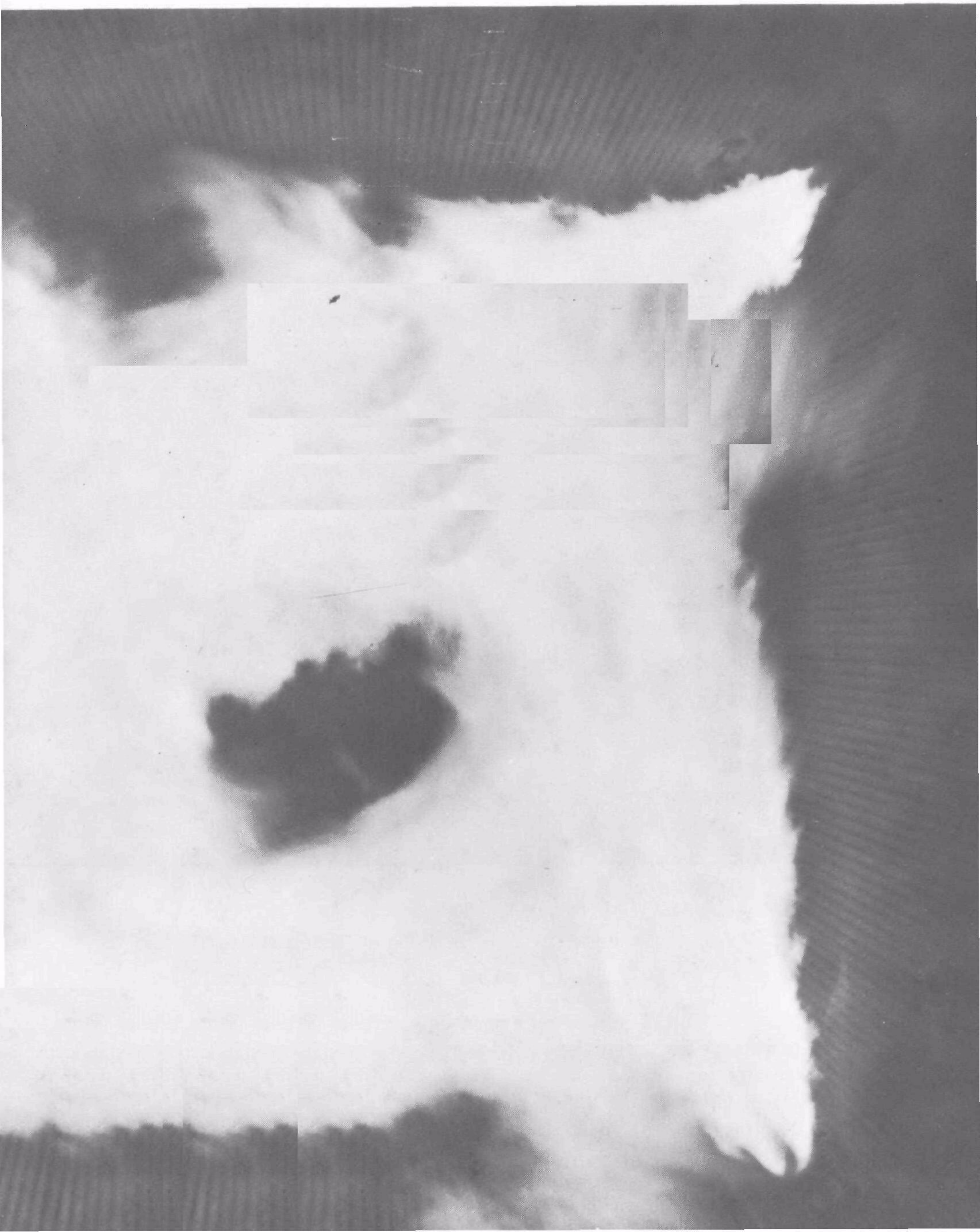
Energy Recovery from Waste



COVER PHOTOGRAPH: The flame pattern, viewed from the top of a tangentially-fired boiler, shows how solid waste fuel and coal are fired from the corners of the boiler. (Photograph courtesy of Combustion Engineering, Inc.)

Energy Recovery from Waste

SOLID WASTE AS SUPPLEMENTARY FUEL IN POWER PLANT BOILERS

This second interim report (SW-36d.ii) on work performed under Federal solid waste management demonstration grant No. S-802255 to the City of St. Louis, was written by ROBERT A. LOWE

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Acknowledgments

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The success of this project is the result of the progressive and cooperative spirit of the participating organizations and their principal representatives: G. Wayne Sutterfield, City of St. Louis, Missouri; Earl K. Dille, Charles J. Dougherty, and David L. Klumb, Union Electric Company; Dr. Donald F. Cairns and H. M. Love, Granite City Steel Company; F. E. Wisely, Horner & Shifrin, Inc.

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FOREWORD

GROWING CONCERN for the environment has changed our thinking about solid waste. Although disguised as a *nuisance*, solid waste can be an environmental *asset*. It contains a wealth of recyclable materials—paper, cardboard, metals, and glass—and offers the potential for conserving a seriously diminishing resource—fuel.

In this period of concern about shortages of energy and material resources, the mere existence of untapped resources commands our attention. Recycling and reuse of waste materials makes good sense environmentally and economically. Information is emerging to show that recovering and reusing our resources is sound practice for more reasons than appear on the surface. When two production systems are compared, one using virgin materials, the other secondary or waste materials, the system using wastes almost always causes less air and water pollution, generates less solid wastes, and consumes less energy. This is true if the environmental impacts of all activities in a system are measured—mining, processing, fabrication, manufacturing, and the transportation and disposal steps in between.

The Nation's task, then, is to organize our systems and institutions so that the economy can begin to receive the benefits and reflect the savings from using more secondary materials. One way to help accomplish this is through new technology. But technological advances are usually expensive, are relatively untried, and therefore entail some risk. The Resource Recovery Act of 1970 enabled the Federal solid waste management program to assist States and municipalities by assuming part of the risk of trying new technologies. The result was a significant expansion of the Federal resource recovery demonstration program. This report describes one part of that program: the recovery of energy by burning shredded residential solid waste as a supplementary fuel in power plant boiler furnaces.

This process was initially studied in 1968 by the City of St. Louis and the Union Electric Company, with financial support from the Federal solid waste management program. The results of the study were encouraging. In 1970, the demonstration was initiated when the U.S. Environmental Protection Agency's Office of Solid Waste Management Programs and Office of Air Programs jointly awarded a grant to the City of St. Louis for two-thirds of the cost of the project.

Operations began in April 1972 and continued intermittently until May 1973, when construction of the air classifier began. Operations then ceased while the air classifier was being installed and resumed in November 1973.

Much has been learned since our first report on this project was published in April 1972.* The present report is a second interim summary and includes discussion of the current technical, marketing, and economic aspects of the solid-waste-as-fuel concept. Thorough testing of air emissions and processing practices were scheduled to begin in late 1973. A third report on the project will be published as soon as test results are known.

