ENERGY RECOVERY FROM RAW VERSUS REFINED MUNICIPAL WASTES

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ABSTRACT

The development and current state of the arts of waste-to-energy systems is described. The technical and economic aspects of mass-burning and waste-refining and burning systems are compared. Some recent developments in technique and the need for some further developments are briefly described.

INTRODUCTION

Solid waste has been burned in open fires since early Biblical times and probably before. Late in the 19th century open burning began to be replaced by burning in simple brick chambers to facilitate control and reduce the odors from incomplete burning [1]. These simple incinerators evolved slowly with many variations in grate, method of feed and configuration. Simple baffled chambers were used to collect the coarser fly ash. Usually these chambers captured less than half of the fly ash. The resulting dust emission became intolerable to some communities trying to improve their environmental quality. Berne, Switzerland in 1954 led the way by applying an electrostatic precipitator to collect the fly ash with an efficiency of over 90% [2]. That application was not simple. The dusty gases leaving an incinerator are too hot, over 1000°F (538°C), to be passed into a precision-made chamber full of fine high-voltage charging wires and accurately spaced metal collection plates. Accordingly, the hot exhaust had first to be partially cooled. Frequent subsequent experiences have demonstrated that the gas temperature must be kept below 500°F (260°C) to avoid corrosion and deterioration of the precipitator elements [3].

HEAT RECOVERY BOILERS

Water sprays are used occasionally for exhaust-gas cooling, but they are difficult to maintain and control when gas temperature and flow fluctuate rapidly and unpredictably, and the heat absorbed by evaporation of the water is wasted. Accordingly, at Berne in 1954 the gases were cooled by means of a waste heat boiler and the steam generated was used for district heating. Waste heat boilers had been applied previously in Oldham, England in 1896 [1] and soon afterward in the U.S. (Delancy Street in Manhattan), Germany and Denmark, but not to protect precipitators. Actually, the heat value of Municipal Solid Waste (MSW) in those days was so low that not much heat was available for recovery. For example, the refuse composition in London in 1892 was [1]:

Fine ash and cinders	83%
Vegetable, putrescibles, bone	8%
Metal	1%
Paper and rags	5%
Glass	2%
Miscellaneous	1%

Not much heat value in that waste! Then, as production of consumer products grew and standards of living rose, the heat value of waste increased. By 1955 in Berne the average lower heat value was 1160 kcal/kg (2088 Btu/lb) (4.857 MJ/kg).

Figure 1 shows the rise in lower heat value of refuse in European cities compared to approximate average data for Japan and the U.S. [4]. The effect of differences in living standard are apparent.

Building from experiences in mass burning for heat recovery at Copenhagen, Basel and Berne, various equipment manufacturers in Europe began application of coal-burning boiler techniques to waste disposal. Stimulating these developments was the rise in heat value of municipal wastes. This rise occurred much earlier in the U.S., but because of higher fuel costs, the major evolution of waste-to-energy systems occurred in Denmark, Germany and Switzerland.

WATER-TUBE-WALLED INCINERATORS

As these evolving systems became larger, many designers faced the same furnace temperature problems that coal boiler designers had encountered 50 years before [5]. The problem is that as furnace size increases, the volume and capacity for burning increases almost as the cube of the average dimension, but the wall surface for cooling the flame increases only as the square. Thus, as the ratio of surface to volume shrinks, it becomes increasingly difficult to keep the walls relatively cool. Thus, overheating of the walls and slagging and wall deterioration can occur.

To solve the problem of wall cooling, coal burning practice began incorporating boiler tubes on the inner furnace walls in the 1920's.

The technique of the "water-walled" furnace was introduced to waste burners about 1965 [2], but this introduced some new problems. Where abrasion of MSW against the furnace wall tubes caused tube erosion, augmented by corrosion by high temperature chlorides, the lower wall tubes had to be protected by silicon carbide or other refractory held in place by steel studs welded to the tubes. Then, as steam temperatures increased, corrosion of superheaters emerged.

