

ENVIRONMENTAL TECHNOLOGY VERIFICATION REPORT FOR THE PLASMA ENHANCED MELTER™



Prepared by the
Environmental Technology
Evaluation Center (EvTEC),
a service center of CERF/IEEC

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Cover Photos: PEM™ Pilot Plant, Hawaii Medical Waste Facility

Abstract

This Technology Verification report describes the nature and scope of the environmental evaluation of the performance of the Plasma Enhanced Melter™ (PEM™) system for waste treatment. The evaluation was conducted through a cooperative program established in 1998 between the Washington State Department of Ecology (WSDOE), Integrated Environmental Technology Inc. (IET), Allied Technology Group (ATG) and the Civil Engineering Research Foundation (CERF). The goal of this report is to provide potential users and purchasers of the PEM™ system with information they need to make more informed decisions regarding the performance of PEM™ as an equivalent or alternative to incineration for treating hazardous waste.

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Disclaimer

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Abbreviations and Acronyms

AC	Alternating current
acfm	Actual cubic feet per minute
ATG	Allied Technology Group, Inc.
CARB	California Air Resources Board
CB	Chlorinated biphenyl
CEMS	Continuous emissions monitoring system
CERF	Civil Engineering Research Foundation
CFR	Code of Federal Regulations (United States)
CO	Carbon monoxide
DC	Direct current
D/F	Polychlorinated dibenzo-p-dioxin/Polychlorinated dibenzofuran
dioxin	Polychlorinated dibenzo-p-dioxin
DOE	U.S. Department of Energy
DRE	Destruction and removal efficiency
dscf	Dry standard cubic feet
dscm	Dry standard cubic meters
DUV	Dispersive ultraviolet
ETV	Environmental Technology Verification
EPA	U.S. Environmental Protection Agency
EvTEC	Environmental Technology Evaluation Center
ft	Feet
furan	Polychlorinated dibenzofuran
g	Gram
GC	Gas chromatograph or gas chromatography
genset	Engine-generator set
HEPA	High efficiency particulate arrester
hr	Hour
HRGC	High resolution gas chromatography
HRMS	High resolution mass spectrometry
HWC	Hazardous waste combustor
ICP	Inductively coupled argon plasma
IET	Integrated Environmental Technology, Inc.
I/O	Input/output
JHM	Joule-heated melter
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
lb	Pound
lpm	Liters per minute
LRGC	Low resolution gas chromatography
LRMS	Low resolution mass spectrometry
LVM	Low volatility metal

m	Meter
MACT	Maximum achievable control technology
mg	Milligram
mg	Microgram
min	Minute
MPC	Main process control
MS	Mass spectrometer or mass spectrometry
MSW	Municipal solid waste
na	Not available
NESHAPs	National Emission Standards for Hazardous Air Pollutants
nd	Not detected
ng	Nanogram
NDIR	Non-dispersive infrared
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated dibenzo-p-dioxin
PCDF	Polychlorinated dibenzofuran
PEM™	Plasma Enhanced Melter™
PIC	Product of incomplete combustion
PID	Proportional-Integral-Derivative
PIR	Product of incomplete reaction
PLC	Programmable logic controllers
PM	Particulate matter
PODC	Principal organic dangerous constituent
POHC	Principal organic hazardous constituent
ppm	Parts per million by volume
QA	Quality assurance
QC	Quality control
RAM	Reliability, availability, and maintenance
RPD	Relative Percent Difference
Scfm	Standard cubic feet per minute
sec	Second
SMVOC	Sampling Method for Volatile Organic Compounds
SRM	Standard reference material
SVM	Semivolatile metal
SVOC	Semivolatile organic compound
syngas	Synthesis gas
TCDD	Tetrachlorodibenzo-p-dioxin
TCLP	Toxicity Characteristic Leachability Procedure
TEF	Toxicity equivalency factor
THC	Total hydrocarbon
TIC	Tentatively identified compound
TRC	Thermal residence chamber
TSCA	Toxic Substances Control Act
ug	Microgram
VOC	Volatile organic compound
WDOE	Washington State Department of Ecology
XAD	Brand name for Amberlite XAD-2 adsorbent resin
XRF	X-ray fluorescence

Preface

The Environmental Technology Verification (EvTEC) Program was established by the U.S. Environmental Protection Agency (EPA) to evaluate the performance characteristics of innovative environmental technologies across all media and to report this objective information to permittees, buyers and users of environmental technology.

EvTEC operates as an innovation center of the Civil Engineering Research Foundation, an affiliate of the American Society of Civil Engineers. EvTEC was contracted by the Integrated Environmental Technologies, LLC (IET) to perform a technology verification of the Plasma Enhanced Melter™ system. Part of this evaluation process involved assembling a Technology Evaluation Panel of experts and users who are knowledgeable in hazardous waste and waste treatment processes. EvTEC developed the Evaluation Plan through contact and consensus building within the Technology Evaluation Panel.

Acknowledgements

The Environmental Technology Evaluation Center (EvTEC) acknowledges the support of all those who helped plan and conduct the verification activities. In particular, we would like to thank Norma Lewis, U.S. Environmental Protection Agency (EPA) Environmental Technology Verification (ETV) Project Manager, and Lauren Drees, EPA ETV Project Quality Assurance/Quality Control Manager, both of EPA's National Risk Management Research Laboratory in Cincinnati, Ohio.

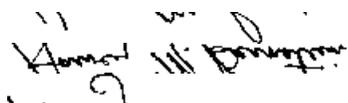
We would also like to thank the Plasma Enhanced Melter™ Technical Evaluation Panel which included: Ernesto Brown, USEPA; Louis Circeo, Ph.D., Georgia Tech Research Institute; Robert S. (Stu) Dinwiddie, Ph.D., Environmental Sciences; Paul Dwiggin, Massachusetts Department of Environmental Protection; Moses Jarayssi, WA State Department of Ecology/Nuclear Waste Program; Michael Katona, Ph.D., Washington State University, Department of Civil & Environmental Engineering; Cathy Massimino, USEPA Region 10; Gary Mescavage, US Army, ARDEC; Ed Smith, Ph.D., USACE-CERL, Greg Williams, PE, California Environmental Protection Agency.

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Among the staff who worked on this project, I wish to acknowledge the efforts of the EvTEC team: Director William E. Kirksey, PE.; Senior Program Manager, Brian Rustia, PE.; Project Managers: Deborah Snoonian, PE., Heather Warkentien, PE., Anita Celdran, and Communications Coordinator, Kanako Beringer.

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Harvey M. Bernstein
President & CEO, CERF/IEEC

Technical Evaluation Panel Key Contacts

Panelists: **Ernesto Brown**
U.S. Environmental Protection Agency

Louis Circeo, Ph.D.
Georgia Tech Research Institute,
Georgia Institute of Technology

Robert S. (Stu) Dinwiddie, Ph.D.
Environmental Sciences, Rowe, New Mexico

Paul Dwiggin
Massachusetts, Department of Environmental
Protection

Moses Jarayssi
Washington State Department of Ecology/
Nuclear Waste Program

Michael Katona, Ph.D.
Washington State University
Department of Civil & Environmental
Engineering

Cathy Massimino
U.S. Environmental Protection Agency,
Region 10

Gary Mescavage
U.S. Army, ARDEC

Ed Smith, Ph.D.
U.S. ACE-CERL

Greg Williams, PE.
California Environmental Protection Agency

Consultant: **Nicholas Soelberg**
Idaho National Engineering and Environmental
Laboratory
Bechtel BWXT Idaho, LLC

Quality Assurance
Consultant: **Norma Lewis**
U.S. Environmental Protection Agency
ETV Program Manager

Lauren Drees
U.S. Environmental Protection Agency
ETV Project Quality Assurance/Quality Control
Manager

EvTEC Staff: **William E. Kirksey, PE.**
Director

Brian M. Rustia, PE.
Senior Program Manager

Heather Warkentien, PE.
Project Manager

Anita M. Celdran
Project Manager

Verification Statement

Environmental Technology Evaluation Center's Verification Statement for the Plasma Enhanced Melter™

Technology Type:	Waste Treatment, Recycling, and Stabilization System
Application:	Treat wastes to destroy or immobilize hazardous constituents, reduce waste volume and mass for final disposal, and recover energy and valuable products, as an alternative to incineration or direct disposal.
Technology Name:	Plasma Enhanced Melter™ (PEM™)
Company:	Integrated Environmental Technology, LLC (IET)
Address:	1935 Butler Loop, Richland, Washington 99352
Phone:	509.946.5700
Fax:	509.946.1819
URL:	www.inentec.com

The performance verification activities described in this document were co-funded by Integrated Environmental Technologies, LLC (IET) and the U.S. Environmental Protection Agency (EPA). The Civil Engineering Research Foundation (CERF) Environmental Technology Evaluation Center (EvTEC) directed this verification program under a Cooperative Agreement (#824884-01-0) with the EPA.

