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Suspension Firing - The Heart of An Integrated Waste-to-Energy System

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ABSTRACT

Initially, Waste-to-Energy Systems were built for the sole purpose of reducing the volume of waste to be landfilled. The energy released by burning waste was converted to steam and electricity which was used to operate the facility and surplus energy was sold. With increased public interest in recycling and conservation of resources, a heirarchy established by EPA integrating waste disposal into four acceptable approaches, Reuse (of products), Recycling (of the materials in the waste for new uses), Waste-to-Energy (burning of the wastes to produce energy) and, as a last and least desirable solution, landfill. This paper examines the Integration of waste disposal activities after delivery of the waste to a Waste-to-Energy Facility.

In 1989, Energy Answers Corporation (EAC) opened the SEMASS suspension-fired 2700 tons per day facility in Rochester, Massachusetts. The technology minimizes landfill needs by accomplishing extremely good burnout of the waste and by recovering for recycling virtually all the valuable materials in the bottom ash. Efficient energy recovery as accomplished at SEMASS can encourage development of industries nearby by providing low cost energy and recovered metals are a source of raw materials. The Boiler Aggregate™ produced at SEMASS, can replace natural aggregates in concrete and asphalt applications. The system also has been shown to be capable of burning selected industrial wastes, high moisture wastes and sewage sludge which can be a useful service for the industries.

This paper discusses EAC's experience at providing significant integration and presents a roadmap for development of further integration in the future. The paper also presents the case for private development in which communities could be shareholders but where technical and managerial decisions remain in the hands of private management.

INTEGRATION OF WASTE DISPOSAL, ENERGY AND RECYCLING

There has been a great deal of talk about "Integration" of Waste Disposal Services and yet little indication as to what is meant by the term. With increased public interest in recycling and conservation of resources, the United States Environmental Protection Agency some ten years ago developed a concept of an Integrated Waste System. Under the protocol established by EPA, waste handling was prioritized into four distinct steps, Reuse (of products), Recycling (of the materials for different uses), Waste-to-Energy (burning of the wastes to produce energy) and, as a last and least desirable solution, landfill. This paper examines the Integration of Waste Management after the first two steps have taken place and stresses the need for technology which will enable additional recycling of material and minimization of landfill.

I first learned of the term "Vertical Integration" years ago, when I was involved in the design of a dill pickle factory where the manufacturer provided seed to selected farmers and guaranteed to purchase each farmer's entire crop of cucumbers. This first step assured that the quality and quantity of cucumbers available to the manufacture would meet his needs. All sales of the finished product were negotiated directly between the manufacturer and the ultimate users such as restaurants and stores and all shipping was directly from the factory. This Vertically Integrated approach is still used and the company has become very successful. And the pickles were, and still are, delicious.

Energy Answers Corporation believes that it is possible and appropriate to Vertically Integrate Waste Disposal and the steps are fairly clear:

- Receipt of Waste
- Combustion of Waste
- Generation of Steam and Electricity
- Recovery of Valuable Materials
- Sale of Recovered Materials to Manufacturer
- Sale of Energy to Manufacturer
- Sale of Manufactured Products

These activities are demonstrated graphically in **Figure 1**.

A key to the success of this approach is to be able to economically recover materials for reuse, to generate energy efficiently and to provide the necessary incentives which will encourage industries which can use the recovered products as raw stock. Such incentives can be an adequate supply of raw material, a market for the finished products and low cost energy. And if, during initial site planning, space has been allocated for industrial development, low cost land can be an additional incentive.

THE EAC PHILOSOPHY

Modern Waste-to-Energy systems are generally large scale in order to justify the high costs of sophisticated pollution control systems required to meet the ever more stringent standards being applied by regulatory agencies. And to accomplish the thorough and efficient recovery of valuable materials can require a significant capital investment even though the equipment and the separation capacity may, even in the smallest facility, be far greater than the total plant requirements.

Although there are many ways to separate valuable materials for recycling, EAC's approach has been that the items in the waste which are most likely to attract prices which justify the cost of separation are non-combustible materials such as metals. Although scrap metal values can fluctuate somewhat, the range of values is narrow and metals are easily stored to wait for the prices to rise. Paper is often separated in public recycling approaches, but the costs of separating, processing and transportation are often much greater than the income which can be generated from sales. Plastics for recycling require extensive and accurate separation into categories and processing and the light weight of plastics makes for a very expensive product which often cannot attract a price which will cover costs. Burning the plastics in combination with other wastes converts the high energy in the plastics into useful steam and electrical energy. Fears of possible dioxin generation and other pollution problems due to burning plastics have proven to be unfounded with high temperature combustion and state of the art air pollution controls.