ELECTRIC GENERATION—SUPERHEATER CORROSION

If the energy recovery plant has a steady customer for hot water or low pressure steam, the peak temperatures in the boiler circuits can be modest, under 500°F (260°C), and the potential for high temperature corrosion is avoided. However, if the demand for steam or hot water is intermittent, as is very often the case, much of the energy recovered may have to be wasted. Thus, there is often an incentive to generate electricity which usually can be fed into the local electrical grid. However, the efficient generation of electricity from steam requires the use of superheated steam, at least 700°F (371°C), which can place the steel superheater tubes in the temperature range where chloride corrosion occurs. Chlorides appear naturally in MSW and are augmented by chlorinated plastics. The chlorides in the hot gases become very corrosive [6]. The use of alloy tubes and design changes in many plants have virtually eliminated superheater corrosion. However, some new plants, where not enough attention has been paid to the lessons available on corrosion protection, are even today requiring remedial treatment and retrofit to reduce severe superheater corrosion [7].

GRATES

The predominant mass burning systems that have evolved depend upon gravity action on a sloping reciprocating or moving grate to use gravity to tumble the mass of refuse slowly down a sloping reciprocating or moving grate, thereby exposing fresh combustible surfaces to ignition and combustion. A refuse hopper at the boiler front supplies the unprepared waste to feeders, usually hydraulic rams, which feed the raw refuse into the grate. Most sloping, moving grate systems characteristically experience a 2 or 3 ft mass of refuse at the front of the furnace. As the refuse is agitated by the grate action and moves slowly down the slope, the thick burning fuel bed thins and becomes distributed along the length of the grate. Over the past decade, some manufacturers of mass burning systems have introduced level or near-level grates which depend not on gravity but on vigorous grate motion to move the refuse horizontally across the furnace [7]. In these the fuel bed is thinner and more uniformly distributed over the length of the grate and combustion is somewhat more even.

