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ENVIRONMENTAL IMPACTS
OF RESOURCE RECOVERY FACILITIES

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INTRODUCTION

The issue of solid waste disposal is increasingly becoming a dilemma in many areas of the United States. Existing landfills are quickly reaching full capacity, and the number of new sites available for safe landfilling is diminishing. Furthermore, public opposition to the proposal of such new sites is becoming an obstacle that is difficult to overcome. Thus, many municipalities are looking toward an alternative means of waste disposal: resource recovery. The general function of resource recovery is to separate, extract and recover useable materials or energy from the municipal solid waste stream. Consequently, resource recovery not only offers an alternative means of disposing solid waste, but can supplement energy and natural resource supplies, and reduce the costs of solid waste management, as well.

A number of waste to energy processes are employed by resource recovery systems. These include incineration of raw or processed refuse to generate steam, or thermal and mechanical processing of refuse to produce a fuel product. Marketable materials such as glass, aluminum, or ferrous metals can be separated from the waste and recycled. As with any other power or industrial process, the practice of processing and converting refuse to energy does have an impact on the environment. The sources of environmental impacts include collection vehicles that deliver refuse to the facility, operations taking place within the facility,

and waste products generated by the plant itself. This report explores the potential environmental and health impacts associated with many facets of resource recovery facilities.

RESOURCE RECOVERY TECHNOLOGIES

There are a variety of operations involved in the processing and conversion of municipal solid waste to usable materials and energy. The operations entail the movement of waste, extraction of usable materials, separation of different waste components, alteration of the waste character, and conversion to energy or a fuel product. Refuse energy technologies may be grouped into four general categories (McGowin, 1985):

1. Combustion of unprocessed (raw) municipal refuse
2. Production and direct combustion of refuse-derived fuel (RDF)
3. Pyrolysis
4. Biological Processing

Some of these technologies have been successful in large-scale facilities. Others are still in the development stage and have yet to be demonstrated in full-scale operation. A brief overview of these technologies and of some of the more commonly used processing and conversion equipment are presented in this section.

Incineration

Incineration is defined as the controlled combustion of solid, liquid, and gaseous substances for conversion to primarily carbon dioxide, other gases, and a relatively noncombustible residue (Pavoni et al., 1975). It is considered second to landfilling as the oldest means of waste disposal. Primitive forms of waste incineration probably existed since primeval man first learned to control fire (Pavoni et al., 1975). This practice was probably more of an act of throwing waste debris on the fire to get heat rather than a direct means of waste disposal. In medieval times, waste was incinerated in fire wagons drawn by horses. As the wagons passed through the streets, people tossed their garbage into the fire contained in the wagon.

The first incinerators specifically designed to burn municipal solid waste were constructed in England in 1874. Batch destructors, as they were called, were ideal for cities since there was rarely very much landfill space within urban boundaries (Dudley, 1980). These incinerators spread throughout Great Britain and Western Europe in subsequent years. By the 1920's, incineration became the only large-scale method of waste disposal in England.

In the U.S., the first incinerator was built in 1885 on Governor's Island, NY Harbor. Two years later, the first grate-type incinerator was constructed in Des Moines, Iowa. The idea that use could be made from the heat released by combustion soon was realized. The first incinerator equipped with heat recovery using steam-raising boilers was

erected in Hamburg, Germany in 1896 (Dudley, 1985). Heat recovery systems soon arose in the U.S., and by the beginning of 1920, more than 200 incinerators existed with many generating steam for heat and electricity production. However, due to poor designs, unskilled operators, and low energy yield from refuse, facilities yielded poor results (Pavoni et al., 1975). Later designs still were largely concerned with waste disposal rather than energy recovery.

Today, incinerator technology has greatly improved mainly through the effort of Western Europe. Incinerators now have a greater efficiency and capacity to burn waste and to recover energy. The combination of waste disposal and energy recovery has become an attractive alternative to landfilling. More than 350 waste-to-energy incinerators exist worldwide with Japan and Western Europe using this technology most as a method of waste disposal (Peterson, 1985). The lack of land suitable for disposal, as well as a need for more energy, are primarily responsible for the prevalence of incineration with energy recovery in these countries.

Combustion of Unprocessed Refuse

Municipal solid waste (MSW) is burned in two general forms: as unprocessed, raw refuse; and after either shredding, or processing to form refuse derived-fuel (RDF). Energy conversion by direct combustion of unprocessed MSW is commonly referred to as mass-burning or bulk-burning. A list of some mass-burning systems in the U.S. appears in

Table 1. Facilities that burn unprocessed refuse are of two types--the large waterwall systems and smaller modular incinerators. A schematic drawing of a typical mass-burning system is depicted in Figure 1. The basic features of the facilities are: a tipping area; storage pit; equipment that charges the furnace; a combustion chamber and grate system; pollution control devices; and a boiler for energy recovery.

The trash received from delivery trucks is dumped on a tipping floor, or in a storage pit, which provides space for refuse storage and for removal of large noncombustible materials. The refuse is then transferred to a charging hopper using a crane, or a front-end loader. The charging hopper feeds refuse to the furnace, and maintains a continuous flow of fuel to the furnace chamber. The chamber is normally cylindrical or rectangular, and may consist of a single unit as in waterwall systems, or consist of primary and secondary units as in modular furnaces. Temperatures of incineration are usually kept at 900 to 1000°C (Diaz et al., 1982).

Combustion takes place on the furnace stoker, which consists of a series of grates with openings through which air can pass to sustain combustion. A variety of grate types are employed in waste-to-energy systems. The grates may either travel, vibrate, rock, or reciprocate. In many cases, the particular grate design defines the type of incineration system. Commonly used grate designs include the Von Roll system, the Martin system, and the

Table 1. A list of some mass-burning, waste-to-energy incinerators.

Location	Process	Capacity (TPD)	Product
Chicago, Ill. (NW)	Waterwall Incinerator	1600	Steam
Pittsfield, Mass.	Modular Incinerator	240	Steam
Saugus, Mass.	Waterwall Incinerator	1500	Steam & ferrous metals
Onondaga County, NY	Waterwall Incinerator	1400	Steam & ferrous metals
Washington County, NY	Modular Incinerator	240	Cogeneration of Steam and electricity
Westchester County, NY	Waterwall Incinerator	2250	Steam & ferrous metals
Harrisburg, Penn.	Waterwall Incinerator	720	Steam & ferrous metals
Nashville, Tenn.	Waterwall Incinerator	400/7 days	Steam
Rutland, Vermont	Modular Incinerator	240	Electricity
Hampton, Virginia	Waterwall Incinerator	1200	Steam
Newport News, Virginia	Modular Incinerator	40	Steam

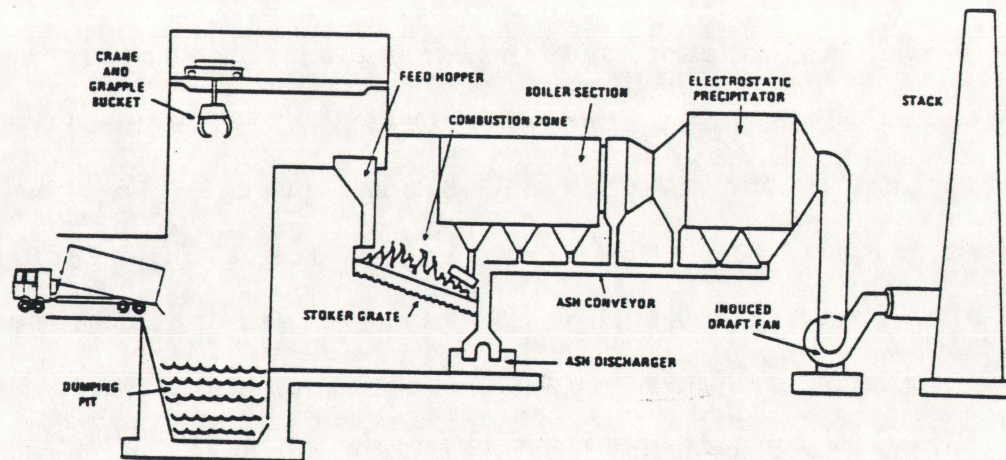


Figure 1. Schematic drawing of a typical mass-incinerator.

VKW grate system, which were all developed by European manufacturers, and a travelling grate system, which is manufactured in the United States (Figures 2 through 5). The grate movement mixes and agitates the refuse, facilitating both combustion and the removal of ash from the grates.

The heat generated from the burning waste is captured by a boiler system. Waterwall incinerators were the first waste incinerator systems designed for both efficient refuse combustion and energy recovery. They were developed in Europe in the 1940's, and became popular in the 1960's (Diaz et. al., 1982). The first large-scale unit (360 TPD) in the U.S. was built at the U.S. Naval Station in Norfolk, Virginia, and has been in operation since 1967. A waterwall incinerator consists of a single combustion chamber that is jacketed with water filled tubes. The flue gases rising from the burning waste heat the water in the tubes and generate steam. The steam may be used within the facility, or can be exported off-site to a nearby customer that uses the steam either for heating, cooling, or producing electricity. The water-filled tubes also help maintain stable combustion temperatures and reduce the temperature of the exhaust gases, thereby decreasing the volume of flue gas needing treatment for pollution control. Waterwall mass-burning systems range in waste capacity from 120 to 3000 TPD.

Modular incinerators are smaller than waterwall systems (Figure 6) burning up to 120 TPD, but multiple units may be installed to give a total capacity of up to 600 TPD. Modular

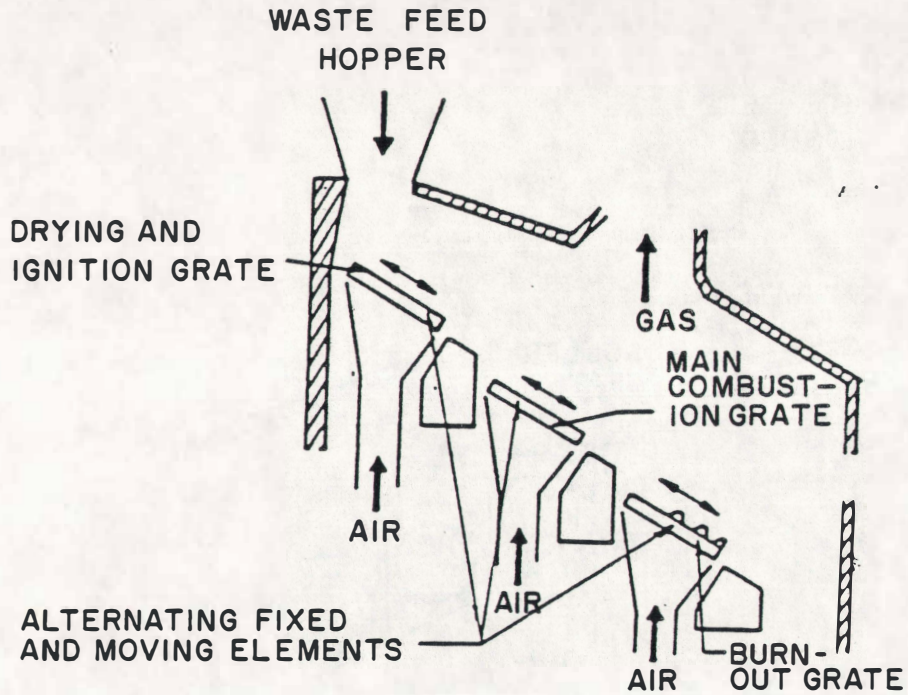


Figure 2. Reciprocating grate system (Von Roll System)

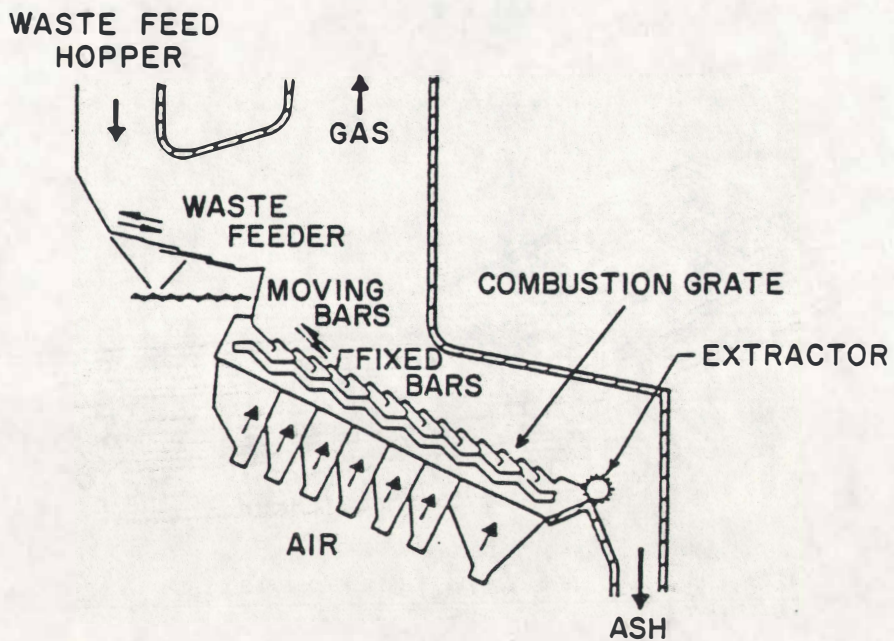


Figure 3. Reverse reciprocating grate system (Martin System)

Source: C.E. Brunner, 1985

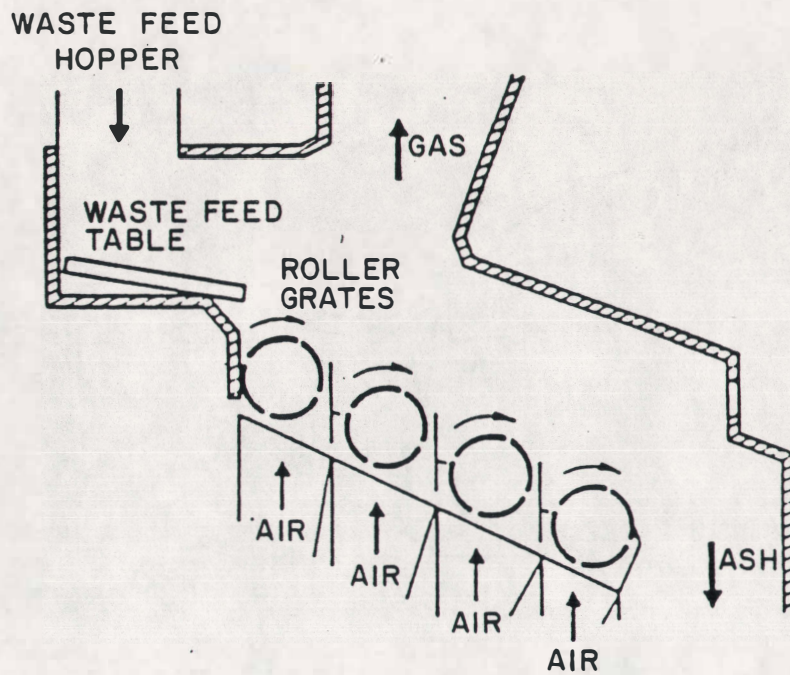


Figure 4. Drum grate system
(VKW System)

