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# PLASMA ARC MELTERS FOR CONVERSION OF WASTE TO VALUE-ADDED PRODUCTS

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## ABSTRACT

Materials recovery facilities (MRFs) and waste-to-energy (WTE) systems are making significant contributions to reducing the need for landfill disposal by producing useful products. The purpose of this paper is to examine the effects and costs when using plasma arc melters in the thermal treatment process. Plasma arc melters can decrease offgas volume, pyrolize organics, reduce equipment size, separate materials, and generate a homogeneous, stable, solid residue. However, they use electricity for power and may be more expensive to operate. The differences between plasma torch and arc melters is discussed and a typical melter system presented. Various recycling or product output options are discussed based on the composition of the input waste stream composition. An economic comparison between different systems includes both capital and operating costs.

### INTRODUCTION

Municipal Solid Waste (MSW) management has evolved from simple dumping in landfills and the oceans to improved classified landfills and a number of methods to recycle or produce value added products from the waste material. Improved landfills include barriers to separate the leached products from the environment and to meet stiffer landfill regulations. Some landfills are configured to route the methane gas resulting from decomposition to units for cogeneration purposes. Sorting and recycling newspapers, various plastics, and different colored glass has joined the recycling of metal as an economical practice in MRFs. The initial attempts to incinerate solid waste are often met with public resistance because of the lack of control of the combustion products, inadequate air pollution control, and the accompanying offensive odor from the input waste. The early waste to energy plants used several methods to produce and recycle the energy. The waterwalled incinerators were used to provide steam for district heating or to steam turbines, but many of these suffered from the same community problems as incinerators. Attempts to use the combustion gas products directly in gas turbines went through the learning process of how well the particulates and acid forming gases must be separated out to give acceptable maintenance periods. Some processes converted commercial solid waste in a dry process to briquettes to be added to the coal in stoker-fed power plants. Early practices have led to the present successful WTE plants that burn the solid waste to generate steam for turbine-generator production of electricity. The latest trend appears to be to combine the MRF on the front end of a WTE plant for an increase in overall recycling efficiency (Hilts, 1994).

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There are a number of other processes in development that can be used for converting MSW, as well as hazardous wastes, into recyclable products with either a drastic reduction in volume or an elimination of an "ultimate" waste. An ultimate waste is defined here as that which would need to be placed in a repository or landfill. The Molten Metal Technologies (MMT) system is an inductionheated molten metal bath in which the waste material is passed through the molten metal under a baffle, becoming transformed into simple gaseous or vapor compounds and reformed on the other side of the baffle (MMT, 1993). Some constituents remain in the bath or rise to the top as slag. The composition of the slag and metal bath can apparently be (and must be) controlled to produce the desired products. The process is capable of some sophisticated partitioning, but has yet to be demonstrated in practice, and is probably size limited for MSW application.

Another method uses plasma arc processes, to be discussed below, with commercially available equipment that ranges in size from 10 kW (10 kg/h) to 250 MW (250 tonnes/h). This method has the advantage of more than 50 years of development in the related scrap melting, steel smelting, mineral wool making industries, and their auxiliary equipment industries.

This paper discusses the use of plasma arc melters in systems for treating MSW, including a discussion of different types of plasma arc melters (PAMtm), types of PAMtm waste treatment systems, various

value added products, and cost comparisons of application systems as a function of throughput.

#### PLASMA ARC MELTER CHARACTERISTICS

A more detailed comparison of plasma arc melter systems is contained elsewhere (Eddy, 1993). The term "plasma arc melters" is used here as a group classification for plasma torch melters (PTMs) and graphite-arc melters (GAMs) shown in Figure 1. Plasma torches used in PTMs are usually a long or short pipe containing electrodes, water cooling, and a gas flow. The arc mode is either transferred or non-transferred (described later), operates in DC power levels up to 10 MW. Maintenance includes replacing electrodes as they wear. GAMs usually have one, two or three graphite rod electrodes and may have an electrode in the bottom of the melt chamber. Operation can be AC or DC powered. Power levels go up to 250 MW per unit. The electrodes are consumable with consumption rates on the order of 1-5 wt% of the throughput capacity.

