SELECTING FUELS WITHIN ENVIRONMENTAL IMPACT REQUIREMENTS: CONVERTING A PRESENT COMBUSTION SYSTEM TO ALTERNATIVES OR SUBSTITUTIONS: WHAT IS FEASIBLE?

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ABSTRACT
This paper gives a partial listing of fuels, primarily wastes, as alternatives to traditional fossil fuels. Next, the alternative fuels with large potential energy recovery are selected and present combustion system conversions to burn these fuels are discussed. Factors involved in a feasibility study for a specific application are reviewed.

The objectives are to suggest alternative fuels and to evaluate the feasibility of converting a present combustion system to an alternative fuel within environmental impact requirements.

The combination of dramatically rising fossil fuel (coal, oil, and gas) costs and the uncertain availability of these fuels (particularly oil and gas) has stimulated consideration of alternative fuels.

The ideas reviewed in this paper offer some or all of the following benefits:
- lower thermal energy costs
- nondepletable energy supply
- reduction of waste problem
- conservation of natural resources (fossil fuels, metal raw materials, land areas).

INTRODUCTION
Waste fuels (solid, liquid, or gaseous) should be considered as alternatives to traditional fossil fuels because of the rapidly rising costs and uncertain availability of these fossil fuels. The survival of certain industrial and utility plants, now primarily dependent on natural gas, may depend upon the substitution of waste fuels for 100 percent or supplementary firing. This paper is directed primarily to the feasibility of converting a present combustion system to use the waste fuels which are most widely available and in substantial quantities. Fuels, such as gas from coal gasification processes or oil from oil shale, are touched on only briefly because these are the subject of companion papers.

A feasibility study requires consideration of many factors peculiar to the specific installation and area. Usually several alternative solutions must be investigated, including whether the alternative fuel should be a primary or supplementary fuel. Present studies are further complicated in evaluating the risks in recommending promising but not well proved technology, during this period of rapidly developing technology and the introduction of several innovative processes.

While this paper covers converting a present combustion system, several studies recently made indicate that under the study conditions, the economics are attractive in shutting down a present combustion system and installing a new system designed specifically for 100 percent firing of a waste fuel.

Comments are included on the substitution of high sulfur coals and oils for the low sulfur versions of these fuels, used to comply with present stack gas $\text{SO}_2$ (sulfur dioxide) and particulate emission regulations.

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CONVERSION FEASIBILITY TO SELECTED ALTERNATIVE FUELS

Municipal solid waste has the largest potential energy recovery of the alternative waste fuels. Estimates indicate that about 6 to 7 percent [1] of the fossil fuel requirements of electric utilities in the U.S., could be supplied by municipal solid waste, if all of the municipal solid waste available in collected form in urban areas were to be utilized (data estimated for 1980).

Present boiler conversions to burn the alternative fuels from municipal solid waste in Table 1 are discussed first, followed by a brief discussion of some of the alternative fuels in Table 2.

"Boiler" is intended to cover steam generating, hot water generating, or process liquid heating units. Separate reference is made to process applications such as rotary dryers and kilns.

Except for the Table 1 fuels specifically noted in this discussion, the municipal solid waste fuel processing systems may be on-site to serve only the specific boiler or boilers or a large central facility supplying fuel (for example, a solid fuel for direct firing or as a feedstock for further processing, such as by pyrolysis) to one or more users. The on-site processing system is considered as part of the overall conversion program and, in some cases, may be a simplified version of the typical systems in Appendix A.

Except for the Table 1 fuels specifically noted in the discussion, each of the processed fuels in Table 1 would be fired as a supplementary fuel at a rate of about 10 to 30 percent (higher percentages would be possible for certain boiler designs) of the boiler's fuel requirements.

Most boilers, designed for coal firing, can be converted to use a suitable form of the solid fuel or oil/gas in Table 1.

Most boilers, designed for only oil and/or gas firing, can be converted to use the oil/gas in Table 1. These boilers probably cannot be converted to the solid fuels in Table 1, because of inadequacies in furnace volume and other details, combined with lack of bottom ash and flyash handling provisions.

Fuel No. 1 - Raw Municipal Solid Waste (MSW). Virtually no present boiler, not specifically designed originally for this highly heterogeneous fuel, can be converted feasibly for this fuel's direct firing. The reasons are the difficulty in meeting the special requirements, such as large feed openings, special stokers, and special ash handling system, combined with possible severe derating of steam generation capability, because of the boiler's wide variation from design criteria discussed in Appendix B.

