IV. ENERGY RECOVERY AND COMPOSTING

CHAPTER A - ENERGY RECOVERY FROM SOLID WASTE BY THERMAL PROCESSES

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Abstract

Thermal processing of solid waste offers an attractive alternative to landfilling as a means of dealing with solid waste in the Bay Area. The great reduction of volume resulting from incineration, pyrolysis, or combustion of fuels derived from urban waste can extend landfill lifetimes as much as ten-fold. The combustion of refuse and refuse-derived fuels also provides a source of untapped energy. Air pollution effects, large capital costs, and unproven technologies are the chief drawbacks in the implementation of these systems in the Bay Area. This chapter will investigate the technologies involved in the thermal processing of solid waste and the current and future feasibility of their implementation in the Bay Area.

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Introduction

The organic fraction of solid waste, like all biomass, is composed of high energy molecules formed by photosynthesis. Low energy inorganic chemicals and nutrients are combined during photosynthesis with the net result being the storage of solar-derived energy in plant biomass. The recovery of energy from plant biomass is life's primary source of energy. Not until recent years, however, have organic wastes been considered to have significant potential as an energy resource. Fossil fuels, which are also organic but of much higher energy content, have until recently been abundant and cheap, thus keeping any attempt at large scale energy recovery from waste materials generally uneconomical. At present, however, the picture is rapidly changing. In addition to diminishing the need for alternative energy sources, energy recovery programs will also decrease the volume of the solid waste stream. This will effectively diminish the present fill-related problems of rising costs and disappearing disposal sites.

Thermal Processes

Thermal processing of solid waste is a means of rapidly oxidizing the organic, combustible fraction of solid waste to carbon dioxide and water vapor under conditions of extreme heat. There are several basic methods utilized in the thermal processing of solid waste. These methods can be categorized under the broad headings of incineration, pyrolysis, and supplementary or refuse-derived fuels (RDF). These latter fuels can be used in modified coal or fuel oil fired power plants.

Incineration is the most common method of thermally processing solid waste. In this process, the solid waste undergoes little or no preparation before being combusted in the incinerator. Because the refuse is essentially untreated, may be bulky and may have a high moisture content, large excesses of air are required for complete combustion.

Pyrolysis, on the other hand, converts the original solid waste into a relatively high quality fuel before it is finally combusted. This process of converting solid waste to a high quality fuel is achieved by heating the solid waste to high temperatures in an environment devoid of oxygen. Under these conditions, the large, complex organic molecules contained in the solid waste undergo decomposition to a mixture of lighter organic molecules. The result is a relatively high energy pyrolytic fuel whose properties approximate those of bituminous coal, fuel oil, or natural gas, depending on the nature of the pyrolysis process.

The refuse derived fuel (RDF) process also involves pre-treatment before combustion. In this process, solid waste is generally shredded and then air-classified or mechanically sorted to remove non-combustibles such as metals and glass. The resultant fuel has been found to be of a quality suitable for substitution in modified coal and fuel oil fired power plants (Lingle, 1976).

The total quantity of solid waste available for energy conversion in the Bay Area in 1975 was estimated at nearly 5.0 million tons (4.5 mln metric tons [MT]). (This figure is the total ABAG estimate for solid waste production in the Bay Area, not including wastes resulting from agriculture, uncollected and hazardous wastes). Of this tonnage, about 80 percent is estimated to be organic and combustible on a dry weight basis (Wilson, 1976). Significant amounts of energy could be provided by this waste. It has been estimated that 5 to 10 percent of the energy needs of Alameda County could be met by the combustion of its refuse ("Waste Age," October 1975).

Much of the energy derived from solid waste is likely to be in the form of steam. Except in the case of the higher quality pyrolytic fuels and those combusted along with another fossil fuel, temperatures generated by the combustion of refuse do not produce a steam of sufficient pressure to drive an electricity generating turbine. For this reason solid waste is usually used to generate a low energy steam that can be used to drive a variety of turbomachinery. Steam users must be close to the facility, however (EPRI Journal, November 1977).

