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;

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- 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, SO₂, CO, NO_x and CH₄ 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
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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.

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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
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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 HENSCHTEL 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, SO₂, NO_x, CO and so-called equivalent emissions according to the formula:

$$Er = 2.9 (Ep + ENO_x) + 0.5 ECO + ESO_2$$

The amount of emissions (concentrations of pollutants) are related to annual standard values, i.e. 32 µg/m³ for SO₂ and 50 µg/m³ 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 SO₂ 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

0.1 / 100

3578 20.2 646.2 428.3

310.3 2.1.7

CITY PLAN