While there is still much to be learned, it is already apparent that this demonstration represents a practical step in the right direction and exemplifies the kinds of creative solutions that government at all levels, industry, and the public must pursue to bring our environmental and resource conservation problems under control.

— ARSEN J. DARNAY

Acting Deputy Assistant Administrator
U.S. Environmental Protection Agency
Office of Solid Waste Management Programs

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* Horner & Shifrin, Inc. Energy recovery from waste. Washington, U.S. Government Printing Office, 1972. 15 p.

Energy Recovery from Waste

SOLID WASTE AS SUPPLEMENTARY FUEL IN POWER PLANT BOILERS

CONVERTING MUNICIPAL SOLID WASTE into energy is a solid waste management option that has recently become attractive, both environmentally and economically. Although a number of European countries have been generating electricity from municipal solid waste for years, in the United States recovery of heat from municipal solid waste has been limited. Until recently, it consisted of relatively inefficient waste-heat boilers installed in conventional incinerators. In the past five years, however, more sophisticated solid waste incinerators have been built, which incorporate boilers for the recovery of steam.

But these newer facilities, known as waterwall incinerators, have several important limitations. First, reliable markets for steam are not always readily available. Secondly, new facilities are relatively expensive both in capital cost and operating cost. Third, their relative reliability has not always been acceptable.

By burning the solid waste in a utility power plant, the process can take advantage of an established system for producing, distributing, and marketing electricity through use of an existing boiler, or a new power-producing unit designed for this purpose. Thus, the energy recovered from solid waste can have an assured market.

Although coal-fired power plant boilers are not without operating problems of their own, a comprehensive study by Horner & Shifrin, Inc., with the close cooperation of the Union Electric Company and Combustion Engineering, Inc., concluded that such problems would not be significantly increased, if increased at all, by burning prepared solid waste as supplementary fuel.[1] The concept

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[1] Horner & Shifrin, Inc. Solid waste as fuel for power plants. U.S. Environmental Protection Agency, 1973. 146 p. (Distributed by National Technical Information Service, Springfield, Va., as PB-220-316.)

was considered attractive enough for the City of St. Louis, Missouri, and the Union Electric Company to undertake an innovative joint venture. With financial support from the U.S. Environmental Protection Agency, the project began to operate in April 1972.

The Process

Perhaps the most striking aspect of the process is its simplicity. Domestic solid waste, collected from residential areas of the City of St. Louis, is ground up in a large hammermill. The shredded wastes are air-classified and the light combustible waste fraction is fired pneumatically into existing boilers in the Union Electric Company system. Magnetic metals are recovered from the heavier, mostly noncombustible, fraction. The remaining glass, ceramics, and other nonmagnetic materials are landfilled. All of this can be achieved by applying existing technology with equipment that already is commercially available.

Potential Benefits

This waste disposal system promises to be attractive, both economically and environmentally. The value of the fuel produced, together with revenues from the ferrous metals and other materials that may be recovered from the waste for sales,reduce the cost of disposal. At the same time, energy and materials are conserved, air and water pollution are decreased, and land required for waste disposal is reduced by about 95 percent.

Present Status

The results of this experimental project to date are encouraging. As evidence of this, the Union Electric Company is considering the adaptation of additional boilers to handle more solid waste fuel.

At the present time, four aspects of the concept must be evaluated before the experiment can be proclaimed a complete success. These are: (1) the quality of air emissions from the boiler stacks, (2) the performance of the air classifier, (3) the long-term effect on boiler operations and feed mechanisms, (4) the economics of the process. Air emission tests will be conducted in the fall of 1973, after the air classifier has been installed. The air classifier is expected to reduce significantly the two major operating problems encountered so far: blockages in the feeders that inject the solid waste fuel into the pressurized pneumatic pipeline system; and excessive internal wear and tear on those pipelines that feed the solid waste into the boilers.

In general, although the operating results must at this time be regarded as preliminary, the project is operating essentially as predicted. A one-year comprehensive evaluation of the system operating at full capacity was scheduled to begin in late 1973.

THE PROCESSING SYSTEM AND ITS OPERATION

Type of Waste Processed

The only type of solid waste currently accepted at the St. Louis processing facility is from residential sources. Certain selected commercial and industrial wastes may be accepted later. The system was designed to exclude oversized bulky wastes, such as tires, appliances, furniture, engine blocks, and land-clearing and demolition wastes. This limitation is a function of the capacity of the shredders and the fuel quality objective. Operating personnel have reported, however, that occasionally tires and even mattresses have been processed without problems. In other circumstances the system can be designed to accept certain bulky wastes (*see* Economics).

Capacity

The processing system was designed to handle 325 tons per 8-hour shift, with a maximum practical throughput of about 650 tons per day. Because of the one-stage shredding operation (*see* Hammermill and Particle Size, below), hammer retipping is required almost daily. This maintenance requires nearly a full 8-hour shift to complete. Two-stage shredding may permit less frequent scheduling of hammer retipping. The hammermill, air classifier, and conveyors were selected to provide a nominal production rate of 45 tons of raw solid waste per hour.

Redundancy

Because a community will generate waste whether its resource recovery system is operating or not, a standby disposal method must be provided. Extra storage space can accommodate waste during relatively short periods of downtime. For more extended periods, the waste can be diverted to a standby processing line, incinerator, or sanitary landfill. The choice will depend upon the economics of the alternatives and the availability of an incinerator or landfill.

The St. Louis plant consists of only one processing line, with the City's incinerator available as a backup method. The existing incinerator was selected as the standby method instead of an auxiliary processing line because of the desire to minimize capital costs in this experimental project. At the power plant, however, to assure standby capacity, two boilers have been modified so that one will be available at all times.

Receiving Area

Raw solid waste is discharged from packer-type collection trucks onto the floor of the receiving building (Figure 1). Front-end loaders are used to push the solid waste to a receiving belt conveyor. This method of handling the waste was selected over the pit and crane method because it would be more economical and would enable the operator to remove unwanted materials. This method also permits greater and more uniform production rates. From the receiving conveyor, the raw solid waste is transferred to the hammermill.

Hammermill and Particle Size

Residential solid waste, in its raw state, is remarkably heterogeneous. After shredding, however, the solid waste becomes more homogeneous. Shredded waste is generally easier to separate into salable components than is raw solid waste. Shredding also reduces odors and makes the waste easier to handle.

In the St. Louis shredder, 30 large metal hammers swing around a horizontal shaft, grinding the solid waste against an iron grate until the material is shredded into particles small enough to drop through the grate openings. This model was selected on the basis of three operating parameters: the heterogeneous nature of the waste stream, the production rate required, and the desired control over the particle size.