Electricity generation from solid wastes has other difficulties also. Inconsistencies in the heat contents of refuse can lead to "hot spots" on the grates and result in corrosion. In addition, chlorides resulting from salt and plastics in the waste stream also contribute to corrosion (General Electric, 1975).

The reclamation of waste heat from the thermal processing of solid waste is novel and largely untested. The first large scale (1000 tons per day or greater) energy recovery incinerators, refuse derived fuel operations and pyrolysis plants have all been in operation for less than ten years in the United States. Not all have been entirely successful. Corrosion and storage problems are difficulties that have yet to be solved in many systems, especially the pyrolysis process.

Air pollutant emissions from these plants are also a serious problem. Particulate emissions can be reduced to acceptable levels only with the addition of air pollution control devices. The cost of these devices rises exponentially as standards become stricter (Williamson, 1973). Meeting California's strict particulate standard may prove economically prohibitive for incinerators. Emissions from pyrolytic and refuse-derived fuel processes are probably lower than those from incinerators. Emissions from these systems can be met with smaller, more economical control devices (Levy, 1974). For this reason these processes are less proven than incineration, however, and their emissions records are incomplete.

Gaseous emissions from the combustion of refuse and refuse-derived fuels appear to be less of a problem than the emission of particulates. The sulfur and nitrogen content of refuse and refuse-derived fuels is fairly low. Refuse fuels generally have less than half the amount of sulfur and nitrogen as fuel oil or bituminous coal (See Figure 1). As a result, sulfur and nitrogen oxides emissions from incinerators and other thermal processing plants do not appear to be an especially serious problem (General Electric, 1975).

The large capital expenditures required for the construction of large scale incinerators and pyrolysis plants may act as a barrier to their construction. Capital expenditures for a typical installation range from fifteen to more than fifty million dollars. Meeting these capital requirements may involve fiscal and jurisdictional cooperation between counties, cities and private disposal companies, as well as assistance from the State and Federal government. Trash flows may have to be re-routed to justify the construction of large scale plants. A single, large scale, 1500 tons per day plant would process nearly one-tenth of the total solid waste stream in the Bay Area. In many instances supplying this amount would require contributions from several disposal agencies.

Current Energy Recovery Projects in the Bay Area

Thermal processing of solid waste has been avoided in the Bay Area for economic and aesthetic reasons. Unlike some areas of the densely populated East, landfill has been readily available in the Bay Area at reasonable cost. Incineration, at least until recently, has been regarded as less desirable than landfilling. Incinerators have a notoriously poor emissions record, especially in regard to particulates.

The advent of new air pollution control devices and the continuing development of pyrolysis and RDF processes has led to a reevaluation of the role of incinerators and other processes in the treatment of solid waste. Pyrolysis in particular has attracted the attention of many agencies in the Bay Area (ABAG, a, 1977). Although unproven, pyrolysis offers the potential to limit emissions to a level safely below California's standard.

Pursuant to California Assembly Bill AB1395 (1976), several projects proposed by the various cities and counties in the Bay Area are undergoing economic analysis in order to develop funding recommendations to the State Legislature (ABAG, b, 1977). The farthest along of these projects is the one being undertaken by the Contra Costa Sanitary District. It has already completed a 600 to 800 tons per day pilot project involving a starved air incinerator. This method is essentially a two-stage combustion process in which refuse-derived fuel is pyrolyzed and then combusted. (This process is discussed later in the technical section). The RDF used in this process is prepared by shredding and mechanically sorting the original waste to a diameter of less than three inches and a composition of greater than 95 percent combustibles.

The full-scale plant is expected to go into the design stage by September 1978, after an environmental impact statement has been completed. As of now, funding is expected only for the incinerator and not for the energy conversion facility. Energy conversion funds are expected to be appropriated soon, however, and the 12 million watt energy recovery facility is hoped to be in complete operation by 1983 or 1984. The incinerator itself should be in operation a year or two earlier (Larson, 1978, oral communication).