There are many different configurations and operating methods for PAM. In general, PAM can operate in a non-transferred arc mode, a transferred arc mode, or a Joule-heating (resistance-heating) mode:

- Non-transferred mode: Both DC electrodes are located within the torch and the hot plasma is blown out as with a propane or blow torch. The radiation and convection heat the melt and waste.
- Transferred mode: One DC electrode is located within the torch. The other is usually part of the bottom of the chamber containing the melt or could be the whole chamber, in graphite crucible applications. In 3-phase AC applications, the arc is transferred into the conducting melt and then into one of the other electrodes, with no bottom electrode. If the arc length to the melt surface is long and the conducting path in the melt short, the heating may be predominantly radiation and convection to the waste and melt. If the arc length is short, the heating mechanism is predominantly Joule heating.
- Joule-heating mode: This is a transferred mode in which the electrodes are very near to or submerged into the melt giving predominantly Joule heating in the melt.

Some of the different PAM configurations are shown in Figure 1 to approximate scale for the same throughput.

Operating conditions can be varied to obtain the desired processing conditions or operating environment. Typical PAM operation is with the molten glass made up of metal oxides at 1,500-1,800 C. There are separate (immiscible) molten glass and molten metal regions with the metal on the bottom, since it is three times as dense as the glass. Air, oxygen or an inert gas can be injected into the melt (or upper chamber) to change the oxidation state, liberate fixed carbon as CO or CO<sub>2</sub>, or to enhance mixing. Feed size is limited by the feedport size, thus by the size of the melter itself. Offgas is taken off the top and treatment systems are required, but are usually much smaller than for fuel-fired or incinerated systems. A discussion of some of the variable operating conditions follows.

#### **Glass Melters**

Glass Melters for treatment of primarily nonmetallic wastes have operating characteristics that are much different than metal scrap melters. Scrap melters are known for their violent arcing, noise and luminosity. In waste melters the objective is usually to liberate the hydrocarbons and possibly the chloride and sulfur compounds, but retain most of the hazardous and other substances in the melt. The metallic material in scrap melters has a high electrical conductivity compared to molten glass. In scrap melters the long-arc radiation is beneficial in heating the scrap, because the Joule-heating contribution is relatively low. The opposite effect is obtained in glass melting where the Joule-heating effect is usually dominant. It is therefore desirable to operate in a relatively quiescent, Joule-heated melt, simulating a weak rolling boil. The offgas from the melt region can be pyrolyzed or oxidized in the melter prior to entering the offgas treatment system.

#### With/Without Cold Top

The melt can be operated with a thick cold top of waste feed to minimize volatilization of hazardous and non-hazardous metals which can be oxidized and remain in the molten glass or reduced to obtain a pig iron or steel feedstock. This condition reduces heat transfer to the top of the chamber and can produce pyrolized organics. Operating without a cold top enhances volatilization of high vapor pressure metals (Pb, Zn, Cd, etc.) for metals recovery when combined with high electric current and longer arc lengths. This condition is used in the treatment of electric arc furnace dust.

#### Melt Containment

Melt Containment can be a water-cooled metal pot, water-cooled metal/refractory pot, air-cooled metal/refractory pot, or an air-cooled graphite pot. The top or lid of the furnace is usually water-cooled. The water-cooled pots can operate with a layer of cooled melt next to the innermost metal/refractory surface that provides additional corrosion resistance because the cooled melt is the same composition as in the molten melt.

#### Melt Tapping

Melt tapping, either continuously or semicontinuously, or tipping and pouring can be used to provide semicontinuous operation. The tapped material can be cast into monoliths or quenched in water to make an aggregate for construction applications.

A wide variety of options exist dependent on the waste stream composition, the objectives of treatment, and the throughput requirements.

### PLASMA ARC MELTER SYSTEMS AND WASTE TREATMENT

Some of the major potential applications for PAM systems are municipal solid waste (MSW), industrial hazardous waste, hospital waste, and radioactive waste. The major issues in treating waste are:

- Elimination or reduction of the hazardous nature of the waste.
- Processing to meet regulatory requirements for the air, land, and water environment.

- Recovery of useful products, to the extent economically practical.
- Volume reduction of the ultimate waste.

For treatment alternatives, the proposed treatment must have economic or other advantages over direct landfill options. Customers want the treatment process to do the following:

- Treat all kinds of heterogeneous waste.
- Result in no air emission.
- Result in no solid or liquid "ultimate" waste.
- Eliminate the customer's liability for the waste.
- Provide the treatment at little or no cost.

These goals are difficult, if not impossible to achieve, but the plasma arc melter systems come as close to accomplishing these goals as any system available.