Program Operation

The CERF EvTEC program, in partnership with a panel of experts, i.e., a unique EvTEC Technical Evaluation Panel and recognized testing organizations, objectively and systematically documents the performance of commercial-ready technologies. Together with the full participation of the technology developer, they develop plans, conduct tests, collect and analyze data, and report findings. Verifications are conducted according to a rigorous work plan and established protocols for quality assurance. CERF's EvTEC program acts as an objective third-party evaluation service. Where existing data are used, the data must have been collected by independent sources using similar quality assurance protocols.

The EPA's Environmental Technology Verification (ETV) program, through the National Risk Management Research Laboratory, has partnered with CERF, under an ETV Independent Pilot Project, to verify the performance of environmental technologies. The EPA created the ETV program to facilitate the deployment of innovative environmental technologies through performance verification and information dissemination. The goal of the EvTEC and ETV programs is to enhance environmental protection by substantially accelerating the acceptance and use of innovative, improved, and cost-effective technologies. The primary mission of the EvTEC and ETV programs is to assist and inform individuals and organizations requiring credible data concerning the design, distribution, permitting, and purchase of environmental technologies with balanced, third-party analyses of the performance of individual systems and technologies.

Technology Description

The PEM™ system was developed in the 1990's and patented by its inventors shortly after IET was founded in 1995. This system integrates many subsystems and specific technologies, some with their own IET patents, into a waste treatment system designed to treat wastes to destroy or immobilize hazardous constituents, reduce waste volume and mass for final disposal, and recover energy and valuable products. Included in the EvTEC verification program was a test to establish the PEM™ as equivalent to incineration for treating hazardous wastes, or as an alternative to incineration or direct disposal.

The PEM™ system electrically heats waste fed to a refractory-lined processing chamber to gasify organic material and melt inorganic components and metals at temperatures often higher than 1,400°C. The gasification products form a synthesis gas (syngas), from impurities such as particulate matter and acid gases are scrubbed in the syngas processing subsystem. Depending on customer economics, the syngas can be oxidized prior to atmospheric release or it can be used to produce electrical power or other forms of energy. Molten glass is tapped to produce a vitrified, very leach-resistant and durable glass product for final disposal or for recycling, depending on the input waste material and on customer needs or economics. Any separate molten metal phase can be separately tapped to provide a recyclable metal product.

The PEM™ system is unique because the waste is heated in the processing chamber using two separate power systems:

- A direct-current (DC) arc plasma for high temperature organic waste destruction and gasification
- An alternating current (AC) powered, resistance (Joule) heating system to maintain a more even temperature distribution in the molten bath

Evaluation Description

A cooperative program was established in 1998 between Washington State Department of Ecology (WSDOE), IET, Allied Technology Group, Inc. (ATG), and the CERF to verify the performance of the PEM™ system for waste treatment. In addition to being an EvTEC verification program, the program was designed to test and evaluate a collaborative approach to carrying out the provisions of Washington State House Bill *HB1792*, which required WDOE to establish a program to verify the performance of new environmental technologies, with special reference to technologies addressing the U.S. Department of Energy (DOE) Hanford Site.

The goal of this verification program was to verify the performance of the PEM™ system for waste treatment. The program scope included:

- Establishment of a technical evaluation panel
- Identification of performance criteria
- Preparation of the verification plan
- Verification tests performed by IET and observed by CERF representatives
- Provision of other data by IET
- Preparation of the report and verification statement based on verification panel consensus

The technical evaluation panel, initially established in 1998, included regulatory agency representatives, stakeholders, and technical experts. Performance criteria that the panel could use to perform the evaluation were identified and included in the verification plan. Ultimately, only some of these criteria could be addressed in specific tests that could be observed by EvTEC representatives. Such criteria as reliability, maintainability, and economics of the PEM™ were not included in the evaluation because the verification tests did not provide sufficient data to address these criteria. IET has extensive information regarding these criteria, but the verification program could not readily evaluate that information. Criteria that could not be addressed with the verification test data are not

addressed in this report. The interested reader may contact IET directly to obtain any such information. IET can be contacted through their web site at www.inentec.com, by telephone at 509-946-5700, or by mail at 1935 Butler Loop, Richland, WA 99352.

The verification report is being made available to provide potential users of this system, potential federal, state, and local regulators, and other stakeholder groups with performance information so they can make more informed decisions about accepting and regulating the PEM™ system for waste treatment. The verification report was reviewed in detail by the technical evaluation panel and finalized by panel consensus.

Verification of Performance

Results of three separate EvTEC-observed PEM™ system tests are included in this evaluation: a solid circuitboard fabrication waste, bagged municipal solid waste (MSW) and bagged medical waste. It should be noted that only the MSW tests were observed by U.S. EPA personnel. Results from three other, smaller-scale tests not observed by EvTEC representatives are also included. The tests were performed using two prototype system designs at the IET facility in Richland, Washington. The tests addressed the two most significant evaluation criteria, based on IET, customer, and regulatory needs:

- Show how the system operates while feeding a variety of different feed materials
- Extensively characterize offgas emissions

The tests demonstrated complete system operation while (a) continuously feeding solid and liquid materials, (b) continuously heating, gasifying, and melting the feed material in the processing chamber, (c) tapping molten products as needed, (d) continuously scrubbing the syngas, and (e) continuously either flaring the syngas or producing electrical power in a gas-fired electric generator set (genset). The two prototype systems were demonstrated at feedrates ranging from 12-68% of their nominal design capacities, which were 2 and 10 tons/day of waste feed. The range depended on specific test objectives and properties of the feed material. Operating conditions (temperatures, pressures, flowrates, and process stream compositions) were generally under control and within design operating limits.

The organic constituents in the feed materials were successfully gasified in the processing chamber and in the thermal residence chamber (TRC), with the exception of some residual unreacted char consisting of mainly “fixed carbon” left after more volatile components have been gasified. Char gasification is a slow, heterogeneous process identified and studied in other industries such as coal gasification and combustion. Perhaps the design or operation of the prototype TRC should be modified for improved char gasification if the amount of char collection in the TRC or downstream equipment is problematic for any specific application.

Offgas emissions were extensively evaluated in these tests. Besides waste treatment capabilities and overall costs, offgas emissions to the atmosphere are a significant customer, regulator, and stakeholder concern, and so received considerable emphasis in the verification program. Emission measurements were made at the outlet of an enclosed flare in some tests. The enclosed flare converted the syngas fuel produced in the verification tests (mainly H₂, CO, and CH₄) to fully oxidized products (mainly CO₂ and H₂O) for environmentally approved emission to the atmosphere. Emission measurements in other tests were made at the outlet of the genset, to demonstrate emissions performance when the PEM™ system operates in a configuration that provides electrical power generation from the syngas.

During each test, IET and the testing subcontractors provided qualified personnel to accomplish the test objectives. IET personnel operated the PEM™ system. All offgas measurements were made by an independent emissions testing subcontractor with the appropriate expertise. During two of the tests (the Equivalency and Circuitboard tests) another subcontractor with expertise in planning and executing complex emissions testing directed the work of the emissions testing subcontractor. EvTEC observed those two tests and confirmed through field audits that the appropriate procedures were observed.

Emission measurements were performed using EPA-promulgated procedures, and followed the method-specified quality assurance and quality control (QA/QC) procedures. Emission measurements were performed during at least one or more of the tests for:

- Offgas velocity, flowrate, temperature, and moisture content (% H₂O)
- Continuous monitoring for O₂, CO₂, CO, total NO_x, SO₂, and total hydrocarbons (THC)
- HCl and Cl₂, particulate matter (PM), and metals
- Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDFs or D/Fs)
- Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs)
- Other semivolatile organic compounds (SVOCs) besides D/Fs, PAHs, and PCBs
- Volatile organic compounds (VOCs) including primary organic dangerous compounds (POHCs)
- Determination of destruction and removal efficiency (DRE) for PODCs spiked into the feed material

The term PODC is used in this report in place of the more commonly used term “principal organic hazardous constituent” (POHC), because this term is used in the State of Washington. The term “product of incomplete reaction” (PIR) is used instead of the more commonly used combustion term “product of incomplete combustion” (PIC) because of the differences between the PEM™ system and traditional incineration systems.

Offgas conditions and emissions were typical for a well-designed and operated enclosed flare and gas engine. All offgas emissions must comply with expected regulatory and permit limits, but those limits may vary for each individual PEM™ installation. For simplicity, compliance with the U. S. EPA National Emission Standards for Hazardous Air Pollutants (NESHAPs) for Hazardous Waste Combustors (HWCs) based on maximum achievable control technology (MACT) (EPA 1999, Bastian 2002) was assumed for this verification program. Air emission limits and requirements for any specific PEM™ installation may be more or less stringent than the current HWC MACT standards, since each installation will require its own site-specific evaluation of compliance to applicable air emission regulations.