The recovery of metals and other valuable non-combustibles from the waste in the EAC technology can be compared to "finding a needle in a haystack". If the hay is burned, the needles can be easily found. The same applies to the recovery of materials from Solid Waste. If the combustible material in the waste is first burned, recovery of the non-combustible materials is much easier and more efficient.

Finally, one of the most important recovered products is energy generated by the combustion of high heating value waste to generate steam and electricity which replaces fossil fuels used in power stations.

This approach is well demonstrated in the award-winning SEMASS Resource Recovery Project in Rochester Massachusetts. This paper provides a description of the activities which are in place at SEMASS, the attempts, successes and failures, and the possibility of further successes in the future.

THE SEMASS FACILITY

SEMASS receives about one million tons of waste each year. It recovers for recycling over 40,000 tons of ferrous metal, 4,000 tons of non-ferrous metals and 85,000 tons of Boiler Aggregate^{TM}, an aggregate which is generated from the non-metallic non-combustibles in the bottom ash. An interesting note is that from the non-ferrous metals, coins valued at between $800 and $1000 are retrieved each day and sent to the mint for redemption.

In addition, the facility annually generates over 650,000 megawatt-hours of electricity, 86% of which is purchased by the local power company and as a result, each year, the power company's consumption of oil is reduced by 66,000,000 gallons.

Recognizing that the heavy metals accumulated in the fly ash can cause problems with leachate contaminating underground water, SEMASS conditions the fly ash using a patented system prior to delivering the material to landfill. EAC is investigating potential uses for the conditioned fly ash in order to eliminate the need to landfill the material.

The SEMASS project has welcomed several hundred visitors from Asia who have toured the facility. However, for those who are not familiar with the technology, a brief presentation of how it works will provide an understanding of how it enabled SEMASS to provide "Integrated" services.

THE TECHNOLOGY... IDEAL FOR INTEGRATION

The EAC technology as used at SEMASS is shown in graphic form in **Figure 2**.

Waste Receipt

After crossing the weigh scale, the delivery vehicles discharge the waste onto the tipping floor. As a waste is dumped, an attendant watches for unacceptable materials and either refuses them or sets them aside. Unacceptable items are such things as large rolls of carpet or wire fencing, tires, tree trunks and similar items which should not be processed in the shredders. At both the weigh scale and the tipping floor, the waste is scanned for any radioactive content.

Waste Processing to Create Processed Refuse Fuel (PRF)

From the tipping floor, the waste is delivered by loaders to conveyors feeding shredders which reduce all the material to pieces of nominal maximum size of 15 to 20 cm. Most of the particles in the shredded waste are below 5 cm and friable materials such as glass are much smaller still. This shredded waste is then conveyed under magnets which remove most of the ferrous metals for sale to metal scrap dealers. The balance of the material remaining after magnetic separation is Processed Refuse Fuel or PRF. Although PRF is in fact a "Refuse Derived Fuel", the name PRF has been adopted to distinguish PRF from other Refuse Derived Fuels such as "fluff" and "pellets" which require extensive processing of the waste compared to the two-step processing used by EAC.

Combustion of the Heavy Materials in the PRF

PRF is fed into automatically controlled feed systems which blow the PRF into the furnace section of water wall boilers, similar to boilers used in coal-burning power stations.

Heavy materials drop onto a simple horizontal moving grate at the bottom of the furnace. The material on the grate consists of non-combustibles such as metal, glass, ceramic and sand combined with small pieces of heavier combustible materials such as wood. The grate moves from back to the front of the furnace over a one hour period with a 20 to 30 cm deep bed on top. For the first 2/3 of the 6 meter long grate, the heavy combustible materials burn and on the last 1/3, the material on the grate is merely a granular ash being cooled by underfire air coming through the grate. It should be noted that grate temperatures are kept below the melting point of glass to avoid slag formation. Because of the long period allowed for the combustibles on the grate to burn, this "bottom ash" contains less than 1/2% unburned carbon.

Combustion of the Light Materials in the PRF

The lighter materials in the PRF go upwards in the furnace and catch fire in midair forming a high temperature "fire-ball" a few meters above the grate. In this location, because of the ease with which the fuel (PRF) can intermix with air, there is a reduced need for excess air into the system and thus temperatures of up to1250°C are reached . Any dioxins which have formed are promptly destroyed when passing through this high temperature zone. The lower excess air provides maximum thermal efficiency and therefore more electricity is generated per ton of waste than would normally be accomplished in a common mass burn system.

