Material Recycling using Plasma Technology

James Batdorf, Ph.D.
ISPC-18 Kyoto, Japan
August 31, 2007

Outline of Presentation

- Integrated Environmental Technologies, LLC
- Battelle Partnership
- IET PEM™ Technology

- Environmental Performance
- Applications
- Current Projects
Integrated Environmental Technologies, LLC

- Founded in 1995; located in Richland, WA
- Exclusive license for Plasma Enhanced Melter™ (PEM™) technology.
- IET has over 40 patents on PEM™ related technology.
- PEM™ builds on $300 million dollar DOE-sponsored research conducted at Battelle PNNL and MIT
- Delivered and installed six commercial PEM™ systems
- Joint marketing agreements with Kawasaki Heavy Industries & Hitachi (Japan) and Ansaldo (Italy)

Pacific Northwest National Laboratory

- Operated by Battelle since 1965
- $725 million annual business volume
- 4,200 scientists, engineers and support staff
- National user facilities for research
- More than 1,200 patents and 200 active licenses
IET / Battelle Partnership

IET/Battelle partnership established in 2006 to conduct joint research of gasification and gas-to-liquids technologies.

- **IET Research Activities**
  - Waste and biomass gasification
  - Standard cleaning of synthesis gas
  - Ultra-deep cleaning of synthesis gas
  - Gas to liquids conversion (alcohol and FT)
- **Battelle**
  - Coal gasification
  - In-situ Gasification Diagnostics
  - Gas to liquids catalyst development
  - High heat transfer catalytic reactor development

IET Technology

- **Plasma Enhanced Melter™ (PEM™)**
- **Plasma + Joule Heated Glass Melter**
- **PEM™** gasifies waste
- Creates valuable products
  - Electricity via engine generator
  - Hydrogen via PSA
  - Methanol / ethanol via gas to liquids
  - Chemical recovery
- **Not combustion process - does not create dioxin**
- **Products:**
  - Clean synthesis gas (H₂ and CO)
  - Stable glass
  - Metal for recycle
IET’s PEM™ Process

Chemical Reactions in PEM™ Process

- Organic Material + Steam + Limited Oxygen + Plasma Energy
  - Synthesis Gas - H₂, CO, CO₂, N₂, H₂O
  - Trace Contaminants - HCl, H₂S, volatile metals, particulate
- Metal Oxides + Glass Formers + Plasma Energy
  - Stable glass product
- Metals + Plasma Energy
  - Metal for recycle
  - Typically a ferro-silicon alloy
The IET Plasma Heat Source

Very High Temperature Region

Power Supply

Graphite Electrodes

PEM™ Processing Waste
Examples of Wastes Tested in the PEM™

- Hazardous Wastes
  - Chlorinated organics
  - Non-chlorinated organic
  - PCBs
- Inorganic materials - ash, soil, concrete, glass, asbestos
- Waste with mercury, lead, and cadmium
- Batteries - alkaline, nickel cadmium
- Auto Shredder Residue
- Municipal Solid Waste
- Electronic Waste
- Medical Waste

Waste volume reduction . . .

1 Ton = 182 Cu Ft
Generic Mass Balance (Varies by Waste)

- Waste Feed
  - 20 tons/day, 1,666 lb/hr

- PEM™ 35+ Patents
  - Glass – 100 lb/hr
  - Steam – 1477 lb/hr
  - Oxygen – 1371 lb/hr

- Caustic 25 lb/hr

- Syngas Cleaning*
  - Syngas 2,459 lb/hr

- Glass 644 lb/hr
- Metal 42 lb/hr

- Thermal Energy
  - 12.5 MMBTU/hr
  - or 3,673 kWth

- Syngas Composition (vol%)
  - CO 37.7%
  - H2 42.7%
  - CO2 16.1%
  - CH4 0.0%
  - H2O 1.8%
  - N2 1.7%

- Hydrogen Production
  - 445,000 scf/day

- Alcohol Production
  - Ethanol/Methanol
  - 2000 gal/day

- Electricity Production
  - 1.2 mW total
  - 0.5 mW net
  - 0.8 mW steam

Generic Mass Balance (Varies by Waste)

- Waste Composition
  - C 48.1%
  - H 6.1%
  - O 0.0%
  - N 2.0%
  - S 0.3%
  - Cl 2.0%
  - Ash 32%
  - Metal 2.5%
  - H2O 7.1%