There are two other proposed projects that are now undergoing economic analysis pursuant to AB1395. A waterwall incinerator (See technical section of this chapter for description) is proposed for Alameda (Larson, 1978), and another energy recovery project is proposed for San Francisco. Projects not yet included under AB1395 include a 3000 tons per day electricity generating pyrolysis plant in Redwood City, a steam generation project in Berkeley, A RDF steam generation project to be operated by U.S. Steel in Pittsburgh, and other projects proposed for the San Jose and Santa Clara area (ABAG, b, 1977).

The large capital costs of these facilities may delay their implementation in the Bay Area. Private and public agencies may be unwilling to amortize projects that are still technically unproven. The financing of these operations often will depend on markets for steam and energy that do not exist at the initiation of the project. Oakland Scavenger Company cited these uncertainties as the reason for its unwillingness to go ahead with a 45 million dollar, 1750 tons per day energy recovery facility in San Leandro. Rising energy prices may sway their interest toward the project again, however ("Waste Age," October 1975).

Technical Processes: Incineration

Incineration has been a common method of dealing with solid waste for centuries. The basic principle remains the same today. Through rapid oxidation, the combustible fraction of refuse can be converted to carbon dioxide and water vapor, leaving behind a smaller volume of non-combustibles such as glass and metals. In this way a municipality can reduce what was once a large volume of putrescible, pest-attracting refuse to a more manageable volume of relatively inert, largely inorganic ash. Modern incinerators can reduce the solid waste to 5 to 20 percent of its initial volume (Wilson, 1977).

It is not until recent years that the heat created by the combustion of urban refuse has been converted into usable energy. The technology for modern, relatively clean burning and steam producing incinerators was developed primarily in Western Europe and Japan where high costs of energy focused attention on this untapped energy source. The first of these incinerators went into operation in the early sixties in West Germany and Switzerland (U.S. Solid Waste Study Team, 1967).

The design of these incinerators varies widely. Municipal incinerators commonly have three main components: the storage and receiving area, the refuse feed system, and the combustion chamber. Incinerators equipped with energy recovery systems have boilers that are fired either by gases emitted by the combustion chamber or heat captured by a "waterwall" lining that surrounds the combustion chamber

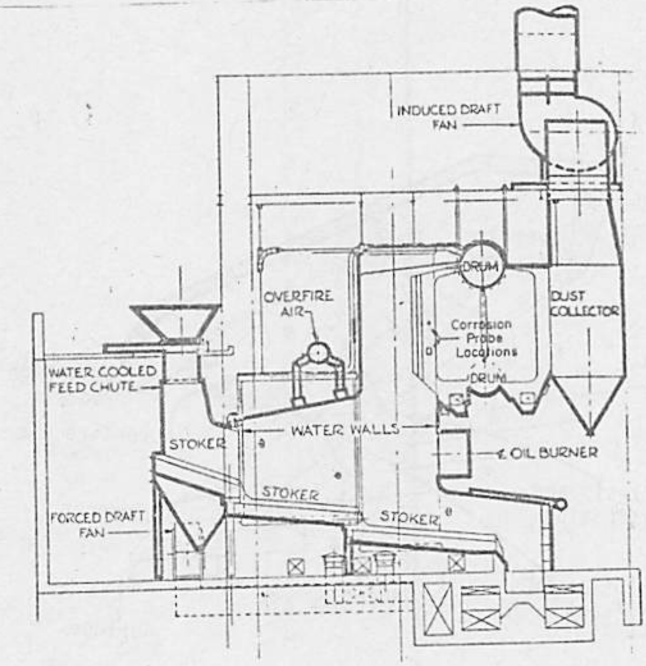

Figure 1. A Waterwall Incinerator (U.S. Naval Base, Norfolk, Va.)
(from Wilson, 1977)

and feed chute.

In a municipal incinerator, the storage and receiving areas are designed to be large enough to contain a sufficient supply of rubbish to maintain continuous operation during weekends or other periods when refuse is not collected. (Repeated shutdowns and startups cause temperature fluctuations that can strain combustion chamber and feed chute walls and thus reduce their lifetimes.) Some storage areas have mechanical shredders that reduce the size of bulky items. Refuse is generally fed into the feed chute by cranes.