Source: C.E. Brunner, 1985

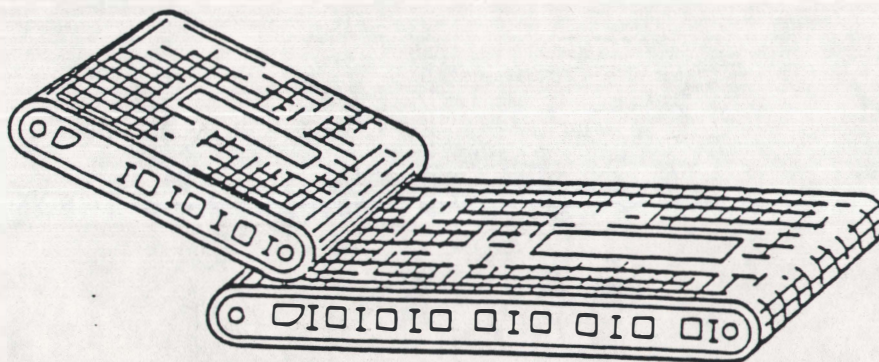


Figure 5. Travelling grate system

Source: Howard et al., 1984

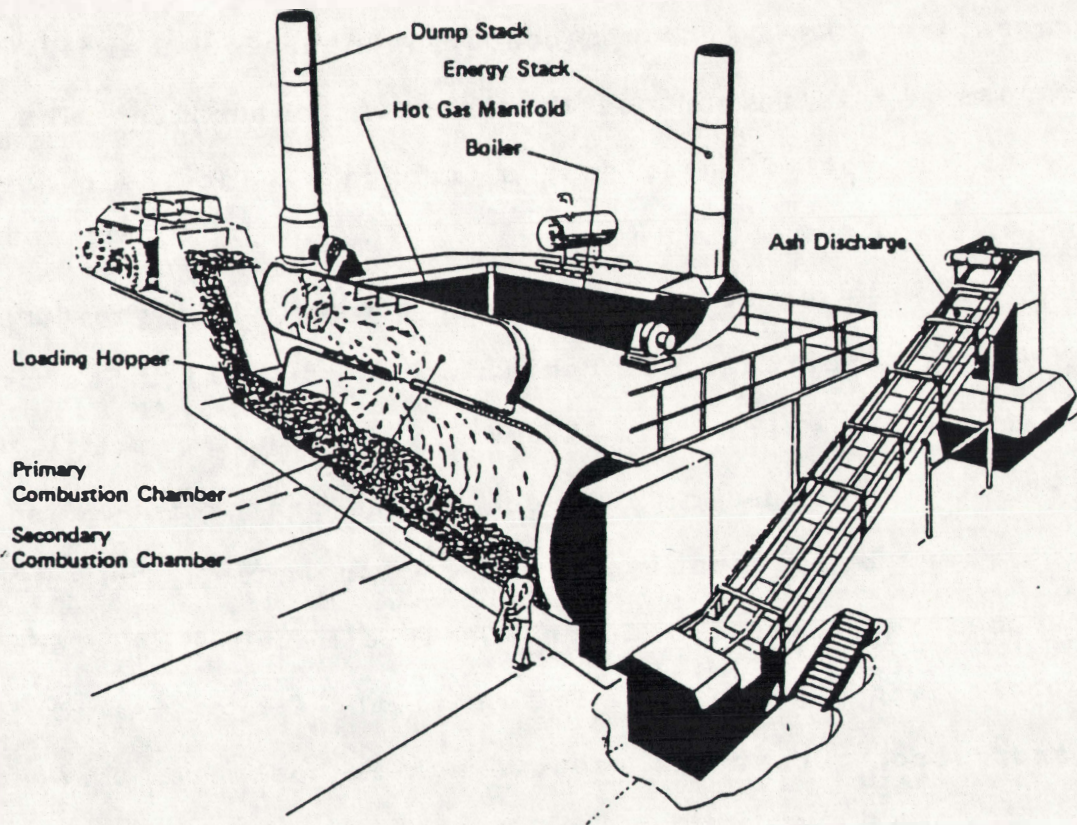


Figure 6. Modular waste-to-energy incinerator (from Diaz et al., 1982).

incinerators are also known as starved-air incinerators because refuse is burned in an oxygen-deficient environment. Waste is introduced into a primary refractory-lined furnace and is ignited under low oxygen levels. The combustion gases are passed into a secondary combustion chamber where excess air is introduced to complete combustion. The resulting hot effluent passes through a waste heat boiler to generate steam.

Not all waste is completely combusted in the furnace. There is a residual ash remaining on the grate. The ash is about 10% by volume and 25% by weight of the original refuse. It is dumped off the end of the grates into a storage pit where it is usually quenched with water. The ash may be further processed to recover useable metals (i.e. ferrous metals) and aggregates. The remaining ash ordinarily is landfilled, but may be used in making concrete, construction metals, embankments, and roadbase.

Refuse-Derived Fuel (RDF) Production and Incineration

Solid waste may be processed to make a refuse derivative of higher heating value (RDF). Refuse-derived fuel may be either directly burned in dedicated boilers, or burned as a supplement with coal or oil utility boilers. In the U.S., the first full-scale project using RDF was conducted by the city of St. Louis and the Union Electric Company in 1972 (Diaz et al., 1982). Many more RDF facilities have sprung up across the U.S. since that time.

A list of some RDF facilities that are either currently in operation or recently have been closed appears in Table 2.

There are different types of RDF. These include coarse RDF, fluff RDF, densified RDF, and wet RDF. Each form is a function of the type and arrangement of unit operations implemented in processing the refuse. A flow chart giving the sequence of unit operations in dry processing appears in Figure 7. The initial processing normally incorporates size reduction, magnetic separation of ferrous metals, screening or trommelling to remove small, dense material, and separation of light and heavy material by air classification (Diaz et al., 1982). In wet RDF processing, light and heavy material is separated using a hydropulper.

The general function of the size reduction step is to produce a homogeneous mixture that is more easily controlled. Refuse typically is shredded into 10 to 15 cm diameter fragments in the primary shredding step. One of four different types of shredding equipment may be used. These include hammermills, drum pulverizers, crushers, and wet pulverizers. Hammermills are the most widely used in dry processing operations, perhaps because of their versatility. Hammermills shred refuse by high-speed rotation of a rotor and attached hammers. The rotor may be oriented horizontally or vertically (Figure 8). Shredders are generally noisy equipment, expensive to operate, and subject to intense wear as well as damage by explosions from materials such as discarded gas containers and explosives.

Extraction of ferrous metals (iron and steel) from the

Table 2. Status of selected RDF facilities in the U.S.

Facility	Capacity (TPD)	Process	Product
Lakeland, Fl	300	Shredding and magnetic separation-burning RDF with coal	Steam and electric production-ferrous metal sold
Ames, IA	200	Baling waste paper, shredding, mag. sep., air classifying and screening	RDF used in a utility boiler, baled paper, ferrous and non-ferrous metal sold
Haverhill/ Lawrence, MA	1300	Shredding, magnetic separation, trommel screening	RDF burned to generate steam and electricity
Baltimore County, MD	1200	Shredding, magnetic and mechanical separation	RDF, ferrous and glass sold
Albany, NY	2250	Shredding, magnetic separation-metals and aggregate recovered from ash	RDF burned in state office building boilers, recovered mat. sold
Monroe County, NY	200	Shredding, air class., froth flotation, mag. and mech. separation	RDF burned in a utility boiler, recovered mat. sold
Niagara Falls, NY	2000	Shredding, magnetic separation	RDF burned for steam and elec.-ferrous metals sold
Akron, OH	1000	Shredding, magnetic separation	RDF burned for steam and hot water prod.-for District Heating, ferrous metals sold
Colubmus, OH	2000	Shredding, magnetic separation	RDF burned for steam and elec. production, ferrous sold

<u>Shutdown Facilities</u>	<u>Capacity (TPD)</u>	<u>Process</u>	<u>Status</u>
Hempstead NY	2000	wet pulping, mag. separation, RDF for dedicated combustion	Contractural problems and strong community opposition over env. concerns. A mass-burn system is planned for the interior of the structure.
Bridgeport, CT	1800	Mechanical and chem. processing to produce "ECO-Fuel II"	Shutdown, under arbitration and litigation
East Bridgewater, MA	500	Mechanical and chem. processing to produce "ECO-Fuel II"	Shutdown, materials handling problems. Future uncertain.
Chicago, IL	1000	Shredding, air class. mechanical operation, RDF for use in boilers	Shutdown, past performance operations under evaluation. Future uncertain

(Source: City of New York-Department of Sanitation, 1985)

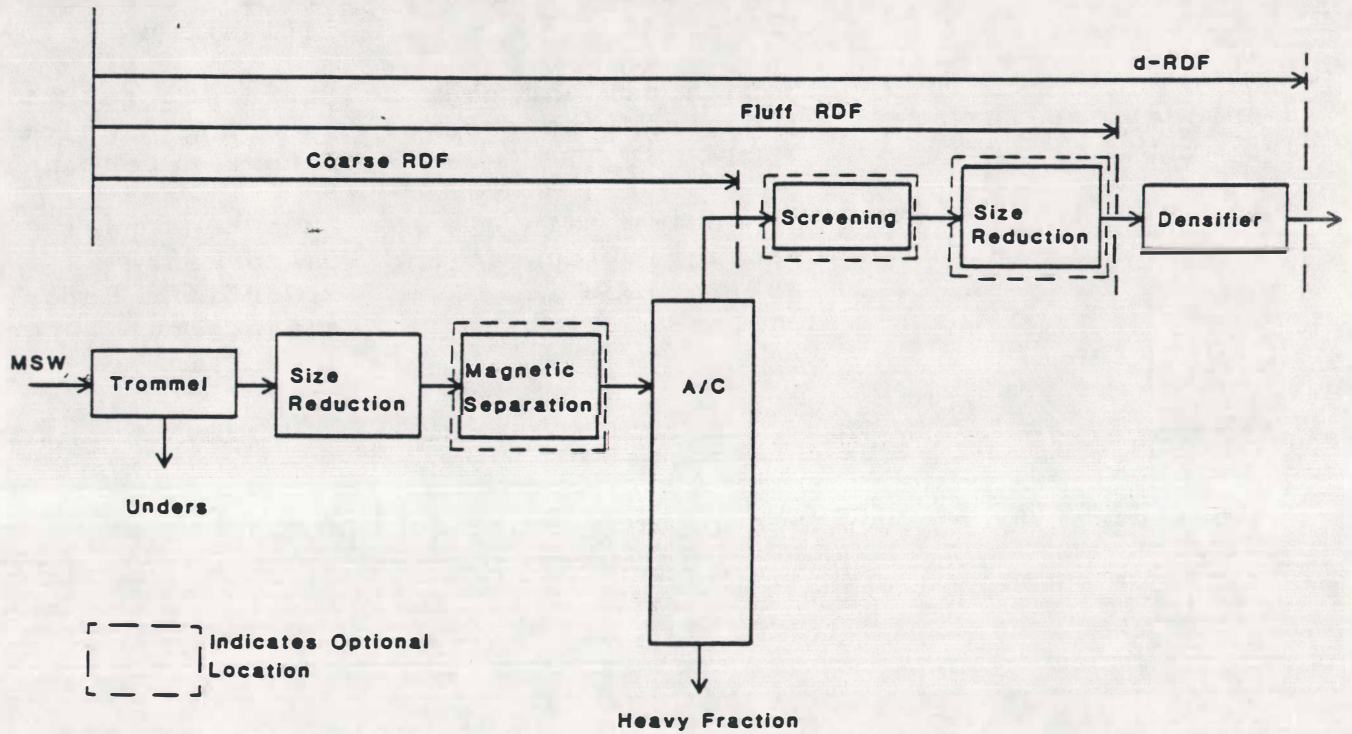


Figure 7. Typical sequence of unit processes for RDF production (from Diaz et al., 1982).

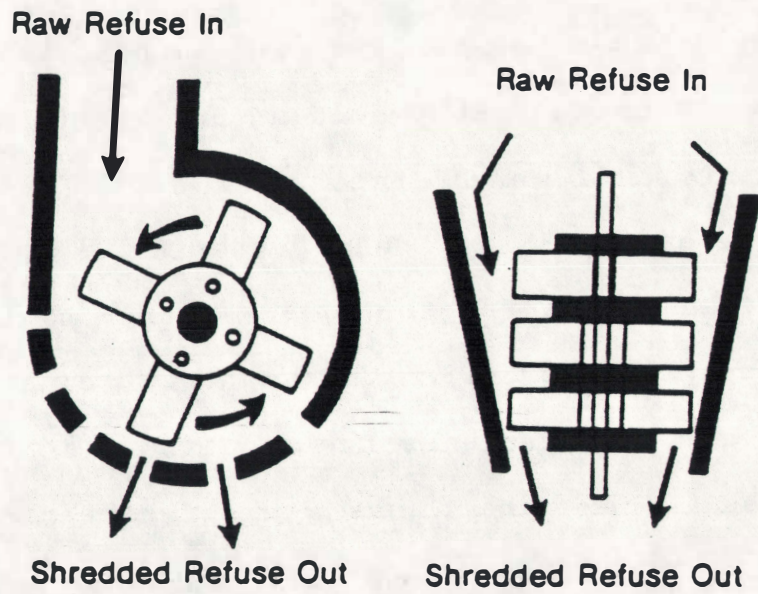


Figure 8. Horizontal and vertical shredder units (from Vesilind and Warner, 1980).

waste stream is accomplished by magnetic separation. The magnets may be the large permanent type or electromagnetic. They may be arranged in several different configurations (Figure 9). The magnetic drum is an electromagnetic assembly mounted inside an outer rotating drum. The drum can be suspended as an overfeed or underfeed system. The magnetic head pulley consists of a magnetic pulley mounted in a conveyor. The magnetic belt conveyor has magnets located between two pulleys that support the conveyor belt system. These magnetic systems have about an 80% extraction efficiency on a weight basis.

Screening small, dense material, such as grit, dirt, stones, and glass fragments, is another basic operation in the preparation of RDF. This material constitutes impurities that decrease fuel quality and cause slagging in furnaces. There are three types of screening devices: vibrating flat-bed screens, disk screens, and trommels. Of the three, trommels have been proven most successful (Figure 10). A trommel is a cylindrical screen consisting of either wire mesh or a perforated plate. The screen rotates and allows refuse to tumble, which facilitates separation of the fine particles. The trommelling step may be placed at the beginning of the processing line, or at the end, after air-classification.

