FEASIBILITY OF 100 PERCENT RDF FIRING FOR POWER GENERATION

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ABSTRACT

Applying the basic combustion principles and the current boiler technology, 100 percent refuse-derived fuel (RDF) can be burned in dedicated boilers. However, due to the heterogeneous nature of RDF and the problems associated with feeding, cyclic steam flow conditions may exist. The feed system by itself cannot control the heat release rate in the furnace. An alternative approach is to use coal trimming for generating a smooth and reliable steam flow.

In this paper, the state-of-the-art of RDF combustion technology and the status of existing RDF-fired power plants are discussed. A 16-MW power plant case study based on the findings of a current RDF/coal-fired cogeneration project for the U.S. Navy is also presented.

INTRODUCTION

Using municipal solid waste (MSW) is advantageous not only for its recovery of material and fuel potential, but also because it eliminates the need for disposing of the garbage. The 175 million tons of MSW generated annually in the U.S. have an energy content equal to about 7 percent of the energy content of U.S. oil production [1]. The annual cost of collecting and disposing of MSW, on the other hand, has been estimated at about $4.0 billion and has been climbing steadily [2].

Refuse-derived fuels (RDF) represent an upgrading of the fuel value of MSW. RDF can be produced in a shredded, powdered, or fibrous form, using either wet or dry processing. Most RDF is processed by shredding in one or two stages, by magnetic separation for ferrous metal recovery and by classification for removal of non-combustibles. Central power stations using RDF as a fuel are generally less efficient than coal-fired power plants without flue gas desulfurization. The lower efficiency results from the need to vaporize the large moisture content of the RDF, a process which absorbs a fraction of the heat released in combustion. Furthermore, because of RDF's low heating value, RDF-fired boiler volume must be up to approximately three times greater than coal-fired boiler volumes to be able to generate the same amount of steam. Increased boiler size is associated with increased air flow, fuel, and ash transport rates which increase the ancillary power needs of the power plant. As a result, the overall plant efficiencies for RDF-fired power plants ranges from 20 to 23 percent.

Boiler efficiency is sensitive to the moisture content of fuel and to the amount of excess air required. For successful boiler operation, the excess air should be kept above 50 percent. With a RDF heating value varying from 4800 to 7000 Btu/lb (11,162 to 16,278 kJ/kg), boiler efficiency may range from 70 to 75 percent.

CURRENT STATUS OF THE RDF-TO-ENERGY PLANTS

While making a preliminary survey of the RDF-to-energy plants, distinction was made between projects using RDF to supplement the fossil fuel burned in existing boilers and those involving dedicated boilers designed for 100 percent RDF firing.

The first major attempts to recovery energy from municipal solid waste started in the early 1970's in the U.S. This movement was led by electric utilities that wanted to use RDF as a supplementary fuel in existing boilers.
The first major demonstration of burning RDF with coal in a coal-fired power plant took place in St. Louis, Missouri, under a joint venture of the City of St. Louis and the Union Electric Company between 1972 and 1976. Union Electric burned refuse-derived fuel at its coal-fired Meramec plant. Except for solid-waste burning ports located in each corner of the boiler furnace at the top of the burner assembly, no modifications to the burner were made during the three years in which the Meramec plant burned the mixture of coal and refuse-derived fuel. The RFD contributed to about 10 percent of the heat input.

As a result of the technical and economic analyses made of this demonstration, Union Electric announced plans to build and operate its own MSW-processing plant capable of processing up to 8000 tons (7,257,600 kg) of garbage per day collected from St. Louis and the surrounding communities. The plans were not realized, however, due to various local political factors. Still, much of Union Electric's experience — operational, economic, and environmental — is directly useful for the planning of other co-combustion systems.

This experience did serve, though, as a model for the one system that is fully operational in the U.S. today — the co-combustion plant of the City of Ames (Iowa) Municipal Electric System. This plant has a maximum capacity of 53 MW(e) and a nominal capacity of 150 tons (136,080 kg) of MSW per day. Subsequent experiences have occurred in Chicago, Milwaukee, Madison, Bridgeport, and Rochester [3, 4].