PAM systems (PAMS) are extremely robust, both in type of waste handled and in flexibility of operation. They can treat almost all, if not all types of heterogeneous solid waste, most sludges and liquid wastes (though it may be impractical to treat dilute liquid wastes). In general, treatment will result in a primary solid product and an offgas, that will have gaseous, furning particulates, condensables, and inorganic compounds that can be precipitated in a scrubber. The primary product is a glass-ceramic product that can be a glass-like, rock-like, or glass-rock-like material. The glass-like product would be similar to obsidian; the rock-like product is similar to basalt, and the glass-rock is more crystalline than the glass. The offgas products can be separated as appropriate. Pyrolysis and reforming can yield a syngas for liquid hydrocarbon generation or for cogeneration of electric power. Returning all the solidified offgas products to the melter is an option, but in most cases futile, because the non-solids will again volatilize, and in increasing proportions, thus taxing the offgas system capabilities. Recycling could be advantageous in the case of high concentrations of high vapor pressure metals (HVPM), because a larger fraction of the HVPM can then be incorporated in the melt. Options depend on the composition of the waste. HVTM in the form of a secondary solid product is discussed below. If warranted, chlorides and sulfur compounds can be separated from the other condensable metals and oxides as a tertiary solid product. Either dry-wet or wet-dry offgas systems are used depending on the particular requirements.

Optimum operation with PAMS utilizes oxygen or oxygenenriched air. As a result the exhaust gas emissions are greatly reduced from that of incinerators used in WTE plants, that are typically fired on air and have large amounts of nitrogen in the offgas. Exhaust gas recirculation (like in an automobile) can be used for temperature control. Because of the reduced offgas flow rate, the air pollution control systems are reduced in size and emissions are reduced. With an appropriate offgas control system, all regulations can be met with large safety factors. The exhaust gases are  $CO_2$ , water vapor, and some N<sub>2</sub>. NOx is, rarely an issue because the low nitrogen content combined with temperature control results in negligible NOx formation.

The solid and liquid "ultimate" waste effluent is negligible if not eliminated. The primary product can be recycled as aggregate, bricks, or a higher-valued product. Depending on the economics, three options exist for the condensables: 1) use to form a low-temperature construction product, 2) store until extractive metallurgy can be done in quantity of the metals, or 3) send to a classified landfill. The chloride and sulfur precipitates can be used to augment road salt mixtures or disposed of, as appropriate for the local area.

The initial waste characteristics are totally altered by the treatment process. Liability for the original waste is eliminated or assumed by the purchaser of the (raw) product. This feature is a major consideration for industrial hazardous wastes.

For large systems, e.g., several hundred tonnes/day, the installation of a PAMS can provide an economic advantage, even over that of the present WTE plants. The tipping fee represents a <u>negative</u> raw material cost, which is a bonus for a manufacturing or industrial business. The waste haulers still get their business. The processing plant simply replaces the landfill, eliminating all the problems associated therewith and turning the waste into a raw material for producing useful products. Plants operate around the clock, with a 70% or higher duty cycle. Specific economics are discussed later.

PAM pilot plants have been built and operated for a number of The U.S. Department of Energy has funded applications. demonstration work on both PTM and GAM treatment of low-level radioactive and hazardous wastes. Much of this waste is similar to MSW. Most of the pilot plants used in recent DOE-funded research range in size up to approximately 1-tonne/hour, are operational, and are available for testing. A Retech PTM with a rotating chamber that taps when the rotation slows (see Fig. 2) is installed at the Western Environmental Center operated by Mountain States Energy in Butte, Montana (Ruffner, 1994). A similar, but larger, unit is to be used in treatment demonstrations of Pit 9 at the Idaho National Engineering Another Retech PTM is employed by SAIC in the Laboratory. plasma hearth melter configuration (see Fig. 3, Wolfe, 1995). Preliminary cold testing was done at Retech in Ukiah, California and at the SAIC STAR Center in Idaho Falls, Idaho. Electro-Pyrolysis, Inc. installed and tested a GAM with concentric graphite electrodes and a graphite chamber at Massachusetts Institute of Technology (see Fig. 4, Watkins, 1993).

