing very difficult separations, i.e., those involving dust particles with small aerodynamic diameters. More recently, license agreements have been completed with firms in the U.K. and Australia.

Historically, mechanical separators have been ineffective in removing dust particles with diameters below 10 microns. In comparison, the *Core Separator* is able to remove a high percentage of particles even at 2-3 microns in diameter. This is roughly equivalent to the performance of a medium-efficiency electrostatic precipitator (ESP). Figure 3, which was created by Industrial Filter & Pump Mfg. Co., illustrates the relative performance of several particulate control devices including cyclones, barrier filters, ESPs and wet scrubbers. The *Core Separator* performance is also superimposed on this figure. As illustrated, its performance is comparable to a medium-efficiency ESP or a high-energy venturi scrubber. Yet, the *Core Separator* still has the traditional advantages of mechanical collectors such as simplicity, reliability, compactness, and low maintenance.

A simplified schematic of the *Core Separator* system is shown in Figure 4. The system includes two conventional components, a cyclone collector for extracting solids and a fan for flow recirculation. The *Core Separator* is actually a multitude of cylindrical units. Each unit has a single inlet for the stream to be treated and two outlets, one for the cleaned gas stream and the other containing a highly concentrated recirculation stream. The dust-laden recirculation stream is fed to the cyclone and then returns again by means of the fan. The processes of separation and collection are accomplished separately in different components. The *Core Separator* cleans the inlet stream and detains dust particles in the system. Since its efficiency is quite high, the dust particles cannot leave the system. They recirculate again and again until collected in the cyclone.

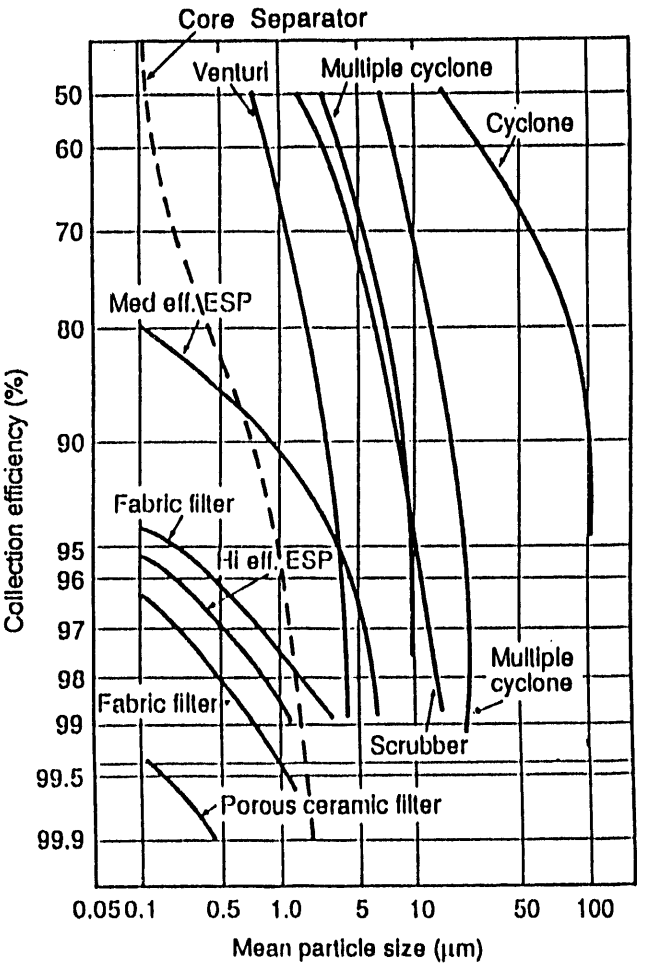


Fig.3 Particle Collector Performance (Printed with permission of Industrial Filter & Pump Mfg. Co.)

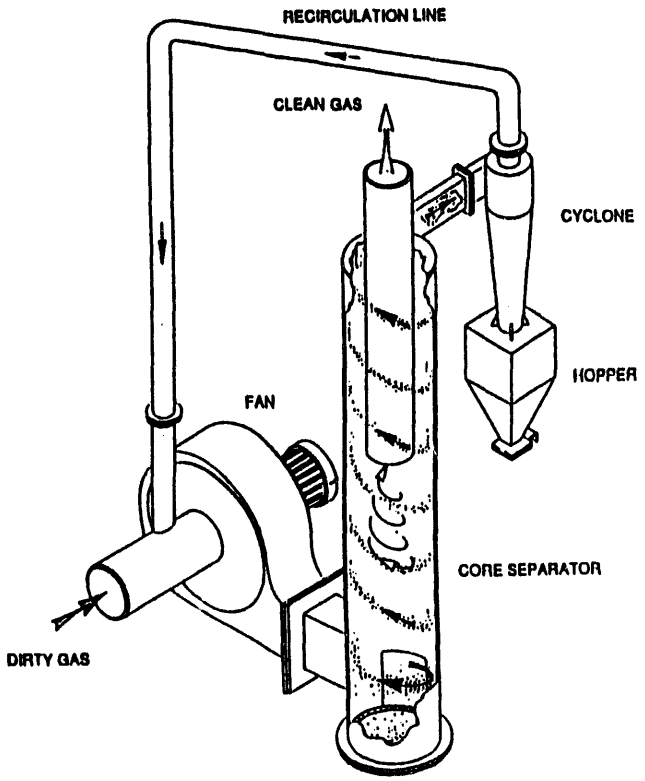


Fig.4 Simplified Arrangement - Core Separator

Two factors govern the performance of *Core Separator* systems: (1) a high separation efficiency of the *Core Separator* component, and (2) an interaction between individual components. To achieve high separation efficiency, a proper bleed flow value (ratio of the recirculation flow to the total flow) is required. By controlling bleed flow in the *Core Separator*, the tangential and radial velocities can be controlled independently to maintain them in the desirable range.

High efficiency in the *Core Separator* is due to low particle reentrainment. In this regard, the system is designed in such a way as to avoid formation of toroidal vortices. The *Core Separator* component functions as a separator, but not as a solids collector. This permits the avoidance of a flow U-turn within the device. It has a cylindrical shape, and surfaces promoting formation of vortices are moved away from the clean flow outlet. It should be pointed out that all these factors work together, and taken individually cannot prevent vorticity.

The separation efficiency of the *Core Separator* actually predetermines the efficiency of the system even if the collector efficiency if relatively low. The following formula can be used to calculate partial collection efficiency when the collector is situated downstream of the *Core Separator*,

$$E_{sys} = \frac{E_{cs} \times E_{cyc}}{1 - E_{cs}\left(1 - E_{cyc}\right)}$$

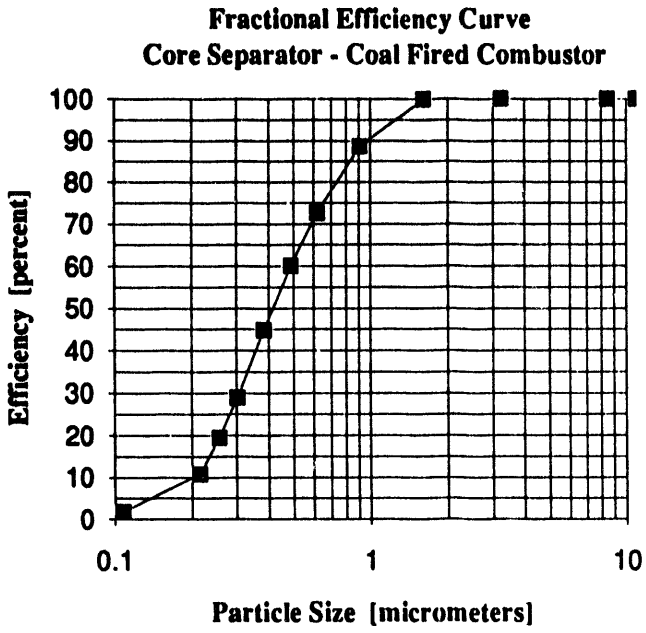
When the collector is situated upstream of the *Core Separator*,

$$E_{sys} = \frac{E_{cyc}}{1 - E_{cs}\left(1 - E_{cyc}\right)}$$

Here E_{CS}, E_{cyc} and E_{sys} relate to the *Core Separator*, collector and *Core Separator* system partial separation efficiencies, respectively.

The *Core Separator* System can actually be arranged in a variety of configurations depending on process conditions, required performance, inlet dust concentration, abrasiveness of solids, etc. A single fan arrangement is the lowest cost design and can be used in most coal-fired boiler applications.

The *Core Separator* has been tested on the effluent stream from a pulverized coal-fired combustor. The site selected for this work was the Pilot Scale Combustor Test Facility owned and operated by the Riley Stoker Corporation, a major U.S. boiler manufacturer. Riley Research performed many tests to evaluate *Core Separator* performance in removing fine particulate matter in the combustor off-gas. A high volatile Eastern Bituminous coal from West Virginia was used to fuel the Combustor Test Facility and generate a typical flue gas condition (ie., 150-200 deg. C). This testing showed that particle retention under controlled test conditions ranged from 95 to 98%. This performance is actually higher than that of some ESP units under similar conditions. The cut point diameter (d_{50}) in these tests was consistently found to be below 0.5 μm, and the particle outlet concentration from the *Core Separator* was in some cases less than 100 mg/M^3. A fractional separation efficiency curve was produced with data taken by Riley Research is shown in Figure 5.



Currently, particulate control devices can be grouped into four(4) different categories: electrostatic precipitators, fabric filters,wet scrubbers, and mechanical collectors. The *Core Separator* is actually an advanced high performance mechanical collector. However, for the sake of comparison, it will be considered as a separate category.

In Table 2, many features used in the purchasing decision for this equipment are compared. The features of the *Core Separator* are highly differentiated from other methods of particulate control as shown in this table. Mechanical collectors are currently used to remove coarse particles (> 10 microns in diameter). They are preferred in this application since they require low capital and operating expenditures. However, mechanical collectors are inefficient in the removal of small particles (< 10 microns), sometimes referred to as "*respirable particulates*".

These particles are typically separated in a final stage by electrostatic precipitators, fabric filters, or in some cases, wet scrubbers. Each of these are high cost devices. As shown in Table 2, the *Core Separator* compares quite favorably against other devices in terms of fine particle performance. Also, it has most other attributes of mechanical collectors, making it highly desirable in dust collection applications.

The *Core Separator* has been under development since 1989. During its research, numerous laboratory and field prototypes were built and tested. As noted earlier, the Riley Stoker Corporation installed a *Core Separator* unit to remove flyash from their PC-fired Combustor Test Facility. Test results conducted by Riley Research showed the particulate removal efficiency of the *Core Separator* to range between 95 and 98% over a series of several controlled tests.

Several *Core Separator* units have also been sold on a commercial basis in the U.S. and abroad. These units range in size from 850 to 11,900 NM^3/h (500 - 7,000 ACFM) and each perform difficult separations, i.e., those removing dust particles with small aerodynamic diameters. The boiler houses in Krakow are of a comparable scale to the *Core Separator* units currently in operation. Therefore, the only significant development issues and technology unknowns are as follows:

(1) Performance with Polish Coals
(2) Performance with Crushed Coal Feed Systems

Through this project and with the assistance of the Department of Energy, six demonstration units will be placed in operation in the City of Krakow during 1994-1995. These units will demonstrate performance of this technology with different Polish coals and firing systems.

Table 2 - Characteristics of Particulate Control Devices

FEATURE	ELECTROSTATIC PRECIPITATORS	FABRIC FILTERS	CYCLONE COLLECTORS	WET SCRUBBERS	CORE SEPARATOR
COLLECTION EFFICIENCY	HIGH	HIGH	LOW	HIGH	HIGH
CAPABILITY FOR HIGH SOLIDS LOADING	NO	NO	YES	NO	YES
PRESSURE DROP	VERY LOW	LOW-MED.	LOW-MED.	MED.-HIGH	LOW-MED.
CAPITAL COST	VERY HIGH	HIGH	LOW	HIGH	LOW-MED.
OPERATING COST	HIGH	HIGH	LOW	MED.-HIGH	LOW
HIGH TEMP./PRESS.CAPABILITY	YES	NO	YES	NO	YES
SPACE REQUIREMENTS	HIGH	HIGH	LOW	MEDIUM	LOW
DIFFICULTY WITH CERTAIN SUBSTANCES	SOME	SOME	NONE	NONE	NONE
EXPLOSION,FIRE,OR VOLTAGE HAZARDS	YES	YES	NO	NO	NO
SPECIAL MAINTENANCE REQUIREMENTS	YES	YES	NO	NO	NO
OZONE PRODUCED	YES	NO	NO	NO	NO
WASTEWATER TREATMENT REQUIRED	NO	NO	NO	YES	NO

Emissions Reduction Potential and Impact on Heating Cost

The City of Krakow has about 1300 boiler houses providing heat for industrial, commercial, and residential use. The boiler houses contain about 2250 boilers, some with no emission controls at all. Many boilers are equipped with cyclone collectors, which remove roughly 80% of the total particulate emissions. High efficiency collectors such as bagfilter units and electrostatic precipitators are practically non-existent due to their high cost and maintenance requirements.

The cost of emission reduction options requires careful analysis, and it is unlikely that any one option is best in all cases. In this section, attention will focus on ways to modernize boiler houses through the addition of particulate control equipment. The choices include:

- Addition of Cyclone Collectors
- Addition of Bagfilter Units
- Addition of *Core Separator* Systems

A cost analysis was performed based on data for particulate control equipment sold in the U.S. Table 3 provides a cost comparison of cyclones, pulse-jet bagfilters, reverse-air bagfilters, and the *Core Separator*. Cost data for the *Core Separator* was based on historical costs, whereas data for cyclones and bagfilters were based on recently completed studies by the Electric Power Research Institute (EPRI). The capacities shown in this table are typical of boiler capacities throughout the City of Krakow.

It is also interesting to compare the cost and respective benefit of each of these alternatives. As shown in Table 4, conventional cyclones provide the lowest cost per ton of pollutant removal. However, this criterion is not normally used in the U.S. or EC nations, since (1) cyclones cannot meet most regulatory standards, and (2) the incremental cost of higher efficiency increases sharply. For this reason, the penetration of the pollutant into the atmosphere is more meaningful. Such a comparison reveals that the *Core Separator* costs a little more than twice that of an equivalent sized cyclone, but allows only about 1/5 of the total penetration of solids to the atmosphere. The *Core Separator* also has the ability to meet future emission standards in Poland, which may not be within reach of cyclones.

The addition of any emission control equipment will involve some parasitic losses which must be factored into the total heating cost. For the *Core Separator*, the draft loss through the system is reflected in the power for the recirculation fan which is ultimately part of the operating cost. It has been demonstrated that the operating cost of the *Core Separator* is less than 1.0% of the boiler thermal input. And, unlike ESPs and fabric filters, maintenance costs are almost non-existent.

The *Core Separator* is very well suited to the LES sources of particulate emissions in Krakow. It is unique in that it has the following attributes:

(1) Cost-effectiveness even at boiler capacities below 500 kw

(2) Efficient in removing respirable (PM_{10}) particles

In recent years, particulate emissions have been the largest component of the air pollution control market, claiming well over 60% of annual expenditures. In addition to the 1300 boiler houses in the City of Krakow, the region also has many other industries requiring fine particle control equipment. The following industries require such equipment:

CombustorFlyash	Hazardous Waste
Smelters	Incineration
Sinter Dusts	Sludge Incineration
Crushers	Waste Heat Boilers
Iron Ore	Saw Dust
Gypsum	Roasting
Fiberglass Dust	Catalyst Recovery
Pulp & Paper	Paints & Pigments
Pharmaceuticals	Coal Preparation
Asphalt Plants	Fertilizer Dusts
Furnaces	Cement Kilns
Solid Waste Recycling	Plastics Processing
Cereal/Grain	Lime/Limestone Dust
Glass Melting	Stone Dusts
Thermal Driers	

Table 3 Total Installed Cost - Particulate Control Devices

Size or Capacity		Device Type			
Gas Flow M3/h	Thermal Input KW	Cyclone $/(M3/h) [$/KW]	Pulse Jet Baghouse $/(M3/h) [$/KW]	Reverse Air Baghouse $/(M3/h) [$/KW]	Core Separator $/(M3/h) [$/KW]
2,000	402	0.99 [4.90]	14.52 [72.16]	22.47 [111.69]	2.47 [12.28]
5,000	1007	0.90 [4.47]	11.69 [58.06]	18.10 [89.86]	2.36 [11.71]
10,000	2,012	0.84 [4.18]	9.93 [49.36]	15.37 [76.39]	2.28 [11.32]
15,000	3,018	0.79 [3.92]	8.43 [41.90]	13.05 [64.85]	2.20 [10.93]
25,000	5,030	0.76 [3.77]	7.66 [38.07]	11.85 [58.91]	2.16 [10.73]

Basis: (1) Boiler Heat Rate 3150 Kcal/KWH

(2) Baghouse Data "Sloat, D.G., et al 1991 EPRI Particulate Control Symposium

(3) Cyclone Data "Vatavuk, W.M., Chemical Engineering, May 1990

(4) Core Separator Data from Historic Costs

Table 4
Cost/Benefit Comparison - Particulate Control Equipment

	Cyclone	*Core Separator*	Baghouse
Overall Collection Efficiency, %	75 - 85	94 - 98	98.0 - 99.9
PM10 Collection Efficiency, % (particles < 10 μm)	20	94	99.5
Cost,$/($M^3$/h)	0.79	2.20	8.43
Cost, $/(Kg/h) solids removal *	54.	126.	464.
Cost,$/(Kg/h) PM10 solids removal **	1353.	803.	2908.

* Based on 0.4 g/M^3 solids loading

** Based on 0.1 g/M^3 PM10 solids loading

Conclusion

The U.S. and Polish Bilateral Steering Committee with the assistance of DOE contractors have identified specific methods to improve air quality and reduce emissions throughout the city. These include:

- Extensions to the district heating system, which could eliminate many small uncontrolled boilers
- Conversion of hand-fired boilers to natural gas
- Elimination of home stoves in selected parts of the city
- Use of improved home stove designs
- Modernization of boiler houses to reduce emissions

This project addresses modernization of boiler houses through the application of new technology recently developed in the U.S. for particulate emissions. The technology is well-suited to the industrial size boilers located in Southern Poland and is capable of removing dust particles below 10 microns in diameter, the so called PM-10 emissions. Its performance is almost as good as ESPs and fabric filters, but without the attendant cost and maintenance. In small boiler applications such as those in Central Europe, it may be the Best Available Control Technology (BACT).

Acknowledgement

The authors would like to thank Mr. Douglas Gyorke for his guidance in preparing this paper and the Department of Energy for supporting this important project.

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MICRONIZED COAL FIRING APPLIED TO PLANTS IN THE CZECH REPUBLIC AND KRAKOW, POLAND

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ABSTRACT

A TCS Micronized Coal-Fired System offers The Czech Republic and Poland a unique opportunity to retrofit its existing industrial, utility and district heating plants and achieve increased combustion efficiencies coupled with reduced air emissions.

Micronized coal is coal ground to a micron-size "talcum powder" consistency; which, because of its extremely fine particle size, has unique characteristics affecting combustion efficiency, reduction of sulfur dioxide and nitrogen oxide air emissions and the potential for producing by-product markets for its resulting ash.

There are numerous and unique micronized coal market applications in The Czech Republic and Poland, including:

* Retrofits to existing coal-fired stoker units, to achieve reduced air emissions and increase boiler efficiency.
* Ability to burn brown coal and brown coal dust with reduced sulfur dioxide emissions.
* Ability to burn black coal on boilers originally designed to burn brown coal.
* Ability to co-fire multiple fuels with micronized coal (e.g., gas, oil, waste oil, wood waste, etc.).
* Application to industrial process heat applications (e.g., kilns, air preheaters, etc.).

This paper describes principals of a TCS micronized coal fired system and, its advantages and applications as they exist for utilization in the Czech Republic and Poland. For orientation, a description is given for three TCS projects, including:

(1). Rochelle, Illinois: Electric utility project that is currently operating.
(2). Krakow, Poland: Heating plant located at the Polish Military Base near Krakow, which is currently being evaluated as part of a cooperative agreement with the U.S. Department of Energy's "Krakow Clean Fossil Fuels and Energy Efficiency Program".
(3). Dvur Kralove, Czech Republic: District heating-cogeneration plant being financed by The Czech Ministry of Industry.

The paper will describe fundamental advantages of micronized coal firing as they relate to the technical, financial and regulatory criteria evaluated by Rochelle in its decision to implement its project. The paper will also outline important emission control retrofit considerations of the Rochelle project which should be considered by other utility and industrial boiler owners in the Czech Republic. Emphasis will be placed on lessons learned at Rochelle that could be considered for decisionmaking criteria in The Czech Republic and Poland, including fuel utilization such as: (a). brown coal, (b). brown coal dust, (c). black coal, and (d). co-firing with natural gas, oil, and waste oils.

UNIQUE ADVANTAGES OF MICRONIZED COAL FIRING

Micronized coal is defined as coal ground to micron size "talcum powder" consistency yielding a size distribution with an average particle diameter of about 17 to 20 microns, or about one-half the diameter of a human hair. Because of its extremely fine particle size, micronized coal has unique characteristics affecting combustion efficiency, air emission criteria and potential by-product markets for ash, including: 1). flame and heat release characteristics similar to oil, 2). reduced sulfur dioxide air emissions, resulting from co-micronization of coal with limestone, 3). lower nitrogen oxide air emissions, and 4). superior by-product market potential in the cement and asphalt manufacturing industry, as compared to other coal combustion processes.

HIGH EFFICIENCY COMBUSTION CHARACTERISTICS SIMILAR TO OIL

Coal reactivity, although a function of coal rank, volatile content, hydrogen, oxygen and pyrolysis plasticity, is also a function of total surface area of the fuel to be fired. For the same unit weight of coal, micronized coal has about three times the surface area of conventional pulverized coal and about 5.5 times as many particles.

This size differential for micronized coal results in numerous combustion advantages, when compared to a conventional pulverized coal-fired flame, including:

(1). Ignites at a lower temperature, and completes combustion sooner.
(2). Amount of surrounding air required for combustion is decreased (i.e., lower excess air); thus, increasing combustion efficiency.
(3). Produces a shorter and more intense flame; thus, better than doubling combustion intensity (e.g., flame length is reduced about 60 percent).
(4). Volatiles are released at a more uniform rate over the combustion temperature range.
(5). Radiation heat flux and overall amount of heat absorbed by furnace load is considerably higher.
(6). Slag and ash deposition rate on convective tube passes is significantly reduced.

Essentially, these results indicate that micronized coal has similar combustion characteristics and flame size as compared to oil. Because of

these unique combustion characteristics, micronized coal can and has been successfully and commercially fired in packaged gas/oil boilers, in addition to conventional coal fired units.

SULFUR DIOXIDE AIR EMISSION REDUCTION

TCS holds the only U.S. Patent involving the process of burning co-micronized limestone and coal. Co-micronized coal and limestone results in significant sulfur dioxide air emission reductions during combustion caused synergistically by:

(1). Lower flame temperatures which are close to the optimum sulfur-calcium reaction temperature spectrum.
(2). Intimate mixing and contact between coal and limestone particles.
(3). Accelerated calcination and sulfation reactions resulting from the small particle size distribution of coal and limestone.

Limestones are like "fingerprints", there are no two exactly alike. Composition of limestones vary considerable, depending on their geologic formation and chemical and physical characteristics. These variances affect the ability of a limestone to act as a effective sulfur sorbent.

Calcium is the primary chemical component in limestones which reacts with the coal's sulfur during combustion. However, the percent chemical content of calcium in a limestone does not necessarily mean that it is a good sorbent. Other primary factors that appear to affect a sorbent's performance ability include: particle size, grain structure, porosity, and magnesium content. For example, tests sponsored by TCS and numerous other organizations, show that samples of two different limestones, both having the same calcium content, can produce vastly different results as sulfur sorbents; wherein, one might be excellent while the other terrible.

Reasons why these variations in sorbent efficacy exist is not clearly understood by the research community, at least to the point that a clearly understood physical or chemical test indicator can predict a limestone's performance efficiency. The only sure way to determine how a limestone will perform as a sulfur sorbent is to conduct a test burn.

Generally, sulfur capture results realized by a TCS system co-micronizing limestone and coal, having acceptable calcium-sulfur molar ratios, range from about 40 to 70 percent capture, depending on the limestone performance characteristics.

NITROGEN OXIDE EMISSION REDUCTION

In addition to lower sulfur dioxide emissions with a TCS system, it is also possible to realize lower nitrogen oxide air emissions due to several reasons, including:

(1). Generally lower flame temperature due to small particle sizing.
(2). Lower excess air.

(3). Staged combustion achieved through proprietary TCS Low-NOx burner.
(4). When co-micronizing coal and limestone, the limestone acts as a flame temperature retardant; thus, contributing to a lowered nitrogen oxide emission, in addition to sulfur reduction.

Although the aforementioned factors assist in reducing nitrogen oxide emissions, without testing, it is impossible to precisely predict NOx emission rates in a new or retrofit application, since they are affected by many project specific criteria, including: nitrogen content in coal, combustion air temperature, furnace chamber size and configuration, and other factors.

Based on micronized coal firing tests conducted by TCS and other independent organizations, nitrogen oxide emission rates appear to range between 0.3 lb/MMbtu (370 mg/Nm^3) and 0.5 lb/MMBtu (620 mg/Nm^3).

MICRONIZED COAL ASH BY-PRODUCT MARKET POTENTIAL

It appears that micronized coal ash is a highly attractive recyclable material with by-product market value as a cement feedstock that is superior to conventional pulverized coal flyash. Micronized coal ash has all the advantageous chemical and physical properties of conventional flyash while improving on two very important factors: particle fineness and low carbon content. It is a cementitious and pozzolanic material (i.e., hardens in the presence of calcium and water - a requirement for cement feedstock); likewise, its particle size distribution is about half that of conventional fly ash. Fine particles increase the compressive strength of concrete structures and asphalt pavement. Thus, micronized coal should be usable for super-strength concrete; thus, commanding a premium by-product price.

TCS MICRONIZED COAL COMBUSTION SYSTEM

TAS COAL (TM) was established as a business organization in 1980. In 1988, TCS, Inc. acquired the worldwide patent rights to the technology and in the same year formulated a joint-marketing relationship with Babcock & Wilcox directed toward the U.S. industrial and utility boiler market.

* Since 1980, about one-hundred (100) TCS micronized coal mills have been successfully marketed, manufactured and installed in the United States, Canada, Europe, South America, and Israel. Commercially installed applications include industrial boiler retrofits, industrial process heaters, kilns and other applications.

The TCS micronization mill is a proprietary patented single-pass attrition mill in which regular coal is introduced into the top of a vertical cylindrical vessel equipped with rotating discs and impact blocks, which progressively reduces coal particle sizing down to micron consistency; whereupon, it is entrained in an exiting air flow and conveyed directly to a burner (Figure 1).

The TCS Low NOx burner is a proprietary multi-channel burner capable of a highly controlled staged combustion air flow which forms a "cool" flame envelope and regulates flame size and shape. Limestone acts as a flame temperature retardant; therefore, concurrent with micron particle sizing, when coal and limestone are co-micronized, a relatively "cool" flame results that promotes SOx capture and reinforces a significant staged combustion profile to reduce NOx formation.

ROCHELLE MUNICIPAL PLANT PROJECT

Rochelle's Utility Plant has been operating since the early-1960's and was originally designed to burn coal on stoker-grate units. The facility was converted to natural gas-only firing in the late-1980's as an interim measure until engineering, financing and permitting could be completed for a retrofit system to again burn coal.

During mid-1991, the City contracted with TCS to began installing micronized coal mills and Low-NOx burners, coal and limestone storage handling, baghouses, and required ancillary equipment to:

1). Reduce operating costs.
2). Achieve improved combustion efficiency.
3). Demonstrate 50 percent reduction of sulfur dioxide gas emissions by co-micronizing high sulfur Illinois coal with various Illinois limestones. Likewise, an SOx reduction option exists by co-firing coal and gas.
4). Reduce nitrogen dioxide gas emissions by use of low-NOx burners utilizing staged combustion and the relative "cool" flame temperature of micronized coal.
5). Achieve higher degree of load following control, as compared to original stoker system.
6). Assess the potential by-product market value of micronized coal ash in the cement and asphalt manufacturing industry.

Figure 2 presents a conceptual plan of the project.

The $17.5 million construction, plus two year demonstration program, will be funded through a combination of financing sources, including: a). City of Rochelle bonding and contributions, b). State of Illinois Clean Coal grant, and c). contributions from Peabody Coal Company and TCS, Inc.

Factors which the City of Rochelle considered in its decisionmaking process were multi-faceted and primarily included: 1). desire to preserve coal permit, 2). incorporate dual fuel capability, 3). eliminate stoker firing and its attendant high maintenance costs, 4). improve boiler efficiency, and 5). generate sulfur dioxide credits which potentially could provide benefits to the City by "opting in" for SOx allowances in response to the Clean Air Act Amendments of 1990.

The Rochelle Project is currently in a start-up and testing mode.

KRAKOW CLEAN FOSSIL FUELS AND ENERGY EFFICIENCY PROGRAM

The project proposes to retrofit the Balice Boilerhouse with a TCS Coal Micronization System and Amerex baghouses to achieve higher combustion efficiencies and lower air emissions, including SO2, NOx, CO and particulate matter. The Balice Boilerhouse is located adjacent to the Krakow Airport and provides heating steam for the Polish Military Unit No. 1616, which is based in the vicinity of the airport.

Project participants include:

* Polish Military Unit No. 1616; Krakow, Poland
* OPAM; Katowice, Poland
* U.S. Department of Energy
* TCS, Inc., Oakland, Maryland; USA
* Amerex, Inc.; Woodstock, Georgia; USA

The Balice Boilerhouse currently burns a Polish Fine Coal Type 31.2 coal (e.g., 21-22 MJ/kg, 15% ash, 0.6-0.8% S, 25% M.C.) on four (4) travelling grate boilers, which include three (3) SWC-900 and (1) SWC-600 Polish manufactured boilers.

Generally, the equipment necessary for the retrofit include: modification to existing coal handling system, TCS micronized coal mills, TCS Low-NOx burners, Amerex baghouse(s), new limestone storage silo and handling system, new ash storage silo and handling system, new I.D. fans, either new or modified F.D. fans, and other minor ancillary equipment and modifications.

The objective of the project will be to retrofit the existing Balice boilers to: (a). increase boiler efficiency due to the aforementioned advantages of micronized coal combustion, (b). achieve up to 50 percent SOx reduction, or more, through the co-micronization of coal and limestone, (c). reduce particulate emissions through the utilization of Amerex baghouses, (d). reduce NOx emissions through the use of TCS Low-NOx burners, and (e). reduce carbon monoxide (CO) through more complete combustion which is achievable with micronized coal.

Phase I engineering evaluation began in mid-March 1994, and will include:

* Identification, assessment and combustion testing of Polish coal(s) and limestone(s).
* Engineering assessment and design of retrofit options to existing and possibly new boilers.
* Environmental and health safety considerations.
* Cost and operating considerations.

It is anticipated that a preliminary report will be available by September 1994 to meet the Polish Military's fiscal year budgetary schedule. Final report will be available in late-1994.

DISTRICT HEATING-COGENERATION PLANT - DVUR KRALOVE, CZECH REPUBLIC

The district heating plant in Dvur Kralove provides electricity and heat to the City. The plant, owned by CEZ (Czech Power Company), burns a locally available brown coal and currently experiences excessive sulfur dioxide air emissions. As an attempted sulfur emission reduction program, Dvur Kralove personnel test-burned a higher energy content-low sulfur black coal available from Ostrava, Czech Republic.

Results of the Ostrava coal test burns were not satisfactory due to unacceptable combustion performance resulting from a mismatched grate size and configuration which was originally designed for lower energy-content brown coals. The project will entail the retrofit of a TCS micronized coal fired system to the existing boiler to allow multiple-fuel capability, including: (a). black coal from Ostrava, (b). co-micronized brown coal and limestone, (c). brown coal dust from existing processing plants, (d). possibly other fuels.

The project is being financed by the Czech Ministry of Industry in cooperation with CEZ. Project participants include:

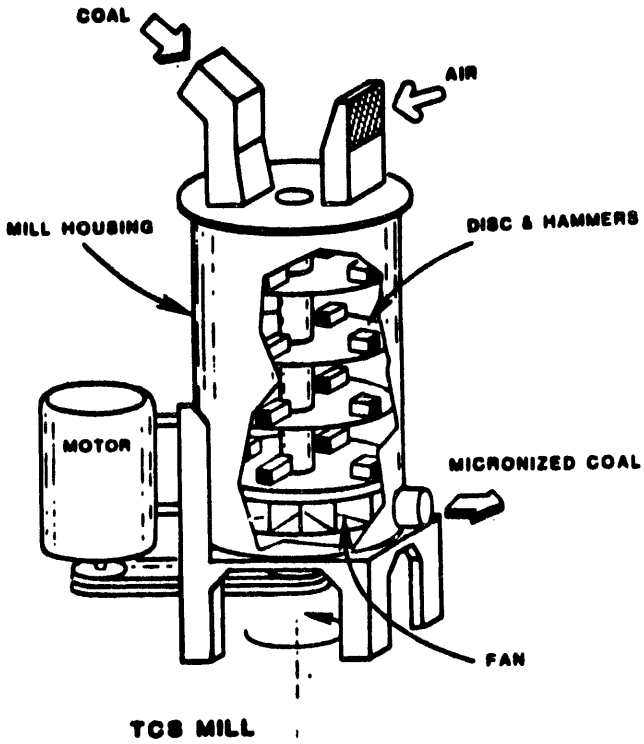
* Czech Ministry of Industry
* Dvur Kralove District Heating Plant (CEZ).
* ENVEN, Ltd.; Milevsko, Czech Republic.
* TCS, Inc.; Oakland, Maryland; USA.

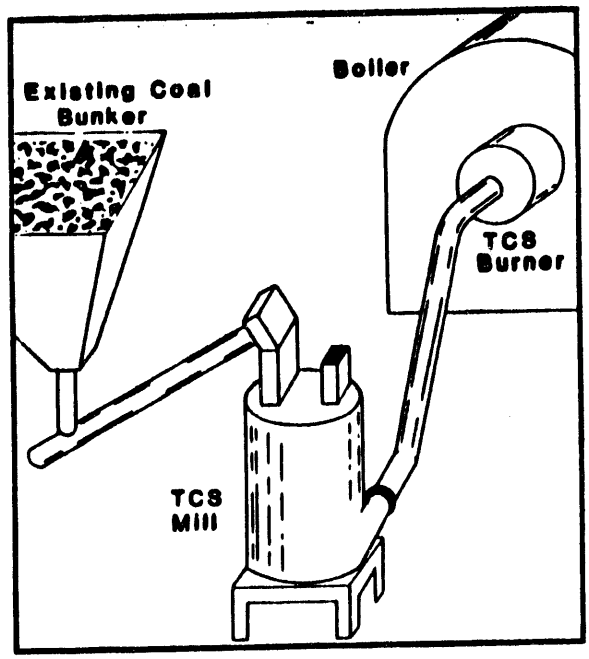
SUMMARY

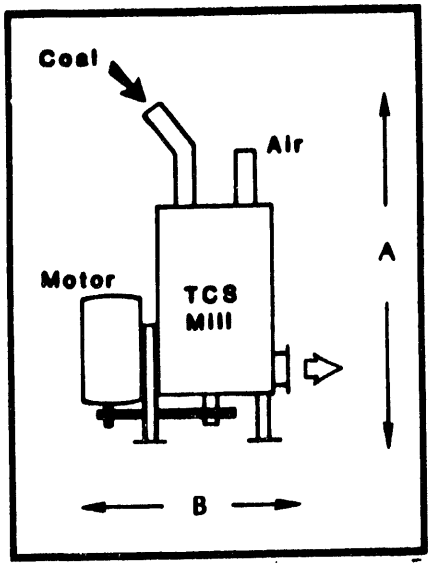
Micronized coal has combustion characteristics similar to oil, burns more efficiently than other coal options, can be co-micronized with limestone to reduce sulfur dioxide emissions, can reduce nitrogen oxide formation due to an inherently "cooler" flame and staged combustion. Since 1980, close to one-hundred TCS micronized coal mills have been commercially installed in the United States and overseas in conjunction with utility and industrial boiler retrofits, industrial process heaters, kilns and other applications.

There are numerous and unique TCS micronized coal market applications in The Czech Republic and Poland, including:

* Retrofits to existing coal-fired stoker units, to achieve reduced air emissions and increase boiler efficiency.
* Ability to burn brown coal and brown coal dust with reduced sulfur dioxide emissions.
* Ability to burn black coal on boilers originally designed to burn brown coal.
* Ability to co-fire multiple fuels with micronized coal (e.g., gas, oil, waste oil, wood waste, etc.).
* Application to industrial process heat applications (e.g., kilns, air preheaters, etc.).



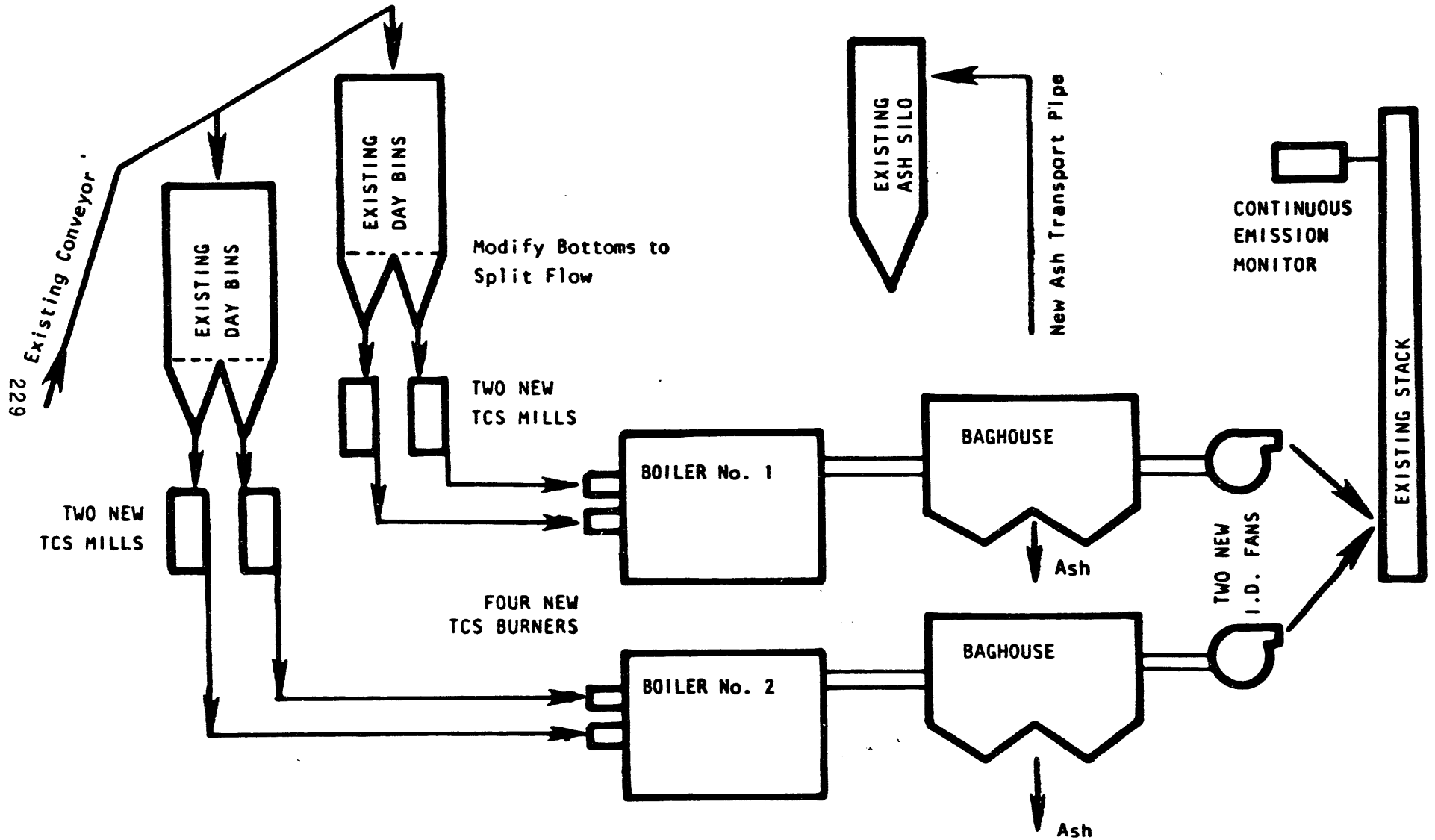




MILL SIZE	A	B	MOTOR HP.	RATING (MMBtu/hr)
24"	7'-6"	4'-3"	30	5 to 15
26"	7'-6"	4'-5"	40	15 to 35
28"	7'-9"	4'-8"	75	35 to 50
32"	7'-9"	5'-4"	125	50 to 80
38"	9'-8"	5'-11"	200	80 to 100
42"	10'-9"	6'-9"	300	100 to 150

Figure 1: TCS MICRONIZED COAL SYSTEM

Figure 2: **ROCHELLE MUNICIPAL UTILITIES**
TCS Micronized Coal Retrofit Conceptual Plan
Boiler Building



Application of American Stoker Coal Preparation and Combustion Practice to Solving Eastern European Emissions Problems

Peter L. Rozelle

1. Introduction

At many locations in Eastern Europe, there are air quality problems that can have undesirable effects on human health, property, and the appearance of a city. Contributory to this poor air quality are vehicle emissions, emissions from industrial activities such as power generation and metals production, and emissions from space heating activities. These space heating activities include home heating,municipal district heating systems, and small commercial heating activities. Collectively, these space heating activities are referred to as "low stack sources", as these heating systems frequently employ short stacks and discharge their products of combustion close to the ground. When these systems are fired with coal, the potential exists for significant amounts of sulfur dioxide, hydrocarbon, and particulate emissions to be emitted directly into areas of significant human activity. This effect can combine with meteorological and topographical conditions to produce serious low level pollution problems, affecting human health and the quality of life in the vicinity. Reduction of these low stack emissions from coal fired sources is central in any plan to improve the air quality at a given location.

In embarking on a pollution abatement program, experience by other cities in elimination of air quality problems can be of valuable assistance. Many cities in the United States have eliminated serious air pollution problems through judicious use of technology and the enactment of laws designed to prevent practice that can cause emissions. These laws, often referred to as "smoke ordinances", have regulated allowable fuel quality and firing practice, established legal guidelines for boiler operation, provided for monetary fines for offending parties, and made it legal to terminate operations of repeat offenders.

As a result of smoke reduction measures, technology, both in fuel and in firing practice, has been improved in the U.S. Small coal fired boilers using stoker firing can be operated in full compliance with American air quality regulations.

The United States Department of Energy (DOE) has embarked on a pilot program to demonstrate the lowering of emissions from low stack sources in Eastern Europe using American technologies and practices. The location of this

program is the city of Krakow. EFH Coal Company, located in Pennsylvania, has begun a pilot project as part of the DOE program, with the participation of Polish firms. The focus of the program is the reduction of emissions from stoker fired boilers. In the United States, high volatile bituminous coal can be fired in stoker combustion systems while maintaining compliance with American air quality standards. The objective of the EFH Coal Company is to use a combination of American stoker coal preparation and combustion practice to produce reductions in emissions from stoker fired systems in the Krakow area. A second objective is to form a corporation with Polish partners to market similar emissions reduction activities elsewhere in Eastern Europe.

Of particular interest are reductions in sulfur dioxide and hydrocarbon emissions from low stack sources, which can impact human health.

2. American Experience

Coal is a major fuel in the United States which consumes about 900 million short tons annually. During the first half of the twentieth century, many cities in the United States had serious air quality problems. Among these cities were Chicago, Pittsburgh, and St. Louis. In addition to obvious health problems, in 1937, annual property damage in Chicago due to air pollution was $43 million (1). This figure in 1957 was estimated at $4 billion for the entire United States (2).

These considerations led to the development of citizens movements to improve air quality. In addition to low stack sources, other identified pollution sources included railroads, steamships, and metallurgical facilities. In St. Louis, it was often the case that coal with 20 - 25 wt% ash was used for heating, with sulfur contents as high as 7 wt%(3). A smoke ordinance was passed in 1937 that included requirements for boiler operations, maximum emissions limits, and specifying the use of washed coal. There were also quality limits applied to fuel for home heating.

The results of this program included a visible improvement in air quality in a relatively short period of time. Smoke density readings were applied to industrial and commercial coal burning installations. Within 16 months of the enactment of the legislation, the average stack smoke density measured at coal burning installations in the city dropped from 13% to 0.9%(3).

The key components of American experience in low stack emissions reductions applied to the EFH Coal Company project in Krakow include the furnishing of coal meeting American stoker coal specifications and the development of expertise in Poland of firing these fuels to minimize emissions.

3. Fundamentals of Fixed Bed Coal Combustion and Emissions Evolution

The EFH Coal Company project concerns the fuel practice of traveling grate stoker fired heating systems in the Krakow region. The practice of firing bituminous

coal for minimal emissions in the United States, on travelling grates, is relatively well established. Simultaneously with minimized emissions, maximum fuel efficiency is stressed to minimize steam raising costs. As the release of pollutants such as carbon monoxide and hydrocarbons represents efficiency losses, economic and environmental benefits can be coexistent in the Krakow region. In order to understand the rationale for the use of washed, double screened coal for emissions reductions a brief examination of fixed bed combustion is in order.

3.1 Fixed Bed Combustion

Combustion of coal on a traveling grate stoker features coal being fed horizontally to the system, with primary combustion air introduced through the grate. As such, the system is considered to employ crossfeed combustion. A detailed discussion of fixed bed combustion principles is outside the scope of this paper, however many references can be found that discuss these principles. Included are works by Kreisinger(4), Nicholls(5), and Carman et al (6).

The traveling grate stoker system regulates the rate of fuel feed through controlling fuel bed height, typically with a gate mechanism, and grate speed. These in turn control the volume of fuel that is fed per unit time. For a given combustion rate, a fuel that has a higher combustible content will require a lower volumetric feed rate.

As a batch of fuel enters the furnace, ignition occurs at the top of the bed, with combustion air and gases traveling vertically through the bed from the grate. As heat is transferred from burning particles in the bed, the plane of ignition travels downward in the opposite direction of the air flow. Volatile matter is released near the ignition plane and travels with combustion gases. The rate of volatile matter combustion in the fuel bed is influenced by the concentration of oxygen in the gases above the ignition plane.

When the plane of ignition travel reaches the grate, combustion is completed in the bed from the grate upward, as fuel in the lower sections of the bed encounters higher oxygen concentrations in the combustion gases. The progress of ignition travel and combustion in a section of fuel on a traveling grate is shown in figure 1.

Tests of bituminous coals in fixed bed combustion have shown that smoke evolution and bed pressure drop are at a maximum during the travel of the ignition plane to the grate (6,7).

3.2 Evolution and Control of Pollutants in Fixed Bed Combustion

One goal of the program discussed here is the demonstration of emissions reductions from traveling grate firing systems. Emissions of interest are:

1. Hydrocarbons
2. Carbon Monoxide
3. Sulfur Dioxide
4. Particulates

Following is a discussion of

the generation and control of these emissions.

Hydrocarbon evolution from bituminous coal fired traveling grates is largely due to the evolution of volatile matter from the fuel bed and its degree of combustion in the furnace. Volatiles that are evolved from the fuel bed require high furnace temperatures, turbulence, the availability of oxygen, and a given residence time for complete combustion. As the combustion gases pass from the furnace they encounter relatively cool heat exchange surfaces and combustion is quenched. Hydrocarbon evolution from the stack is influenced by the degree of volatiles combustion prior to the gases contacting heat exchange surfaces(8,9).

As volatiles are typically released as the ignition plane travels to the grate, volatile evolution typically occurs toward the front of the furnace(9,10). Methods to ensure volatiles combustion include the introduction of overfire air at the front of the furnace, as well as the optimization of furnace geometry to ensure mixing of volatiles with oxidizing gases evolving from the rear of the furnace.

Where fuel bed pressure drop is relatively high as encountered using unwashed, unsized coal, channels or blowholes can develop at locations in the fuel bed. This will cause a reduction of oxygen availability above some zones of the grate, and this can reduce volatiles combustion, increasing hydrocarbon emissions. The use of washed, double screened coal can minimize this effect by minimizing fuel bed height per unit firing requirement, as well as minimizing fuel bed resistance to gas flow.

Carbon Monoxide can be produced in a traveling grate fired furnace by incomplete combustion of carbon in the fuel, as well as by reaction of CO_2 with carbon in deep fuel beds(7). The second consideration may be countered by minimizing bed height. Coal with increased combustibles content will require a smaller volumetric input per unit firing requirement, which can dictate smaller bed heights. Washing coal will increase its combustibles content.

Sulfur dioxide evolution is affected by fuel calorific value and sulfur content. Combustion of fuelbound sulfur and the release of SO_2 from the fuel bed result in SO_2 emissions. Washing of coal can reduce SO_2 evolution by reducing fuel sulfur content per unit of calorific value.

Particulate emissions from traveling grate stokers can include fine fuel particles entrained from the fuel bed, fine ash particles entrained from the fuel bed, and soot from volatiles combustion(1). The use of double screened coal can minimize the entrainment of fuel from the grate, While reducing the ash content (washing) will reduce the ash produced per unit firing capacity, reducing the potential for evolution of fine ash particles.