As an alternative to direct firing, present coal, oil, or gas fired boilers, or process equipment such as a rotary dryer, may be adaptable to recovering waste heat from the mass burning of this fuel in one or more separate modular type "starved air" incinerators. The flue gas at 870 to 980 deg C (1,600 to 1,800 deg F) from the incinerators would be introduced to the boiler bank (assuming a water tube boiler) as waste heat. The present burner would be retained for supplementary firing to sustain steam generation. Additional soot blowers and an induced draft fan, if not presently installed, might be required. Because the incinerator flue gas would meet Federal and State particulate emission regulations, no additional particulate emission control equipment would be required, assuming the boiler complies with the regulations when burning the present fuel.

Fuel No. 2 — Light Fraction — 100 mm (4 in.)

Particle Size

Fuel No. 5 — Optional Pellets

Fuel No. 6 — Pulped Fibers — 25 mm (1 in.)

Particle Size or Optional Pellets

Present spreader-stoker-fueled boilers (combination suspension and grate burning) are adaptable to these fuels. A process schematic diagram, showing a suitable on-site processing system and the boiler for Fuel No. 2, is shown on Figure 1 (prime fuel burning equipment is not shown). Boiler conversion would include the addition of solid fuel distributor spouts located above the coal feeders (or conversion of some of the coal feeders), additional overfire air (if necessary), and associated materials handling equipment. The low bulk density of Fuel No. 2 would require special attention to handling and storage. The same comment would apply to Fuel No. 6, (pulped fibers), if the moisture content were substantially reduced by additional drying. The higher bulk density of the optional pellets would simplify this problem.

Fuel No. 3 — Light Fraction — 32 mm (1¼ in.)

Particle Size

Fuel No. 5 — Powder

Fuel No. 6 — Pulped Fibers — 25 mm (1 in.)

Particle Size

Fuel No. 4 — Raw Municipal Solid Waste (MSW).
TABLE 1.
PARTIAL LISTING OF ALTERNATIVE FUELS FROM MUNICIPAL SOLID WASTE (MSW)

<table>
<thead>
<tr>
<th>Fuel No.</th>
<th>Supplier</th>
<th>Process</th>
<th>Form of Fuel</th>
<th>Approx. maximum particle size, mm</th>
<th>Process commercially available</th>
<th>HHV MJ/kg, as fired</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Solid Fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Generic</td>
<td>None</td>
<td>Raw MSW</td>
<td>Widely variable</td>
<td>—</td>
<td>10.5-15.1(1)</td>
</tr>
<tr>
<td>2</td>
<td>Generic</td>
<td>One-stage shredding/classification(4)</td>
<td>Light fraction</td>
<td>100</td>
<td>Yes</td>
<td>11.6-16.3(1)</td>
</tr>
<tr>
<td>3</td>
<td>Generic</td>
<td>Two-stage shredding/classification(4)</td>
<td>Light fraction</td>
<td>32</td>
<td>Yes</td>
<td>11.6-16.3(1)</td>
</tr>
<tr>
<td>4</td>
<td>Generic</td>
<td>One-stage shredding/classification/briquetting</td>
<td>Briquettes</td>
<td>38x38x50</td>
<td>Yes</td>
<td>11.6-16.3(1)</td>
</tr>
<tr>
<td>5</td>
<td>Combustion Equipment Assoc.</td>
<td>One-stage shredding/chemical treatment/classification</td>
<td>Powder(5)</td>
<td>6 to 0.1</td>
<td>Yes</td>
<td>17.4-18.6</td>
</tr>
<tr>
<td>6</td>
<td>Black-Clawson Company</td>
<td>Wet pulping/separation/thickening(4)</td>
<td>Pulped fibers(5)</td>
<td>25</td>
<td>Yes</td>
<td>9.5-15.1(1)</td>
</tr>
<tr>
<td>Liquid Fuel</td>
<td>Occidental Research &amp; Development Corp.</td>
<td>Pyrolysis</td>
<td>Fuel oil</td>
<td>—</td>
<td>No</td>
<td>24.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Union Carbide Corp.</td>
<td>Pyrolysis (1,650 deg C), oxygen to slagging shaft furnace</td>
<td>Gas</td>
<td>—</td>
<td>Yes</td>
<td>11.3-13.2</td>
</tr>
<tr>
<td>9</td>
<td>Carborundum Environmental Systems, Inc. (Torax Division)</td>
<td>Pyrolysis (1,650 deg C), air to slagging shaft furnace</td>
<td>Gas</td>
<td>—</td>
<td>Yes</td>
<td>4.2-5.6 (dry gas)</td>
</tr>
<tr>
<td>10</td>
<td>Monsanto Enviro-Chem Systems, Inc.</td>
<td>Pyrolysis (980 deg C), air to rotary kiln</td>
<td>Gas</td>
<td>—</td>
<td>Yes</td>
<td>4.2-5.3</td>
</tr>
</tbody>
</table>