The City of Chicago built a RDF plant designed to produce 700 tons (635,040 kg) of RDF per day on a five-day-a-week basis. The RDF was co-fired with coal in Commonwealth Edison's 200-MW Crawford Unit 7 from late 1978 to December 1979 when RDF production was stopped due to multiple problems with both the RDF production facility and the boiler. The processing facility cannot resume operation until major modifications are made requiring funds which are presently not available.

In the Milwaukee project, RDF was co-fired with coal in the 310-MW Oak Creek Units 7 and 8 owned by Wisconsin Electric Power Co. (WEPCO) from March 1977 to August 1980. The RDF was produced in a 1,200-ton/day plant built and operated by the Americology Division of American Can Co. During this period, more than 100,000 tons (90,720,000 kg) of RDF were burned in these two pulverized coal-fired units normally at rates of approximately 10 percent on the basis of heat input. WEPCO stopped burning RDF in August 1980 because of combustion problems. Table 1 summarizes the status of these plants. The relatively negative experiences at several projects have made the utilities shift away from supplementary RDF firing to 100 percent refuse burning in dedicated boilers [4]. The status of the six plants constructed for 100 percent RDF firing is given in Table 2.

### RDF COMBUSTION

#### FULL LOAD FROM RDF BURNING

Of the two distinctly different methods of burning (suspension firing and spreader-stoker firing), spreader-stoker boiler design is better suited to RDF, considering the extent of the fuel preparation and size reduction required. The following discussion of the feasibility of 100 percent RDF firing is focused on this type of boiler design.

The main factors which influence combustion and steam stability are uniformity of fuel value, flexible combustion air control, and uniformity of feed rate. In order to distribute the RDF fuel evenly over the grate surface, there must be several distributing devices in the front wall of the furnace, the number of which depends on the width of the furnace. A means must be provided to individually meter the RDF fuel to each of the distributors. The RDF fuel is a composition of many materials in varying proportions. As this varies, so does the bulk density. Fuel moisture can also affect the bulk density.

In a volumetric fuel metering device, the heat content per cubic feet of fuel varies with the bulk density of the fuel. Changes in bulk density such as a change in moisture content require adjustments in the metering speed. Further, if the furnace is equipped with multiple-fuel feeding devices, it may be necessary to be able to independently vary the metering speed of each device to assure an even input across the furnace width. Rapid variations in moisture are unlikely at any given time; however, variations in bulk density due to sizing characteristics can certainly occur.

Better feed control can be achieved by mass metering devices. There are several types of devices which can be designed to individually meter the RDF fuel to each feeder in the furnace front wall. One such device is the conveyor feeder which has a drag chain in the bottom of the chute, the speed of which is controlled to regulate the fuel feed. Another device is a screw feeder which has several variable speed screws in the bottom of a chute, the rotational speed of which is correlated with the RDF discharge rate. The main problem with the variable speed screw feeding system is that it does not provide a fine control of the RDF feed rate. For example, at a fixed screw rotational speed, the discharge rate does not remain constant and can vary for different reasons. RDF is such an agglomeration of material that it does not flow easily from the bins. As a result, the RDF falls in chunks from the screws into the conveying system or into chutes. A 10 to 15 percent change in screw speed does not make...
an appreciable change in the RDF feed rate. In reviewing the operation of the RDF feeding systems at the Madison and Albany plants, it was noted that a 50 percent increase in screw speed increases the feed rate by only about 20 to 30 percent. This feed rate problem can be improved by careful consideration of the choice of metering and storage devices but probably cannot be completely corrected due to the uneven consistency of the RDF.

In conclusion, steam flow stability cannot be achieved by the RDF feeding control alone. Simultaneous boiler air management is also needed.

**RDF COMBUSTION CONTROL**

It is important to consider the characteristics of the variables that affect the combustion process in order to comprehend the boiler combustion control system. These variables can be categorized into fuel-related and air-related factors.

Fuel-related factors include size, moisture content, ultimate analyses, proximate analyses, heating value, method of feeding, distribution of RDF in the furnace, depth of fuel pile, and auxiliary fuel usage.