The American Society of Mechanical Engineers and the U.S. Bureau of Mines sponsored a project on vitrification of incinerator ash from a variety of municipal incinerators using a 3-phase AC GAM (Hollander, 1995). This facility has been modified by the Bureau of Mines and the Department of Energy to treat combustible waste, operates at near capacity of 1-ton/h, and is one of the most complete pilot plants available as a user test facility (see Fig. 5, Soelberg, 1995). Many other PAM test facilities and installations are discussed elsewhere (Eddy, 1992). The above pilot plants have demonstrated the robust processing of heterogeneous waste streams, including combustibles, and the generation of extremely stable waste form products that meet regulatory requirements.

#### TYPICAL PLASMA ARC MELTER SYSTEMS

A conceptual plasma arc melter system is shown in plan view in Fig. 6a and in elevation in Fig. 6b. This system is a 1-5 MW PAMS for treating radioactive and hazardous waste. Corresponding flow diagrams are shown in Fig. 7 (with a preheater/pyrolizer before the melter) and Fig. 8 (without the preheater/pyrolizer) as shown in Fig. 6. Flow rates are given in Fig. 7 for selected components and different input waste streams. The system shown is for low-level radioactive waste treatment based on a 1-tonne/h throughput, which is relatively small for MSW plants. MSW applications are expected to be from 200 to 1000 tonne/day throughput capacity. For larger flow rates, the values in Fig. 7 can be considered as on a tonne/h basis. The illustrations are for a low-level radioactive waste with six major heterogeneous input waste streams that are predominantly glass (G1), metal (M1), combustibles (C5), Portland-cemented organics (P), organic liquids adsorbed in Oil-dri (S), and a hydrated metal oxide sludge in drums (HD1) as described elsewhere (Eddy, 1992 & 1995). The combustible stream, C5, is the closest to MSW.

Front-end staging will be similar to that for WTE plants. The feedstock would be prepared through appropriate shredding systems that would size the material relative to the size of the melter system with a nominal size of 2 to 6 inches. In small systems, sizing will be necessary to be able to feed the material into the melter in a sufficiently dense form to meet power-density capabilities of melters.

Several melter configurations are shown in Figure 1. Additional options include the cupola and non-transferred torch system of Westinghouse (McLaughlin, 1995) and the "silo" and non-transferred Aerospaciale torch used by Europlasma and INERTAM (Francois, 1994). The selection of a PAMS is affected by the composition of the waste, the recovery methods to be applied, and the sizing requirements. For more than 240 tonnes/day, an MSW plant would require more than 10 MW of melter power, which may be more conveniently obtained with one GAM or multiple PTM systems. Essentially all of the systems will work, but some will have economic advantages not achievable by others.

For large systems, production of a syngas to produce liquid hydrocarbons is advantageous because of the higher-value-added product. The capital cost and minimum throughput capacity requirements for a methanol system dictate capacities larger than 200 tonnes/day. Site-specific economic studies are required to justify this option.

For medium-sized and larger systems, cogeneration of electricity and/or district heating is an option. A medium heating value fuel gas can be generated that is about 400 Btu/ft<sup>3</sup> compared to 1,000 Btu /ft<sup>3</sup> for natural gas. Cogeneration of electricity can be accomplished with gas-turbine generators for lower capacities, steam-turbine generators for large capacities, and combined systems for intermediate capacities. Calculations indicate that more power is generated than used by the melter and auxiliaries; hence, electric power can be marketed.

The primary waste form or solid product is a glass-ceramic and can be recycled as a low-value aggregate for construction or cast into bricks or other higher-value construction products. The size and sophistication of the casting plant depends on the MSW plant capacity. The aggregate is made by tapping the molten glass into water whereby it is granulated by the rapid quenching. Casting plants would emulate metal casting plants, with the appropriate modifications for glass-ceramic versus metallic melts.

Offgas control can be achieved using "dry-wet," "wet-dry," or "dry" offgas control systems. A dry-wet offgas treatment system (see Fig. 9) can be used for separating filtered particulate from the salts of scrubbed acid gases for return to the melter, generation of a secondary solid construction product, or special waste stabilization and disposal. Typical components can include a post combustor (to efficiently oxidize pyrolysis products), spray-dry quench, air quench, cyclone, baghouse filter, acid-gas scrubber, reheat, prefilter, activated carbon filter, HEPA filter, and stack. Three major output streams exit as dry particulates collected in the cyclone and baghouse, scrubber solution with dissolved and undissolved material, and the cleaned gaseous exhaust. Inclusion of final filtration equipment downstream of the wet scrubber may be unnecessary for most systems except those designed for processing radioactive waste. The extremely small amount of material reaching the prefilter, carbon, and HEPA filters can be returned to the melter by shredding the filters and feeding them into the melt. Otherwise, the filters can be reactivated with the contaminants being returned to the melter, stabilized in the secondary product, or disposed of separately.