4. Fuel Quality Effects on Combustion Performance

4.1 American Experience

American practice for

firing bituminous coal on traveling grate stokers can furnish heat release rates in excess of 400,000 BTU/ft²-hr(11). Coal quality can affect the rate of ignition plane travel, maximum combustion rates, and the influence of grate air rates on combustion performance.

Carman et al (6) extensively studied the effect of fuel quality on fixed bed combustion performance for fuels ranging from Lignite to Anthracite. For high volatile bituminous coals, particle size was found to have a profound effect on combustion performance. Combustion rates, ignition rates, and ignition plane travel rates were found to be lower for 1 1/2 x 0 unsized fuels than for double screened fuels. Ignition and combustion rates typically increased with increasing grate air rates for double screened products. At higher grate air rates ignition rates decreased for unsized (1 1/2"x 0) fuels, and in the case of high volatile B coal from Illinois, the fuel bed became unstable at higher air rates. Fuel ash percentage was also found to have a significant influence on combustion performance. Double screened fuel with 10% ash exhibited a 25% higher rate of combustibles ignition as compared to a similarly sized 25% ash fuel. The maximum combustion rate for the 10% ash fuel was over 20% higher than that of the 25% ash fuel.

Recommendations for optimizing the combustion of bituminous coal have included burning the coal as rapidly as possible after ignition, and minimizing excess air convective losses.(9). As such, maximizing combustion rates for a given grate airflow rate is desirable.

A modified version of the fixed bed combustion apparatus used by Carman et al is to be used in the present work to optimize fuel quality and combustion parameters and assist in preparation plant implementation.

4.2 Polish Experience

In order to establish baseline data for emissions from traveling grate stokers in the Krakow area, a study of emissions from a Krakow boiler was released in 1992 (12). This test program featured a WR-10-011 boiler fitted with a traveling grate stoker for firing Silesian bituminous coal.

The stoker features an 8.2 ft. width and a 19 ft. length. The system can vary both bed heights and grate speeds. The forced draft fan supplying grate air can supply 10600 CFM with a 3.2" H_2O pressure.

Fuels tested in this report included two high ash products (>20% ash) and a washed product with 9% ash. The high ash products contained 38 and 45% of -3mm material, while the washed product was somewhat finer, with 56% finer than 3 mm. In American practice, it has been recommended that the presence of particles finer than 1/4" be minimized or eliminated for optimum performance (9). As such, these fuel size distributions may not be ideal.

In American practice, it is recommended that fuel bed heights be kept constant, and that fuel bed heights be kept constant, and that grate speeds be varied to follow load (12). The practice for the Krakow

boiler is to maintain a constant grate speed and vary the bed height to follow load (13). This practice can complicate fuel bed airflow distribution and compound emissions problems.

Grate speeds were either 26 ft/hr or 36 ft/hr. Fuel bed heights ranged from 2.4 to 5.4 inches. With the forced draft fan operating at its maximum setting, combustion rates ranged from 10 to 18 lbs combustible/ft^2-hr. Data from Carman et al (6) suggest that the forced draft fan capacity (310 lb/ft^2-hr) was capable of burning over 30 lb combustible/ft^2-hr of a low ash high volatile A bituminous coal. These data suggest that fuel quality may suppress combustion rates when firing the coals tested in the Polish report.

The program discussed here will furnish washed, double screened Polish coal for similar boiler testing, with special attention paid to optimizing combustion rates, volatiles combustion, fuel bed heights, and grate speeds. Also included is the placement of Polish personnel at American stoker boiler plants to observe firing and emissions monitoring practices. The objective is to bring stoker emissions rates in line with all applicable and future regulations in Poland.

5. Commercial Aspects of Program

Included in this program is the development, construction, and operation of a preparation plant to produce washed 20 mm x 3 mm stoker coal. It is recognized that the state of many aspects of Polish coal preparation practice is advanced as any in the world. However, the financial state of the Polish coal industry has left many preparation operations without sufficient capacity to wash coal in this particle size range (13,14). This may in part explain the widespread use of high ash coal in the Polish steam raising sector.

In the American coal industry, competition is intense, and the objective is to produce a consistent quality product for the lowest possible price. For production of American stoker coal, this typically entails production of stoker coal simultaneously with unsized washed coal for pulverized coal firing. In addition to these considerations, the program in Krakow must:

1. Minimize preparation refuse production
2. Pay special attention to water quality and its impact on plant availability
3. Minimize water requirements and operate a closed water system.

In order to minimize refuse production, the highest possible yield must be attained for a given product quality. This has dictated the choice of dense medium cyclones for separation vessels, over higher probable error machines such as jigs.

This is a pilot program designed to demonstrate a strategy for low stack emissions reductions in Eastern Europe using American technology. In addition to this demonstration, the following are anticipated:

1. The establishment of a Polish/American enterprise to furnish similar emissions reductions elsewhere in Eastern Europe.

2. The large scale reduction of emissions from low stack sources in the Krakow region fired with traveling grates.

3. The increased availability of washed steam coal for Polish utilities.

4. The creation of private sector jobs in the Krakow region.

5. The reduction of truck traffic in the Krakow region.

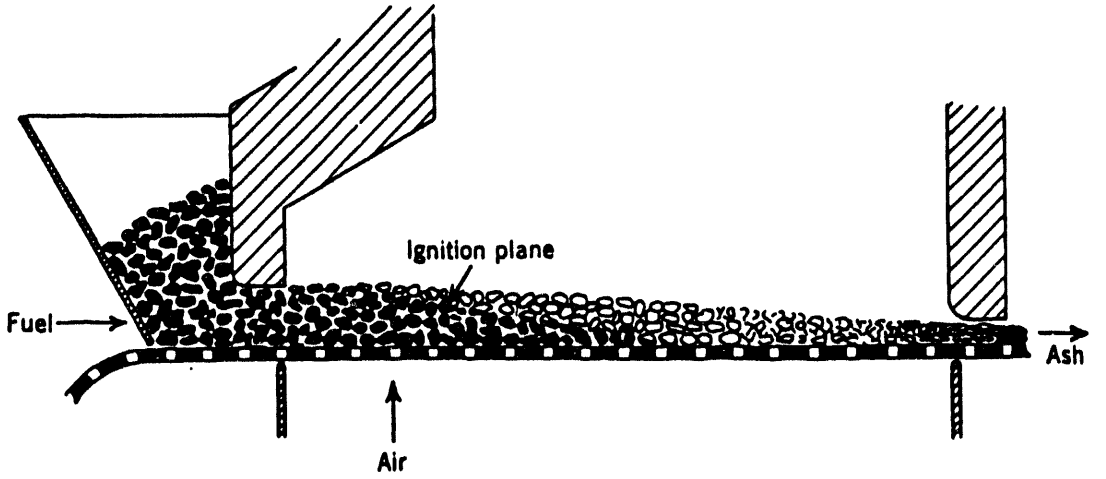


FIGURE 1.—Diagrammatic Representation of Fuel Bed on Traveling-Grate Stoker.

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CLEAN BURNING BRIQUETTES FOR POLLUTION CONTROL FROM LOW EMISSION SOURCES

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INTRODUCTION

Acurex Environmental Corporation has been awarded a Cooperative Agreement with the U.S. Department of Energy (DOE) to apply the technology of manufacturing and selling coal briquettes to reduce pollution from coal-fired low emission sources (LES) in Kraków, Poland. Acurex Environmental has built a multimember U.S./Polish team to ensure the technical and commercial success of the project. As a result of DOE- and U.S. Agency for International Development (AID)-sponsored activities, a new U.S./Polish company will be formed. The company will be capable of securing at least 50 percent of the LES coal market in Kraków. The briquettes will be manufactured according to a proprietary concept and will produce approximately 70 percent less pollutant emissions upon combustion than coal, thus dramatically reducing pollution from LES in Kraków.

Mass production of briquettes for the LES coal market in Kraków will be preceded by the exploration of market strategies applicable there, gathering business information necessary to form a new company, preparation of a detailed business plan, and collecting technical performance data on the briquette under Polish conditions.

TECHNICAL BACKGROUND

The Acurex Environmental briquette (Acurex briquette) is prepared by a low cost process from washed coal fines and a proprietary binder. This binder is unique in that it has an active role in reducing emissions during combustion. Compared with coal firing, combustion tests with these briquettes show a 70 percent reduction in particulate emissions and a 75 percent reduction in total hydrocarbon emissions. These numbers have been corrected for the binder's dilution effect and are based upon run-of-the-mill (ROM), rather than beneficiated, coal fines.

Manufacturing Process

Figure 1 presents the Acurex briquette manufacturing process as planned for the Kraków project. ROM fines will be graded and reduced in size prior to the washing process. The beneficiated coal fines will be mixed with the binder material and the homogeneous mixture will be pressed or extruded.

Water will be removed in low temperature ovens. For economic reasons, the washing stage will be a simple, water based process using proven technology, such as wet concentrating tables. Separation will be based upon density so that the final product will have a higher heating value, lower ash content, and lower pyritic sulfur content. Khoury[1] describes wet concentrating tables as a "Level 3" beneficiated process and presents data in which heating value improves by 18 percent, ash content is reduced by 52 percent and sulfur content by 45 percent. In addition, soluble impurities will also be removed from coal fires.

Emissions Data

Some of the results of original work by Acurex Environmental are presented in Figure 2 and Table 1. During this work, Tenax resin sorbent, XAD-2 resin sorbent, and filter samples were used to collect volatile, semi-volatile, and non-volatile organic material, respectively. Tenax samples were analyzed by thermal desorption GC/FID. XAD-2 and filter samples were

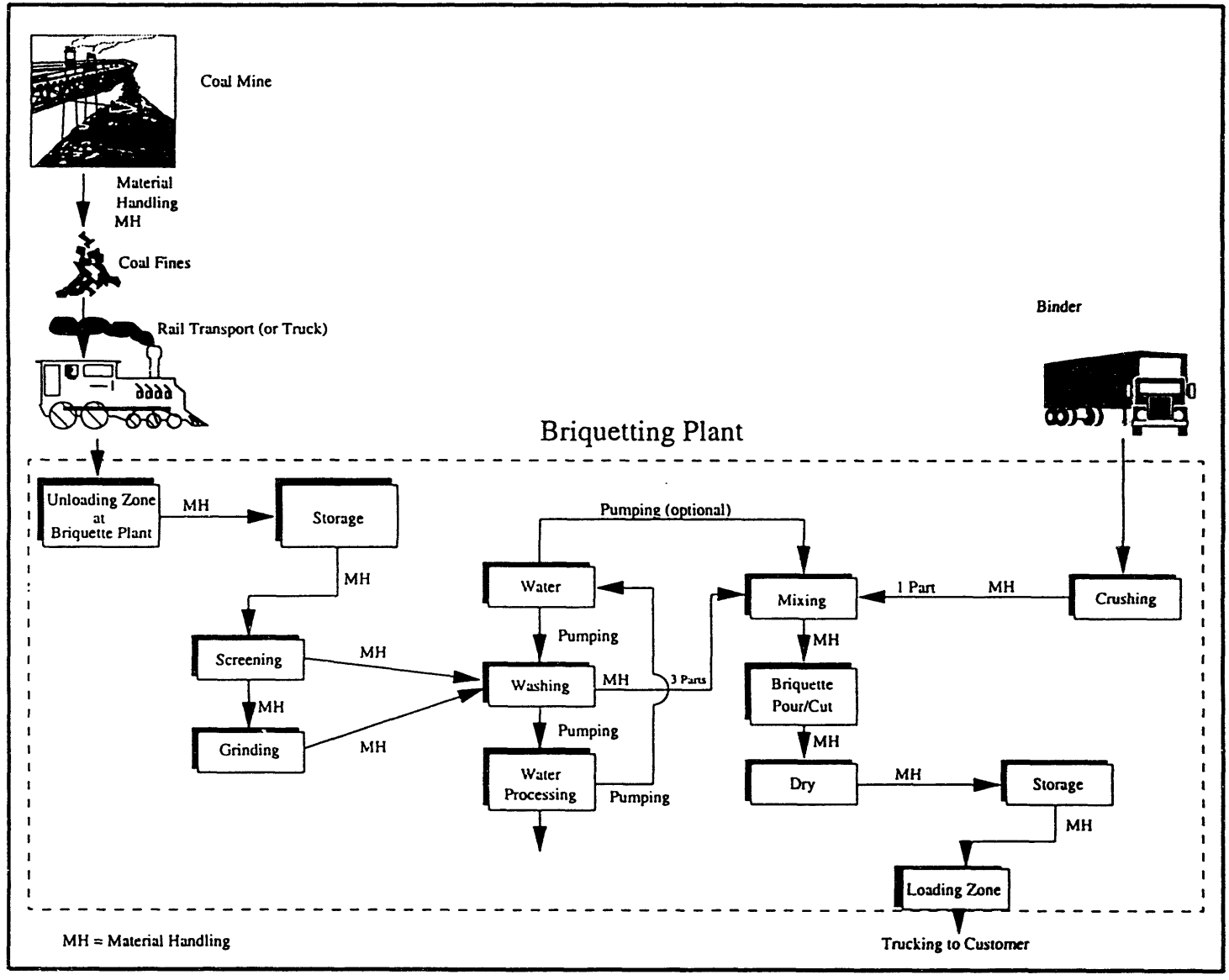

Figure 1. Acurex Environmental Corporation briquette manufacturing process.

extracted with dichloromethane. These extracts were analyzed by GC/FID for total chromatographable organics (TCO) and by gravimetric techniques (GRAV) for non-volatile components. TCO represents those organic compounds with boiling points between 98 and 300 °C while GRAV represents those compounds with boiling points greater than 300 °C. Table 1 presents the filter capture data. In this table, percent dry particulate represents the non-extractable filter capture material as a fraction of the total capture. In Figure 2 the area of the total pie presents the total organic concentration while the distribution by compound volatility is presented by the slices.

TABLE 1. DRY PARTICULATE DATA

Coal	Average Filter Capture (mg/m^3)	Percent Dry Particulate
Coal 1	37.4	26.9
Coal 2	26.7	5.2
Coal 3	17.4	4.6
Briquette	17.8	45.3

As Figure 2 shows, the three chunk coal-only burns were fairly consistent in terms of the total organic concentration and the distribution between volatile, semi-volatile, and non-volatile organics. The briquetted coal emitted a fraction of ordinary coal combustion on a concentration basis. More significantly, the distribution was shifted from a majority of non-volatile material to mostly volatile material. In line with these results was the high percentage of dry particulate in the filter capture from the briquette burn. The data for briquetted coal represents a fourth coal which was only available as fines. Examination of this data did suggest that the binder had an active role in pollution reduction.

A separate study was performed using coal 2 in both a chunk and briquetted form. Replicate burns were performed with the two fuels. While Tenax and XAD-2 samples were not collected, filter samples and reactive gas continuous emission monitor data were. Continuous load cell and thermocouple data were collected and used to calculate the heat content of the two fuels. Nitrous oxide was measured by an automated GC with gas loop sampling. Figure 3 presents normalized data of Lutes[2]. The data has been normalized such that 100 equals the mean chunk coal result and each bar represents one standard deviation about the mean for the replicate burns. THC stands for total hydrocarbons, TSP stands for total solid particulate, and BaP stands for benzo(a)pyrene. These results are very much in keeping with the previous study in that the mean briquette organic and particulate (THC, GRAV, BaP, TCO and TSP) are 30 percent or less of the chunk coal result. Heat content, carbon monoxide, and carbon dioxide are not statistically differentiable though, taken together, there is a suggestion that the briquette combustion is slightly more efficient.

The mechanism by which this binder reduces pollution is not known in detail. One possible mechanism is that a cracking process takes place before the gasified coal enters the combustion zone. Unlike many other materials used as binders, ours is noncombustible. The binder forms a solid matrix which does not flake off or break away during combustion. Thus, the actual combustion zone must remain at the exterior of the briquette while gasified coal must diffuse through a hot matrix to reach the combustion zone. If cracking of the coal molecule occurs during the relatively long residence time within the briquette, then smaller molecular weight material will enter the combustion zone. Particulate material remains physically occluded within this binder matrix and, therefore, is not emitted.

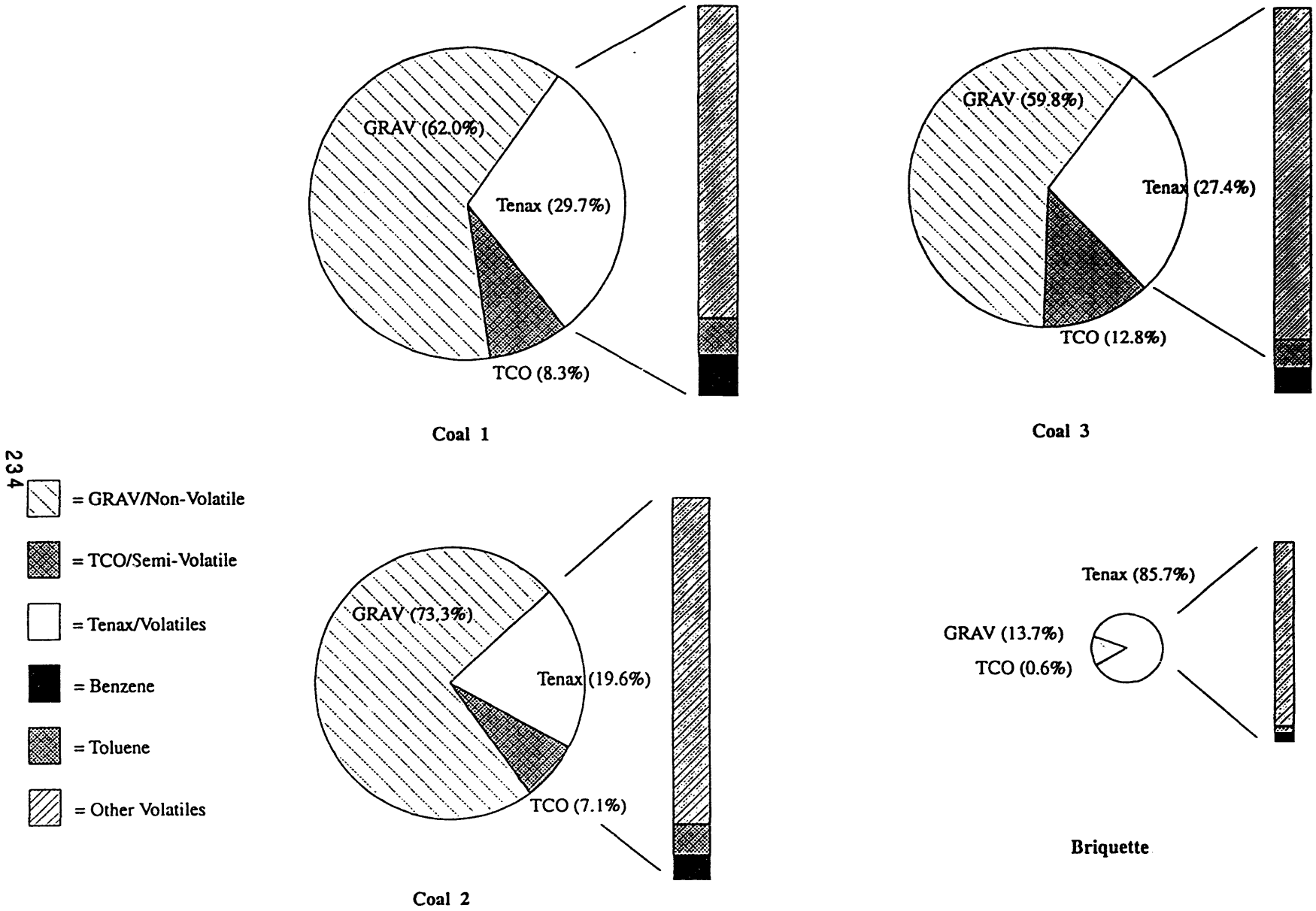

Figure 2. Results of coal burning study.

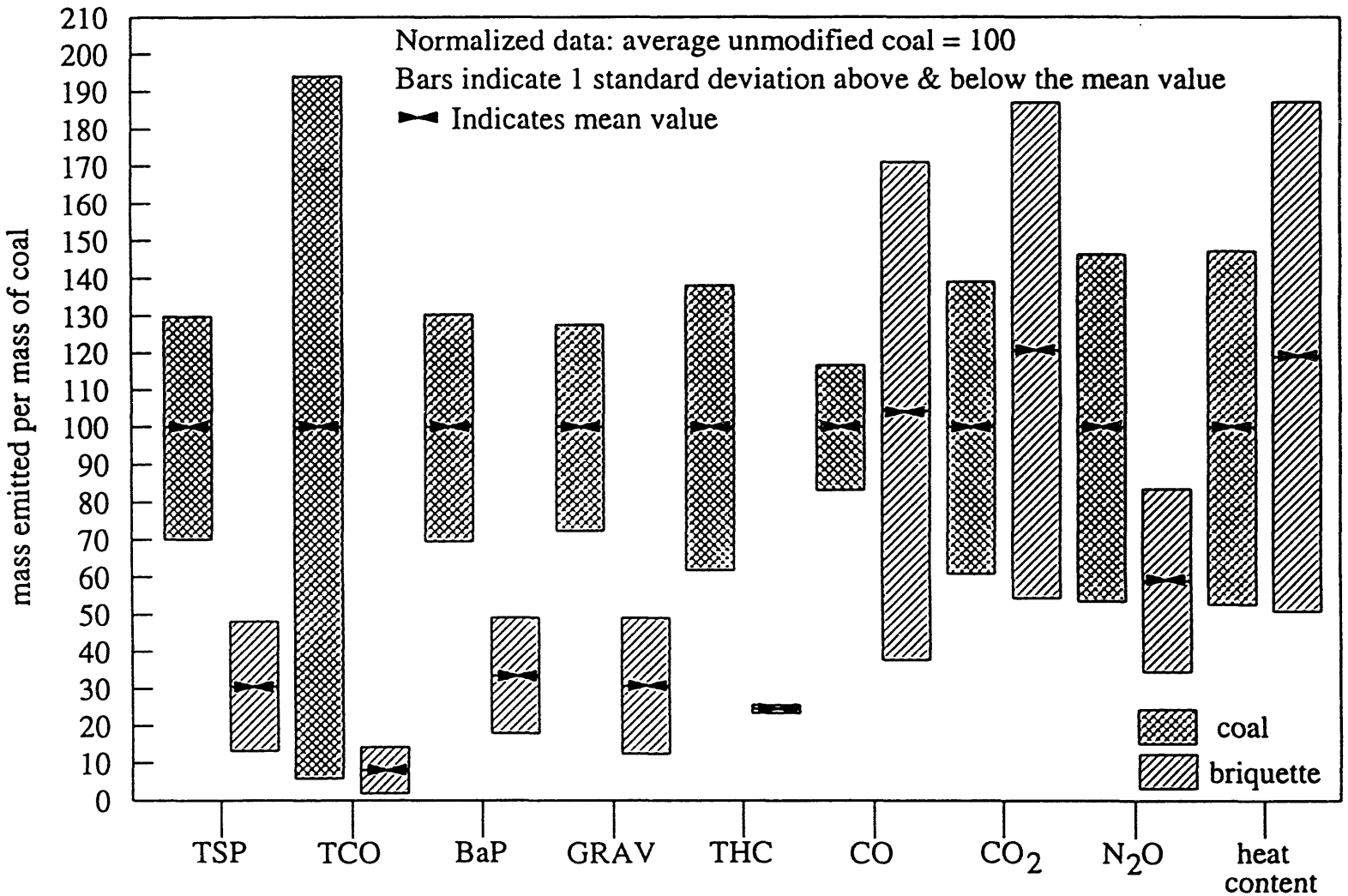

Figure 3. Comparison of coal and briquette with reproducibility data.

Environmental Impact

Table 2 presents projections for pollution reduction in the city of Kraków as the Acurex briquette penetrates the residential heating market. This table is based upon a spreadsheet model of Kraków coal use prepared by the DOE. The first two columns represent 1992 and 1993 residential heating coal use. The 1992 column represents data gathered by DOE while the 1993 column estimates the entry of high sulfur coal into a previously closed market. Approximately 500 additional tons of sulfur dioxide were emitted because of that event. The last three columns represent projected emission reductions as a function of market penetration by the Acurex briquette. It is estimated that about a fourth of the hydrocarbons and a tenth of the particulate will be removed from Kraków's atmosphere at a 50 percent market penetration. While sulfur dioxide control is not attributed to the binder, the addition of simple coal washing to the production process is expected to provide an 8 percent reduction in that pollutant also.

MARKET APPROACH

Market description

As a preliminary step in developing market approach strategy, a draft business plan has been developed. It describes the potential LES and small, hand-fed boiler house coal markets. It also explores possible use of Acurex briquette in the district heating system. As a result of the business plan implementation, a novel technology will be introduced that is anticipated to have such widespread and rapid acceptance that it will create not only a new company in Kraków, but also a whole new industry in Poland. This industry—the manufacture, sale, and distribution of non-polluting coal-based fuel—will provide many advantages to the people of Kraków including:

- Reduction in pollution from coal burning stoves
- New employment opportunities
- No significant increase in fuel costs
- No increase in taxes to fund infrastructure changes
- No expenditure to retrofit existing coal stoves

TABLE 2. COMPARISON OF ACUREX BRIQUETTE TO PREVIOUS YEARS

	Winter 1992	Winter 1993	15% market	25% market	50% market
Consumer annual costs	$55,715,318	$60,907,923	$61,023,743	$61,100,956	$61,293,989
Difference	($5,192,606)	$0	$115,820	$193,033	$386,066
Consumer SO_2, tons	7842	8326	8125	7991	7655
SO_2 removed, tons	484	0	201	335	671
$ per ton SO_2 removed	($10,719)	--	$575	$575	$575
Consumer particulate, tons	10952	10952	10641	10433	9914
Particulate removed, tons	0	0	312	519	1039
$ per ton particulate removed	--	--	$372	$372	$372
Consumer hydrocarbons, tons	134.1	134.1	124.7	118.5	102.9
Hydrocarbons removed, tons	0	0	9	16	31
$ per ton hydrocarbons removed	--	--	$12,373	$12,373	$12,373

Winter 1993 used as baseline for comparisons; 60 % of market High Sulfur (1.23 %) coal

Once the product gains market shares in Kraków, additional companies or subsidiaries can be established to market the fuel in other cities where coal stoves are commonly used. The growth of Kraków, with its population increase and significant building construction growth rate, caused infrastructure problems and increased air (and other) pollution. Air pollution reduction is, therefore, a major step toward improving the quality of life in Kraków. Acurex briquettes offer significant air pollution reduction without disrupting traffic or requiring heavy investment as in other air pollution reduction methods. Briquette fuel provides early results and two significant advantages: no investment by residents and no capital investment by city or other government agencies for infrastructure.

The key advantage of this product is the significant (about 70 percent) reduction of pollutants currently generated from the burning of coal in private LES and in small, hand-fed boiler houses. Both particulate matter and gaseous pollutants are significantly reduced by this new technology. In addition, because the technology is making use, at least initially, of existing materials and production facilities, there is very low investment in capital equipment involved. One special benefit to consumers is the fact that all the pollution reduction potential is built into the fuel itself. This means there is absolutely no cost or investment by home or apartment owners to retrofit stoves and boilers. Furthermore, the same physical distribution system in use today to get coal to the end user can be used to distribute the briquettes. The new industry will employ a number of people in the briquetting plant. There will also be new jobs added through marketing, sales, and distribution operations extended to the new business entity. As the business develops, production tonnage will rise dramatically and provide two economic advantages:

- Additional employment
- Exports of briquettes

Business Objectives

Two business objectives have been formulated:

- Obtain a 50 percent market share of the solid fossil fuel home heating market within three years of the initial product launch
- Transfer the technology and business strategy developed in Kraków to other cities with similar fuel/heating markets

Through the fulfillment of these objectives, a new industry in Poland will be created that will provide home owners and apartment dwellers with a quality, clean-burning, solid fuel. The industry will create jobs and capital investment returns for Polish people and firms. Financial assumptions for the business plan are shown in Table 3 in terms of gross sales over the year, expressed as the percent of market share in Kraków.

TABLE 3. FINANCIAL ASSUMPTIONS FOR THE BUSINESS PLAN

Project Year	Percent Market Share
I	15
II	25
III	50

Strategy

The broad strategy contains several basic elements that address consumers and producers. The strategy regarding consumers is as follows:

- Make no physical changes to present combustion units in homes and apartments, thus no new investment for consumers or property owners
- Make use of the same or very similar product distribution channels from producers of solid fuel to consumers
- Create a heating value the same or better than current solid fossil fuels
- Provide education, incentives, and after-sale service to customers

The strategy regarding producers and distributors is as follows:

- Minimize cash investment by using capital goods already in place
- Maximize Polish company participation in management, materials, personnel, equipment, etc.; i.e., create a company with significant Polish participation and investment

A number of potential risks to the project exist and while they can not be eliminated they are being carefully calculated. Political and economic risks to this venture from a Polish government policy standpoint

appear to be acceptable. The project is being started in a time of positive political shifts in favor of privatization. Such economic changes can cause labor unrest because of unemployment and inflation. Negotiations with government agencies will address state or municipal laws which apply to the manufacture, sale, and use of briquettes. However, there are potential licensing and royalties risks. Another potential risk is a possibility of a low consumer acceptance of the new product. Acurex Environmental and its partners recognize that creating a whole new industry is a major undertaking requiring serious attention to the permits and laws governing such areas as labor, the environment, local ordinances, taxes, and profit distribution. In conclusion, the opportunity to reduce pollution at little or no increase in cost to the coal burning public, is an opportunity to reduce LES pollution in Kraków that should be seized, and made ready for market as quickly as possible.

PROJECT TEAM

Acurex Environmental has built a multi-partner, U.S.-Polish team to commercially implement under Polish conditions proprietary technology for the production of low cost, low emission briquettes intended to reduce SO_2, particulate matter, and hydrocarbons emitted from LES (coal-fired home heating stoves) and from small hand-fed boilers used for residential heating in Kraków. The project team is built from members who have been selected based on their specific project related experience and who collectively are experienced in all facets of project requirements. This collective experience will assure the fulfillment of the mission to provide quality coal briquettes for home heating at affordable prices while reducing by significant amounts the pollution normally associated with the burning of coal in Kraków. The collective experience of the team, with a number of team members strongly rooted in and familiar with Polish technical practices (combustion, briquette manufacturing, etc.) and consumer habits, will also allow for possible expansion into the small hand-fed boiler (residential home heating) market following the successful handling of the home stove market.

The team includes two U.S. companies:

- Acurex Environmental Corporation
- Planmar Consulting, Inc. (PCI)

and the following Polish companies:

- Przedsiębiorstwo Energetyki Cieplnej in Chrzanów (PEC)
- Akademia Górniczo Hutnicza (AGH)
- Zakłady Chemii Gospodaczej INCO-VERITAS (Inco)
- Kopalnia Węgla Kamiennego Jankowice (KWK Jankowice)
- Larive Poland

The schematic project organizational chart is shown in Figure 4. Acurex Environmental, the team leader, is a full-service, nationwide environmental consulting and engineering firm in the United States. The corporation provides environmental engineering, research and development, and technical support services in air and multimedia regulatory development, assessment and compliance. Specific services include environmental monitoring, process and emission characterization and controls, environmental facilities operation, clean alternative fuels, incineration technology, and pesticides evaluation. Customers include federal, state, and local governments, national research institutes, utilities, and industry. Acurex Environmental has been providing engineering services and systems involving environmental and energy technologies since 1971.

PCI is a market consultant for the team. PCI has been creating and executing strategic plans plus marketing and sales methods, procedures, and systems worldwide since 1977. PCI maintains close contact with its network of international partner companies (Larive Group) located throughout Europe (including Warsaw, Prague, and Budapest) and Asia. Larive Poland worked for several Polish and international companies. PCI can access Larive Poland's resources on an as-needed basis. Initially, PCI will verify facts and assumptions in the preliminary business plan, and later will ensure that marketing strategies and the process of product launch are progressing according to the plan.

PEC is a producer of thermal energy in the Kraków-Katowice region. PEC has an outstanding record of activities designed to sustain the company's exceptional environmental compliance record (e.g., a 200,000 m^3/h wet FGD system capable of 95 percent SO_2 reduction has been built by PEC). PEC has a significant share in the Kraków-Katowice home heating market and is experienced with a broad spectrum of consumers. PEC will coordinate activities by and process the information from other Polish members of the team: KWK Jankowice, AGH, and Inco.

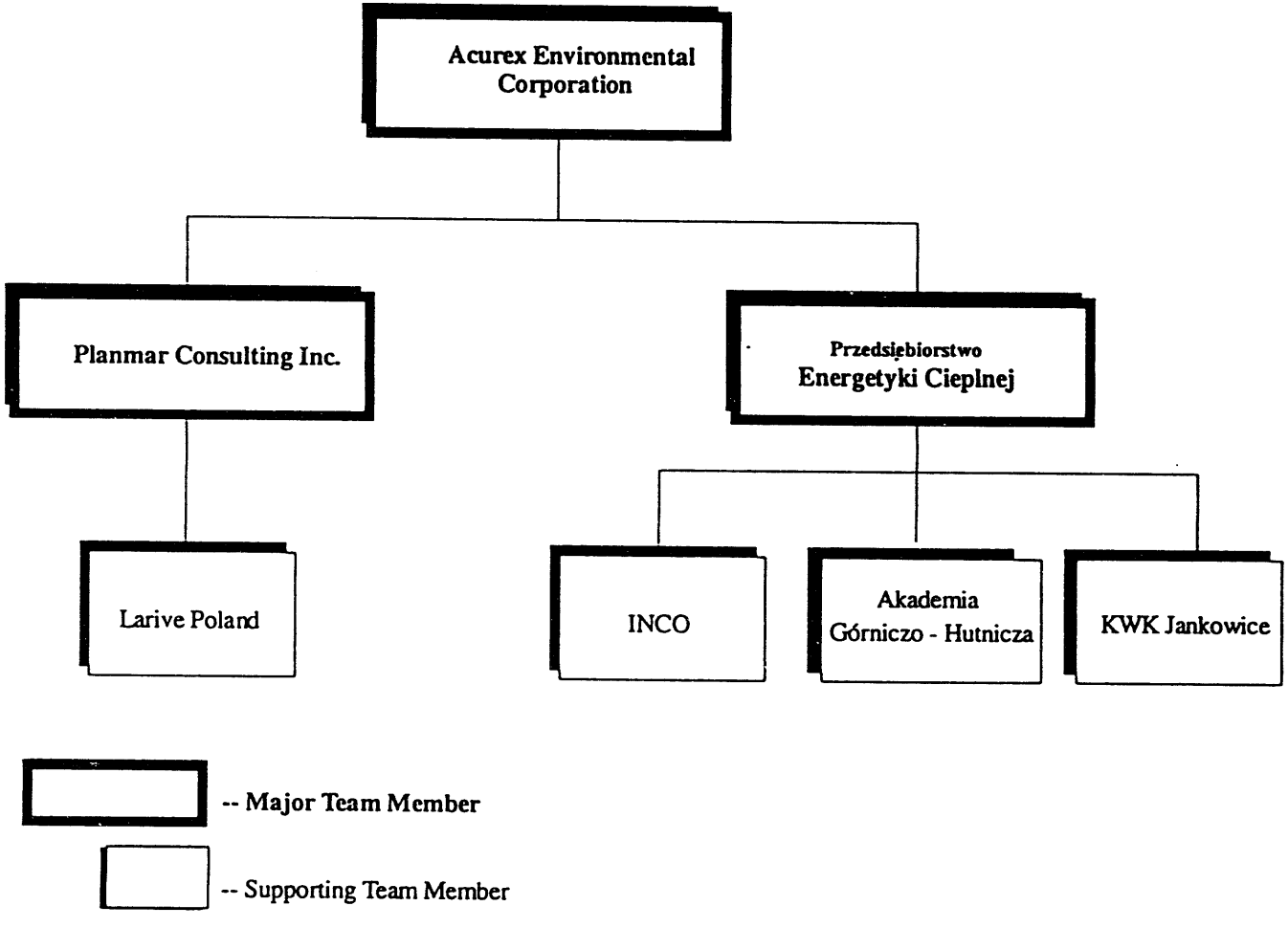

Figure 4. Project team organizational chart.

KWK Jankowice is a briquetting site. The facility was designed in a modular arrangement and has six parallel lines, each producing 40 tons of briquettes per hour. Each line consists of coal bins, a solids handling system for transportation of coal from the spur to the bins, coal fines dryers, additive bins, mixers, briquetting machinery, briquette dryers, and a solids handling system to transport briquettes from the dryer to the railway spur. KWK Jankowice facilities will be used in a manner assuring full environmental compliance with Polish environmental law.

AGH is an institution of higher learning with long lasting traditions in educating engineers and scientists for mining and metallurgical industries. It has been long recognized as one of the leading schools of its profile in Europe. The personnel is intimately familiar with DOE's Kraków initiative and has actively participated in the initial phase of DOE's program in Kraków.

Inco is a test site for small hand-fed boilers. Their heating and process systems consist of four "Eca IV A" type boilers which are installed on site. Each boiler is rated at 334 kW_t and is a hand-fed boiler set up for coal or coke combustion.

Additional contacts have been made with a number of companies and individuals in Poland whose contributions may be necessary for the success of the project.

PROJECT SCHEDULE

The completion of the DOE-sponsored project is scheduled to occur in two years, following the completion of two phases, Phase I and Phase II. Phase I activities are scheduled for completion approximately one year after the project's beginning date. During Phase I, the preliminary business activities necessary to demonstrate the product, to investigate the market, and to setup the joint venture company will be carried out. To demonstrate the benefits of the product, a small quantities of the Acurex briquette will be manufactured and tested. Coal fines from five different mines will be used to determine the properties of Polish raw materials. In addition, one hard coal will be purchased and manufactured into briquettes according to the process presented in Figure 1. The coal chosen will be one thoroughly tested by DOE during the earlier research. The data collected during these tests will be compared with earlier results to provide an objective description of the product's effect on LES emissions. The schedule of Phase I is shown in Figure 5. Phase I will end with completed technical testing of a trial batch of Acurex briquette and an updated business plan.

During Phase II, promotional plans for bringing the product to market, as well as recruitment and training of personnel will take place. Technically, the briquetting plant will be refurbished and the lines will be converted to meet process requirements. A key element of this will be the addition of coal washing facilities. The schedule of Phase II is shown in Figure 6. Phase II will end with the briquetting plant functional, contracts for raw materials in place, marketing, sales, and distribution agreements completed, and all activities brought to the point of revenue generation.

CONCLUSIONS

Because of limited funds available to achieve a significant reduction in the levels of particulate and gaseous pollution in Kraków from LES, Acurex Environmental Corporation's low-cost technology requiring minimal investment is very attractive. The raw materials necessary for the production of Acurex briquette are readily available. There is an available briquetting facility at a coal mine site.

The changeover from extensive coal use to the extensive use of low-emission Acurex briquettes can be accomplished in a very short time since absolutely no investments are required by individual end users of the fuel.

Considering all the aforementioned advantages for using solid fuel briquettes, it appears that this new industry will be highly beneficial to the air quality in Kraków.

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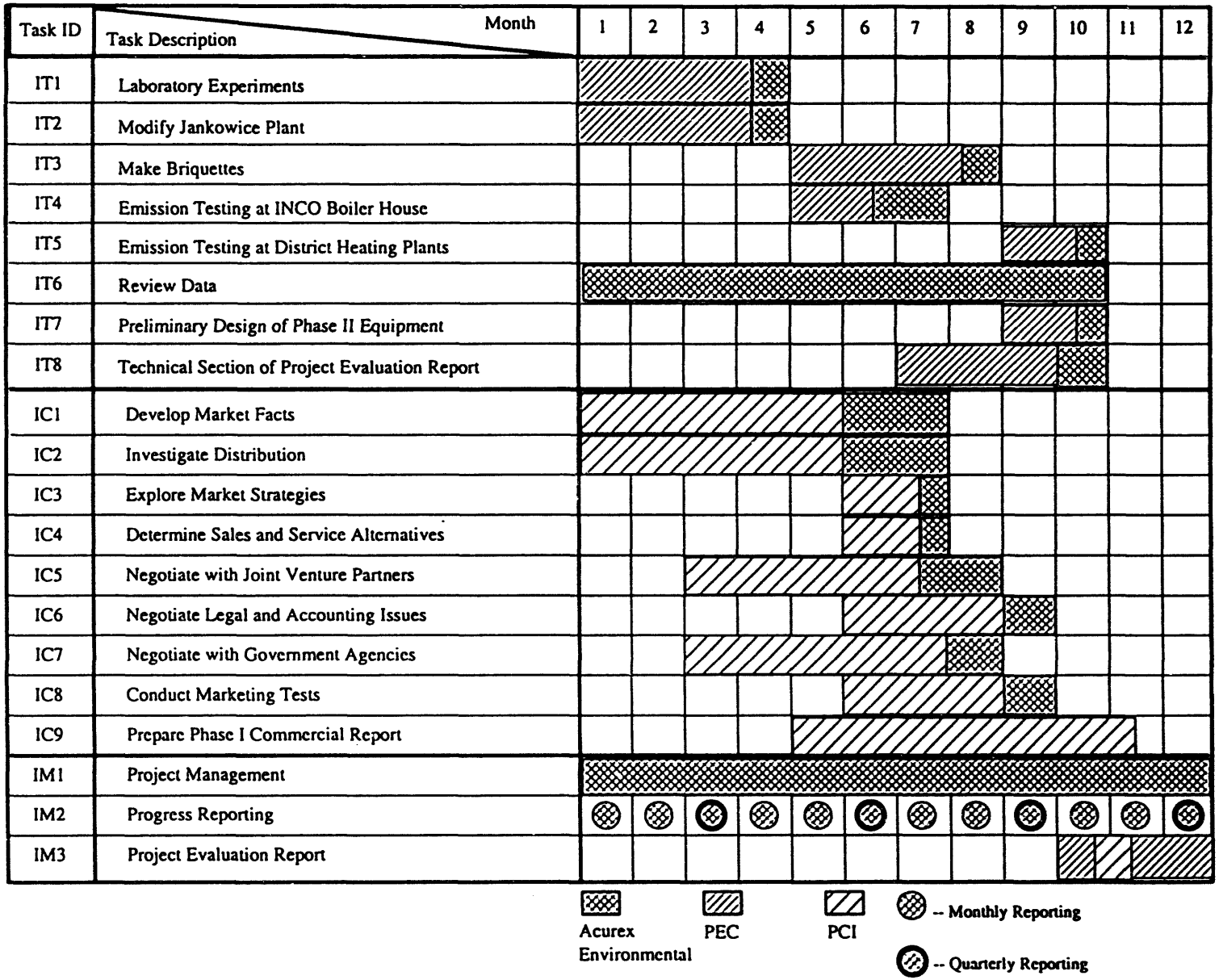


Figure 5. New Phase I schedule.

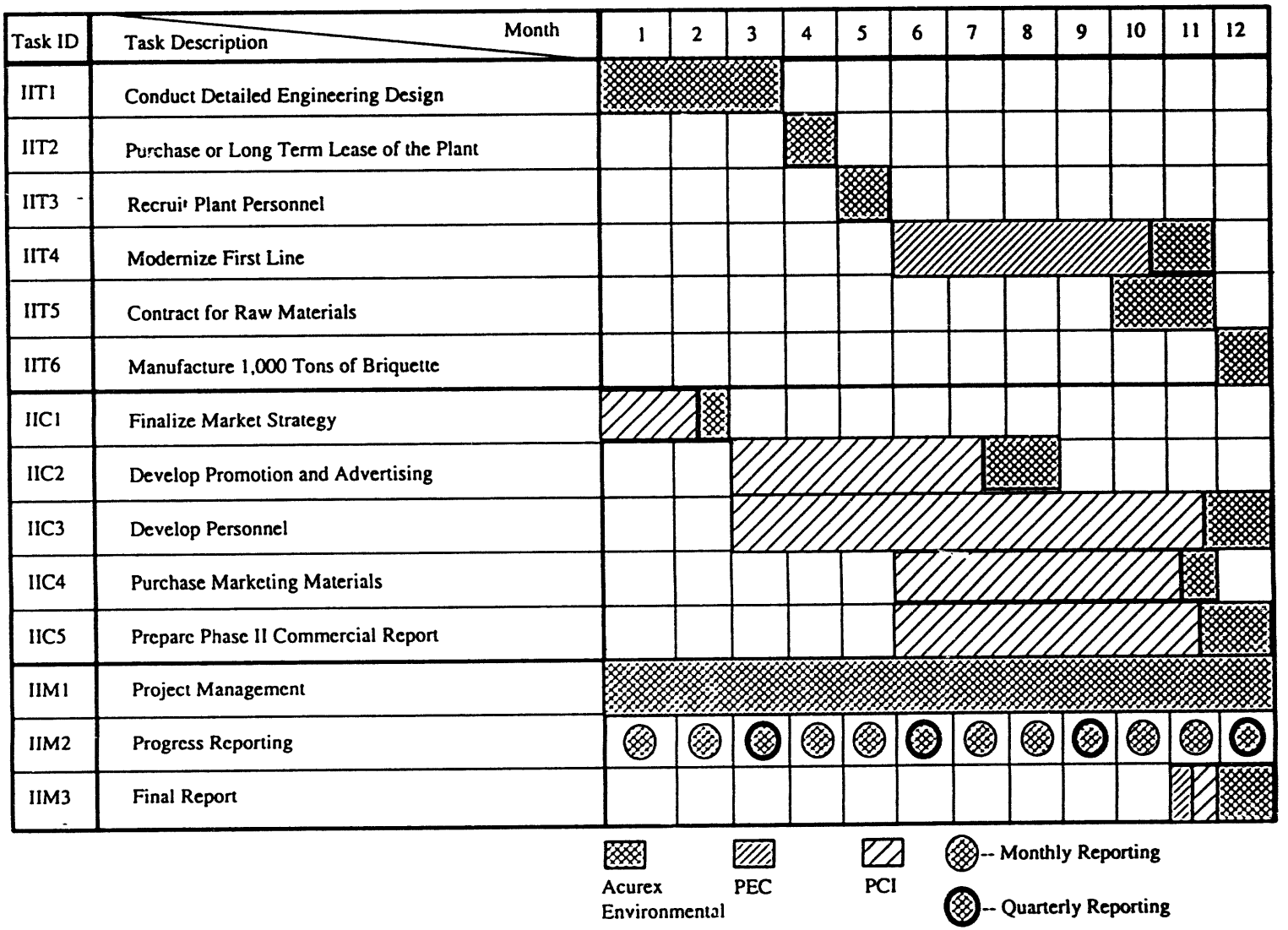


Figure 6. New Phase II schedule.

Session VII
Technology Options

Chairman: Jan Pisko, U.S.AID

Energy Efficiency: A New Energy Source Demand-Side Analysis in Plzen and Cesky Krumlov—Andrew Popelka, Tecogen • Thomas Secrest, Pacific Northwest Laboratory • Jiri Zeman, SEVEn • Frantisek Polasek, ESC Prague • Martin Pys, Pys Energy and Economics

Multiple Stoker-Fired Retrofit with Fluidized Bed Combustion—J. Vorel, Ing. Vladimir Prerad, Gerry C. Snow, L. Wally Jacobson, POWER International

Fuel Upgrading as a Method for Pollution Control and Power Plant Performance Improvement—Robin L. Godfrey, Custom Coals Corp.

Gravimelt Coal Refinery Project in North Bohemia—Stein Storsul, Selfint a.s. Czech GCR Consortium, TRW Inc., • Ing. Frantisek Titl, Czech GCR Consortium • Dr. Robert Meyers, TRW, Inc.

Role of Fuel Upgrading for Industry and Residential Heating—Norman Merriam, Western Research Institute • Robert H. Gentile, KFxAtlantic Partners

Non-Catalytic NOx-Reduction: Design Features and Experiences With a Brown-Coal-Fired Boiler in the Czech Republic–Dipl.-Ing. Ales Seitz, JCE-District Heating Strakonice•Dipl.-Ing. Bernd von der Heide, Dipl.-Ing. Christian Heiermann, Nalco Fuel Tech GmbH

ENERGY EFFICIENCY: A NEW ENERGY SOURCE DEMAND-SIDE ANALYSIS IN PLZEŇ AND ČESKÝ KRUMLOV

Jiří Zeman, Czech Team Leader, SEVEn - The Energy Efficiency Center
František Polášek, ESC Prague
Andrew Popelka, Tecogen Team Leader, Tecogen, Inc.
Martin Pyš, Pyš Energy and Economics
Tom Secrest, Project Manager, Battelle, Pacific Northwest Laboratories

ABSTRACT

This paper presents a revolutionary approach to assessing options for developing municipal district heating systems, applied in the Czech Republic for the first time in the projects sponsored by US AID in Plzeň and Český Krumlov. The authors describe the structure of this type of project, the new method used for analysis, and the findings of the study.

PROJECT FOCUS

The Czech Republic is one of the few countries that experienced quite a large expansion of co-generation in its major municipal district heating systems. In deciding how to cover the expected growth in demand for heat, various technologies for heat production that were available in this country at that time were evaluated. The technologies researched generally relied on burning inexpensive domestic coal, in rare cases gas. In the case of larger plants, the possibility of producing electricity in a combined cycle was also evaluated.

