THE ROLE OF ENERGY MARKETS IN INFLUENCING SYSTEM DESIGN

by

Miro Dvirka, P.E.
Engineering Foundation Conference
Hueston Woods State Park
Oxford, Ohio

Introduction

With skyrocketing costs of fuels and energy, resource recovery from municipal refuse became a priority in solid waste management in the United States.

Resource recovery from municipal refuse can have many forms, ranging from source separation of materials (paper, ferrous and non ferrous metals, bottles), mechanical processing and separation, direct conversion to energy by combustion processes, to conversion of raw refuse to various types of fuels, which in turn are converted to energy by secondary combustion systems.

The proliferation of various resource and energy recovery systems in the past few years, all allegedly designed to optimize the ultimate use of solid wastes, resulted in considerable confusion. As resource recovery became "fashionable" in addition to its true economic justification, a number of resource recovery processes have been developed in parallel with known reliable and proven methods, which are actually varations of basic concepts and border very often on "gimmickry."

Many times the differences between systems are so subtle and their relative efficiencies, advantages and disadvantages so difficult to discern, that it requires an in-depth analysis of competitive systems to arrive at a proper selection of a process which would best fit a given set of conditions and site-specific requirements.

Some of the major considerations are: availability of landfill areas, cost of landfill disposal and transportation, markets for energy and recoverable commodities, markets for refuse derived fuels and general assessment of economic viability of a particular system with respect to competitive costs of energy and commodities in a given area.

A particular resource recovery system may satisfy the requirements of a specific remote site within a relatively remote metropolitan area, yet the same system may not be acceptable or economically justifiable in a densely populated section of a city, due to traffic problems, public acceptance and political considerations.

Given these constrictions one must evaluate various energy recovery systems as self-contained processes, emphasizing their relative thermal conversion efficiencies and cost effectiveness, adjusted to raw refuse or Refuse Derived Fuel preparation and haul costs, recoverable materials haul costs and energy distribution costs as compared to commodities and energy markets.

Systems Classification

The variety of resource recovery processes makes a strict classification rather difficult since many systems are a combination of processes used as main systems in one instance and as auxiliary systems in another instance.

For the purpose of better understanding, the systems classification includes the description of as many processes as possible, although their economic and efficiency evaluation may not be justified based on gross examination of various process characteristics, state of the art, estimated process energy intensity, etc..

Four basic categories of resource recovery processes emerge from an overall review of presently available technology:

A. Mass (unprepared) refuse combustion
B. Solid refuse derived fuel (RDF) combustion
C. Gaseous refuse derived fuel combustion
D. Liquid refuse derived fuel combustion

The classification of the processes is limited to systems applicable to large capacity installations, eliminating special industrial types of incinerators, converters and equipment designed for specific liquid, pathological, pathogenic and chemical wastes.

A. Mass Refuse Combustion (Incineration)--Incineration of unprocessed solid waste, combined with heat recovery, is currently the most developed and widely practiced resource recovery technique.

Only oversized wastes, such as brush, trees, tree stumps, dicarded furniture, large crates, etc., must be processed to reduce their size so thatthey can be charged into an incinerator furnace.

Latest developments in incinerator technology include, but are not limited to, efficient stokers designed specifically for refuse incineration, combustion control systems yielding uniform temperatures throughout the combustion process in spite of variable characteristics of the fuel(refuse), improved combustion efficiency of the furnaces using optimum distribution of combustion air and air pollution control systems capable of meeting the most stringent requirements.

Since urban solid waste is very low in Sulphur content, the main potential gaseous pollutant from a well designed combustion system is HCl generated by the combustion of chlorinated plastics. Nevertheless, the content of chlorinated plastics in municipal refuse is so low that the HCl concentration in the effluent products of combustion does not represent a serious problem. Due to moderate process temperatures the NO_x emissions are practically nonexistant, therefore the incineration of nitrogenated plastics, which are replacing chlorinated plastics in many industries, is not a problem.

1. Refractory furnace - convection boiler systems

The system consists of a traditional stoker fired refractory furnace where raw refuse is incinerated, and of a convection type boiler to extract the sensible heat from the products of combustion (flue gas).

Latest technology allows the control of the combustion process to a point that the flue gas temperatures can be kept nearly constant even with relatively wide variation in refuse characteristics.