1. Partial list of suppliers:
   Browning Ferris Industries
   Research-Cottrell, Inc.
   SCA Services

2. Partial list of suppliers:
   American Can Company
   Continental Can Company
   Occidental Research & Development Corporation
   Research-Cottrell, Inc.
   SCA Services

3. Partial list of suppliers:
   SCA Services

4. Drying equipment can be added to reduce moisture content.

5. Pellets available as optional form of fuel. Pellets may also be available from other processes.

6. HHV (higher heating value) varies with moisture content, raw MSW composition, etc.

Conversion Factors:
1 mm = 0.039 in.
1 MJ/kg = 430 Btu/lb
deg F = 9/5 deg C + 32
1 MJ/Nm³ = 26.5 Btu/scf (standard cubic foot)
TABLE 2.
PARTIAL LISTING OF ALTERNATIVE WASTE FUELS WITH AVERAGE OR AVERAGE RANGE OF HEATING VALUES

<table>
<thead>
<tr>
<th>Fuel No.</th>
<th>Description as fired</th>
<th>HHV MJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Industrial</td>
<td>15.3-16.9</td>
</tr>
<tr>
<td>12</td>
<td>Agricultural</td>
<td>7.0-13.9</td>
</tr>
<tr>
<td>13</td>
<td>Coal (prime fuel for comparison)</td>
<td>16.9-32.5</td>
</tr>
<tr>
<td>14</td>
<td>Bagasse</td>
<td>8.4-15.1</td>
</tr>
<tr>
<td>15</td>
<td>Bark</td>
<td>10.4-12.1</td>
</tr>
<tr>
<td>16</td>
<td>General wood wastes</td>
<td>10.4-15.1</td>
</tr>
<tr>
<td>17</td>
<td>Sawdust and shavings</td>
<td>10.4-17.4</td>
</tr>
<tr>
<td>18</td>
<td>Coffee grounds</td>
<td>11.4-15.1</td>
</tr>
<tr>
<td>19</td>
<td>Nut hulls</td>
<td>17.9</td>
</tr>
<tr>
<td>20</td>
<td>Rice hulls</td>
<td>12.1-15.1</td>
</tr>
<tr>
<td>21</td>
<td>Corn cobs</td>
<td>18.6-19.3</td>
</tr>
<tr>
<td>22</td>
<td>Oil (prime fuel for comparison)</td>
<td>42.9</td>
</tr>
<tr>
<td>23</td>
<td>Industrial sludge</td>
<td>8.6-9.7</td>
</tr>
<tr>
<td>24</td>
<td>Black liquor</td>
<td>10.2</td>
</tr>
<tr>
<td>25</td>
<td>Sulfite liquor</td>
<td>9.7</td>
</tr>
<tr>
<td>26</td>
<td>Dirty solvents</td>
<td>23.2-37.1</td>
</tr>
<tr>
<td>27</td>
<td>Spent lubricants</td>
<td>23.2-32.5</td>
</tr>
<tr>
<td>28</td>
<td>Paints and resins</td>
<td>13.9-23.2</td>
</tr>
<tr>
<td>29</td>
<td>Oil waste, fuel oil residue</td>
<td>41.8</td>
</tr>
</tbody>
</table>

Conversion factors:
1 MJ/kg = 430 Btu/lb
1 MJ/Nm³ = 26.5 Btu/scf

Present boilers, designed for suspension firing of coal, are adaptable to these fuels. A process schematic diagram, showing a suitable on-site processing system and the boiler for Fuel No. 3, is shown on Figure 2 (prime fuel burning equipment is not shown). Boiler conversion would include the addition of solid fuel nozzles and associated materials handling equipment. According to the supplier of Fuel No. 5, special burners are recommended for this fuel. The low bulk density of Fuels No. 3 and 6 (if the moisture content of Fuel No. 6 were substantially reduced by additional drying) requires special attention to handling and storage. A small grate would be added, if required, to complete the burning of the larger particles.