Air classification, or air density separation, is another important operation in RDF production. Air classifiers separate heavy materials from the more combustible material contained in the light fraction (Figure

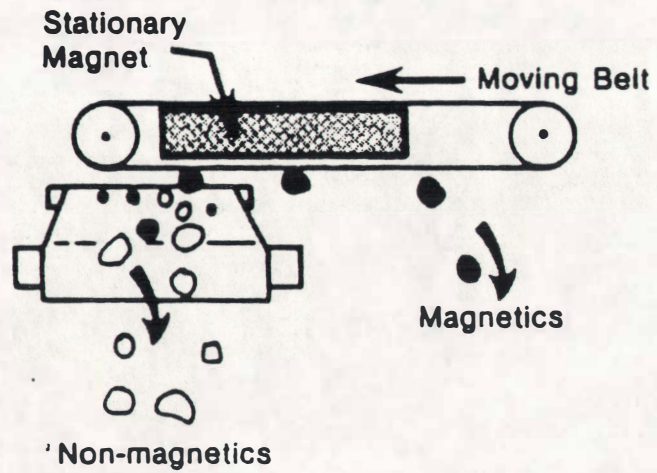
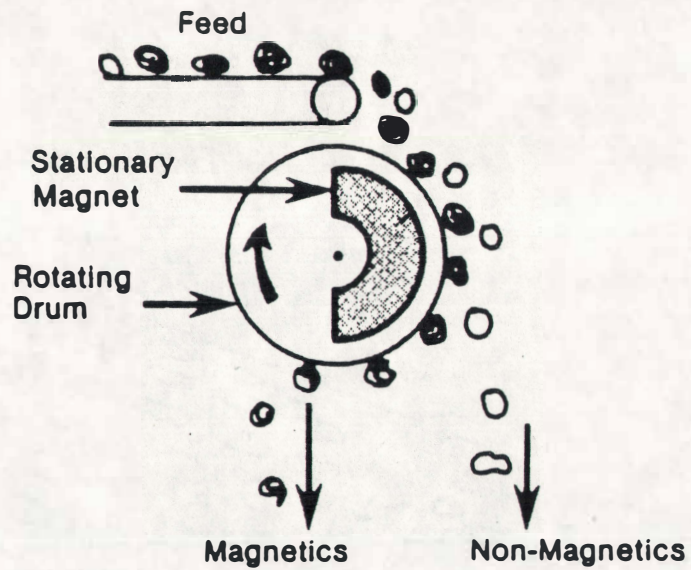


Figure 9. Magnetic extraction assemblies (from Vesilind and Warner, 1980).

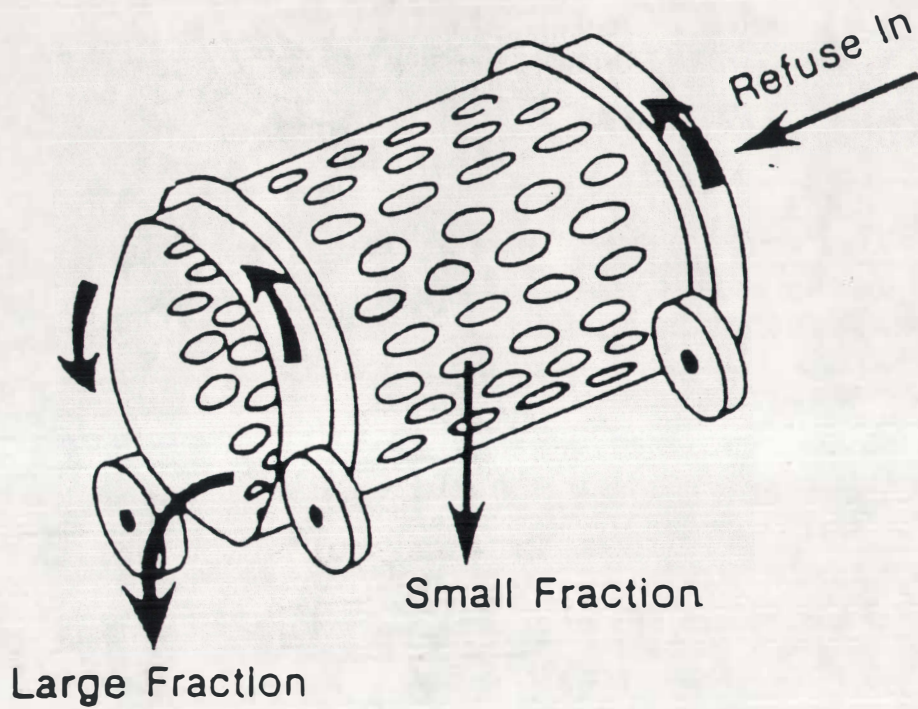


Figure 10. Trommel screen (from Vesilind and Warner, 1980).

11). The light fraction consists mainly of plastics, paper, wood, textiles, food wastes, and small amounts of light metals, whereas the heavy fraction is principally composed of metals, glass, and ceramics. Air classifiers may be horizontal, vertical, or inclined units. The vertical-type unit is most commonly employed. In this system, waste is introduced into a controlled vertical flow of air in which the light material is carried with the airstream through the unit, and the heavy fraction falls to the bottom where it is removed. The separation process is affected by many physical properties such as size, shape, aerodynamic characteristics, or specific gravity of the waste fragments, and also, the velocity of the air current in the unit. Air classifiers are second only to shredders in energy consumption. They can handle up to 80 tons of refuse per hour (Diaz et al., 1982).

The above unit operations make up the basic processing system in the production of "coarse" RDF. Further processing that includes another screening step and an additional size reduction step to decrease waste fragments to 2 to 3 cm diameter produces "fluff" RDF (Figure 12). Both types of RDF may be burned in dedicated boiler systems such as spreader stoker-fired furnaces, or semi suspension-fired furnaces (Figure 13). In these systems, RDF is ignited while falling through the chamber, and combustion is completed on the grate.

RDF may also be formed into pellets or cubettes by a densifier process. Densified RDF (d-RDF) has been used

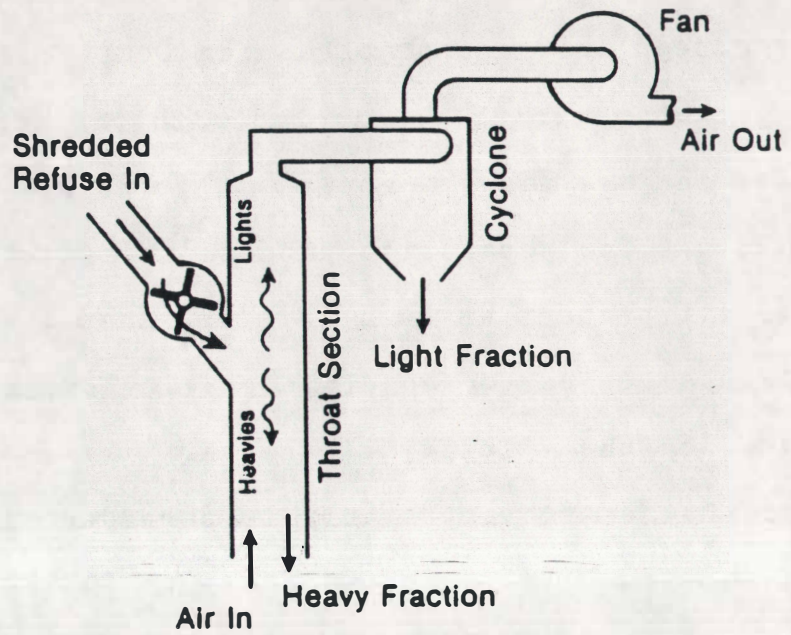


Figure 11. Vertical air classifier (from Vesilind and Warner, 1980).

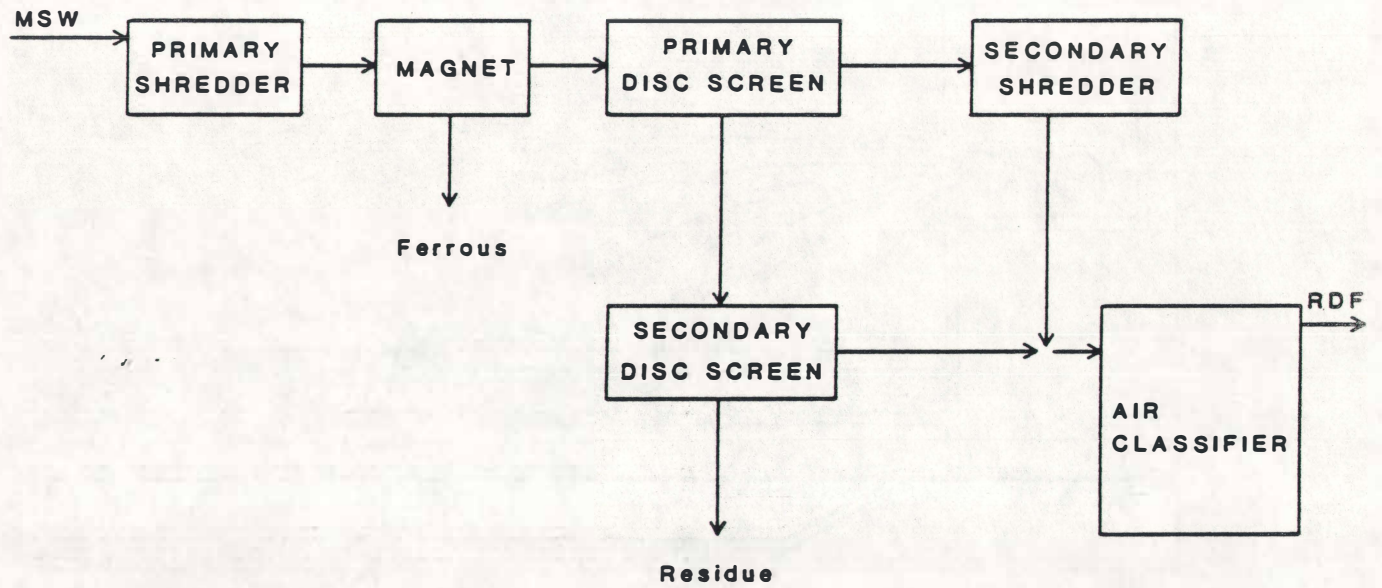


Figure 12. Flow diagram of RDF production at Ames, IA facility (from Diaz et al., 1982).

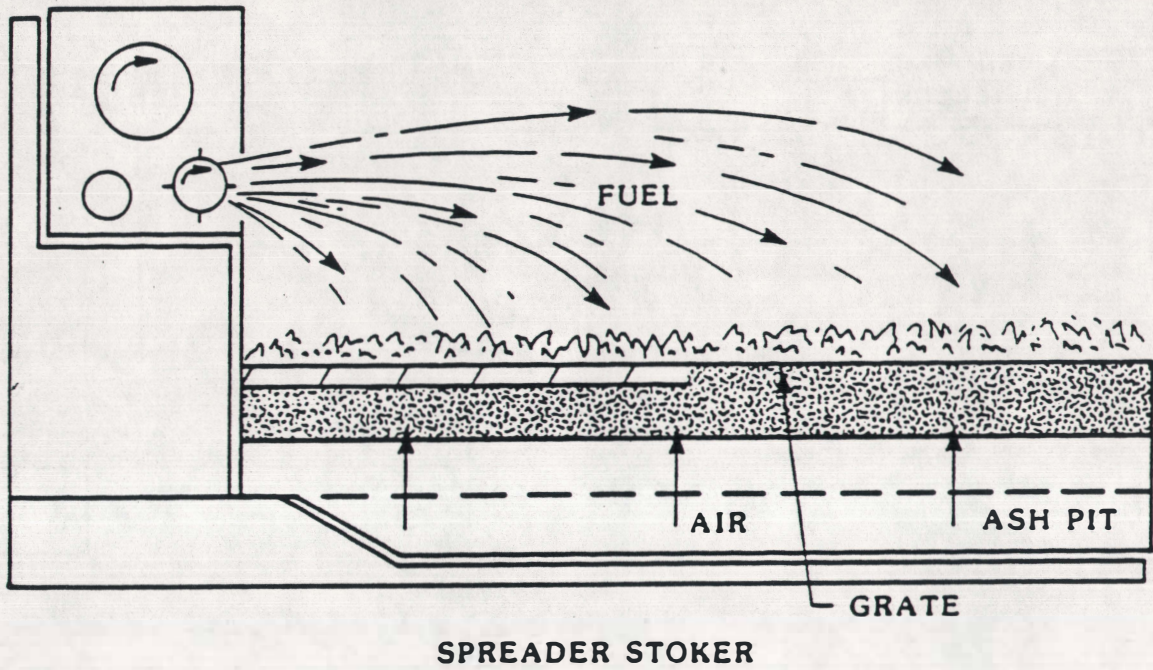


Figure 13. Spreader-stoker furnace (from Howard et al., 1984).

largely as a supplement to coal in stoker-fired furnaces and less often in suspension-firing. RDF is densified by either cubette or pellet mills. Densification is performed by the use of friction-driven rolls that force the RDF through openings in a rotating die. The extruded pellets or cubettes are then sheared by knives mounted on the inside of the die.

The use of refuse-derived fuel in incineration to produce energy has encountered problems due to varying particle sizes and composition; the containment of non- or poor-combustible materials; high moisture content; relatively high ash content; and lower heat value relative to conventional fuels such as coal and oil (Diaz et al., 1982; McGowin, 1985). RDF is roughly 60% of the heating value of coal. Heating values are approximately 5700 to 7000 BTU/lb. for refuse-derived fuel compared to 8000 to 12,000 BTU/lb. for various coal types.

Pyrolysis

Pyrolysis is a destructive distillation process in which either processed or unprocessed waste is decomposed by the action of heat under an oxygen-deficient atmosphere. In the presence of low oxygen levels, only limited combustion takes place. Instead, a complex series of decomposition and other chemical reactions occur producing gaseous or liquid products that can be used as a fuel for conversion to usable energy, or as chemical raw materials. The products are generally high in hydrocarbons such as methane, ethylene, or

propylene. The nature of the products is a function of the waste composition, pyrolysis temperature, pressure, and residence time in the pyrolysis reactor (Public Works Manual, 1985). Two other non-oxidative processes sometimes called pyrolysis are reduction and partial oxidation. Reduction involves the thermal processing of waste with either hydrogen or carbon monoxide. Partial oxidation is accomplished by the addition of appreciable amounts of oxygen or air in the heating chamber. This process yields large amounts of carbon monoxide, hydrogen, carbon dioxide, and water.