Glass and Metal Products

- Glass and Metal Products

- Integrated Environmental Technologies, LLC
### Glass is not leachable

<table>
<thead>
<tr>
<th>Analyte</th>
<th>TCLP Limit</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>5 ppm</td>
<td>&lt;0.01 ppm</td>
<td>&lt;0.01 ppm</td>
<td>&lt;0.01 ppm</td>
</tr>
<tr>
<td>Ba</td>
<td>100 ppm</td>
<td>0.03 ppm</td>
<td>0.04 ppm</td>
<td>0.04 ppm</td>
</tr>
<tr>
<td>Cd</td>
<td>1 ppm</td>
<td>&lt;0.01 ppm</td>
<td>&lt;0.01 ppm</td>
<td>&lt;0.01 ppm</td>
</tr>
<tr>
<td>Cr</td>
<td>5 ppm</td>
<td>&lt;0.02 ppm</td>
<td>&lt;0.02 ppm</td>
<td>&lt;0.02 ppm</td>
</tr>
<tr>
<td>Pb</td>
<td>5 ppm</td>
<td>&lt;0.05 ppm</td>
<td>&lt;0.05 ppm</td>
<td>&lt;0.05 ppm</td>
</tr>
<tr>
<td>Hg</td>
<td>0.2 ppm</td>
<td>&lt;0.0001 ppm</td>
<td>&lt;0.0001 ppm</td>
<td>&lt;0.0001 ppm</td>
</tr>
<tr>
<td>Se</td>
<td>1 ppm</td>
<td>&lt;0.02 ppm</td>
<td>&lt;0.02 ppm</td>
<td>&lt;0.02 ppm</td>
</tr>
<tr>
<td>Ag</td>
<td>5 ppm</td>
<td>&lt;0.01 ppm</td>
<td>&lt;0.01 ppm</td>
<td>&lt;0.01 ppm</td>
</tr>
<tr>
<td>SVOC</td>
<td>---</td>
<td>BDL</td>
<td>BDL</td>
<td>BDL</td>
</tr>
</tbody>
</table>

### Extensive Environmental Testing in USA & Japan

- **EvTEC tests (US EPA sponsored)**
  - Simulated hazardous waste
  - Electronic scrap
  - Medical waste
- **Demonstrated Destruction and Removal Efficiency (DRE) >99.9999% for chlorinated hydrocarbons**
- Exceeded EPA performance requirements for DRE, Dioxins, Metals, particulate
- Extensive testing in Japan by Kawasaki Heavy Industries and IET
  - Processed PCBs - pure oils and transformer assemblies
  - Passed all criteria
Syngas Dioxin Levels Similar to Outdoor Air

Dioxin Concentration

Air in California
Synthesis Gas Produced by PEM™ Processing PCBs

- Peak
- Minimum
- PCB 1
- PCB 2
- PCB 4
- PCB 5
- PCB 6
- PCB 7

Dioxins and Furans (fg-TEQ/dscm)

Oakland
Livermore
Wilmington
Sacramento

Combusted Syngas Has Low Dioxin Emissions

Dioxin Emissions from Syngas Combustion Compared to US EPA Hazardous Waste Incinerator Limit
IET Technology Center, Richland, WA

Model 10 Commercial Scale Prototype
ATG Facility, Richland, Washington

Fuji Kaihatsu, Japan
Kawasaki Heavy Industries, Japan

Global Plasma, Taiwan
Kawasaki Plant Systems, Harima, Japan

Hydrogen Production using IET’s PEM with PSA
Current IET Projects

**IET Conventional PEM™ Technology**
- Chemical product recycle for a large US Chemical Company (15 tpd) - under construction
- Portable Demonstration (40 kg/hr) - operating

**IET Enhanced PEM™ Technology**
- Demonstration system at IET Richland facility (24 tpd) - under construction, startup in October
- Industrial waste conversion to into methanol (250 tpd) - construction mid-2008
- Municipal solid waste conversion to into alcohol (250 tpd) - construction late 2008

Semi-trailer mounted system - Tested at Fort Riley, Kansas, Spring 2007
New Enhanced PEM™ Process Flow Diagram

IET 250 Ton Per Day System
PEM™ Technology Benefits

- Waste Destruction
- Volume Reduction
- Electricity Production
- Chemical Recovery
- Chemical Synthesis
  - High Purity Hydrogen - 99.99+%  
  - Liquid Methanol  
  - Higher Alcohols (ethanol)  
  - Fischer-Tropsch Liquids