Air-related factors include percentage of excess air, air temperature, ratio of over-fire air to under-fire air, turbulence of air, and flow relation between forced draft and induced draft systems.

Combustion control systems must be arranged to control fuel input to a boiler furnace in the correct relationship to combustion air requirements so as to maintain safe conditions over the operating range of the boiler.

**RDF PARTICLE SIZE DISTRIBUTION**

The size of the fuel particles directly affects their ability to devolatilize. The smaller the pieces, the more rapidly their volatile components will evolve and burn. Larger pieces have reduced surface area available for de-

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**TABLE 1 RETROFITTED BOILERS (SUPPLEMENTARY RDF FIRING)**

<table>
<thead>
<tr>
<th>Location</th>
<th>RDF Capacity, Ton/day</th>
<th>RDF Type</th>
<th>Boiler Type &amp; Rating</th>
<th>RDF %</th>
<th>Project Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>200</td>
<td>Shredded</td>
<td>35-MW CE Pulverized-Coal Boiler</td>
<td>10-20</td>
<td>Operating</td>
</tr>
<tr>
<td>Bridgeport, CT</td>
<td>1,800</td>
<td>ECO-Fuel II</td>
<td>86-MW Boiler</td>
<td>10</td>
<td>Shut Down Due to Financial Difficulties</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>1,000</td>
<td>Shredded</td>
<td>200-MW Pulverized-Coal Boiler</td>
<td>-</td>
<td>Shut Down</td>
</tr>
<tr>
<td>East Bridgewater, MA</td>
<td>160</td>
<td>ECO-Fuel II</td>
<td>Test Burns in Oil-fired Boilers</td>
<td>-</td>
<td>Shut Down</td>
</tr>
<tr>
<td>Madison, WI</td>
<td>250</td>
<td>Shredded</td>
<td>Two 50-MW B&amp;W Pulverized-Coal Boilers</td>
<td>11</td>
<td>Operating</td>
</tr>
<tr>
<td>Milwaukee, WI</td>
<td>1,600</td>
<td>Shredded</td>
<td>Two Pulverized-Coal Boilers</td>
<td>15</td>
<td>Shut Down</td>
</tr>
<tr>
<td>Rochester, NY</td>
<td>2,000</td>
<td>Shredded</td>
<td>Four CE Pulverized-Coal totaling 235 MW</td>
<td>10</td>
<td>Operating</td>
</tr>
</tbody>
</table>
volatization to occur. Furthermore, large pieces of RDF tend to insulate their interior, so more time is required for the volatile material to become sufficiently hot to vaporize. Large particles can plug the feed system and cause slower ignition of the fuel which can result in increased carbon loss and loss of flame stability. More of the large particles will burn on the grate than in suspension. While carbon loss due to a thicker grate bed will occur, carbon loss due to connection section carry-over will be reduced. While this qualitative analysis favors a more uniform fuel size distribution, there is no quantitative analysis available to set the limits on particle size. The lack of controlled experimental data is due mainly to the limited RDF burning experience.

Boiler manufacturers have serious concerns with respect to particle size requirements but there is no consensus on the optimum particle size distribution. Some manufacturers require the quantity of fines (less than 1 in. x 1 in.) to be at least 50 percent, while others do not object to the amount of small particles, but do not want large particles (greater than 6 in. x 6 in.). The disagreements on this issue are common to all RDF projects and can be resolved by negotiations between manufacturer and designer.

**METHOD OF FEEDING FUEL**

The method of feeding fuel to a boiler furnace is dependent upon the furnace design. For spreader-stoker furnace designs, the fuel is spread across a grate with a mechanical or pneumatic spreader. The desired result is to lay a thin, uniform pile of RDF across the entire area of the grates. Mechanical spreaders can be slowed or increased in speed. They are equipped with baffle plates to control the angle at which fuel is injected into the furnace. These same capabilities are often available on pneumatic spreader systems.