The control of furnace and flue gas temperatures, which is of importance in a steam generation process, results in a considerable increase in the useful life of the furnace refractory linings. Where a 2-3 year life span of refractory linings in older incinerators was considered normal, a 5-7 year life span has been obtained with cyclic operations.

Based on actual experience with cyclic systems it can be stated that the refractory lining of a modern continuously fired incinerator furnace will last 8-10 years or more with minor repairs.

A convection boiler system offers considerable flexibility in operation with partially capped-off tubes without endangering the overall system performance. Generally up to 10% of the tubes that failed can be cut out and capped in a relatively short period of time and the operation can continue until a major boiler overhaul is needed. A boiler life in excess of 8 years has been demonstrated on actual installations.

Although the heat recovery efficiency of a convection type boiler is lower than the efficiency of a radiant heat transfer (waterfall) boiler, the mechanical availability and overall reliability is generally higher.

2. Waterwall boiler systems

Waterwall incinerator boiler technology has been developed primarily in Europe in the sixties by applying power plant design criteria to refuse incineration.

Due to the lack of precise data, the earlier systems have been plagued by reducing atmosphere corrosion of tubes in the luminous flame zone, low temperature dewpoint corrosion and high temperature liquid phase corrosion by chlorides, alkali and metal sulfates.

While the reducing atmosphere and low temperature dewpoint corrosion problems have been overcome by special refractory lining of the tubes, the high temperature liquid phase corrosion problems can be avoided only by limiting the steam pressure and temperature.

Until the high temperature corrosion mechanism is fully explained and counteracted either by tube metalurgy or special coatings, high pressure steam systems and the use of superheaters in refuse burning applications must be given special consideration.

Recent studies of waterwall systems in Europe indicate that higher thermal efficiency of waterwall incinerator boilers and therefore higher income from the sale of steam does not necessarily offset higher capital and maintenance costs of waterwall plants as compared to refractory furnace - convection boiler installations.

B. Solid Refuse Derived Fuel (RDF) Combustion--A number of Refuse Derived Fuel Systems have been introduced on the market in the past 4 or 5 years with a varying degree of success.

Earlier systems have experienced serious problems with the shredding operations, various steps of materials separation and storage of the RDF. Some of the problems, such as high rate of wear of the shredder components and long term storage, have not been ressolved up to this point and represent a major setback for any RDF operation.

The high maintenance cost of shredder installations has been accepted as normal operational expense and the difficulties with long term RDF storage are being overcome by careful scheduling of the processing operations so that facilities, intended originally for RDF storage, are used as "surge" silos or bins.

Until RDF storage technology is improved or new technology developed, the use of surge bins in plants where the processing of raw refuse is done at a separate remote site, requires careful scheduling of the RDF delivery.

The use of bridge cranes with grapples, normally used for handling of unprepared refuse, seems the most reliable method of RDF handling at this time. Nevertheless, the cost of bridge crane installation adds further to an already increased processing cost of an RDF system as compared to raw refuse combustion systems.

The cost of RDF preparation can be partially offset by the sale of recovered ferrous and nonferrrous metals which will yield a higher rate of return when separated before burning, as opposed to the value of ferrous metals recovered from the residue after burning.

The latest developments in scrap steel recovery processes, namely the development of plasma furnaces, might negate the alleged benefits of "front end" recovered metals. Although fluctuating from time to time, the ferrous and nonferrous scrap market seems to be the most stable as compared to other retrievablecommodities such as paper, fiber or glass. In view of the fact that long term market committments for such materials are very difficult, if not impossible to obtain, the paper and glass recovery has not been economically justified up to the present time and it is doubtful that stable markets can be established in the near future.

The following description of RDF processing systems gives an overview of available technology and a critical evaluation of advantages and disadvantages of various RDF energy recovery comcepts.

1. Stoker fired refractory furnace - convection boiler system

A stoker fired furnace requires a minimum preparation of the RDF. In fact, the only reason for RDF preparation is the front end ferrous metals recovery where warranted by available long term markets. The combustion process is essentially the same as in the case of unprepared refuse burning and most of the basic design parameters apply with the exception of fuel bed depth and the rate of firing in terms of kgs. per unit area of the stoker per unit time.