Process equipment, such as rotary dryers and kilns, appears to be well adapted to these fuels by the addition of special burners. Some further reduction in the particle size of Fuels No. 3 and 6 may be necessary for this application. The solid fuel can probably be used as a prime fuel without derating the equipment.

Fuel No. 4 - Briquettes
Fuel No. 5 - Optional Pellets
Fuel No. 6 - Optional Pellets

Present underfeed or overfeed stoker-fired boilers are adaptable to these fuels. Pulverized coal-fired boilers may be adaptable to these fuels if the pulverizers are suitable for processing a blend of the fuel and coal. Boiler conversion would consist mainly of suitable material handling equipment for blending the fuel with the coal.

Fuel No. 7 - Fuel Oil

Present boilers, designed for only oil and/or firing, are adaptable to this fuel. Coal-fired boilers, rotary dryers, and kilns are also suitable for conversion. Limited tests indicate that only minor modifications and adjustments to present burner systems, designed for No. 6 fuel oil firing, would be necessary to burn this fuel and that 100 percent firing would probably be feasible. Gas and/or coal-fired boilers would be converted by the addition of suitable oil burners and associated fuel handling and storage systems.

Fuel No. 8 - Gas - 11.3-13.2 MJ/Nm³ (300-350 Btu/scf)

Present boilers, designed for only oil and/or gas firing, are adaptable to this fuel. Coal-fired boilers, rotary dryers, and kilns are also suitable for conversion. Present natural gas burners would be converted to use this gas with only minor changes, primarily enlarging the burners and inlet piping systems (and possibly increasing the number of burners) to accommodate the larger volume flow, compared to natural gas, for the same heat input. Studies and reports by EPRI [5] and others indicate that 11.3 MJ/Nm³ (300 Btu/scf) or higher fuel gases can be used in present natural gas fired burners, because these gases involve a negligible
FIG. 1  PROCESS SCHEMATIC DIAGRAM: SINGLE-STAGE SHREDDING AND SPREADER-STOKER-FIRED BOILERS – FUEL NO. 2
FIG. 2  PROCESS SCHEMATIC DIAGRAM: TWO-STAGE SHREDDING AND SUSPENSION-FIRED BOILERS – FUEL NO. 3
change in the volume of flue gases and in boiler performance. This fuel can probably be used for 100 percent firing without derating the boiler. Gaseous fuels, less than 11.3 MJ/Nm³ (300 Btu/scf), require special consideration as discussed subsequently for Fuels No. 9 and 10.

Oil and/or coal-fired boilers would be converted by the addition of suitable gas burners and associated fuel piping systems.

Fuels No. 9 and 10 - Gas – 4.2-5.6 MJ/Nm³ (110-150 Btu/scf)

Present boilers, designed for only oil and/or gas firing, rotary dryers and kilns may be adaptable to this fuel, depending upon the particular design and proportions. Coal-fired boilers may be more suitable for conversion, because of design and proportions favorable to handling a low MJ/Nm³ (Btu/scf) gas.

This gas is used most effectively by piping the hot gas [approximately 320 to 650 deg C (600 to 1,200 deg F) leaving the gasifier or rotary kiln] directly to the boilers with only minimum cooling and clean-up of particulates and with minimum practical fuel pipe length. Therefore, the pyrolysis system should be on-site to serve only the specific boilers. The high volume flow because of the high temperature and low heating value involves large fuel pipes and burners. Because of the fuel’s low heating value, the volume of flue gas increases significantly and the boiler’s efficiency falls off rapidly, compared to gases having heating values of 11.3 KJ/Nm³ (300 Btu/scf) or higher. [5]

The conversion program for coal, oil, or gas-fired boilers would involve the installation of the pyrolysis system with the gas cooled and cleaned to the degree dictated by detailed engineering study, the fuel pipes to the boilers, additional soot blowers (if required), and special burners.

A brief discussion of some of the alternative fuels in Table 2 follows:

Fuel No. 11 - Industrial Solid Waste

Industrial solid waste is similar to municipal solid waste and, in many cases, is mixed with municipal solid waste. Industrial solid waste is usually more homogeneous than municipal solid waste and has higher heating values, depending upon the industrial process involved.