Dry offgas treatment systems use sorbent injection upstream of the baghouse to scrub acid gases in the baghouse. This eliminates the wet scrubbing step and can result in a single dry secondary waste form.

A wet-dry offgas treatment system (see Fig. 10) can be used when one secondary waste form or product is appropriate. This is the offgas system shown in Fig. 6a&b. The particulates and acid gas salts are collected together in the scrubber sludge and marketed or disposed of as discussed above. This system precludes the formation of dioxins, gives a much more compact offgas system with lower capital cost than the dry-wet system. Typical components can include a post combustor, a spray quench and acid gas scrubber, demister, reheater, and prefilter, activated carbon, and HEPA filters as appropriate, and stack.

The actual offgas treatment system for a PAMS recovery plant will depend on the plant components. In a PAMS with a methanol plant, electrical cogeneration, and a brick plant, the melter would be the first stage of reforming the syngas, followed by a syngas reactor, a syngas cleanup system for removing condensables and particulates, as well as the chlorine and sulfur compounds, the methanol plant, the cogeneration plant which provides the secondary combustion and appropriate final filters.

#### ECONOMICS

Present assumptions represent approximations based on the selected scenario. For an actual location, cost values are site-specific and estimates must be made in detail for that site. A typical composition of MSW is given in Table I for the economic calculations in this paper. Typical flow rates are given for an input of 240 tonnes/day. The concentrations are limited to the major components for the economic calculations. Other calculations, not included here, are used to design the components to obtain the desired efficiency.

The potential partitioning of the MSW can be estimated from the compositions given in Table I. The composition used is similar to a Class 2 refuse with about a 60/40 rubbish/garbage split. The water (40 wt%) will be either exhausted, partially condensed, or used in reforming the syngas. The hydrocarbons (42 wt%) can be partially converted into liquid organics and/or burned in a cogeneration plant. The metal (5 wt%) is salvageable as a pig iron. The ash residue (10 wt%) can be made into aggregate or bricks. For this example it is assumed that the ultimate hazardous waste is as large as 1-wt%, which could be a component of a low temperature concrete. Each MSW treatment site must be evaluated for the typical composition of its waste to obtain valid product flow rates and economics.

The data for the calculations were run under certain assumptions. Units are in Standard International Units (metric tonnes, etc.). Currency is in US Dollars. Plant operating duty cycle is 70% with a 5-shift, around the clock operation. Base plant costs were used as reference to calculate the current plant costs corrected

for size. A 250 tonne/day melter processing plant is estimated to cost \$20,000,000. A 60 tonne/day methanol plant cost is estimated at \$4,500,000. A combined cycle cogeneration plant costs \$750,000 per MWh. A 100 tonne/day casting plant costs \$3,800,000. A 100 tonne/day aggregate plant costs 1/3 of a casting plant. Estimated product recovery unit costs include methanol at \$0.80 per US gallon, electricity bought/sold at \$0.05 per kWh, and scrap iron at \$200/tonne. The basalt by-product is made into bricks and sold for an estimated \$0.40 per brick or \$400 per tonne. Salt (sodium chloride) has a resale value of \$20 per tonne. Toxic metals and waste can be disposed of for \$400 per tonne. Operating cost assumptions included insurance that could be arranged for 0.67% of the capital cost. Labor for 5-shift operation would require 20 personnel at the melter facility, with additional personnel as needed for the product plants. Salaries averaged \$40,000 per year. Annual maintenance costs are assumed as 5% of capital costs.

Table II gives the electric power requirements for the melter, based on 8.0 Mwh/tonne for a 240 tonne/day MSW plant. Tables III and IV give the capital cost and operating cost values for the same plant assuming methanol generation, electric cogeneration, and a brick plant in operation.

It is important to know the capacity ranges when the various product options become economical. These are site specific. Typical examples are plotted in Fig. 11 for the MSW composition considered here. The options considered are based on combined cycle cogeneration systems. The plot gives the effective tipping fee (negative raw material cost) in \$/tonne versus throughput in tonnes/day. The tipping fee is that required to reach the breakeven point at that capacity. Front end costs, amortization of capital costs, and operating costs are included.