2. Stoker fired waterwall boiler

All considerations and design parameters remain essentially the same as in the case of unprepared refuse firing in a waterwall boiler.

3. Spreader stoker firing

The "spreader stoker" concept has been derived from granulated coal firing systems. Granular fuel (shredded refuse in this case) is introduced into the furnace by air assisted mechanical spreaders. It ignites and burns partially in suspension and unburned particles drop on a traveling type stoker where the burn-out is completed.

Somewhat similar to a total suspension burning concept, the system requires a more extensive shredding processing as compared to simple stoker firing with gravity feed.

The first plant of this type is in operation in the City of Hamilton, Ontario. The operational experience reveals serious problems with the materials handling systems including conveying of raw refuse, shredding and storage of the RDF.

Alleged savings in the size of the furnaces, supposedly inherent to the semi-suspension burning concept, have not been ascertained at this time, since the rated furnace capacity could not be reached due to the materials handling problems and other difficulties.

At times, when the rated furnace capacity was approached, high percentage of carbonaceous materials in the residue was reported, indicating questionable combustion efficiency.

This conclusion is further supported by stack emissions. Visual observations suggest the presence of unburned carbon black in the stack effluent in spite of relatively high efficiency two-field electrostatic precipitators.

No boiler tube corrosion has been reported so far, nevertheless, it is believed that no conclusions can be made in this respect until the system operates at its full rated capacity for a reasonable time.

4. Suspension firing

The first RDF suspension firing system was developed in a joint effort by the City of St. Louis, Missouri, Union Electric Co. and Combustion Engineering Co.

Not mentioning various materials handling problems, it was found that extensive preparation of RDF is needed in order to obtain complete combustion of the RDF within a very short retention time inherent to a suspension fired boiler. A suspension burning plant can convert about 60% of raw incoming refuse, processed through a double shredding and air classification system, to useful energy when fired in conjunction with pulverized coal.

The St. Louis experiment indicates a confidence level of about 15% RDF and 85% pulverized coal as a threshold limit.

Firing quantities of RDF in excess of this level might result in steam load flucutations, which cannot be tolerated by a power plant, and in excess of combustibles in the bottom ash rendering the pulverized coal ash unsalable.

The fact that only the very light fraction of the RDF can be fired in suspension as an additive to fossil fuels, limits applications of this type to relatively few select locations where existing power plant boilers can be converted to combined RDF and pulverized coal firing and where sufficient landfill capacity is available to dispose of 40% of the total incoming refuse consisting of the "heavy fraction" of the waste stream.

As to the potential corrosion of the boiler tubes, no problems have been reported by Union Electric Co. The absence of corrosion has been attributed to the fact that the ratio of RDF to pulverized coal is small and that the coal ash, which is alkaline, shields the boiler tubes from potentially acid forming substances, resulting from the RDF combustion process.

The possibility of RDF firing in conjunction with fuel oil or natural gas has been questioned with respect to the absence of coal ash, and therefore increased potential of tube corrosion, disregarding the fact that such installations would have to be retrofitted with electrostatic precipitators to prevent the increase in particulate emissions caused by partial solid fuel (RDF) firing.

In conclusion, the St. Louis experiment showed that RDF suspension firing is limited to a few select applications and cannot be considered as an ultimate solution to the solid waste disposal problem.

5. Combustion Equipment Associates

"Eco-Fuel-^{TM}-II"

The "Eco-Fuel-^{TM}- II" process, developed by Combustion Equipment Associates and Arthur D. Little, Inc., produces pulverized fuel essentially derived from the cellulose content of typical urban solid wastes.

Raw refuse is first shredded, inerts, metals and glass are separated and the remaining combustible fraction with the exception of plastics and rubber is broken down into a powder by a "dry pulping process" used in some paper mills.

The powder fuel is realtively high in heat content and is suitable for suspension firing in conjunction with pulverized coal or fuel oil.

Up to this time only a laboratory scale process has been tested. The fuel, produced in small quantities, has been test fired through specially designed burners and early data indicate a tendency for slagging apparently due to the presence of glass and silica dust in the fuel, a by-product of the shredding process.

Capital costs and estimates, offered by the manufacturer, are based at this point, on assumptions and extrapolations. No actual data, which would offer a solid basis for evaluation, are available at the present time. It is anticipated, however, that the applicability of the system will be limited due to the inherently high cost of the fuel processing.