Pyrolysis has been used most successfully in converting wood to charcoal, and coal to coke. A number of different systems have been developed for MSW over the past decade or more. However, no full-scale operation has achieved commercial success due to a variety of technical and economic problems (City of NY-Dept of Sanitation, 1985). Presently, no major pyrolysis facilities are in operation in the United States. The only full-scale plant operating in the world today exists in Japan (Igarashi et al., 1984). The Japanese system employs a dual fluidized bed reactor (Figure 14) developed to pyrolyze organic solid waste and obtain a high calorific value fuel gas. Each reactor contains sand into which superheated steam is injected. The steam causes the sand to rise up and recirculate through the reactors. Solid waste is introduced into the reactor, mixed with the sand, and pyrolyzed. The organic material is

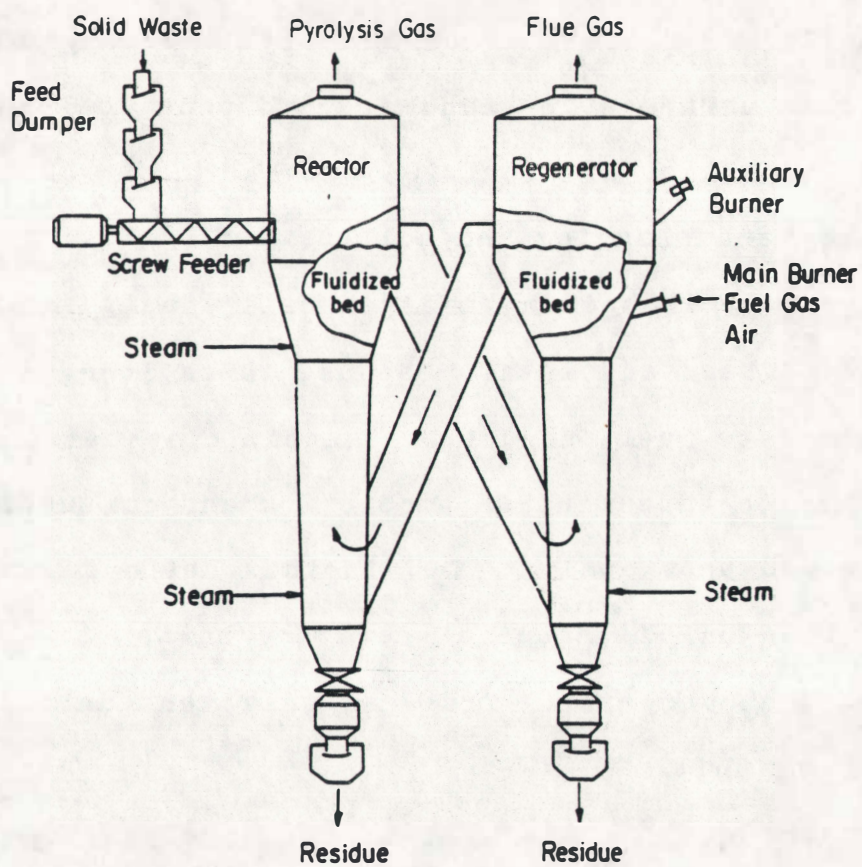


Figure 14. Fluidized bed reactor (from Igarashi et al., 1985).

pyrolyzed into three components: fuel gas, oil and tar, and char (carbon). Other systems developed in the U.S. include the Monsanto Langard system, Occidental Petroleum Company's flash pyrolysis system, Union Carbide Purox System, and the Andco Torrax System. Problems with these systems have included unfavorable economics and poor fuel quality, or other technical difficulties such as high pollutant emission levels, and slagging and boiler wear.

Pyrolysis systems are generally designed to separate and recover glass and metals because these inorganic constituents contaminate fuel products. The basic system components are similar to those in RDF production and combustion processes discussed previously. They include solid waste holding and size reduction units, material recovery units, the pyrolysis unit, energy recovery unit, flue gas treatment unit, and an ash handling unit.

Depending on the system, the pyrolysis process does generate many liquid, solid, and gaseous discharges that require management from an environmental standpoint. Air emissions result from production and combustion of pyrolytic fuel product. Liquid effluents arise from gas scrubber devices and from other treatments that improve fuel quality. Difficulties with air emission control appear to be less serious than those in incineration, because the volume of waste gases is smaller (Public Works Manual, 1985). Wastewater production and management, however, is a much larger problem in pyrolysis systems, because water usage is greater.

Biological Conversion Systems

Biological conversion systems promote decomposition of solid waste by bacterial action to produce combustible gases, such as methane. The technology is still under development and is yet to be implemented in a full-scale operation. A 200 TPD-capacity anaerobic waste digestion facility is currently being tested in Pompano Beach, Florida. Other hybrid systems that are in various stages of development are designed for hydrolytic conversion of cellulosic wastes (e.g. paper) to ethanol and conversion of refuse to alcohol.

Pollution Control Technologies

Pollution control is a critical component of all resource recovery systems. The need to meet strict emission standards has necessitated the implementation of efficient pollution control devices. The general types of devices used are electrostatic precipitators, wet and dry flue gas scrubbing systems, and baghouse filters.

Electrostatic precipitators (ESPs) are the most widely used devices for controlling particulate matter emissions. ESPs remove particulate matter from the flue gas by charging particles in a high voltage field and collecting them on an electrode of opposite polarity. The electrode is vibrated to discharge particles from its surface into a collection bin. ESPs have high collection efficiencies, although efficiency is lowest for the fine particle sizes (0.1 to 1.0

microns) (Howard et al., 1984). They require a large amount of space, and therefore, are housed outside of incinerators. ESPs also have high capital costs, although operation costs are low.

Wet scrubbers use a liquid that is either in an atomized spray, or coated onto an impaction surface, to remove particles and gases from the flue stream. These devices are particularly effective for removal of soluble gaseous pollutants such as HCL and SO₂. They are also adaptable to varying gas flow rates and characteristics. Disadvantages of wet scrubbers include a high energy requirement, and the production of a large volume of wastewater. Wet scrubbers also generate a visible plume of vapor from cooling stacks that is less easily dispersed in the atmosphere.

Dry scrubbers use an alkaline or caustic reagent to remove SO₂ and acid gases. A slurry of the reagent is injected as a fine mist into the chamber to react with the flue gas. The pollutants are absorbed on the surface of the droplets, forming neutral salts. The water in the droplets evaporates, leaving behind a dry powder that is easily collected. Removal efficiencies for SO₂ and HCL are 80-90% and 80-98%, respectively (Howard et al., 1984). One advantage of dry scrubbers is that large volumes of contaminated water are not produced. Wet or dry scrubbers may be used in combination with ESPs, since the latter is not effective for removal of gases.

Baghouses, or fabric filter systems, have only recently

been used in resource recovery facilities. A baghouse contains a filter bag that screens out and collects particles from the flue gas--much like a vacuum cleaner bag. The filter fabric is generally composed of fiberglass, which is coated with Teflon, silicone, or graphite applied singly, or in combination. The coating protects the fabric against abrasion and chemical attack. Baghouses are highly efficient at removing particulate matter--commonly having greater than a 99% collection efficiency (Carr and Smith, 1984). They also are successful at collecting very fine particles that escape collection in ESPs more easily. One disadvantage is that the filters may decompose when exposed to high temperature, high pressure, and acidic chemicals that are present in the gas stream. Baghouses also are expensive to operate.

ENVIRONMENTAL IMPACTS

Air Emissions

Waste-to-energy conversion facilities that process, pyrolyze, or incinerate municipal solid waste can have a negative impact on air quality. Air emissions from these systems include dust and odor generation during handling and processing of refuse, and particulates and gases released during the conversion process. An additional impact on air quality indirectly involved in a resource recovery system is the emissions from refuse delivery vehicles to and from the facility. Many of the constituents of emissions are considered pollutants and require some measure of pollution control before being discharged to the atmosphere.

Air Quality Standards

Solid waste incineration produces less than 5% of the total nationwide emissions, which is estimated to be about 264 million tons per year (Brunner, 1985). The largest contributory sources are transportation and power plants that combust conventional fuels. Nonetheless, resource recovery facilities discharge a wide range of pollutants into the atmosphere, and consequently, must comply to Federal and State emission standards.

In 1977, the Environmental Protection Agency (EPA) established the National Ambient Air Quality Standards (NAAQS) as a means of controlling pollutants emitted from

the above sources. These standards define the maximum levels of pollutants safely permissible in the air. Air quality is defined in terms of six "criteria pollutants": sulfur dioxide, carbon monoxide, nitrogen oxides, photochemical oxidants (ozone), total suspended particulate matter, and lead. Values to these standards are listed in Table 3. The two categories of standards are primary standards and secondary standards. Primary standards are the maximum emission levels established to protect public health with an adequate margin of safety. Secondary standards are set to protect the public welfare through adverse effects on manmade structures and the natural environment.

Additional pollutants from resource recovery facilities are apart of the "non-criteria" pollutant category (Table 3). Metals and organic compounds compose most of the pollutants in this class. "Non-criteria" pollutants lack EPA documentation on levels causing adverse health and environmental effects. Therefore, no air quality standards can be established for these pollutants. They are regulated, however, under the Clean Air Act and also on State levels.

Airborne Dust

Facilities that receive and process MSW (separation or size reduction) generate airborne particulates. Conveyors, shredders, and air classifiers generate the largest

Table 3. National Ambient Air Quality Standards (NAAQS)
for Criteria Pollutants

Pollutant	Averaging Period	Federal Standards	
		Primary	Secondary
Total Suspended Particles (TSP)	Annual	75	60
	24-hour	260	150
Sulfur Dioxide (SO ₂)	Annual	80	---
	24-hour	365	---
	3-hour	---	1,300
Carbon Monoxide (CO)	8-hour	10,000	10,000
	1-hour	40,000	40,000
Nitrogen Dioxide (NO ₂)	Annual	100	100
Lead (Pb)	3-Month	1.5	---
Ozone (O ₃)	1-hour	235	235

Non-Criteria Pollutants

Hydrogen Sulfide (H ₂ S)	Nickel (Ni)
Beryllium (Be)	Selenium (Se)
Flourides (F)	Zinc (Zn)
Arsenic (As)	Hydrogen Chloride (HCl)
Cadmium (Cd)	Polyaromatic Hydrocarbons (PAHs)
Chromium (Cr)	Tetrachlorinated Dioxins (TCDDS)
Copper (Cu)	
Mercury (Hg)	

quantities of dust (Reilly and Powers, 1980). Dust-laden air is normally controlled by hoods located over shredders and conveyors, and is vented off to cyclones and fabric filters before being discharged to the atmosphere (Serper, 1978).

Not all airborne dust is collected and vented from resource recovery facilities. It can accumulate in work areas and pose a health hazard to workers. Standards of concentrations of dirt and nuisance dust in work areas are set by the Occupational Safety and Health Administration (OSHA). OSHA standards limit an 8-hour exposure to inert or nuisance dusts to 15 mg per cubic meter for total dust concentration, and 5 mg per cubic meter for respirable dusts which have a mass median diameter of 3.5 um or less (U.S. OSHA, 1976).

Studies conducted at the Equipment Test and Evaluation Facility (ETEF) detected dusts that were primarily nonrespirable, organic, and fibrous (Duckett et al., 1980). No asbestos or heavy metals such as Pb and Cd were found. Concentrations of respirable dusts collected in areas most likely to be occupied by personnel were all within OSHA limits. The respirable dust collected averaged only about 12% of the total. The low concentration of respirable dust was attributed to the processing operation, which generally produces a high proportion of large dust particles having smaller particles (respirable size) attached to the surfaces.

Another study reported total dust levels in three

different plants that were well below OSHA standard of 15 mg/cubic meter (Mansdorf et al., 1980). The average concentration range was 0.2 to 3.0 mg/cubic meter. These investigators also observed that the majority of dusts were in the non-respirable dust range. Respirable dusts ranged in concentration from 0.09 to 0.5 mg/cubic meter, which is also substantially below the OSHA standard of 5.0 mg/cubic meter for nuisance dust. Furthermore, particulate matter showed negligible amounts of trace metals such as Zn, Pb, Cr, Cd, and Be. Lead and zinc were detected in each collection sample, but were present at very low levels. These findings suggest that trace metals generated during processing operations do not pose a health hazard to plant employees.

Decaying animal and vegetable matter, disposal diapers, and pet feces in MSW can contain a diverse and variable microbial population. Aerosols containing a high microbial content can be generated when the waste is processed. Studies of microbial populations in dust from facilities processing solid waste reported potentially harmful levels of fecal coliforms and streptococci bacteria (Duckett et al., 1980; Daly et al., 1984). Most of the fecal coliforms were concentrated on nonrespirable fraction. High fecal streptococci to coliform ratios detected in aerosols indicate that enteric microorganisms are largely of animal origin. Also, coliform concentrations are positively correlated with the amount of particulates in the air.

Coliform levels in a resource recovery facility also

have been compared to those at a landfill and a wastewater treatment plant (Lembke and Knisely, 1980). Highest concentrations were found in the resource recovery facility. Coliform levels of 10^5 CFU per cubic meter were observed inside the facility compared to 10^4 at the landfill, and $10^3 - 10^4$ in the wastewater treatment plant. Remote locations, such as a shopping mall and a municipal park, contained coliform levels of $10^2 - 10^3$ CFU per cubic meter. Coliform levels measured upwind and downwind (100m and 300m) from the facility were comparable to those measured at the remote locations. Therefore, airborne microbes are not necessarily a problem beyond the plant's interior. They are either released from a facility at minimum levels, or diluted immediately outside the facility.

Microbial levels measured in waste processing facilities indicate that workers are exposed to pathogens in the waste. Pathways of exposure are through either inhalation of microbial aerosols, or ingestion of microbes attached to larger airborne dust particules, which ultimately can enter the gastrointestinal system. In one study, however, the maximum accumulated doses were lower than the accepted infective dose of the gastrointestinal system (Duckett et al., 1980). Workers probably inhale fungi and other respiratory pathogens such as klebsiella pneumoniae, as well. One study conducted on at the Ames SWRS, however, indicated that no adverse health effects of these factors on employees. In any case, investigators suggest that all workers should wear protective gear and perform other

occupational hygiene practices to minimize contact with the microorganisms. In addition, dust generation can be reduced by use of filter dust control devices and water-mist sprayers for shredding equipment.

Particulate Emissions from Stacks

Incineration of MSW produces an ash, part of which remains on the bottom of the combustion chamber (bottom ash) and part of which rises with the gas stream (fly ash). Most of the fly ash in the flue gas stream is collected by pollution control devices such as electrostatic precipitators or baghouses. The small percentage that escapes collection exits with the stack gases, and constitutes a source of air pollution (Table 3). Fly ash consists of very small particles ranging in size from about 120 microns to less than 5 microns diameter (Pavoni et al, 1975). It contains ashes, cinders, mineral dust, soot charred paper, and other partially burned materials.

The amount of ash produced upon incineration of MSW depends on many factors: 1) moisture and ash content of refuse, 2) completeness of combustion, 3) burning rate, 4) grate system, 5) underfire air injection rate, and 6) the type and efficiency of the combustion process (Abert, 1977; Niessen and Sarafim, 1980). For instance, higher ash production results from incineration with higher ratios of air to waste than originally intended. Waterwall combustion units normally produce uncontrolled emission rates of 15 to

24 lbs. per ton of refuse burned (Reilly and Powers, 1980), but highest particulate matter emissions occurs in RDF-fired spreader stoker units. Slightly lower rates occur in mass-burning waterwall and rotary combustion units, and lowest emission rates are observed in mass-burning refractory wall units (Howard et al., 1984). The high emission rates in spreader-stoker units are attributed to a greater ash content of RDF, higher burning rates, and a larger percentage of the RDF that is burned while suspended in air than on grates. These factors also contribute to the larger amounts of submicron-sized particles (< 2 microns) produced in RDF-fired facilities.

The amount of particulates discharged from the stack of an incinerator is a function of the quantity of fly ash production and the efficiency of the pollution control devices. The particles most likely to escape the collection devices are in the finest fraction (0.1 to 1 um diameter). These fine particles can be absorbed deep into the lungs of humans, and may cause the greatest health hazard (Hileman, 1981). The finest particles also can contain relatively high concentrations of metals and perhaps organic compounds that may further aggravate health problems. No epidemiological studies have been performed to assess the impact of resource recovery facilities on the incidence of lung diseases. Adverse health effects due to particulate matter emissions from resource recovery operations, however, probably will depend on emission rates, composition, and dispersion patterns on the population distribution around

the facility (Howard et al., 1984).

Metals

A number of studies indicate that emissions contain elevated metal concentrations. Metals exit incinerator stacks either attached to fly ash particles or in the vapor phase. A list of the metals contained in emissions from the refuse incineration appears in Table 4. Zinc, lead, tin, molybdenum, and manganese are released in high concentrations. Several of these metals can pose severe health risks (Table 5). Particle emission studies on three different municipal incinerators observed that incinerators can be the major sources of cadmium, zinc, and antimony and possibly, tin and silver on aerosols in many urban areas (Greenberg, et al., 1978; Gordon, 1978).