The design called for a nominal particle size of 1½ inches. Preliminary data show that over 90 percent by weight of the incoming waste is reduced to particles not greater than one inch in any dimension. The optimum particle size has not been determined. Tests scheduled for the fall of 1973 will attempt to determine the particle size that will provide the best shredding economics, materials handling, combustibility, and air emissions.

Shredding in one step to a particle size as small as 1½ inches causes severe wear on the shredder's hammers, requiring maintenance almost daily with the throughput planned by St. Louis.

Single-stage milling (all shredding in one pass through the shredder) was selected for the prototype system to minimize capital costs. For future applications, however, its designers, Horner & Shifrin, Inc., and other experts recommend a two-stage shredding operation, with air classification between the two shredding steps. The first shredding would reduce the waste to a particle size of about 4 to 6 or 8 inches. After removal of the heavier materials by the air classifier, the second shredding would reduce particle size of the light fraction to 1 or 2 inches. Hammer wear should be reduced considerably.

Air Classifier

From the hammermill, the shredded waste is conveyed to the air classifier. The air classifier separates the heavier, mostly noncombustible particles from the lighter ones. The shredded waste is dropped into a vertical chute. A column of air blowing upward from the bottom of the chute catches the lighter materials, causing them to fly to the top. The heavier materials drop to the bottom. By varying the air velocity and the cross-sectional area of the chute, the percentage split between heavy and light fractions can be controlled. The St. Louis air classifier is designed to permit 75 to 80 percent of the shredded waste to be separated into the light group for use as fuel.

The light fraction is expected to be composed of paper, light cardboard and plastics, textiles and light food wastes, and other organics, all of which are combustible, plus a small percentage of light noncombustibles like aluminum foil. It also will contain small particles of heavier materials such as pulverized glass that stick to pieces of organic materials.

The heavy fraction is expected to contain ferrous and nonferrous metals, glass, dirt, and other noncombustibles. Certain heavier combustible materials, such as grapefruit rinds and heavier pieces of cardboard, plastics, woodchips, and rubber, will also drop into the heavy group.

By removing the heavier materials—both combustible and noncombustible—from the fuel, three benefits should result: an increase in the heating value of the fuel, an increase in the transportability of the fuel through the pneumatic pipelines, and an increase in the suitability of the boiler's bottom ash for reuse. And the ash content of the waste fuel should decrease. The presence of the small bits of glass and other materials remaining in the fuel is not expected to have a significant effect on the suitability of the waste as a fuel.

The light materials are carried pneumatically from the separation chute to the cyclone separator, where they are removed from the air stream and allowed to fall onto the conveyor leading to the storage bin.

Storage and Transportation

At scheduled intervals, quantities of the solid waste fuel are removed from the storage bin and loaded onto trailer trucks for the

18-mile trip to the power plant. Two trailer trucks, each with a capacity of 20 to 25 tons, deliver fuel to the power plant around the clock five days per week. The trucks are loaded by a ram-type stationary packer and are unloaded by a ram located within the trailer of the truck. Both the loading and unloading operations are controlled by the truck driver.

Ferrous Metal Recovery System

The heavy fraction is processed to recover ferrous (magnetic) metals. The entire heavy fraction is passed under a magnetic belt. The nonmagnetic materials are hauled away to be landfilled. They can be further separated for resale when technology and economics permit. The ferrous metals are then densified in an Eidal nuggetizer or densifier (Figure 1). After passing under a magnetic drum for a final cleanup, the ferrous metals are transported to the Granite City Steel Company, Granite City, Illinois, in trucks owned and operated by the City.

The densifier and magnetic drum were added in the summer of 1973 to meet the market specifications of the steel industry (*see* Markets). Before this equipment was added to the system, the magnetic metals removed from the waste stream were not marketable because of low density and impurities.

About 7 percent of the St. Louis waste stream is ferrous metal. By removing fuel and ferrous metal, the City of St. Louis has reduced its landfill volume requirements by 95 percent of the solid waste processed.

Unloading and Transfer at the Power Plant

The trailer trucks unload the fuel into a receiving bin, which is unloaded continuously into a pneumatic pipeline transport system (Figure 2). This part of the operation is owned and operated by the City.

Surge Bin and Firing System

The City's responsibility ends at the point where the City's pneumatic pipeline discharges the fuel into the utility's surge bin. The surge bin serves to smooth and distribute the flow of the fuel from each batch-type delivery into four continuously fed pipelines leading to the boilers.

The surge bin uses four drag-chain unloading conveyors to move the solid waste fuel to four separate feeders that introduce the supplementary fuel into the pneumatic pipeline system. The pipelines, each about 700 feet long, blow the fuel to firing ports in each corner of the boiler furnace.

Prior to air classification, larger and heavier particles have caused feeder blockages, and the glass caused serious wear to the pipelines, especially at the elbows. These conditions have required excessive maintenance and an operator to monitor the system. If the air classifier performs as expected, the system can be operated on an unattended basis with routine maintenance only.

BOILER MODIFICATION AND OPERATING EXPERIENCE

Boiler Modification

Two identical boilers (Units 1 and 2) at Union Electric Company's Meramec Plant near St. Louis have been modified to burn prepared solid waste. They are 125-megawatt tangentially suspension-fired boilers that were designed to burn pulverized coal or gas. There are now four coal-firing, one solid-waste-firing, and five gas-firing ports in each corner of each boiler.

Other than installing a solid-waste-burning port in each corner of the furnace, no modifications to the boilers were made. The refuse-burning ports were installed between the two middle coal burners. No alterations to the pressure parts of the boilers were necessary. (Pressure parts are the water/steam pipes that line the inside of the boiler walls.) The prepared solid waste is burned in suspension, in the same flame pattern as the pulverized coal or gas.

As is typical of large utility boilers, the furnaces have no grates. Fuels are burned in suspension at temperatures of 2,400 F to 2,600 F. The retention time of 1 to 2 seconds is not long enough for the heavier particles of combustible materials to be consumed, and they fall to the bottom ash hopper along with the noncombustible materials. Removal of heavier combustibles and noncombustibles by air classification is expected to result in more efficient combustion of the solid waste fuel.

The two boilers are 20 years old and are small compared to newer units in the Union Electric Company system. They are of modern reheat design, however, and burn 56.5 tons of Illinois coal per hour at rated load.

At rated load, the quantity of solid waste for each boiler, equivalent in heating value to 10 percent of the coal, is about 12.5 tons per hour, or 300 tons per 24-hour day. Solid waste will be fired 24 hours per day, but only five days per week, since City residential solid waste collections are scheduled on a five-day-per-week basis.

Boiler Operations

The boiler operators and shift superintendents report that solid waste firing has had no discernible effect on the boiler furnace or convection passes. (Convection passes are hot gas passages containing heat-transfer surfaces between the boiler furnace and the air pollution control equipment.) Frequent and sudden interruptions of the solid waste feed have not required any change in operating techniques. Existing boiler combustion controls easily accommodate the variations in solid waste quantity and quality by varying the amount of pulverized coal fired to the boiler.