The measured offgas emissions are compared to the HWC MACT standards in Table VS-1. **Acid gas (HCl, Cl₂, and SO₂) concentration results** reported for all the tests were either near or below detection limits, except for during the Equivalency Test, when the pH of the scrubbers used to absorb HCl ranged as low as 1 for some of the time (well under standard pH limits for acid gas scrubbers of 7-9), which may have reduced the HCl scrubbing efficiency. HCl/Cl₂ levels ranged from less than 10% to 67% of the HWC MACT limit. While the HCl/Cl₂ measurements are acceptable in comparison to the HWC MACT limit, they probably overstate the true HCl/Cl₂ levels, since the measured values were at or below detection limits, or resulted from an operating condition outside standard acceptance limits.

Residual CO and THC in the genset offgas, ranging between 100-200 ppm and 8-13 ppm (dry, corrected to 7% O₂) exceed the HWC MACT limits for CO and THC. This is true for both propane fuel and syngas co-fired with propane. If offgas emission limits as low as the HWC MACT standards are applied to genset emissions, then the genset design or operation will need to be modified for compliance. CO and THC emissions for the flare offgas ranged between 2-5% of the HWC MACT limits.

PM levels were low, at or near detection limits, for all tests. PM concentrations are less than about 24% of the HWC MACT limit, except for the February 16-18 medical waste test results that were about 30% of the limit. While the PM measurements are acceptable in comparison to the HWC MACT limit, they probably overstate the true PM levels, since the measured values were at or below detection limits.

While the **D/F levels** from the medical waste tests are higher than those from the other tests, all of the D/F measurements are under 11% of the HWC MACT limit. The D/F levels from the Equivalency and Circuitboard tests are respectively under 5% and 0.02% of the

Table EV-1. Offgas measurement results from the tests

	EvTEC-observed verification tests		Other supplementary tests not observed by EvTEC				HWC MACT (a)
	Equivalency test	Circuit-board test	Propane test, Feb 15-16	Med waste tests			
				Feb 16-18	Mar 8-9		
Syngas conversion stage	Flare	Genset	Genset	Flare	Genset	---	
Offgas composition (as measured, dry volume basis, unless otherwise indicated):							
O ₂ , %	14.4	0.0	0.0	0.0	16.5	0.0	---
CO ₂ , %	5.2	12.5	14.0	14.0	3.1	14.3	---
CO, ppm	0.8	159	197	359	1.7	258	---
Total NO _x , ppm	62	57.7	15.9	18.0	25	125	---
SO ₂ , ppm	0.05	1.2	0.3	0.3	2.3	0.4	---
THC, wet ppm	0.5	15.6	11.3	16	0.1	9.9	---
HCl, ppm	6.4 total HCl/Cl ₂ as HCl	---	<0.6	<0.6	---	<0.6	---
Cl ₂ , ppm	<0.17 (b)	---	<0.6	<0.6	---	<0.6	---
H ₂ O, wet %	na (c)	14.5	16.1	15.9	5.9	18.1	---
Total PM, mg/dscm	<4	<5	<3	<2	3.5 ± 32%	<2	---
Total PAHs, µg/dscm (d)	<3.52	<8.06	---	---	4.31	---	---
Total PCBs, µg/dscm (d)	---	0.00269	---	---	0.00680	---	---
Total SVOCs, µg/dscm (e)	---	<53 (f)	---	---	---	---	---
Total VOCs, µg/dscm	<1.4 (f)	<12 (f)	1,321	203	427	722	---
Offgas composition, key species corrected to 7% O₂, dry basis:							
CO, ppm	1.7	107	132	241	5.3	173	100 (and 10 ppm THC)
THC, ppm	1	12.2	9.0	13	0.3	8.1	10
Total HCl/Cl ₂ as HCl, ppm	14	---	<1.2	<1.2	---	<1.2	21
PM, mg/dscm	<8	<3	<2	<1	10+ 32%	<1	34
D/Fs, ng TEQ/dscm (d)	0.010	0.000035	---	---	0.0173	0.0226	0.2
Hg, µg/dscm	---	---	---	---	---	232	45
SVMs (Cd, Pb), µg/dscm	---	15	---	---	---	0.412	120
LVMs (As, Be, Cr), µg/dscm	---	1.2	---	---	---	---	97
PODC DRE, %							
Benzene	>99.999939	---	---	---	---	---	99.99
Chlorobenzene	>99.999963	---	---	---	---	---	99.99
Tetrachloroethene	>99.999968	---	---	---	---	---	99.99
Toluene	>99.999955	---	---	---	---	---	99.99
PCBs (based on total PCB homolog groups)	>99.99978 to 99.99991	---	---	---	---	---	99.9999

Note: Bolded values are near to or greater than the HWC MACT standards.

- For new sources.
- The “<” sign indicates that the species was not detected at a level greater than the indicated detection limit.
- na = Not available.
- For conservatism, the highest (or lowest for DREs) of any single measurement of multiple measurements are shown here.
- Total SVOCs not including D/Fs, PAHs, and PCBs measured using other methods.
- The highest individual detection limit, since no species were detected in this test, or any detected species were detected at concentrations much lower than the highest detection limit.

HWC MACT limit.

Like the D/Fs, the **PAHs** for the Equivalency and Circuitboard tests are mostly not detected. Naphthalene was the only PAH detected in every test. Naphthalene is commonly detected in larger amounts than other PAHs in thermal process emissions, but is relatively less hazardous than some other PAHs. Levels of naphthalene on the order observed in these tests are not expected to present any regulatory concerns.

PCB measurements were made during one of the medical waste tests and during the equivalency test. The PCB measurements during the equivalency test included both total PCB homologue groups and also dioxin-like coplanar PCBs that were spiked into the equivalency test feed. Many of the PCBs were not detected in the offgas. The PCB DRE target of 99.9999% (six 9s) for total PCB homologue groups was not demonstrated because the feedrate of PCBs was not high enough to demonstrate the target efficiency compared to the offgas PCB measurements, some of which were above detection limits. A PCB DRE range between > 99.99978% to 99.9991% was demonstrated, just slightly under the 99.9999% target. Based on the high destruction efficiency of the VOC PODCs, a higher PCB destruction efficiency which may have been demonstrated had higher levels of total PCB homologue groups spiked into the feed.

Two factors that affected the inability to demonstrate at least six 9s DRE may have been due to the relatively small amount of PCBs spiked into the feed. First, the spiked PCB total homolog concentrations ranged about 40 times lower than the spiked concentrations of the volatile PODCs, which all showed over six 9s DRE. If the PCBs were spiked at a higher concentration in the feed, then an adequate PCB DRE may have been demonstrated, since the DREs for the volatile PODCs all exceeded six 9s. Second, all of the four detected total PCB homologs (di- through pentachlorinated biphenyls) were detected in the field blank at levels ranging from 40-150% of the levels detected in the offgas samples. These blank values were not subtracted from the measured values in the mass emission rate calculations, according to standard conservative practice. If they were subtracted, the DRE values would have exceeded six 9s DRE.

No other **SVOC species** besides D/Fs, PAHs, and PCBs were detected above their respective detection limits, which ranged up to 53 mg/dscm. No tentatively identified compounds (TICs) were reported from the SVOC analyses. Levels of SVOCs on the order of the detection limits observed in these tests are not expected to present any regulatory concerns.

Most **VOCs** were not detected above the detection limits of the methods. No VOCs were detected in the Equivalency Test, and only one VOC (acrylonitrile) was detected in one of three runs in the Circuitboard Test. The sums of those VOCs detected in the medical waste tests ranged from 3-1,320 mg/dscm. No VOC TICs were reported from the VOC analyses. Levels of VOCs on the order of the levels observed in these tests are not expected to present any regulatory concerns.

Four VOCs were used as PODCs in the equivalency test. The **DREs** for these VOCs exceeded 99.9999%, at least two orders of magnitude greater than the target DRE of 99.99%.

Total **SVM (Cd and Pb) emissions** for the Circuitboard Test were under 13% of the HWC MACT standard. Total SVM emissions for the March 8-9, 2000 medical waste test were under 0.4% of the standard.

Hg was not spiked into any of the feed materials, and was not supposed to be in any of the feed materials, but was detected in the offgas during one of the medical waste tests. The measured offgas Hg level for this test was 5x higher than the HWC MACT limit. If Hg regulatory or permit emission limits for medical waste treatment are equivalent to the HWC MACT limit, then a medical waste treatment facility may need to include mercury control such as carbon absorption in the offgas system if the medical waste contains levels of Hg similar to the levels in waste during this test.