**TABLE 2 DEDICATED BOILERS (RDF AS PRIMARY FUEL)**

<table>
<thead>
<tr>
<th>Location</th>
<th>RDF Capacity, Ton/day</th>
<th>RDF Type</th>
<th>Boiler Type &amp; Rating</th>
<th>Project Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akron, OH</td>
<td>1,000</td>
<td>Shredded</td>
<td>B&amp;W Semi-Suspension</td>
<td>RDF Feed System being Modified</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stoker Grate</td>
<td></td>
</tr>
<tr>
<td>Albany, NY</td>
<td>750</td>
<td>Shredded</td>
<td>Zurn Boilers (Steam</td>
<td>Operating</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>only, for District</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heating)</td>
<td></td>
</tr>
<tr>
<td>Columbus, OH</td>
<td>2,000</td>
<td>Shredded</td>
<td>B&amp;W Semi-Suspension</td>
<td>Operating</td>
</tr>
<tr>
<td></td>
<td>(3,000 Peak)</td>
<td></td>
<td>Stoker Grate totaling</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>90 MW</td>
<td></td>
</tr>
<tr>
<td>Dade County, FL</td>
<td>3,000</td>
<td>Wet pulp</td>
<td>Four Spreader Stoker</td>
<td>Operating</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Boilers totaling</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60 MW</td>
<td></td>
</tr>
<tr>
<td>Hempstead, NY</td>
<td>2,000</td>
<td>Wet pulp</td>
<td>40-MW On-Site Power</td>
<td>Shut Down due to Environmental</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plant</td>
<td>Problems</td>
</tr>
<tr>
<td>Naval Shipyard,</td>
<td>2,200</td>
<td>Shredded</td>
<td>Two Foster Wheeler</td>
<td>Operating</td>
</tr>
<tr>
<td>Portsmouth, VA</td>
<td></td>
<td></td>
<td>Boilers totaling</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50 MW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Four Combustion</td>
<td>Under Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Engineering Boilers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>totaling 40 MW</td>
<td></td>
</tr>
</tbody>
</table>
The problems of feeding RDF are historically caused by overly large particles which initiate bridging, wrapping, and plugging. At a few plants, feeding problems have been reduced by using smaller-size distribution. The reason for these reduced problems can be attributed to smaller quantities of large (larger than 8 in.) pieces, and not larger quantities of smaller (less than 1 in.) pieces.

VARIATIONS IN THE FUEL FEED RATES

In almost all boilers, swings occur in the steam demand under normal operation. As the steam demand increases, the fuel feed rate increases. The furnace receives RDF with a high moisture content of approximately 30 percent. This increase in feed rate of wet fuel will decrease the combustion zone temperature which, in turn, will reduce the burning rate. To compensate for this, more air is added, usually as under-fire air, to help dry the fuel and increase the burning rate. The percentage of excess air, therefore, increases. This tends to reduce combustion efficiency and results in the discharge of substantial amounts of unburned material out of the furnace. Gradually, the wet fuel dries and the combustion zone temperature and the burning rate increase, thereby increasing the steam output of the boiler.

The degree to which the upset in combustion occurs is dependent upon several factors, including change in fuel feed rate and to keep the ratio of over-fire to under-fire air constant.

PERCENTAGE OF EXCESS AIR

Some excess air is necessary for complete combustion of the RDF. There is a limit to how much excess air can be added because of reduced thermal efficiency, requirements for extra power in the fan system, and potential operational problems in the particulate control equipment if the gas flow exceeds design conditions. Excess air for RDF combustion will vary typically from 40 to 60 percent.

RATIO OF OVER-FIRE TO UNDER-FIRE AIR

In a RDF-fired boiler, the incoming air for combustion is split into air for under the grate and air for over the fuel pile. Part of the over-fire air is used to pneumatically spread the fuel across the grates.

The percentage of total combustion air going into the under-fire and over-fire air ducts influences the combustion process. The ratio of the two flows is, therefore, one of the parameters of concern.