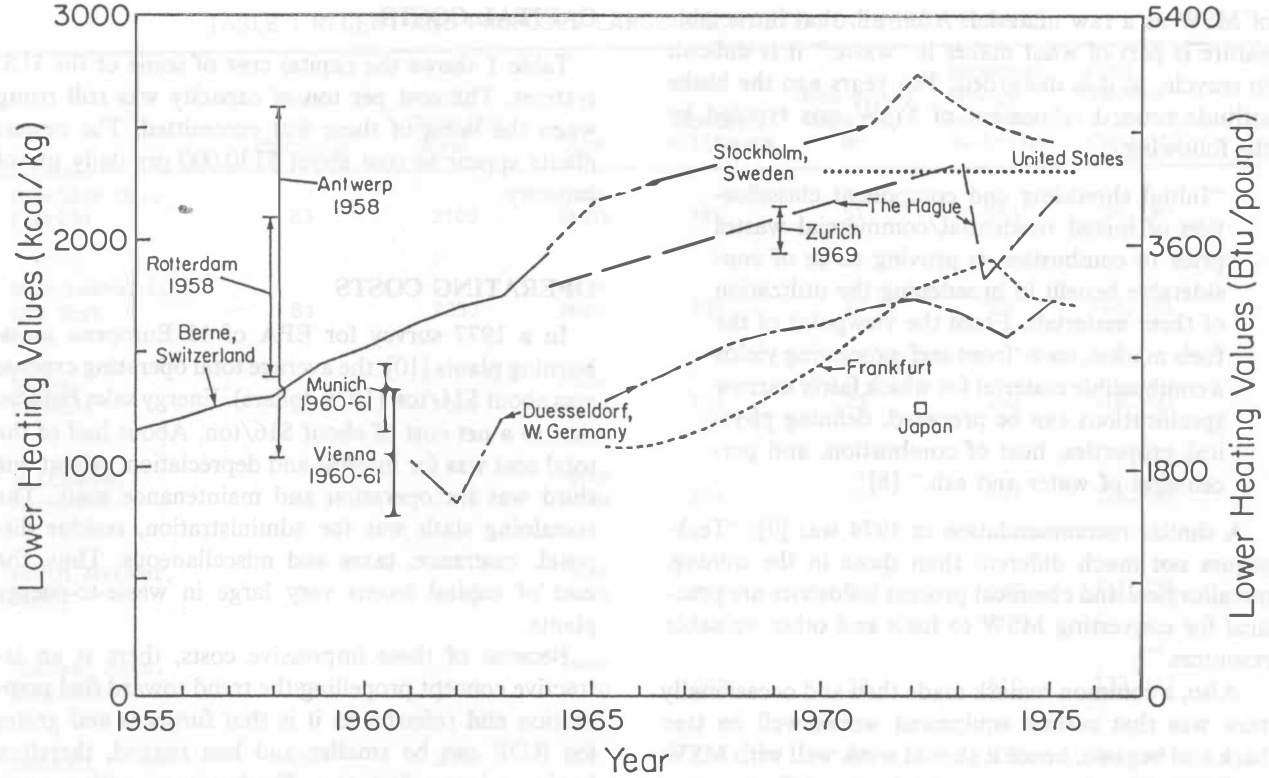

FIG. 1 TRENDS IN LOWER HEAT VALUES OF MSW

THE IMPETUS FOR WASTE FUEL REFINEMENT

At the fuel bed, mass burning is inevitably highly variable. The heterogeneous nature of community wastes makes irregular burning on the grate inevitable. Tanner described the condition in 1965 [2]:

> ". . . the fuel bed of a (mass) refuse fire is very uneven, unlike that of a coal fire. The grate shows a haphazard pattern of dark patches and bright lance-like flames; the latter produce locally high gas velocities and thus entrain light refuse constituents . . ."[1]

In practice, this nonuniformity in burning is corrected in the large furnace volume by the use of intense jets of secondary air which provide mixing of the stratified burning gases with oxygen so that combustion is completed rapidly. Later, a new system of air jets will be described.

It is natural, when viewing the stratified streams of rich and lean flames rising from a mass burning fuel bed, to think of ways to improve on such a random process. An obvious improvement would be to produce a more uniform, smaller sized fuel particle and, in that size-reduction process, perhaps remove some or all of the items that will not burn. There is compelling logic in that view. We don't burn raw coal any longer. Most coal is now washed free of up to half of its impurities at the mine and then is further refined by pulverizing to a powder before being mixed with air and blown into large, highly efficient furnaces developed by and for the electric utilities. Similarly, it would be possible to build an automobile to run on raw crude oil, but it would be inherently inefficient and fraught with reliability problems. Thus crude oil is rarely burned, but is refined to produce clean, uniform motor fuel, an essential substance for life in modern society.

Unfortunately, the techniques which have been evolved over many years for refining coal and oil are not useful for MSW. Therein lies a major obstacle which systems for Refuse Derived Fuel (RDF) are now in the process of surmounting. Inevitably, many of those new RDF systems are encountering major problems, too often exacerbated by otherwise skilled technologists who fail to respect the inherent recalcitrance

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[1] Courtesy of Schweizer Ingenieur und Architekt.

of MSW as a raw material. After all, that intractable nature is part of what makes it "waste;" it is difficult to recycle, so it is discarded. Ten years ago the blithe attitude toward refinement of MSW was typified by the following:

> "Initial shredding and component classification of mixed residential/commercial wastes prior to combustion is proving to be of considerable benefit in broadening the utilization of these materials. From the viewpoint of the fuels market, such 'front end' processing yields a combustible material for which fairly narrow specifications can be prepared, defining physical properties, heat of combustion, and percentages of water and ash." [8][2]

A similar recommendation in 1974 was [9]: "Techniques not much different than those in the mining, metallurgical and chemical process industries are practical for converting MSW to fuels and other valuable resources."[3]

Also, a common remark made then and occasionally now was that certain equipment works well on tree bark and bagasse, hence it should work well with MSW or RDF. This ignores completely the difficult properties combined in MSW. Today that same tendency of inexperienced designers to ignore the adhesive, abrasive, erosive, corrosive, explosive and packing and plugging properties of MSW is too common. This, in spite of costly failures at Rochester, Chicago-Southwest and Akron and the need for extensive modifications at Madison, Ames, Columbus, Niagara Falls, Albany and Duluth.

Over an evolutionary period of more than 30 years, mass burning technology has developed ways of coping with the difficult characteristics of MSW. RDF technology, much younger, is still on the learning curve.

ECONOMICS

Because of the inherent problems in utilizing MSW as fuel, waste-to-energy systems are expensive. Landfills, if available, are cheaper. But landfills are not nearly as available as they once were; in some areas, not at all. Hence, in the world's crowded metropolitan areas, landfills, if any, must be reserved for noncombustible wastes, and waste-to-energy systems are growing in acceptance.