Exhaust Gas Treatment

The time period during which boiler exhaust gases pass through the dioxin-generating temperature range is very short and should any new dioxins be formed, they are subsequently captured in the spray drier where acid gases are neutralized. The gases then pass through a baghouse (fabric filter) where the particulate matter is captured and transported in sealed conveyors to the fly ash silo.

Table 1 shows results of exhaust gas testing at SEMASS. This table compares actual results with the most recent MACT Standards but for the purpose of this conference, all values are expressed in units used in Japan.

Ash Handling

Unlike other Waste-to-Energy systems, in the EAC technology, bottom ash and fly ash are collected and handled separately.

The bottom ash, which is generally granular in form, is discharged from the boiler without quenching in water and transported to the on-site Bottom Ash Processing Building. In this building, using EAC's patented Ash-Processing System, three products are recovered, the ferrous metals not removed prior to combustion, the non-ferrous metals and Boiler Aggregate^{TM}, a granular material which can be substituted for natural aggregates used for landfill daily cover and as an ingredient in asphalt and concrete. The non-ferrous metals are sold to a dealer who separates the contents of the mix into separate metals and the ferrous metals are sold to scrap dealers.

Because the heavy metals concentrate in the fly ash, fly ash is conditioned as it is discharged from the silo into trucks for delivery to the landfill. Within 24 hours, the conditioned fly ash hardens into a concrete-like material which, although not high strength, does not absorb water. Testing of the conditioned fly ash using state-mandated procedures indicates that the heavy metals are permanently bound in and will not leach.

Table 2 shows the test results for the Bottom Ash.

Table 3 shows test results for the Fly Ash.

Although the Boiler Aggregate™ has been used (with regulatory approval) for the purposes described above, investigation of uses for the fly ash are ongoing but no conclusions have yet been reached.

It is quite clear that with the EAC Technology at the heart of the system, SEMASS is a good example of Vertical Integration of Waste Disposal. It is also clear that such vertical integration is possible because of the extraordinary ash quality which is accomplished by the Shred-and Burn Suspension Firing System. The integrated procedures in place at SEMASS can be easily identified and listed:

1. **Receipt and storage of the waste**. Waste deliveries take place from 6 AM to 6 PM and a large tipping floor provides storage for over 4000 tons of waste.

2. **Inspection of the waste to remove unacceptable materials**. Metals are retrieved for recycling and other unacceptable items are landfilled. Approximately 1.5% of the waste is removed at this stage.

3. **Shredding of the waste and magnetic separation of ferrous metals.** Over one half of the ferrous metals in the waste are recovered for recycling at this stage and the shredded waste left is now Processed Refuse Fuel (PRF). This stage takes place during 16 to 18 hours each day. PRF is sent to an 5000 ton storage area.

4. **Feeding of the PRF to the boilers**. SEMASS has three boilers which operate 24 hour per day, 7 days per week.

5. **Combustion "In-Suspension" of the PRF.** The PRF is blown into the furnace section of the boiler. Because of the shredding process, refractory linings are not needed in the furnace to protect against tube damage due to sharp metal objects. This lack of refractory improves heat transfer into the water walls and eliminates formation of slag on the tubes due to melting glass.

6. **Removal of the bottom ash from the boilers.** The ash is discharged from the boilers without water quenching and delivered continuously to storage in the on-site bottom ash processing facility. Lack of quenching reduces minimizes water consumption at the plant and eliminates a source of water pollution.

7. **Removal of the fly ash collected in the air pollution control equipment**. This material is transported continuously and is stored in silos. It is interesting to note that the percentage of the ash which is fly ash is greater than in mass burn systems. However, in the EAC Technology , the fly ash is not mixed with the bottom ash but instead is conditioned and landfilled.

8. **Conditioning of the fly ash**. The fly ash is removed from the silos as necessary and as it is removed, additives are mixed with it which lock in heavy metals in order to avoid leaching out of these metals in the landfill.

9. **Delivery of the fly ash to the landfill.** SEMASS delivers the conditioned fly ash to the landfill which is operated by SEMASS.

10. **Processing of the Bottom Ash.** The on-site Ash Processing facility recovers the metals for recycling and the non-metallic non-combustible materials in the form of Boiler Aggregate™ which has been used as a substitute for natural aggregates in asphalt and concrete products and as a landfill vent layer cover material.

11. **Sale of metals for recycling.** Ferrous metals are sold and the metal is ultimately melted down for th manufacture of new steel. The mixed non-ferrous metals are sold to a company which separates componen metal which are sold for the manufacture of new metals. Coins are also recovered and redeemed at the mint

12. **Sale of electricity.** After providing the power needed to operate the facility (14% of total electricit production), the balance of the power is sold the local Power Company which is able to reduce its oil need by over 60,000,000 gallons per year.