Control of this variable must be accomplished with properly installed fans, air ducts, and dampers. For wet fuel, adequate under-fire air must be provided to help drive off the moisture from RDF. For pneumatic-spreader systems, sufficient over-fire air must be provided to distribute the fuel. As ash or fuel builds up on the grates, under-fire air flow is reduced. This is caused by greater pressure across the grate and ash. Reduction of under-fire air flow may also mean a proportionate increase in over-fire air flow, depending on the fan system used.

Over-fire air must create maximum turbulence without disturbing the ash or fuel on the grate and must avoid impinging directly on hot refractory or metal surfaces, thereby limiting the damage resulting from condensation, thermal stresses, and thermal shock.

The current boiler control philosophy regarding this variable is to allow the under-grate air to follow the fuel feed rate and to keep the ratio of over-fire to under-fire air constant.

FOULING AND CORROSION

There are two major boiler design problems associated with RDF firing which must be given special consideration: fouling of heating surfaces and corrosion [5, 6]. All of the heating surface walls — superheater, boiler bank, economizer, and air heater — are subjected to fouling from slag and fly ash deposition. Slagging, fouling, and metal wastage in boiler furnaces are related both to the design and operation of the combustion system and to the characteristics of the inorganic matter in the fuel. Ash composition varies widely among fuels. For coals, good correlations have been developed between the ash constituents determined by a routine chemical analysis and the behavior of that ash at furnace temperatures.

In the case of RDF firing, the form in which the noncombustible material occurs is important. Particles of glass, for example, will introduce a sodium into the system that is entirely different from the sodium which comes from common salt. Lime from paper coatings will not act the same as CaO from other sources. Furthermore, particle size may be important. For example, large particles of glass may generate nuclei that encourage slagforming reactions. As with coal, the major factors affecting fouling and slagging in a RDF-fired boiler are ash composition, slag viscosity, \( \frac{SiO_2}{Al_2O_3} \) ratio, base acid ratio, slagging factor, and fouling factor, but the interrelationships of these factors are not yet known.

Problems with both slagging and fouling are also related closely to boiler furnace design and to the number and location of wall blowers and sootblowers. Proper furnace sizing, arrangement of heating surfaces, and correct use of sootblowers can reduce fouling to an acceptable level.
RDF fly ash particles consist of easily meltable clinker, and remain soft down to a temperature of approximately 1,100°F (866 K) as opposed to coal fly ash particles which harden at approximately 2,000°F (1,366 K). Even after the surface of the fly ash particle is cooled below the freezing point, the center remains soft for some time, increasing the risk of the particles sticking to the boiler tubes when they flatten on impact. This, coupled with the traditional close spacing of boiler tubes, causes undue tube fouling. Fouling of the tubes requires sootblowing and/or manual cleaning of the boiler.

The second major problem is gas-side corrosion. There are at least four types of corrosion which must be considered:

2. Corrosion due to a non-uniform furnace atmosphere.
3. Corrosion by HCl.
4. Low-temperature or dew-point corrosion.

High-temperature, liquid-phase corrosion is caused by molten alkali-metal sulfates. While the exact corrosion mechanism and temperature range in which this occurs have not been verified, there is a general consensus, based on operating experiences, that this type of corrosion occurs at metal temperatures above 900°F (755 K).

The product of partial combustion creates a reducing atmosphere in the boiler in which carbon monoxide and hydrogen sulfide are produced. These gases react with the protective layer of iron oxide on the water tubes, exposing them to a corrosive attack due to non-uniform furnace atmosphere. It is important that the burning system provides the correct fuel-to-air ratio, proper distribution of air to the fuel, and sufficient turbulence to prevent stratification, so that an atmosphere fluctuating between reducing and oxidizing will not be created locally.

The third type of corrosion, resulting from HCl and Cl, has been recognized for years [7, 8]. Hydrogen chloride is formed in the combustion process from plastics and other constituents. It is an aggressive compound and presents the hazard of corrosion of the boiler walls and superheater tubes. There is no consensus among the boiler manufacturers on the mechanism and temperature range of hydrochloric acid attack. However, it is generally agreed that metals will not be severely affected if the surfaces in critical locations are kept below 700°F (644 K) and above the dew point of the flue gases.