A continuous refuse feed system is generally more desirable than a batch feed system. The continuous feed system affords more control of the air supply. In the continuous feed system the refuse constantly blocks the feed chute, preventing large influxes of air from entering the combustion chamber. Control of the air supply is important in controlling temperatures, rates, and efficiencies of the combustion reaction.

The combustion chambers of incinerators are designed in a way to maximize total combustion and thus decrease residual ash output. This can be done through careful design of air inputs and agitation of the refuse in the chamber. Air is fed to the burning refuse from jets located both above and below the grates that support the refuse. The ratio of overfire to underfire jets can be manipulated to control combustion rates and reduce particulate emissions from the combustion chamber. The grates of a modern incinerator serve the dual purpose of transporting the refuse through the combustion chamber to the ash quench and agitating the refuse. The grates usually undergo some sort of rocking motion as they travel through the chamber. Additionally, some chamber designs include mechanical stokers that further agitate the refuse.

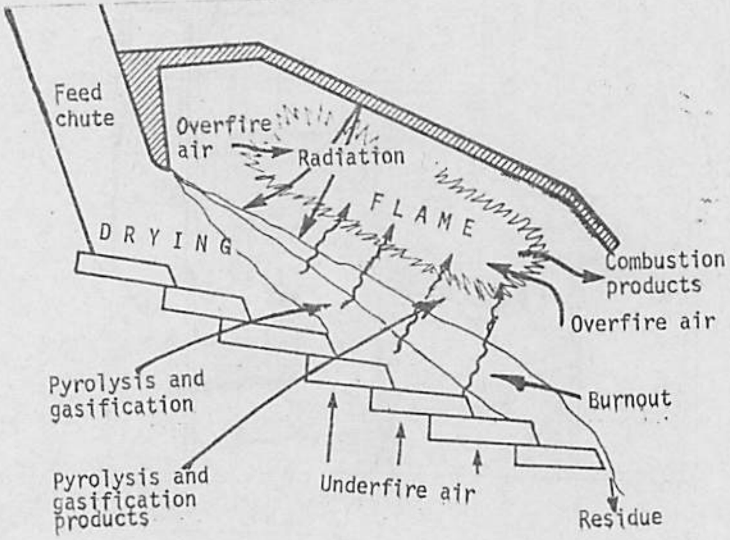

Figure 2. Schematic Diagram of Processes Occurring on Grate and in the Combustion Chamber (from Wilson, 1977)

The total air supplied to the combustion reaction varies from 100 to 400 percent excess of that required for stoichiometric combustion (Levy, 1974). The variation in air requirements depends mostly on the degree of mixing that can be attained in the combustion chamber. Air pollution control costs rise steeply with the volume of air treated and for this reason it is generally considered to be good practice to minimize the air flow required for complete combustion.

The boilers of an evergy recovery incinerator can directly help to abate some of the air pollution control problems by reducing the volume of exhaust gases. Both waterwall and exhaust gas fired boilers absorb the heat released in the combustion reaction and thus contribute to an overall cooling of the gases emitted from the combustion chamber to the air pollution control device ("Environmental Science and Technology," March, 1971). Incinerators without boilers often require a gas quench system to cool exhaust gases.

Recently the more expensive waterwall boilers have gained favor over the flue or exhaust gas boilers with refractory walls. The waterwall construction seems to be more durable. The inevitable shutdowns for maintenance and cleaning of the incinerator put heavy temperature strains on refractory linings, but in the waterwall design these strains are tempered by the high heat capacity of the water contained in pipes within their walls (Wilson, 1977).

The first of the steam producing municipal incinerators went into operation in Chicago in 1971. It processes 1600 tons of Chicago's refuse per day. Its four waterwall boilers can produce a combined output of 440,000 pounds of steam per hour. Of these 440,000 pounds, approximately 240,000 pounds are used within the plant itself for turbine powered shredders, feeders and stokers. The rest of the steam is available for sale to a nearby planned industrial area ("Environmental Science and Technology," March 1971). Revenue and savings from the sale and in-plant use of steam are expected to reduce the cost of incineration to half that of conventional, non-steam producing incinerators in the same area. Particulate emissions from the plant are controlled by a venturi scrubber. Particulate levels are held to 0.05 grains per cubic foot, below Federal, State, and City standards ("Solid Waste Management," May 1971).