One of these large district heating system (DHS) grids is in Plzeň, where heat is produced in interconnected satellite heating plants and in the central co-generation plant. Since the mid 1980's several studies have been developed in Plzeň that researched the options for expanding the present capacity of generation plants in the network. After 1989 expanded number of options were evaluated and compared: adding new units of various sizes and burning various types of brown and black coal or gas to the system and producing various amounts of electricity in a combined cycle. Construction of a nuclear heating plant on the outskirts of the city was also considered.

Thanks to technical assistance from the United States Agency for International Development (US AID), it was possible to implement a revolutionary project in Plzeň: a study that evaluates the options for meeting future demand with current heat savings and that subsequently serves as the basis for deciding about DHS development. In such an approach, customer based (demand-side) energy efficiency - as a new source of energy - is analyzed in a similar way and as an equivalent option to traditional energy sources. This approach represents a radical change in the view on the energy sector and an absolute novelty in the standard way materials for decisionmaking had been prepared in this country.

What is the cornerstone of this radically new method?

This method is based primarily on recognizing energy efficiency in end-use consumption as a new source of energy, just as a coal heating plant. The evaluation of energy efficiency is conducted at the same time and under the same conditions as an analysis of new sources of energy production.
If it is less costly to save a unit of capacity or energy than to construct new capacity and generate energy, then energy efficiency should be implemented.

For example, in constructing new residential buildings connected to the DHS grid, it is possible to reliably supply heat and hot household water (HHW) either through existing sources in the DHS grid if their capacity permits or through the construction of additional sources. Or - and herein lies the novelty - it is possible to guarantee these supplies through conserved energy obtained through increased efficiency in the energy consumption of current heat consumers and to do this cost-effectively.

In the United States this method of analysis is entirely common in deciding on development in many energy utilities. Primarily electric utilities providing the production and distribution of electricity have many years of experience with this approach. With the exception of large military bases and university campuses, heating grids supplying heat to residential areas are not very common in the United States. In this sense the US AID study in Plzeň has become a pioneer and an exceptional opportunity to disseminate this approach to municipal DHS networks. Plzeň is the first of several East European cities where this type of project was implemented.

A DESCRIPTION OF THE DEMAND-SIDE ANALYSIS

The entire US AID project in Plzeň comprised two studies. The demand-side study analyzed heat consumption and the potential for energy efficiency, and the supply-side study analyzed potential new sources of energy production. This paper focuses on the study of the potential for energy efficiency on the demand side in the building sector (demand-side analysis) in Plzeň. Another part of this US AID project was a similar study developed for the city of Český Krumlov.

Determining actual energy consumption and categorizing buildings

The study's first task on the demand side was to determine the actual current consumption of all forms of energy in the city and to analyze energy flow. Given the aim of the study and the composition of consumption from the DHS grid, the analysis focused on heat consumption for space heating and heating household water. The primary focus was the residential sector.

A general overview of the consumption of all fuels had never before been put together in such detail, and so it was very difficult to obtain and classify the necessary data. It was only thanks to good cooperation between the project staff, Plzeň authorities and the energy suppliers that it was possible to develop an extensive database of consumption of all forms of energy for individual buildings.

An investigation of Plzeň residential buildings was conducted at the same time. All residential buildings in individual city districts were divided into 11 basic categories according to their heating profiles. For each category, the number of buildings, their heated area and a typical example were compiled. To acquire all this data for all

categories of buildings, it was necessary to conduct several special field studies throughout the entire city.

Buildings Groups

Group#	Description
1	300 - 400 years old houses
2	150 - 180 years old houses
3	Houses from the beginning of the 20th century
4	Villa houses from the thirties
5	One-floor detached houses
6	Two-floor detached houses
7	Cooperative buildings from the fifties - sixties
8	Eight-floor pre-fab houses PS 69, type 324 (before 1981)
9	Eight-floor pre-fab houses PS 69, type 324 (after 1981)
10	Eight-floor pre-fab houses PS 69, type 34143 (before 1981)
11	Eight-floor pre-fab houses T06 B

The result of the investigation and data analysis is the following table of end-use heat consumption in residential buildings. A by-product of this phase of the project was the provision of these extensive databases to individual departments of the city's administration upon their request for use in their further work.

Table 1: End Use Heat Consumption in Residential Buildings (Without Warm Water)

GB	SF local	GF local	Boiler plants		Distr. heat	ELECT	TOTAL	Area	Specif cons.
			SF	GF					
	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]	[m^2]	GJ/m^2
1	16157	9854	0	0	0	644	26655	56370	0.47
2	41623	68990	3995	17616	7258	4829	144311	392287	0.37
3	19445	121252	50822	15273	70150	6117	283059	718741	0.39
4	15445	46368	0	1220	0	2575	65608	142347	0.46
5	129739	93229	0	485	112	9658	233223	464088	0.50
6	86493	69287	0	1	280	6439	162499	364716	0.45
7	9267	69532	5882	23075	51682	1932	161371	334522	0.48
8	0	0	0	0	457987	0	457987	836628	0.55
9	0	0	0	0	235101	0	235101	399284	0.59
10	0	0	0	1078	88778	0	89856	180560	0.50
11	0	20197	116591	23856	393449	0	554093	1123488	0.49
Σ	318169	498709	177290	82604	1304797	32194	2413763	5013031	0.48

GB = Buildings Group, SF = Solid Fuels, GF = Gaseous Fuels

The results of the analysis is shown in a Table 1. The average energy intensity for the residential building sector is 0.48 GJ/m^2, with the range from a high of 0.59 GJ/m^2 for building group 8 (8-floor prefab post 1981) to a low of 0.37 GJ/m_2 for energy group 2 (150-180 year old houses).

Plans and options for constructing new buildings in individual districts as well as population forecasts were thoroughly researched in close cooperation with professionals in the city administration. The findings from this research were reflected in the heat demand forecast variants for the next decade.

Analysis of heat-efficient technologies

Availability, price, and other conditions of technology supply for energy-efficient consumption in some cases are very different than in the US. For this reason a special extensive overview of heat-efficient products offered on the domestic market, including their technical and economic profiles, was developed. All possible measures for energy efficiency in heating residential buildings and household water were divided into 24 realistically usable types of efficiency measures. All of them were profiled for their technical parameters, price, and lifespan. The following efficiency measures were assessed in three areas.

Building Envelope: Insulate building exterior side walls, insulate top floor ceiling, insulate attic, insulate floor above basement, weatherstrip elevator penthouse, stairway, doors and windows, weatherstrip windows and doors, install revolving or double door in building vestibule, install triple pane windows, install storm windows, install heat reflectors behind each radiator or heater, remove draperies from radiator.

Domestic Water Heating: Install low-flow shower heads, install flow restrictors in faucets, insulate hot water pipes in unconditioned spaces, install hot water flow meters.

Heating system: Balance heating system using existing valves, install balancing valves on each radiator, install thermostatic radiator valves (TRVs), install zone valves on each radiator and install central thermostat with "ON time counter" in each apartment, install zone valves on each radiator and install central thermostat with TOD and "ON-time" counter in each apartment, install building energy management system (EMS), temperature and flow control regulation of hot water, ventilation and heat recovery, install waste water heat recovery heat exchanger, install bath/kitchen vent heat recovery heat exchanger.

Energy Savings Simulation

To reliably determine the conservation potential, the energy savings for each category of buildings and efficiency measures were calculated using the DOE developed ASEAM 3 Simulation Model. By simulating the installation of individual efficiency measures on the sample building in each category, it was possible to calculate the reduction in heat consumption. Given that individual efficiency measures can mutually affect each other, it was also necessary to fine tune the division of efficiency measures and their combination into optimalized groups.

This analysis provided all permissible combinations of building categories, fuels used, applicable efficiency measures, and calculated level of energy savings potential. These were than subjected to economic criteria to identify the cost-effective levels of energy efficiency by building category and fuel source.

Economic Evaluation

For every such combination of building, fuel, and efficiency measure the net present value of the installation of the efficiency measure and other auxiliary economic indicators were calculated. In the calculation, the present value of savings, here calculated as the fuel savings achieved and the price of fuel, was compared with the present value of costs for installing and operating efficiency measures for their entire lifespan. Those whose net present value was positive were selected as cost efficient.

The economic analysis was conducted for a period of 30 years, with a real discount rate of 2%, and including three pricing scenarios. The baseline scenario represents the real price of energy in 1993, the mid scenario the estimate of price increases for the near future after the elimination of subsidies, and the high scenario the estimate of prices for the long term. The following are the prices for individual fuels according to the baseline scenario (the figure in parentheses indicates an increase in the baseline price according to the mid and high scenarios): on-site gas 68 Kč/GJ (+48%, +300%), on-site coal 55 Kč/GJ (+46%, +174%), electricity 94 Kč/GJ (+113%, +272%), boilerhouse gas 97 Kč/GJ (+23%, +64%), boilerhouse coal 32 Kč/GJ (+59%, +218%), district heat 136 Kč/GJ (+47%, +156%).

Analysis Results

Table 2 shows the cost-effective savings potential in GJ and its share in the consumption of individual fuels for various price scenarios.

Table 2: Cost-Effective Savings By Fuel (Incl. Hot Water)

				Price Scenario		
				1993 Price	Mid Scenario	High Scenario
Fuel	Baseline Use [GJ]	Percent of Total Use	Cost - Effective Savings [GJ]	Cost - Effective Savings [%]	Cost - Effective Savings [%]	Cost - Effective Savings [%]
On-site Gas	633 911	21%	72 711	11%	16%	25%
On-site Coal	318 169	10%	15 962	5%	7%	16%
Electricity	47 690	2%	6 012	13%	15%	15%
BH Gas	108 689	4%	29 586	27%	32%	33%
BH Coal	233 277	8%	476	0%	2%	32%
District	1 673 466	55%	672 034	40%	41%	41%
Total	3 015 202	100%	796 781	26%	28%	33%

Over 40% of the efficiency potential exists in buildings served by district heat to all three price scenarios. The cost-effective conservation potential increases from 26% of total consumption under 1993 prices to 33% of total consumption for heat and warm water in buildings under the high price scenario

Selected results of the economic analysis are presented in the table on the following page. For clarity, the results of the economic analysis were also presented in the form of a supply curve. This curve indicates the relation between the amount of energy saved and the costs for achieving these savings. It is thus easy to see how much it costs to save a certain amount of energy. Individual "steps" on the supply curve represent individual efficiency measures.

The supply curve included here represents efficiency measures applicable in buildings connected to the DHS network. From the energy price scenarios presented, it is possible to determine that the cost-effective potential for saving heat for space heating and heating household water is 40% for buildings connected to the grid. Simply stated, this statistic means that at current prices, it would be less expensive not to produce this 40% of heat in the DHS grid, but rather to acquire this heat through the installation of energy efficiency technologies. Among buildings with the highest potential for savings are pre-fabricated panel buildings from the early 1960's.

The results of the detailed analysis of heat savings potential in residential buildings were used in estimating the potential for savings in other buildings.

No special analysis was conducted to estimate the heat savings in industry; rather, information and estimates available from other sources and consultations with representatives of key industrial enterprises in Plzeň were used. The total potential of cost-effective but also easily attainable savings is estimated to be between 15-20% depending on the branch of industry.

The main result of the demand-side analysis was that in current consumption there already exists at current prices a significant cost-effective energy savings potential. In the case of buildings supplied from the DHS, the cost-effective conservation potential is 40%. The existence of this potential alone, however, does not mean that it will be utilized "all by itself". The achievable potential will always be slightly lower; it depends primarily on whether and how the energy conservation program (Demand-Side Management or DSM program) is conceived. This does not change the fact that efficiency measures represent the **least expensive** method of gaining an additional energy source in the Plzeň DHS.

COMPARISON WITH OTHER STUDIES AND DEMONSTRATION PROJECTS

The primary way in which this project differs from other analyses of the heat savings potential in buildings is the purpose of developing this study. As emphasized in the introduction, the project was designed so that in deciding about the development of the DHS network, no possibilities for meeting the demand for heat in the future were eliminated a priori. The result of comparing the costs for acquiring new sources of heat from the installation of efficiency measures with the costs for heat production is the most financially profitable variant possible. This new approach - integrating the demand and supply sides and comparing all possibilities for acquiring new sources of heat - is unique in the Czech Republic.

The calculated heat savings were also compared to several completed energy efficiency demonstration projects. Although the quality of evaluating completed demonstration projects varies, sometimes because of the very short time that the efficiency measures are in place, it has become clear that actual energy savings achieved in pre-fabricated panel buildings correspond very closely to our calculations of simulated savings.

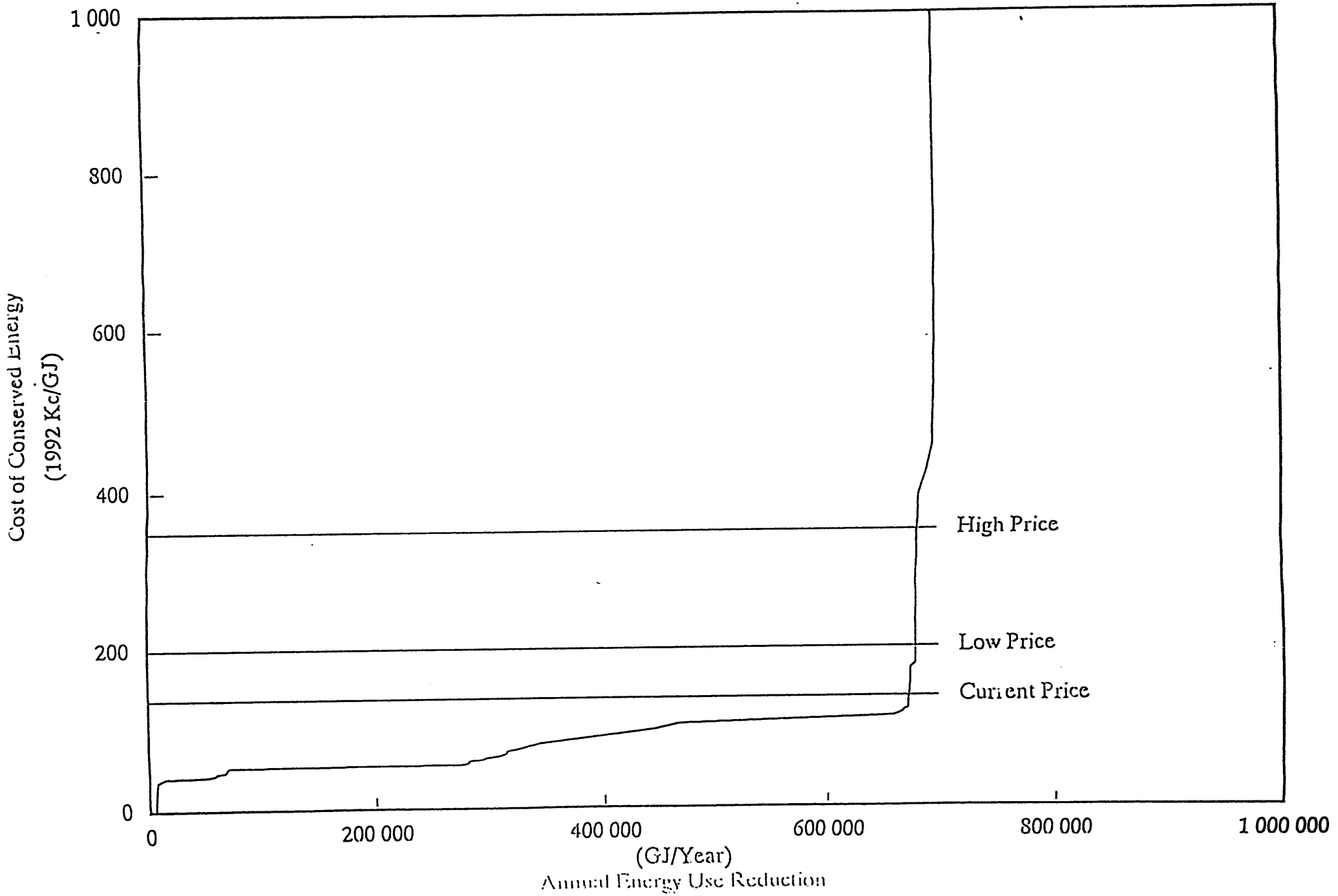
An Economic Assessment of Cost-Effective Potential Savings

Thirty-year Comparison Period, 2% real discount rate

	All Fuels, All Building Groups			District Heating, Building Groups 8-11		
Fuel Prices	1993	Low Estimate	High Estimate	1993	Low Estimate	High Estimate
Annual Energy Savings [GJ]	796 781	847 354	1 005 844	619 412	625 727	625 727
Value of Annual Energy Savings [mil. 1993 Kç]	101	153	304	84	125	219
Present Value of Energy Savings [mil. 1993 Kç]	2 260	3 433	6 800	1 892	2 803	4 905
Total Installed Costs [mil. 1993 Kç]	1 167	1 234	1 509	980	987	987
Present Value of Installed Costs [mil. 1993 Kç]	1 323	1 429	1 773	1 100	1 125	1 125
Net Present Value [mil. 1993 Kç]	937	2 004	5 027	792	1 678	3 780
Average Cost of Energy Savings [1993 Kç/GJ]	74	75	79	79	80	80
Simple Average Payback Period [years]	12	8	5	12	8	5

PLZEN ENERGY EFFICIENCY SUPPLY CURVE

District Heat, All Building Groups



THE STRATEGY FOR DECISIONMAKING

Despite the fact that the analysis was conducted on the basis of data gained from special investigation in Plzeň, it is possible to generalize some of the results and put them to good use for other cities in the Czech Republic and in Slovakia, and possibly in some other countries of Eastern Europe.

In cities that have a similar building sector composition to that of Plzeň, meaning a historical center and family homes as well as satellite apartment complexes of comparable age, it is possible, with a slight loss of accuracy, to make good use of this analysis - i.e. the cost-effective energy savings potential. An example is the completed study for Český Krumlov, the results of which, although they were based on special independent investigation, are comparable to the results of the Plzeň study.

Although the cost-effective heat savings potential is roughly the same or at least comparable in various Czech cities, the benefit of implementing efficiency measures can vary a great deal. This factor depends to a great extent on the degree to which the capacity of the system's existing supply sources is utilized. In this aspect, the situation in individual city DHS networks varies significantly.

Unutilized capacity: Where the DHS system is oversized and the existing capacity is largely unutilized, it appears beneficial to focus attention primarily on making the operation of existing sources more effective and gaining new heat consumers for the DHS network for the long term. Energy efficiency on the demand side in this case is postponed until the load factor is increased to an acceptable level. And that is despite the fact that underutilizing production sources increases heat prices, which is subsequently a greater incentive for reducing heat consumption.

The city of Český Krumlov was in a similar situation, where a decision had been made in the past to build what was at the time new and rather clean technology for producing heat utilizing fluidized-bed boilers. When the decision was being made, however, it was expected that the consumption of heat would quickly increase. Actual demand for heat from DHS sources, however, in reality turned out to be considerably lower than planned. This situation meant that expensive production capacity in a modern source went unused. Costs for heat sold from the DHS grid thus rose to more than 300 Kč/GJ, more than twice the costs in Plzeň.

Insufficient capacity: If a system is under capacity and demand for heat is growing rapidly, it is necessary to meet this unsatisfied demand in as short a time as possible. In this case the best solution is often the addition of production technology with which local experts already have experience, as it is not always possible quickly implement large blocks of efficiency.

Although objectively a significant, cost-effective heat savings potential in demand exists in these two cases, it may not be financially viable to acquire the efficiency resource.

Utilized Capacity and Slow Growth in Demand: Acquisition f energy efficiency is most favorable when one or more the following conditions exist: existing capacity is well utilized; the system is experiencing low to moderate growth; the possibility for expanding load exists; and/or existing capacity must be rebuilt and/or replaced. The Plzeň DHS network is in such a situation today.

In this case it is appropriate to prepare, implement, and evaluate in detail a small demonstration project focused on energy efficiency. This type of project would provide practical experience with managing a DSM program and would verify its economic aspects. If the demand for heat were to grow slowly in the future, it would be possible to prepare a savings program on a larger scale. If the demand began to grow at an unexpectedly rapid rate, it would be possible to proceed with construction of a new source, or possibly with a combination of both possibilities. In this way, by a combination of DSM programs and supply-side measures, it is possible to ensure that the demand for heat in the DH system is met in the most cost-effective way.

CONCLUSION

The US AID project in Plzeň introduced a revolutionary change to the Czech method of evaluating the development of DHS networks: it opened the door for energy efficiency to compete as a new source of energy. In such an analysis energy savings are evaluated in the same way as traditional sources of energy production.

The demand-side study showed that a significant cost-effective energy savings potential exists in the city of Plzeň. The greatest potential in residential buildings - 40% of current consumption - exists in heat consumption from the DHS grid.

The conditions in Plzeň provide room for the gradual accumulation of experience with heat conservation programs. After gaining initial experience and evaluating the first projects, it becomes possible to implement these programs on a larger scale. By a combination of new energy production sources and program efficiency measures, it would be possible to realize the most cost-effective variant of developing the DHS network.

The city, or at least some of its officials, have already expressed interest in utilizing extensive experience from abroad and in becoming a pioneer in the Czech Republic in the field of energy efficiency. The city is motivated toward this effort not only by political responsibility to its citizens, but primarily by the fact that it is assuming majority ownership of the DHS network. At the same time the city is the owner of a large number of buildings connected to the DHS, including residential buildings.

On the other hand, however, potential pioneers in this effort are deterred precisely by the lack of experience with energy efficiency programs, mistrust in anything other than conventional solutions, and by legislative shortcomings that complicate, but in no way prevent efficiency programs on a large scale.

The economic analysis and evaluation of heat savings as the least expensive variant for acquiring new production sources in the DHS network is one thing. Another thing is additional, non-economic criteria that it will be necessary to take into consideration when making the final decision. The decision is completely in the hands of city officials and managers, but city residents also have a responsibility to take an active role.

The US AID project team prepared exhaustive materials for such a decision. It could do this thanks only to the comprehensive support of unnamed individuals from both the Plzeň administration and a host of other organizations in Plzeň, who always willingly provided project staff with all necessary information.

MULTIPLE STOKER-FIRED RETROFIT WITH FLUIDIZED-BED COMBUSTION

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ABSTRACT

The design basis, performance, and implementation schedule for an atmospheric fluidized bed boiler bottom retrofit to ten boilers at a 927 MWth power station and district heating plant in North Bohemia, Czech Republic, is presented. The existing boilers are traveling grate stoker units firing a local, low-rank brown coal. The same fuel supply, together with limestone supplied from the region, will be utilized in the retrofit fluidized bed boilers. As a result of the AFBC retrofit, the particulate matter emissions will be reduced by over 98 percent, SO_2 emissions will be reduced by 88 percent, and NO_x emissions will be reduced by 38 percent compared to the present grate-fired configuration. As the AFBC retrofits are completed, the power station will be able to meet all emissions limits under the new Czech Republic Clean Air Act. The first retrofit boiler is scheduled for startup in July of 1994 to be on-line and fully dispatchable by December, 1994. The rest of the boiler retrofits will be completed in phases with the final unit, boiler K10 scheduled to be on-line in December of 1998.

INTRODUCTION

The region of North Bohemia in the Czech Republic is an area of great natural beauty and history. However, over the last 50 years, the region has become heavily industrialized and is now host to a high concentration of factories and power stations. The fuel most commonly used in this region is a local high sulfur, high ash brown coal. A significant percentage of the boilers utilizing this fuel in the region are traveling grate stoker units or old generation suspension-fired designs, many of which are equipped with minimal or undersized air pollution control systems. As a result, North Bohemia has become one of the most heavily polluted regions of Europe.

Beginning in September of 1991, POWER began a series of comprehensive feasibility studies to identify the best technical and economic solution to upgrade power plants and minimize environmental emissions in North Bohemia. One of the sites studied is a large power station and district heating plant located at Komorany near the City of Most. This power station, known as the First Northwest Power and Heating Plant (1.SZT), was one of the first firms to be privatized during the restructuring of the political and economic system in Czechoslovakia. The feasibility studies resulted in the conclusion that atmospheric fluidized bed combustion (AFBC) represented the best technical solution for the utilization of the local supplies of brown coal while meeting the strict emission limits under the new Czech Clean Air Act, Law No. 309.

As a result of the initial feasibility studies, 1.SZT contracted with POWER for the design and engineering of an AFBC system suitable for the Komorany Power Station. The basis of design report, representing the final concept of an AFBC application to Komorany, was completed in December of 1992. This document identified bubbling fluidized bed bottom retrofits to each of the ten boilers as the most cost effective means to achieve the plant upgrade and emission reduction goals.

POWER Engineers, Inc. is nearing completion of the necessary designs to implement the first boiler retrofit. Construction at the project site is currently underway. The first phase, boiler K1, is scheduled for startup in July of 1994 to be on-line and fully dispatchable by December, 1994. The rest of the boiler retrofits will be completed in phases with the final unit, boiler K10, scheduled to be on-line in December of 1998. On-site management of the first phase of the project is being carried out by POWER International, s.r.o., the Czech Republic-based subsidiary of POWER Engineers' international group, POWER International, Inc. The site contractor is Elektrim, a Polish company which previously performed construction and maintenance

services, including reconstruction of the plant's electrostatic precipitators.

The total project value for all phases of the ten-boiler retrofit is $100 million. $70 million of the completed project will represent equipment and construction costs, and $30 million is for design, engineering, and project management. The retrofit of the first boiler is being financed from the plant's own resources. Financing of the retrofit of the remaining boilers is currently being discussed with local and international investment companies.

BACKGROUND

The Komorany Power Station was constructed in the 1950s to provide district heating and electric power to the surrounding communities and industries. The plant comprises ten traveling grate stoker boilers, each with a maximum steam output rating of 125 tonne/hr (275,000 PPH) at conditions of 500°C and 7.5 MPa (932°F, 1089 psia). The overall plant design thermal output is 927 MWth based on the steam capacity and conditions. Over the years, however, this output has degraded to approximately 750 MWth due to aging equipment and various operational problems.

Electrical output is produced by seven steam turbine generators, including condensing, extraction, and backpressure configurations. The present gross electrical capacity is 196 MWe. As part of the overall upgrade at Komorany, a new 22 MWe backpressure steam turbine generator is being added, increasing the plant gross electrical capacity to 218 MWe.

The brown coal currently fired at Komorany, and to be used in the AFBC retrofit, has the following characteristics:

Lower Heating Value: (As Fired)	8.0 - 11.0 MJ/kg (3,440 - 4,728 Btu/lb)
Higher Heating Value: (As Fired)	8.9 - 12.1 MJ/kg (3,841 - 5,214 Btu/lb)
Higher Heating Value: (Moisture Free)	12.1 - 17.1 MJ/kg (5,210 - 7,344 Btu/lb)
Moisture: (As Fired)	23 - 29 %
Ash: (Moisture Free)	40 - 54 %
Sulfur: (Moisture Free)	1.0 - 1.8 %

The nominal size of the current stoker fuel is 0 to 40 mm with 15 percent greater than 40 mm. For use in the AFBC retrofit, this fuel will be crushed and screened to a nominal size of 0 to 20 mm with 15 percent greater than 20 mm.

AFBC RETROFIT APPROACH

Each of the ten boilers at Komorany will be retrofitted using the same design and overall approach. Each boiler will be equipped with its own coal and limestone metering systems, ash removal equipment, emissions control system, and instrumentation and control equipment. Common systems include main steam and feedwater headers, coal handling, limestone storage and handling, and final ash storage and disposal. Following final cleanup in individual fabric filters, the flue gas from the ten boilers exhaust through a common stack. A process flow diagram representing a single retrofit boiler is shown in Figure 1.

An elevation view of a single retrofit boiler is shown in Figure 2. The plan area of each grate bottom is 6.5 m by 10.5 m. The existing combustion chamber is about 13 m in height from the highest point of the traveling grate to the convective section inlet. The basic approach to the retrofit is to remove the existing traveling grate bottom and the lower portion of the existing furnace walls to an elevation of approximately 3 m above the highest point of the grate (about 13 m above the building floor level).

Combustion Power Company of Menlo Park, California, is providing the detailed design of the fluidized bed combustion system and boiler interface. The new fluid bed combustor is bottom supported and will interface with the existing furnace walls through a flexible seal. The fuel handling systems

will remain almost totally intact, in that the belt conveyors delivering coal from the adjacent mine will be reused, as will the 1,175 m^3 storage bunkers on each boiler. The existing stoker feeders will be replaced with new spreader stokers to uniformly distribute the fuel across the fluid bed area in an over-bed feed configuration.

Retrofit Options Considered

At least seven conceptual design options were evaluated in order to arrive at the best retrofit approach. Most of the options involved the relocation or replacement of the existing electrostatic precipitators (ESP) on each boiler. The existing ESPs have a relatively low specific collection area of 44 s/m (0.22 ft^2/acfm) and only a single field in the direction of flow (vertical). With the addition of limestone in the AFBC for sulfur capture, the resulting increase in both particle loading and particle resistivity at the ESP inlet would not allow the existing ESPs to meet the particle emission limit. Therefore, consideration was given to the installation of additional ESP modules; retrofit of the ESP housings with fabric filters; removal of the existing ESPs and utilizing the space for mechanical pre-collectors and/or new air heaters; and the addition of new baghouses.

Final Configuration

The option selected for implementation utilizes the existing ESPs in their present locations supplemented by new baghouses located on the roof of the boiler house. A three dimensional drawing of a single retrofit boiler is shown in Figure 3.

The ESPs will serve primarily as a pre-collector to each baghouse and as a source for material to be reinjected into the fluid bed. The expected ESP collection efficiency following the AFBC retrofit is between 80 and 90 percent. Between 50 and 60 percent of the ESP ash will be reinjected into the fluid bed together with ash collected from the superheater and air heater hoppers. The total reinjected ash represents a recycle ratio (ash to fuel) of about 0.5. This recycled ash will improve both carbon burnout and limestone calcium utilization so that the SO_2 capture requirements can be met without excessive limestone usage.

Other key aspects of the selected retrofit configuration are the addition of new limestone storage, handling, and metering systems. The fluid bed combustors will incorporate new forced circulation heat transfer surfaces within the dense bed to maintain bed temperature below 843°C (1550°F) in order to minimize bed material agglomeration, as well as to maximize sulfur capture reactions. Additional pendant superheaters will be added upstream of the existing superheaters to ensure maintenance of final superheat temperature. New economizers will replace the existing units and will be installed in the same locations. The new economizer design was chosen to avoid erosion problems associated with the higher inlet particle loading resulting from the AFBC retrofit, and provide for improved cleanability with new sootblowers. New tubular air heaters will replace the current cross-flow channel design in the same locations.

Process Design

The process flow diagram for the retrofit is shown in Figure 1. The main operating parameters for the AFBC retrofit (for each boiler) are as follows:

Steam output	125 t/h
Minimum steam output	50 t/h
Maximum superheat temperature	500°C
Nominal superheater pressure	7.5 MPa
Maximum superheater pressure	7.7 MPa
Maximum drum pressure	8.24 MPa
Feed water temperature	170°C
Boiler efficiency (LHV)	85 %

Fuel System

The existing fuel system uses belt conveyors to transport brown coal from the neighboring mines within the Komorany area. From the main conveyors, two parallel conveyors along the top of the boiler house transport the coal to individual bunkers near the boilers. The volume of each bunker is 1,175 cubic meters. The new fuel metering systems will start at the lower outlet flange of each bunker and will consist of new surge bins and over-bed feed stokers for each boiler. This system incorporates controllable drives for the control and

supervision of fuel feeding into each combustion chamber.

During the construction and erection of the retrofit, it will be necessary to supply the boiler house with two size ranges of fuel to feed both the grate-fired boilers and the FBC retrofits. The preparation and transportation of the fuel to coal feeding conveyor belts will be the responsibility of the fuel supplier.

Limestone System

The implementation of the new limestone handling system will be divided into two phases. The first phase addresses only the limestone supply to the first boiler, K1. In this phase, the limestone will be transported to the plant by truck or rail. The limestone will be unloaded and pneumatically transported to a service bin located near the boiler. The limestone will then be delivered directly to the boiler by a feeder.

During the second phase of construction, a limestone handling system sufficient for the operation of all ten retrofit boilers will be installed. This system will include the transportation by rail cars to the point of offloading into underground limestone storage bunkers. Within the plant site, the limestone will be transported from underground storage into silos with a capacity equivalent to three days of supply. From the silos, the limestone will be transported to surge bins near the boiler house. In the boiler house, there will be service bins from which the limestone will be transported directly to each boiler by feeders. The transportation from the storage silos to the boiler house is pneumatic.

The limestone to be used in the AFBC retrofit has the following properties (dry basis):

$CaCO_3$	75 %
$MgCO_3$	3 %
SiO_2	17 %
Al_2O_3	4 %
Fe_2O_3	1 %
Moisture	4-6 %
Grain Size	0.34-3.9 mm

Ash Disposal

Similar to the limestone system, the ash disposal system has been divided into two phases. In the first phase, both the existing boilers and the newly retrofitted units will produce ash simultaneously. In the second phase, following completion of the entire retrofit program, ash will be produced only by the AFBC boilers. Table 1 shows the production of ash (bottom ash and fly ash) from both the existing boilers and the AFBC retrofit units over the duration of the retrofit program.

The new ash disposal system will utilize the existing equipment and the current manner of operation to the extent possible. In other words, the discharged bottom ash and fly ash will be transported from individual collectors into the existing conveyors. These conveyors empty into the existing slag storage silos which is the termination point of the "in house" ash disposal. From the slag storage silos, the ash will be transported by rail car for final disposal or for use in other mining related purposes. For dust suppression, the fly ash will be moistened prior to loading into rail cars.

Boiler Startup

Startup from a cold condition will require 4 to 6 hours to achieve a bed temperature of 500 to 600^{o}C before coal feed can be initiated. An under-bed burner, rated at about 17.6 MJ/s, firing natural gas will be placed in the air plenum.

Instrumentation and Control

As a part of the retrofit, new instrumentation and control (I&C) equipment will be installed in two stages. The I&C system for the first retrofit boiler, K1, will be installed in the first phase. As the retrofit program continues, the I&C system will be extended to the other boilers. The I&C system is based on graphic CRT consoles, and operated by keyboard interface. This system provides the user with all basic functions, such as start/stop, loop control, programming, prediction, and alarm signal control. A full set of continuous emissions monitors for each boiler is also part of the system. A computer work station is also included to allow filing of information and data for inspection/control reports and evaluation.

PROCESS AND EMISSIONS PERFORMANCE

Summary of Heat and Mass Balance

Heat and mass balance calculations were performed at three design point conditions to determine the range of fuel and limestone flow requirements, the ash flows, steam conditions and flows, and boiler efficiency. The design point conditions were defined at the low, intermediate, and maximum points for the coal heating value. The three coal heating values analyzed were 8.0, 10.2, and 11.0 MJ/kg on a lower heating value (LHV or net), as fired (23 -29 % moisture) basis. The other design conditions are 816°C bed temperature (812°C at the low range LHV of 8.0 MJ/kg), and a steam flow of 125 tonne/hr. The heat and mass balance calculations are summarized in Table 2.

Stack Emissions

As the AFBC retrofits are completed, the Komorany Power Station will be able to meet all emissions limits under Czech Republic Law No. 309, "The Clean Air Act." The Czech Clean Air Act applicable to the Komorany Power Station requires an SO_2 emission limit of 500 mg/Nm^3. For comparison, the U.S. EPA 1978 New Source Performance Standard (NSPS) for large boilers is 1.20 lb/MMBtu which is equivalent to about 1500 mg/Nm^3 with the Komorany specification brown coal. The Czech Clean Air Act emission limits for NO_x and particulate matter are similar to the comparable limits under the 1978 NSPS.

Table 3 summarizes Law No. 309, the current emissions from the traveling grate boilers, and the retrofit AFBC emissions performance for the Komorany plant. The emissions are shown at normal conditions (0°C, 101.32 kPa), corrected to 6 percent oxygen and dry conditions. The estimated emissions from the Komorany FBC are based on pilot plant test data. Testing was conducted in June 1993 by POWER International and CERCHAR, the Research Center of Charbonnages de France. To obtain accurate predictions of the Komorany FBC performance, representative samples of coal and limestone were shipped from Most in the Czech Republic to the CERCHAR test facility at Mazingarbe in the north of France. The estimated particulate matter emissions are based on the vendor guarantee for the new baghouse.

As a result of the AFBC retrofit, the particulate matter emissions will be reduced by over 98 percent, SO_2 emissions will be reduced by 88 percent, and NO_x emissions will be reduced by 38 percent compared to the present grate-fired configuration. The predicted emissions shown in Table 3 are well within the emission limits of Law No. 309 and the contract guarantees. The total annual emissions of SO_2, NO_x, and particulate matter over the duration of the AFBC retrofit program are shown in Table 4.

Ash Disposal

Transport of bottom ash and fly ash away from the Komorany plant site will be by rail car. This ash will be mixed with overburden removed during mining operations ("spoil material") and used to fill and reclaim exhausted open cast mines. The mixing ratio between the Komorany ash and the spoil material is between 1:5 and 1:10. After these materials are landfilled, a permanent vegetation cover is established.

IMPLEMENTATION SCHEDULE

The schedule for retrofit of Boiler K1 is shown in Figure 4. Conceptual and process designs and preliminary engineering are all complete. Detailed engineering and design activities are proceeding simultaneously on a number of systems. Contracts have been let for most major subsystems. Major on-site construction activities are currently underway. Boiler K1 is scheduled for startup in July, 1994 to be on-line and fully dispatchable by December, 1994.

Figure 5 shows the schedule for the AFBC retrofit of all ten boilers in the Komorany Power Plant. The construction and erection is divided into five phases. The first phase is the retrofit of boiler K1. Following the first phase, the remaining phases will be implemented.

A key requirement for the retrofit program is that the supply of heat and electricity to the surrounding users must continue uninterrupted over the duration

of the project. In practice, this means that a minimum of seven boilers, having a total combined steam output of 630 tonne/hr, must be in operation during each heating season.

SUMMARY

This AFBC retrofit represents one of the largest bubbling bed retrofit programs in the world. The project illustrates that through careful analysis and design, fluidized bed retrofits can be used to upgrade and reduce environmental emissions from Central and Eastern European power stations which fire local low-rank and brown coals. Through such a retrofit approach, plant upgrades can be achieved with a substantial reduction in investment capital as compared with new, greenfield technologies. Furthermore, these benefits can be realized while utilizing local fuels and feedstocks, and with minimal disruption of services and employment.

TABLE 1

ESTIMATED TOTAL PLANT ASH FLOWS
DURING THE KOMORANY POWER PLANT RETROFIT PROGRAM (tonne/yr)

SOURCE	1994	1995	1996	1997	1998	1999
Grate Boilers						
- slag	435,170	348,122	248,658	146,485	0	0
- fly ash	186,502	149,195	106,568	62,779	0	0
AFBC						
- bottom ash	18,497	69,077	128,217	187,388	272,685	279,741
- fly ash	34,351	128,286	238,117	348,007	506,415	519,519

TABLE 2

SUMMARY OF PROCESS CONDITIONS FOR THE KOMORANY AFBC RETROFIT (EACH BOILER)

COAL LHV AS FIRED, MJ/kg	FUEL FLOW, kg/hr	STEAM FLOW, tonne/hr	FBC BED TEMP., °C	BOILER LHV THERMAL EFFICIENCY, %	LIMESTONE ADDITION TO MEET EMISSION LIMIT, kg/hr	TOTAL BOTTOM ASH AND FLY ASH FOR REMOVAL, kg/hr
11.0	35,200	125	816	85.0	3,520 [a] 3,168 [b]	15,720 [a] 15,380 [b]
10.2	38,200	125	816	85.0	3,820 [a] 3,438 [b]	17,060 [a] 16,690 [b]
8.0	48,700	125	812	84.2	4,870 [a] 4,383 [b]	21,750 [a] 21,280 [b]

[a] Without ash reinjection.
[b] With ash reinjection at 0.5 recycle ratio.

TABLE 3

STACK EMISSIONS SUMMARY

EMISSION	EMISSION LIMIT VOL. 84/1992 CLEAN AIR ACT No. 309/1991 mg/Nm^3 [a]	CURRENT EMISSIONS FROM KOMORANY TRAVELING GRATE BOILERS [b]		ESTIMATED EMISSIONS FOLLOWING KOMORANY FBC RETROFIT		
		mg/Nm^3 [a]	t/d [c]	mg/Nm^3 [a]	t/d [d]	t/d [e]
SO_2	500	3330	137.3	399	10.4	14.4
NO_x	400	589	24.3	362	9.43	13.1
CO	250	100	3.99	155	4.05	5.61
Particulate Matter	50	2080	85.9	23	0.60	0.83

[a] 0°C, 101.32 kPa, 6% O_2, dry.
[b] 1991 Data
[c] Total potential emissions for 10 traveling grate boilers operating at rated capacity of 90 t/h each.
[d] Total potential emissions for 10 FBC retrofit boilers operating at 90 t/h each.
[e] Total potential emissions for 10 FBC retrofit boilers operating at rated capacity of 125 t/h each.

TABLE 4

ESTIMATED TOTAL PLANT ANNUAL STACK EMISSIONS DURING THE KOMORANY POWER PLANT RETROFIT PROGRAM (tonne/yr)

EMISSION	1994	1995	1996	1997	1998	1999
SO_2	22,500	21,700	16,700	11,300	5,900	3,600
NO_x	4,100	4,100	4,000	2,800	2,200	2,200
Particulate Matter	17,500	14,200	10,400	6,500	830	800