13. **Wood Waste Composting.** EAC recognized that another opportunity for integration was creation of facility which could receive wood waste and convert it into useful materials for the landscaping industr Thus, EAC owns and operates a composting facility which provides this service to SEMASS' customers an others who generate wood waste.

EXPANSION OF INTEGRATION ACTIVITIES

Although EAC can claim Vertical Integration from receipt of the waste to sale of raw products and energ nevertheless additional integration could take place. In the design of the SEMASS facilities, EAC foresaw th possibility of additional activities which could become part of the overall system. To this end, the SEMASS sit allocated some 30 acres of land for the future development of industrial activity which could take advantage of bein close to a source of low cost raw materials and potentially low cost energy.

Figure 3 is a graphical representation of potential developments which would be possible with the Waste-to-Energ facility as the linchpin which justifies the total integration from receipt of waste to manufacture of finished products

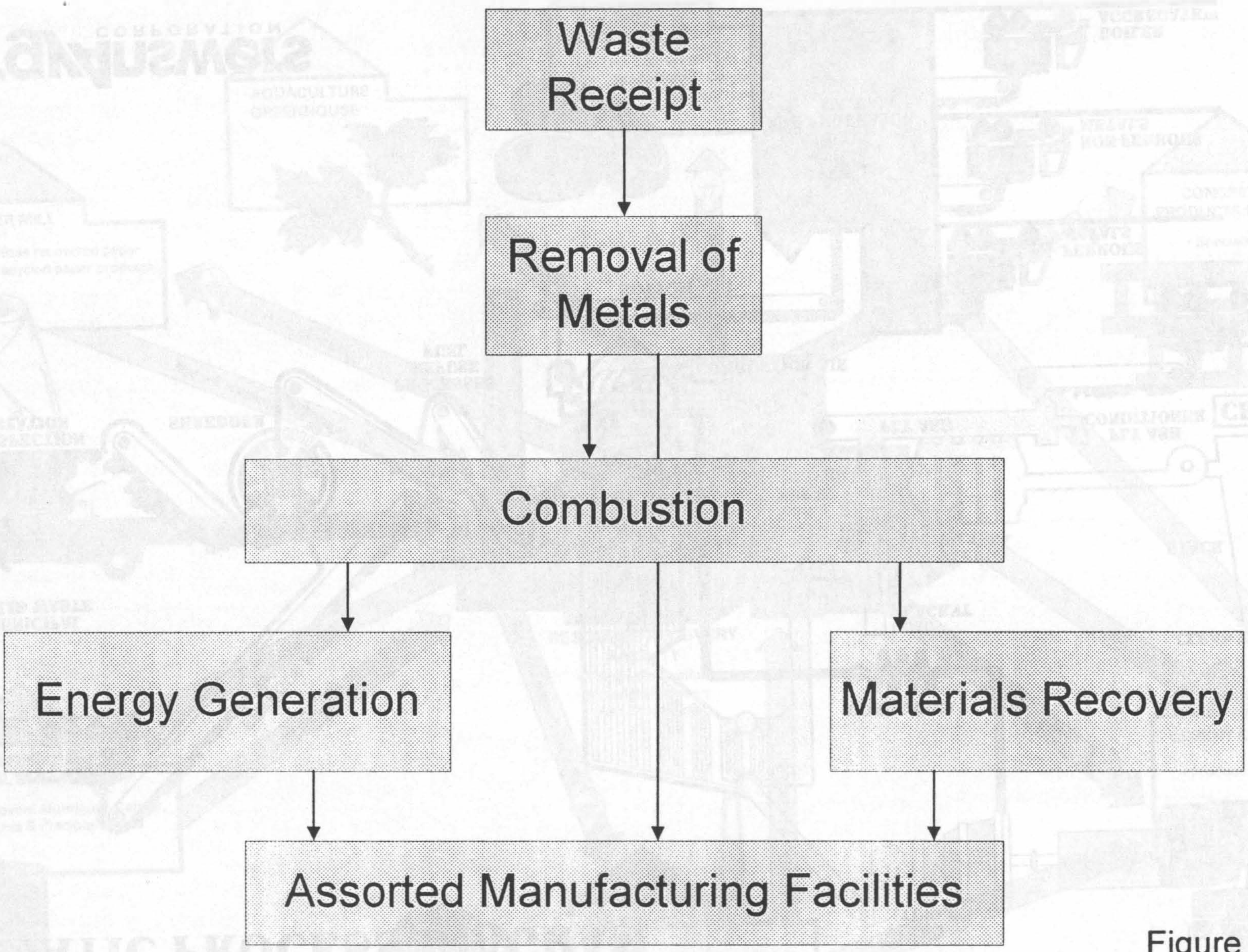
Whether it is appropriate for the owner of the Waste-to-Energy Facility to also own and operate the ancillar facilities which could be part of Vertical Integration is an open question. More likely, the plants which can use th raw products supplied by the waste facility would be provided by companies already in the business. In this manner purchasers of the raw material generated by the waste-to-energy facility would be expert in the technology and woul also have a ready market for their finished products.