Pyrolysis

In the absence of oxygen and with the addition of heat, large organic molecules such as those found in solid wastes can be decomposed into lighter, higher energy organic molecules that are more suitable as fuels. This process is called pyrolysis. Though it is largely unproven on the full scale, it offers certain advantages over incinerators as a means of disposing of solid waste. The potential air pollution problems are minimized by the smaller volumes of air required in the manufacture and combustion of pyrolytic fuels. Whereas incinerators require large excesses of air to successfully combust refuse, the higher grade pyrolytic fuels perform similarly to high grade fossil fuels and require only slightly greater than stoichiometric amounts for complete combustion (Levy, 1974). (The manufacture of the fuel itself requires little if any air). Another advantage in some pyrolysis processes is the production of a high quality transportable fuel that can be used directly in existing power plants (Wilson, 1977).

There are many pyrolysis processes under investigation at the present time. By varying the temperature and rate of heating, different fuels can be produced from the same refuse. Generally, higher temperatures and longer heating periods favor the formation of lighter liquid and gaseous fuels. Fuels resulting from the pyrolysis process range from an impure carbon char similar in composition to bituminous coal to a gaseous product similar to natural gas.

Three of the pyrolytic processes furthest along in testing are the Monsanto "Landguard" System in Baltimore, the Purox System developed by Union Carbide in South Charleston, West Virginia, and the Garrett Corporation's system in San Diego (Levy, 1974).

The Monsanto system uses the starved air incinerator concept. (This is similar to the one planned by the Contra Costa County Sanitary District). In this system, shredded refuse is partially pyrolyzed and partially combusted in a rotating, refractory walled kiln containing 40 percent of the stoichiometric combustion requirements. The small amount of air allowed into the kiln drives a limited combustion reaction that provides the heat to pyrolyze the refuse. Fuel oil is sometimes added to supplement the reaction. The pyrolysis products are then burned in an afterburner to produce steam. The plant was designed to process 1000 tons (908 MT) per day and produce 200,000 pounds (90,000 kg.) of steam per hour from two waste heat boilers (Levy, 1974).

The Monsanto plant has been plagued by problems since its completion in 1975. Problems with particulate emissions (seven times the state standard) and the refuse feed system have caused repeated shutdowns. A new air pollution control device (a wet electostatic precipitator) is being installed along with other modifications at a cost of 9.65 million dollars (This is more than half the original total plant cost) (Lingle, 1976). In February of 1977 Monsanto decided to terminate its involvement in the project, recommending that the system be converted to a conventional incinerator. The city of Baltimore, however, is continuing its operation as a pyrolysis system. The longest non-stop run of the plant to date occurred during 25 days in June, 1977 (Solid Waste Report, 1977).

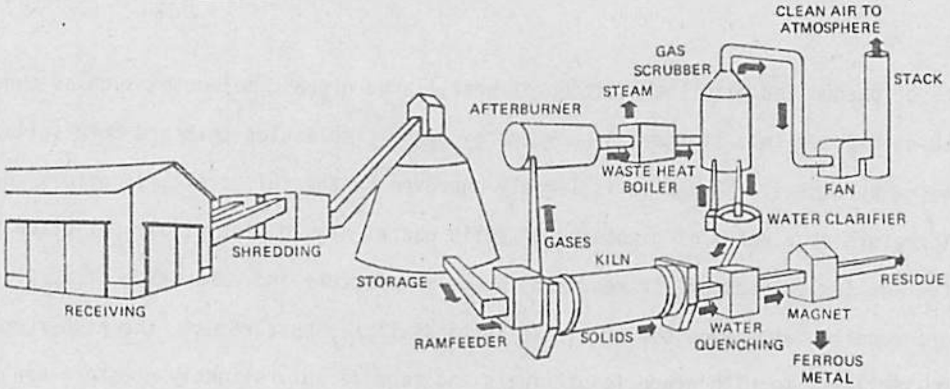

Figure 3. The Monsanto Landguard System Uses the Starved Air Incinerator Concept. (Levy, 1974)