The boiler's efficiency or power-producing capability when firing solid waste in combination with coal is essentially identical to the "coal only" performance.

Ash Content. The ash content (residue after burning) of raw refuse, including metallics, is about 25 to 30 percent. Without magnetic metals, the ash content is in the 20 to 25 percent range. Removal of the heavier nonburnable particles should reduce the ash content further, possibly to the 10 to 15 percent range. The ash content of Illinois bituminous coal, by comparison, is about 10 percent.

Slagging. There has been no indication to date from the St. Louis experience that solid waste fuel has any greater tendency to form slag (deposits of melted material) than does Illinois bituminous coal. The ash fusion (melting) temperatures of solid waste apparently are similar to those of Illinois bituminous coal. Utility personnel have voiced the opinion that the furnace appears to be cleaner when solid waste is fired in combination with coal than when coal is fired alone. Although the reason for this is not clear, it is known that paper forms a nonslagging dry ash and that glass and metals fall into the bottom ash hopper before the heat can affect them.

Carryover. There has been no evidence to date of any unburned materials being carried into the back passages of the boiler by the gas stream.

Corrosion Potential. As part of the testing program of the St. Louis project, probes have been inserted in the boiler to determine whether corrosion potential is any greater when solid waste is fired in combination with coal than when coal is fired alone. The results of these investigations are not yet available.

Odors. The shredding process homogenizes the wastes and tends to disperse the odor-producing materials to a sufficient degree to make odors far less noticeable than from unshredded waste. It appears that no further treatment such as deodorizing will be necessary.

AIR POLLUTION CONSIDERATIONS

Utility boiler air pollutants cause justifiable concern because of their potential health effects. The most significant pollutants are sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter. The use of solid waste as a supplementary fuel in Union Electric's coal-fired utility boiler will probably result in a reduction in SO_2 and NO_x air pollution emissions. It is believed that particulate emissions will be essentially unchanged. In-depth air pollution tests are planned to verify these expectations.

Sulfur Dioxide

Oxidization (combustion) of the sulfur contained in fuels such as coal and solid waste result in sulfur dioxide, a pollutant that is emitted from the boiler as a gas. The low-sulfur coal currently used in the Meramec boilers has a sulfur content of approximately 1.12 lb per million Btu of fuel value. By contrast the air-classified solid waste will probably have a sulfur content of approximately 0.5 lb per million Btu of fuel value. Using solid waste to provide 20 percent of the boiler heat input would result in an average sulfur content of 0.996 lb per million Btu. This sulfur content represents the maximum potential sulfur emissions that could be expected; actual emission levels are normally less because some sulfur remains in the boiler bottom ash or is collected as fly ash. Even the maximum potential sulfur emissions are significantly less than Federal and local standards (1.2 lb per million Btu and 2.3 lb per million Btu, respectively).

Nitrogen Oxides

Nitrogen oxides emitted in the boiler flue gases result from oxidization of nitrogen present in the air needed for combustion and, to a lesser extent, in the fuel. The quantity of nitrogen oxides formed generally increases as the temperature of combustion increases. Since the combustion temperature of solid waste is lower than that of coal, the nitrogen oxides resulting from burning solid waste in combination with coal should be less than when coal is burned alone. During the air pollution tests, measurements will be made to determine the amount of nitrogen oxides resulting from various ratios of solid waste to coal.

Particulate Matter

Particulate matter formed during the combustion process is carried out of the boiler by hot gases. Before leaving the 250-foot boiler stack, the gases pass through the electrostatic precipitator (ESP). Particulate emissions are controlled by using an ESP. In the ESP, the particles are charged by an electric field and collected on large electrically charged metal plates called electrodes. Periodically the accumulated dust, or fly ash, is knocked free from the