In September 1998, EAC began construction of a facility in New York State which will manufacture compost fro organic waste. This is EAC's latest activity towards to integration and avoidance of landfill.

The Total Integration of Waste Disposal and Full Resource Recovery including Manufacture of Products made fro Waste has not yet taken place but components of the system are no doubt in place throughout the world. An of quoted demonstration is a group of industries in Denmark which over a 25-year period has developed into a unofficial Industrial Park where one manufacturer's waste is another's raw material.

Perhaps the first full integration will take place in Asia where Energy Answers Corporation intends to be a key lin in the chain which will lead to Vertical Integration from Waste to Reuse.

Vertically Integrated Waste Disposal



Waste Receipt

Removal of Metals

Combustion

Energy Generation

Materials Recovery

Assorted Manufacturing Facilities

Figure 1

SCHEMATIC PROCESS DIAGRAM

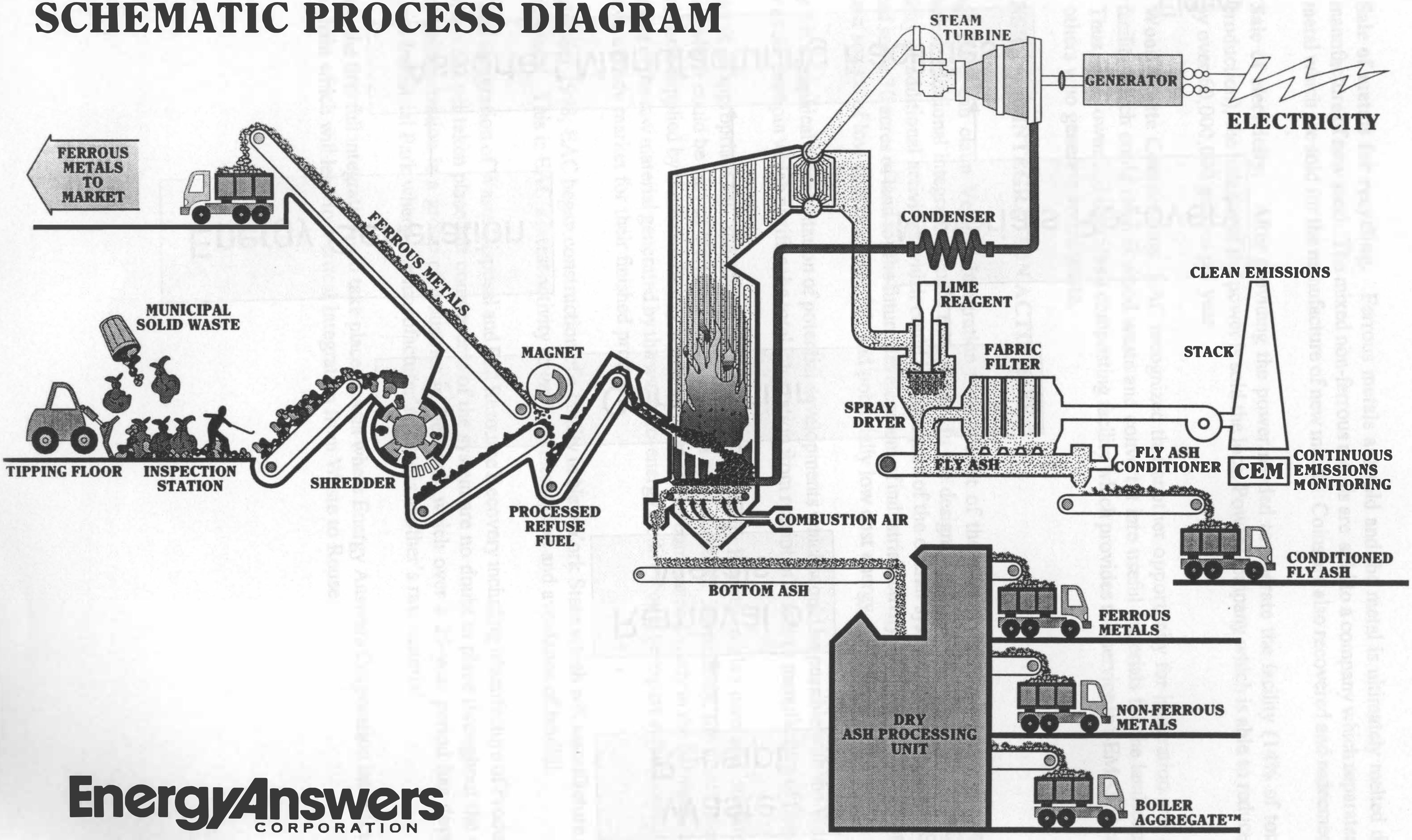


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Figure 2

INTEGRATED INDUSTRIAL RESOURCE RECOVERY COMPLEX

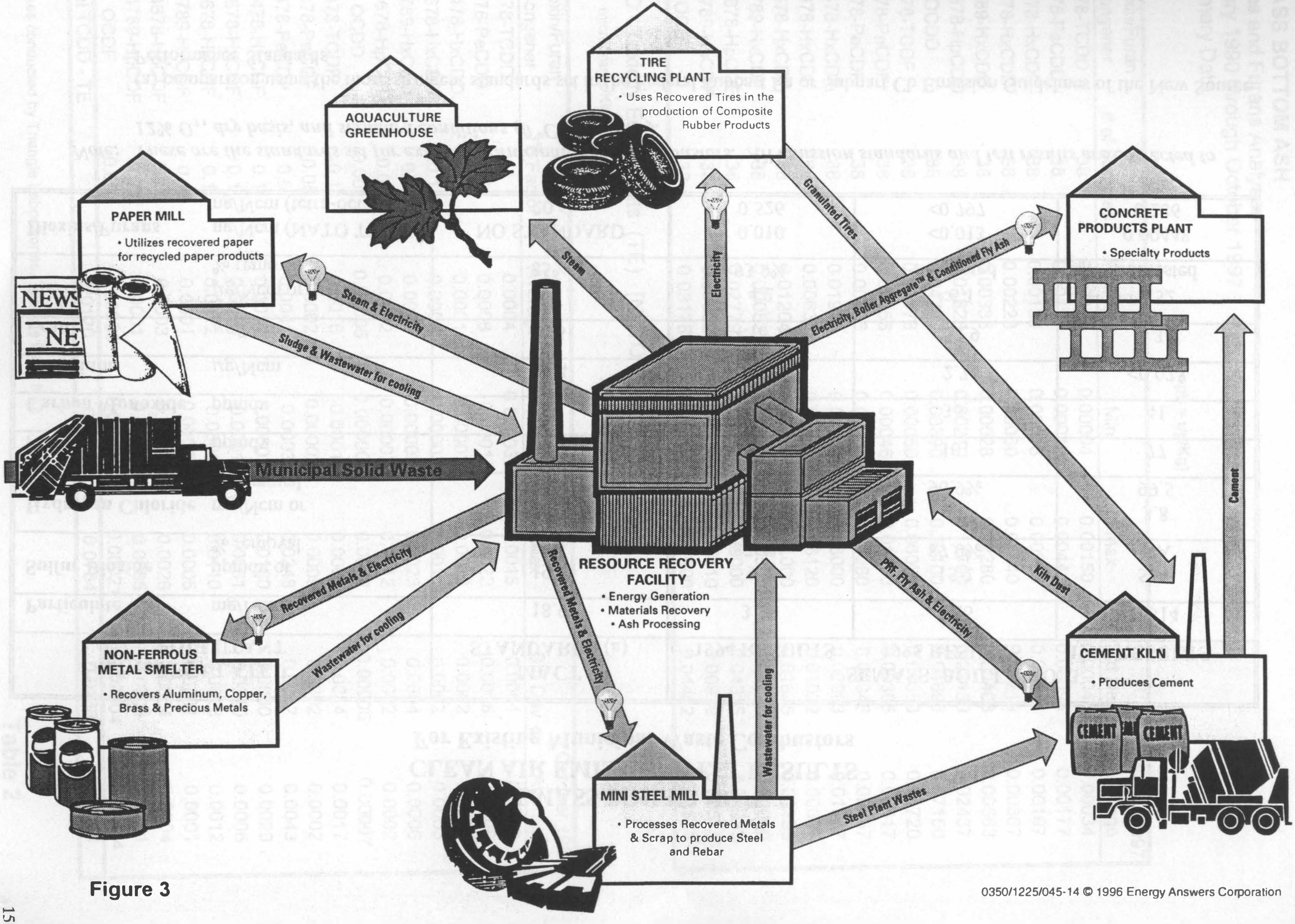

Figure 3

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SEMASS BOILER NO. 3
CLEAN AIR EMISSION TEST RESULTS
For Existing Municipal Waste Combustors