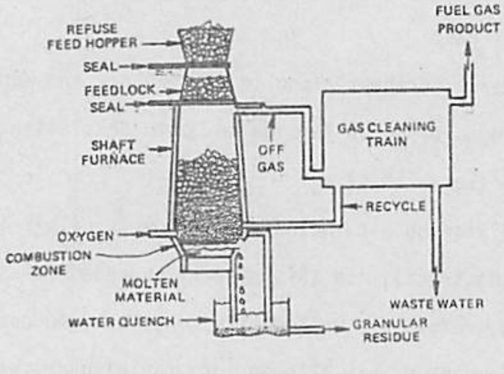

Figure 4. The Purox Process Produces a High Quality Pyrolytic Gas (Levy, 1974)

The Purox system uses a high temperature reactor to produce pyrolytic gas for offsite use. The two hundred ton per day plant consists of a vertical kiln in which pure oxygen (hence Purox) is fed in at the bottom at a rate sufficient to ignite residual char left over from previous pyrolytic reactions. The ignited char then provides enough heat to pyrolyze the refuse above it. In this way no exterior source of heat is required except to initiate the original pyrolysis reaction. The gaseous products are off-gassed, cleaned and piped away. The gaseous fuel is of relatively high quality and can thus be economically transported. This high quality is a result of using only pure oxygen in manufacture of the fuel. (Using pure oxygen is expensive and this system is more costly than others) (Lingle, 1976). In August, 1977 the Purox system completed a successful 60 day demonstration run (Solid Waste Report, 1977).

The Garrett process in San Diego produces a liquid pyrolysis product similar to No. 6 fuel oil. This system relies on a flash pyrolysis method. Before flash pyrolysis can take place the refuse must be shredded, air classified and dried to obtain a RDF of high organic content and less than 3 percent moisture content. The pyrolysis reaction takes place in a narrow vertical chamber. As in the Union Carbide System, combustion of residual char is used to drive the pyrolysis reaction. The pyrolysis product, which resembles No. 6 fuel oil at room temperature, is cleaned of debris in the gaseous state as it leaves the 900 degree Fahrenheit chamber. This pyrolytic oil has approximately 57 percent of the energy content of No. 6 fuel oil (by weight) and contains less than half the ash and sulfur (Levy, 1974).

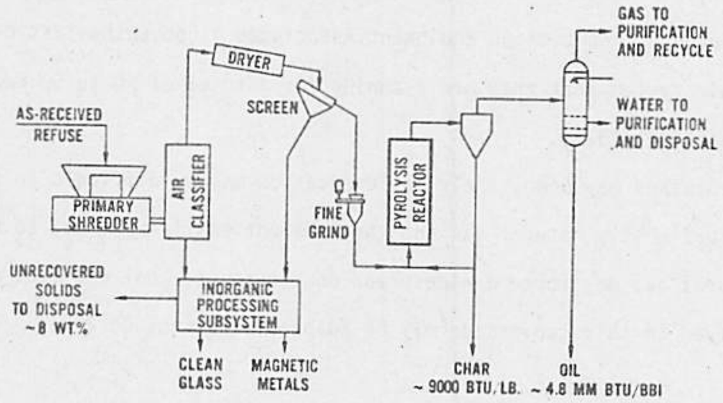

Figure 5. The Garrett Process Produces a Liquid Fuel Similar to #6 Fuel Oil. (Levy, 1974)

Refuse Derived Fuels (RDF)

The use of shredded, sorted solid waste has been demonstrated in several plants in the United States. One such plant in St. Louis has been operating for several years in a study sponsored by the EPA. The refuse is shredded to 1.5 inch (4 cm) size particles and then air classified to separate light and heavy fractions. The heavy fraction is sorted to recover ferrous metals and the lighter fraction (which comprises about 80 percent of the total input) is used to supplement Union Electric Company's Meramac Power Station. This RDF has an average heating value of about half that of bituminous coal. It has been shown that this RDF can be substituted in amounts ranging from 5 to 27 percent without adversely affecting the coal fired boilers (Lingle, 1976).