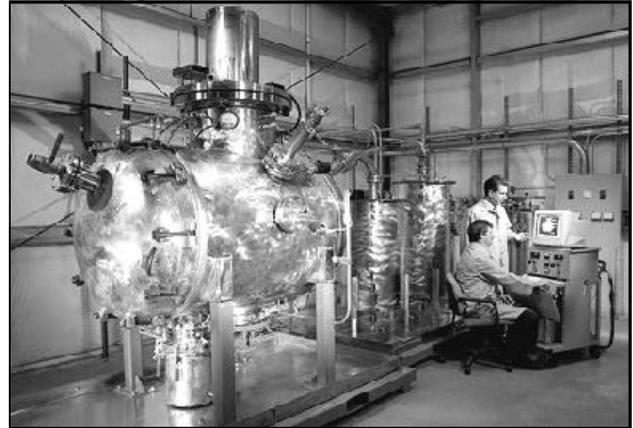
As a result of the equivalency test, the US EPA has concurred in writing that the PEMTM system, when operated within applicable

technical requirements, performs in a manner equivalent to other thermal treatment technologies consistent with criteria set forth in the definition of CMBST found in 40CFR 268.42 (EPA 2001, Appendix A).

Test durations were typically 1-3 days long. Because of these relatively short-duration tests, test data was insufficient for such evaluation criteria as reliability, availability, and maintenance (RAM), lifecycle costs, and hazard exposures to workers from operations and maintenance. Ultimately, these criteria, and how the PEM™ system meets these criteria, depend largely on site-specific customer and regulatory requirements.

CHAPTER 1

Introduction



Prototype PEM™ system

A cooperative program was established in 1998 to verify the performance of the Plasma Enhanced Melter™ (PEM™) technology for waste treatment. The PEM™ was developed and is being marketed by Integrated Environmental Technology, LLC (IET). The verification program was a cooperation between Washington State Department of Ecology (WSDOE), IET, Allied Technology Group, Inc. (ATG), and the Civil Engineering Research Foundation (CERF). The program was implemented using the consensus-based evaluation process of the CERF Innovation Centers. The process was managed by CERF's Environmental Technology Evaluation Center (EvTEC), operating under a cooperative agreement with U.S. Environmental Protection Agency (EPA).

In addition to being an EvTEC verification program, the program was designed to test and evaluate a collaborative approach to carry out the provisions of Washington State House Bill *HB1792*, which requires WDOE to establish a program to verify the performance of new environmental technologies, with special reference to technologies addressing the U.S. Department of Energy (DOE) Hanford Site. The program goals were to promote and enhance the identification of innovative environmental technologies, verify environmental technology performance, and transfer beneficial environmental technologies into the marketplace.

1.1 IET PEM™ Background

IET was formed in 1995 to commercialize the innovative integration of joule heated melting and electric arc (also called plasma arc) melting. Joule heated melting (JHM) processes have been used for decades in the glass manufacturing industry and for treating high level radioactive wastes (IET 2001 and CRC Press 2001). Plasma arc melting has been used worldwide for decades in the steel and specialty metals industries, and has been studied and used to a limited degree in the U.S. and worldwide for waste treatment since the 1980's by the DOE, the U.S. Department of Defense, the U.S. EPA, the American Society of Mechanical Engineers, the U.S. Bureau of Mines (now combined with the DOE), universities such as Massachusetts Institute of Technology, and several private companies, and several foreign national entities (Eddy 1994, Soelberg 1997, Zaghoul 1997). The integration of joule heated melter (JHM) and plasma arc melter technologies in the PEM™ process, patented by IET, is designed to optimize the capabilities of both melting techniques to provide an effective and controllable process for treating a wide variety of waste materials including solid and liquid hazardous, municipal, hospital, radioactive, and mixed wastes.

Since 1995, IET has performed PEM™ testing, technology and system design and improvement, and marketing. IET has performed small, medium (engineering) scale, and demonstration (full) scale testing, at nominal melter sizes of 0.5, 2, and 10 tons/day. Some of these melters have been operated continuously in feed and idle modes for many months. During these tests, IET has processed

hazardous metals-spiked inorganic materials, incinerator ash, soil, combustibles including wood and plastics, medical wastes, municipal solid wastes, hazardous organic-spiked methanol, chemical weapons materials, hazardous chemical waste, coal, and circuitboard fabrication waste.

Much of IET's development, design, and demonstration work has focused not on the melter technology itself but on peripheral equipment needed to make the entire process commercially viable. Perhaps the greatest challenge for waste melting processes is making the peripheral processes work – those that feed the waste into the melter, provide heating and cooling, control and scrub the offgas/syngas, and take the vitrified glass and metal products out of the melter.

1.2 Verification Program Objective and Scope

The goal of this verification program was to verify the performance of the PEM™ system for waste treatment. The program scope included:

- Establishment of a technical evaluation panel
- Identification of performance criteria
- Preparation of the verification plan (IET 2000)
- Tests performed by IET and observed by CERF/IEEC representatives
- Provision of other data by IET
- Preparation of the report and verification statement based on verification panel consensus.

The technical evaluation panel included regulatory agency representatives, stakeholders, and technical experts. The panel was initially established in 1998.

The verification plan was initially drafted following the format of a traditional incinerator trial burn, but was subsequently modified to redirect the focus from a trial burn to a broader performance verification including identification of performance criteria and evaluation of the PEM™ based on the performance criteria. Ultimately, only some of these criteria could be addressed in specific tests that could be observed by EvTEC representatives.

Such criteria as reliability, maintainability, and economics of the PEM™ were not included in the evaluation because the verification tests did not provide sufficient data to address these criteria. IET has extensive information regarding these criteria, but the verification program could not readily evaluate that information. Criteria that could not be addressed with the verification test data are not addressed in this report. The interested reader may contact IET directly to obtain any such information. IET can be contacted through their web site at www.inentec.com, by telephone at 509-946-5700, or by mail at 1935 Butler Loop, Richland, WA 99352.

1.3 Verification Test Objectives

The tests addressed the two most significant evaluation criteria, based on IET, customer, and regulatory needs:

- Show how the system operates while feeding a variety of different feed materials
- Extensively characterize offgas emissions

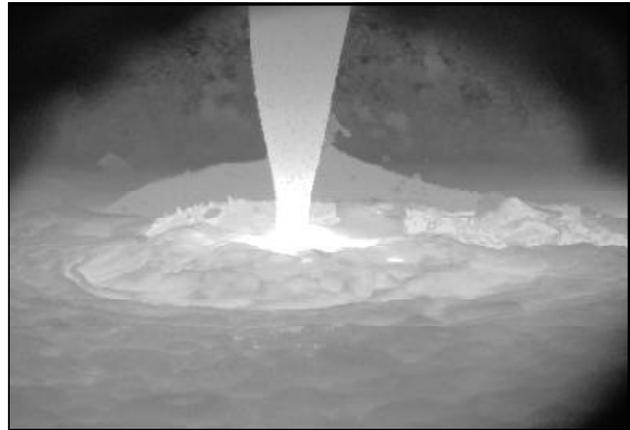
Specific test objectives used to address the two above criteria were:

- Demonstrate the efficacy of the process for various types of waste
- Provide sufficient information about system performance to show PEM™ system equivalency to other Best Demonstrated Available Technologies, namely incineration
- Characterize amounts and properties of outlet streams
- Characterize products of incomplete reaction (PIRs) in outlet streams
- Characterize metals content in outlet streams

Test results were evaluated and compiled into a draft verification report and draft verification statement by CERF/IEEC. The draft verification report and draft verification statement were reviewed in detail by the technical evaluation panel and finalized by panel consensus.

CHAPTER 2

PEM™ System Description and Operation



Graphite electrode and molten bath in the process chamber

The prototype PEM™ system design that was tested during the EvTEC-observed verification tests is shown in Figures 1 and 2. Specific components can vary depending on customer requirements. For example, during the equivalency test, an enclosed flare was used to convert the syngas to fully oxidized gas prior to atmospheric release. During the Circuitboard Test, the syngas was co-fired with propane in a power-generating stationary internal combustion engine (genset) to recover the energy of the syngas. The genset and the enclosed flare were both used in different medical waste tests reported here.

Feed materials may contain both organic and inorganic matter without regard to their net heating value or their exothermic contribution to the treatment process. The process is designed to (a) destroy toxic and non-toxic organics, (b) reduce the waste volume, and (c) vitrify the inert residues including if present, radioactive residues, from the destruction process.

Depending on properties of the feed and on system operating conditions, products can include (a) a vitrified glass or rock like material, which is highly durable and leach resistant, (b) solidified metal, (c) synthesis gas that is either used as a fuel for electricity generation or converted to water and carbon dioxide before being discharged to the atmosphere, and (d) syngas control system secondary wastes including scrubber solution, baghouse ash, and high efficiency particulate arrestor (HEPA) filters. Baghouse ash and HEPA filters may be recycled to the melter to appreciably reduce the amount of these wastes that need to be disposed.