REGULATED POLLUTANT		MACT STANDARDS (a)	SEMASS BOILER NO. 3 1994 RESULTS	1995 RESULTS	1996 RESULTS
Particulate	mg/Ncm	18.9	3.15	1.26	0.314
Sulfur Dioxide	ppmdv or % removal	19.2 80%	9.4 87.4%	15.2 87.0%	5.96 NA
Hydrogen Chloride	mg/Ncm or % removal	26.1 95%	2.9 96.2%	4.6 96.9%	3.8 99.5
Nitrogen Oxides	ppmdv	115	86	101	77
Carbon Monoxide	ppmdv	96	40	36	41
Cadmium	μg/Ncm	27.4	0.89	2.7	<0.075
Lead	μg/Ncm	336	<16.7	<53.9	4.36
Mercury	μg/Ncm or % removal	55 85%	4.2 93.9%	<6.1 not tested	2.52 not tested
Dioxins/Furans	ng/Ncm (NATO TEQ) ng/Ncm (tetra-octa)	NO STANDARD 20.6	0.010 0.526	<0.013 <0.797	0.00448 0.286

Note: ***These are the standards set for existing Municipal Waste Combustors. All emission standards and test results are corrected to 12% O_2, dry basis, and standard conditions (0 °C and 1 atm).***

(a) comparison using the more stringent standards set in the Federal Subpart Ea or Subpart Cb Emission Guidelines of the New Source Performance Standards

Table 1

SEMASS BOTTOM ASH
Dioxins and Furans Analyses
January 1990 through October 1997
Summary Data

(ppb = ug/Kg)

Dioxin/Furan Congener	# of Samples	Average	Min	Max	Std Dev	October 1997 Average
2378-TCDD	38	0.00045	0.00004	0.00150	0.00043	0.00034
12378-PeCDD	38	0.00117	0.00010	0.00440	0.00096	0.00177
123478-HxCDD	38	0.00139	0.00016	0.00980	0.00163	0.00197
123678-HxCDD	38	0.00223	0.00030	0.01140	0.00219	0.00307
123789-HxCDD	38	0.00333	0.00028	0.02280	0.00403	0.00563
1234678-HpCDD	38	0.01828	0.00210	0.11700	0.02180	0.02437
OCDD	38	0.04709	0.00390	0.20100	0.04698	0.07150
2378-TCDF	38	0.01578	0.00050	0.06000	0.01358	0.01720
12378-PeCDF	38	0.00356	0.00046	0.01770	0.00365	0.00417
23478-PeCDF	38	0.00816	0.00060	0.04960	0.00946	0.00857
123478-HxCDF	38	0.01943	0.00030	0.18000	0.02983	0.01967
123678-HxCDF	38	0.00632	0.00059	0.06120	0.01022	0.00627
234678-HxCDF	38	0.01204	0.00100	0.11000	0.01845	0.01153
123789-HxCDF	38	0.00082	0.00010	0.00500	0.00090	0.00060
1234678-HpCDF	38	0.02779	0.00250	0.26000	0.04315	0.04233
1234789-HpCDF	38	0.00502	0.00050	0.05410	0.00919	0.00513
OCDF	38	0.03178	0.00250	0.21000	0.04402	0.03577

TCDD - Toxicity Equivalents (TE) [NATO Standard]

(ppb or micrograms/Kilogram)

Dioxin/Furan Congener	TE Factor	Average	Min	Max	Std Dev	October 1997 Average
2378-TCDD	1	0.0004	0.000035	0.0015	0.0004	0.0003
12378-PeCDD	0.5	0.0006	0.0001	0.0022	0.0005	0.0009
123478-HxCDD	0.1	0.0001	0.00002	0.0010	0.0002	0.0002
123678-HxCDD	0.1	0.0002	0.00003	0.0011	0.0002	0.0003
123789-HxCDD	0.1	0.0003	0.00003	0.0023	0.0004	0.0006
1234678-HpCDD	0.01	0.0002	0.00002	0.0012	0.0002	0.0002
OCDD	0.001	0.00005	0.000004	0.0002	0.00005	0.00007
2378-TCDF	0.1	0.0016	0.0001	0.0060	0.0014	0.0017
12378-PeCDF	0.05	0.0002	0.00002	0.0009	0.0002	0.0002
23478-PeCDF	0.5	0.0041	0.0003	0.0248	0.0047	0.0043
123478-HxCDF	0.1	0.0019	0.00003	0.0180	0.0030	0.0020
123678-HxCDF	0.1	0.0006	0.0001	0.0061	0.0010	0.0006
234678-HxCDF	0.1	0.0012	0.0001	0.0110	0.0018	0.0012
123789-HxCDF	0.1	0.0001	0.00001	0.0005	0.0001	0.0001
1234678-HpCDF	0.01	0.0003	0.00003	0.0026	0.0004	0.0004
1234789-HpCDF	0.01	0.0001	0.00001	0.0005	0.0001	0.0001
OCDF	0.001	0.00003	0.000003	0.00021	0.00004	0.00004
Total TCDD - TE		0.0120	0.0016	0.0784	0.0138	0.0131