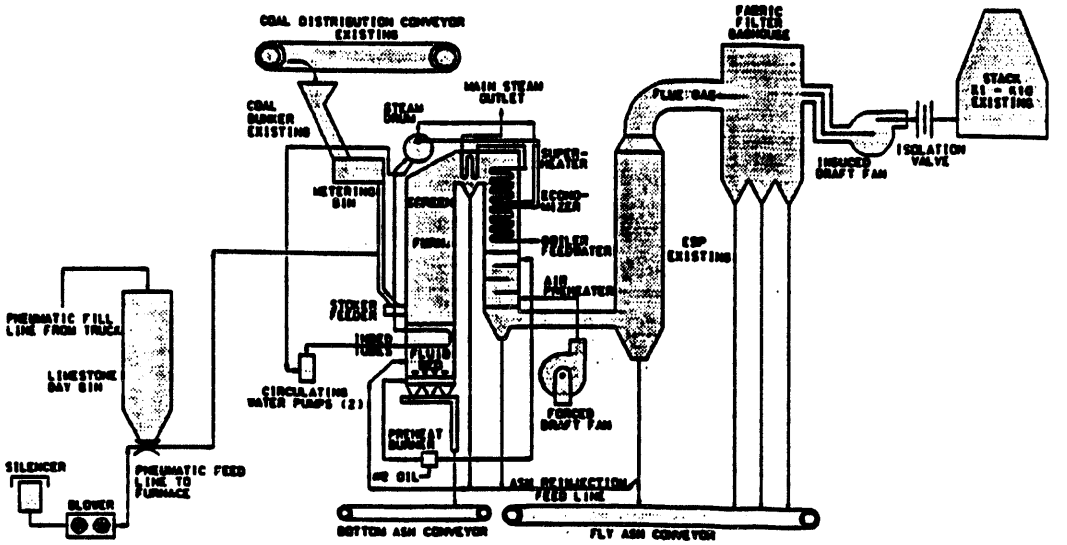

FIGURE 1 - PROCESS FLOW DIAGRAM

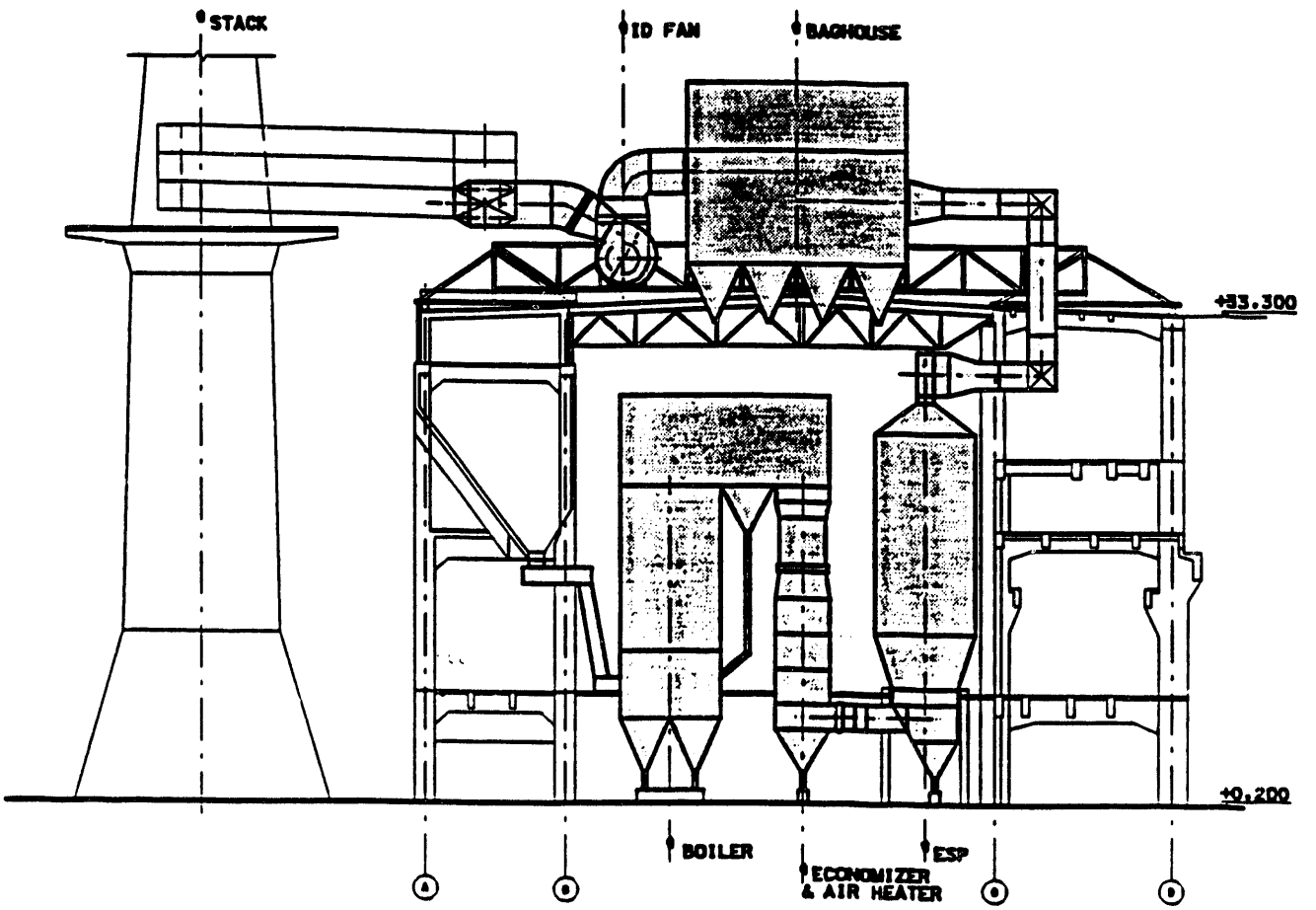

FIGURE 2 - BOILER K1

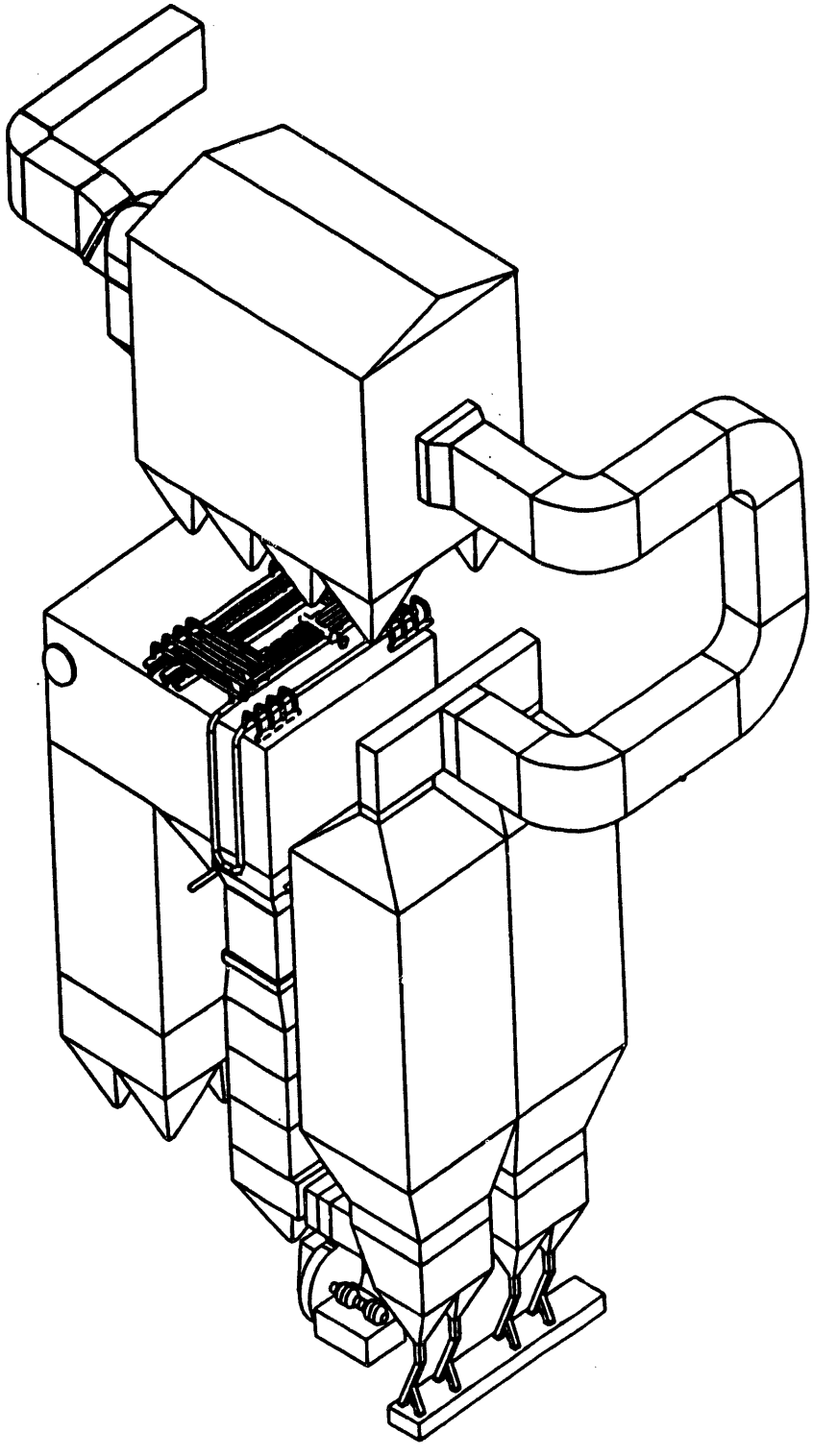

FIGURE 3 - SOUTHEAST VIEW OF BOILER K1 AFBC RETROFIT

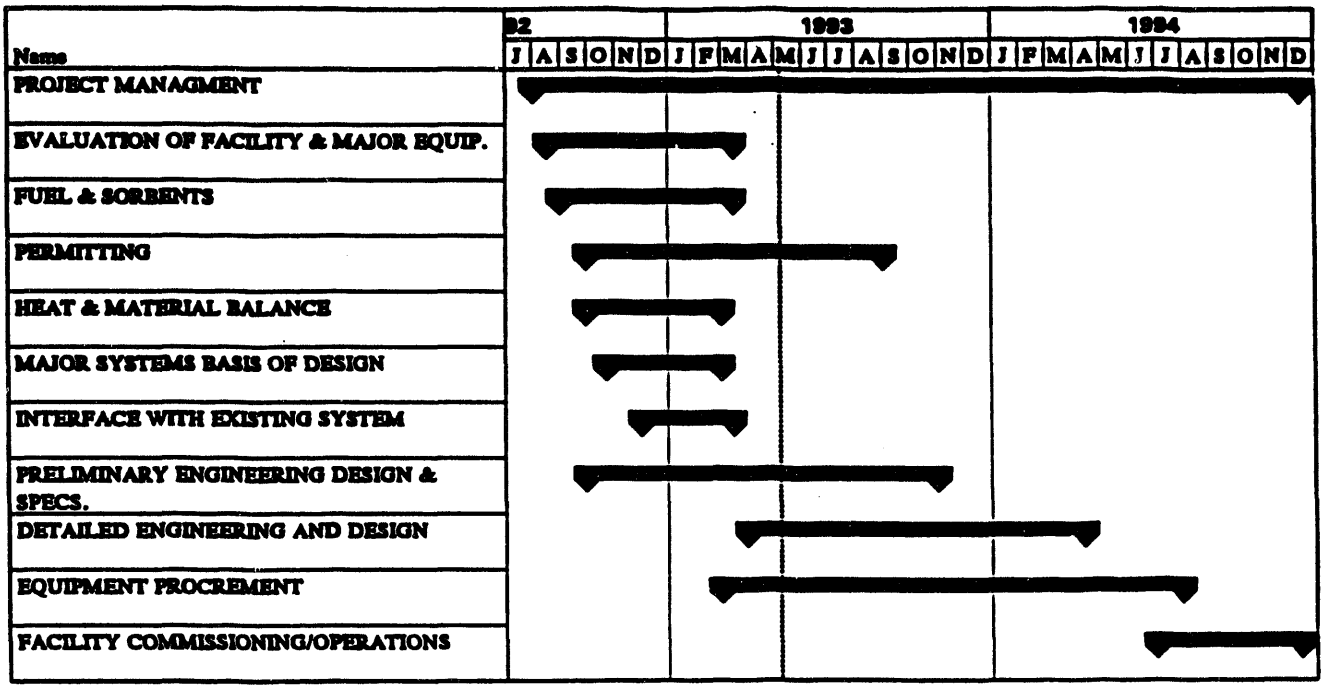

FIGURE 4 - SCHEDULE FOR AFBC RETROFIT OF BOILER K1

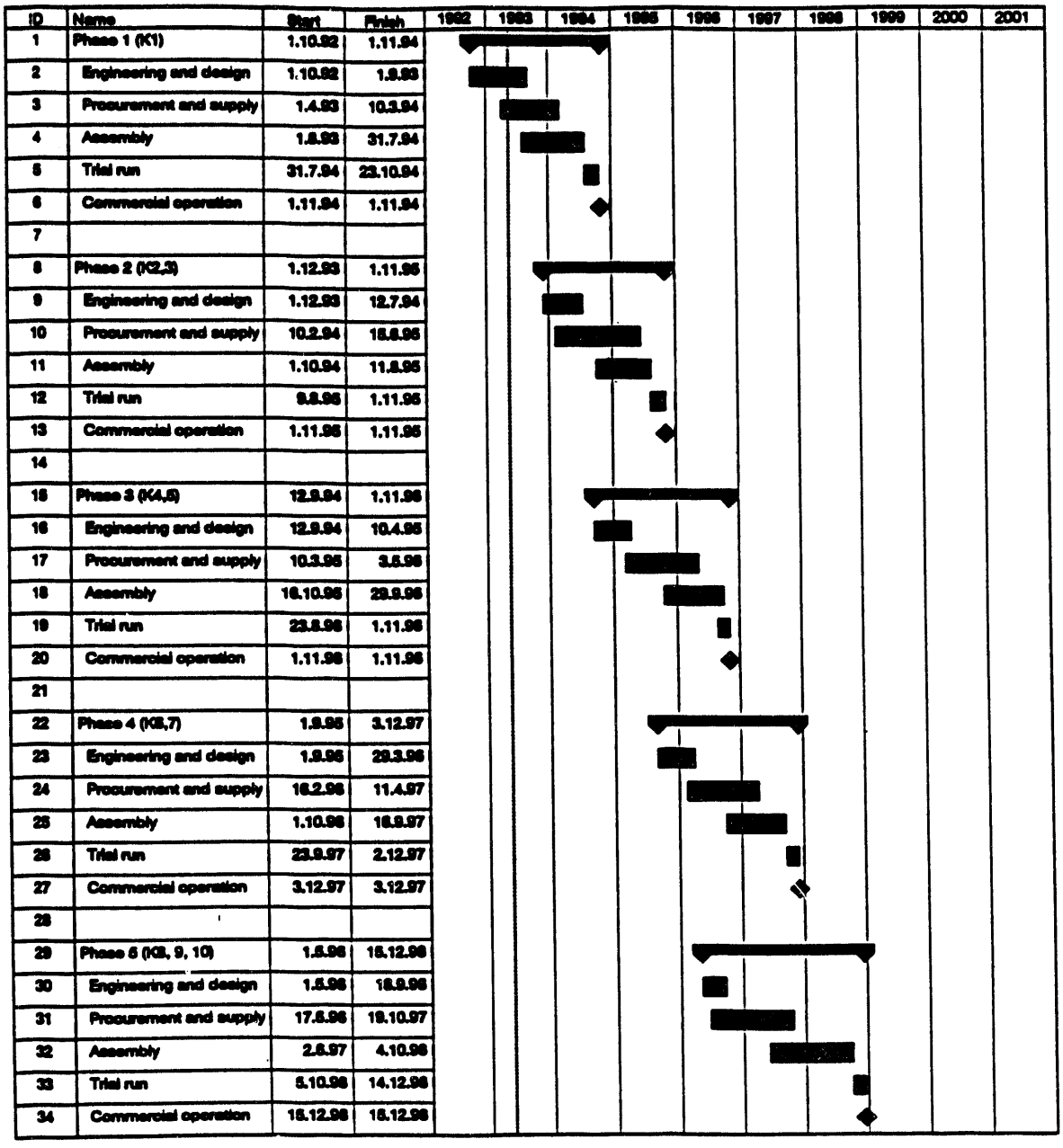

FIGURE 5 - SCHEDULE OF AFBC RETROFIT PROGRAM FOR TEN BOILERS AT THE KOMORANY POWER STATION

FUEL UPGRADING AS A METHOD FOR POLLUTION CONTROL AND POWER PLANT PERFORMANCE IMPROVEMENT

CUSTOM COALS CORPORATION

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Coal-Fired Low Emission Sources

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INTRODUCTION

Air pollution, resulting from the combustion of coal for home uses, centralized heating and the generation of electricity, is a problem world-wide. Aggressive coal preparation represents a method for reducing air pollution as well as improving the economics of generating electricity.

Custom Coals Corporation has exclusive world-wide rights to several developed, proven and patented technologies which reduce sulfur and other toxic pollutants from raw coal feed stocks producing compliance products. These products, Carefree Coal™ and Self-Scrubbing Coal™ are available at market-competitive prices.

Custom Coals has been developing these products for use in the United States since 1984. A commercial facility demonstrating these technologies, which has been jointly funded with the U.S. Department of Energy through its Clean Coal Technology Program, is under construction in the U.S. and will be completed by the end of 1994.

Under a grant of matching funds from the U.S. Agency for International Development, Custom Coals is performing a study of the feasibility of using aggressive coal preparation in Poland to address air pollution issues.

AGGRESSIVE COAL PREPARATION - CAREFREE COAL

Aggressive beneficiation is characterized by the following:

- Liberation of coal from pyrite and other ash-forming minerals by crushing locked particles,
- A proprietary fine-coal cleaning circuit that efficiently recovers fine coal and rejects pyrite and other ash-forming minerals,
- Thermal drying and agglomeration of fine clean coal, as required to meet market specifications for moisture and size consist, and
- Integration of these advanced operations with conventional coal preparation processes.

COMPOSITION OF RAW COAL

Coal may be viewed as an aggregate of three types of components:

- Organic material or "pure" coal, specific gravity typically less than 1.3,
- Pyrite (iron disulfide), specific gravity about 5.0, and
- Rock, specific gravity averaging about 2.6.

The breakage that occurs when coal is mined produces some amount of liberated organic material, liberated pyrite and liberated rock. Unfortunately, a large portion of the broken raw coal, especially the larger material, is comprised of two or all of these components locked together. It is the locking of the separate components (organic material, pyrite and rock) into larger particles that creates the spectrum of specific gravities characteristic of raw coal.

Material with a specific gravity between 1.3 and 2.0, comprised entirely of locked particles, is referred to as middlings. The amount of middlings in raw coal is usually substantial but varies considerably. Fifty percent might by typical.

CONVENTIONAL COAL CLEANING

In conventional coal cleaning, raw coal is partitioned into two components on the basis of some pre-selected specific gravity in the range between 1.3 and 2.0. The locked (middlings) particles must therefore report either to the clean coal or refuse. Both are undesirable. If locked particles report to the clean coal, unwanted pyrite (sulfur) and rock (ash) are carried into the clean coal thereby reducing its quality. If they report to the refuse, valuable coal is lost thereby reducing the yield of clean coal.

LIBERATION

Locked particles (middlings) can be converted to free or liberated particles by crushing. The ease and extent to which the rock and pyrite liberate from the coal matrix upon crushing of the locked particles is a significant factor affecting the cost of producing a clean coal. For many coals, fortuitously, crushing the plus 1/2 mm locked particles produces a substantial number of smaller but liberated particles (even though inevitably some locked particles remain).

Crushing to minus 1/2 mm to achieve liberation of pyrite and rock from the coal matrix is not generally practiced by the coal industry. The major reason for this is that there is no efficient method for separating the resulting fine pyrite and rock from the fine coal.

EFFICIENT CLEANING OF FINE RAW COAL

The widespread use of conventional dense media cycloning attests to its superior performance and versatility in beneficiating intermediate and small-size raw coal. Cleaning raw coal finer than 1/2 mm in conventional dense media cyclones, however, gives poor results. Efficiency drops off sharply and the separation gravity rises dramatically as particle size decreases. Both are undesirable. Both are also consequences of two theoretical limitations of commercial dense media cyclones for properly sorting fine particles.

These limitations are:

1. The medium is not homogeneous with respect to the fine size of the raw coal. Stated another way, the particle size of the commercial magnetite comprising the media is too large.

   To illustrate, as the size of a particle of coal approaches the size of the magnetite comprising the media, the coal particle ceases to be submerged in media, which would buoy it up into the clean coal product. Rather, the coal particle is increasingly immersed in water in which it sinks, thereby becoming coal which is misplaced to refuse.

2. The forces operating on fine particles inside a conventionally designed and operated cyclones are too weak with respect to the fluid resistance to impart the velocity required for separation.

To obviate these two theoretical limitations the following steps were taken:

1. A new extraordinarily-fine magnetite was developed which is minus 5 microns (0.005 mm). This extraordinarily-fine magnetite eliminates the problem of conventional magnetite which is too coarse to be effective in cleaning fine and ultra-fine coal.

2. Both the design and operating conditions of the cyclone were altered to overcome the problem of forces being too weak to effectively clean fine coal without, at the same time, overloading the cyclone.

THERMAL DRYING AND AGGLOMERATION OF ULTRA-FINE CLEAN COAL

Aggressive coal cleaning which includes crushing middlings produces more fines than produced by conventional coal cleaning. To control moisture content and size consist some thermal drying and agglomeration is needed.

For many coals conventional dewatering of the coarser sizes coupled with thermal drying and agglomeration of just the ultra-fines is sufficient to meet market requirements regarding moisture and size consist. Thermal drying of the ultra-fines is achieved by indirectly heated dryers. The dried ultra-fines are briquetted. No binder is required, presumably due to the narrow size consist of the ultra-fines.

APPLICABILITY TO POLISH COALS

Although the technology was developed in the U.S., in general, the coal cleaning approach described above is expected to be equally applicable to Polish coals. As part of the AID feasibility study, raw coals from several mines in Poland are being sampled and washability/liberation testing will be performed. The laboratory data produced from this effort will define the lowest ash and sulfur levels achievable from a specific raw coal cleaned according to the system described above.

SORBENT ADDITION - SELF-SCRUBBING COAL

Self-Scrubbing Coal is a clean coal product prepared from raw coals that have a moderate amount of organic sulfur and pyrite that liberates easily and a sorbent. For Self-Scrubbing Coal, substantial sulfur is removed in the coal preparation plant, by the same methods used for Carefree Coal. Additional sulfur as sulfur dioxide, however, must be captured in the boiler through the action of the sorbent in order to achieve desired SO_2 emission levels.

Several improvements result from using Self-Scrubbing Coal compared to earlier combustion trials by others in which the sorbent and coal were injected together through the burner.

1. Slagging and fouling are reduced. The presence of ferrous iron aggravates slagging. Removal of 85 to 95 percent of the pyrite during coal cleaning substantially eliminates ferrous iron and therefore its fluxing action on siliceous constituents.

   Most minerals found in the mineral matter of coal are not volatile at the flame temperatures encountered during combustion. Illite and biotite are exceptions. These minerals form a glassy phase around 1750°F and 2000°F, respectively. Illite and biotite, found in the shale and clay groups, are effectively removed by the unique countercurrent desliming step, part of the aggressive beneficiation process.

   Calcium is sometimes implicated as an element that contributes to slagging. This is true of calcium found in low rank coals. Calcium from dolomite or limestone, however, does not cause slagging at the temperatures encountered at potential slagging surfaces.

2. The quantity of ash is not excessive. Aggressively beneficiating the coal before introduction of the sorbent keeps ash levels near or below pre-established levels.

3. Higher removals of sulfur dioxide are possible due to greater calcium-to-sulfur stoichiometry. The aggressive beneficiation reduces sulfur substantially. For a given quantity of sorbent, lower sulfur levels mean greater calcium-to-sulfur ratios. Proportionately greater capture of sulfur dioxide occurs with higher calcium-to-sulfur ratios.

4. The percent removal of sulfur dioxide is good. For example, a capture of 43 percent achieved in the boiler would be considered poor if viewed as stand-alone technology. When sorbent addition is integrated with Custom Coals' aggressive coal cleaning process, total sulfur reduction increases to a very respectable 81 percent. This is sufficient to bring many coals into long-term compliance.

5. Water soluble alkalis are removed by the beneficiation process thus reducing the potential for fouling.

No additions to or modifications of the boiler are required with Self-Scrubbing Coal. It is received, stored, reclaimed, pulverized and burned the same as conventionally prepared coal.

IMPLICATIONS FOR POLISH COALS

Self-Scrubbing Coal may be particularly applicable in Poland where ash levels in coal used in the production of electricity are significantly higher than is common in the U.S. After reviewing the sulfur and ash reductions achievable through the cleaning process, a series of computer models will be utilized to project the reduction of sulfur emissions possible through the addition of limestone. By removing substantial amounts of rock and pyritic sulfur in the cleaning plant and the briquetting sorbent with the finest portion of the clean coal, the 1998 Polish emission standards for SO_2 should be achievable for almost all Polish coals.

POWER PLANT MODELING

Over the past quarter of a century there has been a consistent effort to quantify the cost savings resulting from burning cleaner coals. The culmination of that effort is a comprehensive computer model of a power plant developed by the U.S. Electric Power Research Institute (EPRI). This model, Coal Quality Impact Model (CQIM™), is a state-of-the-art engineering tool for predicting the impacts of changing feed to conventional pulverized coal or cyclone-fired power plant. The model was written by Black & Veatch under contract from EPRI. Many utilities use CQIM to evaluate the effect of changes in fuel quality on power plant performance.

CQIM uses engineering calculations to obtain energy and material balances around each major equipment system in a power plant. Performance of each piece of equipment is calculated, and a cost for each derate is predicted based on any loss of capacity that occurs and the cost of replacement power. Based on these calculations and predictions, the model provides a relative ranking of coal purchase options, either on a net-plant-heat-rate, dollars-per-ton, or mills-per-kilowatt-hour basis.

The latest version of CQIM allows the user to establish "break-even" costs for each coal. This break-even cost is the price-per-ton for the coal that will give the same cost of power generation as the user-defined baseline coal.

As part of the AID feasibility study, three Polish power stations, Dolna Odra, Kozienice and Ostroleka, are being modeled at CQIM. The clean coal information from the earlier part of the study will then be substituted in the CQIM model for the coal currently being used by the power stations. CQIM will identify any potential operating problems from the new fuel and will also quantify the operating cost savings expected to be achieved.

ECONOMICS

The cost of processing a given tonnage of raw coal through Custom Coals' aggressive coal cleaning plants is higher than processing the same tonnage through a conventional coal preparation plant. The clean coal yield, however, is also higher. This is a consequence of liberation. When middlings are crushed to liberate pyrite and rock, the question is, "Liberated from what?" The answer, of course, is coal. Typically, therefore, an additional 10 to 25 percent clean coal is the bonus for aggressive coal cleaning. The increased clean coal yield essentially offsets the higher processing costs -- and, produces an environmentally superior product.

In Poland, where it is common for power plants to burn higher ash coals the analysis of the cost effectiveness of coal cleaning needs to encompass a number of factors including heat content per ton, transportation costs and power plant operating costs impacts. In some instances, these cost impacts substantially offset the cleaning cost while also achieving significant sulfur reductions. The effective cost of the sulfur reduction becomes extremely attractive compared to other options such as flue gas desulfurization.

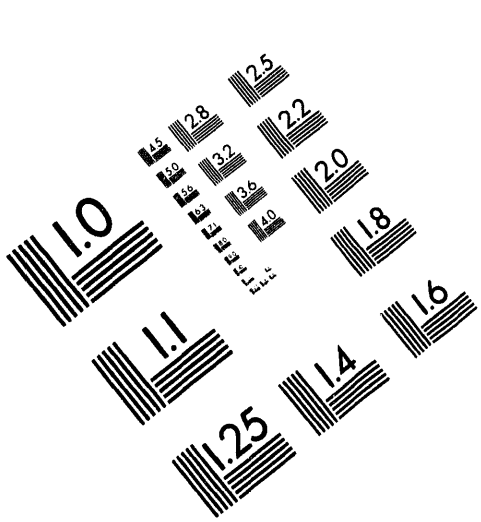
The feasibility study in Poland encompasses the development of complete capital and operating cost estimates for the coal cleaning facility. From that data the economics of utilizing coal cleaning as a pollution reduction alternative can be assessed.

CONCLUSIONS

Custom Coals has developed an aggressive coal preparation process which converts most high ash, high sulfur coals into market-competitive products, Carefree Coal and Self-Scrubbing Coal.

The process is based on isolating locked particles (middlings); crushing these particles to liberate pyrite, other ash forming minerals and coal; recovering the fine liberated coal by an efficient, novel process; drying and briquetting the fine liberated coal; and blending the briquettes with the coarse clean coal to make the final product. For coals with moderate or high organic sulfur, sorbent is added to the briquettes. This removes additional sulfur by capturing sulfur dioxide, released when the coal is burned, in the boiler.

These products have been designed to address the coal-fired power plants need to reduce emissions at the lowest possible cost and to also avoid substantial up-front capital expenditures. By incurring a modest net increase in fuel cost the power plant achieves its emission reductions and finances the cost over the life of the coal contract.



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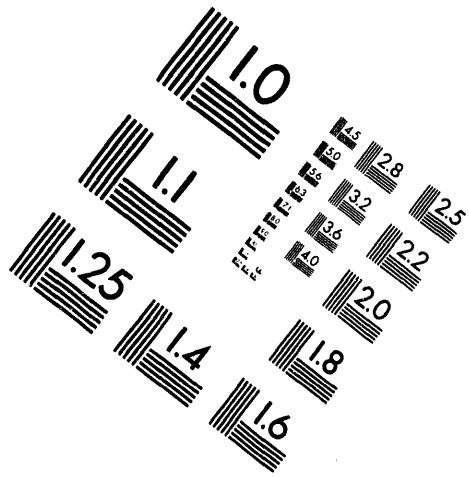

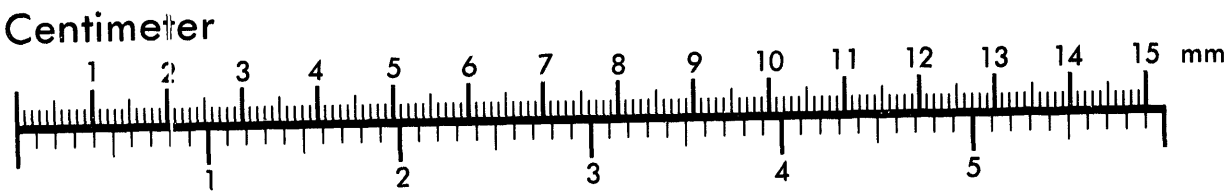

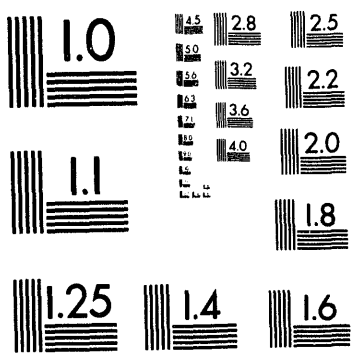

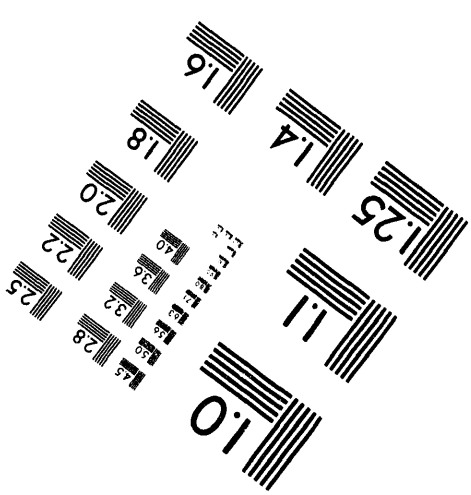

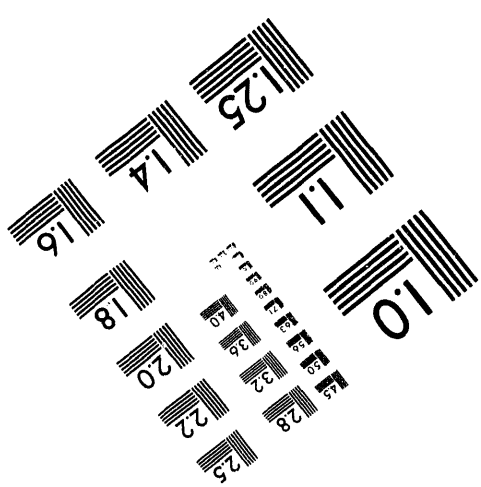

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Conference on Alternatives for Pollution Control from Coal-Fired Low Emission Sources
April 26 - 28, 1994, Plzen, Czech Republic

Gravimelt Coal Refinery Project in Northern Bohemia

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Los Angeles/Most/Steinkjer, April 10, 1994

THE GRAVIMELT TECHNOLOGY AND CZECH GCR PROJECT'S BACKGROUND

Project History

Introduction to the Czech Market

The GCR Technology was first time introduced to the Czech market during the Norwegian Environmental Days in Prague in 1990. Within end of 1990, a basic interest was established between a number of Czech companies and Ministries' representatives to make a closer evaluation of the GCR technology's options for objectives within the fields of pollution control and environmental restoration, sustainable energy supply based upon the nation's own coal resources, and at same time creating an option for the development of new production programs for the skilled mechanical industry.

Initial Assessment

The Czech GCR Project has emerged through a careful, step-wise development, which in the very beginning has included:

* Initial laboratory studies and GCR tests on various samples of Czech brown coal in order to assess the technical feasibility.
* Initial conceptual design studies in order to assess the cost profile and Czech equipment supply option.
* Initial application and market studies in order to assess the economic feasibility.

Feasibility Study

On basis of the promising results from the initial assessment, the Czech partner companies formed by the end of 1992 a "Informal GCR Consortium" as the basis for the further project development work. The GCR Project was approved and supported by the Czech Ministry for Industry and Trade.

The Feasibility Study work was based upon a contracted, joint work program that defined the task- and cost-sharing between the Czech companies, TRW and Selfint. Selfint coordinated the total Study work. Upon the Czech Ministry's recommendation, the Government of Norway granted the Feasibility Study as a part of the bilateral support program between the two countries.

The Feasibility Study was completed by September 30, 1993. The results of the Study confirmed the Project's technical and economical feasibility. There was documented a low sensitivity to technical risk and wide-ranged market options, which creating the basis for a highly profit-generating venture.

Czech Brown Coal test-runs in the TRW/DoE's GCR Pilot Plant, California

As a follow-up of the Feasibility Study, TRW made in November 1993 a demonstration operation of the GCR Pilot Plant with Czech Brown Coal. The demonstration confirmed all the previous performance studies and calculations.

In-principal Investment Conclusion

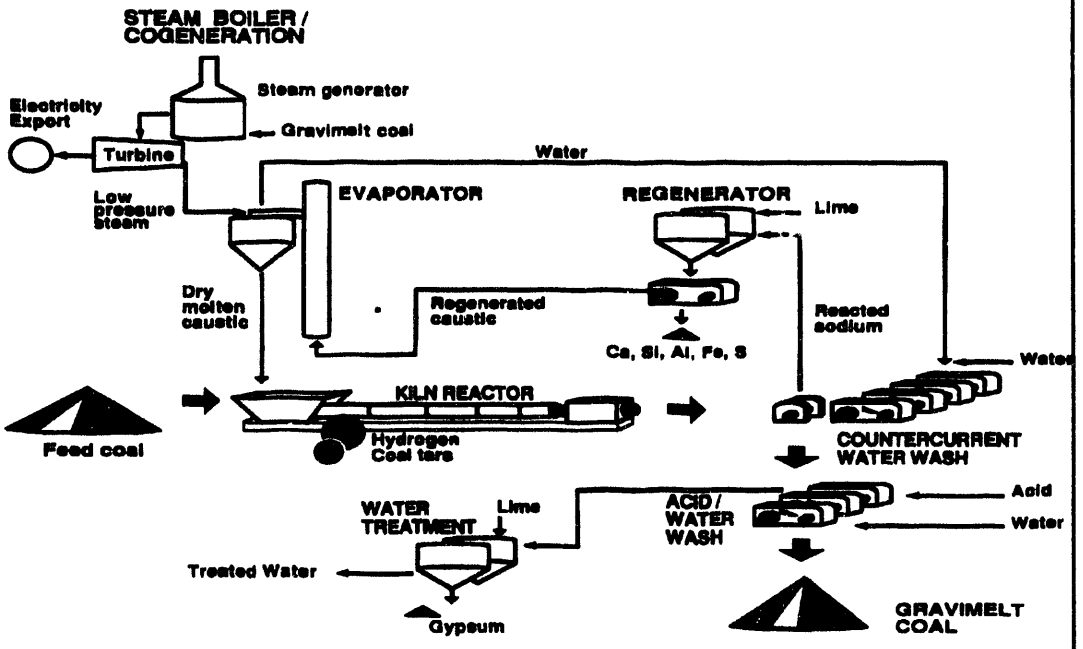
On basis of these studies, assessments etc, the Czech Informal Consortium companies made their decisions to go forward with the project, according to the realization program, aiming at a production start-up in 1998.

The TRW Gravimelt Coal Refinery (GCR) Technology

The GCR Technology is a pre-combustion coal cleaning process that removes sulfur down to a residual content below 0,2% and mineral matters to a residual ash content below 0,4%. GCR is a thermo-chemical leaching process. The plant design (see flow diagram on next page) includes a reaction section (kiln) where the impurities in the crushed coal are reacted with caustic; washing sections where ultra-clean coal is separated from the reacted caustic/mineral matters; and regeneration sections where caustic and water is recycled into the process, and the mineral matters are precipitated for recovery ans sale, or for for disposal.

All combustion of GCR Coals will meet and beat the strictest emission standards established in Western European countries.

Coal test data and engineering data for up-scaling design to industrial/commercial plants are generated at the DoE/TRW GCR integrated Test Circuit in San Juan Capistrano, California, - the GCR Pilot Plant. Since 1990, TRW has been test-operating coal samples from a number of European countries, showing technical and economic feasibility for a various selection of bituminous and sub-bituminous coals.



Gravimelt Coal Refinery Process Flow Diagram

THE GCR COAL PRODUCTS

Three Product Groups

The GCR Process is capable of producing coal products over a wide range of specifications. The actual products to be provided to the markets, will therefore be tuned to meet the various customers' requirements.

In order to summarize the variations according to applications, there are presented three main product groups according to typical applications and markets:

GCR Fuel Coal: By combustion, it meets and beats the strictest emission standards without pollution control systems.

GCR Metallurgical Coal: Ultra-Clean feed for manufacturing of the highest quality alloys and steels.

GCR Sorbent and Ion Exchange Resin: Extracts from water and waste-water: organic pollutants due to high surface area, and heavy metal pollutants due to ion exchange properties.

Typical qualities and properties as test-produced:

Czech Brown Coal Analysis	ROM Brown Coal Input to Refinery	GCR Product Coal, Alternative 1	GCR Product Coal, Alternative 2
Sulfur, %	1,5 - 4,5	0,1 - 0,2	0,1 - 0,2
Ash, %	12 - 30	0,1 - 0,5	3 - 10
Heat, MJ/Kg	7 - 15	32	30
Volatiles, %	31 - 40	25 - 35	25 - 35
SO_2, mg/Nm^3	6000 - 18000	200 - 400	200 - 400
Ash, mg/Nm^3	25000 - 60000	200 - 400	2500 - 9000

Limited Focus of this Paper

This paper will elaborate on the GCR Fuel Coal and its applications. Detailed information about the GCR Metallurgical Coal and the GCR Sorbent and Ion Exchange Resin is however available upon request, see contact addresses at the end of this paper.

The GCR Fuel Coal

The GCR Fuel Coal will be available as:

* Micronized coal feed (70-80 % at 200 mesh)
* Pelletized of Briquetted to sizes compatible with current furnaces
* Slurry, coal-water mixture or coal-oil mixture (CWM or COM)

These coals can be used in standard pulverized coal burners (micronized) and in boilers, heaters and stoves (pellets and briquettes). The heat release is similar to oil. Combustion tests are performed by US DoE's Pittsburgh Energy Technology Center, and provides detailed data for the further application assessments.

THE CZECH GCR PROJECT IN NORTHERN BOHEMIA

The Basic Business Idea for the Fuel Market

The basic idea is to provide a ultra-clean GCR Fuel Coal, derived from Czech brown coal, that allows for a combustion that meets and beats the pollution control standards without the use of costly flue gas treatment system or any other pollution control remedies. This is the basic energy and environmental opportunity at a price level comfortably price competitive with any environmentally safe alternative. This allows for a continued utilization of the national coal resources as a broadly applied energy strategy also under stricter and safer environmental standards. This opportunity is of course important not only to the coal-mining industries, but to the nation as a whole.

The Czech GCR Consortium

The Consortium is under formation according to Czech corporate law with the following participants and shares of responsibility:

Most Coal Company j.s.c.	40%
North Bohemian Mines Chomutov j.s.c	40%
Vitkovice j.s.c.	20%

VUHU - Brown Coal Research Institute j.s.c.

The Czech GCR Consortium Partner Companies

Most Coal Company j.s.c.
is established as a independent company since January 1, 1994. In 1993, the company mined and sold 25,8 millions tons of brown coal, creating a turnover of 12 billions Kcs. The company employs 16.366 people.

North Bohemian Mines Chomutov j.s.c
is established as an independent company since January 1, 1994. In 1993, the company mined and sold 21,3 million tons of brown coal, creating a turnover of 7,9 billions Kcs. The company employs 8.785 people.

Vitkovice j.s.c.
Vitkovice was established, and has been in business since 1828. Vitkovice is the largest metallurgical/engineering enterprise in the Czech Republic. The production range is broadly scoped, for example: Metallurgical production works, Engineering production of heavy equipment, Industry boilers, energy and electro-technology, Production of technical gas, New production lines within environmental applications. Vitkovice is exporting to 60 countries world wide. In 1993, Vitkovice created a turnover of 21,8 billions Kcs. The company employs 29 900 people. Vitkovice wants to supply to the construction of GCR plants engineering and design services, equipment and parts, and maybe turn.key factories. Vitkovice wants also to supply equipment to the utilization of the unique capabilities of the GCR coal products, water treatment plants are examples.

VUHU - Brown Coal Research Institute j.s.c.
is working within the fields of research and development of engineering technologies for mining industry. Important activities are Geological activities, Geotechnical services and services in environmental protection technologies. Number of employees is 130.

GCR Bohemia j.s.c.
The Consortium will form a separate company GCR Bohemia j.s.c. for the purpose of construction and operation of the first GCR plant unit.

The Western Partners are the following:

TRW Inc.
is a major U.S. corporation within the industrial sectors of Space and Electronics, Automotive and Information Technology. Annual turnover of this 74.000 population company is approximately USD 8 billions. TRW has developed the GCR Technology under contract with U.S. Department of Energy since 1978, and holds all patents.

Selfint a.s
is a joint stock company, established Steinkjer, Norway. Selfint's line of business is consultancy services within industrial applications of environmental technologies, technology transfer and international market development.

Selfint supplies business development services to the Czech GCR Consortium. Selfint is since 1990 TRW's exclusive European Agent for the GCR Technology.

GCR Norway a.s
is established for coordinating western venture investors and partners for injecting equity capital to the GCR Consortium.

Western Equipment Suppliers
are in the process of being contracted as partners to the process realization.

The Licensing Agreement
is the tool for the technology transfer and the basic requirement for the Czech GCR Project's realization. The format of this agreement has therefore been an integrated issue during the Czech Consortium Companies', TRW's and Selfint's cooperation in the GCR Project's development program since 1990.

The Agreement is to be effective by July 29, upon acceptable completion of the large scale coal pilot ITC-operation, the marketing/sales work, and a profitability review on that basis.

Project Key Economic Figures

The profitability has been calculated in a Feasibility Study according to World Bank format. The Project is approved by the Czech Ministry for Industry and Trade for realization.

The follow-up Project elaboration, has confirmed the Feasibility Study's profitability assessment according to the following, preliminary numbers:
Internal Rate of Return, Fixed Prices: > 21 %
Return on Equity, Fixed Prices: > 35 %

The Project's income base is calculated according to sales programs for the domestic and the export markets for each of the GCR product groups:

GCR Fuel Coal	200.000 tons/year
GCR Metallurgical Coal	150.000 tons/year
GCR Sorbent and Ion Exchange Resin	22.000 tons/year

Project Risk Factors' Economic Impact

GCR Technology's Performance Risk:
The Czech GCR Plant will be the first, commercial plant based upon the new GCR Technology. This first plant will be of approximately 10-15% of a full scale. Engineering/design work and product application tests has been conducted since 1978 by TRW, US DoE's Pittsburgh Energy Technology Center and R&D institutions contracted by DoE for that work. This documentation shows limited economic impact of risk factors such as #\capital cost, #\production efficiency, #\operating costs.

Markets' Performance Risk:
Because the Czech sub-scale plant will represent supplies of marginal volumes to the markets, this Project has the opportunity to take advantage of specific market niches for ultra-clean coals, and also of the increasing international market for clean coals. This is a position that creates basis for a high average selling price.

For larger-scale GCR plants, the GCR Fuel Coal prices will compete comfortably with end-of-stack pollution control systems and alternative energies.

The GCR Project in-market prices are seen as:

GCR Fuel Coal:	90-120 USD/ton.
GCR Metallurgical Coal:	160 - 200 USD/ton.
GCR Sorbent and Ion Exchange Resin:	1200 - 2200 USD/ton.

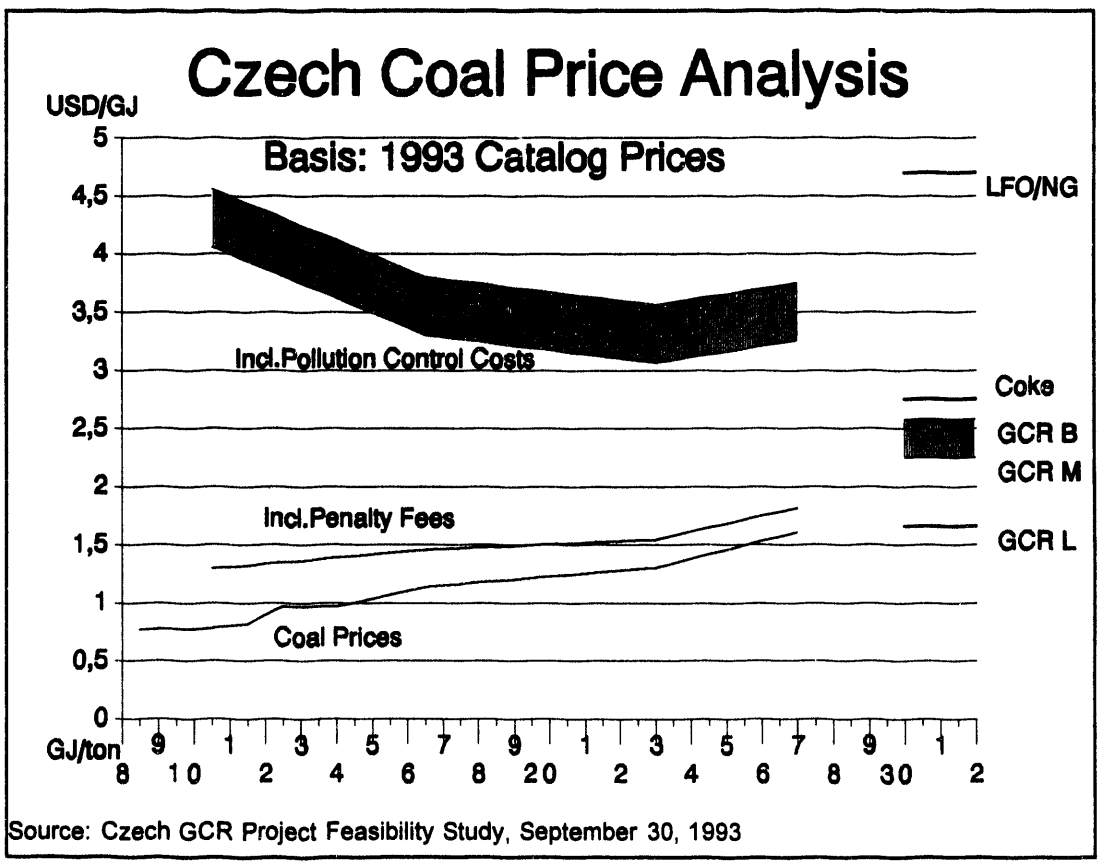
Political Risk:
There is a stable political situation in the Czech Republic. The Czech economy is in a strong process of integration into the Western market economy. The scenario for the up-coming development does not indicate any substantial risk for political back-lash or the enforcement of any un-known regulation that can damage the investments' viability.

Product handling risks
Explosion danger is less than for unrefined coal, because gaseous methane and hydrogen are removed and used as energy to the process. The major mechanism for self-ignition (pyrite interaction with oxygen from air) is eliminated because pyrite is totally removed.

APPLICATIONS, COAL USER'S ADVANTAGES. - MARKETS

Pollution Control Costs, Coal Prices and GCR Fuel Coal Price Comparisons

GCR Coal is a refined coal product that allows for combustion of the coal without the use of costly flue gas treatment systems that derate the efficiency of the utilities for generating electric power. The GCR Fuel Coal can be used in stoves, heaters and small boilers with emissions similar to the case of Light Fuel Oil or Natural Gas. GCR Coal will meet or exceed U.S. and European regulations for combustion without expensive FGD systems. In the Feasibility Study, we have been able to calculate energy price comparisons on basis of (a) the on conceptual designs for large and small scale GCR plants, (b) Czech energy market prices and supply conditions in 1993, (c) pollution penalties established by Czech law. The calculation is made on a typical boiler size of 140 MWe, and is based upon computerized comparison models. In order to facilitate direct comparisons, all prices are converted to $/GJ.



Source: Czech GCR Project Feasibility Study, September 30, 1993

Small Scale Fuel Consumers

Characteristic for the smaller energy generating coal-fired units (stoves, heaters, boilers etc) is that the installation of pollution control systems is too expensive, and that the only available strategy for pursuing environmental goals is to change the source of energy supply into a cleaner alternative.

Imported, expensive light fuel oils (LFO) and natural gas (NG) has for years been the standard solution, and will for sure take a higher market share. Natural gas and oil must be imported, and to a price far higher than domestic coals. Added to that comes investments in infrastructure and home heating systems.

The GCR Coal solves the small sources pollution problem, and is economically superior to the oil or natural gas substitutes.

The GCR Fuel Coal

Combustion testing has been performed by three organizations in the U.S. (DoE, Pittsburg Energy Technology Center, University of Arizona and EER Inc). Basicly, the conclusions are:

* Ignition characteristics are acceptable
* Mid range char activity is not greatly effected, and is comparable to characteristics of similar rank coal.
* Slag deposit growth is slower - fine ash size reduces the inertial impaction and increased ash viscosity reduces adherence.
* Staged combustion tests show potential for lower NO_x while unstaged testing shows anticipated NO_x levels.
* There is no noticeable ignition delay
* Temperature profiles are comparable to untreated coal.

Combusters for GCR Fuel Coals

Due to the purity, the ignition characteristics and the temperature profiles, there is no significant compromise involved when adapting GCR fuel in small heating systems. Available fuel handling and combustion technology implies that coal-based fuels can meet standards of performance required for widespread acceptance within the sectors of small energy generators within home heating, local and district heating, industry, power generation etc.

In the burners and feed systems that so far is tested with GCR Fuel Coal, there is not indicated need for substantial modifications. This has however to be assessed for each type of combustion system, but such adjustments are not regarded as a major problem. Boilers designed for firing oils, can easily burn GCR Fuel Coal as slurry. The performance will correspond to that of for example conventional oil-fired residential heating systems.

Safety and Handling Parameters

Since the iron pyrite, - which is often considered to be an important factor in ignition and weathering, - is removed, this mechanism of self-ignition and weathering is eliminated compared to untreated coal. The surface of the GCR Coals are blanketed with carboxyl groups that are essentially immune to further reaction with oxygen from air. GCR coals have been stored for periods up to one year in a various forms and conditions with no indication of self-ignition or explosion, or even of weathering.

The GCR Fuel Coal storage and transportation can take the forms that follow from the customer's requirements. That is (a) in tanks as powder or slurry, or (b) on trucks and trains as briquettes or pellets or other forms of agglomerations.

GCR Fuels' Overall Economy

Preliminary calculations show that GCR Fuel Coals can be supplied at a price per energy unit of ½ to ⅔ of LFO or NG price. Compared to utilizing ordinary fuel coals, GCR fuel for home- or residential heating systems allows increased efficiency and cost-effective furnace or boiler operation. There will be significantly lower "down-time" for soot blowing and cleaning due to the very low ash content. There will be lower maintenance costs because the low sulfur content reduces corrosion of heat transfer surfaces. The filtration systems will be diminutive or eliminated, and the ash handling systems will be significantly reduced. A combustion efficiency of 99% or greater represents an important environmentally-related goal for stringent control of airborne emissions of carbonaceous particulate matter, carbon monoxide and volatile organic compounds.

Other Applications and Consumers

According to the focus of this conference, we have elaborated this paper on the opportunities for applying the GCR coals as fuel for home stoves, small and medium-size heaters for home and panel-house heating, and for small

and medium-size boilers in industry and other utilities. The GCR Coals are however an alternative and environmentally safe energy supply to a number of applications.

Large Scale Fuel Consumers
GCR Coal allows for combustion of the coal without the use of costly flue gas treatment systems that derate the efficiency of the utilities for generating electric power. GCR Coal will meet or exceed all U.S. and European regulations for combustion without expensive FGD systems.

The large power plants can utilize the GCR Coal with minor boiler adjustments and simplifying of coal and ash handling systems. GCR coal is enabling electricity production at a far higher efficiency and without adding pollution control systems. As shown, GCR-cost is only half of the FGD cost required.

Water Treatment
The GCR Coal has a large potential to the activated carbon market. The water quality standards creates a developing high value market for treatment of drinking and waste water, and opens substantial business opportunities for GCR Coal.

Metallurgical applications
The GCR coal is an ultra-clean and excellent substitute to coke in metallurgical industries. This specialized market opens business opportunities for the metallurgical industries to develop new product qualities, and thus for the GCR enterprise.

Byproduct sales
Minerals extracted from the brown coal through the refining process may under certain conditions be developed for profitable sale in markets of metallurgical and chemical industries. Under certain conditions, the byproduct income may cover 80% of total refining cost in a full scale Gravimelt Coal Refinery.

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ROLE OF FUEL UPGRADING FOR INDUSTRY AND RESIDENTIAL HEATING

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CLEAN COAL TECHNOLOGY VERSUS NATURAL GAS

Many cities and villages of central and eastern Europe are plagued by pollution from coal-burning stoves, furnaces, and small boilers. The challenge for these cities and villages is to find cost-effective means of providing heat and energy to their residents, businesses, and institutions while bringing under control the rampant pollution that has burdened these areas for decades and even centuries.

The U.S. Department of Energy recently completed a three-year, comprehensive study of the trade-offs of costs and emissions for the city of Krakow Poland. Krakow is one of those many cities troubled by coal-fired, low-level emissions. As a result of the study, Krakow found they could control 90% of their particulate emissions for a mere 11% increase in annual heating costs by deploying a variety of low-cost, coal-based technologies. Although converting to natural gas could result in a more significant 99% reduction in emissions, the cost of that conversion would be a 106% increase in annual costs.

All decision-makers in the region are facing tough environmental problems with limited financial resources. This is the dilemma of "sustainable development"; ameliorating and protecting the environment while assuring growth and sustainability of the economy. The work in Krakow has shown us that the analysis for the decision-making process must include the annualized long-term, life-cycle costs of indigenous versus imported fuels in addition to short-term, capital (equipment) costs. The costs of these decisions will greatly impact the local economy. Only if both the environment and the economy are protected will sustainable development occur.

KFx Atlantic Partners is one of those companies that offers a low-cost, coal-based solution to the environmental problems of the region.

KFx Inc. is a technology company that has developed and controls worldwide patents to the K-Fuel technologies which are expected to play a vital role in facilitating the compliance in the United States with the Clean Air Act of 1990. The technologies are also expected to play very significant roles in other countries with indigenous low-rank coal resources, such as the Czech Republic, where the challenge is to use those resources in an economic and environmentally acceptable manner. KFx operates internationally under the names KFx International and KFx Atlantic Partners.

Approximately $50 million and ten years have been spent developing these patented processes. The technologies transform high-moisture, low-heat value coal and other carbonaceous feedstocks into a lower-moisture, higher-heat value solid fuel, which can be custom designed to meet the end user requirements.

There are currently two principal series of the technology which can produce equivalent products. The first is the steam-based Series B technology which will be used at the large commercial facility to be constructed by Heartland Fuels Corporation, a holding of the American utility, Wisconsin Power and Light. This technology will be deployed in conjunction with the Thermochem Gasifier under the auspices of the U.S. Department of Energy's Clean Coal Program. The second technology is the Series C technology which we will discuss here in greater detail.