There are several problems with this sort of RDF. It can be stored only for short periods of time because it decomposes rapidly. Transportation of RDF is generally uneconomical because of its low heating value. The long term effects of RDF substitution on corrosion in coal fired plants is unknown. Present information about effects of RDF substitution on emissions are somewhat contradictory ("Waste Age," August 1976). These problems do not seem unsolvable, however, and future plant designs are likely to solve many of the problems encountered in these first RDF operations (Lingle, 1976).

RDF storage problems are being solved by a process developed by Combustion Equipment Associates in Brockton, Massachusetts. In this process raw RDF is converted into a fine dry powder, called Eco-Fuel II, which can be stored without decomposing. During the latter part of 1977 1200 tons (1070 mt) of garbage were converted into Eco-Fuel II. This fuel was then combusted in a modified oil fired power plant some 160 miles (250 km) away. The relatively high energy content of this fuel permits economical transport. Combustion Equipment Associates is so enthusiastic about the "superior economics" of their system that they are planning for a total of 40 to 50 new facilities in the next twelve years (Gallese, 1977).

As promising as RDF processes may seem, their implementation may be difficult in the Bay Area. Power plants in this area burn mostly natural gas and they are not easily modified to burn RDF. Tightening supplies of natural gas may force a widespread conversion to coal and fuel oil, however, and the modifications involved in this conversion may be adaptable to include RDF.

Table 1. Approximate Analysis of Refuse Fuels and Comparative Fossil Fuels.

FUEL	% MOISTURE	% ASH	KJ/KG*	% S	% N
Refuse (raw)	25.0	22.5	11,000	0.10	0.58
RDF	23.7	9.2	13,645	0.11	0.56
Bituminous Coal	8.6	8.4	27,298	0.2-7.0	1.00
"Purox" gas	0.0	0.0	14,000-20,000	?	?
Natural gas	0.0	0.0	50,143	-	-
"Garrett" oil	0.5	0.2-0.4	24,500	0.1-0.3	0.9
#6 fuel oil	0.5	0.5	42,300	0.7-3.5	2.0

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*1 KJ/KG = 2.33 BTU/LB

(After General Electric, 1975)

Conclusion

Thermal processing of solid waste offers an attractive alternative to the present practice of landfilling in the Bay Area. The volume reduction that results from incineration, pyrolysis, and other thermal processes can extend landfill lifetimes as much as ten-fold. In addition, the energy recovered from these processes could supply as much as ten percent of the energy demand in the Bay Area.

There are several outstanding problems involved in the thermal processing of solid waste, however. Capital costs can be met only with long periods of amortization during times when energy prices are unpredictable and markets for recovered materials and energy are undeveloped. Technological problems remain to be worked out in large scale modules, especially those involving pyrolysis. The first large scale thermal processing plants have not been entirely successful. Recent experiences in Baltimore and St. Louis have shown that there are a variety of technological problems yet to be solved.

The potential air pollution effects of these systems are especially critical in the Bay Area. Particulate emissions, especially from incinerators, may be difficult to control. The expensive air pollution control devices required to control emissions from some systems may prove economically prohibitive. Implementation of ABAG's Air Quality Management Plan may require that incinerators and other thermal processing systems conform to emissions standards that are stricter than have been encountered in past testing.

Despite these problems, it is almost certain that energy recovery will occur in the next few years in the Bay Area. Full scale plants such as the one slated for Contra Costa County will present the opportunity to closely scrutinize plans for similar systems in the Bay Area. The widespread implementation of thermal processing in the Bay Area is probably not feasible for a decade or more, however. Implementation will depend upon more than just technical feasibility. Cooperation between the various agencies and communities in the funding and management of thermal processing plants will be an important factor in determining the success of these energy recovery facilities.

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