Analyses conducted by Triangle Laboratories, Triangle Park, N.C.

Table 2

SEMASS FLY ASH

Dioxins and Furans Analyses
January 1990 through October 1997
Summary Data

(ppb=ug/Kg)

Dioxin/Furan Congener	# of Samples	Average	Min	Max	Std Dev	October 1997 Average
2378-TCDD	38	0.0948	0.0412	0.24	0.0484	0.0567
12378-PeCDD	38	0.2615	0.096	0.604	0.1276	0.1943
123478-HxCDD	38	0.1901	0.078	0.55	0.1134	0.1593
123678-HxCDD	38	0.2480	0.0717	0.62	0.1369	0.1863
123789-HxCDD	38	0.4681	0.117	1.65	0.3257	0.3437
1234678-HpCDD	38	1.5289	0.508	3.43	0.8257	1.1200
OCDD	38	2.4755	1.05	5	1.1080	2.4533
2378-TCDF	38	2.2776	1	5.6	1.0096	1.2400
12378-PeCDF	38	0.9750	0.448	1.84	0.3693	0.5873
23478-PeCDF	38	1.1843	0.508	2.5	0.4809	0.7250
123478-HxCDF	38	1.9620	0.977	5.08	0.9921	1.1860
123678-HxCDF	38	0.9735	0.455	2.61	0.4730	0.6230
234678-HxCDF	38	1.2408	0.531	5.3	0.8854	0.6710
123789-HxCDF	38	0.1066	0.024	0.38	0.0752	0.0570
1234678-HpCDF	38	2.2813	0.931	7.76	1.4795	1.4243
1234789-HpCDF	38	0.4335	0.153	1.3	0.2329	0.2677
OCDF	38	1.0824	0.325	3.2	0.6397	0.6863

TCDD - Toxicity Equivalents (TE) [NATO STANDARD]
(ppb or micrograms/Kilogram)

Dioxin/Furan Congener	TE Factor	Average	Min	Max	Std Dev	October 1997 Average
2378-TCDD	1	0.0948	0.0412	0.2400	0.0484	0.0567
12378-PeCDD	0.5	0.1307	0.0480	0.3020	0.0638	0.0972
123478-HxCDD	0.1	0.0190	0.0078	0.0550	0.0113	0.0159
123678-HxCDD	0.1	0.0248	0.0072	0.0620	0.0137	0.0186
123789-HxCDD	0.1	0.0468	0.0117	0.1650	0.0326	0.0344
1234678-HpCDD	0.01	0.0153	0.0051	0.0343	0.0083	0.0112
OCDD	0.001	0.0025	0.001050	0.0050	0.0011	0.0025
2378-TCDF	0.1	0.2278	0.1000	0.5600	0.1010	0.1240
12378-PeCDF	0.05	0.0487	0.0224	0.0920	0.0185	0.0294
23478-PeCDF	0.5	0.5922	0.2540	1.2500	0.2404	0.3625
123478-HxCDF	0.1	0.1962	0.0977	0.5080	0.0992	0.1186
123678-HxCDF	0.1	0.0973	0.0455	0.2610	0.0473	0.0623
234678-HxCDF	0.1	0.1241	0.0531	0.5300	0.0885	0.0671
123789-HxCDF	0.1	0.0107	0.00240	0.0380	0.0075	0.0057
1234678-HpCDF	0.01	0.0228	0.0093	0.0776	0.0148	0.0142
1234789-HpCDF	0.01	0.0043	0.0015	0.0130	0.0023	0.0027
OCDF	0.001	0.00108	0.000325	0.00320	0.00064	0.00069
Total TCDD - TE		1.659	0.774	3.225	0.692	1.024

pjm..dioxins.wb2 update 07/30/98

Table 3