The previous discussion for boiler conversions to fuels from municipal solid waste applies largely to industrial solid waste. Some process simplifications may be possible because of the characteristics of the particular industrial solid waste.

Fuels No. 15, 16, and 17 - Bark, Wood Wastes, and Sawdust

Special reference is made to these fuels because the wastes from the wood industry are estimated to have the next largest potential energy recovery after municipal solid waste of the alternative waste fuels (10 percent of the available heat content in solid wastes versus 70 percent for municipal solid waste [1] [6]).

The previous discussion for boiler conversions to solid Fuels No. 2 and 3, Table 1, from municipal solid waste generally apply to these wastes. The preparation processes would be simplified and would usually be located on-site.

Fuels No. 13 and 22 - Coal and Oil

Present coal-fired and oil-fired boilers, which were switched to low sulfur versions of these fuels to comply with SO₂ (sulfur dioxide) emission regulations, can be reconverted to the high sulfur fuels (usually less expensive and more readily available) by adding SO₂ removal systems. While there is a difference of opinion about the commercial feasibility of present SO₂ scrubber systems, it is probable that lower cost and more reliable systems will be available soon. No burner changes would be involved. The addition of the scrubbing systems would be considered as a combustion system conversion.

Fuel No. 35 - Gas from Coal Gasification – 11.3 MJ/Nm³ (300 Btu/scf)

This fuel has a large potential energy recovery in the future. Boiler conversion for this fuel would be similar to that described for gaseous Fuel No. 8, Table 1.

PARTIAL LISTING OF ALTERNATIVE FUELS

Table 1 gives a partial listing of alternative fuels from municipal solid waste, including pertinent data to identify each fuel as regards suppliers, process, form of fuel, approximate particle size for solid fuels, process commercial availability, and HHV (higher heating value). These processes also recover other resources, such as ferrous metals,
aluminum, and glass, but only the fuel recovery is considered in this discussion except for Hypothetical Study No. 2 presented subsequently. The process must be considered because certain conversion programs include the addition of on-site processing systems. The principal thrust of this paper is on a discussion of these fuels as applicable to present combustion systems. Data for these fuels and processes have previously been published in several reports, technical papers, and articles. Recent reports by U. S. Environmental Protection Agency (EPA) [2] and Electric Power Research Institute (EPRI) [1] are very comprehensive and are valuable sources of reference for anyone working in the field. Metcalf & Eddy has also prepared recent reports [3,4] for power generation from municipal solid waste, based on several alternative processes, (private reports available subject to clients' approval). Block diagrams or process schematic diagrams of the various processes are in Appendix A.

A partial listing of other alternative fuels and their approximate heating values is shown in Table 2. These fuels are waste fuels except for coal, oil, natural gas, and gas from coal gasification, included for heating value comparison purposes.

ENVIRONMENTAL IMPACT

Present boilers, converted to the alternative fuels discussed previously, should be able to meet the Federal EPA and State SO₂ and particulate emission regulations, assuming suitable APC (air pollution control) equipment is already installed or would be added. The municipal solid waste-derived fuels in Table 1 have low sulfur content (usually 0.2 percent by weight “as fired” or less) and present a minimum problem as regards SO₂ contribution.

The variety of alternative fuels and present combustion systems places a detailed discussion of APC requirements beyond this paper's scope. Some general guidelines of APC requirements are as follows:

- Present coal-fired boilers, converted to oil and/or gas firing to comply with APC requirements, would require the addition of APC equipment when firing a suitable solid fuel from Tables 1 or 2. No additional APC equipment would be needed when firing liquid Fuel No. 7 or gaseous Fuel No. 8, Table 1. The addition of APC equipment would probably be needed when firing gaseous Fuels No. 9 and 10, Table 1.
- Present oil and/or gas-fired boilers, currently complying with APC regulations, would continue to meet APC regulations when firing Fuels No. 7 and 8. Fuels No. 9 and 10 would probably require the addition of APC equipment.

Some processes, such as that for gaseous Fuel No. 8, generate condensed water vapor containing soluble organics or other types of wastewater. These materials would be processed within the system to make the effluent acceptable to municipal sewers or would be piped to a treatment plant, if suitably located.