CAPITAL COSTS

Table 1 shows the capital cost of some of the U.S. systems. The cost per ton of capacity was still rising when the latest of these was committed. The newest plants appear to cost about $130,000 per daily ton of capacity.

OPERATING COSTS

In a 1977 survey for EPA of 15 European mass-burning plants [10], the average total operating expense was about $24/ton (1976 dollars). Energy sales reduced that to a net cost of about $16/ton. About half of the total cost was for interest and depreciation. About one third was for operation and maintenance costs. The remaining sixth was for administration, residue disposal, insurance, taxes and miscellaneous. Thus, the cost of capital looms very large in waste-to-energy plants.

Because of these impressive costs, there is an attractive concept propelling the trend toward fuel preparation and refinement: it is that furnaces and grates for RDF can be smaller and less rugged, therefore having a lower first cost. Furthermore, with a more uniformly sized, "cleaned" fuel, combustion should be more efficient, excess combustion air can be less, and therefore more useful energy should be recovered. The practical fruition of these attractive concepts remains to be proven. Some furnaces, both for mass burning and RDF, have been found to be undersized, causing wall slagging and superheater overheating problems. They have had to be down-rated and operated at reduced capacity, hence their actual owning and operating costs per ton of capacity have increased beyond the design expectations. Whether RDF furnaces can, in good practice, be made smaller than for mass burners remains to be determined. Meanwhile, the emerging use in mass burners of thinner fuel beds on nearly horizontal grates could reduce grate costs for that method of burning. Also, some minimal fuel size reduction could improve the thin fuel bed. Whether such a saving will be significant remains to be determined.

Not enough RDF plants have been built and operated long enough to show total owning and operating costs. Also, practical, reliable methods for shredding and cleaning the refuse are still under development. Hence their total capital and operating cost cannot be established at this time. When enough experience and cost data do become available for RDF, it seems reasonable that the added costs of shredding, shredder explosion protection, power consumption, and screening and transport of the RDF to the boilers will add

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[2] Courtesy of American Chemical Society.

[3] Taken from *Chemical Engineering* Vol. 81, No. 22, Oct. 21, 1974, p. 65. Courtesy of McGraw-Hill Pubns. Co.

TABLE 1 RECENT AND PROPOSED LARGE U.S. WASTE-TO-ENERGY PLANTS

	Year of Start-Up	Daily Capacity Tons	Type	Costs, Millions $	Generating Capacity MW	Expected Energy Recovery kw-hr/ton	Cost Factor $/ton of Capacity
Pinellas Co., Florida	83	2100	Mass Burn	160	51	583	76,190
Westchester Co., New York	84	2250	Mass Burn	237	47	501	105,333
Tampa, Florida	85	1000	Mass Burn	118	23	552	118,000
Baltimore, Maryland	85	2010	Mass Burn	254	50	597	126,368
North Andover, Mass.	85	1500	Mass Burn	197	40	640	131,333
Central Mass. (Worcester)	87	1500	Mass Burn	200	38	610	133,333
Detroit	88	3300	RDF	---	65	473	-------
Columbus							
Orig. Est. (1979)	83	3000	RDF-Coal	118	90	720	39,333 (Est.)
Nominal (1985)		2000	RDF	208	60	720	104,000

considerably to total owning and operating costs. Often it is speculated that revenue from the recovery of iron, aluminum, glass and plastics recovered from RDF will offset all of the cost of processing. So far these hopes have not been borne out. Perhaps, as virgin raw materials rise in price, some reliable revenue from materials salvage may benefit RDF plants significantly.

FURNACE GAS MIXING

Much remains to be learned in both RDF and mass-burning systems about the effective use of secondary air jets in shortening the furnace flame, improving utilization of furnace volume, and increasing combustion efficiency. One unique development in this direction is the application of an air-jet manifold across the furnace at Wupertal, Germany as shown in Fig. 2 [11]. The steel manifold containing 260 small air nozzles is located near the region of highest gas temperature and gas velocity. This location could be a zone of very rapid and complete combustion if the oxygen is thoroughly mixed with the combustible gases. Whether the cooling effect of the air flow inside the manifold is enough to protect it from overheating without supplementary water or steam cooling remains to be demonstrated. To protect the fireside of the manifold from high-temperature chloride attack, it would seem essential to use high-alloy steel construction. Studding for holding a protective coating of silicon carbide or other refractory on the fireside does not seem practical because of rapid dimensional changes when fuel of furnace conditions fluctuate.