The PEM™ process accomplishes both gasification and vitrification simultaneously. Organic materials in the feed are gasified in reactions at high temperatures with steam to produce a synthesis gas (syngas) containing H_2 , CO , and CH_4 . Inorganic components in the feed (like metals and minerals) are melted and incorporated into a leach-resistant vitrified product. Unlike a combustion process that produces heat, the gasification and melting processes absorb heat (are endothermic processes) and thus require an outside heat source.

A plasma-arc provides the outside source of heat to process primarily organic wastes. The process chamber also uses electrical resistance heating (joule heating) to maintain the desired temperature distribution of the molten bath. The plasma arc also heats the bath, but the joule heating better disperses the heat put into the bath. Steam in the chamber (evolved from the feed or added separately) reacts with volatilized feed organics to produce the syngas.

The combined plasma and joule-heating melts inorganic waste components into glass and metal products. Periodically, molten glass and metal are withdrawn and cooled to form monoliths in separate receiving canisters. Glass forming additives may be added to the feed to control glass chemistry for high leach resistance, for immobilizing hazardous materials, or to achieve glass characteristics that make the glass suitable for recycling into construction products (Quapp 2002).

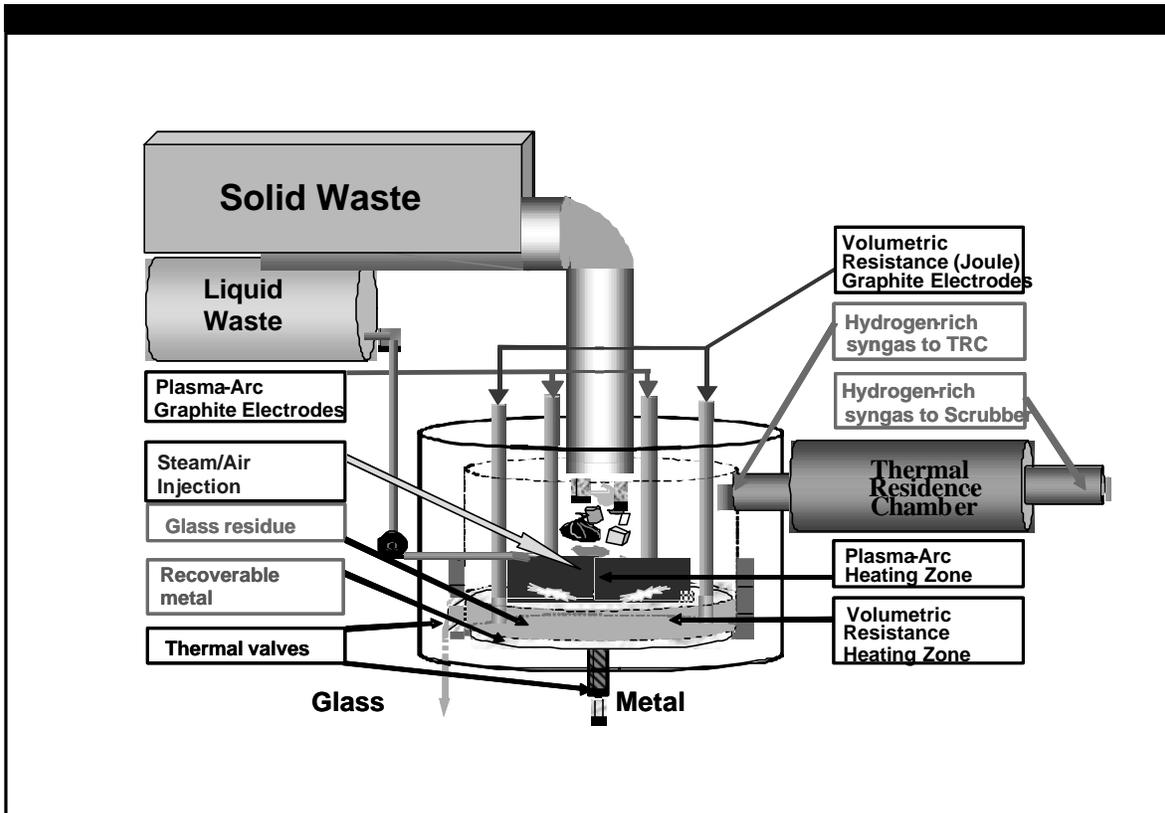


Figure 1. Process schematic for the PEM™ process chamber

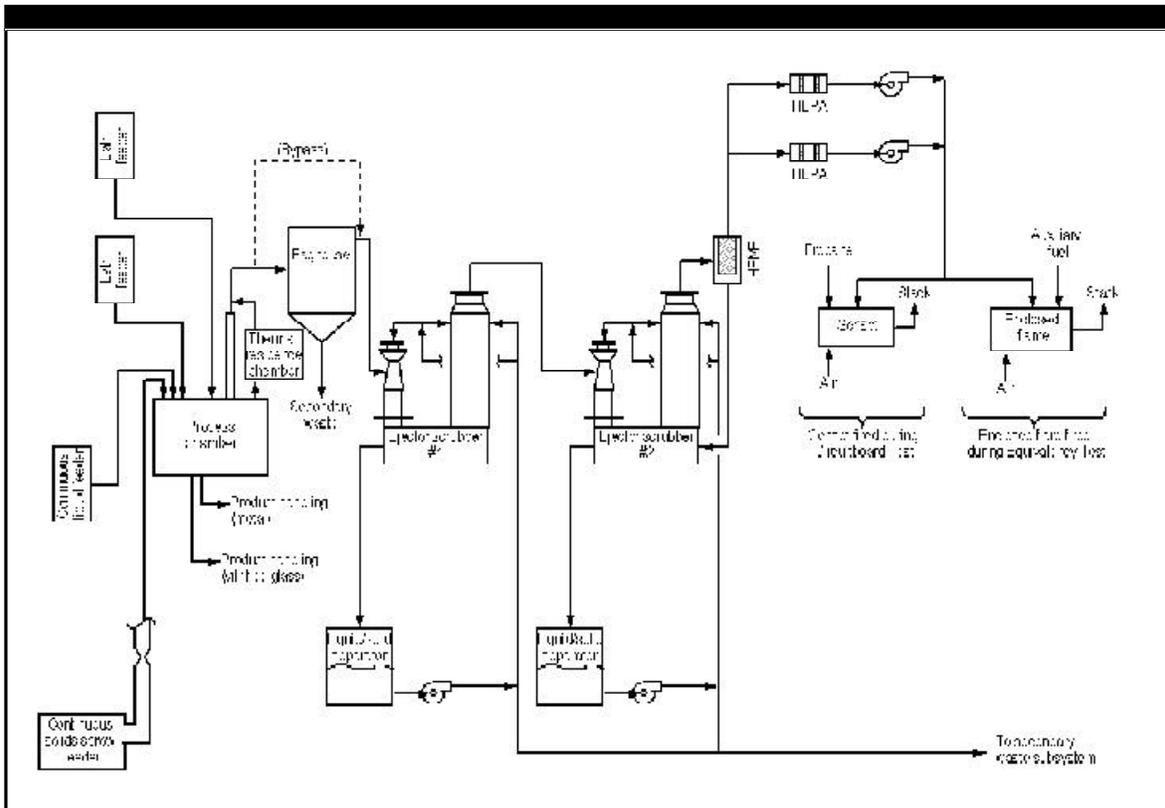


Figure 2. PEM™ process flow diagram

The syngas typically is a mix of H₂, CO, CO₂, N₂, H₂O, steam, acid gases, particulate matter including any entrained or condensed metals, and products of incomplete reaction (PIRs). This mixture is discharged from the process chamber at temperatures exceeding 1,000°C (1,800°F), although the reaction zone in the plasma arc region is much hotter. The syngas is further reacted in a thermal residence chamber (TRC) maintained at a high temperature to complete steam reforming reactions or to further react PIRs. In the prototype syngas treatment system used in the verification tests, the gas is then partially quenched, passed through a baghouse for PM removal, fully quenched to below saturation, and scrubbed to remove acid gases and small amounts of residual PM that may remain after baghouse filtration, and then finally HEPA filtered prior to conversion to fully oxidized gases in either the enclosed flare or the genset.

Depending on actual customer needs or site-specific requirements, waste treatment installations may include additional offgas control steps such as activated charcoal absorption for mercury control. The cleaned, treated syngas can be either used as a fuel to produce electricity, as a gaseous fuel in other on-site processes, or flared to CO₂ and water prior to being discharged to the atmosphere.