Many metals exhibit fine particle enrichment. More than 75% of the Zn, Sn, Sb, Pb, Cs, Cu, As, Au, and Cd in fly ash are present in the smallest size fraction (< 2 microns) (Greenberg et al., 1978). Nickel, Mo, Se, and V are also enriched in fine particles (Howard et al., 1984). These observations are consistent with volatilization of metals in the furnace and subsequent condensation on the finer particles at lower temperatures, because fine particles have a comparatively large surface area available for condensation. Less than 1% condensation is believed to occur at temperatures above 260°C (see Howard et al., 1984). Therefore, volatile metallic compounds can only be

Table 4. Partial list of metals emitted from resource recovery facilities.

Antimony	Arsenic
Beryllium	Cadmium
Chromium	Copper
Lead	Manganese
Mercury	Molybdenum
Nickel	Selenium
Silver	Tin
Vanadium	Zinc

Table 5. Adverse environmental and health effects of selected pollutants associated with MSW combustion.

Pollutant	Effects
Lead (Pb):	Lead accumulates within the human body. It causes symptoms such as anemia, headaches, sterility, miscarriages, or the birth of handicapped children. Handicaps include convulsions, coma, blindness, mental retardation, and/or death.
Nickel (Ni):	Nickel carbonyl (NiCO) is a hazardous nickel compound. It causes changes in lung structure, which results in respiratory diseases, including lung cancer.
Mercury (Hg):	Mercury is a priority toxic pollutant. Mercury and its salts have a low boiling point, so most mercury from combustion of fuels is emitted in the vapor form. Mercury poisoning in humans produces blindness, progressive weakening of the muscles, numbness, paralysis, coma, and death.
Antimony: (Sb)	Antimony produces adverse cardiovascular, pulmonary and reproductive development effects.
Cadmium: (Cd)	Cadmium is a priority toxic pollutant. It is extremely toxic to some forms of aquatic life. In humans, it interferes with the natural processes of zinc and copper metabolism, and also causes cardiovascular disease and hypertension.
Chromium : (Cr)	Chromium and its compounds are respiratory irritants, particularly the hexavalent chromates. Chromium can produce dermatitis, perforation of nasal septum, ulcers and cancer of the nasal tract. Cr also contributes in the production of lung cancer. Chromium is toxic to aquatic organisms, as well.
Zinc (Zn):	Although zinc is an essential nutrient, consumption of large amounts in food or water can lead to digestive disorders. Inhalation of zinc and its chlorides can damage the lungs and liver, and possibly other organs.
Nitrogen : Dioxide (NO ₂)	NO ₂ causes significant effects in the atmosphere, i.e. photochemical smog, yellows white fabrics, creates plant leaf injury, reduces plant yields.

Sulfur : SO_2 is oxidized to sulfur trioxide (SO_3), which
Dioxide combines with water droplets to form sulfuric
(SO_2) acid. The presence of sulfuric acid in the
atmosphere results in reduced visibility,
corrodes metals, and forms acid rain or fog.

Hydrochloride: An acid gas that can cause corrosion and
(HCl) irritate the eyes nose and throat.

(Sources: Howard et al., 1984; Brunner, 1985).

removed from the gas phase by lowering the flue gas temperature below 260°C, which will force the metals to adsorb onto fly ash particles.

The shape of the fly ash particles may also contribute to enrichment of metals on fine particles. Taylor et al. (1982) observed fine fly ash particles from RDF often take on a sponge-like shape. This type of particle has a particularly high specific surface area. Specific surface area is the ratio of the surface area to mass. Metal enrichment on fine particles also is partially due to the density of the fine particles suspended in the flue gas. A greater number of suspended fine particles will increase the probability of a volatile metal condensing on a particle.

Mercury is a special case. It generally is not enriched in fine particles, as are other metals. Instead, mercury is believed to exit the stack primarily in the vapor phase. This behavior results from the high vapor pressure of mercury that favors gas formation at the temperatures of the flue gas. Therefore, it tends not to condense onto fly ash particles.

The removal of certain refuse components before incineration could reduce the magnitude of certain metal species released in stack emissions. Studies have been conducted on the sources of metals MSW (Cambell, 1976; Law and Gordon, 1979). Printing inks are found to be significant sources of lead and zinc. Other chemicals used extensively in publications that are sources of metals include titanium dioxide, lead chromate molybdate orange (Pb

and Mo), pthalocyanime blue (9-10% Cu), calcium carbonate, kaolin, barium sulfate, iron blue, and magnesium carbonate (Law and Gordon, 1979). Paints contribute lead, titanium, and chromium to metal emissions, too. Cadmium and copper are concentrated in heavy combustibles like heavy-guaged plastics; and plastic stabilizers are sources of tin and cadmium.

Metals largely coming from combustible material include Cu, Cd, Hg, and Mg. Combustible and noncombustible material both are sources of Cd, Cr, Pb, Mn, Ag, Sn, and Zn; however, lead mainly is derived from the noncombustible fraction. In the noncombustible material, these metals are present as galvanizing agents, solders, pigments, and other surface applications (Law et al., 1978). They may also be present in thin foils or wires. The high temperatures of incineration cause flaking and volatilization of the metals from bulk metal scrap. In light of these observations, removal of the non-combustible fraction before incineration could diminish the emission levels of many metals, such as Cd, Cr, Pb, Mn, Ag, Sn, and Zn.

Although the health effects of individual metals are known, the impact from stack emissions of resource recovery facilities is uncertain, and will depend on a number of different variables. The environmental impact can be minimized by efficient collection of fly ash, particularly the fine particles on which many of the metals occur. Also, operation of the pollution control devices at temperatures

below 260°C can reduce the amount of volatile metal compounds (except mercury) in stack emissions. Finally, metal emissions may be further reduced by operating combustion conditions correctly in order to keep particulate production at a minimum.

Gaseous Emissions

A number of gases emitted from waste-to-energy incinerators are of interest from a pollution control standpoint. The inorganic gases generated from refuse combustion normally include carbon dioxide, carbon monoxide, sulfur oxides, oxides of nitrogen, and acid gases like hydrochloric acid (HCl) and hydrofluoric acid (HF). Hydrogen sulfide and methane are also gaseous products from low oxygen heating in the pyrolysis conversion process. Sulfur dioxide (SO₂), nitrogen dioxide (NO_x), and carbon monoxide (CO) constitute 3 of the 6 previously mentioned "criteria pollutants" (Table 3). The environmental problems associated with many of these gases has prompted much interest in emission control, particularly on State and local levels (Skizim, 1982). For instance, the role of sulfur dioxide emissions in the acid rain formation is a serious environmental concern, as well as is the corrosiveness of HCl toward manmade structures. The negative environmental impacts of the gaseous pollutants are described in Table 5. The nature and magnitude of gaseous emissions depend upon the composition of the fuel waste, the combustion system and the efficiency of the

pollution control technology (Howard et al., 1984; Shimell, 1985). The composition of the fuel waste will vary over different areas of the country, during different seasons of the year, and also depending upon the degree of processing. The quantities of nitrogen, sulfur, and chlorine are of particular interest regarding gas production. Nitrogen concentrations in MSW range from about 0.4% to 0.7%, sulfur ranges from 0.1% to 0.3%, and chlorine content ranges from 0.4% to 0.8% by dry weight of refuse (Howard et al., 1984). Nitrogen is largely found in textiles, foodwastes, yardwastes, and plastics (Freeman, 1976). Sulfur is derived mainly from rubber, plastics, foodwastes, yardwastes, and paper. Plastics are the major source of chlorine. The nature in which these elements are released is a function of the combustion temperature, oxidizing or reducing conditions, and the presence of other gaseous compounds.

Sulfur oxides (SO_x) are produced by the oxidation of sulfur in the refuse. Sulfur dioxide (SO_2) is generally the predominant gaseous sulfur compound produced from combustion, and SO_3 normally is produced in smaller amounts. Under oxygen-poor conditions, hydrogen sulfide and carbonyl sulfide are also released. The percentage of sulfur in the waste fuel that is converted to SO_x ranges from 14 to over 90 percent (Howard et al., 1984). Spreader stoker type refuse-burning systems convert greater percentages of waste sulfur to SO_x than mass-burning waterwall furnaces and other burning systems. Sulfur

emissions from refuse-burning facilities, however, are low compared to those from combustion of coal, which contains about 1% to 3% sulfur by weight.

Nitric oxide (NO) is the principal nitrogen oxide produced during the combustion of MSW, although NO₂ is released in smaller amounts. In the atmosphere, NO converts to NO₂, which is the most harmful pollutant of the nitrogen gases. It reacts with hydrocarbons to produce photochemical smog and other secondary pollutants. It may also be oxidized to yield HNO₃, a component of acid rain.

Nitrogen oxides can be formed from either the oxidation of nitrogen contained in the refuse, or from the oxidation of atmospheric nitrogen at high temperatures. The latter is often referred to as "thermal nitrogen" (Niessen, 1978). A majority of the NO_x (75-80%) is produced by the oxidation of refuse nitrogen because very little thermal nitrogen is generated below operating temperatures of most resource recovery facilities (< 1600°C). The degree of refuse nitrogen conversion to NO_x is governed by the distribution of underfire and overfire combustion air, the nitrogen content of the refuse, total excess air injection rates, and to a lesser extent the constancy flue gas temperatures (Turner et al., 1972).

Gaseous HCl is the principal chlorine compound discharged from refuse incinerators. Energy recovery incinerators have been observed to emit about 2g of gaseous HCl for every kg of refuse fired (Rollins and Homolya, 1979). Plastics and sodium chloride are the main

Polyvinyl chloride (PVC) may be the greatest source (Shimell, 1985). More than 70% of the chlorine in RDF is converted to HCl emissions by spreader-stoker furnaces. On the other hand, mass-burning facilities convert less than 55% of the chlorine in MSW to HCl emissions. Due to the greater chlorine content of MSW, HCl emissions are higher from resource recovery facilities than from coal burning power plants.

The other acid gas of interest is hydrofluoric acid. It is produced from the combustion of organic halogens. Information on HF emission rates and content in refuse is sparse; however, HF emissions, as well as HCl, are dependent on refuse composition (Shimell, 1985).

Carbon monoxide (CO) is not considered a primary emission problem since firing systems normally operate at high flame turbulence and long combustion times (Serper, 1977). If improper combustion conditions exist, significant CO production may occur. Improper combustion may result from fuel-rich conditions, or lower than optimum incineration temperatures. These conditions can arise from high over-fire rates, inadequate supply of air, or combustion of an overly large or wet load of refuse. Improper combustion also can produce substantial amounts of hydrocarbons, some of which are harmful to air quality and health (discussed later).

The West German Experience

Most steam-generating incinerators in West Germany are located near or within population centers (Mutke, 1981). Consequently, strict controls over air emissions have been established, particularly for HCl and HF (100 mg/Nm³ and 5.0 mg/Nm³ respectively). Uncontrolled HCl emissions from refuse incinerators can be several times greater than those from U.S. refuse incinerators due to the large amounts of plastics used in West German consumer packaging. The West Germans have accomplished high removal efficiencies of HCl from flue gas. Some of their incinerators use ESPs in conjunction with wet scrubbing systems, which have achieved HCl removal efficiencies of greater than 95%. West Germany has also enacted a recycling project to reduce the amount of plastics in the waste fuel that will decrease HCl emissions. Unfortunately, many plastic scrap dealers are concerned that there will be no markets for the recycled plastics. The West Germans also will not compost the plastics for use on land because of the high heavy metal content in the plastics. Therefore, they are attempting to perfect and incorporate pyrolysis into their solid waste disposal program (Shimell, 1985).

Fogging and Icing

During the colder months of the year, the operation of the cooling towers may cause local fogging and icing of adjacent structures. These conditions can cause hazardous travelling conditions in areas surrounding the stack. The

cooling of moist effluent is the cause of a visible plume exiting stacks. Under certain atmospheric and wind conditions, the plume may persist and cause fogging in the adjacent area. At temperatures below freezing under a high relative humidity, the plume may cause icing, as well.

Dioxins and Furans

Stack emissions and recovered ash from waste incinerators have been shown to contain a number of potentially harmful organic compounds. Polynuclear aromatic hydrocarbons, dioxins, and furans are some of the organic compounds that have brought forth serious concern for the practice of incinerating MSW as a means of resource recovery. This section principally discusses the issue of dioxin and furan production associated with resource recovery operations.

The most critical issue and highly publicized item in the list of environmental impacts is the emission of dioxins and dibenzofurans from refuse incineration. Dioxins and furans have been detected in the flue gas, particulates, and fly ash generated from many resource recovery facilities. Concentrations of these organic compounds in emissions have been measured in trace quantities, ranging from less than 0.1 to 1000 ug/kg (Graham et al., 1984).

The term dioxin refers to a class of chlorinated organic compounds, some of which have been found to be highly toxic. The molecular structure consists of two

benzene rings connected by two oxygen bridges (Figure 15). Chlorine atoms may be situated at two or more of the eight numbered locations. There are 75 different dioxin compounds, which are collectively termed polychlorinated dibenzo-p-dioxins (PCDDs). Dibenzofurans are structurally very similar to dioxins (Figure 15). They differ in that they have a five-sided core containing only one oxygen. The family of dibenzofurans is collectively termed polychlorinated dibenzofurans (PCDFs). Thirty-eight furan isomers are known to exist. The subclass of dioxins that have received greatest attention due to potential health hazards are the tetrachlorodibenzo-p-dioxins (TCDDs). There are 22 different TCDD isomers. The isomer that is most toxic and hence, best known, is 2,3,7,8-tetrachlorodibenzo-p-dioxin. This isomer is reported to be 3 to 100 times more toxic than other TCDDs that have been tested for toxicity (Ruf, 1978). Some PCDFs that are also highly toxic include 2,3,7,8-TCDF, 2,3,4,7,8-PCDF, and 1,2,3,7,8-PCDF (Rappe, 1984).

Dioxins are chiefly recognized as the toxic components of the defoliant Agent Orange and of many improper disposal sites for contaminated production wastes. Evidence indicates that dioxins and dibenzofurans are created in trace amounts by the many chemical reactions that take place during combustion (Bumb et al., 1980). Dioxins and furans have been detected in industrial incinerators, city dust, an oil-burning plant, commercial sludge fertilizer, particulate deposits in car and truck mufflers, cigarette smoke, soot from home fire

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and dibenzofurans (PCDFs)

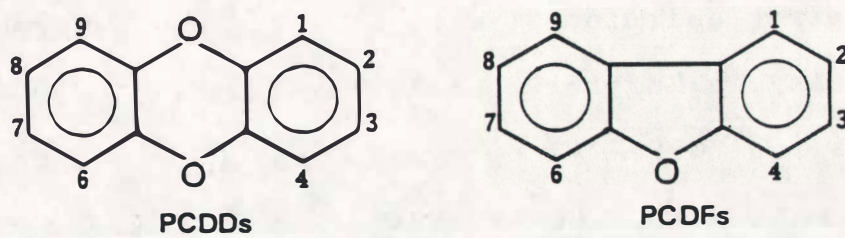


Figure 15. The molecular structures of PCDDs and PCDFs

places, and even charcoal-broiled steak. Dioxins emitted from waste incinerators were first detected in the Netherlands in 1976 (Olie et al., 1977). In the U.S., dioxins were first discovered at the Hempstead, NY wet-pulp processing plant in 1977. This plant is still closed because of fear over dioxin releases. Waste-to-energy incinerators in Nashville, Chicago, and Hampton, Virginia are other facilities where dioxins have been detected in ash and stack emissions (Table 6). The fly ash from the facility in Hampton contained relatively high amounts of PCDDs and PCDFs. The mean total PCDD concentration was 800 ng/g, and mean PCDF concentration was 3000 ng/g (Haile et al., 1984). Fly ash from the Nashville incinerator contained 7.7 ppb of 2,3,7,8-TCDD. Dioxin and dibenzofuran emissions also are quite variable. Total emissions ranged from 0.97 mg/ton of MSW at the Chicago Northwest incinerator to 127 mg/ton of MSW burned at Hampton, VA.