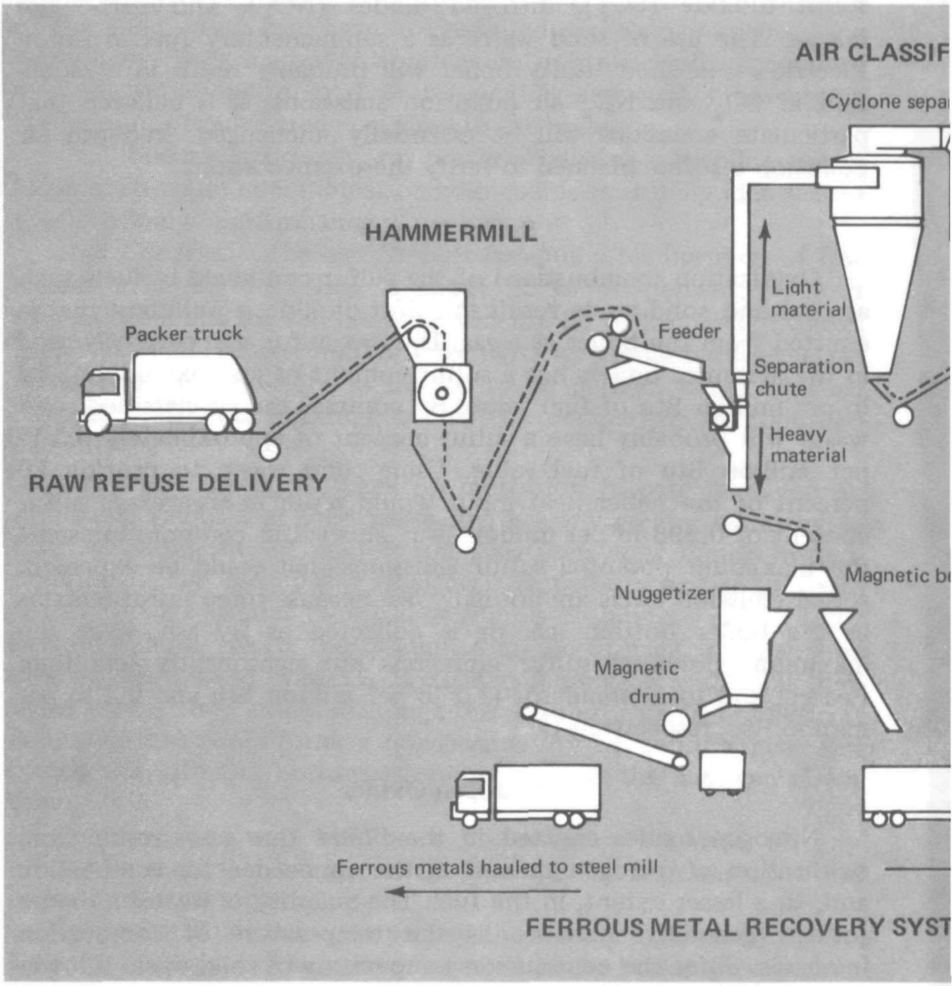


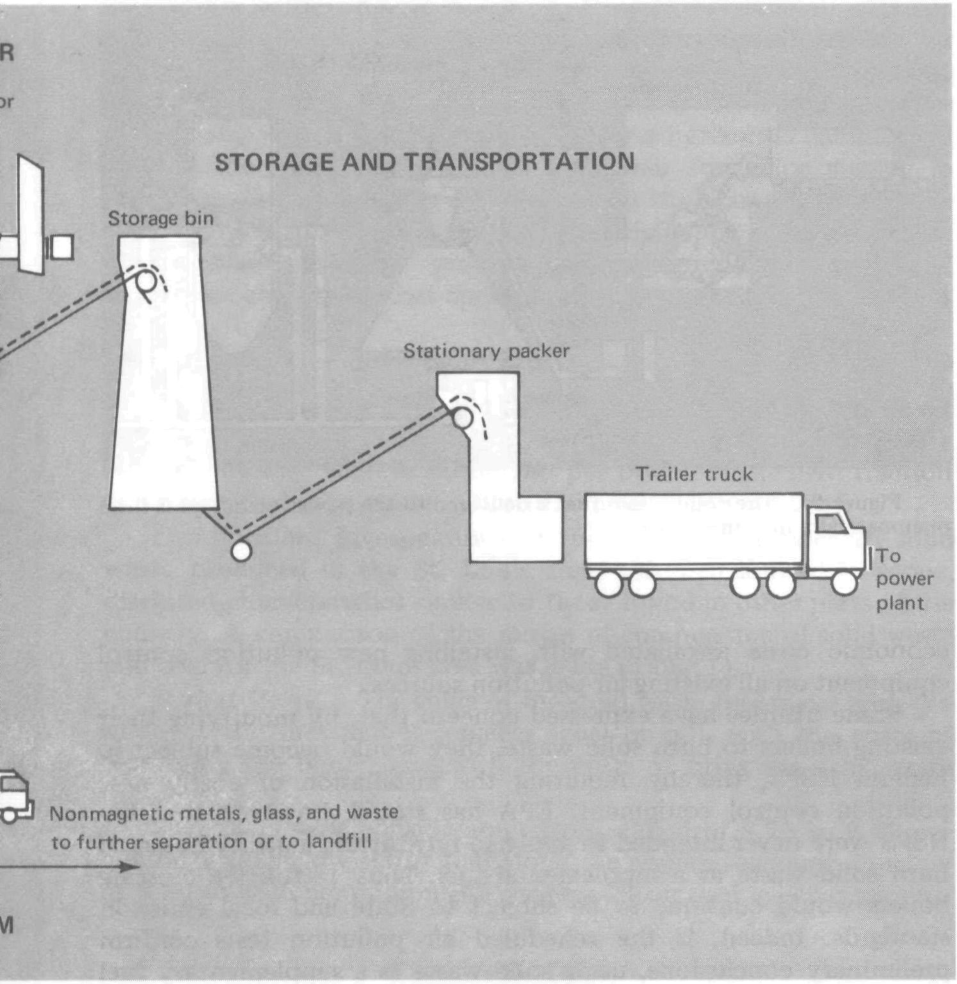
Figure 1. The fuel preparation and resource recovery system

electrodes and settles into hoppers in the bottom of the ESP. At scheduled intervals the collected fly ash is pneumatically removed from the hoppers and sold by the utility to the cement industry.

Based upon tests on incinerators and utility boilers, it is expected that the quantity of particles emitted from the boiler stack will probably remain essentially unchanged by using solid waste as a supplementary fuel.

New Source Performance Standards

To guard against possible health hazards from air pollution emission, Federal and local air pollution control agencies have established regulations to limit utility boiler emissions of SO_2,



eceives raw solid waste and produces fuel and ferrous metal.

NO_x, and particulate matter. Federal regulations, called New Source Performance Standards (NSPS) and written by the U.S. Environmental Protection Agency, apply to new utility boilers and older boilers modified in certain ways after the NSPS went into effect. Boilers that were already in existence when the NSPS went into effect are subject to local standards. These local standards are generally based upon emission levels needed to meet Federal ambient air quality standards and are often less strict than the NSPS. NSPS require the best demonstrated commercial control technology for new or modified boilers, while allowing local standards to determine the best mechanism to control emissions from older boilers to safeguard the public health, without the large

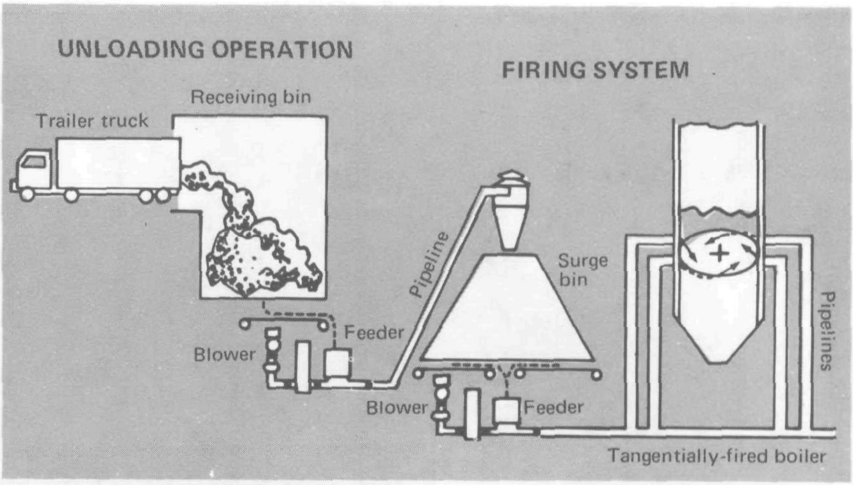


Figure 2. The solid waste fuel is delivered to the power plant and is fired pneumatically into the boiler.

economic costs associated with installing new pollution control equipment on all existing air pollution sources.

Some utilities have expressed concern that, by modifying their existing boilers to burn solid waste, they would become subject to Federal NSPS, thereby requiring the installation of costly new pollution control equipment. EPA has stated, however, that the NSPS were never intended to apply to retrofitting a utility boiler to burn solid waste as a supplemental fuel. Thus, retrofitted existing boilers would continue to be subject to State and local emission standards. Indeed, if the scheduled air pollution tests confirm preliminary conclusions, using solid waste as a supplementary fuel may enable some utility boilers to meet SO_2 and NO_x standards without having to install expensive air pollution control equipment.

MARKETS

The St. Louis demonstration resource recovery project recovers two products—fuel and ferrous metals. In addition, the fly ash and bottom ash, which historically have been sold by the utility, are expected to continue to have market potential.

No other products are being recovered. There are several reasons for this. First, recovery of other materials is beyond the original scope of the project, which was limited to demonstrating that solid waste could be prepared and fired as a supplementary fuel. (The separation of ferrous metals was originally intended only to improve the quality of the fuel.) Second, the quantity of nonferrous metals in St. Louis solid waste has not yet been determined. Third, the value of the glass fraction is limited by its particle size. Shredding the solid waste in a horizontal hammermill crushes the glass into particles too small for color sorting, a procedure that potentially could increase the market value of the glass. In other situations, however, depending upon the composition of the waste and the processing procedure, the recovery of aluminum, glass, and other materials might be profitable.