6. Combustion Power Corp.-High Temperature Turbine

The Combustion Power Corporation concept is based on the direct use of the products of combustion from an RDF fluidized bed high pressure combustor to run a specially designed gas turbine.

The RDF preparation includes two stage shredding with ferrous and non-ferrous metal extraction, air classification and inerts and glass separation.

The extensive RDF processing would indicate that the remaining pulverized fiber is suitable for the direct energy conversion process. It was found however, that the attainable efficiency in glass and aluminum separation is not sufficient to prevent slagging of the fluidized bed combustor and carry-over of the traces of aluminum in liquid form, passing through the gas cleaning system and depositing in the form of aluminum oxide on the high temperature gas turbine blades.

Under development since 1976, under the EPA sponsorship, the system has not passed the laboratory stage.

7. Densified RDF Systems

To further homogenize shredded and classified RDF, some manufacturers have developed or adapted pelletizing and other densification processes, yielding more or less constant quality type of solid fuel such as pellets, brickets, etc.

Such homogenized solid fuels can be burned in stoker or spreader stoker fired furnaces without major modifications.

With the availability of automated combustion control systems the RDF densification actually appears superfluous and only increases the fuel processing cost beyond a practical limit.

The exception might be the application to existing coal fired boilers using traveling stokers or spreader stokers where the densified RDF could be burned as an additive to granulated coal.

C. Gaseous Refuse Derived Fuel Combustion--A great many processes for converting solid waste into energy can be grouped under this category. Specific processes, which are of interest are limited to pyrolysis.

Other processes, such as anaerobic digestion, hydrogenation and hydrogasification are either too costly or too unreliable to be considered, or they have been developed only on a laboratory scale not suitable for scaling up without further extensive research and development of new process technology.

In general, the products of a gas producing pyrolysis system consist mainly of combustible hydrocarbons (hydrogen, methane, CO and CO_2). The solids, produced by some systems, consist of carbon-rich residue plus any inerts (glass, metal, rocks). The quality and quantity of products obtained depend upon many factors, some of the most important being the type of carbonaceous solids, the ultimate temperature attained, the heating rate and the type of equipment used. Within certain limits, manipulation of these variables offers a mechanism for controlling the quality and yield of the products.

Pyrolysis has been used commercially for many years in the production of methanol, acetic acids, gasification of coal and turpentine from wood, plus recovery of residual charcoal. Nevertheless, the process of refuse pyrolysis is a relatively new concept.

Various processes have been developed since about 1968. In general, a typical process employs a storage bin, a feeder, a front-end RDF system. a pyrolysis reactor, a combustion product cleaning and/or treating system, collection, storage and/or upgrading system for the solid, liquid and gaseous by-products, and a residue removal system.

Individual process schemes differ in many details, such as the degree of shredding, the methods of feeding refuse and the technique of product recovery. Also, the amount and types of products recovered can vary between the two extremes in which either all products are recovered and separated into several components or no products are recovered. The latter process, where no condensed phase products are recovered, is usually known as a gasifier instead of a pyrolyzer.

1. Union Carbide "PUROX" System

A 181 metric tons (200 U.S. ton) per day demonstration "PUROX" system has been in intermittent operation in Charleston, West Virginia since 1974.

The original concept required a number of modifications, the latest being performed at the present time.

One of the major modifications was the installation of a raw refuse processing (shredding) train since it was found that the operation with unprepared refuse, as originally intended, created uncontrollable process difficulties.

Prepared refuse (RDF) is fed into the top of a vertical shaft furnace via an air seal ram type feeder and pure oxygen is supplied at the base of the furnace where it oxidizes the pyrolyzed charcoal.

The combustion temperatures, which are in the range of 1,922°K (3,000°F), are sufficient to melt any inert, non-combustible materials introduced into the reactor with the RDF. The molten slag is continuously tapped off and quenched in a water filled trough, forming inert granular residue.

Hot gases, produced by the combustion of char, rise up through the descending column of RDF to provide the energy for the endothermic pyrolytic reaction.

Pyrolytic fuel gas, produced by the Union Carbide Purox process, is a clean-burning fuel comparable to natural gas in combustion characteristics. It is essentially free of sulfur compounds and nitrogen oxides and burns at approximately the same temperature as natural gas.