It is important to note that no cases of human death or longterm disability have been linked to dioxins in the U.S. or any other country (Brunner, 1985). In studies conducted on animals, the effects of dioxins and dibenzofurans vary in type and importance among different animal species. In general, these organic compounds have been found to be carcinogenic, teratogenic, mutagenic, and toxic to the reproductive and immunological systems of animals.

Accurate knowledge on the levels and duration of exposure of humans to TCDD and PCDF that are necessary to produce adverse health effects are uncertain. Exposure to

Table 6. Dioxin (PCDD) and dibenzofuran (PCDF) emissions from MSW incinerators in U.S.A. and Europe.

Source	4-CDD	5-CDD	6-CDD	7-CDD	8-CDD	2,3,7,8-TCDD
Nashville Incinerator (ppb) a	7.7	N.R.	14	28	30	0.4
Chicago NW Incinerator (mg/ton MSW)d	.030	N.R.	.080	.040	N.R.	N.R.
Hampton, VA Incinerator (mg/ton MSW)d	2.400	13.700	9.400	2.900	N.R.	N.R.
European Incinerators (ppb) a	2-20	N.R.	30-200	60-130	40-120	N.R.
Italian Incinerators (fly ash-ppb) b	1-46	0-65	0-2500	0-90	0-295	N.R.
USA Incinerators (ug/tonne) c	32	N.R.	82	37	13	N.R.
European Incinerators (ug/tonne) c	266	853	1,209	1,218	776	N.R.
Mean						
	<u>4-CDF</u>	<u>5-CDF</u>	<u>6-CDF</u>	<u>7-CDF</u>	<u>8-CDF</u>	
USA Incinerators (ug/tonne) c	446	N.R.	306	37	3	
European Incinerators (ug/tonne) c	667	1,042	1,655	1,054	326	
Mean						

References: a (Bumb et al., 1980) c (Graham et al., 1984)
 b (Cavallaro et al., 1982) d (Commoner et al., 1984)

2,3,7,8-TCDD is known to cause a skin disorder, chloracne, which produces severe facial eruptions that are often irritating and disfiguring. Other effects include fatigue, disturbances in responses of the peripheral nervous system, changes in liver enzyme levels, and possible enlargement of the liver (see Howard et al., 1984).

Presently, no standards exist governing the acceptability of PCDD/PCDF emissions from incinerators. This is partly due to the uncertainty of the health effects of the trace amounts in emissions. Health effects of PCDD/PCDF from incinerator emissions will depend on many factors: 1) the rate they are introduced into the atmosphere; 2) the degree of dispersion in the atmosphere; and 3) the uptake rate by the affected population (Commoner et al., 1984).

PCDDs and PCDFs have been detected in the emissions from refuse incinerators in the Netherlands, Italy, Canada, and Sweden (Olie et al., 1977; Cavallaro et al., 1980; Expert Advisory Committee on Dioxins, 1983; Rappe and Markland, 1978, respectively). Dioxin in the fly ash emissions of Canadian waste incinerators are reported to be 10 to 20 times greater than those in other countries. Fly ash from waste incineration is considered the number one source of dioxins in the Canadian environment. In Sweden, the Swiss EPA has recently placed a moratorium on all new incinerators based on high dioxin emissions from municipal incinerators as well as high dioxin levels found in milk from dairy cows that grazed near the plants (Raloff, 1985). Consumption of

the contaminated milk is believed to be a more probable primary route to humans than is inhalation of air near the facilities.

European dioxin and dibenzofuran emission levels are generally higher than those in the U.S. (Table 6). Mean PCDD emissions European incinerators are 4,322 ug/tonne compared to 229 ug/tonne from U.S. incinerators (Graham et al., 1984). Mean PCDF emissions from European incinerators are about twice as twice as those from U.S. incinerators-- 4,744 ug/tonne versus 2,231 ug/tonne. An explanation for these higher levels may be related to differences in refuse composition between the countries. European refuse generally has a higher wood to paper ratio than that in the U.S. Wood contains large amounts of lignin, a compound believed to be involved in the production of PCDDs and PCDFs. Therefore, the higher lignin content in European refuse may be responsible for higher PCDD and PCDF emission levels relative to U.S. incinerators. Differences between countries may also be partially attributable to different analytical methods employed among countries.

Despite the large number of studies reporting dioxin and dibenzofuran emissions, the exact origin of these compounds from waste incineration remains unknown. A number of theories have been presented, but are yet to be conclusive. Three possible explanations are (Lustenhower et al., 1980; Huntzinger et al., 1985):

1. PCDDs and PCDFs are trace components of the refuse,

and are not entirely destroyed during combustion.

2. PCDDs and PCDFs are synthesized from precursor compounds such as polychlorinated biphenyls (PCBs), chlorophenols, and chlorobenzenes contained in the raw refuse.
3. PCDDs and PCDFs are formed via a de novo synthesis when non-chlorinated organic materials, such as lignin cellulose, polystyrene, and coal, are burned in the presence of oxygen and chlorine, or when chemically unrelated compounds such as PVC and other chlorocarbons are pyrolyzed.

PCDDs and PCDFs have been detected in trace quantities (less than 100 ng/g) in raw refuse (Ozvacic et al., 1983; Tosine et al., 1985). It is believed that they are not effectively destroyed during combustion, and consequently, are entrained with the combustion gases. Emissions, however, contain much higher concentrations than are accountable by the raw refuse component, alone. For instance, emissions from a Canadian incinerator contained 24 times more PCDF and 13% higher PCDD concentrations than were present in the MSW (Commoner et al., 1984). Many researchers, therefore, do not consider the MSW alone as a significant contributor to emission levels. The contribution of PCDDs and PCDFs in raw refuse should not be neglected altogether, because low concentrations in MSW translates into large amounts of PCDD/PCDF combusted when many tons of refuse are incinerated per day (Tosine et al., 1985).

PCDD/PCDF synthesis from certain precursor compounds is more generally accepted as the main contributory source in incinerator emissions. The precursors that are responsible for dioxin formation are probably chlorinated organic compounds. Chlorophenols, chlorobenzenes, and PCBs are the most likely candidates because the chemical structure of these compounds is similar to PCDD and PCDF. The chlorinated precursor compounds in the raw refuse may be present in herbicides, treated wood, or products containing PCBs (Lustenhower et al., 1980). Ozvacic et al. detected 12.6 ng/g chlorobenzenes, 79.8 ng/g PCBs, and 521.3 ng/g chlorophenols on a dry weight basis in raw waste. Conversion to PCDD/PCDF takes place if chlorine is present in the form of organo-chloride compounds (Commoner et al., 1984). The content of chlorinated precursor compounds in MSW is highly variable. Therefore, the amount of PCDD or PCDF from these compounds is difficult to predict (Shaub, 1984). Moreover, research shows that the amount of known precursors present in the waste does not solely determine the amount of PCDD and PCDF in emissions (Huntzinger et al, 1985).

Dioxins and dibenzofurans may be created by chlorination reactions involving particular chemically unrelated materials such as lignin and cellulose. When this material is burned, it will react with chlorocarbons in the presence of oxygen and chlorine to form PCDDs and PCDFs. Chlorobenzenes, chlorophenols, and PCBs may be important

intermediates in the process (Choudhry et al., 1982). PVC also has been found to be a precursor for chlorobenzenes, which can pyrolyze in the presence of air to yield PCDDs/PCDFs (Lustenhower et al., 1980). Although there is evidence supporting both the direct precursor and de novo synthesis hypotheses, the relative significance of either one as sources to emissions is still uncertain.

During refuse combustion, PCDDs and PCDFs may form either on the incinerator grates or fly ash in post-combustion zones (Shaub, 1984). Temperatures on the furnace grates, however, should also be hot enough to destroy these compounds. In post combustion zones, temperatures may be too cool to allow destruction. Laboratory studies have shown that catalytic formation on surfaces under certain conditions is possible (see Shaub, 1984), but no study has conclusively demonstrated that PCDDs and PCDFs form on fly ash of MSW incinerators. Surface reactions on fly ash theoretically should not be possible below 400°C, because sites for reaction on particle surfaces are unavailable. The rate of thermal desorption from the particle surfaces becomes too slow compared to the transit time of the fly ash through the incinerator. Consequently, catalytic formation of PCDD and PCDF most likely takes place in the post-flame combustion zone in a temperature range of about 400°C to the temperature at which thermal destruction of the compounds and the precursors occurs.

Any factor that can perturb the uniformity of the high temperature of combustion may enhance dioxin and dibenzofuran

production. These factors include heterogeneous combustion conditions, wide temperature fluctuations, and low average temperatures. The best controls of PCDDs and PCDFS may be accomplished by operating incinerators at optimum combustion conditions, which can prevent PCDD/PCDF production, or by using the most efficient post-combustion control technologies that will remove the compounds from the flue gas. Combustion conditions believed to be necessary for PCDD/PCDF destruction are 1 to 2 seconds of gas residence time in the furnace, temperatures of 900 to 1000°C, and air/fuel mixtures with a slight excess of oxygen (see Commoner et al, 1984). At the same time, data does not entirely support a direct relationship between emission rates and either combustion temperatures, or combustion efficiency. One study did observe that decreasing combustion temperatures increases dioxin emissions, but no correlations were observed between dioxin emission rates versus average combustion temperature, stack gas temperature, stack flow, and stack gas concentrations of HCl, NO_x, SO₂, and CO (Benfenati et al., 1983).

Post combustion control devices include ESPs, alkaline scrubbers, filter fabric systems, and supplementary burners. Thus far, none of these control devices have reduced emissions of PCDDs and PCDFS to environmental acceptability (Commoner et al., 1984). Dioxins and dibenzofurans also exhibit fine particle enrichment similar to many metals. The finer particles of stack emissions show PCDD and PCDF

concentrations 1.1 to 25 times higher than the particulate matter collected in electrostatic precipitators (Lustenhower et al., 1980). Therefore, efficient collection of the fine particles from the flue stream may be one way to control dioxin emissions. Utilizing ESPs as a control device may not be suitable since the finest particles escape collection in ESPs. Four factors influence fine-particle enrichment: particle size; number of particles; flue gas temperature; and particle composition (Howard et al., 1984).

Another control measure may be the removal of major sources of chlorine prior to burning the refuse. Niessen (1984) contends that PCDD/PCDF emission rate varies with the square of the HCl concentration in the flue gas. Therefore, reductions of HCl concentrations by removing major chlorine sources such as PVC could reduce PCDD/PCDF emissions. This practice still may be ineffective since promotion of chlorination reactions that produce dioxins have been found to be largely independent of chlorine concentrations (mainly HCl) in the flue gas emissions (Eiceman and Rghei, 1982). Schaub (1984) believes that even up to 99% removal of chlorine from the preburned waste would have no effect on chlorination reactions that produce PCDDs and PCDFs. Obviously, there is confusion over the role of HCl in the formation of PCDDs and PCDFs. More research is required to determine the effectiveness of removing chlorine sources from refuse as a control method.

The dioxin problem needs more attention in two general areas. First, the mechanism of formation needs to be

positively identified so that proper control measures can be developed and applied. Secondly, low dose exposure associated with the emissions from refuse incineration and its potential health effects need to be assessed before any conclusions can be drawn regarding the safety of burning refuse for resource recovery.

Vehicle Emissions

A part of the overall environmental impact of resources recovery facilities includes the emissions from refuse delivery trucks along the route of delivery and in the area of the facility. Vehicle emissions can be a source of carbon monoxide, hydrocarbons and other oxidants to the atmosphere (Serper, 1977).

Assessment of vehicle emissions on air quality necessitates a knowledge of the existing traffic conditions, and ambient air quality levels. Environmental impact statements for proposed resource recovery facilities generally contain models (ie. diffusion models) that calculate ambient pollutant patterns, and compare concentration patterns with and without the vehicles associated with the proposed facility. This approach allows the investigators to draw conclusions and make recommendations on the effects of vehicle emissions.

Vehicle emissions may pose a problem within the tipping area of a facility. The tipping area is generally enclosed; and therefore, trucks unloading refuse may produce levels of

pollutants, such as carbon monoxide, that are potentially harmful. For example, it has been estimated that 250 trucks will unload at a 2,000 TPD facility during the course of one day (Serper, 1977). Six to twelve trucks may be in the tipping area at any one, and produce carbon monoxide levels up to 50 ppm. Sufficient ventillation in the tipping area and expediency in the dumping operations are suggested to minimize CO emission levels to the point at which they do not represent a health hazard.

Residuals Disposal

The disposal or utilization of the residual products (wastes) from resources recovery plants may cause impacts on human health and the environment. The residual products consist of bottom and recovered fly ash from waste-to-energy incinerators, the char product from pyrolysis plants, refuse-processing rejects, and wastewater (discussed below) generated from certain operations in the plant. Fly and bottom ash is either landfilled or used as a substitute material in concrete, aggregates, landfill cover, embankments, and roadbase (Gidley and Sack, 1983). Processing rejects include glass, dirt, metals, ceramics, and even some organic material. This material is discarded safely in landfills. The char from refuse pyrolysis is an inert product, and can be either safely landfilled or further refined to produce a fuel product.

The factors that influence the environmental impact of

the residuals are: the properties that make the residual potentially harmful; the properties that make it mobile in the environment; and the location of disposal, or use, which will either increase or decrease the likelihood of harmful exposure (Gidley and Sack, 1983). The disposal of fly and bottom incineration ash represents a major environmental concern. As discussed earlier, residual ash from incineration can contain substantial amounts of heavy metals, and even toxic organic compounds, which may be susceptible to leaching.³ Currently, every State, except California, characterizes refuse ash as a non-hazardous material, which is may be discarded in landfills (Reilly and Powers, 1980). California requires the disposal of residual ash in hazardous waste landfills only.

The leaching characteristics of combustion ash from refuse and refuse/coal mixtures have been examined by Rademaker and Young (1981), Taylor et al.(1982), and Giordano et al. (1983). Taylor and co-workers observed that the amount of metals released from ash increased with the proportion of RDF relative to coal in the combusted fuel. This trend is partly attributable to larger specific-surface area of RDF ash particles, which causes the metals to be more accessible to solvents. Fly ash leachate (0.5N acetic acid extractable) contained high concentrations of cadmium and lead (up to 500 ug/g and 5000 ug/g respectively), which exceed the critical concentrations of hazardous contaminants set by the EPA. Residual ash leachate also is characterized

by a high salt content.