As expected, at low throughput the tipping fees would need to be astronomical to pay for the treatment costs. Some Class I landfills are charging \$400/tonne, so at 30 tonnes/day, some hazardous wastes could be treated economically (<\$400/tonne tipping fee). Stabilization costs for electric arc furnace dust are between 200 and 300 \$/tonne, so processing rates of around 100 tonnes/day are economical. This is also affected by zinc prices. For MSW, tipping fees range from \$15/tonne in the Western U.S., to between 60 and 120 \$/tonne in the East; therefore, the MSW plant size threshold is about 200 tonnes/day.

The more value-added product options, the lower the cost. However, the difference added by the methanol option may only be justified at the largest throughputs. These plots are shown as examples only. For accurate results, site-specific data must be used.

Cost differences using gas turbine generators, steam turbine generators, and combined cycle power plants were also evaluated. Even though their base costs were different, there was little difference indicated between the cogeneration options over the throughputs of Fig. 9 when added to the rest of the system costs.

#### CONCLUSIONS

Though there are no operating plasma arc melter MSW treatment systems, the success of WTE plants, the design of similar plants using commercially available equipment, and the potential environmental and economic advantages of PAMS for large capacity systems indicates that PAMS are probably the next generation in environmental solutions.

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	Percent	Tonnes/day	Tonnes/hr	Tonnes/yr
Input feed				
% Water	40	96.0	4.00	23,520
% Hydrocarbons	42	100.8	4.20	24,696
% metal	5	12.0	0.50	2,940
% ash/slag	10	24.0	1.00	5,880
% halogens/sulfides	2	4.8	0.20	1,176
% toxic metals, waste	1	2.4	0.10	588
Total	100	240	10.00	58,800

Table I. Typical MSW composition used in the economic calculations.

Table II. Electric power requirements for the melter,

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Power Requirements	MWh/Tonne	MWh/day	MW max	MWh/vr	
	0.8	192	8.00	47,04	

based on 8 0 Mwh/tonne and 240 tonnes/day

Capital Costs	Base Cost	Debits	Credits
Melter Processing Plant	20,000,000	19,595,918	
Methanol Plant	4,500,000	2,485,576	
Cogeneration Plant	1,000,000	2,548,967	
Casting Plant	3,800,000	1,614,025	
Total Capital Costs:	29,300,000	26,244,486	
Up Front Cost	20%	5,248,897	
Bal: 10 yr depr. @ 10%	20,995,589	(\$3,416,935)	
UpFr: 10 ут depr.@ 10%	5,248,897	(\$854,234)	

Table III. Capital cost calculation for a 240 tonne/day MSW plant.

Table IV. Annual operating cost calculation for a 240 tonne/day MSW plant including amortization of capital costs.

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Annual Operating Costs	Base Cost	Debits	Credits
Insurance: % of Capital	0.67%	175,838	
Electricity(\$/kWh)	0.05	2,352,000	
Labor (20 personnel/plt)	40,000.00	800,000	
Prod. Cost - Methanol	1,642,500	438,068	
Labor Cogeneration Plt		160,000	
Prod. Cost Casting Plt	1,500,000	555,783	
Maintenance(5% of cap)	5%	1,312,224	
Amortization Costs: Bal		3,416,935	
Amortization Costs: Bonds		854,234	
Methanol recovery: \$/gal	0.80		1,568,331
Elect. Cogen: \$/kWh	0.05		1,636,109
Iron recovery: \$/tonne	200.00		588,000
Basalt recovery: \$/tonne	400.00		2,352,000
Salt recovery: \$/tonne	20.00		23,520
Toxic metal disposal:\$/t	400.00	235,200	
Tipping fee: \$/tonne	70.28		4,132,324
Subtotals		10,300,283	10,300,283
Net Profit			0































Fig. 7. Flow diagram for the conceptual plasma arc melter system with a preheater/desorber/pyrolyzer before the melter.



Fig. 8. Flow diagram for the conceptual plasma arc melter system with no preheater/desorber/pyrolyzer before the melter of Fig. 6a&b.



Fig. 9. Flow diagram for the dry-wet offgas system for the conceptual plasma arc melter system.





Wet / Dry Offigas Treatment System May 3, 1995



Keq. Tipping Fees (\$/tonne)