2.1 Key Subsystems

The PEM™ process consists of five main subsystems:

- Feed subsystem
- Process chamber subsystem
- Product handling subsystem
- Syngas processing subsystem
- Utilities subsystem

The feed subsystem can include up to four different feed systems, depending upon customer requirements, for feeding different kinds and configurations of feed materials into the process chamber. A feed tank/pump assembly can feed liquid or sludge wastes. A continuous screw feeder equipped with an airlock hopper assembly can feed loose bulk solids. A redundant set of batch feeder mechanisms can feed pre-packaged waste canisters or glass forming additives. Glass forming additives can also be fed through a gravimetric, continuous solids feeder. The liquid feed system and the continuous screw feeder were demonstrated during the verification tests.

The process chamber used in these tests was a water-jacketed 304L stainless steel vessel lined with refractory. IET now uses air cooling on the sides of the vessels. The process chamber proper contains two zones, the melt tank which contains the molten slag and molten metal (which lies on the bottom of the melt tank), and the plenum, or vapor space above the melt. The chamber lining is composed of several different types of refractory and insulating materials. These materials serve to reduce energy losses to the water jacket as well as to contain the molten glass and metal phases. The plenum area of the process vessel is lined with both insulating materials as well as material to protect the steel shell from corrosive feed decomposition gases and vapors.

The process chamber is heated by the DC (direct current) arc plasma, and the AC (alternating current) joule-heating. The DC arc plasma is created by applying a DC potential across the three 3-in. diameter graphite arcing electrodes with a single electrode at one polarity and the other two electrodes at the opposite polarity. A stable plasma arc is then formed between the molten bath and arcing electrodes. The electrical current is transferred through the arcs from the arcing electrodes to the melt. The second source of energy to the process chamber is supplied directly to the molten glass via three 6-in. diameter graphite joule-heating electrodes submerged in the melt. A three-phase AC potential is placed across the joule-heating electrodes which results in current flow through the glass. The molten glass acts as a resistor such that power supplied to the graphite electrodes is converted into heat in the molten glass bath.

All of the electrodes enter the process chamber through penetrations in the top lid. The three AC joule-heating electrodes enter the chamber at the perimeter of the melt tank and are equally spaced 120° apart. They extend from the lid through the plenum into the molten glass. The three DC plasma arc electrodes also enter the process chamber through the lid, but near the center of the chamber. Like the AC electrodes, the DC electrodes are equally spaced 120° apart. The seals around the DC electrodes are purged with nitrogen to maintain a good seal of the furnace plenum gases.

In addition to passing AC current between the joule-heating electrodes, the electrical configuration will enable operators to pass AC current to the floor of the melt tank. The bottom of the melt tank is equipped with three electrical connections to allow this operational mode. Current can be transferred to the bottom of the furnace if the temperature of the lower melt needs to be

increased, possibly to assist in pouring material through the bottom drain.

The process chamber encompasses two subsystems for product removal. A vacuum assisted weir overflow is used for slag removal, and an inductively heated bottom drain is used for metal removal. The molten products are drained into disposal containers and allowed to cool to a solid form.

Process syngas is removed from the process chamber via the process syngas removal vent, and is ducted to an insulated thermal residence chamber (TRC) where the steam reforming reactions can continue. The plenum in the main process vessel and the TRC each provide an approximately 2 second residence time for the syngas. Indicators monitor process chamber temperature and pressure, and the temperature of the syngas exiting the thermal residence chamber. The process chamber is maintained under a slight vacuum by the process vent system to assure that no process gases or dust escape untreated from the chamber. The process chamber is also equipped with an emergency off-gas vent to prevent an over pressurization of the process chamber in the event of a plug in the syngas system downstream of the process chamber.

The syngas processing subsystem design used in the verification tests includes a three-stage process to remove particulate matter and acid gas impurities in the syngas, and convert the syngas to fully oxidized products (primarily water and carbon dioxide) for safe and regulator-approved atmospheric release. The first stage of the purification process cools the gas from around 800°C to 200°C followed by a low-temperature pulse-jet baghouse to remove particles larger than 1 micron. The second stage includes two ejector-venturi scrubbers in series, a mist eliminator, a re-heater, and a HEPA filter. In all, this system includes 4 unit operations for PM removal and two unit operations for acid gas removal. The third stage includes final syngas conversion and atmospheric release. In the verification and medical waste tests, both an enclosed flare and a genset were used.

Utility subsystems include service/instrument air, nitrogen supply, process water supply, de-ionized water supply, steam, process cooling water, and chilled water. These subsystems have a set of monitors and alarms that measure various parameters regarding the availability and condition of utility services and supply. These monitors and alarms are annunciated in the main process control panel for operator action.

2.2 Continuous Process Monitoring and Control

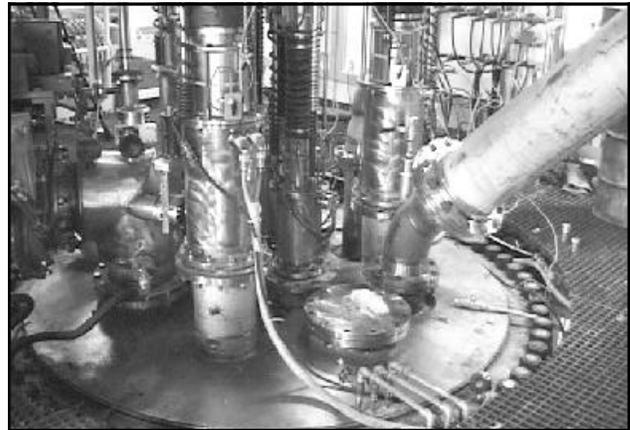
The PEM™ system is equipped with instrumentation to continuously monitor and control process flows, temperatures, and pressures, and to transmit key signals to the main data acquisition and control system. The system can control valves, motors, pumps, and fans, and can alarm and initiate waste feed cutoff interlocks if process conditions deviate from established limits. During system startup and shutdown or during process upsets, the interlock system automatically prevents all waste feeds and locks out their restart until the PEM™ system is at proper operating conditions and the interlock is cleared.

The syngas composition is continuously monitored to provide assurance of safe operating conditions and to provide information for process control and optimization. The syngas is continuously monitored for CO, CO₂, CH₄, H₂, and O₂. The syngas can also be continuously monitored using an added gas chromatograph for He (used as a tracer for flowrate determinations), N₂, and redundant CO, CH₄, H₂, and O₂ measurements.

A centralized main process control (MPC) subsystem uses computers, programmable logic controllers (PLCs), and Proportional-Integral-Derivative (PID) controllers to monitor, control, and alarm system parameters relative to operating limits specified in the permit. All data monitored by the MPC/PLC can be stored on electronic media for later use. A Siemens 505 Programmable Logic Controller (PLC) is the central controller of the process. The PLC contains the controlling logic for the process, as well as the plant monitoring. The Control Room Computer interfaces with the PLC for visual monitoring and operator interface. Process control transfers to a standby PLC if the primary PLC fails. PID controllers are standalone units that operate with only input and output signals. The PID controllers are linked to the MPC/PLC network as remote input/output (I/O), allowing the operator to view and adjust parameters in the PID controllers from the control room.

CHAPTER 3

Verification Test Description



A 10 ton/day melter used during the verification tests

PEMTM system verification tests were conducted during April 2000 (Table 1). Two test series were conducted to provide data for the verification program and to also satisfy other IET objectives. One test series (the Equivalency Test) was conducted using an organic compound-spiked liquid methanol feed material to determine PEMTM system equivalency to incineration (Focus 2001). The second test series (the Circuitboard Test) was conducted to provide test data for a unique, circuit-board fabrication waste material (AmTest 2000c, Focus 2002). The tests were conducted using a 10 ton/day, commercial-scale prototype system at the IET Technology Center in Richland, Washington.

These tests were performed based on the original EvTEC test plan (IET 2000). An independent subcontractor, Focus Environmental, directed offgas sampling and analysis during those tests. Another independent subcontractor, AmTest Air Quality LLC, performed the offgas sampling and analysis. IET and Allied Technology Group (ATG) personnel operated the PEMTM system, collected feed and process samples, and shipped those samples to outside laboratories for specified laboratory analyses. The tests were observed by EvTEC representatives. They observed system operation and offgas measurements and performed onsite quality audit observations, which are included in the results discussion and in Appendix B. EvTEC also performed miscellaneous data checks, collated data, and assessed subcontractor quality assurance and quality control (QA/QC) activities reported in the test reports.

These two tests provided information to address, some, but not all, of the criteria in the test plan (IET 2000). IET has performed other testing that was not observed by EvTEC representatives (AmTest 2000a, AmTest 2000b, IET 2000). Data from these other tests has also been included in this verification program to provide performance information for other waste types. Results of these tests generally corroborate and augment the results of the verification tests, but they are separately identified in this report because these tests were not initially included in the EvTEC verification project planning, and were not monitored by EvTEC representatives. While the onsite testing activities for these tests could not be verified by EvTEC, these tests were performed by the same testing subcontractor, using the same sampling and analysis procedures and laboratories (in most cases). The reported results of these tests were reviewed during the EvTEC verification program and deemed of sufficient quality and validity to include in this report.