In the United States, the Clean Air Act of 1990 provides the impetus for large-scale fuel switching by utilities. Initially, the K-Fuel will be used in cyclone and stoker furnaces which were designed to use high-sulfur, low-ash fusion temperature bituminous coal. The modification costs that a utility will need to expend to accommodate the switch to K-Fuel are minimal, whereas modification costs to scrub emissions or to retrofit the plants for the burning of oil and gas are substantial. In the United States, K-Fuel will be a competitive option because it will produce an efficient fuel product geared specifically to meet SO_2 and NO_x compliance standards at a relatively low cost.

Much like in the United States, the Czech Clean Air Act and the environmental laws of other countries in the region will have dramatic impact on the deployment of clean fuel, combustion and emission control technologies.

PROCESSING LOW-RANK COALS

The seeds for development of the K-Fuel technology were planted in the United States in the late 1970s and the early 1980s after the energy shortages of the early 1970s led American energy producers to develop the huge deposits of low-sulfur coal in the Powder River Basin (PRB) in the Western United States.

PRB coal is a subbituminous C coal containing about 30 wt % moisture and having heating values of about 18.6 MJ/kg (8150 Btu/lb). PRB coal contains from 0.3 to 0.5 wt % sulfur, which is nearly all combined with the organic matrix in the coal, and is in much demand for boiler fuel because of the low-sulfur content and the low price. However, the low-heating value of PRB coal limits the markets for the coal to boilers specially designed for burning the high-moisture coal. Thus, the advantages of the low-sulfur content are not fully available to many potential customers having boilers which were designed for bituminous coal.

Each year about 200 million tons of coal is shipped from the Powder River Basin of Wyoming. The high-moisture content and, consequently, the low-heating value of this coal causes the transportation and combustion of the coal to be inefficient. When this coal is processed to remove the moisture and increase the heating value the same bundle of energy can be shipped by using one-third less train loads. Also, the dried product can be burned much more efficiently in large and small boiler systems. This increase in efficiency reduces the carbon dioxide emissions from combustion of the coal.

Also, the processing used to remove water and restructure the coal removes sulfur, nitrogen, mercury, and chlorides from the coal. This precombustion cleaning is much less costly than postcombustion stack scrubbing.

PRB coal, and other low-rank coals, tend to be highly reactive when freshly mined. These reactive coals must be mixed regularly (every week or two) when fresh, but become somewhat more stable after they have aged for several weeks. PRB coal is relatively dusty and subject to self-ignition compared to bituminous coals. PRB coal dried using conventional technology is even more dusty and more susceptible to spontaneous combustion than the raw coal. Also, PRB coal if dried at low temperature typically readsorbs about two-thirds of the moisture removed by drying. This readsorption of moisture releases the heat of adsorption of the water which is a major cause of self-heating of low-rank coals at low temperature.

Ingram and Rimstidt[1] attribute increased moisture in naturally oxidized coals to the effects of weathering and an increase in organic acids, which are known to attract water to coal particles. Thus, an effective drying process must destroy or remove carboxylic acids and phenolic-like compounds to prevent readsorption of moisture.

The University of North Dakota Energy Research Center has explored the use of various techniques to upgrade low-rank coals[2]. They found that coals processed at low temperature readsorb moisture after cooling and return to essentially the original equilibrium moisture level. In contrast, they found that the processes using temperatures high enough to alter the structure of the coal particles resulted in reduced readsorption of moisture. They also concluded that the lowered equilibrium moisture levels resulted from the rejection of carbon dioxide by the decarboxylation reactions which occur during high-temperature processing.

The readsorption of moisture by coals dried at temperatures much lower than about 260°C (500°F) is consistent with Western Research Institute experience[3].

DEVELOPMENT OF K-FUEL TECHNOLOGY

Mr. Edward Koppelman has developed technologies for over 50 years. All U.S. aircraft used during World War II used deicing and defogging equipment developed and produced by his organization. He has developed three-dimensional weaving techniques for fiber glass used to reinforce complex-shaped military components; antenna systems used on aircraft; the technology used to produce perlite insulation; and has patented processes used to dry wood under vacuum using radio frequency heating. Mr. Koppelman has also developed processes to recover furfural, carbon black, activated carbon, and sodium silicate from rice hulls and his activities have included exploration and production of oil and gas , and mining uranium.

Mr. Koppelman has worked to develop processes which produce clean-burning, high-value fuel from low-rank coals, wood waste materials, and biomass products for over 20 years. Early development work was conducted at the Stanford Research Institute (SRI) in Palo Alto, California. His work at SRI led to the development of numerous processes and many patents were awarded for these processes. The predecessor company of KFx Inc. was started in 1984 to further the development of the Series A Process developed by Mr. Koppelman at SRI.

In 1986 the Series A process pilot plant was relocated to the present site located near Gillette, Wyoming to develop the huge resource of low-rank PRB coal. Since that time KFx Inc. has developed and tested processes to upgrade PRB coal at the site. In the early 1990s Koppelman's Series B Process was tested at the same site. After successful testing, the technology for the Series B Process, in which coal is heated by direct contact with steam at high pressure, was licensed to Heartland Fuels Corporation.

This development work, combined with Koppelman's long experience, has resulted in the Series C Process which is based upon the following principles:

- Nearly all of the moisture is removed in a efficient manner
- Decarboxylation is caused to remove much of the oxygen

- Particles are restructured and shrink during processing
- Sulfur content of sulfur-bearing coals is reduced

The above process concepts require that coal be heated to the range of 325 to 475°C (600 to 900°F) under pressure to confine condensible volatiles within the particles, and that gases and condensate be removed during the processing. The use of pressure combined with careful control of temperature causes nearly all of the energy content of the feed coal to be retained in the process while creating a high-calorific value product

Economic constraints make the process low-cost and efficient. The Series C Process avoids moving coal into or from high pressure. Condensing steam, formed from moisture in the coal, causes efficient heat transfer and uniform heating of particles.

Koppelman has conducted bench-scale tests using the Series C Process to show that subbituminous Powder River Basin (PRB) coal can be converted to a higher-value product having the characteristics of a low-sulfur bituminous coal. In the process, PRB coal (Table 1) having a heating value of 19.5 MJ/kg (8367 Btu/lb) is upgraded to a higher-rank fuel having a heating value of about 28.8 MJ/kg (12,400 Btu/lb) by removing all of the moisture and by reducing the oxygen content of the coal from about 29 wt % (dry basis) to about 7 wt %. The sulfur content of the low-sulfur PRB coal is further reduced in the process resulting in a product containing about 0.56 lb of SO_2/million Btu (Table 2).

The successful conclusion of the bench-scale tests resulted in the need to construct and operate larger-scale test facilities.

OBJECTIVE OF DEMONSTRATION PLANT TESTS

The objective of the tests described in this report is to demonstrate the Koppelman Series C Process in a 450 kg (1000 lb) capacity per batch demonstration plant by upgrading PRB coal to a high-Btu, low-sulfur, fuel. Our early efforts focused upon determining the time-temperature-pressure cycle required to alter the structure of the product to produce a stable, high-heating value, clean fuel from the pilot plant. We later conducted tests to evaluate the effects of varying particle size and have recently conducted tests to gather in-depth information for use in designing effluent water and gas treatment systems for a commercial-scale plant.

Table 1. Analyses of Coal Used for the Bench-Scale Tests, wt %

Proximate Analysis			Ultimate Analysis		
	As Received	Dry		As Received	Dry
Moisture	28.91	--	Moisture	28.91	--
Ash	4.81	6.76	Carbon	42.26	59.45
Volatile	32.17	45.25	Hydrogen	1.98	2.79
Fixed C	34.11	47.99	Nitrogen	1.12	1.57
Total	100.0	100.0	Sulfur	0.26	0.37
			Ash	4.81	6.76
			Oxygen	20.66	29.06
Heating value, MJ/kg	19.5	27.4	Total	100.00	100.00
Sulfur	0.26	0.37			
MAF calorific value, MJ/kg		29.4	Moisture is not included in the hydrogen and oxygen values		

lb SO_2 per million Btu = 0.63

Table 2. Properties of Product Made from Bench-Scale Tests Using the Series C Process, wt %

Proximate Analyses				
Sample	4FT87	4FT89	4FT91	4FT92
Moisture	0.00	0.00	0.00	0.00
Ash	7.41	7.56	7.40	7.75
Volatiles	39.67	36.58	38.68	37.90
Fixed C	52.92	55.86	53.92	54.35
Total	100.00	100.00	100.00	100.00
Heating value, MJ/kg	28.70	29.33	28.96	28.89
Sulfur	0.35	0.34	0.35	0.35
MAF calorific value, MJ/kg	30.99	31.73	31.27	31.32
lb SO_2 per million Btu	0.57	0.54	0.56	0.56
Ultimate Analyses				
Moisture	0.00	0.00	0.00	0.00
Carbon	79.39	79.77	79.08	80.07
Hydrogen	3.46	3.41	3.47	3.60
Nitrogen	1.63	1.79	1.75	1.73
Sulfur	0.35	0.34	0.35	0.35
Ash	7.41	7.56	7.40	7.75
Oxygen	7.76	7.13	7.93	6.50
Total	100.00	100.00	100.00	100.00
Moisture is not included in the hydrogen and oxygen				

DESCRIPTION OF SERIES C DEMONSTRATION PLANT TESTS

The demonstration plant consists of coal feed and product discharge systems, a batch processor, a hot oil heating system, and effluent measurement and control systems (Figure 1). In the demonstration plant, crushed and sized coal from an enclosed bin is weighed and flows through a feed screw into a bucket elevator, where it is lifted into a feed bin located above the 13-meter (40-feet) high reactor system. The coal drains by gravity through an open valve into the top of the preheated reactor and fills the conical cavity below the reactor and the tubes within the reactor. The seats in the valve at the top of the reactor are cleaned by a blast of nitrogen gas, and the valve is then closed by a pneumatic operator. Air is swept from the processor by displacement using nitrogen gas and the pressure is then increased to about 8 atmospheres (atm) using nitrogen.

The processor is heated by a flow of 25 liters per second (400 gpm) of heat transfer fluid, which is continuously circulated through a 1050 MJ (2 million Btu) per hour (net heat transferred) heater fired with propane. As the coal is heated by transfer of heat through the tubes, the water on the coal is evaporated to form steam which again condenses and heats more coal. The condensate from the moisture in the coal, after evaporating and condensing several times, is drained from the bottom of the processor. When the coal has been heated sufficiently to alter the structure and increase the heating value of the product, the reactor is depressured. When the pressure is less than 0.3 atm (5 psig) the valve at the bottom of the processor is opened. The product falls from the reactor into a nitrogen-blanketed product collection bin. The product is then transferred by a screw conveyor to a storage bin where it is held in a nitrogen atmosphere until it is cool enough to be exposed to air (about 120°C or 250°F). The product is then weighed, sampled, and held for evaluation.

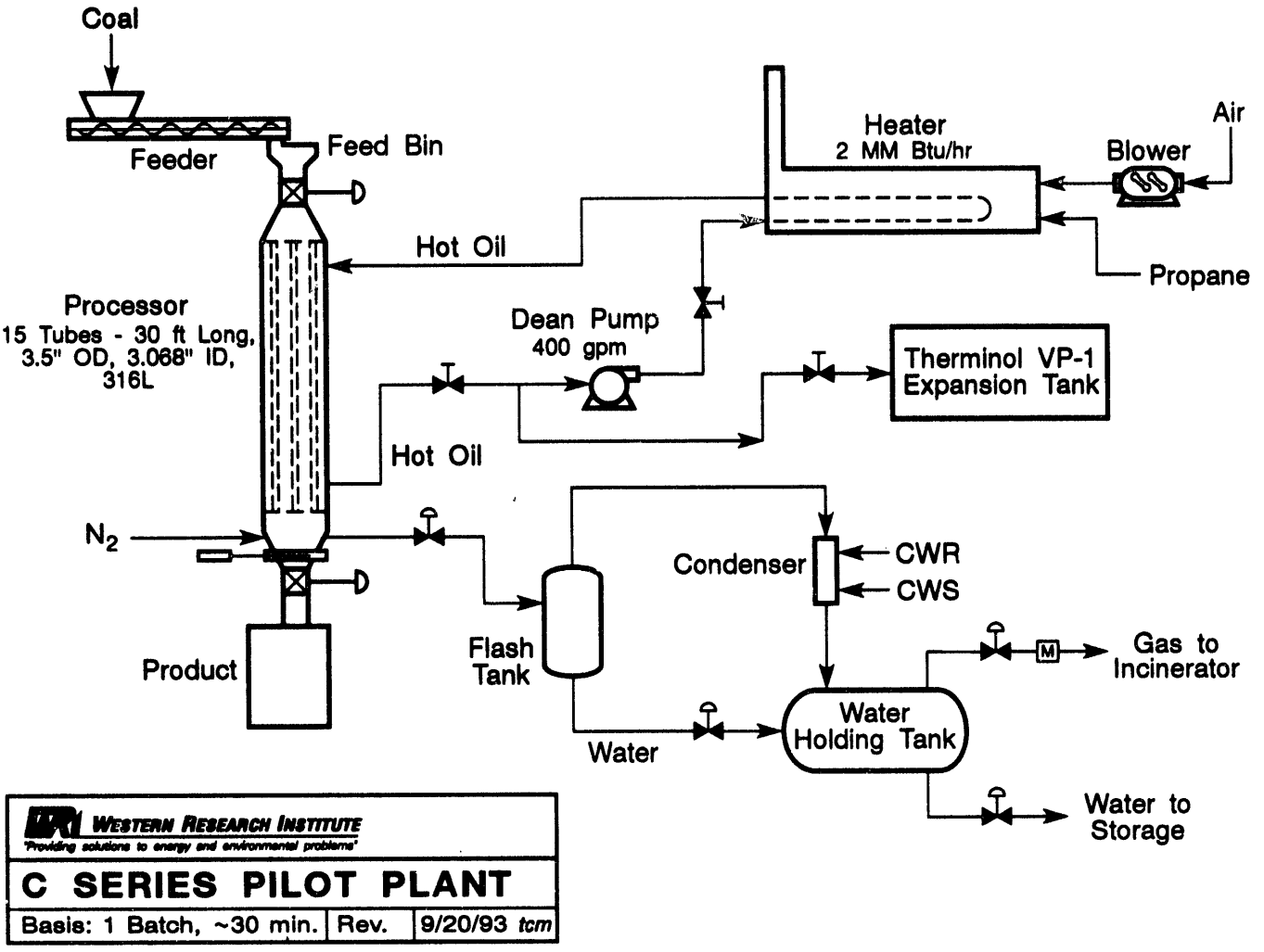

Figure 1. Simplified Flow Diagram of the Series C Pilot Plant

Condensate drained from the processor is cooled by contact with cold water in a flash tank, filtered to remove coal dust and any coal tars released during processing, and transferred to a storage tank. The gas is vented from a gas-water separator, through a gas meter, and into the stack of the hot oil heater for incineration.

Temperatures within the processor are measured by four groups containing 24 thermocouples which are strategically placed within the coal bed. The temperatures of the feed coal, the product, the heat transfer fluid flowing into and out of the heater and into and out of the processor, as well as temperatures in the effluent gas and water lines are recorded. Pressures are recorded using pressure transducers located at the top and the bottom of the processor and in the flash tank. Pressures are also measured in the heat transfer fluid at the circulating pump suction and discharge, on both sides of the filter in the pump suction line, as well as in the cooling water system, the nitrogen system, and the propane supply system. Temperatures and pressures are recorded at preselected intervals using a computer-based data acquisition system. The timer, which controls the programmable logic controller, is used to establish a time-based series of data. The temperature and pressure readings are continuously visible upon a terminal located near the processor.

The rate of water and gas production are measured by instruments selected for those purposes. Samples of coal and product are analyzed following American Society for Testing and Materials procedures. Water samples are collected and analyzed following protocols established by the U.S. Environmental Protection Agency. Gas samples are analyzed using a gas chromatograph.

Characteristics of the Fort Union Coal Used for the Tests

The PRB feed coal used for the tests described in this report was taken from the Fort Union Mine which is located adjacent to the pilot plant northeast of Gillette, Wyoming. The coal was crushed and screened at the mine and was held in 2 ton capacity enclosed bins until used for testing. Typical size distributions of coal used for tests is shown in Table 3.

Table 3. Size Distribution of Fort Union Coal Used for Demonstration Plant Tests, wt % Retained

Test Number		CSER-4	CSER-5	CSER-27	CSER-28
Nominal Size Range, cm.		1/4 by 1/2		1/4 by 3/4	
Screen	Opening				
1.90 cm sq.	1.90 cm	0.0	0.0	0.0	0.0
1.27 cm sq.	1.27	0.1	0.0	0.3	0.6
0.94 cm sq.	0.94	9.6	12.6	9.0	9.4
0.64 cm sq.	0.64	55.9	57.8	47.9	48.2
No. 6 sq.	0.34	28.4	24.5	29.0	30.7
No. 8 sq.	0.24	2.5	1.9	4.5	4.3
No. 16 sq.	0.12	1.3	1.2	4.0	3.0
No. 50 sq.	0.03	0.96	0.9	2.7	1.8
Pan		1.2	1.1	2.7	2.1

Typical composition of Western U.S. PRB coal from the Fort Union mine is shown in Table 4. The high-moisture content prevents the coal from being used in boilers designed for bituminous coal.

Design Conditions in the Processor

We selected the following product quality characteristics to produce a marketable product:

- Heating Value - 28.14-28.38 MJ/kg(12,100-12,200 Btu/lb)
- Yield - Approximately 64%
- [illegible]en Content - 7 to 10 wt % (dry basis)

The bench-scale tests indicated that the product quality characteristics were most likely to be attained by using the following conditions in the processor:

- Initial Nitrogen Pressure - 8 atm (120 psig)
- Maximum Processing Pressure - less than 55 atm (800 psig)
- Heat Time (not including filling or discharge) - 25 minutes
- Initial Reactor Temperature (when loading) - less than 395°C (740°F)

Production Simulation Tests

At first, the coal would not flow into the top of the processor rapidly because gas being displaced from the processor was escaping through the same opening. A vent tube was installed into the bottom of the feed hopper, which permitted air to escape while rapidly loading the coal. No plugging of the processor occurred during this work. After test 11, a screen was added into the condensate vent opening which permitted faster draining of the condensate. The temperature of the heat transfer fluid entering the processor is the primary control variable (Table 5). We also controlled the heating time carefully. Our initial effort with the demonstration plant was to make the processor function mechanically and to determine the inlet temperature of the heat transfer fluid needed to control the product heating value in the range of 28.14 to 28.61 MJ/kg (12,100 to 12,300 Btu/lb). Later tests emphasized variations in pressure, feed coal particle size and heating time. An inspection of the processor after test 29 showed that the center tube was free of any accumulation of particles and the tube walls were shiny clean.

Table 4. Composition of Wyoming PRB Coal Used for Tests, wt%

Proximate Analyses				
Test	CSER-24	CSER-25	CSER-27	CSER-28
Moisture	30.4	30.7	32.2	32.0
Ash	5.9	5.8	5.3	5.5
Volatiles	33.8	35.2	32.6	32.8
Fixed C	29.8	28.3	29.9	29.7
Total	100.00	100.00	100.00	100.00
Heating value, MJ/kg	18.95	18.93	18.55	18.53
Sulfur	0.36	0.35	0.31	0.31
MAF calorific value, Mj/kg	29.75	29.80	29.70	29.66
kg SO_2 per gigajoule	0.39	0.38	0.30	0.34
lb SO_2 per million Btu	0.90	0.88	0.78	0.79
Ultimate Analyses				
Moisture	30.4	30.7	32.2	32.0
Carbon	45.1	45.3	44.3	44.9
Hydrogen	2.4	2.5	2.5	2.5
Nitrogen	0.74	0.85	0.70	0.69
Sulfur	0.36	0.35	0.31	0.31
Ash	5.9	5.80	5.3	5.48
Oxygen	15.1	14.6	14.6	14.1
Total	100.00	100.00	100.00	100.00

Moisture is not included in the hydrogen and oxygen

Table 5. Conditions Used for Series C Pilot Plant Tests

Test	Coal Source	Size, inches	Hot Oil In, Temp. °F	Pressure, psig	Cycle Times, Minutes, Load-Press	Heat	Vent-Disch	Notes
CSER-1	Ft. Union	1/4 by 1/2	500					No coal
CSER-2	Ft. Union	1/4 by 1/2	500					Vent plugged
CSER-3	Ft. Union	1/4 by 1/2	500	700				Feed hopper plugged
CSER-4	Ft. Union	1/4 by 1/2	500	700	7	52	57	
CSER-5	Ft. Union	1/4 by 1/2	550	700	6	41	24	
CSER-6	Ft. Union	1/4 by 1/2	600	700	7	41	26	
CSER-7	Ft. Union	1/4 by 1/2	600	700	6	41	29	
CSER-8	Ft. Union	1/4 by 1/2	650	700	6	45	26	
CSER-9	Ft. Union	1/4 by 1/2	650	700	6	40	3[illegible]	
CSER-10	Ft. Union	1/4 by 1/2	650	700	6	41	32	
CSER-11	Ft. Union	1/4 by 1/2	650	700	6	31	21	Johnson screen in vent
CSER-12	Ft. Union	1/4 by 1/2	700	700	6	28	10	Rupture disc failed
CSER-13	Ft. Union	1/4 by 1/2	700	700	6	41	18	
CSER-14	Ft. Union	1/4 by 1/2	740	700	6	41	15	
CSER-15	Ft. Union	1/4 by 1/2	740	700	8	31	17	
CSER-16	Ft. Union	1/4 by 1/2	740	700	8	24	15	
CSER-17	Ft. Union	1/4 by 1/2	700	700	7	31	18	
CSER-18	Ft. Union	1/4 by 1/2	700	700	6	25	17	
CSER-19	Ft. Union	1/4 by 1/2	700	750	6	25	14	
CSER-20	Ft. Union	1/4 by 1/2	700	800	6	22	4	Rupture disc failed
CSER-21	Ft. Union	1/4 by 1/2	700	700	6	25	20	
CSER-22	Ft. Union	1/4 by 1/2	700	700	6	25	23	
CSER-23	Ft. Union	1/4 by 1/2	700	120	6	61	14	
CSER-24	Ft. Union	1/4 by 1/2	740	50	7	60	8	Water with product
CSER-25	Ft. Union	1/4 by 1/2	740	300	6	64	8	
CSER-26	Ft. Union	1/4 by 3/4	740	700	6	13	11	Rupture disc failed
CSER-27	Ft. Union	1/4 by 3/4	740	650	6	25	16	
CSER-28	Ft. Union	1/4 by 3/4	740	650	6	25	20	
CSER-29	Ft. Union	1/4 by 3/4	740	650	5	31	21	

RESULTS OF TESTS USING PRB COAL

Evaluation of Pressure and Temperatures in the Processor During a Typical Test (CSER-14)

Figure 2 shows the pressure in the processor, the temperature of saturated steam equivalent to the pressure (taken from steam tables), and the temperatures of coal in the tubes and in the chamber below the tubes. During the test the pressure rises quickly to about 8 atm (120 psig) as nitrogen is added. Pressure increases geometrically as the water and gas are driven from the coal and is then controlled at about 48 atm (700 psig) by venting gas and condensate from the processor.

The temperature of the coal corresponds to saturated steam temperature as the pressure rises to about 48 atm (700 psig). The presence of condensate during this period causes uniform heating throughout the processor. When the temperature exceeds about 260°C (500°F) the condensate becomes a heat sink and retards further temperature increase. Thus, control of the removal of condensate is important both for product quality and process thermal efficiency.

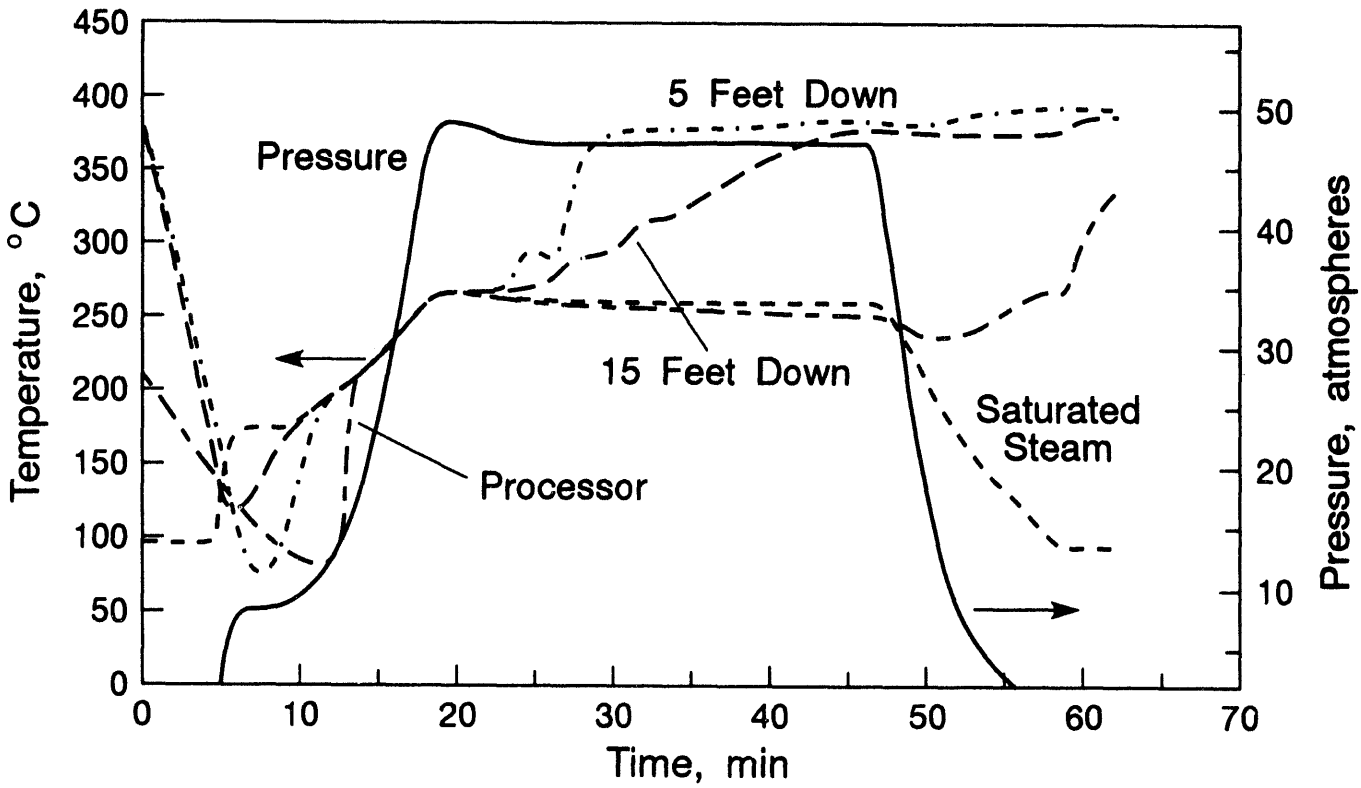

Figure 2. Pressure, Saturated Steam Temperature, and Temperature of Coal at Three Locations in the Processor During Test CSER-14

Figure 3 shows the large differential temperatures between the temperature of the hot oil and the coal early in the test. The differential temperature decreases as the coal is heated rapidly. Temperatures of the coal in the upper part of the processor increase first, followed by the temperatures in the middle, and finally the temperatures in the lower processor increase.

The presence of condensing steam causes uniform heating, but the condensate soaks up energy after the temperature reaches the saturation temperature of steam at the pressure in the processor. The high thermal efficiency for the processor occurs because condensate is removed from the processor as a liquid at low temperature. Nearly all of the energy in the steam driven from the coal is left in the coal.

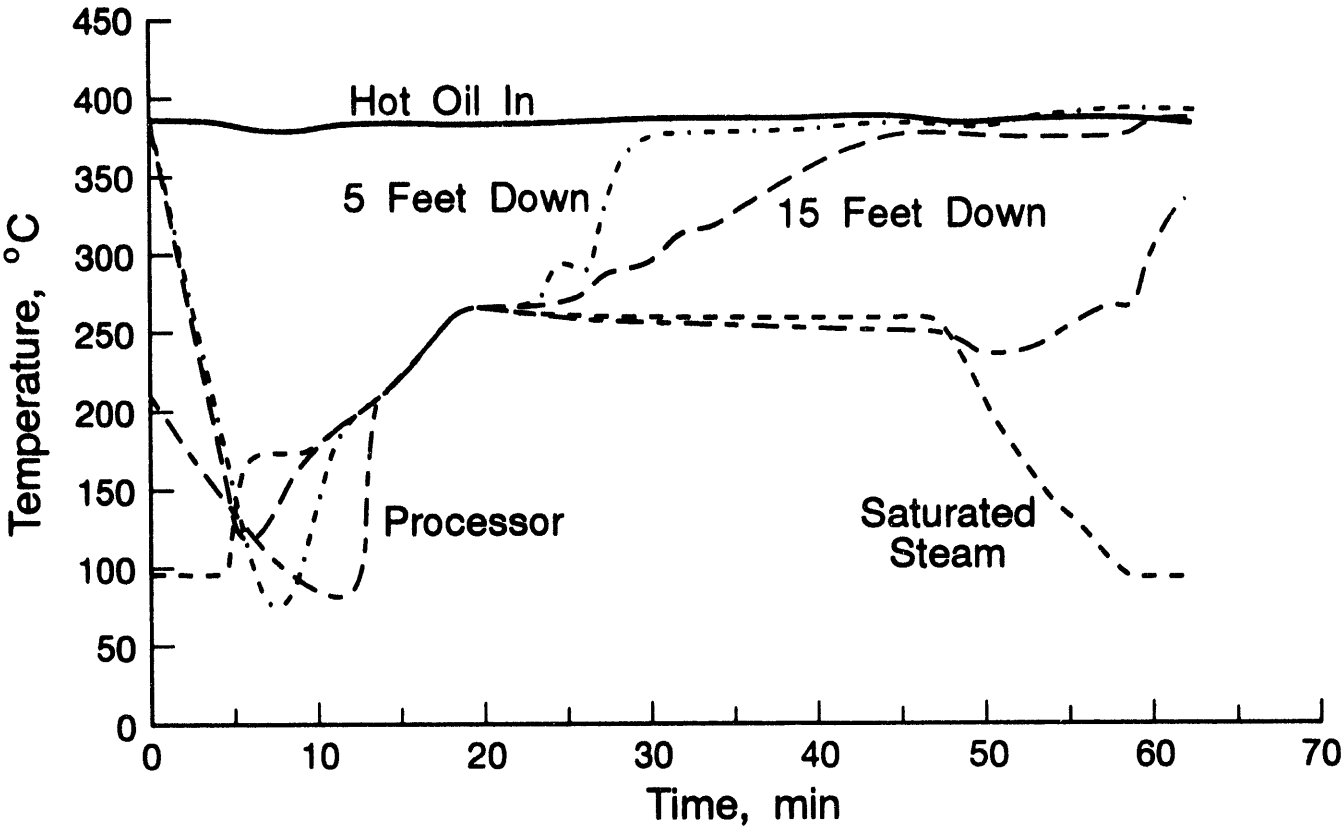

Figure 3. Temperatures of Hot Oil, Saturated Steam, and Coal at Three Locations in the Processor During Test CSER-14

The product characteristics (Table 6) are controlled by the temperature of the heat transfer fluid entering the processor and the heating time (Figure 4). Also, the oxygen content of the product decreases as the processor is operated at higher temperatures. The PRB coal used for the tests described in this paper is a low-sulfur coal in which most of the sulfur exists in the form of organic compounds. The PRB coal contains very little pyrite. The removal of sulfur is increased by using more severe processing conditions (Figure 5). The removal of sulfur in proportion to the weight of the gas and liquid byproducts is typical of organic sulfur compounds found in PRB coal[4].

Table 6 is a summary of the analyses of the products from the Series C plant demonstration tests described in the previous section of this report.

CONCLUSIONS

An extensive series of tests has been conducted using the Koppelman Series C process in a demonstration plant located near Gillette, Wyoming, USA. The demonstration plant has been operated successfully, with no plugging experienced within the processor. We have used the temperature of the heat transfer fluid entering the processor and the heating time to control the heating value of the product within our target range of 28.14 to 28.61 MJ/kg (12,100 to 12,300 Btu/lb). The oxygen content of the product decreases as the heating value increases, resulting in a product containing from 13 to 8 wt % oxygen. We have removed up to 25 wt % of the sulfur from the low-sulfur PRB coal using conditions which were not selected to maximize sulfur removal.

Typical product yields can be varied from about 63 to 70 wt % of the feed coal depending upon the severity of the conditions used. The energy content of the product varies from about 96% of the heating value of the feed coal with a yield of 64 wt % to nearly 100% energy recovery with a yield of 67 wt %.

We are continuing to conduct tests to acquire design data for a commercial plant using the Koppelman Series C Process.

ACKNOWLEDGEMENTS

This work has been supported by the U.S. Department of Energy and KFx Inc.

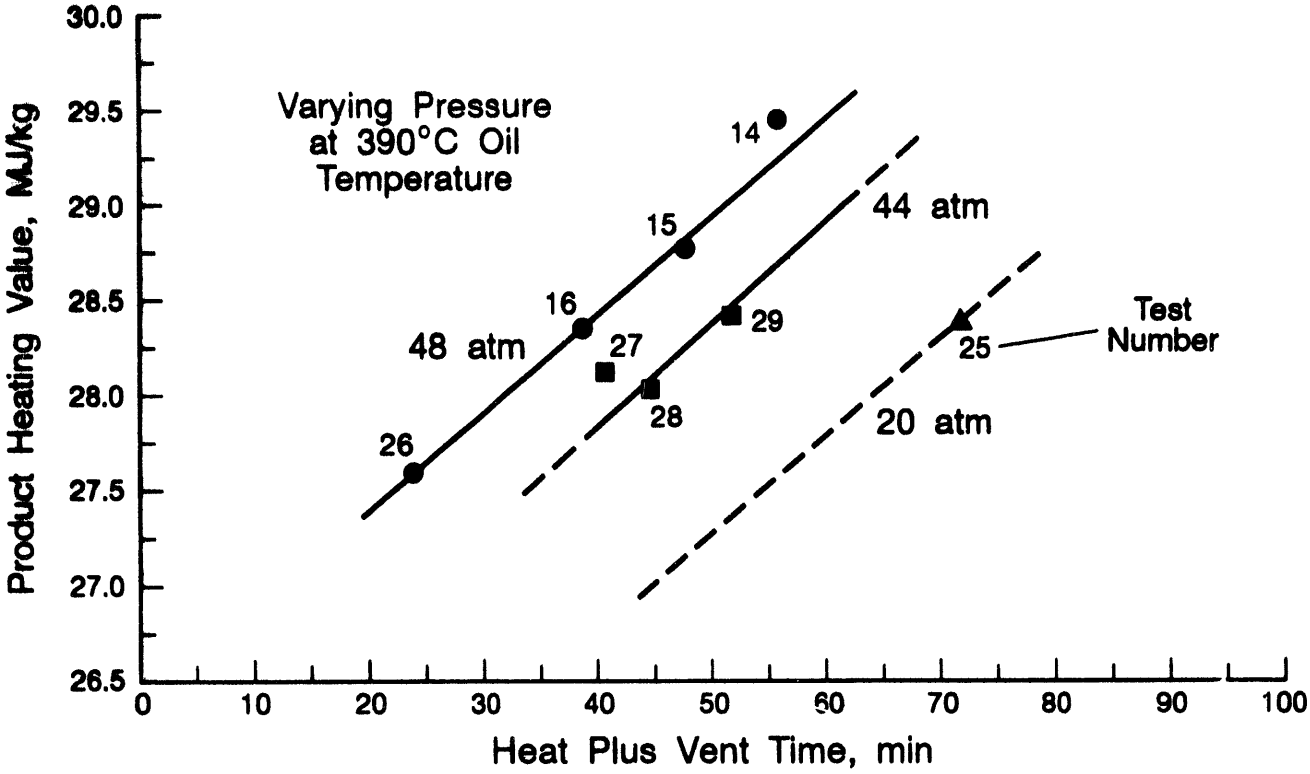

Figure 4. Use of Time and Temperature to Control Heating Value

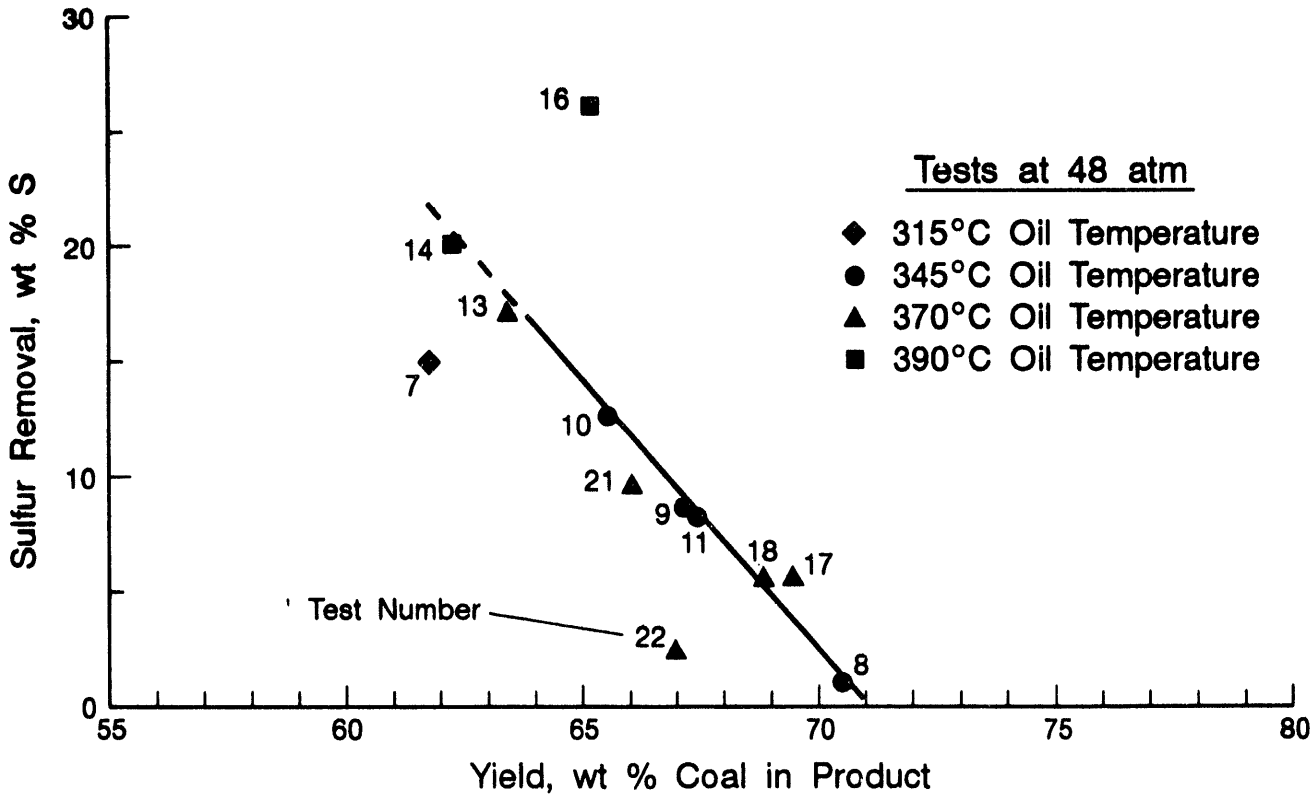

Figure 5. Sulfur Removal from Low-Sulfur Powder River Basin Coal

Table 6. Composition of Products from Typical Demonstration Plant Tests, wt %

Proximate Analyses				
Test	CSER-24	CSER-25	CSER-27	CSER-28
Moisture	1.4	0.310	0.40	1.5
Ash	7.8	8.9	8.9	8.0
Volatiles	44.5	42.3	43.6	44.6
Fixed C	46.4	48.6	47.2	45.9
Total	100.00	100.00	100.00	100.00
Heating value, MJ/kg	27.97	28.39	28.13	28.04
Sulfur	0.48	0.46	0.47	0.45
MAF calorific value, MJ/kg	30.78	31.25	31.00	30.99
kg SO_2 per gigajoule	0.34	0.33	0.33	0.30
lb SO_2 per million Btu	0.80	0.76	0.77	0.75
Ultimate Analyses				
Moisture	1.4	0.31	0.40	1.5
Carbon	70.1	72.0	70.6	69.4
Hydrogen	4.7	4.8	4.7	4.6
Nitrogen	1.1	1.1	1.1	1.0
Sulfur	0.48	0.46	0.47	0.45
Ash	7.8	8.9	8.9	8.0
Oxygen	14.5	12.5	14.0	15.1
Total	100.00	100.00	100.00	100.00

Moisture is not included in the hydrogen and oxygen

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Non-Catalytic NO_X-Reduction: Design Features and Experiences with a Brown-Coal-Fired Boiler in the Czech Republic

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Introduction

JCE-District Heating Plant in Strakonice is currently operating five steam generators for the supply of approximately 6.500 appartements and the local industry with heat. The steam generators are partly fired with brown coal (boilers No. 1,2 and 3) or heavy oil (boilers No. 4 and 5).

Like all combustion of fossil fuels these boilers are sources of different emissions and contribute to smog, ground level ozone formation, and acid rain.

A clean environment has always been a major concern of the district heating plant. Beside the installation of electrostatic Precipitators to control the particulates, the extension of the stack from 60 to 147,5 m was an important step for a clean environment. Since this time JCE is looking intensively for solutions to control SO_2 and NO_x emissions.

For controlling the SO_2 the only practical solution for the present time is to burn the more expensive low sulphur brown coal. The heavy oil is intended to be replaced by natural gas in the future, low sulphur oil is burned already. In order to control NO_x many alternatives have been investigated. After careful comparison the decision was made in favour of the NO_xOUT System for controlling the NO_x emissions of the brown coal fired boiler No. 1.

NO_xOUT Process

The NO_xOUT process removes nitrogen oxides (NO_x) by injecting an aqueous solution of special chemicals into the flue gas stream of a combustor. The overall post-combustion reaction for reducing NO_x with urea is

$$NH_2CONH_2 + 2NO + 1/2\ O_2 \quad ----> \quad 2N_2 + CO_2 + 2H_2O$$

NO_x turns into nitrogen (N_2), water (H_2O) and carbon dioxide (CO_2), which are all natural components of the atmosphere. Some trace quantities of ammonia, carbon monoxide and nitrous oxide can also form; controlling the emission of these byproducts is a part of the NO_xOUT technology.

All SNCR technologies rely on the reductive properties of ammonia based chemicals like urea, ammonia or ammonia water.

The temperature where significant NO_X-Reductions are obtained ranges from 950 - 1.050° C and is called the temperature window, as shown in figure 1. Within this window, the NO_X versus temperature curve consists of three zones: left side, right side and plateau. This shape is a result of the chemical kinetics of the process.

At temperatures lower than this window, the reaction requires longer reaction time than is typically available in most commercial combustion systems. Thus, reductions are negligible and ammonia slip is high. At the left side of the curve, NO_X-Reduction increases with increasing temperature; ammonia slips are still significant.

At the plateau, reaction rates are optimum for NO_X-Reduction; ammonia slips are decreasing. A temperature variation in this zone has only a small effect on NO_X.

A further increase in temperature beyond the plateau zone to the right side decreases reduction and also decreases ammonia slips to negligible amounts. The oxidation reactions of ammonia to NO_X become a significant path and compete with NO_X-Reduction reactions for the reagent. At temperatures beyond the right side, NO_X increases above the baseline value.

Although the reduction is less than the maximum, operation at the right side is recommended to minimize the ammonia slip.

The presence of ammonia may lead to the formation of ammonia salts (ammonia sulphate, ammonia hydrogensulphate and ammoniachlorid), which could cause secondary problems, downstream the fluegas as deposits on heatexchanger surfaces.

In order to avoid these problems, while maintaining the optimum NO_X-Reduction, the NO_XOUT process uses specialty chemicals, which shift or expand the temperature window. (Fig.2)

An independent German research institute has determined the NO_XOUT chemicals to be environmentally safe; their use does not result in addition harmful emissions listed in "TA-Luft". The handling of the chemicals is very simple. For storage, only conventional non-pressurized tanks with an overflow basin are required.

The NO_XOUT process consists of the following four steps:

1. Distribution and mixing of the liquid droplets in the flue gas stream.

2. Evaporation of the water in which the reductant chemicals are diluted

3. Decomposition of the reductant chemicals

4. Gas phase reaction between NH_2 and NO_X

In order to optimize the NO_x-Reduction and the utilisation of chemicals an even distribution of the droplets in the flue gas is essential. This can only be achieved with an injection system, which ensures a narrow droplet size distribution so that all droplets can evaporate and react within the temperature window. The selection and the design of the injection system is therefore as important as the selection and mixing of the reductant chemicals.

Beside the distribution and mixing in the flue gas, the size of the droplets is very important for the results of the process. Droplets which are too small, would evaporate too fast and lead to a reaction at a too high temperature forming NO_x.

Droplets which are too large, would evaporate too slowly so that the reaction would take place at the lower side or outside the temperature window, which would lead to an increasing of the ammonia slip, and decreasing of the NO_x-Reduction.

The NO_xOUT process uses injection nozzles, which match size and velocity of the liquid droplets to the boiler geometry and the flue gas conditions.

The velocity of the two phase mixture (liquid/pressurized air or steam) at the outlet of the nozzle is always the sonic velocity of the mixture, which is generally between 40 and 70 m/sec. The energy consumption of the applied injection system is considerable low compared to other systems.

Design basis

In December 1991, JCE awarded the contract for the delivery, installation and commissioning of the NO_xOUT System for boiler No. 1 at the district heating plant of Strakonice.

The system has to comply with the following criteria:

- NO_x-Reduction of more than 50 %
- low investment cost
- low space requirements
- short shut-down-time of the boiler
- no decrease of the boiler capacity

Futhermore, it should be considered to buy as many components as possible in the Czech Republik and to produce reductant chemicals in the country in order to save foreign currency:

The installation started in August 1992. The first installation of the injection lances could be done without shut-down of the boiler. The necessary openings have been mounted during a planned boiler service.

In December 1992 the NO_xOUT System has been commissioned and is in operation since then.

The NO_xOUT System has been designed for following boiler data:

boiler steam capacity:	36 t/h
fuel:	browncoal
flue gas quantities:	
wet-basis:	82.000 Nm^3/h
dry-basis:	75.000 Nm^3/h
oxygen content:	6 %
load range:	40 - 110 %
NO_x-baseline:	approx. 600 mg/Nm^3
reduced NO_x:	< 300 mg/Nm^3
NH_3-slip:	< 10 mg/Nm^3
reductant chemical:	NO_xOUT A

Before designing the plant temperatures have been measured at different boiler loads, in order to define the optimal position for the injectors (fig.3). Furthermore, NO_x, CO and O_2 have been measured for confirmation, respectively completion of the given flue gas data.

The required NO_x-Reduction of 50 % is relatively low and generally can be reached with one injection level, only. The objective was from the beginning to keep the concept as simple as possible, also with regard to the safe supply of chemicals. In addition to the temperature measurements the process conditions such as flue gas temperatures and flow fields at different loads were evaluated using computer aided fluid dynamics (CFD) modelling techniques (fig.4). The trajectories and evaporation of the droplets from the injectors were simulated through multi-component droplet dynamics calculations (fig.5). As the final design basis the process performance was analysed using a chemical kinetic computer model. It showed that the economical reductant agent NO_xOUT A can be used over the whole load range of the boiler.

NO_xOUT A is an aqueous solution of chemicals which contain 45 % of urea and additives which achieve the following:

- Plugging of piping- and injection system due to calcium precipitation will be prevented. This allows the usage of untreated service water.
- The vapor pressure of NH_3 will be decreased in order to prevent the typical ammonia smell of solution
- The surface tension of the droplets will be drecreased which results in smaller dropletsizes and less energy for atomization

Main components

The function and the scope of the plant can be seen on the simplified process flow diagramm (fig.6). The main components are described as follows:

Storage of chemicals

The reductant chemicals NO_xOUT A are being produced according to the prescription of Nalco Fuel Tech and delivered to the plant by a local company. There they are being stored in an non-pressurized tank with a volume of 50 m^3. The tank is equipped with all necessary armatures and alarms and is located in a catch basin which can take the total content of the tank if required, so that the chemicals cannot get into ground water.

From the storage the chemicals are pumped via a circulation pipe to the mixing and metering module. The tank and the pipes are insulated and equipped with an electrical trace heating in order to avoid the cristallisation of the chemicals at temperatures lower than 12°C. The pumping unit contains two pumps of which only one is in operation. The second one is reserve so that the NO_xOUT plant can stay in operation in case of failure of a pump.

Metering- and Mixing modul

The metering and mixing modul contains the necessary measuring and control devices to control the flow and pressure of the chemicals, the atomizing air and the dilution water. The mixer to dilute the chemical with water is also incorporated in the module.

The pressure of the liquid and air depends on the required penetration of the droplets in the flue gas stream and is in most cases betweeen 3.5 and 4.0 bar at the inlet of the injector. The air flow rate varies between 10 and 25 % (by weight) of the liquid flow rate.

The metering- and mixing modul mainly serves following purposes:

- metering of all massflows (NO_xOUT A, water, air)
- mixing of reductant chemicals with dilution water
- distribution of the liquid and the atomizing air to the injectors.
- shut off of chemical supplies in case of trouble

All mentioned parts of the modul are mounted on a base frame of structural steel. For protection of the instrumentation especially against dust, the modul is installed in a cabin.