The limitation on use of this gas is the extra cost of compressing it for storage and shipment. Energy consumption per million BTU's to compress it is about three times greater than for natural gas.

Furthermore, it cannot be brought up to pipeline pressure without undergoing partial condensation which results in a loss of about 12 percent of the heating value. As a result, markets for this gas should be no more than 1.6 or 3.2 kilometers (1 or 2 miles) from the producing facility and only short term storage should be contemplated.

2. Carborundum Co. "TORRAX" System

Although somewhat similar in appearance to the "PUROX" process, the "TORRAX" system is substantially different.

As-received refuse is fed into a high temperature reactor-gasifier furnace, which is partially water cooled, air, preheated to about 1144°K (1600°F), is introduced at the bottom of the furnace as well as auxiliary fuel to start up and maintain the operation.

The oxygen in air reacts with the refuse char in the lower portion of the furnace and ascending hot products of combustion act as a heat source for the refuse pyrolysis endothermic process.

Non-combustible residue is melted at about 1922°K (3000°F), at the bottom of the furnace. The slag is tapped and quenched in a water trough yielding inert granular residue.

The pyrolysis gas from the reactor has High Heat Value of about 5.59 MJ/m^3 (150 Btu/ft^3) and consists primarily of CO, N_2 and hydrocarbons. It has been found that the off-gas contains a high percentage of carbonaceous solids and hydrocarbon vapor/tars, which constitute an appreciable fraction of the "fuel value" of the gas. In order to be able to utilize the maximum heat value of the gas, the tar vapors must be maintained in gaseous phase by maintaining the sensible heat of the gas, as it leaves the reactor, at approximately 561°K (550°F). Furthermore, the carbonaceous solids (char) are pulverized and also used as part of the process fuel.

While a heat recovery system, using the "PUROX" process fuel gas does not require a supplementary flue gas cleaning system, a boiler, using the "TORRAX" process fuel must be fitted with air pollution control apparatus such as an electrostatic precipitator.

3. Monsanto "LANDGARD" System

The Monsanto "LANDGARD" pyrolysis process has been developed as a result of experience gained with a 32 metric tons (35 U.S. tons) per day plant in St. Louis, Missouri.

The scaling-up of the 32 metric tons (35 U.S. tons) per day unit to a 907 metric tons (1000 U.S. tons) per day plant, installed in the City of Baltimore under the joint auspices of the Federal EPA, the State of Maryland and the City of Baltimore, revealed some serious problems which were difficult to assess on a pilot plant scale.

Major difficulties have been encountered in the processing (shredding), storage and conveying of the RDF as well as in the operation of the gasifier system. It appears at this time that, even if the materials handling problems are solved, other problems may seriously delay or prevent the full capacity operation of the plant.

4. Other gas producing systems

Other gasification pyrolysis systems, which are for the most part in the research or small pilot plant operation are:

Resource Recovery Corp.-Plasma Torch slagging pyrolysis.

Urban Research Development Corp.-Vertical shaft pyrolysis furnace similar to "TORRAX" process.

Battelle Memorial Institute-Vertical shaft, medium temperature [1144°K (1600°F)] pyrolysis furnace.

Devco Management, Inc.-Rotary kiln pyrolysis.

The operational data from the testing of the above processes are inconclusive and information as to capital, operational and maintenance costs, reliability and mechanical availability is for the most part not available.

The listing of the processes is not necessarily all inclusive, nevertheless any other systems, which could be added at this time, would yield very little information that would be of significant interest.

D. Liquid Refuse Derived Fuel Combustion--By limiting the reaction temperatures of a pyrolysis process, significant portion of pyrolysis products can be extracted in the form of high viscosity, highly oxygenated fuel oil in addition to some gas and char residue.

The only process worth mentioning in this case is the Garrett Research Development Corp., Division of Occidental Petroleum, system, developed from pilot work on production of high heat value liquified fuel from low quality coal.

The process is essentially a flash pyrolysis (low temperature high speed reaction).

No large scale plant is in operation at this time as the projected Bridgeport, Connecticut concept has changed to Combustion Equipment Associates Eco-Fuel™-II.

Evaluation of Systems

In order to provide a realistic comparison of efficiencies and capital, maintenance and operating costs, the evaluation of each system must be based on equal parameters as to the plant capacity and operational requirements.