All of the tests were performed at IET's facilities in Richland, Washington, on prototype melter systems sized according to nominal feedrates of 0.5, 2 and 10 tons/day. The actual feedrates for each test depended not only on the melter system size but also on the feed type and on test objectives. All feed handling, feeding, melter system operation, and melter data collection was performed by IET personnel for all tests. ATG personnel participated in these activities for the equivalency tests that were performed to show equivalency to incineration for the ATG mixed waste treatment facility in Richland, Washington. All offgas sample collection and analysis was performed by subcontractors to IET.

As a result of the various tests summarized in Table 1, IET has demonstrated the PEM™ system performance for three different system sizes, different actual and surrogate wastes including medical waste, municipal solid waste, circuitboard fabrication waste, incinerator ash, organic surrogate materials, and inorganic surrogate materials. Some of the tests included spiked metals and organic surrogates of products of incomplete reaction. Final syngas conversion using a lean-burn engine-generator was demonstrated while firing propane auxiliary fuel and while co-firing syngas produced from processing medical waste and the circuitboard fabrication waste. Final syngas conversion using an enclosed flare was also demonstrated while processing medical waste and while processing the spiked organic surrogate (methanol) during the equivalency test.

Verification Test Results



Offgas system with baghouse and two scrubber towers

The verification test results included documentation of operating conditions and comprehensive offgas measurements. As a result of the equivalency test, the US EPA has concurred in writing that the PEM™ system, when operated within applicable technical requirements, performs in a manner equivalent to other thermal treatment technologies consistent with criteria set forth in the definition of CMBST found in 40CFR 268.42 (EPA 2001, Appendix A).

4.1 System Operating Conditions

Operating conditions for the PEM™ demonstration systems during the various tests are summarized in Table 2. Since most of the feed materials for these tests contained significant amounts of volatile and organic material, the feedrates demonstrated were a fraction, typically 10–70%, of the nominal design feedrate for the test system. This range was expected, because the actual feedrate limit for any type of feed material is based on its composition and physical properties. The feedrate is limited based on the syngas processing capacity (which limits the feedrate of organic material), the melting capacity of the process chamber (which limits the feedrate of inorganic material), and the capacity of the feed system(s) for feeds of varying densities. The feedrate for mainly organic materials is typically less than the nominal feedrate, and the feedrate for low-density solid materials can be limited based on the volumetric capacity of the feeders.

In addition to the waste feed material and process chamber electrode power, other process inputs used during the tests included:

- N₂, used for purging seals and providing cool, inert gas protection for system components
- Steam, to react with the organic material
- O₂, used in relatively small amounts, sometimes only during preheat, to exothermically react with a portion of the syngas to heat the TRC and maintain its temperature at least 700°C for syngas production reactions
- Carbon from electrode consumption, which is a routine design feature for graphite electrodes, and is a relatively small added organic component that adds to the syngas
- NaOH used to maintain a neutral or slightly basic pH in the wet scrubber system
- Water, the amount depending on the water balance for the wet scrubber system
- Auxiliary fuel for the final syngas conversion stage (propane for the genset, and natural gas for the enclosed flare).

The AC joule heating and DC arc energy input into the process chamber varied, by design, according to the organic content of the feed material. Based on the limited data available, the joule heating power input ranged between 14-21% of the total power input of 224-273 kW. The DC arc energy input ranged between 79-86% of the energy input.

Energy consumption, based on the amount of energy to the process chamber, the waste feedrate, and the power generated by the genset, was determined during the Circuitboard Test. Data from the other tests was not available to perform this calculation. The energy consumption ranged between 2.7 kW/kg (assuming all of the genset power generation was from the circuitboard waste, although much of the energy input to the genset was from auxiliary propane fuel during this test), and 4.9 kWh/kg (excluding any genset power generation). The net energy efficiency, including power generation from the genset, for other feeds with higher organics content than the circuitboard waste may be better than the values calculated for the Circuitboard Test.

Process temperatures varied within acceptable ranges according to IET. While the glass melt temperature was not directly measured, the process chamber refractory temperature was monitored at several different locations as indicators of the melt temperature and to monitor for any refractory temperature extremes that may suggest excessive refractory heating or cooling. Maximum refractory temperatures ranging between 1,100-1,200°C indicate average melt temperatures ranging between 1,200-1,300°C, which were within design melt temperatures for those tests.

The syngas temperature was measured in the process chamber plenum and at the outlet of the process chamber. The plenum temperature measurement was biased high from the radiant energy shine on the thermocouple from the plasma arc, and so is indicative of an “effective plenum temperature” but does not accurately indicate the true syngas temperature. The best syngas temperature was indicated by the outlet gas temperature.

The minimum design temperature for the TRC was reported by IET to be 700°C. At lower temperatures, syngas formation reactions would be less efficient, especially for heterogeneous reactions that gasify solid-phase char products of organic pyrolysis. TRC temperatures were consistently about 100-200°C higher, but levels of char collected in the TRC, the partial quench chamber, and the baghouse during the EvTEC-observed tests

suggest that at least some char was not reacted. Perhaps the design or operation of the TRC should be modified for improved char gasification if the amount of char collection in the TRC or downstream equipment becomes problematic.

The baghouse low-temperature limit, approximately 100°C, is defined as the temperature at which moisture condensation on the bags or baghouse shell causes problems such as dust agglomeration or metal corrosion. The baghouse high-temperature limit (not reported), is the temperature at which baghouse materials are thermally damaged. The baghouse temperatures typically ranged between 110-200°C, which is within the acceptable range.

The acid gas control performance of the wet scrubber system depends largely on the pH of the scrubber solution. At times during the EvTEC-observed tests, the scrubber solution pH ranged to 1-2. While acid gas (HCl, Cl₂, and SO₂) concentrations measured in the offgas were always below expected regulatory or permit limits, higher HCl levels were measured during low scrubber solution pH time periods during the equivalency test (Focus 2001).

Syngas production was within IET’s acceptable ranges for the EvTEC-observed tests. The syngas flowrate was lower for the Circuitboard Test than for the equivalency test because of the lower organic feedrate during the Circuitboard Test. Because dilution of purge N₂ is relatively constant regardless of waste feed material or feedrate, the syngas from lower organic feedrates is more diluted with N₂ and would have a lower heating value. Interestingly, the mass flowrate of syngas ranged from about 30-140% higher than the mass feedrate of feed material, because of the added steam used for syngas production and the added N₂ used in various purges.

Syngas concentrations ranged from 44-61 volume % N₂, 18-47% H₂, 10-30% CO, 2-11% CO₂, 3-5% H₂O (estimated), and 1-4% CH₄.

4.2 Offgas Air Emissions

Air emissions need to comply with expected regulatory/permit limits. These limits vary for different applications in different parts of the world and for different industries. For simplicity, compliance with the U. S. EPA National Emission Standards for

Hazardous Air Pollutants (NESHAPs) for Hazardous Waste Combustors (HWCs) based on maximum achievable control technology (MACT) (EPA 1999) was assumed for this verification program. The HWC MACT standards promulgated in 1999 are only temporarily in place until final HWC MACT standards are promulgated in 2005. While the new standards may vary from the existing temporary standards, the existing temporary standards are assumed to be reasonably representative and also conservative compared to existing and new standards worldwide for industries where PEM™ may be applied. Of course, any specific installation will require its own site-specific evaluation of regulatory compliance to air emission regulations. Site-specific requirements may be more or less stringent than the current HWC MACT standards.

4.2.1 Offgas Conditions and Compositions

Effluent offgas conditions and compositions for the tests are summarized in Table 3. Except for offgas temperature (which is very high for both the genset, exceeding 800°F, and the flare, exceeding 1,100°F, compared to the offgas effluent from most other thermal treatment processes), offgas conditions for the genset are different from the flare in several respects, regardless of PEM™ process conditions. The offgas velocity for the genset is very high, typically over 100 f/s, and the offgas velocity for the flare is low, around 10-20 f/s. The genset offgas O₂ concentration was 0.0 volume %, since the genset was operated with just the amount of air to stoichiometrically burn the fuel. This result also enables a correction factor of 67% when converting measured concentrations for comparison to concentration-based emission standards such as the HWC MACT standards that use 7% O₂ as the comparison basis. The corrected values used for comparison are 67% lower than the measured values. On the other hand, the flare was operated to stably and safely combust gas streams with offgas O₂ levels ranging between 14-17%. At these higher O₂ levels, the measured species concentrations are increased by an O₂ correction factor of 2-3 for comparison to concentration-based standards.