Injection System

At lower load the boiler is operated with a grate firing only. At higher loads an additional burner with pulverized coal is being utilized which results in considerable changes of the temperature profile as well as the flue gas velocity. In order to maintain the required NO_X-Reduction at all loads two injection levels have been installed, which will be operated alternatively depending on the actual flue gas conditions. For the injection four injection lances for each level have been mounted in the walls of the boiler. Each lance bears five nozzles, which ensure an equal distribution of the diluted reductant chemical. Because of the easy handling JCE has decided to use compressed air instead of steam.

Process Control System

The principle of the process control system is shown on fig. 6.

Because of the time delay between the injection and the NO_X measurement at the stack the necessary chemical flow has to be precalculated.

Based on the boiler load signal and on a presetted NO_X setpoint the amount of chemical is calculated and later corrected by the clean gas NO_X signal.

During start up to the control loop is optimized by changing the boiler load between 30 and 100 %.

As process control a PC-based system is used. It consists of:

- the process interface, where all the signals from/to the plant are converted into digital signals
- a VGA-monitor, for the visualisation of a process flow diagram with actual signal indication
- the computer itself, for control, calculation and interlocking of all system functions
- data aquisition of important plant data.

Operating results

The NO_XOUT plant has been put into operation in December 1992. After a short period of optimization and adjustment of the automatic control-system the guaranteed NO_X-Reduction of 50 % could be maintained or exceeded over the whole load range. The consumption of NO_XOUT A is always below the guaranteed values.

The ammonia slip in the flue gas after the boiler varies between 2-5 mg/Nm^3. Negative influences on components downstream of the boiler like deposits of ammonia salts on heating surfaces could not been noticed until today.

On the diagram (fig.7) the measured NO_x value in the flue gas can be seen with and without injection. It is clearly visible how the NO_x value decreases immediately after injection of NO_xOUT A.

Fig.8 shows a constant NO_x value at variing boiler loads. It also shows that the consumption of NO_xOUT A varies with changing boiler loads. The water consumption, however, remains constant independant of the boiler load.

After several months of operation major problems with the NO_xOUT System did not occur. It still works with the first set of injectors.

Summary

In the district heating plant at Strakonice the NO_xOUT System is operating since December 1992 reliable. It shows that with only one injection level operating at the same time NO_x-Reductions of 50 % and more can be achieved with a brown coal fired boiler over the whole load range.

The results of this plant and others which are not specifically mentioned here, indicate that the reliability of a boiler practically is not being influenced by the operation of the NO_xOUT System. Regarding the economy of the process the NO_xOUT process is less costly than the SCR Process with only a few excéptions where high quantities of NO_x have to be removed.

The cost of investment depend very much on the specific requirements and are generally between 10 and 20 % of a comparable SCR-system.

The realisation from signing the contract until commissioning is possible within six months, without interrupting the operation of the boiler. Therefore, the NO_xOUT System is the ideal application for regions like the Czech Republik where a reduction of emissions like NO_x should be realized in short time.

The NO_xOUT process can be ideally combined with primary measures, in this case the investment- and operating cost could be decreased considerably. Furthermore NO_x-Reductions could be achieved which otherwise are only possible with the catalytic NO_x-Reduction.

Because of the positive experience, JCE-District Heating plant Strakonice has ordered a further NO_xOUT plant for boiler No.2. Commissioning is scheduled for June 1993.

U/HZ14VENG

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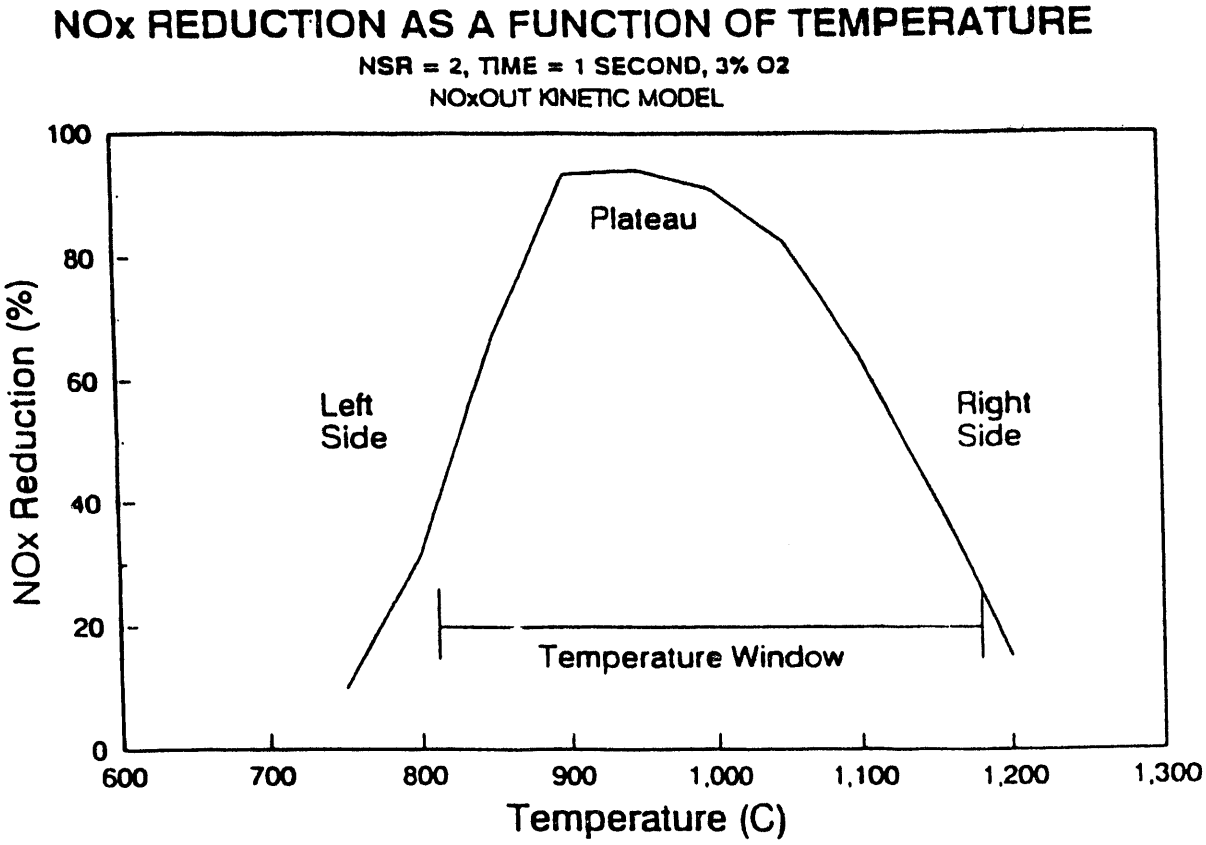


Figure 1

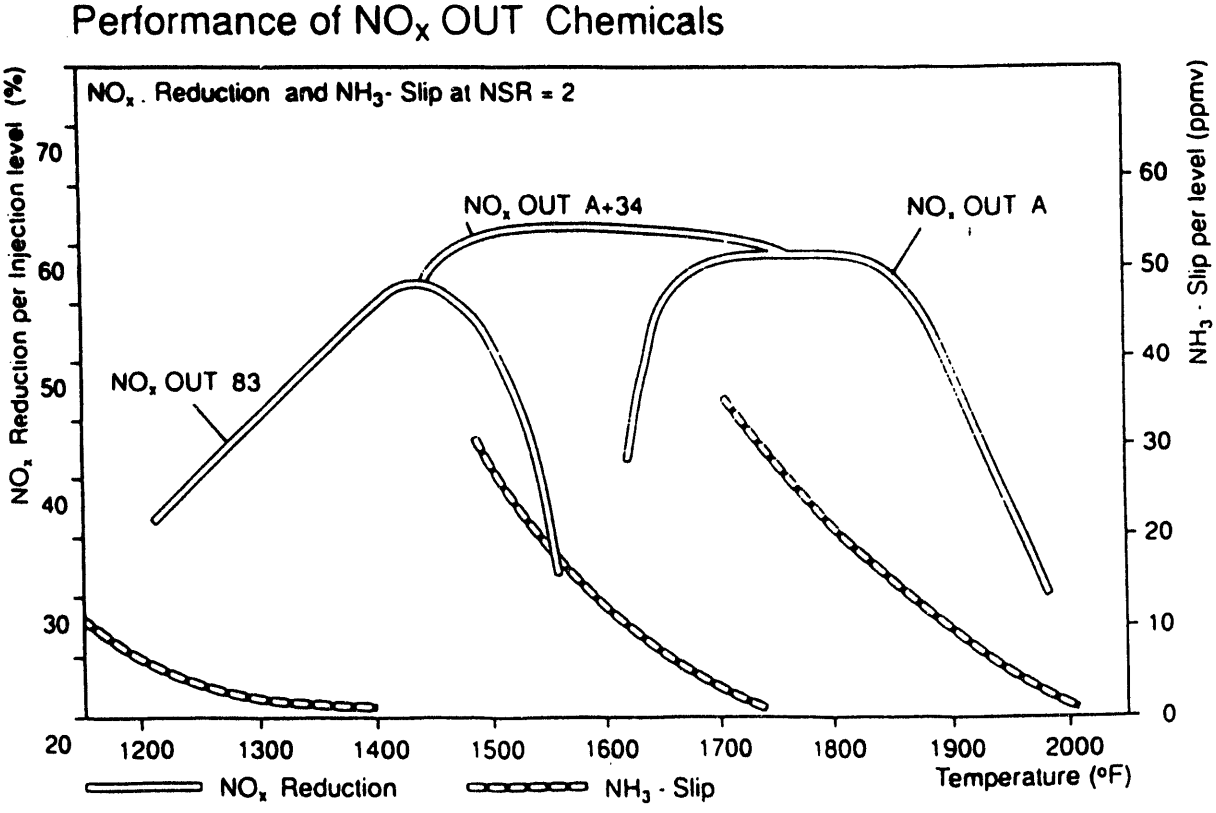
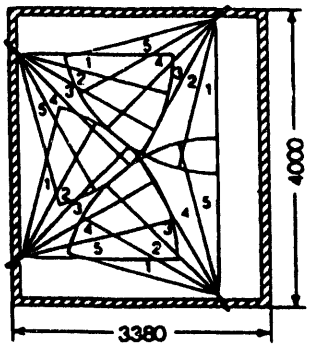
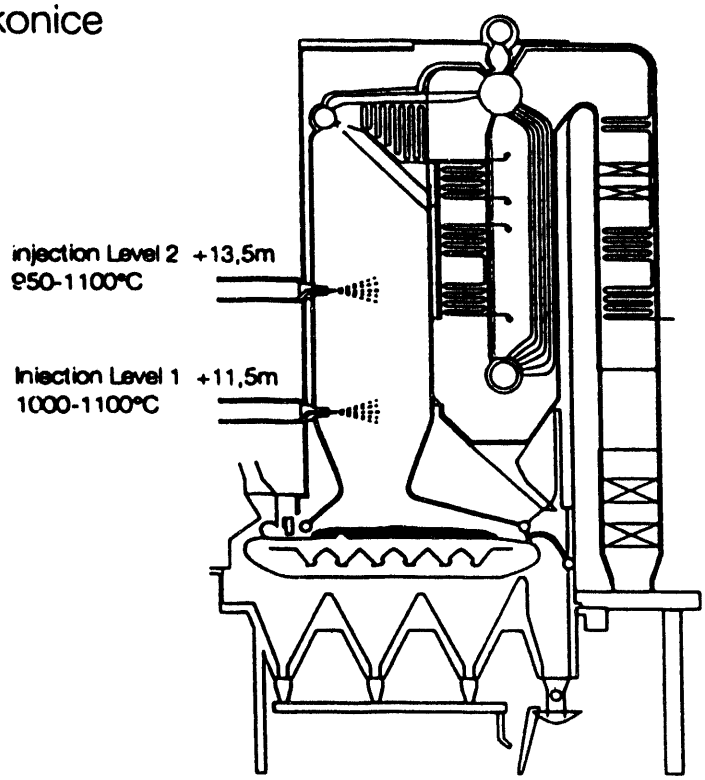


Figure 2

District Heating Plant Strakonice

Injection Level 2





Operating Data:

Boiler Steam Capacity (t/h):	36
Flue Gas Flow Rate (m³/h)	
- wet basis:	82.000
- dry basis:	75.000
Load Range (%):	40-110
Oxygen content (% by vol.):	< 6
NO_X-baseline (mg/m³):	ca. 600
Reduced NO_X (mg/m³):	< 300
NH_3-Slip (mg/m³):	< 10
Reductant Chemicals:	
NO_XOUT A (kg/h)	< 90

Figure 3

Side Sectional Temperature Profile 30 t/h Steam

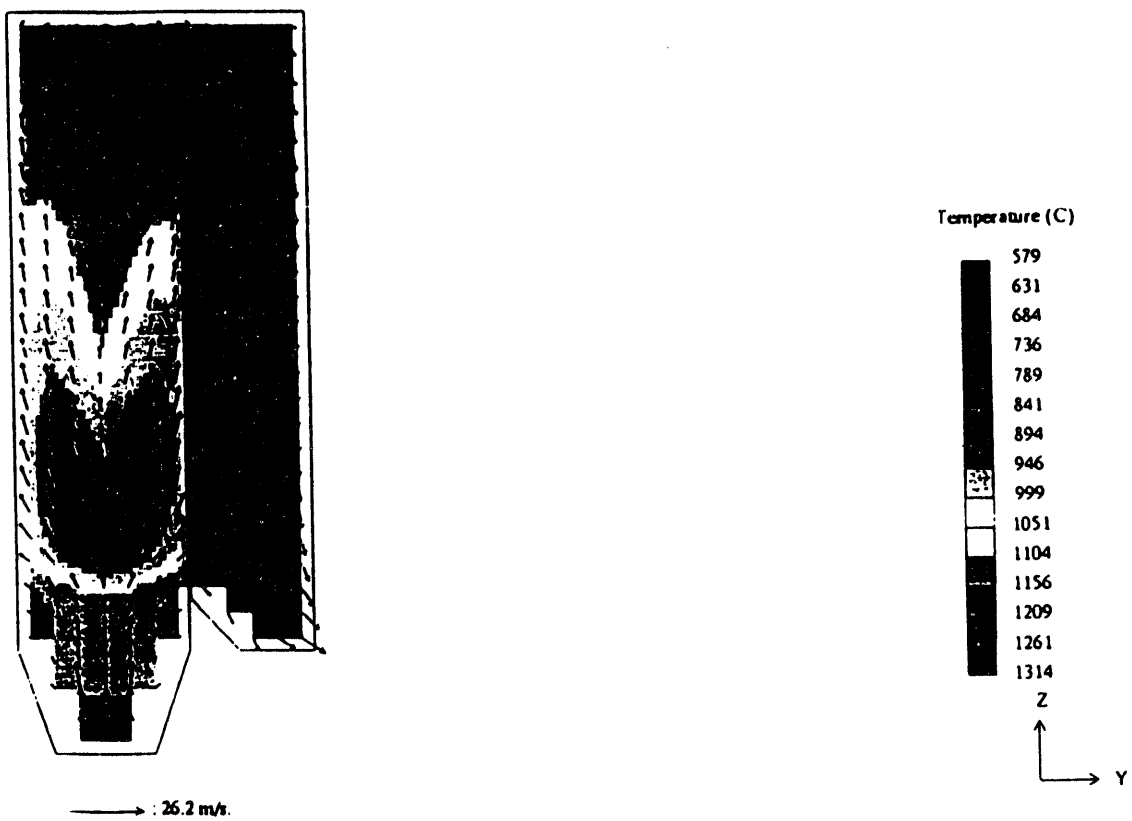


Figure 4

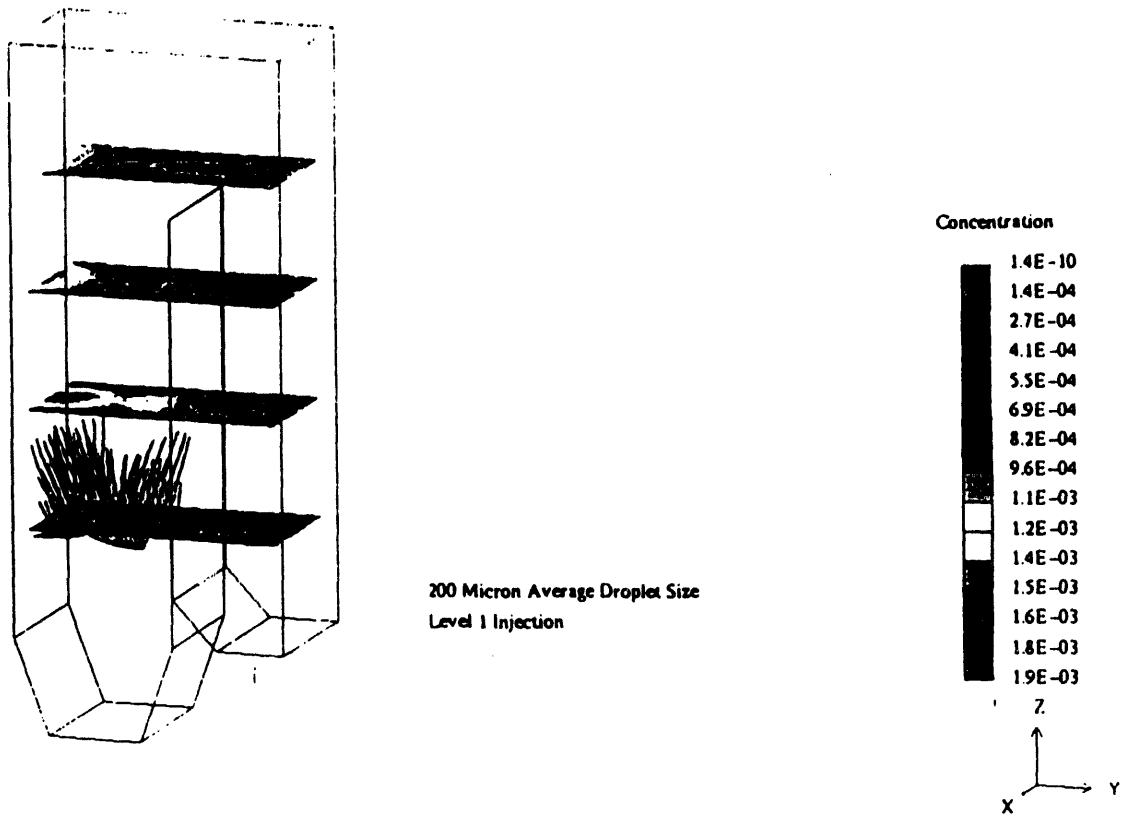


Figure 5

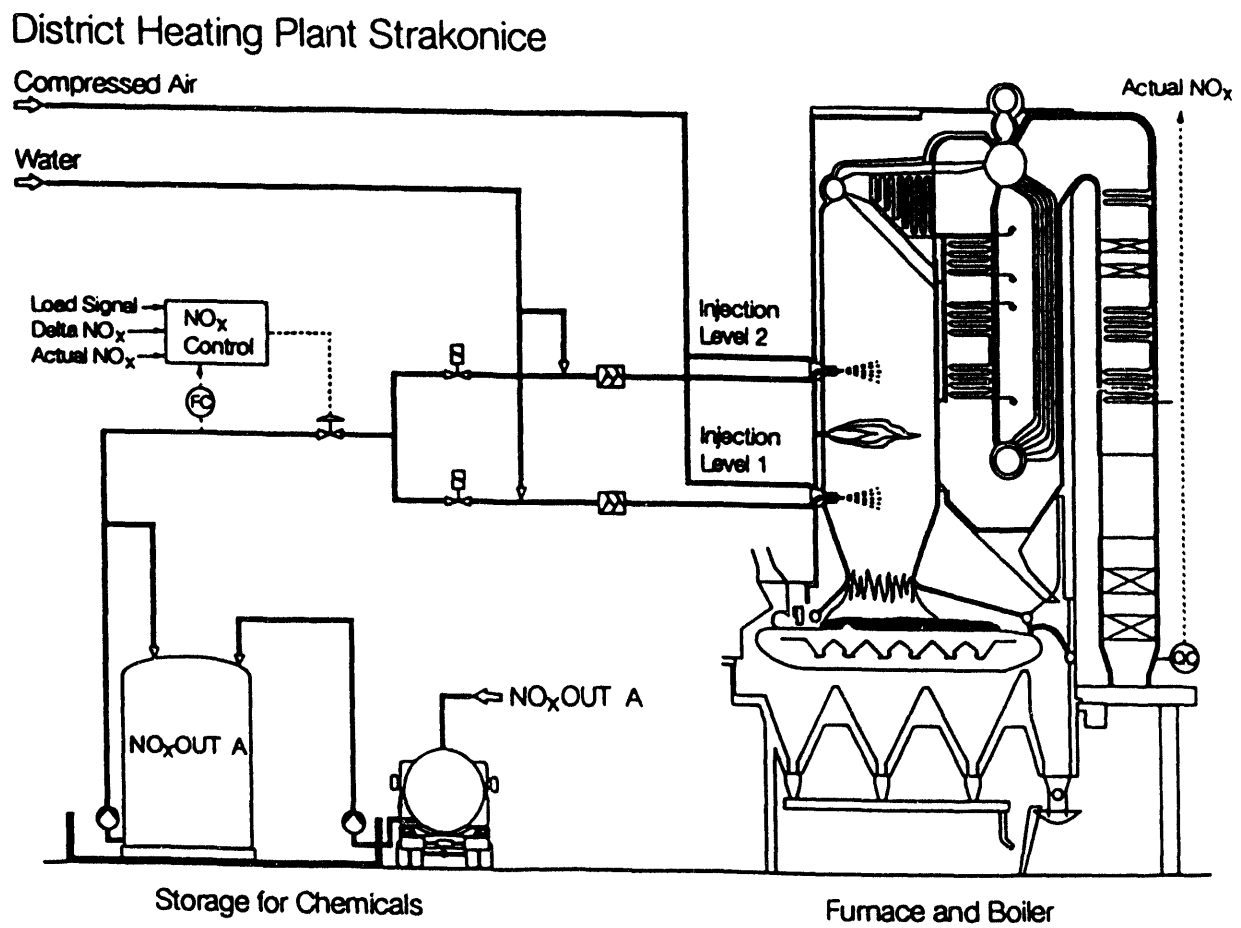
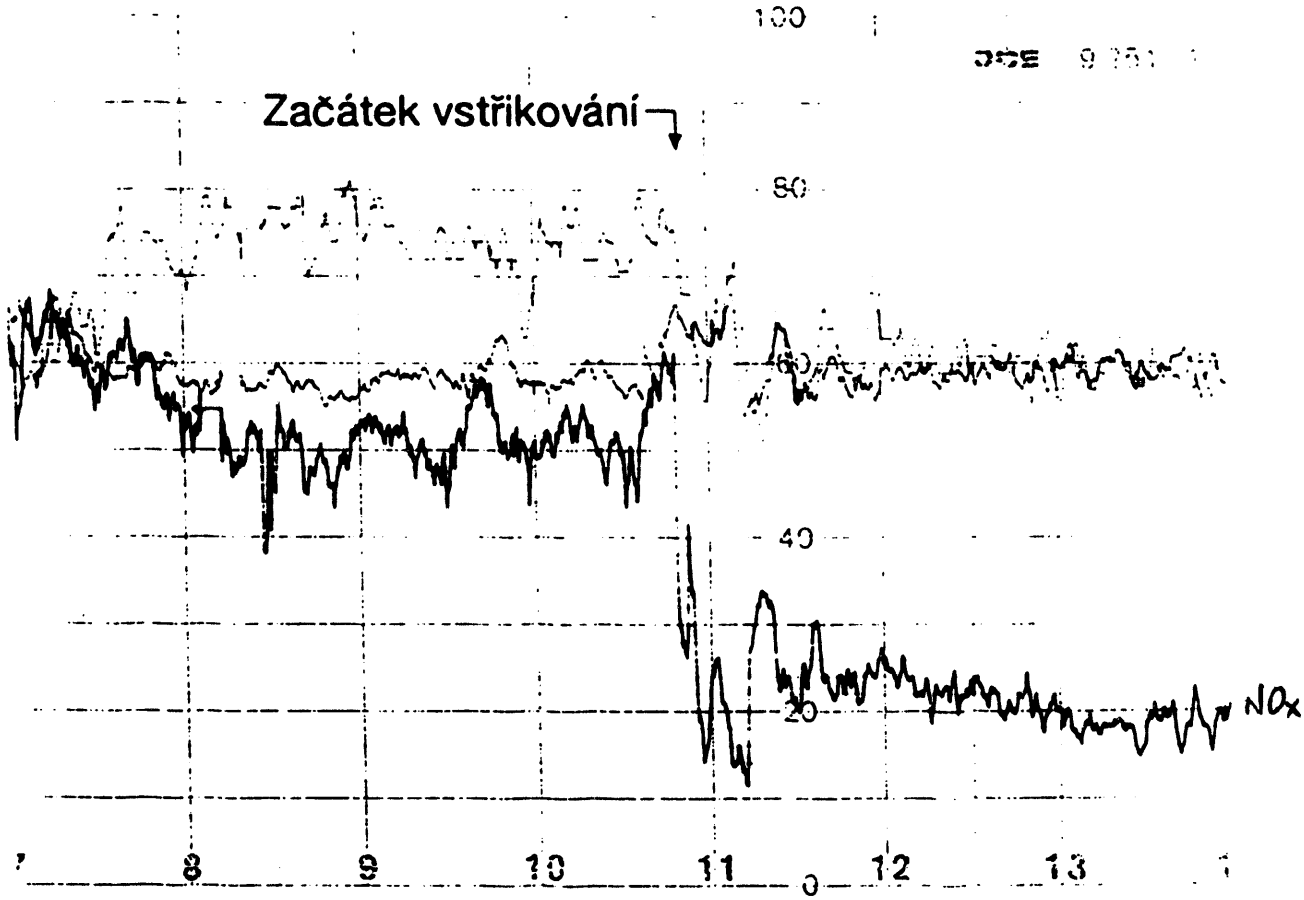


Figure 6

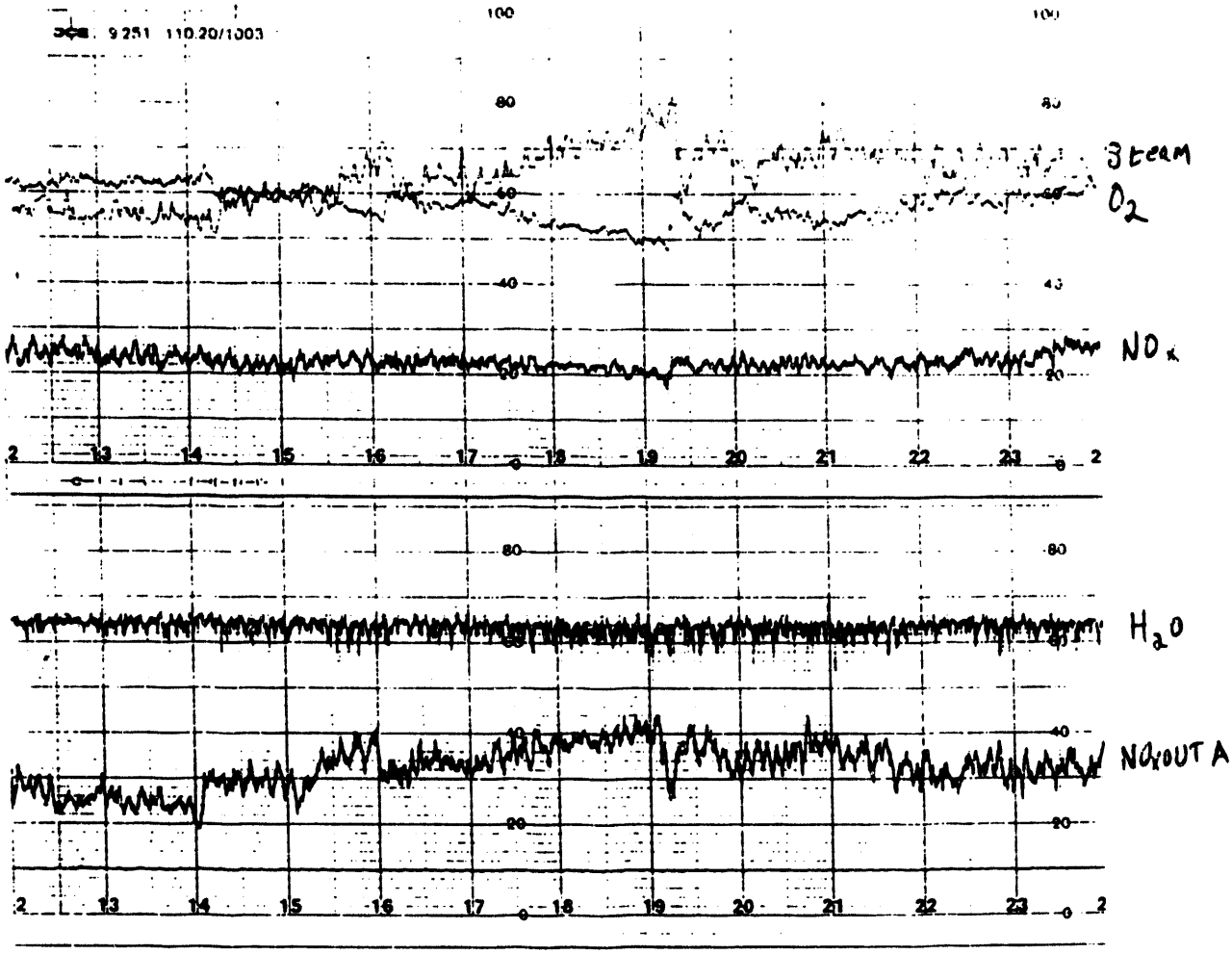
Registration of Measurements



Blue:	**Boiler load:**	**0 - 50 t/h steam**
Red:	**O_2:**	**0 - 21 %**
Green:	**NO_x:**	**0 - 1000 mg/Nm^3**

Figure 7

Registration of Measurements



Blue:	**Boiler load:**	**0 - 50 t/h steam**
Red:	**O_2:**	**0 - 21 %**
Green:	**NO_x:**	**0 - 1000 mg/Nm^3**
Red:	**Water:**	**0 - 1200 kg/h**
Green:	**NO_xOUT A:**	**0 - 300 kg/h**

Figure 8

Session VIII
Policy and Finance Issues

Chairman: Lynn Rubow, Gilbert/Commonwealth, Inc.

Bulk Power Tariffs for Polish Combined Heat and Power Plants—Carlos Yermoli, RCG/Hagler Bailey

Local Enforcement of Air Quality Standards and Economic Development—Jana Zimmer, Santa Barbara County Air Pollution District Hearing Board Control District

Energy Efficiency Project Financing—Tom Sherwood, ICF Resources, Inc.

Natural Gas Substitution and Independent Power in Central and Eastern Europe—Dr. Robert Ichord Jr., U.S. AID

Role of Clean Coal Technologies to Control Pollution from Low Emission Sources—Dr. Bedrich Moldan, Director, Charles University Environmental Center

BULK POWER TARIFFS FOR POLISH COMBINED HEAT AND POWER PLANTS

Based on Activity in Poland
Funded by USAID Bureau for Europe

by

Carlos A. Yermoli

RCG/HAGLER BAILLY, INC.
Arlington, Virginia, USA

EXHIBIT 1

RELEVANT RECOMMENDATIONS OF THE DBDH DISTRICT HEAT TARIFF STUDY

- **DH CUSTOMERS TO RECEIVE FULL BENEFIT OF COGENERATION**
- **DH UTILITY TO HAVE FREE ACCESS TO POWER MARKET**
- **POWER FROM CHP PRICED AT LRMC**
- **SPECIFIC TARIFF PRINCIPLES FOR EXTRACTION CHP PLANTS**
  - -- Heat tariff based on recovery of additional cost over power-only production limited to cost of heat-only production
- **SPECIFIC TARIFF PRINCIPLES FOR BACK-PRESSURE CHP PLANT**
  - -- Heat tariff based on recovery of equivalent heat-only costs less half or more of the difference between CHP and heat-only cost.
- **PRIVATELY OWNED CHP PLANT**
  - -- Power tariff based on avoided costs

EXHIBIT 2

DEVELOPING PRICING TERMS BASED ON ECONOMIC AVOIDED COSTS

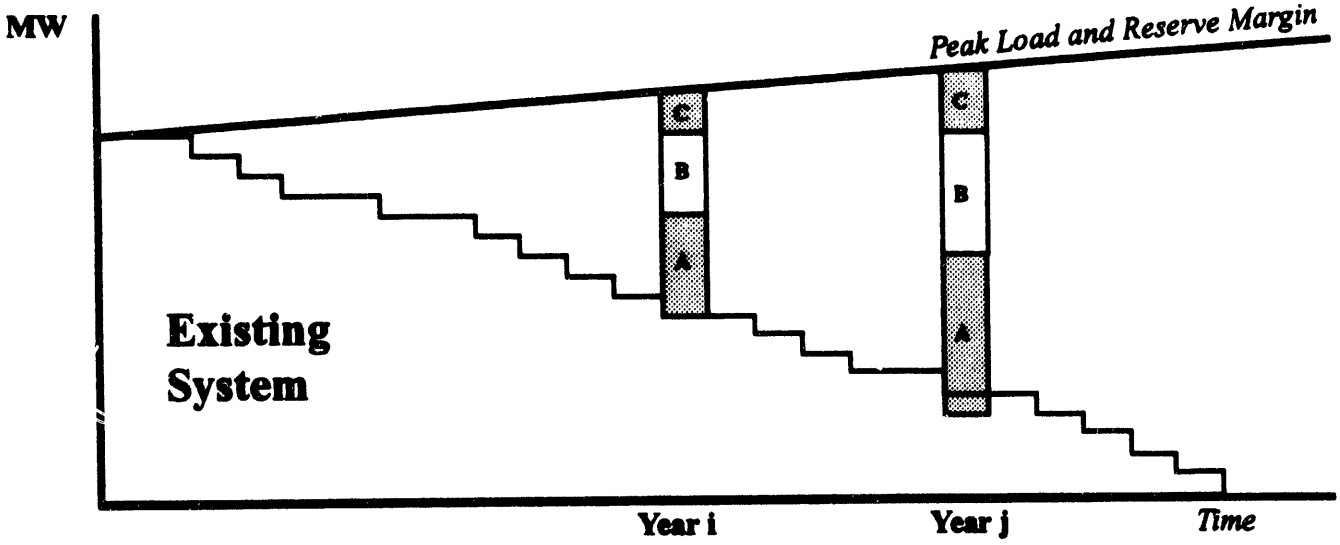
- **OBJECTIVES OF AVOIDED COST PRICING**
  - -- FINAL OBJECTIVE: LEAST COST OF POWER SUPPLY THROUGH COMPETITION
  - -- PURPA: FAIRNESS TO THE INDEPENDENT PRODUCER
  - -- NEW POWER MARKETS: EFFICIENCY THROUGH COMPETITION AND INCENTIVES TO PRIVATE SECTOR
  - -- AVOIDED COST AS A REFERENCE IN COMPETITIVE BIDDING
  - -- ECONOMIC AND FINANCIAL AVOIDED COST

- **ISSUES IN THE DETERMINATION OF TOTAL AVOIDED COST**
  - -- DIFFERENTIAL EXPANSION PLANS AND PROXY PLANT REFERENCE
  - -- DECOUPLED REPLACEMENT OF ENERGY AND CAPACITY
  - -- GENERATION MIX IMBALANCE
  - -- CAPITAL RECOVERY AND ECONOMIC LIFE
  - -- DISPATCH AND RELIABILITY ISSUES
  - -- AVOIDED CAPITAL COST: CAPITAL SCARCITY ISSUES

EXHIBIT 3

COMPUTATION OF MARGINAL COST

Case 1 = Base Expansion



Case 2 = Incremental Load Expansion

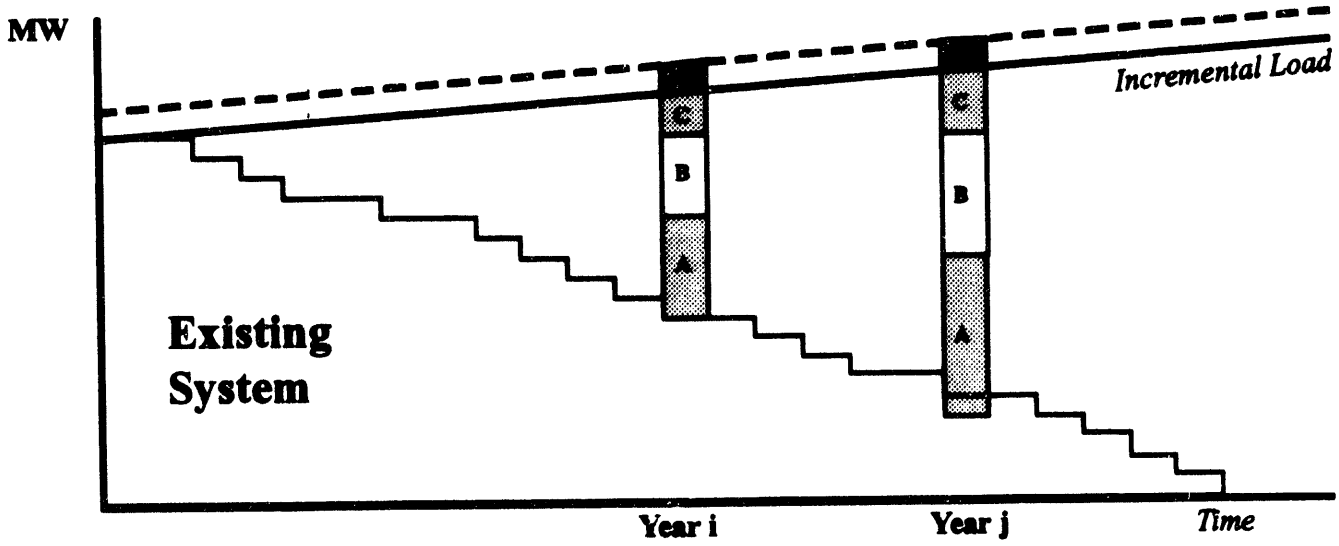
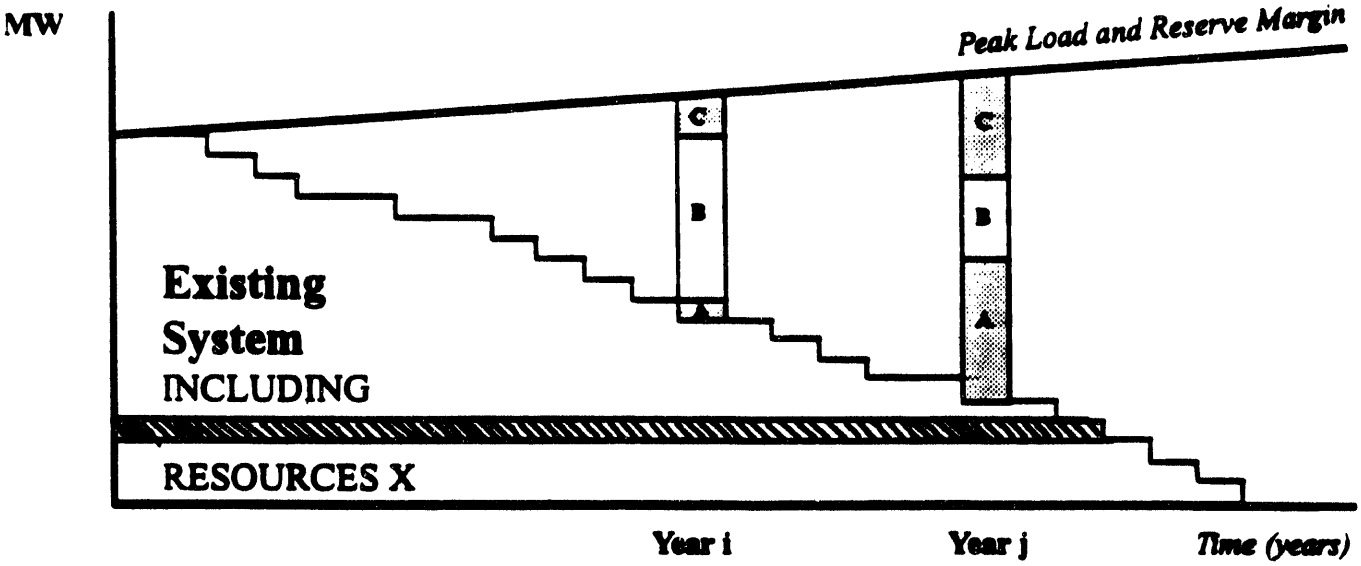


EXHIBIT 4

COMPUTATION OF MARGINAL COST

Case 1 = Base Expansion



Case 2 = Incremental Load Expansion

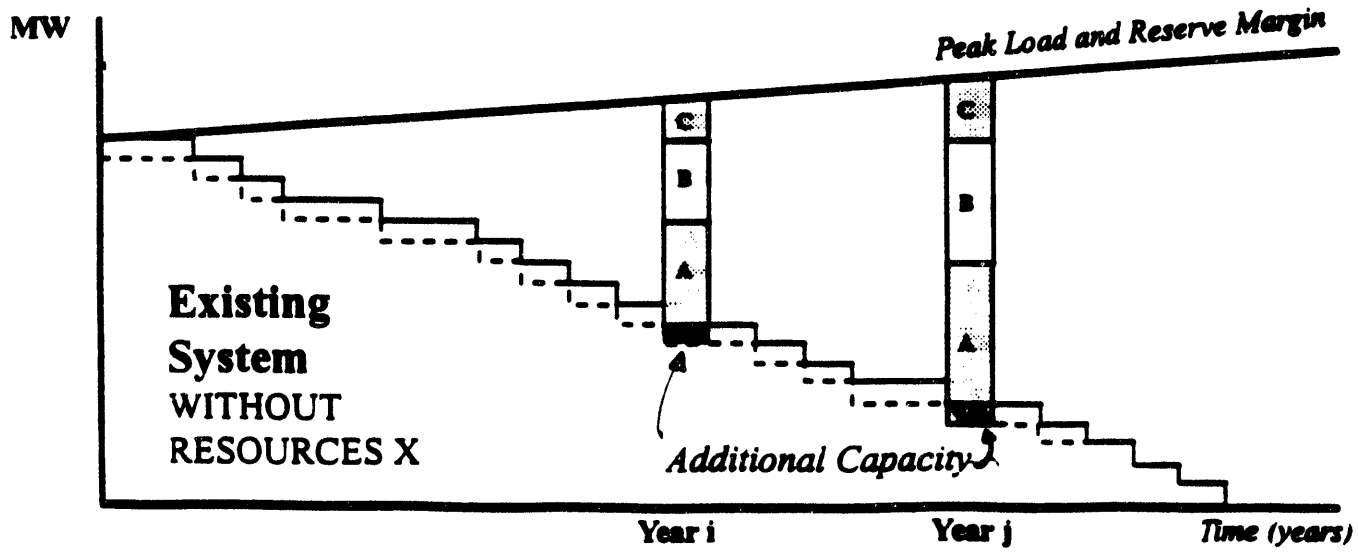


EXHIBIT 5

LRMC VS. AVOIDED COST

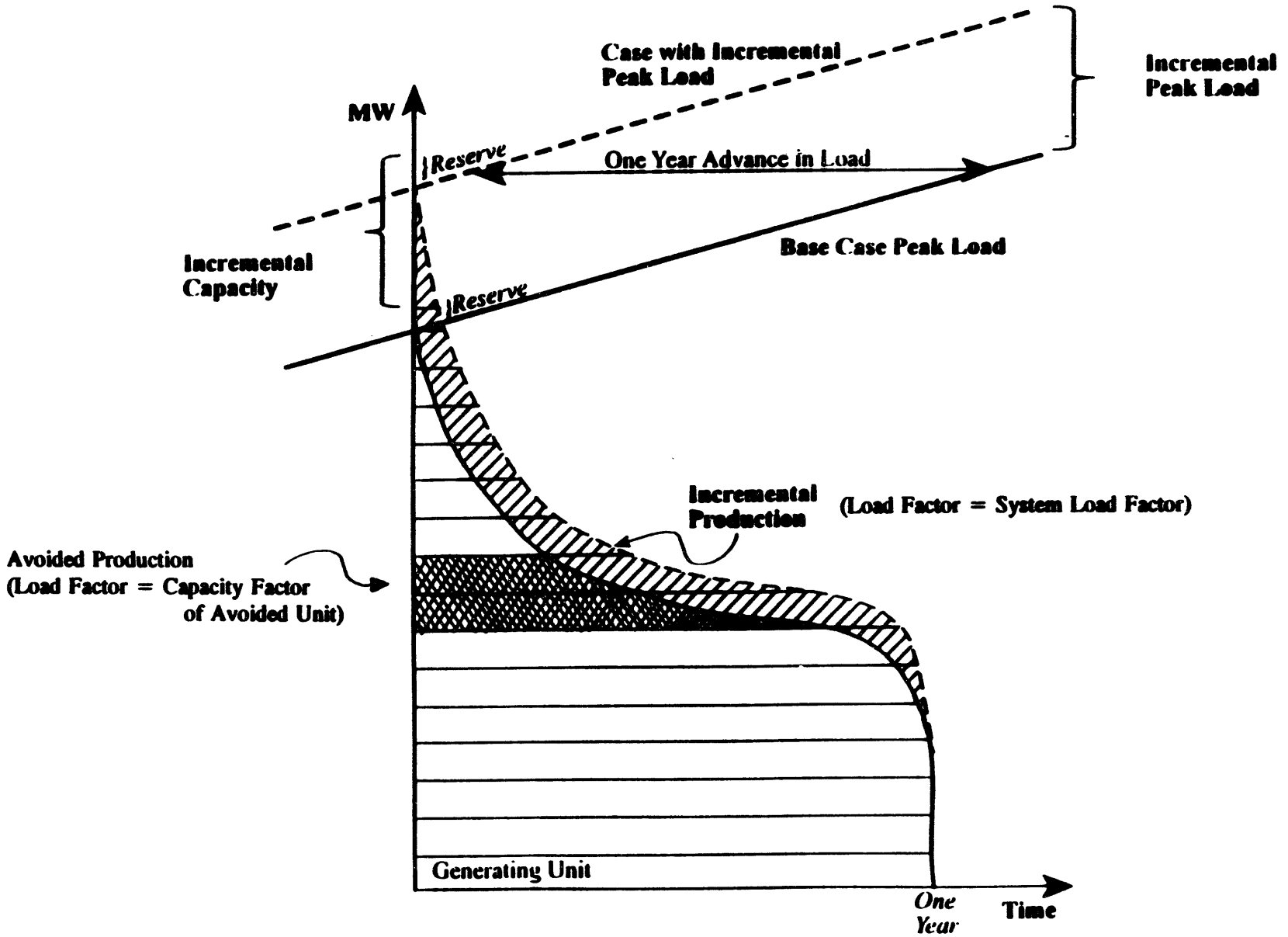


EXHIBIT 6
FUNDAMENTAL EQUATIONS FOR AVOIDED COST

F = **Fixed costs**

V = **Variable costs**

b = **base case with resource x**

r = **reference case without resource x**

kW = **Capacity**

kWh = **Energy production**

$$\frac{F_r - F_b}{kW_x} = \textit{Avoided Fixed Cost}$$

$$\frac{V_r - V_b}{kWh_x} = \textit{Avoided Energy Cost}$$

$$\frac{(F_r + V_r) - (F_b + V_b)}{kWh_x} = \textit{Total Avoided Cost}$$

EXHIBIT 7
REFERENCE AVOIDED COSTS

i = Power utility borrowing cost

	Proxy 1 Base Load Plant	Proxy 2 Peaking Plant	
Fixed Costs	F_1	F_2	
% Avoided Capacity	α_1	α_2	
Avoided Capacity Cost	$\alpha_1 F_1 + \alpha_2 F_2 = F_r^i$		$/kW
Variable Cost	V_1	V_2	
% Avoided Energy	β_1	β_2	
Avoided Energy Cost	$\beta_1 V_1 + \beta_2 V_2 = V_R$		Cts/kWh

EXHIBIT 8
POWER SALES PROPOSAL

$$\frac{F_p \times kW + (V_p - V_r) \times kWh}{kW} = F_p^1$$

F_p^1= Equivalent fixed payment to be compared against fixed voided cost F_r^1

ISSUE

$F_p^1 > F_r^i$ for all proposals

and $F_p^1 = F_r^I$ for $I = i + \boxed{\Delta i}$

Cost of Private Sector Financing

EXHIBIT 9

Δi = INCREMENTAL CAPITAL COST

COMPONENTS

- DECOUPLED CAPACITY + ENERGY
- CAPITAL AMORTIZATION PERIOD
- PRIVATE FINANCING
  - ▸ RISK
  - ▸ PROFIT

  } INTERNATIONAL PRIVATE POWER MARKET

Δi is recovered by sectors that benefit from additional financial support from state

$\Delta i \rightarrow 0$ as private power sector achieves maturity

SUMMARY

- Exhibit 1 summarizes the recommendations of a study on heat tariffs prepared by the Danish Board of District heating that recommends that power from combined heat and power plants be sold to the electric sector at avoided cost, that is, the least cost of power production by power-only plants.