EMISSIONS

The ash content of MSW as received is approximately 25%. During combustion in a mass burner, about 5% of that is carried off as fly ash [12] to be captured with an efficiency of at least 99% in modern installations. In the preparation of RDF, the ash con-

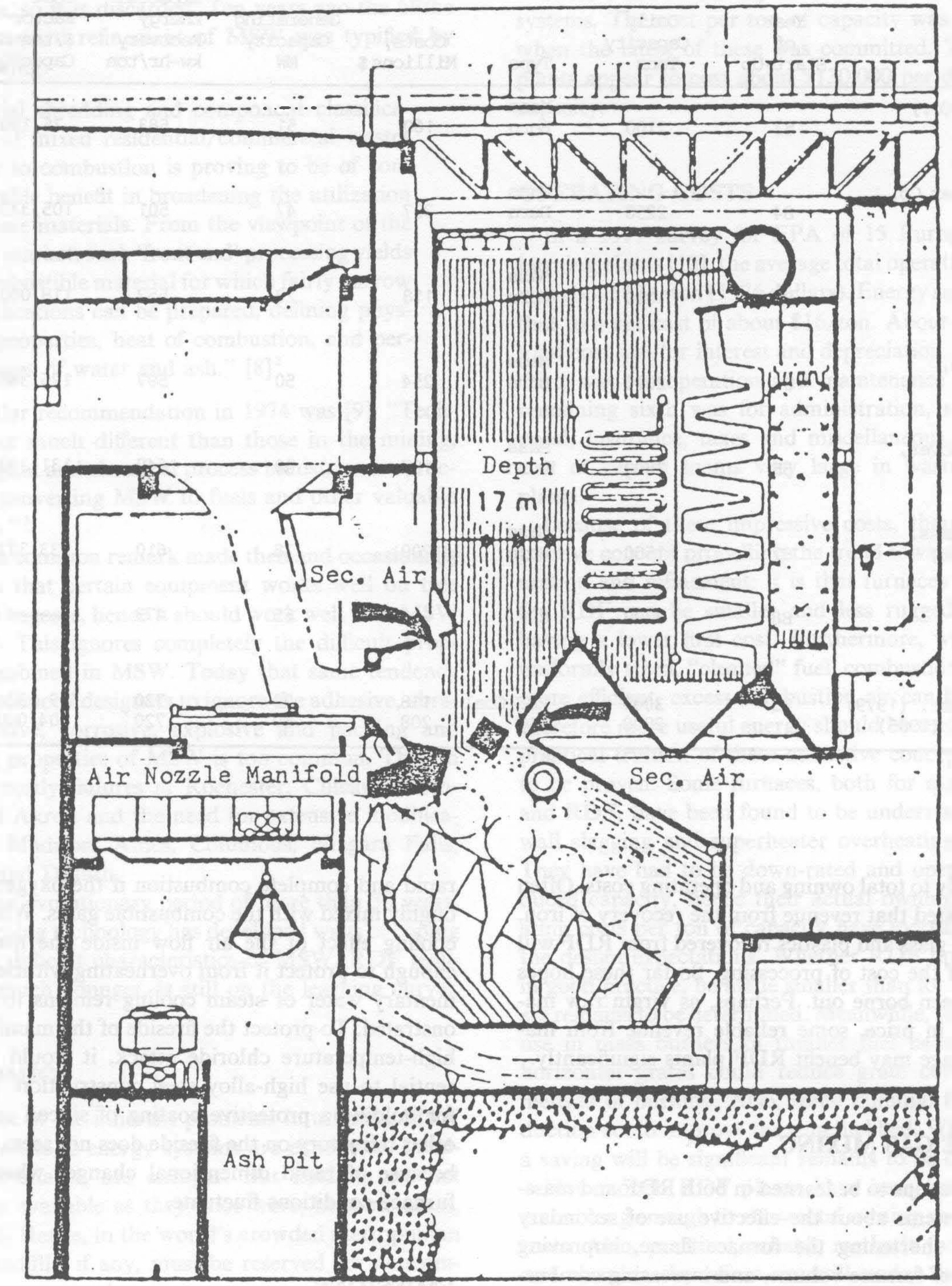

FIG. 2 INSTALLATION OF TRANSVERSE MANIFOLD FOR 260 SECONDARY AIR NOZZLES OVER ROLLER GRATE AT WUPPERTAL, GERMANY

tent is reduced to about 15%, hence there is less total ash entering the furnace than in mass burners. However, waste processing removes little of the fine ash inherent in MSW, and suspension burning releases much of that ash as fine dust which is carried off to the precipitator. Thus, the ash burden entering the precipitator is at least twice that from mass burners, but an increase in collector efficiency can compensate, at a price, for that increased dust loading. The demand on the operators of RDF plants to maintain the precipitators in excellent operating condition is imperative so that continued high efficiency collection is maintained.

ACID GASES

Acid gas emissions result from the burning of refuse containing nitrogen, sulfur, chlorine and fluorine regardless of the method used. The amounts of these elements in MSW are low, 0.1–0.8%, and the impact of the resulting and gases on the neighboring environment is rarely quantified because it is usually so small that it is difficult to measure. Where scrubbers are mandated for acid gas control, dry scrubbers are often favored because they are high in efficiency and they escape the vexing corrosion problems of wet scrubbers.

DIOXIN

After nearly 50 years of development of the heat recovery incinerator, with nearly 500 of them satisfactorily disposing of community wastes in many metropolitan areas worldwide, concern has been raised about possible formation of dioxins from the reaction of chlorine with lignin during combustion. In massive exposures in industrial accidents dioxins have caused temporary skin effects in workers, but not to persons in the surrounding community. No long term effects have resulted from accidental exposure to high concentrations of dioxins in the ambient air [13].

The measured emissions of dioxins range widely, with a median in the range of 400–500 ng/m^3. Measurements of dioxin emissions in 1981 from the newest of two large mass burning plants at Zurich, Switzerland over a period of 5 days averaged up to 50 ng/m^3 depending on the degree of chlorination of the recorded compounds. The report by the Swiss Federal Office for the Protection of the Environment on those tests concluded:

> ". . . the determined emissions during this testing period (5 days) for Dioxins and Furans do not present any health danger . . ." [14][4]

It is possible that mass burners and RDF burners may have characteristic differences in dioxin emissions. However, data available so far are scattered and any definite difference cannot be established. In both systems it seems reasonable that intense combustion will destroy dioxins, but the necessary conditions for that destruction are still unclear.

PYROLYSIS

Several large scale attempts to recover fuel gases and liquids from MSW by pyrolysis have been halted owing to major difficulties with scale up and to the inherent heterogeneity of waste. Here again, although scale-up has become a precise art in many technologies, in the case of heterogeneous wastes, the fact that a small plant works well cannot simply be translated into a much larger scale.

CONCLUSIONS

The well-established mass-burning technique for energy recovery from municipal solid wastes typified by nearly 500 plants operating worldwide is being challenged by new system concepts based on refuse-derived fuel. So far, the number of expensive mothballed RDF plants is about equal to the number that are in reliable operation, but the lure of a uniformly sized, glass-free, metal-free fuel to provide opportunity for better combustion is providing strong impetus toward overcoming the difficulties which have shut down several RDF plants. Crucial to the successful emergence of the RDF method as a reliable waste-to-energy system is keener recognition by plant designers of the inherent recalcitrance of MSW as a raw material. It is abrasive, adhesive, corrosive, explosive and its damp, fibrous nature makes it prone to plugging and clogging whether air borne or tumbling by gravity. In over 30 years of trial and error mass burners have been developed to cope with these properties. RDF systems, with no long history of development, are still evolving with some difficulties yet to overcome.

Owning and operating costs of all systems are high compared to conveniently located landfills. But such landfill locations have vanished in many metropolitan

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[4] Courtesy of Swiss Federal Office for Environmental Protection.

areas, and this trend is accelerating; hence the trend is to burning with energy recovery.

Whether the promise that RDF systems will have lower overall costs cannot be demonstrated until a number of systems are operated over a long enough period to prove their reliability.

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