Cadmium and lead displayed high mobility in soil. These metals normally are not very active in soil; however, the high chloride content of the ash (10%-12%) is believed to complex with the metals and cause the observed high mobility. When the ash was introduced to laboratory soils, it was observed to be toxic to plants (Giordano et al., 1983). The phytotoxicity appeared to be due to a high salt content release rather than with a specific metal. The investigators suggest that the phytotoxicity of leachate may be diminished by mixing fly ash with bottom ash, which has a lower metal concentration, but Pb and Cd uptake by vegetation can still remain high. Therefore, landfilling ash residues could present a danger if metals leach and accumulate in vegetation that enters the food chain.

Wastewater

Water is used in all resource recovery systems. The quantity of water usage depends on the type of resource recovery process and the system design. The water emerging from a resource recovery plant can contain many pollutants that require treatment prior to being discharged into the receiving body of water. Wastewater characteristics include high temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, alkalinity, hardness, total solids, total dissolved solids, heavy metals, odor, and color.

Wastewater from RDF processing systems varies in volume and strength depending on whether the system is a dry or wet process. Dry processing systems use much smaller amounts of water than do wet processing systems. Principal uses are in dust control, facility cleaning, and in glass or aluminum recovery. The most contaminated water emerges from washdown operations, materials recovery, and drainage from refuse storage pits. The effluent from storage pits may contain leachate such as pesticides and organic solvents that are likely to have a negative impact on wastewater treatment processes. Much of the wastewater from dry processing is discharged into sanitary sewers without harm to the environment (Treweek, 1981).

Primary water usage in wet processing are with hydropulping, cleaning, equipment cooling, and materials recovery. The largest volume and highest strength of wastewater is generated from the hydropulping process (Treweek, 1981). Hydropulpers make a thick slurry of MSW from which light and heavy fractions are separated. The wastewater contains a high organic content.

Mass-incinerators normally require a range of about 300 to 2000 gallons of water per ton of waste combusted (Pavoni et al., 1975). Wastewater mainly comes from the cooling tower and boiler blowdown, quenching of ash residue, sluice water, facility cleaning, and gas scrubbers. Most of it is small in volume and in strength (Reilly and Powers, 1980). Therefore, the effluent from most incinerator components,

except from wet scrubbers, is directly discharged into sanitary sewers. Wet scrubbers use atomized water on flue gases to remove corrosive and irritating gases such as HCl, SO₂, and HF. The wastewater is acidic with a pH commonly ranging from 2.5 to 5.0. It is also low in BOD, COD, and suspended solids (less than 1000 mg/liter), but high in heavy metal concentrations (Treweek, 1981). Gas scrubber water can contain up to 3,600 mg/L of iron, 1,050 mg/L of zinc, and 500 mg/L of lead. This water must be treated prior to discharge.

The most contaminated wastewater from pyrolysis systems emerges from scrubbers, condensers, and other gas cleaning devices. The wastewater is very high in organic surrogates. BOD is often greater than 50,000 mg/L due to water-soluble substances such as alcohols, organic acids and aldehydes. Furthermore, COD can range from 30,000 to 52,000 mg/L (Treweek, 1981). The wastewater also contains high concentrations of organic priority pollutants such as phenol (20-50 mg/L), benzene (4 mg/L), and toluene (1 mg/L), and high concentrations of toxic metal pollutants such as lead and zinc (Treweek, 1981).

Anerobic digestion of MSW and sewage sludge mixtures yields wastewater mainly from drainage in storage pits and dewatering from the digested compound. The liquid effluent from the MSW/sludge digesters is similar in character to normal sludge digesters. The wastewater is characterized by high levels of BODs (500-10,000 mg/L) and high concentrations of organic pollutants (650-2800 mg/L).

Resource recovery systems can minimize the volume of wastewater production by recirculating water through certain system components. For example, incineration facilities can minimize water usage by routing blowdown from boilers and cooling towers to ash quenching tanks, or by using dry systems for handling ash. Available treatment practices are sufficient to control potential pollution problems associated with wastewater. Treatment is accomplished by employing aerobic or anerobic biological processes for the biodegradable fraction, and physical-chemical processes for suspended solids and trace metals. Biological processes involve the aerobic or anerobic conversion of soluble organic matter into an active bacterial biomass and gas. Some removal of trace metals also occurs through biological processes. In oxidation processes, the nitrate and phosphate that are produced may require further treatment, particularly if discharged in an area where algal blooms are problematic (Serper, 1977). Physical-chemical treatments include flocculation, sedimentation, filtration, and carbon absorption. They are also effective for removing organic materials, but the total cost is higher than using biological methods (Treweek, 1981).

Other Local and In-Plant Environmental Impacts

Odors and Surface Blown Litter

Decaying refuse will produce many compounds that create malodorous air. These compounds include aldehydes, organic sulfur, acetic acid, butyric acid, and nitrogen compounds. Threshold values of detection for these compounds by humans are below 0.001 ppm, except for acetic acid, which is about 0.5 ppm (Serper, 1978). These low threshold concentrations illustrate the remarkable sensitivity of the human nose. Therefore, it is essential that resource recovery facilities have efficient control systems that prevent odors from escaping the facility to neighboring communities.

Odors are produced in storage pit areas and during the waste conversion processes. In some facilities, odors have been problematic. RDF plants in Bridgeport, Conn. and Hempstead, NY were plagued by odors, which were partially responsible for the plants' closings. Many mass-burning incinerators, such as Martin mass-burning systems, contain odors by keeping the facility at a negative air pressure. Negative pressure is maintained by venting air through boilers and, thereby, bringing in outside air. The odor-producing compounds are drawn into the furnace where they are destroyed. Facilities not equipped with boilers, or those that do not have the capacity to maintain negative air pressure, require odor control systems that absorb odors with activated carbon, or scrub with potassium permanganate.

Any temporary shut-down of operations of resource

recovery plants may cause buildup of refuse in storage pit areas and allow decay to occur for extended periods. Odors can be emitted to an extremely great degree. These problems occurred during the initial operation of the RDF-fired incinerator in Akron, Ohio (Reilly et al., 1981). In this instance, the amount raw refuse and RDF in storage pits was kept at a minimum, which alleviated significant odor problems.

Surface blown litter is usually not a problem at resource recovery plants since storage areas are generally enclosed and kept away from winds. Negative pressure ventilating systems will inhibit litter from escaping outside the facility.

Noise

Noise production from plant operations and from refuse delivery vehicles comprises another potentially adverse effect on the public welfare and plant personnel. Resource recovery facilities will generate noise from many sources depending on the type of operations within the plant (Table 7). Equipment which produce significant amounts of noise are shredders, air classifiers, trommels, and cyclones. These types of equipment can produce noise in excess of existing Occupational Safety and Health Administration (OSHA) standards. Noise levels reported from within some facilities exceed 90dbA, which is the maximum allowable level of exposure permitted for an eight-hour day (Diaz et al., 1982). Normally, workers are not near these devices

Table 7. Measurements of peak noise levels near resource recovery plants.

Vehicle Noise	Location	Noise Level
Refuse vehicle starting	at 25 feet	85 dB(A)
Refuse vehicles on level ground at constant speed	at 25 feet	80 dB(A)
Refuse vehicle on slope at constant speed	at 25 feet	83 dB(A)
Four vehicles unloading in tipping area at the same time	at 50 feet outside	62 dB(A)
<u>External Noise Level Measurements</u>		
General plant noise	at 150 feet	57 dB(A)
	at 300 feet	52-54 dB(A)
	at 1,000 feet	45-46 dB(A)
Cooling tower (mechanical draft)	at 95 feet	69 dB(A)
	at 400 feet	60 dB(A)
	at 800 feet	54 dB(A)
<u>Internal Noise Levels</u>		
General plant noise	Inside metal recovery area	90-92 dB(A)
	Boiler room	78-82 dB(A)
Turbines	Inside turbine room	88 dB(A)
Vehicles tipping	Tipping area	88-91 dB(A)

Source: (Serper, 1977)

for long periods of time. Damage to employee hearing can be controlled by the use of ear protection devices and enclosing the equipment within walls and ceilings having a high-noise adsorption capacity. The effect of the noise on those individuals outside the plant depends on a number of factors such as the background noise level, the degree of isolation of individual components in the plant, the degree to which the plant is enclosed, and the types of construction materials used in the building (Serper, 1977).

Refuse delivery vehicles are a significant source of noise. Certainly, many have experienced a rude awakening very early in the morning on trash collection days. Those communities along the delivery route to the facility are most adversely affected. Peak noise levels for refuse delivery vehicles are listed in Table 7. Assessment of the vehicle impact requires a model with a number of variables which include background noise levels and the distribution of people about the facility.

Explosions

The processing of municipal solid waste occasionally produces explosions and fires that may result in structural damage and even injuries. Explosions normally occur during shredding operations. In a 1976 study of 45 waste shredding facilities, 95 explosions were reported (EDRA, 1976). Injuries occurred in 3 incidents, and damages greater than \$25,000 resulted from 5 explosions. It has been estimated that one explosion will occur for every 85,000 tons of waste

shredded (see Blasius, 1985). Most result in only damage to building enclosures, but some explosions have been responsible for deaths, such as the incidents that caused fatalities at the EcoFuel II Plant in East Bridgewater, Massachusetts in 1977, and recently at the Ames, Iowa SWRS.

The exact causes of explosions vary, and are often difficult to identify. The materials believed to be the major sources are dynamite, gun powder, flammable liquids and gases such as gasoline, propane, butane, paint thinner, and aerosol cans containing flammable substances. Mixtures of combustible dust and flammable vapor can also generate primary or secondary explosions. Dust and vapors can collect in particular areas of the shredder assembly to the point at which they can explode. Ignition may be caused by an attenuating flame or burning shards produced from a primary explosion, which results in a secondary explosion. Alternatively, ignition may be caused by burning fluff that results from the reaction between dry combustibles and hot metal being brought to flame by the rotor windage from shredders (Robinson, 1979). Combustible dust also is likely to maintain fires created from explosions.

There are a number of provisions that minimize the frequency and severity of explosions. These provisions include presorting explosive substances from waste before processing, installation of suppression equipment, use of explosion relief devices, and maintenance of an inert atmosphere (Blasius, 1985). Manual surveillance and removal

of potentially explosive materials before shredding is probably the most effective preventive measure.

Surveillance and extraction is performed in the tipping area or storage pits, and may be aided with television monitors that scan feed conveyors. Removal of potentially explosive material is accomplished using the cranes that feed the charging hopper, or by the employees themselves. Presorting at one facility in Niagara Falls, NY has decreased the frequency of explosions to 1 out of every 175,000 tons of waste processed (Blasius, 1985).

Explosive relief measures include venting of potentially explosive gases out of the shredder compartment and constructing hinged walls and tops on shredders. The latter facilitate venting of the explosive gas. Explosion suppression systems may also be employed. These systems consist of water fog sprays or Halon (a chemical suppression agent) that are triggered upon the detection of a pressure increase caused by an explosion's shock wave. To minimize the potential of injury, shredders may be isolated within enclosed walls, and by keeping employees away from the shredders during operation. Finally, explosions also may be prevented by circulating flue gas through shredders to limit oxygen availability for ignition. Such a system is currently used at the RDF production plant in Akron, Ohio (Reilly et al., 1981).

Aesthetics

Visual quality constitutes another environmental impact--or perhaps more appropriately, a psychological health impact. Plant architecture, landscaping, and containment of litter all contribute to visual quality.

Resource recovery facilities generally require large buildings to house the processing and conversion equipment. The extreme size makes them noticeable for great distances, and also in turn may block existing views such as the sky, and other natural or manmade structures having aesthetic value. The size of a facility depends on the type of recovery system used and the amount of refuse processed per day. For example, waterwall combustion systems processing greater than 500 TPD are large structures with heights often exceeding 100 feet (Reilly and Powers, 1980). Emission stacks and pollution control devices are also large structures, and are normally situated outside the main building. Some facilities may use a horizontal stack design to avoid great stack heights. In contrast, RDF production systems (shredding and separation) generally have a low profile. Air classifiers usually are the tallest component in the building, and may extend above the roofline.

The architecture of the facility is an important factor contributing to visual quality. Resource recovery facilities will appear more pleasing to the eye if they are designed to resemble an office building rather than a power plant. Landscaping the facility with trees and other vegetation also enhances aesthetic value. The character of

the surrounding area also influences the aesthetic value of a facility. For instance, less effort is required to raise the visual quality of a plant located in an industrial area relative to a residential area, or business district.

Containment of surface blown litter is critical for maintaining the aesthetic value of a resource recovery plant. Garbage littered about the plant is not in the least attractive, and it also reminds people that the facility handles waste.

NIMBY Syndrome

Siting is one of the principal problems encountered by many new projects. The industry calls it the NIMBY factor, or NIMBY syndrome--NIMBY being an acronym for "not in my backyard". The NIMBY syndrome is caused by public concern over potential environmental impacts. It is never more evident than at public hearings held for new projects, where there are often hostile confrontations between the opponents and the advocates.

Public opposition to the construction of a new facility can be costly in both time and money. In fact, siting is sometimes the most difficult issue to settle. Problems of this nature were faced by the facilities in Westchester and Onondaga Counties in New York (Johnson, 1980). Moreover, siting is still the major problem inhibiting construction of new waste-to-energy plants in Philadelphia, Boston, and Detroit (Michaels, 1985).

The reasons for opposition to resource recovery siting

are as varied as are the antagonists, themselves. There really is no "general public" encountered in the "selling" of a proposed facility. Rather, there are a number of specific public groups that include wastehaulers, people living along proposed transportation routes, waste management officials, public officials, and people living in the neighborhood of the proposed site (Hendrickson and Romano, 1982). Politics impose another important control on siting, because the success or failure of solid waste management programs can help determine the outcome of elections (Michaels, 1985).

Several factors contribute to public opposition to resource recovery facility siting. The benefits of resource recovery seem to be immediately overlooked and potential problems tend to be magnified. Contributing factors are:

- 1) A poor image of solid waste services or practices, which include poorly operated resource recovery projects and failed attempts, memories of open dump burning, and diastorous events such as explosions. The negative reputation of the past practices often blemishes the new state-of-the-art technology.
- 2) A basic distaste for garbage, and the thought of having the waste of others being brought to a nearby "garbage plant".
- 3) The immediate or short term view of the economics in constructing a waste-to-energy facility. Many tend to look at the immediate cost of these facilities, which often require tens of millions of dollars,

rather than realizing the potential of offsetting costs, and possibly, gaining a profit through materials and energy recovery.

- 4) The displacement of homes and businesses required for proper construction of the facility, as well as an expectation of reduction of property value or business in the area surrounding the facility.
- 5) Environmental concerns, particularly with air emissions which are perceived as having the most direct impact on the environment and health of individuals. Reports of dioxins in incinerator emissions, and its immediate association with cancer, is probably the most critical concern.
- 6) A latent distrust of science and technology as it applies to waste disposal. This distrust may have its foundation in such industrial and technological developments as the production and improper disposal of hazardous wastes, leaks from industrial chemical plants and nuclear energy facilities, a general degradation of the environment during the industrial revolution, and even nuclear weapons.

Some of the factors contributing to opposition to resource recovery facilities may be valid, but others may be unwarranted, being based on ignorance, a misunderstanding of intent in initiating the project, or emotion. Many agree that the best way to overcome the latter is to educate the public on the technology and the benefits of the facility to

a community, and to involve the public in the decision-making process.