- Exhibit 2 presents the major advantages of adopting the principle of avoided cost in CHP plants.

- Exhibit 3 to 5 illustrate the difference between the computation of marginal costs and avoided costs. In Exhibit 3 two cases of system expansion are shown: Case 1 with a base case load and Case 2 with an incremental load. The marginal cost is the cost of supplying the differential capacity additions and the differential production involved in meeting the incremental load. In Exhibit 4 two cases are also shown, one with a base case system expansion and the other with a system without a resource X. The avoided cost is the cost of supplying the differential capacity additions and the differential production involved in meeting the load that is not supplied by the resource X. In Exhibit 5 both cases are superimposed in the load duration curve of one year only to show that the incremental load of Exhibit 3 has a different load factor from the incremental load of Exhibit 4 and thus the marginal cost and the avoided cost could be different.

- Exhibit 6 shows the basic equations involved in computing fixed, variable and total avoided costs. Each symbol corresponds to the accumulated present value of the particular quantity over a period of time.

- Exhibit 7 shows a simplified method of calculating fixed and variable avoided costs. The difference in accumulated present value of fixed and variable costs of two expansion analysis such as illustrated in Exhibit 4 is replaced by the lifetime fixed and variable costs of two reference plants (proxy plants). The contribution to fixed and variable costs of each plant may be different and denoted by the coefficients alpha and beta to yield weighted fixed and variable costs called Reference Costs and offered as proxy for strict avoided costs. In Poland these coefficients were calibrated from expansion plan analyses but could then be used to evaluate avoided costs of power from several different CHP plants.

- Exhibit 8 illustrates the methodology for evaluating offers of power from CHP plants in Poland. First, the total revenue is computed from the proposed fixed (capacity) and variable (energy) prices multiplied by the respective capacity and energy sales. Next, an equivalent fixed price is determined such that total expected revenues remain constant while the variable price is made equal to the Reference Variable Cost. The equivalent fixed price is compared to the Reference Fixed Cost to determine the merit of the power sales proposal. It is noted that the

Fixed Reference Cost is based on a rate of discount i that represents the cost of capital of the public utility.

- Also in Exhibit 8 an issue is presented in the form of two events:

  -- All proposals have an equivalent fixed price that is much greater than the Fixed reference cost.

  -- The interest rate I is the lowest discount rate that makes the fixed price of at least one proposal equal to the Fixed Reference Cost.

  The issue is that the incremental cost of capital from i to I is the cost of private sector financing. If there are no viable alternatives for public financing then I and not i is the true cost of capital and it follows that the lowest equivalent fixed price is equal to the Fixed Reference Cost. This shows that under capital scarcity in the public sector the avoided cost principle can only be used as a basis for relative measure among alternatives.

- In Exhibit 9 the components of the incremental capital cost from i to I are analyzed. The ability of a utility to provide capacity support with one resource but production from another is an important element in the difference between the equivalent fixed price and the Fixed Reference Cost because the equivalent fixed price corresponds to a single project that must supply both capacity and energy. A second element is the difference in amortization from a utility to a private developer, while the utility can amortize its assets along their useful economic life a developer may need to amortize them over the loan repayment period. The third element is the perception of risk and the opportunities for profit available to each.

- Also using Exhibit 9 it is discussed that the incremental cost of capital to the power sector resulting from a process of reform and privatization of power infrastructure is recovered by other sectors that can now tap the public financial resources freed from the power sector. This incremental cost of capital tends to zero as the private power industry achieves maturity thus reducing the risks, receiving longer repayment terms and diversifying resources to permit sales of capacity and energy decoupled from individual projects.

LOCAL ENFORCEMENT OF AIR QUALITY STANDARDS AND ECONOMIC DEVELOPMENT

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Hearing Board Member[1]

Introduction

In difficult economic periods, regardless of the degree of economic stagnation or the extent of environmental degradation in a given nation or locale, the question is posed whether environmental standards must be relaxed to allow for economic growth.

This paper posits that environmental protection and economic development are not only compatible, but interdependent goals and that, in the range of regulatory choices available, all levels of government have a significant role to play in choosing among forms of regulation and governmental programs to best achieve the dual goals of environmental protection and economic development. In particular, local and regional governments can and should provide leadership in creating appropriate levels and types of regulation and in creating economic opportunities most suitable for the particular region.

This paper will summarize the structure of air quality regulation in California, and available regulatory mechanisms to achieve compliance with air quality standards, and will describe some of the efforts of one **local** government to achieve compliance with national and state mandated air quality standards, while encouraging community based economic growth.

Santa Barbara County

Santa Barbara County is a coastal county situated 90 miles northwest of Los Angeles. With a population approaching 400 thousand, the County's major economic sectors include the oil and gas industry [both offshore and onshore]; agriculture, tourism, retail sales and light manufacturing. The County has several urban centers, including the cities of Santa Barbara and Santa Maria, and is home to a major campus of the University of California, and a number of other educational institutions.

Santa Barbara County became known as the "birthplace" of the modern environmental movement in the United States after a major offshore oil spill of 1969, and, like the state of California, has been a leader in requiring environmental protection and pollution controls beyond the minimums specified by federal laws such as the Clean Air Act. Since the County has permitted major oil and gas development to support production from leases in federal waters in the last ten years, the local Air Pollution Control District has been seeking to maintain local control of air quality impacts from offshore oil development, and the transfer of jurisdiction over these impacts from the federal Minerals Management Service of the Department of the Interior to the U.S. EPA.

In recent years, however, a severe economic recession and the "end" of the Cold War have taken a particularly heavy toll on California's defense and aerospace industries, resulting in unemployment figures which, for the first time in history, have become significantly higher than the national average. The economic fears generated by this long recession have found expression in Santa Barbara in concerted efforts to "de-regulate" business, and weaken environmental standards, a phenomenon which is mirrored on the state and national levels.

The Structure of Air Quality Regulation: Role of Local Agencies

Air quality regulation in the U.S consists of a variety of approaches, including public nuisance prevention, point source discharge restrictions, technological pollution controls and socio-economic behavior modification efforts. Because the sources of pollution are too varied for the federal government alone to regulate, air pollution regulation is a federal/state/local joint venture. Federal law sets minimum standards, and directly regulates certain classes of pollution sources, while states and local governments regulate emissions sources through their police power authority, customizing control programs to suit local conditions. Other sources of law , including

environmental assessment laws and toxics notification requirements provide an additional basis to force reductions in emissions.[2]

Both the federal Clean Air Act and the California air pollution laws require local "implementation plans" to be developed to demonstrate how each region will attain specified air quality standards. These clean air plans identify future regulatory activity, including pollution control measures and commitments by state and local agencies to implement them.

The law recognizes the importance of local control and public participation in air pollution control planning, in order to enable regulators to customize attainment and regulatory plans to local conditions. In addition to developing plans to achieve federal and state air quality standards, local Air Pollution Control Districts are responsible for regulating emissions from nonvehicular sources, and handle virtually all permit, enforcement and rule making activities in California. Pursuant to their clean air plans, Districts adopt rules governing emissions from industrial facilities and air pollutant emitting equipment, and in non attainment areas they are given further authority to adopt indirect source control programs and impose transportation control measures.

Local APCD Hearing Boards are bodies appointed under state law to review permits for individual pollution sources, and requests for variance or exception from District rules. Where a source is not in compliance with a District rule or a condition on a permit to construct or operate, the District may issue a Notice of Violation and pursue fines and penalties or abatement against that source. A source may petition to operate without immediate compliance with a District rule, and a Hearing Board may grant a variance if it finds, based on evidence presented, that due to conditions beyond the reasonable control of the petitioner, requiring compliance would result in either (A) an arbitrary or unreasonable "taking" [confiscation] of property, or (B) the practical closing and elimination of a lawful business.

These standards represent an extreme circumstance, and it is difficult, especially in an economic recession, for a hearing board to accurately determine whether the cost of compliance with a rule, or the effect of a recession on a marginally successful business would "cause" a business to fail. As a practical matter, in making this finding, local hearing boards consider whether or not an unreasonable burden would be imposed upon the petitioner if immediate compliance is required. In addition, if the petitioner is defined as a small business, the board must consider the applicant's financial and other abilities to comply; the impact on the applicant's business and the benefit to the environment if the applicant is required to immediately comply with a rule.

It is important to note that local Districts do not regulate all sources of pollution in California. The State Air Resources Board is responsible for setting state ambient air quality standards, which in some cases have been more strict than the federal standard; setting emission standards for new motor vehicles; for consumer products; and establishing statewide standards for sandblasting equipment and abrasives, gasoline vapor recovery systems and agricultural burning regulations. The ARB also reviews and approves the plan prepared by local districts, and prepares California's state implementation plan for approval by the US EPA.

The EPA, in turn, sets national ambient air quality standards, prepares a federal implementation plan [FIP] if the state fails to prepare its own plan; sets emission standards under New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants. However, it must be noted that even though the Santa Barbara County APCD does not directly regulate motor vehicle emissions, it has recognized the role of these emissions in ambient air quality, and therefore has attempted to incorporate these concerns in its Innovative Technology Program described below.

Types of Regulations

1. Command and Control: As the phrase implies, this type of regulation mandates facilities with sources of air pollution to implement certain types of emission control measures. Such regulations can restrict the amount of pollution-causing substances used by a facility; require the construction and operation of 'add-on' emission control technology and/or specify an emissions limit in terms of pounds per hour or concentration of pollutants allowed to be discharged from sources at the facility.

"Command and control" regulation come under increasing criticism as a draconian method which is

overly burdensome on business. For example, critics claim that because of differences in facilities, a control strategy that is cheap and easy in one facility is expensive and burdensome in another, and rules which are too stringent for some, are not strict enough in other cases. In general, this type of regulation leaves little flexibility to regulated businesses to choose appropriate methods to achieve compliance.

A significant subset of "command and control" regulations are "technology forcing" rules, which require use of a technology that has not been demonstrated in practice. Such a rule will require a specified level of emissions to be reached at a future date, with the agency providing lead time for development and installation of emissions controls. Examples of such technology-forcing regulations are the use of selective catalytic reduction (SCR) systems to reduce NOx emissions from gas turbines and large boilers, and, for mobile sources, the state mandate that, by the year 2003, a specified percentage of vehicles within California be Zero Emission Vehicles [ZEV].

2. Marketplace mechanisms Market based regulation is claimed to provide greater emission reductions at less cost using market incentives. This type of regulation sets facility emission limits and allows facility operators to achieve compliance by the most appropriate combination of methods, which can include installation of control equipment, process changes, shutdown of pollution causing processes and/or purchase of excess emission reductions from another facility.

Marketplace mechanisms fall under two different categories: emissions trading and pollution taxes. Under pollution trading programs, industry is granted permits to pollute that can be bought and sold, in the case of acid rain emissions, alongside pork bellies and soybeans at the Chicago Board of Trade. Actual pollution reductions are achieved by limiting, or capping, the total number of permits issued. Then, industry is free to sell or buy more pollution permits. In theory, companies that can reduce their emissions cheaply can sell their permits to companies that would have to pay more for their own reductions. At the same time, the programs keep pollution within a predetermined range.

A second variant of a market based mechanism is the pollution fee. A fee or tax is imposed on sale or use of materials. The fee increases as the pollution causing potential increases. With this type of negative incentive, it is difficult to ensure a specific quantifiable emission reduction will occur due to the higher price of high polluting materials.

While pollution taxes offer polluters the incentive to reduce each increment of pollution, and thereby create a competitive advantage for a company that could eliminate all pollution, pollution trading guarantees that there will be a certain amount of pollution. Tradeable permits do not have any effect on the level of pollution; the amount of pollution must be regulated beforehand. Under a national trading program like the SO2 program, if levels aren't set low enough, emissions in some regions can actually increase. The most serious criticism of pollution trading is its distributional impact. Under this system a refinery in town A could buy credits from town B 500 miles away. The only way to reduce emissions below the cap is for individuals or organizations to buy pollution credits and retire them.

Two examples of the "trading" concept on the federal and local levels are the trading program established under the Clean Air Act amendments of 1990 (federal), and the RECLAIM program in Los Angeles (regional/local). The trading program under the Clean Air Act Amendments of 1990 calls for a 10 million ton reduction of sulfur dioxide emissions from 1980 levels, to be achieved through a market-based trading system of SO2 allowances, An emission allowance, or credit, gives a plant (usually an electric power plant), the right to emit one ton of SO2 per year. EPA gave emissions allowances free to 900 power producers based on previous emissions rates. Allowances are allocated for half the emissions the plants were emitted in 1980. New plants must purchase allowances from the existing lot. EPA delegated administration to the Chicago Board of Trade.

RECLAIM, or the Regional Clean Air Incentives Market was adopted by the South Coast Air Quality Management District [SCAQMD] in October 1993, instituting a market trading program for nitrogen oxides and sulfur oxides. Critics of the program have complained that polluting industries are allowed to pollute at higher than current levels during the first years of the program, so companies won't be "penalized" for previous efforts to reduce emissions; that RECLAIM will not be as effective as the current rulemaking plans in lowering levels of ozone, NOx and SOx; that pollution trading will

undermine the development of new technology; and that the self reporting of emissions will lead to fraud and will encourage sellers to overstate available reductions.

3. Disclosure and Notification Requirements

Consumer/resident notification requirements are proving an effective method to reduce emissions, because companies would rather make process changes than notify affected consumers or residents that their product or process may pose a health hazard. The California Air Toxics Hot Spots Act, for example, requires an inventory of toxic emissions, preparation of a risk assessment of impacts, and ultimately, notification of affected residents if emissions cause a significant health risk. Similarly, California's Proposition 65 was a law passed by citizen initiative whose warning requirements and penalties for violation prompted modification of processes to eliminate hazards in a number of instances.[2] At the federal level, the Emergency Planning and Community Right to Know Act sets forth notification and disclosure requirements for hazardous substances. Such laws also contain provisions allowing enforcement by citizen suit if the government fails to force compliance.

Economic Considerations in Air Pollution Control

1. Economy vs. Environment: A False Polarity?

Recent studies have concluded that strong environmental standards have not limited the relative pace of economic growth and development among the states over the past twenty years.[3] A number of experts argue that no meaningful correlation between environmentalism and economic performance has been found, and that "environmentally stronger states do not experience more precipitous declines in employment during a recession. Nor do they demonstrate a higher rate of business failure. Thus, contrary to what many argue, environmentally stronger states are not more vulnerable to economic decline during recessions." Experts have concluded that based on the evidence there is no reason to expect that loosening environmental standards will have any effect on the pace of state economic growth.[4]

However, it is also believed that any positive association between state-level environmentalism and economic prosperity may be the consequence of some third factor that is positively correlated with both environmentalism and economic growth.[5] States that tend to favor strong environmental policies may also be more likely to invest in education, health, transportation and communications infrastructure, and other elements that stimulate and support growth. Strict environmental controls can have a Darwinian effect, forcing industry to avoid the high costs of waste disposal and abatement, and thereby fueling process and product innovation, which results in improved productivity, higher input and output efficiencies and cost savings. At a minimum, studies have concluded that shifts in environmental policy, whether intended to extend environmental control or reduc it, have no discernable effect on state economic performance. Any negative economic effects are so marginal and transient they are lost in more powerful domestic and international economic influences.

Nevertheless, the argument that there is an inverse relationship between strict regulation for the protection of the environment and the health of private sector businesses has found expression in a number of contexts, and has given rise to political demands that new and existing environmental regulations be subjected to analysis for "cost effectiveness", cost/benefits analysis, and socio-economic impacts analysis. Whether the implementation of strict environmental standards has significantly contributed to the current severe recession in California is the subject of intense debate over the empirical evidence for such a conclusion and the methodology used to assess it.

2. Current Consideration of the Cost of Regulation

The Clean Air Act Amendments of 1990 (Section 812) required EPA to conduct both a retrospective and a prospective study of the benefits and costs of air pollution controls. Similarly, under the California Clean Air Act of 1988 the cost effectiveness of air pollution rules must be addressed. Generally, local Districts must consider cost effectiveness of air quality programs, rules, regulations and enforcement practices, and they must determine that the district plan is a cost effective strategy to achieve attainment of state standards by the earliest possible date. This includes an analysis both of **cost** to a particular business and **cost effectiveness**, i.e, an analysis that determines generally how much pollution a

particular control measure or strategy will eliminate and how much it will cost to implement. This is expressed in dollars/ton of pollution. The **cost** to a particular business which must comply can be addressed through variances or exceptions granted by local Hearing Boards, which have the responsibility to consider the economic consequences of regulations through the variance process.

The recent recession has led to additional demand for "cost-benefit analysis" of environmental regulations. For example, President Clinton's plan to elevate the head of the USEPA to a Cabinet level was tied to a bill in Congress to require a formal risk analysis with any regulation relating to human health, safety, or the environment, and a certification from the Secretary that the regulation would produce benefits to human health and safety or the environment which justify the cost of compliance and implementation.[6] The proposal generated concern about the quality of cost information, and the cost of performing such analysis to the EPA, as well as the difficulty of assessing health and ecological benefits in monetary terms. However, calls for "cost" and "risk" assessments must continue to be critically evaluated, since studies which focus exclusively on the direct expenditure of funds required for compliance with environmental regulations tend to omit analysis of avoided costs and missed economic opportunities attributable to strict environmental standards.

For example, an assessment of health effects due to ozone and particulate matter suggests that each of the 12 million residents of the South Coast Air Basin (an area including Los Angeles) experiences ozone related symptoms on an average of up to 17 days per year and faces an increased risk of death in any year of 1/10,000 as a result of elevated PM10 exposure.[7] The estimated annual economic cost of **avoiding** these effects, based on work loss and medical costs and other factors, is nearly $10 billion.

Similarly, crop losses caused by ozone pollution have been estimated to cost California $1.5 billion per year.[8] Reducing ozone concentrations to an average of 0.04 ppm would produce a direct benefit of $490 million per year: $275 million to consumers through lower prices and $215 million to producers through high crop volumes and lower per unit production costs.

While historically, avoided costs and benefits of regulation have not been included in economic analysis, under current California air pollution law, a socioeconomic assessment must be performed prior to adoption of a rule that significantly alters air quality.[9] The range of socioeconomic impacts is defined by law to include: the type of industries affected by the regulation; the impact on employment and economy of the region affected; the range of probable costs of the regulation; the cost effectiveness of alternatives to the regulation; the emission reduction potential of the regulation and the necessity of adopting the rule to attain state and federal air quality standards.

However, the law does not expressly require analysis of the socioeconomic effects of **not** adopting the rule. Thus, avoided costs such as health costs, crop losses, and economic opportunities created by the rule may still not be adequately considered in the equation. In addition, the relative importance of factors such as the pre-existing health of a business or industry, the contribution of a global recession, and geopolitical changes such as the effect of the end of the Cold War on the aerospace industry are generally not quantified or even considered.

A socioeconomic analysis which fully considers impacts to employment and the general economy, as well as health, economic and quality of life benefits requires an integrated modeling approach.[10] However, existing models are costly, and need to be enhanced to reflect the benefits of environmental protection to health, agriculture and the quality of life, as well as new economic development which could result from adoption of a given strategy.

Without such sophisticated analysis, however,local air districts will remain vulnerable to the "self-reporting" of regulated industries, which often attributes all manner of economic disaster to regulation. Local air districts frequently lack sufficient resources to engage in a meaningful exchange with consultants hired by industry.

For example, in April of 1993, the Santa Barbara County APCD commented to the state Department of Conservation on a draft report prepared by consultants to the oil industry entitled "Status of Petroleum Production Industry in California: The Cost of Regulatory Compliance." The draft report

misrepresented the causes of economic decline in the oil and gas industry by failing to include avoided costs, by overlooking completely the collapse of wellhead prices, and the fact that northern Santa Barbara County oil production was not profitable even if the reported regulatory costs were deleted from per barrel lifting costs. Furthermore, while a portion of regulatory costs from the OuterContinental Shelf [offshore] development were included in the report, the analysis failed to include production volumes from that development.

As this case illustrates, without a full and fair opportunity for the regulating community to comment and rebut factual errors, such a report could easily become the basis for an unjustified demand to eliminate or weaken environmental standards.

Economic Opportunities Generally

Although environmental regulations require that businesses expend funds on control technologies and services, thereby increasing the costs of some goods and reducing jobs in some sectors, environmental expenditures also create business opportunities for firms supplying such goods and services. Many of these jobs are high-skill, high-wage jobs which are very desirable in improving the skill base of the workforce.

The US EPA has undertaken specific studies to analyze business opportunities under provisions of the Clean Air Act Amendments [CAAA] of 1990.[11] These studies have concluded that while there may be various estimates of the full potential of the environmental market, it is clear that industry is driven first and foremost by legislation and regulation which has forced or promoted the development of new technologies and specialized services. While in the 1980's revenues and margins eroded as air quality legislation, regulation and enforcement lagged, revenues are expected to increase dramatically as a result of the recent amendments. In addition, the CAAA are expected to change the stationary source equipment industry by widening the customer base, since pollution controls are now extended to industries which have not traditionally employed such equipment. The federal Clean Air Act Amendments are expected to significantly spur revenues to the air pollution control equipment industry, clean fuels, instrumentation and emissions monitoring, and engineering, design and construction industries.

Similarly, the California Secretary for Environmental Protection recently projected that as much of 3% of GNP will be devoted to environmental investment by the year 2000. In furtherance of its commitment to sustain and promote both environmental and economic progress, the state of California, through its Environmental Technology Advisory Council, has issued a strategic plan for promoting California's environmental technology industry.[12] The plan emphasizes a need to implement environmental and economic programs which encourage business to look for environmental solutions, which provide a competitive advantage, and which maintain high environmental standards combined with simplified processes. The goal of the plan is to assist California companies that research, develop, produce, market and export environmental technologies, goods and services, in part through the formation of partnerships which will create development and marketing opportunities, including marketing in other nations.

In addition, the state recently announced the formation of the California Environmental Technology Partnership. This is a public/private group of cities, utilities and private companies whose purpose is to establish "technology incubators", or low cost business sites to help inventors and entrepreneurs set up their own companies for environmental services. The partners will help to find capital, develop realistic business plans commercialize new products, and assist with permit streamlining.

Local Programs: Air Quality Attainment Plan- From Theory to Practice

1. Measures Considered in the AQAP

Santa Barbara County's Air Quality Attainment Plan [AQAP] was adopted in 1979 and revised in 1991. California's Clean Air Act requires such plans to describe measures for meeting emission reduction requirements of 5% per year to attain the state standard for ozone. The plan was required to contain all feasible control measures for new or modified sources of 25 T or more of ROG or NOx, as well as measures for sources that are individually small but regionally significant [area sources]. At

the time of adoption, Santa Barbara was in non-attainment for federal and state ozone standards, the state PM10 standard, and hydrogen sulfide. At the present time, the County has met the federal ozone standard, and has seen a 60% decrease in the number of ozone violations since 1980, during a period of 30% population growth.[13]

Illustration #1: Command and Control Since NOx is a precursor of ozone, the AQAP inventoried all sources of NOx in the County, including small sources which were individually insignificant but considered cumulatively significant "area sources." Among the control measures recommended for adoption in the AQAP were NOx measures for residential water heaters, residential space heaters, small industrial and commercial boilers. Commercial and industrial boilers, steam generators and process heaters together emit about 160 tons of oxides of nitrogen per year, which react in the atmosphere to form ozone and particulate matter. The proposed control measures would reduce these emissions by approximately 82 tons/year. Suggested compliance methods included pilotless ignition and low NOx combustion design.

Implementation of control measures recommended in the AQAP requires District staff to develop a rule, solicit and respond to public comment, bring the measure to the Board of Directors [currently, the five elected members of the County Board of Supervisors] and allow time for affected industry to implement the control strategy. In the case of the control measures for boilers, a Rule [342] was developed pursuant to this procedure, which imposed an emission standard of 30 ppm NOx, and requires testing, a compliance schedule and monitoring. A cost analysis was performed to determine the cost of retrofit with low NOx burner systems. Despite negative comments from sectors of industry regarding the cost and reliability of the retrofit technology, the rule was adopted in 1992.

Illustration #2: Solar Water Heaters: Relative Cost too High

Solar water heaters were studied in the AQAP as a means to supplement heat produced by external combustion fired water heaters that are found in homes, apartments, businesses, and public facilities. Solar water heaters do not produce NOx or any other criteria pollutant emissions, and can reduce the demand upon residential/commercial type fired water heaters by up to 52%, thus reducing NOx emissions by an equivalent amount. However, based on an unfavorable NOx emission reduction cost estimate, ($450,000 to 1,100,000 per ton NOx reduced) no solar water heater control measure was recommended in the AQAP. However, if the cost of fuel supplies were to increase dramatically, then the relative cost of this measure would decrease, and for this reason it was recommended for further study.

Illustration #3: Market Based Stationary Source Controls

The AQAP described a number of ideas for using market based incentives as a means of achieving emission reductions. These included incentives for going beyond required controls such as emission offsets credits [banking]; tax credits; alternative performance options in District Rules; mobile source offsets; and trading between permits. While a number of these options were reserved for further study, the Innovative Technologies Group, a department of the APCD, has continued to administer the Clean Fuels and Energy Program described below.

2. Clean Fuels and Energy Program

The innovative technologies program was established as a cooperative government/industry partnership to promote the development, testing and application of clean technologies in Santa Barbara County. The program has resulted in reduced air pollution, the creation of new business opportunities and increased flexibility in air pollution control.

The seed money for this project was provided, not through traditional public funding sources, but through exactions on development permits granted to the major oil and gas companies for onshore processing facilities which obtained permits for construction from the County in the mid 1980's.

Although full offsets for emissions from these projects were not available at the time they were permitted, the District allowed them to go forward on condition that the project sponsors provided funds for emission reduction and technology development studies. Rather than a "pay to pollute" approach, this technology-forcing strategy required sufficient funding and commitment to identify and/or develop new and promising emission reduction methodologies, and to field

demonstrate those methodologies for real long term emission reductions.[14]

Projects funded through this program are selected based on their potential to reduce air pollution in Santa Barbara County, with an emphasis on clean fuel vehicles and clean energy production. APCD's role, once a project is identified, is to assemble a team of equipment suppliers, funding parties and users, and secure commitments for cash, in kind support and purchased equipment and services. APCD manages the contracts for any services performed, and all funding passes through the APCD budget. After technology is proved successful at the manufacturer's site, it is installed. APCD supervises the testing of the technology and collect data on the actual pollution reductions, cost-effectiveness and other factors such as fuel usage and maintenance requirements.

This program has achieved substantial air quality benefits, reducing smog forming air pollutants by 250 tons per year, air toxics, and global warming gases by over 3000 tons per year. The program provides jobs to local manufacturers and can result in significant cost savings to local businesses.

The program has created over 30 different low emissions cooperative projects in both stationary and mobile source categories. Stationary source projects include: low emission gas turbines, fuel cell power plants, reduction of sulfur emissions from flares, innovative offsets, and a mercaptan elimination study. Mobile source projects include low emission natural gas engines for heavy duty trucks, transit and highway buses, and light and medium duty vehicles, and natural gas-powered crew and supply boats.[15]

The goals of the Clean Fuels and Energy Demonstration Program are to demonstrate the feasibility of "further study measures" contained in the AQAP, to remove barriers to the acceptance and use of advanced low-emissions technologies the County, to create local business opportunities in environmental technologies, to create incentives and a rebate system to aid in the implementation of low emissions technologies, and to allow local businesses increased flexibility in air pollution reduction. Participants have included several engine manufacturers, utilities, and local businesses. The project has assisted local school districts by helping to provide new low-emission and electric school buses free of charge.

Illustration #1: Low NOx Turbine Combustor Program This ultra-low NOx gas turbine combustor technology is to be applied to an onshore facility that processes oil and gas produced in federal waters offshore Santa Barbara County. The goal of this program is to develop and demonstrate a safe, efficient and cost effective method to meet the NOx emission limit for gas turbines. Previously, this emission limit could only be met with the selective catalytic reduction (SCR) technology, which is an expensive post combustion clean up process which carries its own set of environmental hazards. The benefits of developing a lean pre-mixed combustion technology which does not require water injection or SCR application include cost savings in the form of reduced fuel usage, reduced maintenance, and no water or ammonia injection.

Illustration #2 Fuel Cell Projects: The goal of these projects is to demonstrate the feasibility of a near zero emissions cogeneration power plant. This program is to be applied to the powerplants at Vandenberg Air Force Base and a new County jail annex. The fuel cell is a clean power generation device, similar to that used for the space shuttle, which combines hydrogen and oxygen to produce electricity. The technology is a 200 kilowatt phosphoric acid fuel cell. Its benefits include reduced fuel cost, reduced maintenance cost, no water injection costs, emission reduction, local business participation, and production of clean, potable water as a byproduct. An additional Fuel Cell Use Study has been performed, identifying the most promising fuel cell application, which is the substitution of fuel cell power and electric motors for natural gas fired internal combustion engine (ICE) driven equipment. However, costs must drop from the current $3000/kilowatt level to $1000/kilowatt to be competitive with currently available ICE NOx emission controls.

Illustration #3 Mobile Source Projects

Mobile source projects have included support for clean fuel vehicles such as solid waste transfer trucks, inter-city commuter buses, school buses, and crew and supply boats servicing offshore oil platforms in federal and state waters. Both the regulated community and the unregulated have benefitted in various ways from this program. For example, as participants in the County's Clean Fuels

and Energy Program, oil supply boats are proposed for retrofitting with lean-burn CNG engines. Participants in these projects include Caterpillar (engine and technology); Exxon (vessel operation contract); and SoCal Gas (program direction), among others. Benefits include reduced fuel cost, reduced offset cost, emission reduction, leveraged funding, local business and participation. Successful demonstration will represent approximately a 90% reduction in NOx emissions from baseline emissions established in 1987. Emissions reductions from these boats reduce the overall liability of major oil producers for emissions offsets; and the boat operator is in a better position with respect to other non-modified supply boats competing for the same contracts.

3. Innovative Alternatives to Fines and Penalties

Under federal and state law, a local air district has a variety of enforcement mechanisms at its disposal to assure compliance with air quality standards and project permit conditions. Traditional enforcement mechanisms include fines, penalties, and abatement orders.

In certain instances, both the APCD and the alleged violator have found it mutually beneficial to settle a notice of violation [NOV], or a dispute over authority to regulate. Instead of traditional fines or penalties, the alleged violators have recognized the potential savings in operating costs to be realized under these innovative technology development programs, and have agreed to participate. This was the case in 1988-89 when, rather than litigate an emissions violation, Chevron agreed to participate in the turbine program and natural gas crew boat. Similarly, the U.S. Air Force, which had started up its power plant without permits and with unmitigated emissions, agreed to participate in the Fuel Cell program at Vandenburg Air Force Base.

In the case of Chevron, during the construction phase of Chevron's Point Arguello project, NOx emissions exceeded the projected [and permitted] levels by 350 tons. Rather than retrospectively purchase offsets which were in place but unsecured to any project during the period when excess emissions occurred, or purchase additional offsets over the next several years, it was determined that it would be mutually beneficial to work together with the County on a program funded by Chevron to investigate the application of new low NOx turbine technologies in the offshore environment. Chevron agreed to fund the program in an amount over $5 million dollars over a four year period, in cash payments and in-kind contributions. The benefits to the County included that offshore turbine emissions would be accurately characterized, and low NOx technologies which had been tested in the laboratory would be tested on an offshore platform. The goals of the program state that turbine emissions would be reduced approximately 70%, and if the technology tested were found to be feasible, it would be installed on existing Chevron platforms at the company's expense. The technology also had the potential to be applied in other offshore situations. The benefit to Chevron was that the 350 tons of excess emissions were treated as a "shortfall" in NOx emission reduction credits which could be mitigated through the goals of the program rather than as a violation of the terms of its permit, and any technological developments which resulted from the program and which qualified as trade secrets would be owned by the platform owners, and would be made available to other projects at reasonable cost.

Conclusion

Santa Barbara County has historically enjoyed a relatively good air quality, and is anxious to preserve it, not only for its health and aesthetic benefits, but because it recognizes that its major industries are reliant on clean air. The innovative technologies program of the APCD represents but one example of an approach to implementation of high environmental standards which has enjoyed a significant success, in terms of air quality benefits, enhancement of economic opportunities and public attitude toward a local regulatory agency.

Biographical Note

Jana Zimmer is a Czech-born environmental attorney/educator in Santa Barbara, California. In addition to her law practice, she teaches land use law at the University of California [Extension], has written on Environmental Law of the Czech Republic, and is looking forward to conducting training on integrated waste management in Romania in May, 1994. She has served on the Public Law and Environmental Law Executive Committees of the California State Bar Association, and for the last two years she has sat as an appointed member of the Santa Barbara County Air Pollution Control District Hearing Board.

1. The opinions expressed in this paper are those of the author and do not represent the views of the Santa Barbara County Air Pollution Control District Hearing Board. However, the author wishes to acknowledge the individual assistance of Peter Cantle, Mahesh Talwar and Douglas Allard, staff of the Santa Barbara County APCD in providing background material for this presentation.

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11. "Business Opportunities of the New Clean Air Act: Impact of the CAAA of 1990 on the Air Pollution Industry" [ICF Resources Inc., and Smith Barney, Harris Upham and Co., Inc. 8/92.

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ENERGY EFFICIENCY PROJECT FINANCING

Thomas J. Sherwood,
U.S. A.I.D. — CDI/Energy
and Jan Matejcek,
Squires, Sauders & Dempsey in Prague

The current value of energy consumption in the Czech Republic is approximately $7.4 billion. As an example of energy savings achievable in the economy, surveys have concluded that savings of 15-50 percent are achievable in the ferrous metal sector, 33 percent in the chemical sector, 30 percent on the building sector, 10 percent in the glass, porcelain and ceramics sector; and overall savings of 21-33 percent are obtainable in the economy. While no wide spread indications of waste have been found, a study by Tractebel of Belgium just concluded that energy savings by the year 2010 in the Czech Republic could be as much as 8.6 percent over 1990 levels in spite of a growing industrial production base.

These potential savings translate into real productive gains for the economy because the money saved theoretically should flow into investment, thus boosting the competitiveness of Czech goods and services in world markets. A savings of 21 percent is estimated to translate into an annual savings of $1.5 billion. This annual savings exceeds the annual amount of direct foreign investment in the Republic, and is equivalent to fully 6.25 percent of annual GDP.

On a municipal level, these savings add to the wealth of local government allowing it to expand services and improve the quality of life for its citizens. To achieve these savings, recourse has to be made to lenders to provide the scarce capital necessary for implementation. It is here the problem is encountered.

Municipal financing is a new area for lenders because municipalities up to now were not in a position to control their own local tax revenues. This will change, and as it does, municipalities will have a significantly greater access to banks, leasing companies, and bond markets.

In order for this change to be completed, local government must secure full control over local taxes and other forms of municipal revenue. Local governments will then be able to obtain credit ratings that will be indicative of their ability to borrow and service debt.

Project financing can be an interim approach to achieving energy efficiency goals for a municipality prior to its getting access to the municipal bond markets.

This presentation is broadly titled "Project Financing." Now by definition, project finance means setting up a new legal entity, contributing equity to it, and seeking debt for it. The entity is created with one purpose in mind, usually a long-term project. In order to finance, the project lenders will want to see a significant equity contribution, a projected dedicated cash flow to repay interest and principal, and moveable, salable security that will cover their loans in the case of default.

For example, let's assume the municipality owns a district heating plant and wants to refurbish it. First, a study would be done to see if the project makes economic sense. The viability of the project will depend on the cash generated by the project over some reasonable period. This cash flow will in turn depend on the tariff structure. If it's high enough, the project will be successful. Once the study is completed, the plant assets have to be contributed to a new legal entity, which becomes the borrower.

I will give a brief overview of the sources on money in the Czech economy for project finance and the potential developments in the credit markets that will have a favorable effect a municipality's ability to borrow. One of the things I want to come out of this conference is for you to have a channel through which to advance your projects. For this reason, I have asked Mr. Jan Matejcek, partner in charge of Energy Projects for Squire, Sanders & Dempsey in Prague to join me in this presentation. Mr. Matejcek

is an expert who can address your local needs in more detail than I can.

Let's look at the overall Czech Republic situation.

BANKS

Most surveys of the Czech Republic have concluded that the requisite payback periods for energy efficiency investments in industrial processes range from 3.5 to 7 years. The commercial banking sector routinely takes risks out to four years, however, a recent study commissioned by three of the principal Czech commercial banks concluded that the energy efficiency sector should be prioritized for longer-term loans, which is a positive step if it becomes policy.

Commercial interest rates are pegged at prime (currently 12 percent). Banks lend around this rate; higher in the case of commercial credits and lower in the case of municipal credits. In almost all instances, however, the rate of interest is still high.

Interest rates, however, have been gradually falling over the past year as the government's fiscal and money policies have created stable and sustained growth in the private sector. It is estimated that the government plans to reduce rates further to around eight percent by mid-1995.

LEASING

A leasing industry exists. While the leasing industry lends out to six and seven years, its cost of credit exceeds that of loans obtainable from the banks. This is due to higher overhead and administrative costs inherent in the business. Leasing may be more accessible than bank loans, particularly if you're already fully borrowed. This is because the leasing company retains ownership in the equipment.

THE BOND MARKET

The municipal and commercial bond markets are in their infancy. They do exhibit, however, great promise for obtaining municipal finance. Terms are available up to seven years and fixed-rate financing is available at round 11 percent. Transaction costs are still high because of a one percent fee levied by the Finance Ministry. This fee will be reduced later this year. Another limiting factor is that the bond placement has to be a minimum of 100 MM Kcs ($3.5 MM equivalent). U.S. companies may want to partner with Czech municipalities in issuing bonds. Of particular note for U.S. companies is that the underwriting institutions do not necessarily require a parent company guarantee, which has the effect of isolating currency risk for qualified foreign companies with local subsidiaries.

PENSION FUNDS

The Czech Parliament has passed a bill allowing for the creation of pension funds. These funds will not be limited to particular companies, and, as such, will be dominated by the principal Czech banks that maintain large, private, corporate and municipal customer bases.

Due to the actuarial nature of the funds that will be set up, significant amounts of long-term deposits will develop. The consequence will be the entry of new long-term lenders in the market providing 10-year and longer credits. The first funds are expected to be formed this year. It is my opinion that these funds will potentially become the main source of long-term money at low-fixed rates in the Republic.

THE CHALLENGE TODAY

The challenge is to find lending institutions prepared to lend for such periods in these environments. Since money is generally not always available from commercial sources yet, one other way to achieve energy conservation goals is from local government support in the form of subsidies and special loans.

This conclusion is important if you want to understand where and how to begin to raise money. The degree of government support may be an important factor in getting your project financed. For this reason, it is worth examining the functions of the Czech Energy Agency (EA).

An example of a concerted program undertaken by a Central European government, the activities of the EA can serve as a model for government/industry cooperation.

GOVERNMENT SUPPORT

The principal functions of the EA are to:

1. act as a guarantor of government programs on energy saving
2. initiate energy efficiency legislation
3. prepare energy consumption standards for appliances
4. oversee a system of private energy consultancy companies set up by the Agency
5. prepare and disseminate information through publicity campaigns and other education programs.

Considerable money has been allocated by the government toward these activities. The money is spent in several ways including:

1. Payment of 100 percent of the interest on credits extended to activities involving the measurement and regulation of heating consumption, including the installation of building insulation and heating devices.
2. Direct subsidies of up to 50 percent of the costs of insulation, and up to 70 percent of demonstration projects involving new technologies for energy savings.
3. Direct subsidies to a private energy consultancy network of nine not-for-profit companies and marketing and other assistance for 126 for-profit consultancy companies.
4. The provision of interest free loans for the renovation or construction of alternative energy sources (wind, small hydro power plants, biogas, etc.).

Through the energy consultancy company network, the Energy Agency claims to have initiated the installation of new, efficient electrical generation capacity in 194 projects, with an annual product of 82 million Kwh, and claims to have assisted in technical improvements involving over 261,000 apartment units since 1991.

The driving rational behind the Energy Agency is its calculation that the state is saving money on subsidies by spending money building insulation and efficient heating systems This kind of straight-forward thinking is striking for its pragmatism. The EA calculates that by 1994-95, the amount of money saved annually by the program will exceed expenditures. Currently, the government believes it has achieved a gross reduction in subsidies of 420 MM Kcs since 1991. Concomitant with the direct financial benefit, the agency confidently points to the positive environmental benefits its program produces.

Since all the money can't come from the state budget, cooperative relationships with other financial sources have been struck. Projects underway include:

- energy audits of large industrial enterprises (with PHARE)
- replacement of coal and fuel oil with natural gas (CPP)
- demonstration projects:
  - heating conversion and modernization (British Gas)
  - installation of prefab insulation on housing estates (the union of Housing Association)
  - replacement of electric bulbs with compact florescent bulbs (CEZ).

Additionally, the EA foresees the extensive involvement in the expansion of the local energy consultancy company network; sponsoring legislation aimed at enabling demand side management; and extending subsidies to producers of energy savings' equipment.

ENERGY SERVICE COMPANIES (ESCOS)

A final area where municipalities can expect support in the coming years is from the newly created industry known as the Energy Service Company

(ESCO) business. ESCOs are providers of third party financing and technical expertise. They act as a catalyst to bring together all interested parties in third party financing: banks, energy distribution companies, engineering and consultancy companies, manufacturers and suppliers of equipment and target customers. Their payment comes from the energy savings in the project. This process is otherwise know as Energy Performance Contracting, or EPC.

EPC is a mechanism by which an ESCO offers turnkey services in order to reduce energy consumption in a customer's facility. Services include energy analysis, project design, equipment installation, regular maintenance, personnel training, and project financing. The ESCO receives payment for its services only if the project results in energy savings for the customer. Contracts are generally four to eight years. During this period, the ESCO and the customer divide the amount of cost savings for energy purchase. The ESCO will cover the loan repayments and its own costs from its share.

EPC differs from traditional methods of financing in four ways. First, the ESCO is the only responsible party for the entire project, including financing. Second, the ESCO and the customer negotiate the shape and scope of the project together and arrive at a consensus about its form. Third, the ESCO takes full responsibility for the project's success. Fourth, the ESCO finances the entire project. It can use its own finances or obtain money from third parties. If the ESCO uses its own resources, the customer does not take on debt in the traditional sense of the word. The customer pays only when savings are obtained. If outside financial sources are used, the customer could be in a position to borrow, but contrary to classic loans, the ESCO must make up the difference if energy savings are insufficient to meet the payments.

EPC has several distinct advantages for the customer. First, it significantly reduces energy consumption. Second, it reduces operating costs, particularly the costs of maintaining and operating equipment, and it may reduce fines for air pollution. Third, it improves the work environment. Fourth, it raises production quality by improving manufacturing efficiencies. Fifth, it provides training for personnel and improves motivation. Finally, it provides access to external financial sources to cover investment costs.

Recently, PHARE stated its objective to set up a $7.5 million revolving fund in January 1995, to lend to ESCOs. Hopefully, once projects are shown to be commercially attractive, PHARE's commitment will be augmented by commercial risk takers. PHARE expects that, by establishing a special fund to finance energy efficiency projects by the Energy Performance Contracting (EPC) method, it will be able to demonstrate the viability of the concept. They expect the fund to also serve as an incubator for the first ESCOs to operate in the country.

At the moment, there is only one ESCO which is set up in the Czech Republic, EPS in Prague. EPS is an affiliate of a non-regulated subsidiary of Philadelphia Electric. The company signed up a number of potential credits, and performed an energy audit on a teaching hospital as a preliminary to installing new boilers and heat exchangers.

Another company, SRC International, is attempting to establish an ESCO in the Czech Republic. They are negotiating with CEZ, which has expressed its desire to affiliate with SRC in such a venture. To date, CEZ has not made a commitment, though the issue is in front of CEZ's board. If CEZ does proceed, SRC will act as a financial guarantor in third party financing.

CONCLUSION

I have spoken at length about the environment and the sources of money for your projects. While there are difficulties in obtaining financing, I must state that I am optimistic about the near-term availability of money for municipal energy efficiency projects. I trust that you will have a number of questions, and I trust Mr. Matejcek or I will be able to assist you in getting them answered.

Natural Gas and Independent Power

in Central and Eastern Europe

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Introduction

1. Natural gas has constituted a relatively small share of the total primary energy supply in the countries of Central and Eastern Europe, with the exception of Romania and Hungary.

2. The transition to market economies and the concern with improving efficiency and environmental performance of the energy systems has focused attention on the potential for natural gas to play an increasing role.

3. This paper considers this issue in the broad context of energy supply diversification and the changing institutional and financial context of energy, power, and heat supply in Poland, the Czech Republic, the Slovak Republic, Hungary, Romania, and Bulgaria.
The particular role of independent power development in local cogeneration projects is examined.

Supply Diversification and the Changing Energy Mix

4. The national energy policies being adopted in the CEE countries generally call for supply diversification and import source diversification as well.

5. The energy mix has been dominated by coal and nuclear. Much of the coal used, other than in Poland, has been lignite and brown coals. This meeting has discussed the implications for pollution from the burning of these fuels in district heating, small boilers and residential furnaces.

6. Except for Romania and Hungary, most of the natural gas consumed in the CEE countries is imported from Russia.

7. Natural gas consumption is focused in the industrial sector, with some residential and commercial use. Gas use in the power sector has been quite limited except in Hungary and Romania.

8. Energy consumption has dropped in all countries in the past three years during the economic restructuring process.

9. Projections suggest a recovery in demand in the latter half of the 1990s and natural gas is expected to expand its share in the future.

Potential Impact of Changes in Western European Gas Market

10. Given the import dependence of CEE on imported gas and its position astride the major

gas pipelines from Russia, the decisions of Western European countries and companies on investment in increasing Russian imports and/or diversifying gas supplies from Norway and other sources will have a major impact on the price and availability of gas by CEE countries.

11. In this regard, the plans and projections of former eastern Germany are interesting. While only 3% of east German residential dwellings use natural gas for space heating, Ruhrgas projects that this figure may rise to 40% by 2010.[1]

12. Norway has the largest reserves in Western Europe and is set to double its exports by 2000 from the current 26 billion cubic metres per year and possibly triple them by 2010.[2]

13. The United Kingdom appears to have some potential for expansion until 2000 but some forecasts suggest a significant dropoff by 2010.

14. Projects to expand Algerian pipeline deliveries to Italy and via the planned Magreb pipeline through Morocco to Spain and Portugal appear to be viable options while Gulf projects from Qatar and other large gas producers appear to be too expensive and risky.

15. At present these alternative supply schemes are dwafted by the growing number of contracts and projections of as much as an 80 billion cm/year increase in FSU gas exports by 2010 from Russia and Turkmenistan. This growth would appear to depend considerably on the new field developments in the Yamal region and the construction of a 4000km "northern" pipeline carrying up to 67 billion cm/year of gas through Belaurus and Poland to Germany by 2010. The Russian company Gasprom has signed an agreement with the Polish oil and gas authority permitting transit through Poland and giving Poland an offtake entitlement of 14 billion cm/y.

16. Recent political events in both Russia and in the Ukraine have raised some concerns about the security of future supplies which may deter investors in both the Yamal development and in pipeline construction and upgrading.

Economic Restructuring and the Prospects for Gas in CEE

17. **Poland** with its heavy reliance on coal can be expected to diversify its energy mix and increase oil and gas consumption. With the surplus of power generation capacity, the opportunities for investment in gas-fired power systems is limited at present and most projects are oriented to rehabilitation of coal and lignite fired units. But these investments in

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[1]"Gas in Eastern Europe", Petroleum Economist, March 1994, p. ix.

[2]"Gas in Europe: Supply", Ibid., p. ii.

some locations may not be feasible, especially since the new environmental standards that go into effect in 1987 will require expensive plant investments to control emissions.

18. **The Czech Republic** has decided to proceed with the 2000MW Temelin Nuclear Power Plant as well as projects such as Prunerov to install expensive Flue-Gas Desulphurization Units. The Czechs have security concerns over major expansion of gas supplies from the Former Soviet Union. They are proceeding with the oil pipeline from Ingolstadt, Germany to diversify oil import supplies. Private industries are considering clean coal technologies and at least one plant, Komorany (reported on at this meeting) is pursuing a FBC retrofit. But gas-fired cogeneration units are being considered by several municipal systems.

19. **The Slovak Republic** sits astride the major gas pipeline from the Former Soviet Union to Western Europe. Gas use is forecast to increase from 5.7 billion cubic meteres in 1992 to 9.7 BCM in 2005 due to the increases in demand in electric power/heat and residential subsectors. Power use was only 200 Mcm. in 1992 but several gas combined cycle projects and gas or dual-fired CHP projects are under consideration. These projects are highly dependent on the recovery of electrical load, the decision to complete the Mohovce Nuclear Power Plant and close the Bohunice V-1 units, the economic comparison with rehabilitation options such as Vojany I, and increases in domestic heat and power tariffs..

20. **Hungary** has a firm program to retire old thermal capacity and develop or add to gas fired systems. Plans are to retire 500Mw by 1996 and 1150MW by 2000. The utility MVMRt. will replace this capacity through (1) the conversion of existing heat-producing and conventional cogeneration plants to combined-cycle cogenerating units with gas-fired combustion turbines, (2) open-cycle combustion turbines to meet peak import requirements, and (3) new combined cycle plants located at domesitc gas fields. The World Bank recently approved a $100 million loan to MVMRt. which included financing for the constructuring of a gas-fired combined cycle cogeneration plant at Dunamenti southwest of Budapest with a rating of 235MWe and 240MWt.