The use of fuels from solid waste substantially reduces waste quantities to landfill. Several of the processes recover other valuable resources in addition to energy. The overall impact of waste fuel's use is conservation of natural resources (fossil fuels, metal raw materials, land areas).

FEASIBILITY STUDIES OF CONVERTING TO ALTERNATIVE FUELS

The foregoing discussion provides a warehouse of several alternative fuels and their adaptability to present boilers using various types of firing methods. It is hoped that the information will assist in identifying the alternatives for a specific study. A feasibility study of converting present boilers to an alternative fuel would consider such factors as: boiler type, load factor, steam generation requirements, present operating costs, pollution control equipment, alternative fuels (availability, characteristics, cost), effects on the boilers, etc. Annual total capital and operating costs and availability for technically feasible alternative fuels would be compared with similar present and projected costs and availability using present fuels, in making an evaluation. Appendix B gives design criteria for 100 percent municipal solid waste fired boilers as a guide to possible percent municipal solid waste firing of boilers to be considered. As examples, two simplified hypothetical studies are summarized below:
Hypothetical Study No. 1

The client has a boiler with the following operating conditions:
- 24 hours per day, 312 days per year, 7,488 hours per year
- 4.4 kg/s (35,000 pounds per hour) steam generation
- 1,000 kPa (145 psig) saturated steam
- 110 deg C (228 deg F) feed water
- Fired with No. 6 oil, HHV 41.5 MJ/1 (14,800 Btu/gallon); and natural gas, HHV 38.8 MJ/Nm³ (1,030 Btu/scf)
- Boiler age - 20 years.

The unit was originally designed for pulverized coal firing and converted to oil and gas firing. No pollution control equipment is installed. Since cost and availability of oil and gas are becoming critical, a feasibility study of alternative fuels was instituted.

One alternative fuel is solid Fuel No. 3 light fraction, which would be available from a large central facility at $1.00 per million kJ (million Btu). Present oil cost is $.08 per litre ($13.50 per barrel) or $2.17 per million kJ (million Btu). Natural gas is not considered because it is not expected to be available.

The capital investment for conversion is estimated at $303,000, which includes material storage and handling, new burners, a wet scrubber for APC requirements, and minor changes to the original bottom ash handling system. The furnace proportions and other design details were found to be favorable to prepared municipal solid waste firing. Based on the guidelines in Appendix B, 70 percent alternative fuel/30 percent oil firing is considered feasible.

Annual power costs were computed based on $0.028 per kWh (kilowatt-hour). Annual fuel costs of oil were computed based on the following approximate usage: 70 percent alternative fuel/30 percent oil firing - 2.7 M1 (17,000 barrels) per year; 30 percent alternative fuel/70 percent oil firing - 6.2 M1 (39,000 barrels) per year; 100 percent oil firing - 8.9 M1 (56,000 barrels) per year.

Annual residue disposal costs were calculated based on the following approximate quantities: 70 percent alternative fuel/30 percent oil firing - 885 Mg (975 short tons) per year at $6.60 per Mg ($6.00 per ton); 30 percent alternative fuel/70 percent oil firing - 386 Mg (425 short tons) per year at $6.60 per Mg ($6.00 per ton).

Summary-Estimated Annual Costs

<table>
<thead>
<tr>
<th>Burning alt. fuel and oil</th>
<th>70% alt. fuel</th>
<th>30% oil</th>
<th>70% oil</th>
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</thead>
<tbody>
<tr>
<td>Costs:</td>
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<td></td>
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</tr>
<tr>
<td>Amortization (10 yr. at 10%, capital recovery factor 0.1628)</td>
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<tr>
<td>Power</td>
<td>37,000</td>
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<tr>
<td>Labor</td>
<td>195,000</td>
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<tr>
<td>Maintenance</td>
<td>18,000</td>
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<tr>
<td>Fuel</td>
<td>491,000</td>
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<td>Residue disposal</td>
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<tr>
<td>Total capital and operating cost</td>
<td>$796,000</td>
<td>$941,000</td>
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<table>
<thead>
<tr>
<th>Burning oil only</th>
<th>100% oil</th>
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<td>Costs:</td>
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<tr>
<td>Amortization</td>
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<td>Power</td>
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<td>Labor</td>
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<td>Maintenance</td>
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<td>Fuel</td>
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<td>Total capital and operating cost</td>
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<td>Annual savings before taxes with combination firing</td>
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</tbody>
</table>

The savings with 70 percent alternative fuel/30 percent oil firing are attractive. The savings with 30 percent alternative fuel/70 percent oil firing are marginal, but would become increasingly attractive with escalation in oil prices ($39,000 and $17,000 additional annual savings for each $.006 per litre ($1.00 per barrel) increase in oil price above $.08 per litre ($13.50 per barrel) for 70 percent alternative fuel/30 percent oil firing and 30 percent alternative fuel/70 percent oil firing respectively). Prices of the alternative fuel would be expected to escalate at a lower rate than oil.