CONCLUSION

The use of resource recovery operations in a solid waste management program largely is prompted by closure of existing landfills, lack of space for developing new fills, and the objection to environmental impacts of landfilling. Resource recovery systems can solve these problems by reducing the volume of waste to be landfilled, which in turn, extends the life of existing landfills and conserves valuable space. The recovery of needed energy and usable materials is an added benefit, too. Society's waste product consequently becomes a readily available source of energy and materials.

Resource recovery systems may, however, create problems, among which the potential environmental impacts are of greatest concern. In order to determine whether resource recovery is an acceptable means of waste disposal, one must weigh the costs against the benefits, and then compare them to alternate means. The costs are partially, if not principally, measured in terms of the adverse environmental impacts presented in this paper. They have been identified and measured, but the actual effects are not entirely understood--particularly the effect of longterm exposure to low dose emissions of metals and dioxins.

Indeed, the impacts are difficult to assess against a background of many other contributory sources that degrade the environment and human health. Resource recovery facilities may, in fact, have a minimal impact on air quality relative to other emissions sources. Certain adverse effects may not be detectable for decades. Perhaps, they may be realized sooner if properly directed scientific research is applied. However, proper application of scientific research depends on whether correct methods of analysis are available.

Resource recovery systems have the potential for adverse effects on society, which is sufficient for many to question their safety. At the present time, the uncertainty of the effects should not be enough cause to render resource recovery facilities hazardous. Yet, they should not be proliferated into society until the environmental impacts are better understood. Resource recovery is a developing technology with a large amount of capital and research being invested in improving the quality of its operation, and for rectifying potential environmental effects. The lack of space available for landfills, however, may mean that resource recovery will become the only available and feasible alternative of waste disposal. Its true acceptability, therefore may ultimately depend on need, above all else.

REFERENCES

- Abert, J., "Air Pollution from Burning Refuse Fuels," NCCR Bulletin, Vol. VII, No. 1, Winter 1977, pp. 15-27.
- Benfenati, E., F. Gizzi, R. Reginato, R. Fanelli, M. Lodi, and R. Tagliaferri, "PCDDs and PCDFs in Emissions from an Urban Incinerator. 2. Correlation Between Concentration of Micropollutants and Combustion Conditions," Chemosphere, Vol. 12, 1983, pp. 1151-1157.
- Blasius, G.F., "Municipal Waste Used for Large Scale Cogeneration," Chemical Engineering Progress, March 1985; pp. 64-69.
- Brunner, C.R., Hazardous Air Emissions from Incineration, Chapman and Hall, New York, 1985.
- Bumb, R.R., W.B. Crummett, J.R. Gledhill, R.H. Hummel, R.O. Kagel, L.L. Lamparski, E.V. Luoma, D.L. Miller, T.J. Nestruck, L.A. Shadoff, R.H. Stehl, and J.S. Woods, "Trace Chemistries of Fire: A Source of Chlorinated Dioxins," Science, Vol. 210, No. 4468, 24 October 1980, pp. 385-390.
- Cambell, W.J., "Metals in the Wastes We Burn," Environmental Science and Technology, Vol. 10, No. 5, May 1976, pp. 436-439.
- Carr, R.C., and W.B. Smith, "Utility Baghouse Design and Operation," Journal of the Air Pollution Control Association, Vol. 34, No. 1, January 1984, pp. 80-89.
- Cavallaro, A., L. Luciani, G. Ceroni, I. Rocchi, G. Invernizzi, and A. Gorni, "Summary of Results of PCDDs Analyses from Incinerator Effluents," Chemosphere, Vol. 11, No. 9, 1982, pp. 859-868.
- Choudhry, G.G., Olie, K. and O. Hutzinger, "Mechanisms in the Thermal Formation of Chlorinated Compounds Including Polychlorinated Dibenzo-p-Dioxins," in Chlorinated Dioxins and Related Compounds - Impact on the Environment, edited by O. Hutzinger et al., Pergamon Press, Oxford, 1982, pp. 275-301.
- City of New York, Department of Sanitation, Final Environmental Impact Statement for the Proposed Resource Recovery Facility at the Brooklyn Navy Yard, June 1985.
- Commoner, B., K. Shapiro, M. McNamara, "The Origins and Methods of Controlling Polychlorinated Dibenzo-p-Dioxins and Dibenzofuran Emissions from MSW Incinerators," 1984.

- Daly, E.L. Jr., S.A. Voorhees, R. Narishbahan, H.P. Gerrish, S. Sengupta, N.L. Nemerow, and W. Wong, "Airborne Coliforms at a Municipal Solid Waste Processing Facility", Proceedings of the Second Conference of Management of Municipal, Hazardous, and Coal Wastes, (S. Sengupta, ed.) Sept. 1984, pp. 317-322.
- Diaz, Luis F., G.M. Savage, and C.G. Golueke, Resource Recovery from Municipal Solid Wastes, Volume I: Primary Processing, CRC Press, Inc., 1982a, 166 p.
- Diaz, Luis F. G.M. Savage, and C.G. Golueke, Resource Recovery from Municipal Solid Wastes, Volume II: Final Processing, CRC Press, Inc., 1982b, 178 p.
- Duckett, E.J., J.W. Wagner, R. Welker, B. Rogers, and V. Usdin, "Physical/Chemical and Microbiological Analyses of Dusts at a Resource Recovery Plant," American Industrial Hygiene Association Journal, Vol. 12, No. 41, 908-914.
- Dudley, N., "Waste as a fuel," Coal and Energy Quarterly, Vol. 25, Summer 1980, pp. 33-41.
- ERDA, "Assessment of Explosion Hazards in Refuse Shredders," Factory Mutual Research Corporation, ERD-76-71, June 1976.
- Expert Advisory Committee on Dioxins, "Report of the Joint Health and Welfare Canada/Environment Canada Expert Advisory Committee on Dioxins," November 1983.
- Freeman, H., "Pollutants From Waste-to-Energy Conversion Systems", Environmental Science and Technology, Vol. 12, No. 12, November 1978, pp. 1252-1256.
- Gidley, J.S., and W.S. Sack, "Environmental Aspects of Waste Utilization in Construction," J. ACSE, 1983, pp. 1117-1133.
- Giordano, P.M., A.D. Behel, Jr., J.E. Lawrence, Jr., J.M. Solleau, B.N. Bradford, "Mobility in Soil and Plant Availability of Metals from Incinerated Municipal Refuse," Environmental Science and Technology, Vol. 17, No. 4, 1983, pp. 193-198.
- Graham, S. et al., "Production of polychlorinated dibenzo-p-dioxins (PCDD) and furan (PCDF) from resource recovery facilities, Part I," The American Society of Mechanical Engineers, Solid Waste Processing Division, Proceedings, Orlando, FL, 1984.
- Greenburg, R.R., R. Zoller, and W.H. Gordon, "Composition and Size Distributions of Particles Released in Refuse Incineration," Environmental Science and Technology, Vol. 12, No. 5, May 1978, pp. 566-573.

- Haile, C.L., R.B. Blair, R. Lucas, and T. Walker, Assessment of Emissions of Specific Compounds from a Resource Recovery Municipal Refuse Incinerator, Task 61, Final Report, prepared by Midwest Research Institute for EPA. EPA Contract No. 68-01-5915 (May 22, 1984).
- Hendrickson, M.L., and S.A. Romano, "Citizen Involvement in Waste Facility Siting," Public Works, May 1982; pp. 76-79.
- Hutzinger, O., M.J. Blumich, and K. Olie, "Sources and Fate of PCDDs and PCDFs: An Overview," Chemosphere, Vol. 14, No. 6/7, 1985, pp. 581-600.
- Igarashi, M., Y. Hayafune, R. Sugamiya, Y. Nakagawa, and K. Makishima, "Pyrolysis of Municipal Solid Waste in Japan," Journal of Energy Resources Technology, Vol. 106, September 1984, pp. 377-382.
- Johnson, C., "A full scenario of a resource recovery project implementation," 1980 Sanitation Industry Yearbook, pp. 60-96.
- Law, S., B. Haynes, and W.J. Cambell, "Pre-Burn Separation Should Limit Metal Emissions," Waste Age, Vol. 9, No. 9, September 1978, pp. 51-59.
- Law, S.L., and G.E. Gbrdon, "Sources of Metals in Municipal Incinerator Emissions," Environmental Science and Technology, Vol. 13, No. 4, April 1979, pp.432-438.
- Lembke, L.I., and R.N. Kniseley, "Coliforms in Aerosols Generated by a Municipal Solid Waste Recovery System," Applied and Environmental Microbiology, Vol. 40, No. 5, November 1980, pp. 888-891.
- Lustenhower, J.W.A., K. Olie, and O. Hutzinger, "Chlorinated Dibenzo-p-Dioxins and Related Compounds in Incinerator Effluents: A review of measurements and mechanisms of formation," Chemosphere, Vol. 9, 1980, pp. 501-522.
- Mansdorf, S. Zack, M.A. Golembiewski, C. Reaux, and S. Berardinelli, "Environmental Health and Occupational Safety Aspects of Resource Recovery," in Proceedings of the Seventh Mineral Waste Utilization Symposium, Miner Process Waste - Urban Solid Waste - Ind. Waste Recovery - Scrap Met. Recovery, Chicago, Illinois, October 20-21, 1980. Washington, D.C.: U.S. Bureau of Mines, 1980, pp. 91-100.
- McGowin, C.R., "Municipal Solid Waste as a Utility Fuel," Chemical Engineering Progress, Vol. 3, March 1985, pp. 57-63.

- Michaels, P.E., "Solid Waste Forum: Public Relations," Public Works, February 1985, pp.84-86.
- Mutke, R., "Slash Emissions from Refuse Firing," Power, December 1981, pp. 63-66.
- Niessen, W.R., Combustion and Incineration Processes, Mariel Dekker, Inc., New York, 3rd Edition, 1978.
- Niessen, W.R., and A.F. Sarafim, "Incinerator Air Pollution: Facts and Speculation," Proceedings of the 1980 National Incinerator Conference, Cincinnati, Ohio, May 17-20, 1980.
- Olie, K., P.L. Vermeulen, and O. Hutzinger, "Chlorodibenzo-p-Dioxins and Chlorodibenzofurans are Trace Components of Fly Ash and Flue Gas of Some Municipal Incinerators in The Netherlands," Chemosphere, No. 8, 1977, pp. 455-459.
- Pavoni, Joseph L., J.E. Heer, and D.J. Hagerty, Handbook of Solid Waste Disposal: Materials and Energy Recovery, Van Nostrand Reinhold Co., New York, 1975.
- Peterson, C., "Japanese, Europeans Lead in Waste-to-Energy Incineration," Management of World Wastes, Vol. 28, No. 6, June 1985; pp. 32-33.
- The 1985 Public Works Manual Manual: City, County, and State, "Solid Wastes Management," Section E, 1985.
- Rademaker, A.D., and J.C. Young, "Leachates from Solid Waste Recovery Operations," ASCE, May 1981; pp. 16-29.
- Raloff, J., "Dioxin: Is Everyone Contaminated?" Science News, Vbl. 128, July 13, 1985; pp. 26-29.
- Rappe, C., H. Buser, H. Kuroki, and Y. Masuda, "Identification of Polychlorinated Dibenzofurans (PCDFs) Retained in Patients with Yusho," Chemosphere, No. 4, 1979, p. 4!
- Reilly, T.C., and D.L. Powers, "Resource Recovery Systems, Part II: Environmental, Energy, and Economic Factors," olid Wastes Management/Resource Recovery Journal, Vol. 22, No. 6, June 1980, pp.38+.
- Reilly, T., K. Runyon, and T. Beach, "Resource Recovery Facilities, Part 3: Improving Systems in Shakedown-Akron, OH," Solid Wastes Management/Resource Recovery Journal, Vbl. 24, No. 6; June 1981, pp. 50-56.
- Rghei, H.O., and G.A. Eiceman, "Adsorption and Thermal Reactions of 1,2,3,4-Tetrachlorodibenzo-p-Dioxin on Fly Ash from a Municipal Incinerator," Chemosphere, Vbl. 11, No. 6, 1982, pp. 569-576.

- Robinson, W.D., "Solid Waste Shredder Explosions: What Do They They Have in Common?" Solid Wastes Management/RRJ, Vol. 21, May 1978, pp. 46+.
- Rollins, R. and J.B. Homolya, "Measurement of Gaseous Hydrochloride Emissions from Municipal Refuse Energy Recovery Systems in the United States," Environmental Science and Technology, Vol. 13, No. 11, November 1979, pp. 1380-1383.
- Ruf, G. St., "The Structure and Biochemical Effects of TCDD," Dioxin: Toxicological and Chemical Aspects, F. Cattabeni et al., eds., New York, NY: SP Medical and Scientific Books, 1978.
- Serper, S., "Environmental Impacts of Resource Recovery Facilities Should Be Pre-Determined" Part 1, Solid Wastes Management/Resource Recovery Journal, Vol.20, No. 2; February 1978, pp. 20+.
- Serper, S., "Environmental Impacts of Resource Recovery Facilities Should Be Pre-Determined," Part 2, Solid Wastes Management/Resource Recovery Journal, Vol. 21, No. 3, March 1978, pp. 60+.
- Schaub, W.M., "Technical Issues Concerned with PCDD and PCDF Formation and Destruction in MSW. Fired Incinerators," prepared for P. Casowitz, New York City Dept. of Sanitation, 1984.
- Shimell, P., "Burning Waste Generates Several European Studies," Management of World Wastes, Vol. 28; No. 7, July 1985; pp. 40-44.
- Skizim, D.T., "Gaseous Emission Control Is Vital," Solid Wastes Management, Vol. 25, No. 4, April 1982; pp. 28+.
- Taylor, D.R., M.A. Tompkins, S.E. Kirton, T. Mauney, D.F.S. Natusch, and P.K. Hopke, "Analysis of Fly Ash Produced from Combustion of Refuse-Derived Fuel and Coal Mixtures," Environmental Science and Technology, Vol. 16, No. 3, 1982, pp. 148-154.
- Tosine, H.M., R.E. Clement, V. Ozvacic, and G. Wong, "Levels of PCDD/PCDF and Other Chlorinated Organics in Municipal Refuse," Chemosphere, Vol: 14, No. 6/7, 1985, pp. 821-827.
- Treweek, G.P., "Refuse-to-Energy Wastewater Treatment," ASCE May 1981, pp. 1-16.
- Turner, D.W., R.L. Andrews, and Siegmund, "Influence of Combustion Modifications and Fuel Nitrogen Content on Nitrogen Oxide Emissions From Fuel Oil Combustion," AICHE Symposium Series, Vol. 68, No. 55, 1972.

U.S. Occupational Safety and Health Administration: OSHA Safety and Health Standards: General Industry, Title 29, Chapter XVII, Section 1910.1000. U.S. Department of Labor, Washington DC (1976).

Vence, T.D., and D.L. Powers, "Resource Recovery Systems. Part I: Technological Comparison," 1980 Sanitation Industry Yearbook, pp. 102-109.

Vesilind, P.A. and D. Warner, "Resource Recovery Course. Lesson #2: Cities should first consider the various resource recovery systems," 1980 Sanitation Industry Yearbook, pp. 112-121.