Fuel

Heating Value. The heating value of refuse is somewhat variable, depending mainly upon its moisture content. A generally accepted average value is 5,000 Btu per pound of the light fraction of air-classified solid waste as fired (10 million Btu per ton).

Composition. Investigations of the quality of residential solid waste produced in the St. Louis area, although limited in scope, disclosed characteristics similar to those found in other parts of the country. A comparison of the ranges of composition of solid waste and coal for the St. Louis area was made (Table 1).

Market Value. The value of the solid waste fuel varies with the value of the fuel that it replaces (coal or oil), with the costs of modifying the boiler, and with the costs of firing the solid waste fuel.

Fuel costs vary considerably, from a high of \$.75 to \$.90 per million Btu for low-sulfur fuel along the eastern seaboard, to a low of \$.20 to \$.25 per million Btu for high-sulfur coal in other regions.

Table 1

COMPOSITION OF RESIDENTIAL SOLID WASTE AND COAL SAMPLES BY WEIGHT AND BY HEATING VALUE*

	Percent of sample by weight		Heating value (lbs per million Btu)	
	Solid waste	Coal	Solid waste	Coal
Sulfur	0.1	3—4	0.2	2.6
Ash	20.0	10—11	43.0	9.0
Chlorine	0.3	0.03—0.05	0.6	0.03
Moisture	30.0	6—10	64.0	7.0
Btu per pound	Solid waste: 4,675		Coal: 11,300 to 11,900	

*Solid waste is from 210 samples of St. Louis residential waste, taken April 1972 through February 1973, as received, with magnetic metals removed. Coal is from three samples of Union Electric Company coals. No analysis has been made of air-classified solid waste.

Thus, the gross value of solid waste fuel at 10 million Btu per ton could be as high as $9 per ton in some areas and as low as $2 per ton in others. From this gross value the utility's incremental costs associated with firing the solid waste fuel must be deducted (*see* Economics). The resulting net value of the fuel can represent a significant economic benefit to a community. And because fossil fuel costs are increasing rapidly, the value of the solid waste fuel will increase accordingly.

Mutual Benefit. The net economic value of the fuel is not necessarily the price that the utility would be expected to pay for the fuel. The primary reason for this is that the recovery of fuel from solid waste potentially creates mutual benefits for both the community and the utility. Some benefits may be expressed in dollars; others may not. For example, the community can benefit from lower disposal costs, less air pollution, longer landfill life, and a possible alternative to unacceptable land disposal practices. At the same time, the utility can benefit from lower fuel costs, a reliable source of low sulfur fuel, and an opportunity to provide a community service.

In actual practice, then, the value of the solid waste fuel is established according to how the community and the utility perceive the possible benefits. Any price associated with the solid waste fuel must be negotiated.

Potential Markets. It has been demonstrated that solid waste can be burned as a supplement to coal in power plant boilers. But the concept appears to have even wider possibilities. Many utility personnel and boiler manufacturers believe that solid waste can be burned with oil or gas as well as coal. And electric power plants are not the only potential users. Markets for solid waste fuel can also be found in private industrial plants, where boilers burn fossil fuels for the on-site generation of steam for processing, heating, air conditioning, and power.

Magnetic Metals

The National Steel Corporation evaluated the magnetic metals recovered from the St. Louis waste stream to determine the suitability of that metal for use as scrap in steelmaking. The evaluation report, prepared by E. J. Ostrowski of National Steel Corporation's Research and Development Department, prescribed how the magnetic materials should be processed and recommended the material for use "both in the blast furnace and in the basic oxygen furnace to establish its use potential within the limits calculated from results obtained in the evaluation."

"The evaluation showed that a described bulk density of approximately 75 lb per cu ft can be obtained at a ring setting of one inch on the Eidal Mill. Magnetic separation of the scrap after the mill improves its chemical quality by removing some of the combustibles and some aluminum. The density and cleanliness of the scrap affects the yield obtained during melting as well as the water-absorbing potential of the scrap. The higher density material possesses better yields and retains less water." The average yield at the one-inch ring setting was 94.6 percent.

"The scrap residuals (contaminants) are primarily tin, aluminum, and lead. Carbon levels are high in the melts due to low oxygen levels of the 100-percent scrap melts. The combustibles present form carbon which is absorbed by the metal. The copper level of the scrap is low because it has received no thermal treatment prior to magnetic separation. Tests conducted in the electric arc furnace on melts in excess of 800 pounds showed the residuals to be slightly below the mean value of the levels obtained on the small induction furnace melts. Use of the mean value to calculate use limits should provide a margin of safety for melting steel grade specifications."[2]

Specifications. The following specifications were recommended by National Steel Corporation: (1) The scrap is to be processed in an Eidal Mill or equal at a ring setting of 1 inch followed by magnetic separation; (2) the product is to have a bulk density of 75 lbs per cu ft regardless of the ring setting noted above; (3) the product is to be free flowing, free of greases, oils, paints, and water; (4) scrap from no other source is to be added to the stream. This will avoid changes in chemical composition which could be detrimental to the steelmaking operations.

Contract. The City of St. Louis and the Granite City Steel Company, a subsidiary of National Steel Corporation, signed an agreement on May 1, 1973, for the sale of 3,750 gross tons of prepared ferrous metallic scrap at a price of $20 per gross ton, f.o.b. steel mill. The ferrous scrap will undergo long-term evaluation in the steel mill's blast furnace.

Market Value. It is estimated that ferrous metal like that recovered from the St. Louis solid waste stream will command a price ranging from $13 to $20 per gross ton, f.o.b. steel mill. Depending upon transportation costs, the net revenue to a city will range from zero (when the shipping costs equal the price) to almost $20 per gross ton (2,240 pounds) of scrap (when the processing facility is located next to the steel mill). Based upon a $20 per gross ton selling price and $3 per gross ton transport cost, the revenue

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[2] Ostrowski, E. J. Evaluation of Eidal mill processed solid waste ferrous scrap from St. Louis, Missouri, solid waste recovery system. Weirton, West Virginia, National Steel Corporation Research and Development Department, January 7, 1973. 18 p. (Unpublished report.)

derived from the sale of the nuggetized ferrous metal is equivalent to about $1 per ton of raw solid waste.

Fly Ash and Bottom Ash

Fly ash is fuel ash that is carried out of the boiler and collected by the electrostatic precipitators. The utility has been selling its fly ash to a cement manufacturer. Firing solid waste as fuel has not affected the quality of the fly ash, and the cement manufacturer continues to purchase it.