Low-temperature, dew-point corrosion occurs on metal surfaces exposed to temperatures below the dew point of the flue gases. Temperatures low enough to cause acid condensation on metal surfaces are sometimes found at the water inlet of the economizer, at the cold end of the air heater, and on boiler outer casings.

There is no data on corrosion and sludging of the dedicated boilers designed for 100 percent firing of RDF because of very recent and limited experience, i.e., the existing dedicated RDF-burning facilities have not been operating for more than two years. However, there is ample amount of data available on the corrosion and sludging of the retrofitted utility boilers burning RDF as a supplementary fuel to establish conclusive trends. An extensive corrosion probe study, conducted by Combustion Engineering, Inc. during the co-firing of coal and RDF at the WEPCO’s Oak Creek power plant in Milwaukee, Wisconsin, concluded that wastage of boiler material was not noticeably affected by operation with 10 to 15 percent RDF firing. A similar absence of corrosion was noted at the Ames plant where the RDF was fired with high-sulfur Iowa coal or a blend of this coal with a low-sulfur Western coal.

Fouling was observed to increase at the Ames plant when the RDF was introduced, mainly because of the higher percentage of sodium in the fuel. As a result, sootblowers were installed. The ash fusion temperatures of RDF are typically 60 to 100 degrees lower than those of coal. Although slag formation may be sensitive to lower fusion temperature, no observed effects were attributed to these differences [9].

In conclusion, problem areas in RDF firing comprise corrosion and sludging, and actual field data are not yet available. But the knowledge gained from RDF co-firing with coal and the mass burning of unprepared refuse, coupled with the current boiler technology, will be useful for the future design of dedicated boilers so that these problems can be handled.

**CASE STUDY**

A 16-MW power plant using RDF as a primary fuel has been conceptually designed. The mass and heat balance for this plant is shown in Fig. 1. The boiler fuel mixture was determined to be 80 percent RDF and 20 percent coal on the basis of heat input. Based on current boiler technology, the operating steam conditions at the superheat outlet were selected to be 800 psig (5618 kPa) and 750°F (672 K). The fuel, air, and ash mass flows, shown in Fig. 1, have incorporated the results of a RDF/coal-fired cogeneration plant designed for the U.S. Navy.

Generating smooth and reliable steam in a boiler operating at its rated capacity with 100 percent RDF is hard to achieve because of the fluctuating heat release rate. In the case of the system designed for the U.S. Navy’s cogeneration plant, stoker coal can be used for trimming. The boilers will be operated in a load-following mode with normal operation calling for three of the four boilers in the system to operate at partial load up to 80 percent MCR. Hence, there is no need to design the boilers for
100 percent RDF firing at rated capacity. When the steam demand is less than the boiler's rated output (equal to or less than 80 percent MCR), then the full demand can be realized from 100 percent RDF firing with reduced cyclic steam flow conditions.

Based on this experience, it is felt that coal trimming is advantageous, should the operation of the boilers require going above 80 percent of full load. The homogeneous fuel improves the response time and the basic boiler operation.

CONCLUSIONS

Considering the current state-of-the-art of boiler technology and applying the basic combustion principles, RDF alone can be burned in dedicated boilers. There are no problems with sustaining combustion and flame stability.

However, due to the heterogeneous nature of RDF and the problems associated with feeding, the heat release in the boiler will vary, producing to some extent cyclic steam flow conditions. The major issue is whether or not the heat input to the boiler by 100 percent RDF can be controlled to minimize the cyclic conditions. The answer depends largely on the reliability of the boiler feed system, boiler combustion control, and steam demand fluctuations.

The feed system by itself cannot control the heat release rate in the furnace because of variations in the heating value of RDF on both a volumetric and mass basis. While some improvement in boiler heat release rate control can be achieved by under-fire air variations, there is not enough operational experience to assess its effectiveness. Currently, an alternative approach is to use coal trimming for generating a smooth and reliable steam flow.

REFERENCES


Key Words: Ash • Boiler • Combustion • Corrosion • Grate • Materials Handling • Particulate Matter • Refuse-Derived Fuel • Slag • Spreader-Stoker • State-of-the-Art