Hypothetical Study No. 2

The client has a boiler with the following operating conditions:
- 24 hours per day, 312 days per year, 7,488 hours per year
- 18.9 kg/s (150,000 pounds per hour) steam generation
- 1,000 kPa (145 psig) saturated steam
110 deg C (228 deg F) feed water
Fired with No. 6 oil, HHV 41.5 MJ/l (148,000 Btu/gallon); and natural gas, HHV 38.8 MJ/Nm³ (1,030 Btu/scf)
Boiler age — 11 years.
The unit was originally designed for only oil/gas firing. No pollution control equipment is installed. Since cost and availability of oil and gas are becoming critical, a feasibility study of alternative fuels was instituted.

One alternative fuel is gaseous Fuel No. 8 [11.3-13.2 MJ/Nm³ (300-350 Btu/scf)], which would require an on-site facility to produce the gas from municipal solid waste. The plant is located near a metropolitan area, which would supply about 545 Mg (600 short tons) per day of raw municipal solid waste for six days per week. The communities would be agreeable to delivering the municipal solid waste to the plant and paying a $0.009 per Kg ($8.00 per short ton) “user fee.” Present oil cost is $.08 per litre ($13.50 per barrel). Natural gas is no longer available.
The capital investment for the on-site facility and burner conversion to the gas is estimated at $15,000,000. No additional air pollution control equipment would be needed to clean the boiler flue gas. The converted boiler would be suitable for 100 percent alternative gas firing and would generate approximately 18.9 kg/s (150,000 pounds per hour) steam at 545 Mg (600 short tons) per day raw municipal solid waste input (based on average municipal solid waste higher heating value of 11.0 MJ/kg (4,750 Btu/lb), as fired, fuel gas energy approximately 79 percent of input energy, and 80 percent boiler efficiency).
Annual power costs were computed based on $0.028 per kWh. Annual revenues were calculated, based on approximately 169 x 10⁹ g (187,000 short tons) per year municipal solid waste input, as follows: municipal solid waste “user fee” at $0.009 per kg ($8.00 per ton); ferrous metals (light) at $0.05 per kg ($45.00 per ton) and production 5.9 x 10⁹ g (6,545 short tons) per year; ferrous metals (heavy) at $0.011 per kg ($10.00 per ton) and production 5.9 x 10⁹ g (6,545 short tons) per year; residue at $0.002 per kg ($2.00 per ton) and production 19.1 x 10⁹ g (21,000 short tons) per year (this is a high quality residue salable as road fill, etc.). Annual fuel cost, burning oil only (present system), was computed based on the use of approximately 34.5 Ml (217,000 barrels) per year.

The savings are marginally attractive, but would become increasingly attractive with escalation in oil prices [$217,000 additional annual savings for each $.009 per kg ($1.00 per barrel) increase in oil prices above $.08 per litre ($13.50 per barrel)] and possible escalation in “user fee” [$187,000 additional annual savings for each $.001/kg ($1.00 per ton) increase in “user fee” above $.009 per kg ($8.00 per ton)]. No evaluation is included of the favorable effects of return on investment of such factors as investment tax credit and accelerated depreciation rate.

CONCLUSIONS
The information outlined in the foregoing discussion indicates that it is technically and economically feasible to convert many present boilers to one or more of the listed alternative fuels. The use of these fuels offers some or all of the following benefits: lower thermal energy cost; nondepletable energy supply; reduction of waste problem; conservation of natural resources (fossil fuels, metal raw material, land areas). The technology is progressing rapidly with every expectation that in-
novative processes will be proved and additional processes developed.

The author would particularly welcome the development of smaller packaged-type gasifiers to allow industrial plants to make gas from plant waste and supplementary municipal solid waste (either raw or processed), if necessary. The gas would be used in the plant's own boilers and would dramatically extend feasible waste fuel applications.

REFERENCES