The coal bottom ash has been used by the Missouri State Highway Department on snow-covered roads. After unclassified solid waste was burned in the boiler, the bottom ash contained large particles of metal, wood, plastics, and other materials, making the bottom ash unsuitable for application on roads. The air classification is expected to improve the quality of the bottom ash.

ECONOMICS

The processing of solid waste into a fuel promises, on the basis of one year's start-up experience in St. Louis, to be an economically attractive solid waste disposal option. Although primarily a volume-reduction process, this concept can be evaluated as a disposal system when the cost of residue disposal is included.

Economies of Scale

The use of solid waste as supplementary fuel in power plant boilers obviously becomes more economically attractive as larger quantities are processed and fired. There is a practical upper limit, however, to the quantity of raw solid waste which reasonably can be handled at one site. This upper limit is on the order of 1,500 to 2,500 tons per day, depending upon the method of delivery. Vehicle traffic and unloading time are the primary determining factors. For example, it would be easier to handle larger quantities of waste by barge or pneumatic pipeline than by packer truck.

The capacity of available equipment imposes a further constraint: a reasonable upper limit to the capacity of a single processing line is about 125 tons of raw solid waste per hour, or 2,000 tons in a 16-hour operating day. To handle more waste at a single site, parallel processing lines could be used.

There is also a practical lower limit to the capacity of a single processing line. The size of the object or bundle of raw waste to be processed is more important than the required throughput in determining the size of the milling equipment. The minimum throat dimensions of the feed hopper should be about 4 feet square. When shredding normal residential solid waste to particle sizes of 6 to 8 inches, the throughput of such a mill would be about 30 tons per hour.

Under normal circumstances, it is considered advisable to operate a single processing line no more than 16 hours per day to allow 8 hours for routine maintenance, such as retipping the hammers in the hammermill.

Capital and Operating Costs

Capital and operating costs fall into three main categories: processing, transporting, and firing at the power plant. All such costs are variable, depending upon the circumstances (Table 2).

Processing Facilities. Processing facilities normally would consist of those required to receive, convey, mill, classify, and prepare the solid waste for shipment to the utility. The capital cost and in turn the operating cost of such facilities depend upon the operating schedule and the required throughput. In some cases, it may be appropriate to process the solid waste during only one working shift. The processing requirements in other cases may dictate two-shift operation.

The capital cost per ton of daily capacity is often used as a guide to estimate the capital cost of solid waste disposal operations. Assuming a 16-hour-per-day operation, with processing facilities including two-stage milling and air classification, a 30-ton-per-hour facility may be expected to have a capital cost in the range of $3,500 to $4,500 per ton of daily processing capability. A 125-ton-per-hour facility may be expected to have a capital cost of $2,000 to $3,000 per ton of daily processing capability.

The cost to the community varies with the method of financing the project. And the method of financing is directly related to the ownership and management arrangement that is selected. To illustrate the effect of the financing method, the capital costs per ton have been calculated to include the cost of money.

Six typical financing alternatives are discussed in more detail below. It is important to remember, however, that the effect of the financing alternative on the cost to the community is so significant that the financing mechanism must be designed as early in the project's planning stages as possible.

Operating costs for comparable processing facilities also may vary widely, with the principal variables being labor, maintenance, and utilities. Operating labor costs will depend upon labor rates as well as labor practices. The same variables apply to maintenance. Power costs depend upon the applicable rate structure. Reasonable ranges for the operating costs of processing facilities are illustrated in Table 2. These costs include the recovery of magnetic metals. If markets exist, revenues from the sale of ferrous metals can be as high as $1 per ton of raw solid waste.

The costs we have projected are intended only as guidelines. In specific circumstances, actual costs may be higher or lower than the costs presented here.

Transport Facilities. Even greater variability can be expected in the cost of transportation of the supplementary fuel from the processing plant to the power plant. The least transportation cost will occur when the two facilities are located near each other so that the material can be conveyed by pneumatic pipeline or

Table 2

PROJECTED COSTS FOR A DRY SUPPLEMENTARY FUEL SYSTEM*

	Smaller systems (30 tons per hour)	Larger systems (125 tons per hour)
Processing facilities†		
Capital cost, per ton of daily capacity	$3,500 to $4,500	$2,000 to $3,000
Capital cost per ton‡		
Typical public financing	$1.40 to $1.80	$ .80 to $1.20
Typical private financing	$2.20 to $2.90	$1.30 to $1.90
Operating costs per ton	$4 to $6	$3.50 to $5.50
Transportation facilities, including amortization		
Simpler cases	$.50 to $1 per ton	
Complex cases	$5 to $6 per ton	
Firing facilities		
Capital cost, per ton of daily capacity	$3,000 to $3,500	$2,000 to $2,500
Operating costs, including amortization		
Favorable circumstances	$.50 to $1 per ton	
Less favorable circumstances	$2.50 to $5 per ton	

* For discussion of projected revenues for fuel and magnetic metals, *see* Markets.

†Basic parameters of the processing facilities: two-stage milling, with air classification after the first hammermill; two 8-hour shifts per day, 250 operating days per year; land costs are not included; residue disposal cost is not included.

‡Typical public financing reflects a 6-percent cost of capital over a 15-year life. Typical private financing reflects a 10–percent cost of capital over a 10-year life. A shorter life is used in the private sector to assure the desired return on investment.

conveyor belt. Substantially higher costs will result when transport by truck, rail, or barge becomes necessary. Total transport costs obviously will depend upon individual situations, and could be as low as $0.50 to $1 per ton when the processing and power plants are adjacent to each other. Where the two plants are far apart, the costs of transportation could be as high as $5 to $6 per ton. As a typical example, if truck transport over high-speed highways is available, transport costs will approximate 7 cents per ton-mile of one-way distance. All of these figures include amortization of capital equipment. Each situation requires individual consideration.

Firing Facilities. The factors affecting the costs of firing solid waste as supplementary fuel include the type of boiler to which the process is applied, the type of normal fuel, the method of firing, and the configuration required for the firing system. Other factors include the means of ash disposal, labor practices, and amortization practices. It normally would be expected that the capital costs of the firing systems would be borne by the utility, since such systems usually would be installed on the utility's property. At least a portion of the operating costs would be borne by the utility for the same reason.

The costs of adapting a tangentially-fired boiler normally may be expected to be minimal because such units often may permit the insertion of solid-waste-firing ports without modifying pressure parts. Horizontally-fired boilers usually may be expected to require such pressure part modification, with correspondingly greater cost. Cyclone-fired boilers would require different treatment, conceivably by introducing the solid waste along with crushed coal, or pneumatically along with a portion of the combustion air.

Short-term solid waste storage facilities, along with pneumatic firing systems, may or may not appropriately be located on the utility's property. The length and configuration of the pneumatic pipelines will significantly affect the capital cost.