Where processing of refuse is a prerequisite, it must be included as part of the processing cost and thermal conversion efficiency.

If a remote site is considered for materials recovery and/or RDF preparation, all cost estimates must be adjusted to account for the cost of land required for a processing facility, for the cost of separate buildings and utilities, rehandling of processed refuse (RDF), additional personnel required, RDF transportation cost, etc.

Reviewing the track record of various energy recovery systems, it becomes apparent that, both, from the point of view of thermodynamic efficiency and costs there are only a few systems which would justify a detailed analysis.

A "rating" can be established for each of the systems as the the "State of the Art" technology, reliability and thermal conversion effeciency, yielding an overall "Summary" rating.

For the purpose of this discussion the following system listing was established:

A. Mass refuse combustion (Incineration)

1. Refractory furnace-convection boiler
2. Water wall boiler

B. RDF Combustion

1. Stoker fired refractory furnace-convection boiler
2. Stoker fired waterwall boiler
3. Spreader stoker boiler
4. Suspension fired boiler
5. CEA Ecofuel II system
6. C.P. Corp.-High temperature gas turbine
7. Densified RDF systems

C. Gaseous Refuse Derived Fuel Combustion

1. Union Carbide "PUROX" system
2. Carborumdum Co. "TORRAX" system
3. Monsanto "LANDGARD" system
4. Other gas producing processes

D. Liquid Refuse Derived Fuel Combustion

Table I. shows the individual and summary system ratings by technology, reliability and efficiency, but not necessarily by cost effectiveness.

Cursory review of the table indicates possible selection of systems A.1, 2, B.1,2,3,4, depending on the primary goal of the installation and on the market for energy and recoverable materials.

Conclusions

In the past few years some governmental agencies emphasized novel "advanced" approaches to resource recovery processes, such as the systems listed in Table I. under the designation B.5, 6, and the entire group C and D.

It must be stated, however, that most of the systems failed to demonstrate the desired or anticipated efficiency and reliability, due to the lack of technology, not mentioning extremely high process costs not commensurable with available secondary materials and energy markets.

Many demonstration processes can be put in a category of "progress at any cost."

This leaves us with a rather narrow range of systems, where the final system selection must carefully weighed against site specific conditions.

Where the market for recoverable metals is limited, mass burning with the recovery of ferrous metals from residue is obviously the most efficient alternate. Depending on the steam load requirements and the obtainable price for exported steam or energy a convection waste heat boiler system, characterized by the highest degree of reliability, could be the proper selection in spite of somewhat lower efficiency as compared to a waterwall system.

In other instances, where higher pressure and higher temperature steam is required, the waterwall concept could be the right solution, provided that sufficient redundance is considered to account for more frequent maintenance shutdown periods.

In situations where the recoverable metals market potential is excellent, or where the location of the energy plant is such that transportation of raw refuse is a problem, shredded refuse (RDF) combustion process might be justified, giving essentially the choice of a convection waste heat boiler, waterwall stoker fired boiler or a spreader stoker fired waterwall boiler.

In selected instances the use of existing large utility boilers for the suspension firing of the light fraction of shredded refuse can be considered.

It must be emphasized however, that the application of any system using coarse or fine shredded, air classified or otherwise prepared refuse, requires further research and new technology primarily in the preparation, storage and transportation of the RDF.

Present pilot and full scale operations are not, at this time, effecient and economical no matter how hard we try to justify their existence.

TABLE I

EVALUATION OF SYSTEMS

System	State of the Art (Technology)	Reliability	Efficiency	Summary Rating
A. 1.	1	1	2	4
2.	2	2	1	5
B. 1.	1	1	2	4
2.	2	2	1	5
3.	3	4	1	8
4.	3	4	3	10
5.	3	4	3	10
6.	4	4	4	12
7.	4	4	3	11
C. 1.	2	4	3	9
2.	3	4	3	10
3.	4	4	3	11
4.	4	4	4	12
D.	3	4	4	11

Code:	Technology	Reliability	Efficiency
	1- Most advanced	1- High	1- High
	2- Advanced	2- Medium	2- Medium
	3- Partially developed and demonstrated	3- Low	3- Low
	4- Uncertain	4- Uncertain	4- Uncertain