21. **Romania**'s power system has oil, gas, coal, lignite and hydro plants. In 1992, 18.6 TWh or about % of RENEL's output was from natural gas. A 700MW Candu-type nuclear unit at Cernovoda is nearing completion and rehabilitation projects are underway to upgrade coal and lignite plants. A substantial number of cogeneration plants begun in the 1980s (as much as 1400MW) are in various stages of construction as are some hydro plants. A master investment plan is being developed but the government faces a complex situation given limited resources, uncertain electricity demand, and large sunk investments in thermal, hydro and nuclear plants. The share of gas in future generation is forecast to fall from 8.5 bcm in 1992 (32% of total national gas consumption) to 4.6 % in 2000 (16%).

22. **Bulgaria** is developing with World Bank, European Bank and USAID and EU

assistance a power/heat strategy and least-cost investment program. The strategy is influenced significantly by the agreed objective of developing viable alternatives to the continued operation of Units 1-4 of the Kozluduy Nuclear Power Plant. The main elements of the plan would appear to be to upgrade and increase the availability of the VVER 1000 Units #5&6 at Kozluduy, rehabilitation of a number of thermal units, especially Varna in the east which is currently dependent on imported Ukrainian coal. A recent offshore natural gas discovery by Texaco holds promise of potential domestic gas production in the future. But much definitional drilling will be needed to determine the size and economic viability of developing these resources.

Independent Power Investment and Financing

23. **Energy and Electricity Laws::** All the six countries have been working intently on the preparation and legislative consideration of draft energy and electricity laws. Major debates over ownership, pricing, industry structure and the nature and functions of regulatory bodies have surfaced and blocked government efforts to push through these new legal and institutional frameworks. Recently, Hungary was the first country to pass both an electricity and a gas utilities law, the details of which are not fully available at the time of this writing. These laws are extremely important in establishing the basis for private investment and establishing a process for interested investors to propose ventures, whether jointly with the utility or transmission grid company, or with a municipal authority or industrial company in a cogeneration project with potential sales to the grid or local distribution company.

24. **Privatization and Price Reform:** The process of privatization in the power industry has proceeded slowly compared with other industrial sectors. Governments have clearly viewed this sector as one in which the state has a special interest in maintaining a controlling role. Yet with the huge capital requirements for modernization and the difficulties of generating needed investments through tariff increases or foreign borrowing, a recognition of the need for foreign and local private investment in the sector seems to be growing. The Czech Government has converted the CEZ company to a joint stock company with roughly 30% voucher privatization. The distribution companies are included in the second wave of privatization but the private share is likely to be smaller. Hungary is posed for privatizating certain components of the MVMRt. company, starting with distribution. In Poland, the distribution companies have all become joint stock companies but no real foreign or private involvement in neither distribution or generation has yet been realized. But the EBRD recently approved a project Bieska-Biala involving private limited recourse financing linked to long-term export sales. Several proposed joint ventures with Polish combined heat/power plants, involving foreign investors, are also under negotiation. Bulgarian and Romanian systems remain totally in the government's hands. Price reforms, especially in household rates will be needed to ensure investors of the viability of participation. With inflation rates of over 20%, countries are slipping behind in the adjustment of rates, creating not only

disincentives to potential investors but also problems with new lending from the Multilateral Development Banks..

25. **Cogeneration and District Heating**: If tariff subsidies can be substantially reduced and power companies and governments can develop processes and sound power/heat purchase and implementation agreements, then the potential for investment in the cogeneration and in the rehabilitation of district heating systems would appear to be substantial. Over 1000 centralized district heating systems are found in the six countries with about 300 of these being CHP. Whether these should be retrofited to burn gas ,coal or a mix of fuels will depend on the particular situation. But efficient and environmentally acceptable cogeneration or combined cycle power units based on gas, may be over the long-run a better option that trying to rebuild old coal or lignite based units or installing expensive controls to meet new environmental standards. The typical 10-50MW size of these units would seem to make it an attractive target for independent power developers and a potentially feasible exposure for both developing local capital sources as well as limited recource foreign investment funds if some of the fundamental tariff and risk allocation issues can be overcome. Of course, in some cases, closing district heating systems and moving to direct gas heating units in buildings and residential units may be the best long-term options. But energy efficiency of the existing building stock must be substantially increased to maximize the benefits from such a major switch..

Conclusions

26. Western European decisions on importation and diversification of natural gas supplies will have powerful effects on the countries of Central and Eastern Europe.

27. The market for natural gas in likely to grow quite rapidly if economic growth picks up incomes rise, and subsidies on domestic fuels are removed. This drive will come from industries seeking to modernize and increase productivity and competitiveness, from foreign investors bringing in new facilities and technologies, from utilities faced with new and tougher environmental standards and the need to retire older power and district heating plants, and from consumers who want and can now afford the comfort of gas heat.

28. Gas-fired cogeneration or combined cycle systems may be a viable solution for both local systems and major grid facilities depending on the import price of gas and other fuels compared with domestic coal and lignite prices of oil. If the proper legal and institutional framework can be established and prices rationalized, then these systems, if properly designed, can help increase the flexibility of national grid systems that will continue for some time to be dependence on base-load coal and nuclear plants.

29. Despite legitimate concerns about the security of increasing gas supplies from the

former Soviet Union, the growing dependence of Western Europe on these sources reduces some of the risks for the CEE countries. The purchase of gas also will hopefully lead to an increased ability of Russia to import goods from Central and Eastern Europe.

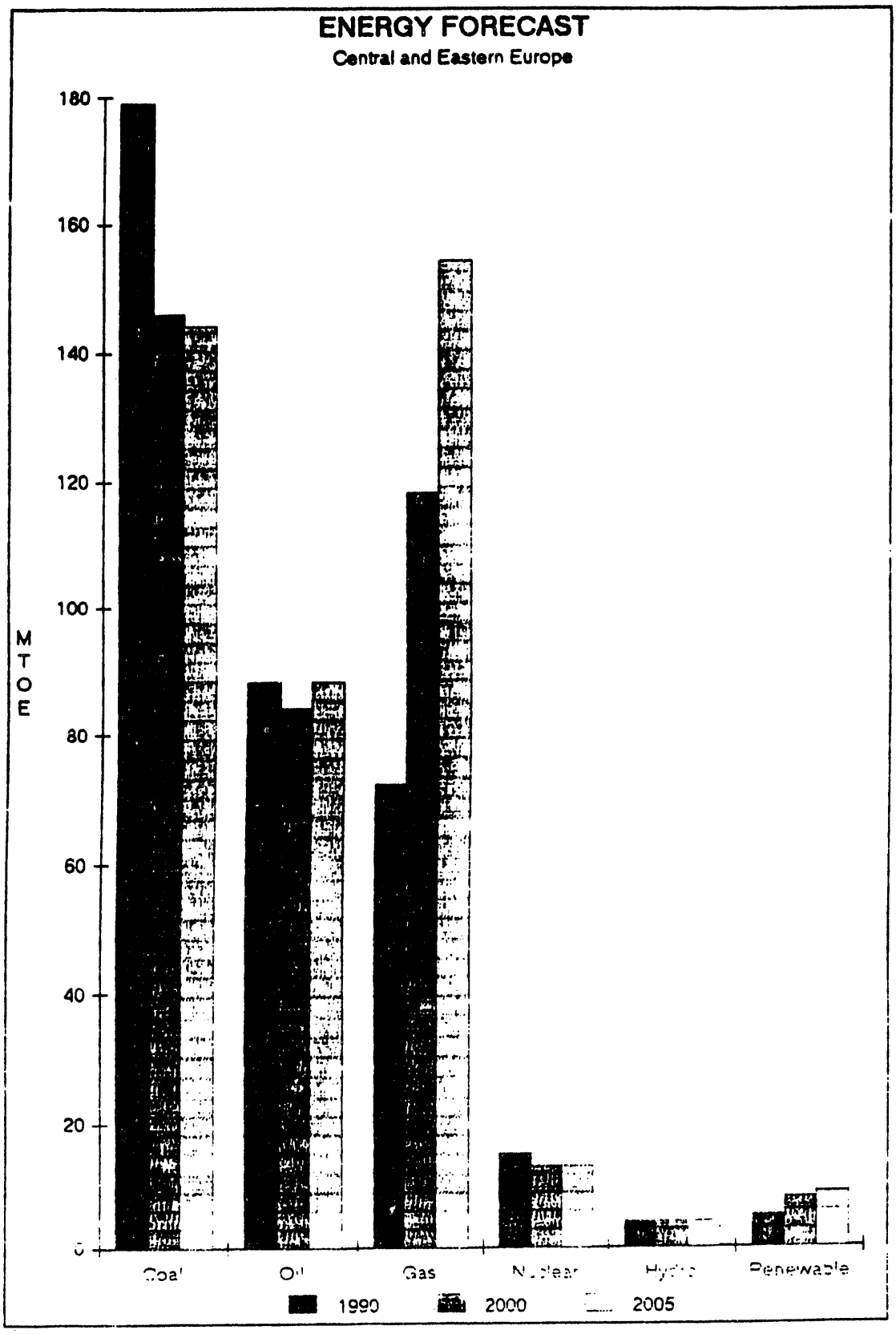
NATURAL GAS AND INDEPENDENT POWER IN CENTRAL AND EASTERN EUROPE

1. ENERGY SUPPLY DIVERSIFICATION

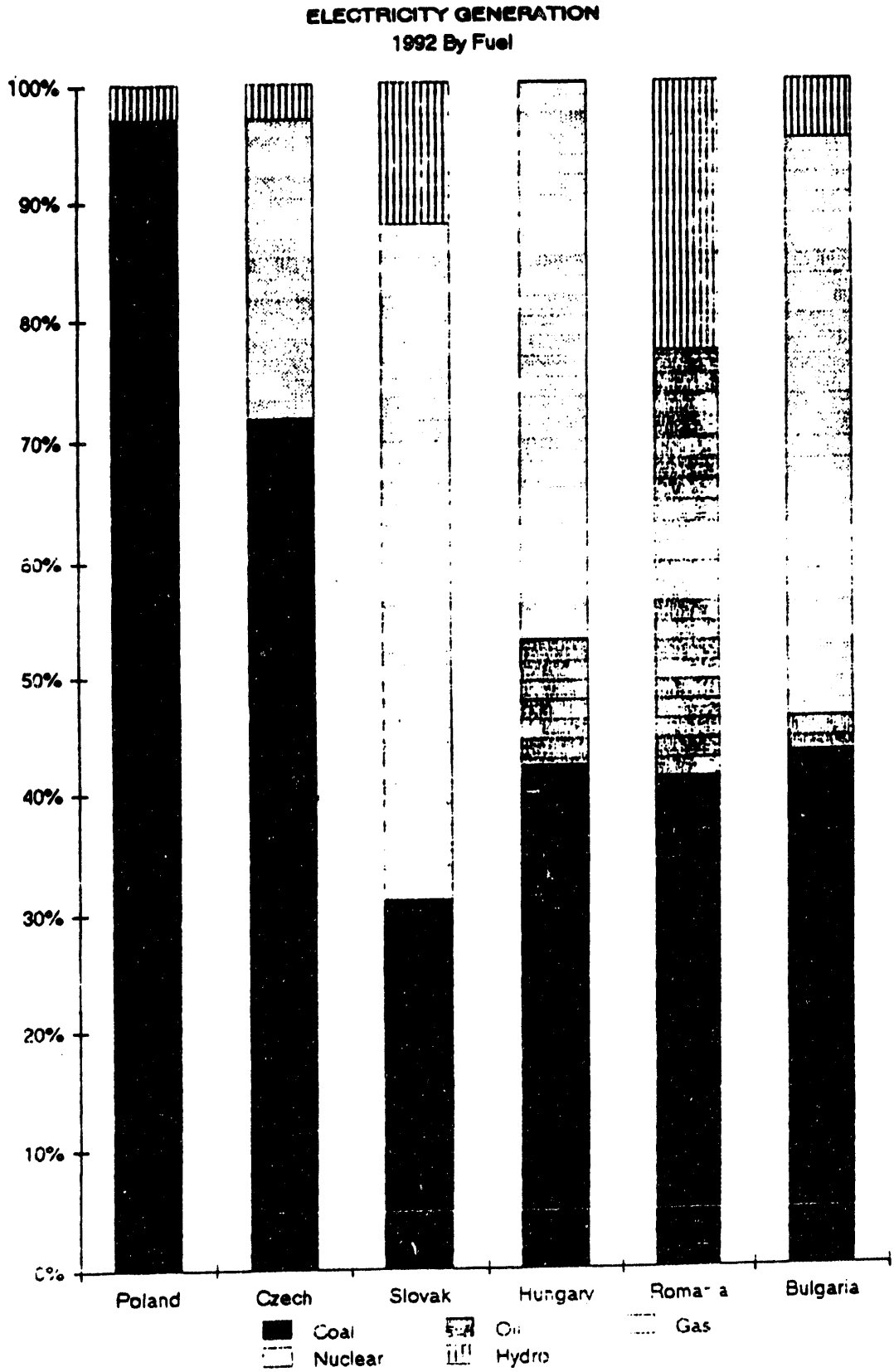
2. GAS MARKET IN WESTERN EUROPE

3. CEE ECONOMIC RESTRUCTURING AND ENVIRONMENTAL IMPROVEMENT

4. INDEPENDENT POWER OPPORTUNITIES AND FINANCING



Source: EC -DG17 Energy in Europe: A View to the Future


ELECTRICITY GENERATION
1992 By Fuel
100%
90%
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Poland
Czech
Slovak
Hungary
Roma- a
Bulgaria
Coal
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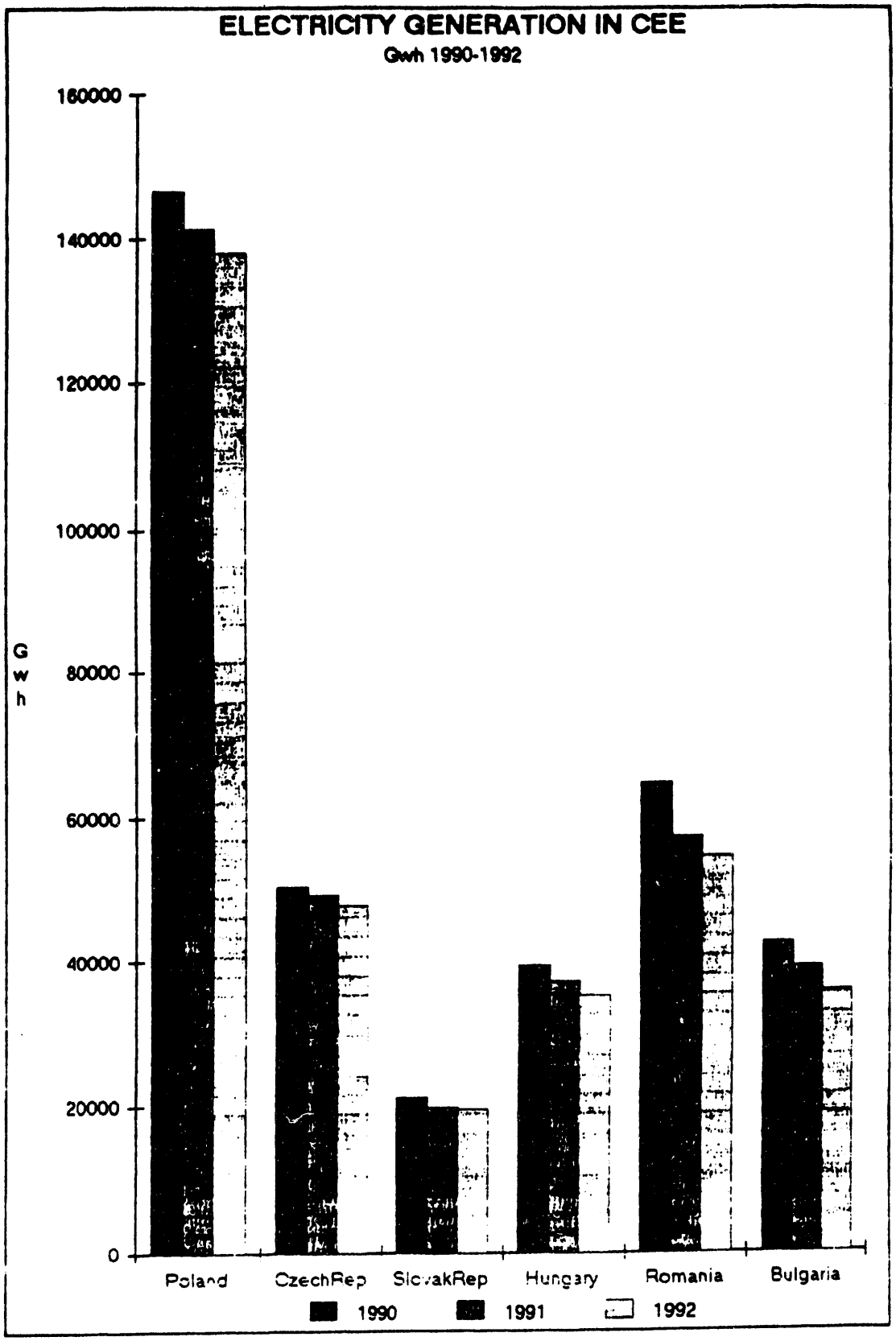
Oil
Hydro
Gas


ELECTRICITY GENERATION IN CEE
Gwh 1990-1992
160000
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SlovakRep
Hungary
Romania
Bulgaria
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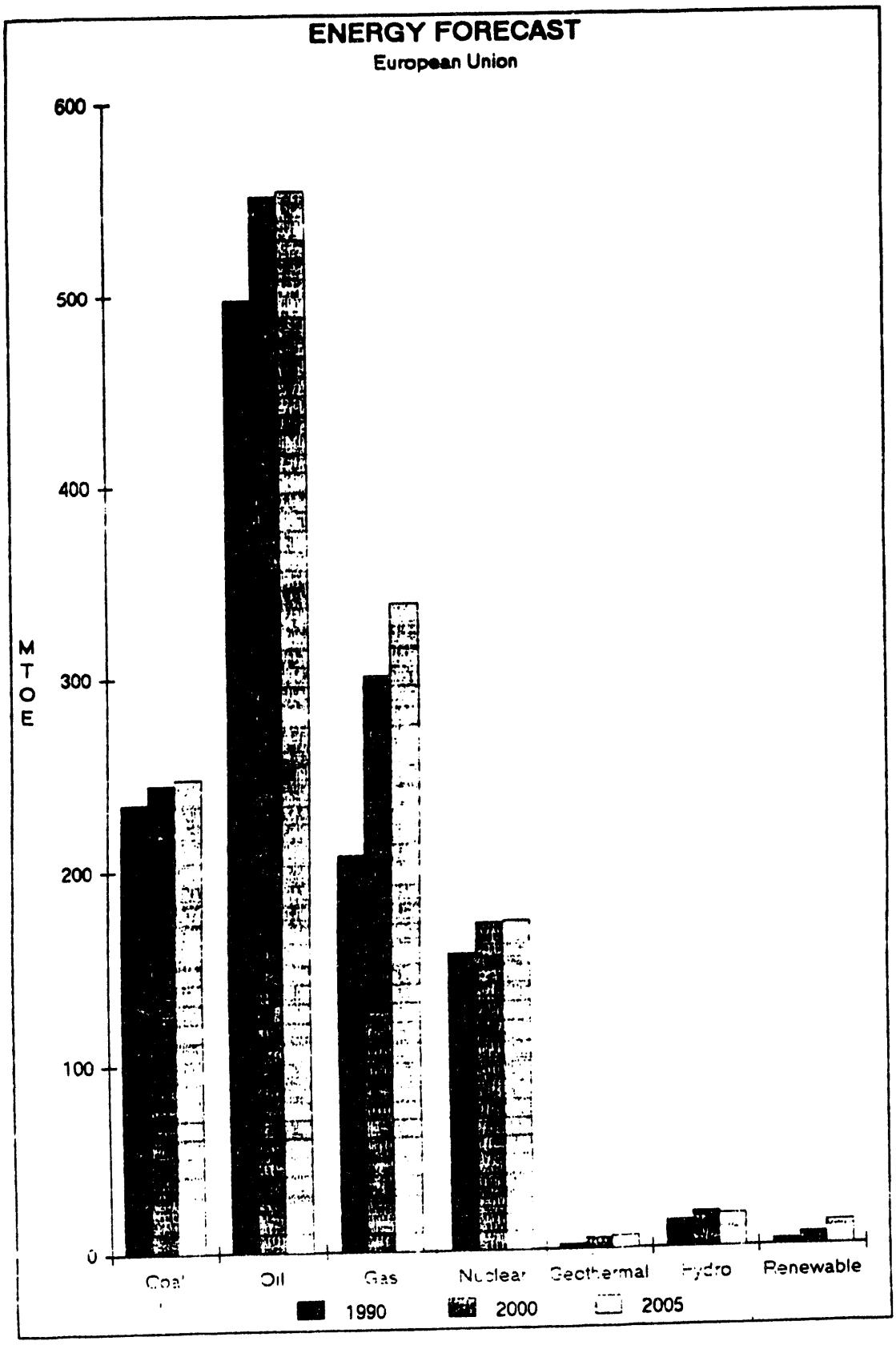
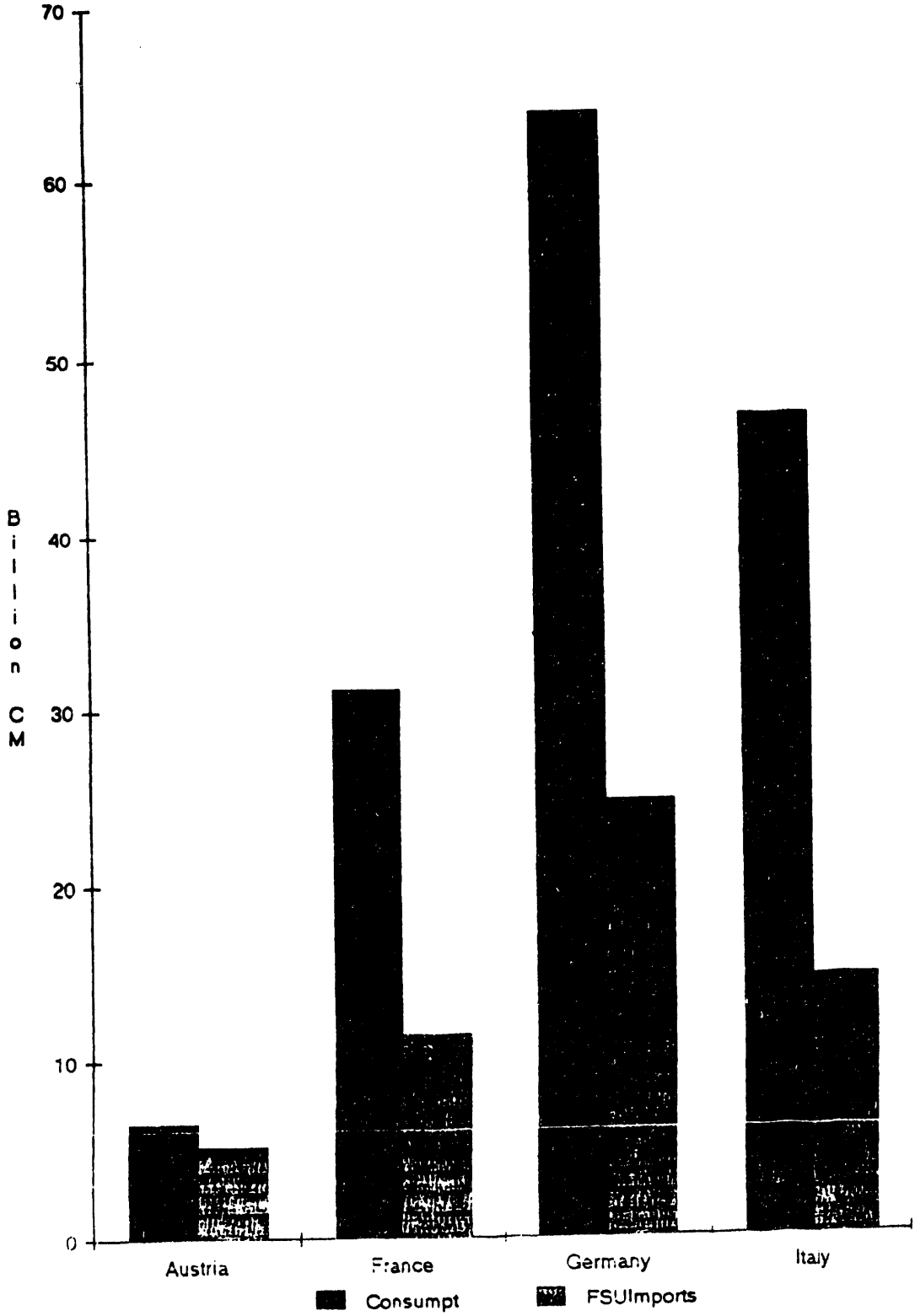
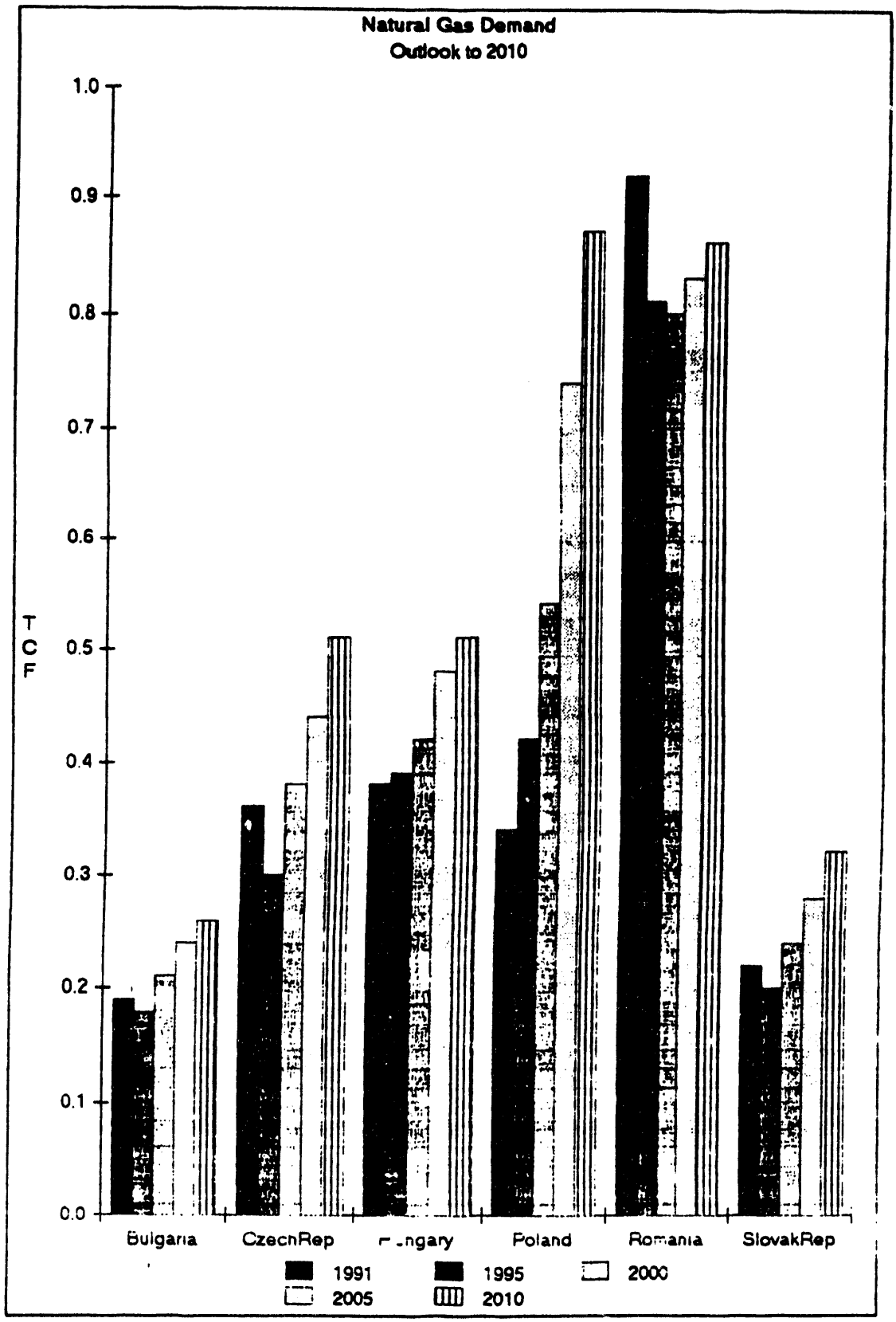


Source: DG17 - Energy in Europe: A View to the Future

Gas Imports from FSU:1991
Selected W.European Countries



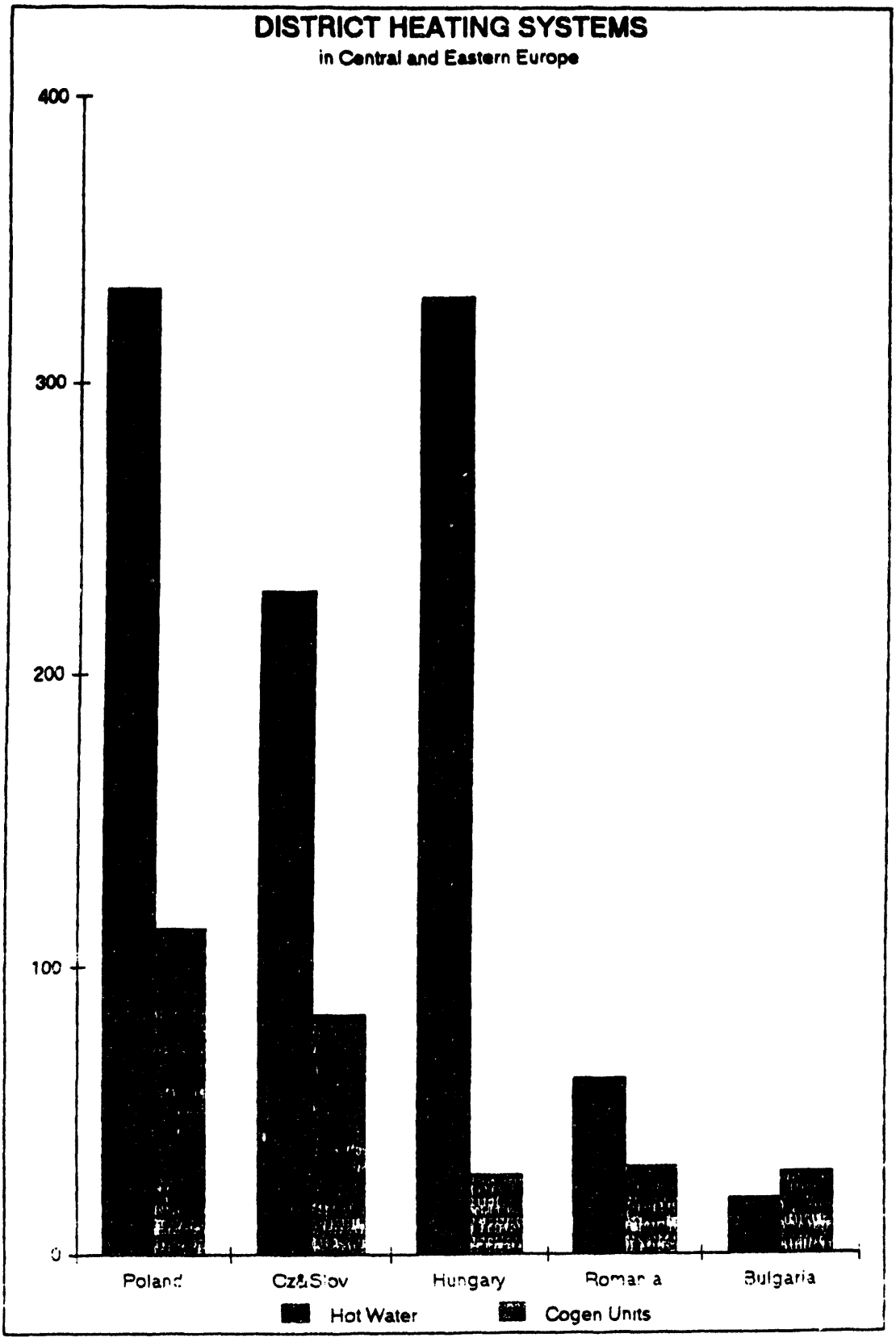


Purvin and Gertz, Inc. in Oil & Gas Journal

HUNGARY:

Construction Schedule for Gas Turbines

Power Plant Units	Capacity [MW]	Electricity [GWh/a]	Heat [TJ/a]	Fuel [TJ/a]	Efficiency [%]
1. MVM's Power Plants	1140	7750	24450	74450	70.3
1.1 Dunamenti Power Plant	530	4100	8800	36000	65.4
- G1 enlargement	150	930	6200	11500	83.0
- G2 enlargement	230 ('80)	1520	2500	12500	63.8
- H enlargement	150 (450)	1650	100	12000	50.3
1.2 Budapesti Power Plant	495	3050	13100	32500	74.0
- Kelenföld	140	700	4700	8700	83.0
- Újpest	195 (40)	1270	4500	12800	70.1
- Kispest	160 (35)	1080	3900	11000	70.8
1.3 TITÁSZ s Power Plants	115	600	2550	5950	79.1
- Debrecen	70 (15)	400	1550	3900	76.7
- Nyíregyháza	45	200	1000	2050	83.9
2. Independent Power Plants	803	6006	7190	49380	58.3
2.1 Algyő PP.	190 (60)	1400	850	10300	57.5
2.2 Győr PP.	160 (35)	1200	2600	10900	65.2
2.3 Duna Power	120 (30)	985	2300	9300	64.9
2.4 Dunaújváros PP.	208 (58)	1454	1440	11600	45.2
2.5 Inke-Liszó PP.	85 (28)	667	—	4710	51.0
2.6 Biharkeresztes PP.	40	300	—	2570	42.0
Total	1943	13756	31640	123830	65.5



Source: Advanced Engineering Associates

Session IX
Panel Discussion
Issues
at the Municipal Level

Moderator: **Leonard Rogers**, U.S.AID

Panelists:

Jan Friedberg ..... Deputy Mayor of Kralow
Steven Giddings ..... U.S.AID
Kenneth Hobbs ..... Director of Arthur Anderson, Prague
Zdenek Proesk ..... Deputy Mayor of Plzen
Delcho Vlchev ..... EBRD, London

Discussion focused on issues specific to municipal decision making, interaction with state government, obtaining financing, and ownership issues.

Session X
Closing Session

Moderator: Howard Feibus, U.S. DOE

Speakers:
Mr. Rucky .....Czech Ministry of Industry and Trade
Robert Ichord .....U.S. AID

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Bardel, Janusz	Biuro Rozwoju Krakowa ul Kordylewskiego 11 Krakow, 31-547	Poland	48 12 11 20 22 48 12 12 55 04
Barta, Edvard	TEZA Vysny Cesky Krumlov,	Czech Rep.	42 337 4038 42 337 67142
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	al. Niepodleglosci 49		48 3 127 42 4
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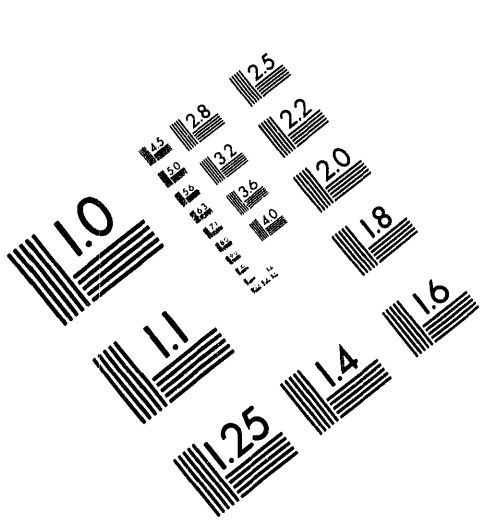
Okarmus, Wilhelm	Cracow University of Technology Krakow,	Poland	48 12 330300 48 12 338451
Pantak, Alexander	Acurex Krakow,	Poland	48 12 90310536
Parks, Paul	US AID New State Office Bldg. 320 21st. St., NW Washington, DC 20523	USA	
Paroha, Lubomir	Foundation Project North Masarykova 43 Usti n. Labem,	Czech Rep.	42 417 41661
Pecikiewicz, Andrezej	US AID AL. Jerozolimskie 56C Warsaw, 00-803	Poland	48 2 630 2480 48 2 628 7486
Petrakis, Dr. Leon	Brookhaven National Laboratories Bldg. 179A - 2 Center St. Upton, NY 11973	USA	516-282-3037 516-282-4130
Picková, Helena	Transgas Vinohradska 8 Praha, 120 00	Czech Rep.	
Pieczyski, Boguslaw	Kompekon Consulting Dabrowskiego 23 Katowice, 40-032	Poland	48 3 1551598 48 3 1545589
Pied, Paul	Thion 44-46 Allee Gambetta 92 Clichy,	France	33 1 47 56 2222 33 1 40 87 0034
Piekarz, Tadeusz	City of Krakow Basztowa 22 Krakow,	Poland	48 12 160207 48 12 224184
Pisch, Jan	Mestsky urad Handlova Handlova,	Slovakia	42 862 915431
Pisczek, Jerzy	The Polish Foundation for Energy Efficiency Powstancon 41A Katowice,	Poland	48 3 1552729 48 3 1552729
Pisko, Jan	US AID US Embassy Trziste 15 Praha, 118 01	Czech Rep.	42 2 2451 0847 42 2 2451 0341



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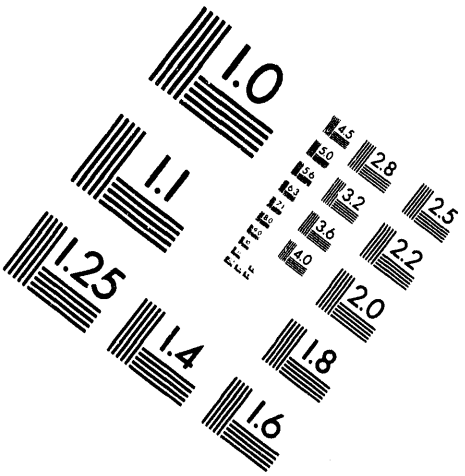

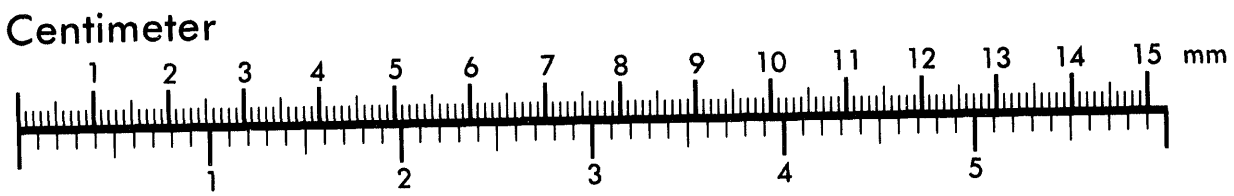

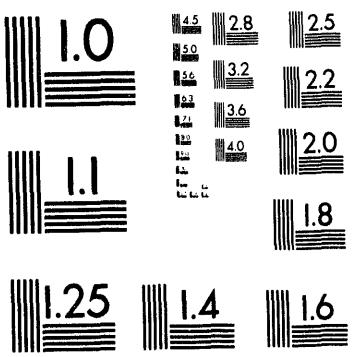

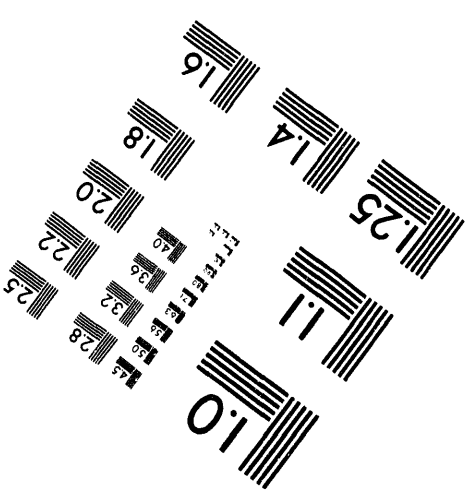

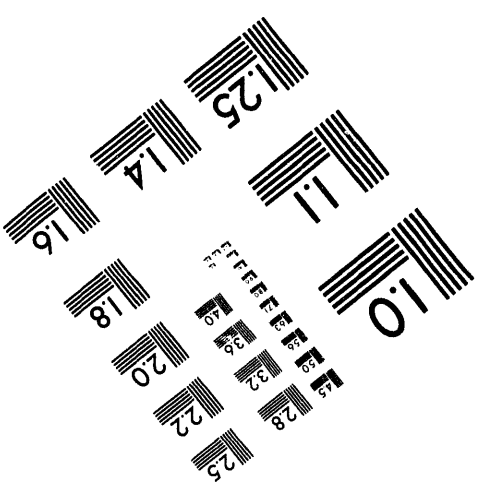

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Attendee List

Name	Organization/Address		Phone/Fax
Pracny, Frantisek	1 SZT Komorany		42 35 27250
	Komovany u Mostu		42 35 22759
	Most, 434 03	Czech Rep.	
Prasek, Karel	USA Style s.r.o.		67021599
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	Praha, 10803	Czech Rep.	
Prerad, Vladimir	POWER International, s.r.o.		
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Presz, Krysztof	Midwest Traders International		48 22 560 592
	Raszyn-Falenty		48 22 560 592
	, 05-090	Poland	
Pytlarz-Denkiewicz, Barbara	State Environmental Protection Inspectorate		48 32 515554
	ul. Wita Stwosza 31		48 32 515554
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Rasala, Jaroslaw	State Environmental Protection Inspectorate		48 32 515554
	ul Wita Stwosza 31		48 32 515554
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	Maiselova 15		42 2 24812299
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Rycula, Rajmund	PEC Tychy		48 31 19 56 27
	ul. Kubicy 6		48 31 19 50 40
	Tychy,	Poland	

Attendee List

Name	Organization/Address		Phone/Fax
Rzewuska, Ewa	Env. Prot. com. Local Parlament of Wroclaw Plac Powstancow Warsaw,	Poland	48 71 355 24 same
Schnotale, Marzanna	Biuro Rozwoju Krakowa ul Kordylewskiego 11 Krakow, 31-547	Poland	48 12 11 20 22 48 12 12 55 04
Secrest, Tom	Pacific Northwest Lab. Battelle Blvd. Richland, WA 99352	USA	509 375-3873 509 375-3614
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Seitz, Ales	Teplarna Strakonice Komenskeho 59 Strakonice, 386 43	Czech Rep.	42342565111 4234224309
Selig, Michael	Shooshanian Engineering Assoc. Inc. 330 Congress St. Boston, MA 02210	USA	617 426 0110 617 426 7358
Sely, Karel	Energoprojekt Bubenska 1 Praha, 170 00	Czech Rep.	
Sestak, Petr	EGU Bratislava Bajkalska 27 Bratislava, 827 21	Slovakia	42 7 292783 42 7 221560
Sheahan, Rick	TCS Inc. 176 Conduit St. Annapolis, MD 21401	USA	410 280 6055 410 280 5007
Sherwood, Thomas T.	US AED U Dubu 13 Praha,	Czech Rep.	42 2 464651 42 2 464651
Shrbeny, Jan	POWER International, s.r.o. Maiselova 15, Prague 1 Praha, 110 00	Czech Rep.	
Simice, Vaclav	Plzenska Teplarenska as Doubravecka 1 Plzen, 304 10	Czech Rep.	42 19 37712 42 19 35845
Slavotinek, Ivo	EPS CR, s.r.o. Rubesova 10 Praha, 120 00	Czech Rep.	42 2 24231204 42 2 24231204

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Sletten, Jeffrey	Custom Coals Intraco building, 2 Stawki St. Warsaw, 00-193	Poland	
Slezak, Teresa	Elektrociptowniz Zerán ul. Modlinska 15 Warsaw, 03-216	Poland	11 30 11 w.671 11 26 44
Snow, Gerry	POWER International 250 Northwest Blvd., Suite 206 Coeur d'Alene, ID 83814	USA	208 664 6400 208 664 2986
Sobota, Jiri	Tepelne zasobovani mesta Plzne F. Benese 23, 320 Plzen,	Czech Rep.	
Srbova, Alena	ZCP Anglicke nabrezi 1 Plzen,	Czech Rep.	4219 227252e206 42 19 223222
Stanek, Miloslav	Nova Hut a.s. zavod 4 energetika Ostrava Kuncice, 707 02	Czech Rep.	42 69 354734 42 69 282536
Starkova, Olga	Cesko-Americky Podnikat Fond Blanicka28 Praha, 120 00	Czech Rep.	42 2 24247046 42 2 24246048
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Storsul, Stein	Selfint AS Ogndalsv 2 Steinkjer, 7700	Norway	47 741 45500 47 741 45550
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Sutkowski, Lawrence	Electrotek Concepts, Inc. 5000 Campuswood Drive East Syracuse, NY 13057	USA	315 437 6003

Attendee List

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Svatuska, Jiri	Plzenska Teplarenska as Doubravecka 1 Plzen, 304 10	Czech Rep.	42 19 37712 42 19 35845
Svoboda, Josef	Energoprojekt a.s. Bubenska 1 Praha, 170 00	Czech Rep.	
Swierz, Adam	MPEC, s.a. al. Jana Pawla II 188 Krakow, 30-969	Poland	48 22 44 55 33 48 22 44 55 10
Sykora, Jiri	Bytovy Podnik Decin Teplicka 45/31 Decin, 405 22	Czech Rep.	42 412 89450 42 412 89451
Syszard, Kalbarczyk	Polske Agencja Ekol Rakowiecka Str. 4 Warsaw, 00-975	Poland	49 95 18 19 50 81
Szewczyk, Witold	Akademia Górniczo-Hutnicza Im St Staszica al Mickiewicza 30 Krakow, 30-059	Poland	48 12 11 20 22 48 12 12 55 04
Tur, Ryszard	Urzad Miejski Slonimska 1 Bialystok, 15-028	Poland	48 411 125 48 414 324
Turczyk, Elzbieta	Electrocieplownia Zerán ul Modlinska 15 Warsaw, 03-216	Poland	11 30 11 w.671 11 26 44
Turner, James	Shooshanian Engineering Assoc. Inc. 330 Congress St. Boston, MA 02210	USA	617 426 0110 617 426 7358
Uberman, Robert	Biuro Doradztwa Ekonomiczno-Prawmiczego POLIN al3 Maja 9 Krakow, 30-062	Poland	48 12 11 20 22 48 12 12 55 04
Uhlir, Martin	SOLIMAR s.r.o. Legerova 15, 120 00 Praha, 120 00	Czech Rep.	42 2 29 45 84 42 2 29 72 56
Urvalek, Petr	US AID Trziste 15 Praha, 110 00	Czech Rep.	42 2 2451 0847 42 2 2451 0341
Vales, Zdenek	Západoceská energetick, a.s. Anglicke nábr 1 303 28 Plzen,	Czech Rep.	42 19 2160/201 42 19 227140

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Vitek, Miloslav	Ostravsko-karvinské doly, a.s. Prokesovo nam 6 Ostrava, 728 30	 Czech Rep.	
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Votava, Jiri	CKD Dukla Thamova 11 Praha, 180 00	 Czech Rep.	 42 2 22812181
Vystrcilova, Darina	Ministerstvo Zivotniho Prostredi Vrsovicka 65 Praha, 100 10	 Czech Rep.	42 2 61722155 42 2 7310308
Walder, Venanc	Energo Steel PO Box 097 Ostrava, 708 00	 Czech Rep.	42 69 6604304 42 69 6624555
Wapiennik, Kazimierz	Voiv. Fund Env. Protection ul. Garbarska 18 Krakow, 31-131	 Poland	22 92 22 22 41 13
Weber, Jan	Okresni urad Karvina Zakladatelska 974 Nova Mesto Karvina, 735 06	 Czech Rep.	42 69 6311942 42 69 6311072
Weinstein, Richard	Gilbert/Commonwealth P.O. Box 1498 Reading, PA 19603	 USA	610 775 2600 610 775 2670
Weiss, Dusan	SEP-Electrárne Nováu, odstepny závod 972 43 Zemianske Kostolany Novaky,	 Slovakia	
Wertz, Jerzy	Wydzial Ochrony Srodowiska Urzedu Wojewodzkiego ul Basztowa 22 Krakow, 31-156	 Poland	48 12 11 20 22 48 12 12 55 04
West, John	Control Techtronics 99 S. Cameron St. Harrisburg, PA 17101	 USA	717 257 5440 717 238 4694
Worthington, Barry	US Energy Association 1620 Eye St., NW, Suite 1000 Washington, DC 20006	 USA	202-331-0415 202-331-0418
Wysk, S. Ronald	LSR Technologies, Inc. 898 Main St. Acton, MA 01720	 USA	508 635 0123 508 635 0058

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	Doly Nastup Tusimice		42 3 984830
	432 01		
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Zdebor, Roman	Skoda Jaderne strojirenstvi plzen		42 19 5042942
	Orlik 266		42 19 520600
	Plzen,	Czech Rep.	
Zelazny, Jan	City Council of Krakow		48 12 161402
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	Bilina,	Czech Rep.	
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von der Heide, Bernd	Nalco Fuel Tech GMBH		49 2054 84041
	Teelbruch 126		49 2054 84692
	Essen,	Germany	

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