The principal factors which normally would have the greatest effect upon operating costs of firing facilities are the type of normal fuel and the means of ash disposal. If the solid waste fuel were fired in combination with pulverized coal, the additional operating costs would probably be moderate, since the labor required for ash handling and disposal probably would be the same whether the solid waste fuel were fired or not. However, if the solid waste fuel were fired in combination with oil or gas, the ash handling and disposal costs would essentially all be attributable to the ash resulting from the burning of solid waste.

Under the most favorable circumstances, it is possible that the solid waste fuel-firing costs would be as low as $0.50 to $1 per ton, including amortization. This would most likely be the case where the modified boiler is tangentially fired with coal and has bottom ash and air pollution control devices. Under less favorable circumstances, the equivalent costs could be on the order of $2.50 to $5 per ton.

Trends in the Cost of Traditional Waste Disposal

The decreasing availability of land for close-in landfills will undoubtedly tend to push communities toward more costly disposal methods such as incineration and remote landfill. Open dumping, which may appear to be the least expensive practice in terms of disposal cost, and which is still the most common practice, will no longer be allowed in many areas as enforcement of land disposal regulations becomes more vigorous. At the same time, stricter air emission standards have already increased the cost of conventional incineration. Overall, recovery of energy and materials from solid waste will become economically more attractive over time as the costs of alternative disposal methods rise and as the Nation puts a price on factors such as protecting the environment and conserving natural resources.

SOME ALTERNATIVES TO THINK ABOUT

Q *If I want to consider this system for my community, what issue should I look at first?*

A Markets for fuel. Markets for recovered products are critical to the success of any resource recovery system.

Q *Where are the markets for solid waste fuel?*

A Both utilities and private industrial plants are potential customers for solid waste fuel. The most important prerequisites are that their boilers have ash-handling capabilities and that they be located within an economical transport distance.

Q *Are any communities looking at implementing a solid-waste-as-a-fuel system?*

A Yes. At least five cities and utilities are publicly committed to fuel recovery from solid waste. The Connecticut State Solid Waste Management Plan has identified energy recovery as its principal component. At least 25 other utilities and seven private industries have expressed an interest in using solid waste as a fuel.

Q *How much of the fuel is replaced by solid waste?*

A Although the system in St. Louis was originally designed to replace 10 percent of the coal with solid waste fuel on the basis of heating value, the system operated well at a 15 percent replacement rate. Utility personnel say that 20 percent is realistic. Further testing is planned to determine the maximum percentage of the fuel that can be replaced by solid waste.

Q *Union Electric Company has been burning solid waste fuel as a supplement to coal in tangentially suspension-fired boilers. Are there any other possibilities?*

A It appears that solid waste can be used economically as a fuel in any boiler that has bottom ash-handling and particulate emission control facilities. This includes front-fired, opposed-fired, cyclone-fired, and stoker-fired boilers. It also includes boilers currently burning gas or oil.

Q *This system is applicable only to large cities. True?*

A Not necessarily. Depending on local conditions, energy recovery may be the best alternative in smaller communities as well as large. The critical conditions are alternative disposal costs, the availability of a boiler, alternative fuel costs, and public opinion about resource recovery.

Q *What about bulky wastes?*

A The capability of a fuel-processing plant to accept bulky wastes is simply a function of design. Shredders and conveyors must be sized to handle larger materials. Any noncombustible or oversized material will be separated from the waste fuel by the air classification process. In general, bulky wastes add little to the heating value of the fuel.

The luxury of disposing of both bulky wastes and municipal wastes at the same facility must be weighed against the added cost to the shredded fuel system.

Q *Why should I process solid waste into fuel if sanitary landfilling is less expensive?*

A If sanitary landfilling is less expensive, then you probably should continue to landfill. However, some communities have indicated that noneconomic factors are important, too, even at a premium in cost. This is not so surprising as it first appears. For example, if the additional disposal cost per ton is $3, the average person would have to pay only $3 more per year. The environmental benefits may be worth the small extra cost. Moreover, the recovery of energy at a time of energy shortage is sure to provide a real community benefit.

Q *How much energy can be recovered from solid waste?*

A The potential energy available from solid waste is significant. If energy recovery were practiced in all urbanized areas in the United States, an estimated 800 trillion Btu's could be utilized annually by 1975. Solid waste is a growing energy source: by 1990, an estimated 1.2 quadrillion Btu's will be available from residential and commercial solid waste in urbanized areas.

In comparison, the potential energy in urbanized areas in the solid waste generated in 1970 in urbanized areas could have supplied two-thirds of the Nation's residential and commercial lighting needs, or about one percent of the Nation's total energy consumption.

Financing Alternatives

Q *Like any capital-intensive high-technology project, an investment in solid waste processing facilities involves some risk. How can this risk be defined?*

A There are three forms of risk exposure.

1. Risk that the town and its economy will not generate the predicted waste stream.
2. Risk that a future technological breakthrough will render the present system obsolete.

3. Risk that the proposed plan incorporating technology, financing, and operating structure cannot meet its predicted performance.

Q *How does one deal with the waste generation risk?*

A There is essentially no waste generation risk if the system provides a disposal alternative at a competitive dump fee. If a close-in sanitary landfill site is not available, and if open dumps are prohibited, then there will be no cost-competitive alternative for disposal other than the resource recovery system.

Q *How does one deal with the risk of obsolescence?*

A Milling of solid waste is applicable in many resource recovery technologies. The risk therefore is limited to the end use of the organic fraction. This kind of risk is inherent in any long-term venture.

Q *How can the risk of performance, the ultimate financial risk, be assigned?*

A The financial risk can be assigned in a variety of ways, depending upon the financing arrangement. There are basically six alternatives:

1. *Town bears complete risk.* Here the town raises funds through general obligation bonds and directly or indirectly operates the facility.
2. *Town indirectly bears complete risk.* Here the town would raise funds through revenue bonds with debt service guaranteed by the town. Some "Authority" would be the financing vehicle and a public or private concern would be contracted for operation over a long term.
3. *Contractor/operator bears complete risk.* Contractor/operator finances by his own means the construction and operation of the system on the basis of a long-term contract from the town.
4. *Contractor/operator and revenue bondholders bear complete risk.* Here the town would raise special revenue bonds secured solely by revenues from the operations or first lien on the financed facility, or both operations and first lien. Revenue bondholders would have indirect control over operation.
5. *Revenue bondholders bear complete risk.* As in alternative 4, the town would raise special revenue bonds secured solely by revenues from operations or first lien on the financed facility or both. Revenue bondholders through an agent would have control over the operation.
6. *Bondholders and equity investors and contractor/operator bear*

complete risk. This would be essentially the same as alternative 5, except that bondholders may want equity investors seeking tax advantages to bear some of the risk. The return to equity investors would, for the most part, result from the investment tax credit and accelerated depreciation provisions of the tax law.

The cost to the community varies with each financing alternative. Each community must assess its own opportunities. It bears repeating that the effect of the financing alternative on the cost to the community is so significant that the financing mechanism must be designed as early in the project's planning stages as possible.

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