Acid gas (HCl, Cl₂, and SO₂) concentration results reported for all the tests were either near or below detection limits (around 0.6 ppm for HCl and Cl₂ and around 0.1-1 ppm for SO₂). The reported HCl/Cl₂ results ranged from less than 10% to 67% of the HWC MACT limit. HCl levels were only

observed above detection limits when the pH of the scrubber solution ranged around 1-2, during a portion of the equivalency test. Nominal design wet scrubber pH levels range above 7-8 for high acid gas scrubbing efficiency.

Residual CO and THC in the genset offgas, ranging between 100-200 ppm and 8-12 ppm (dry, corrected to 7% O₂) exceed the HWC MACT limits for CO and THC. This is true for both propane and fuel and syngas co-fired with propane. If offgas emission limits as low as the HWC MACT standards are applied to genset emissions, then the genset design or operation will need to be modified for compliance. Reported CO and THC emissions for the flare offgas were about between 2% to 5% of the HWC MACT limits.

Particulate matter (PM) was low, at or near detection limits, for all tests. All test reports indicated PM concentrations measurements ranging around 5 mg/dscm or less (uncorrected for O₂), based on triplicate 1-hour sample durations. Such low concentrations (or even lower concentrations) are expected since the syngas in all tests passed through four stages of PM removal in series – the baghouse, two ejector venturi scrubbers, and the HEPA filter. At such low levels, the standard deviation for the triplicate measurements ranged around 50% of the average. Such a high standard deviation, together with studies on PM measurements downstream of HEPA-filtration at the INEEL, indicate that the measured levels were in the range of the detection limit and measurement error for a 1-2 hour test (Soelberg 2001). The results of one test (the February 16-18 medical waste flare tests) were high enough, with a standard deviation of only 32% of the average, so the average value and standard deviation are shown in Table 3. PM measurements for the other tests are shown as “less than” the level of the highest of each test in a triplicate test. When corrected to 7% O₂, the PM concentrations are less than about 24% of the HWC MACT limit, except for the February 16-18 medical waste test results that were about 30% of the limit.

While the PM measurements are acceptable in comparison to the MACT limit, they probably overstate the true PM levels. More accurate, lower PM measurements, if needed, can probably be achieved by sampling for a longer period of time or by using the newly developed EPA Method 5i, designed for PM concentrations.

4.2.2 Organic Species Emissions and Destruction Efficiencies

Semivolatile organic compounds (SVOCs) measured at the offgas emission point in many of the tests included polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs and PCDFs, or D/Fs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other SVOCs. Volatile organic compounds (VOCs, those with boiling points between about 0°C and 121°C) were also measured at the offgas emission point in most tests.

D/F measurements are shown in Table 4. D/F congeners were largely not detected (above the reported detection limits) for the Equivalency Test and the Circuitboard Test. Octachlorinated dibenzo-p-dioxin (OCDD) was the only PCDD detected in these two tests, and no PCDFs were detected in the Circuitboard Test. Such low results for the Circuitboard Test were expected, based on prior low D/F measurements for the PEM™ system and the fact that chlorine was not present in the circuitboard material. In these tests, non-detected congeners are assigned a 0 value summing and toxicity equivalent calculations according to EPA Method 23. This avoids the potential for biasing the total D/F and toxicity equivalent calculations high due to summing a large number of detection limit values.

D/Fs were detected at higher total levels in the medical waste tests. This occurred in part because the detection limits for these tests trended lower than the range of detection limits for the Equivalency and Circuitboard tests. More congeners were detected above the lower detection limits, even though, in some cases, the detected levels in these tests were lower than the detection limit values in the Equivalency and Circuitboard tests. Since these congeners were detected, they were included in the summing and toxicity equivalent calculations. The detection limits were lower in part because of a longer sample duration (up to 4 hours for the medical waste tests compared to 3-4 hours for the other tests) and because, for the March 8-9 medical waste test, only D/Fs were measured using the Method 23 train. The other tests included measurements for PAHs, PCBs, and other SVOCs from the same sample trains. This caused the extracted samples to be split prior to analysis, decreasing the sensitivity of each analysis.

Even though the lower D/F detection limits for the medical waste tests contributed to higher total D/F and toxicity equivalent

results than for the other tests, the greatest cause for the higher values was higher detected levels of many PCDDs and PCDFs. These results suggest that D/F levels were indeed higher in the offgas from the medical waste tests, regardless of whether the syngas was converted in the genset (during the March 8-9 tests) or in the flare (during the February 16-18 tests). These higher levels may be related to the different feed conditions, or to differences in the two systems or operating conditions of the tests. The medical waste tests were performed in the 2 ton/day prototype system, while the EvTEC tests were performed in a different system, the prototype 10 ton/day system.

While the D/F levels from the medical waste tests are higher than those from the other tests, all of the measurements are less than 11% of the HWC MACT limit. The highest O₂-corrected D/F toxicity equivalent quotient (TEQ) level for the equivalency test (from Run 1) was 5% of the HWC MACT limit of 0.2 ng/dscm (TEQ) for new facilities. The highest D/F level for the Circuitboard Test (from Run 1) was 0.02% of the HWC MACT limit. D/F levels for the medical waste tests ranged less than 11% of the limit.

The ratio of total D/Fs to the total TEQ for all tests but the Circuitboard Test ranges between 40-1,000. A ratio between 10-100 is typical for combustion sources. The ratio for the circuitboard test and for two of the three runs for the Equivalency Test is an anomaly at 1,000, outside the typical range, because only a single congener (OCDD with a toxicity equivalency factor (TEF) of 0.001) was detected in those runs.

PAH measurements are shown in Table 5. Only three test series included PAH measurements. Like the D/Fs, the PAHs for the equivalency and Circuitboard Test are mostly not detected, although the detection limits are higher than the PAH concentrations that were detected in the February 16-18 medical waste test. Naphthalene was detected in the Equivalency and Circuitboard Tests, and was detected at a level 10-1,000 times higher than any other PAH in the medical waste test. Naphthalene is commonly detected in larger amounts than other PAHs in thermal process emissions, but is relatively less hazardous than other PAHs.

Naphthalene was detected in the field blanks for the equivalency and Circuitboard Test at levels ranging from 10-66% of the naphthalene detected in the offgas. Several PAHs were detected in the field blank for the medical waste test. None of the offgas PAH measurements were blank-corrected.

Of all the other PAHs, only fluoranthene, pyrene, chrysene, and benzo(b)fluoranthene were detected in only one of the EvTEC-observed tests. Most of the PAHs were detected in all of the medical waste test runs, though at typically lower levels than the detection limits for the EvTEC-observed tests.

While the 19 PAH analytes included in the analyses are specified in California Air Resources Board (CARB) Method 429 (“Determination of Polycyclic Aromatic Hydrocarbon (PAH) Emissions from Stationary Sources,” July 28, 1997), several other PAHs listed in EPA’s guidance for risk assessment testing (EPA 1998) are not included. These are 1-chloronaphthalene, 2-chloronaphthalene, dibenz(a,j)acridine, dibenzo(a,e)pyrene, 7,12-dimethyl(a,e)anthracene, and 3-methylcholanthrene. Future testing for purposes such as risk assessments may need to include these additional PAHs if possible.

Levels of PAHs on the order of the levels observed in these tests are expected to be within applicable regulatory emission limits.

PCB measurements are shown in Table 6. Both total PCB homologue and dioxin-like coplanar PCB analyses were included in the equivalency test measurements, but only total PCB homologues were included in the February 16-18 medical waste test. Some total PCB homologs were detected in the medical waste test at levels 10 times higher than detected (or detection limits) in the Equivalency Test. This may be due to differences between the feed materials, the two different prototype systems (2 ton/day for the medical waste tests versus 10 ton/day for the Equivalency Test), or the syngas conversion system (genset for the medical waste Feb. 16-18 test, versus enclosed flare for the Equivalency Test). The higher PCB levels in the medical waste test are consistent with the higher CO and THC levels in this test.

Levels of PCBs on the order of the levels observed in these tests are expected to be within applicable regulatory emission limits.

Measurements for other SVOC species besides D/Fs, PAHs, and PCB species are shown in Table 7. SVOC measurements were included only in the Circuitboard Test. No SVOC species were detected above their respective detection limits, which ranged from 0.04-1 mg/dscf. The SVOC analyte list included 64 different compounds typically analyzed in offgas emission tests. Compound classes, defined by specific structures and functional groups, that were represented in this list included aliphatic (straight and branched carbon chain), single carbon bonds, double carbon bonds, aromatic (benzene ring), phenols

(-OH substitution), ethers (-C-O-C-), chlorinated, amines (-NH₂), organic acids (-COOH), and PAHs. The PAHs included in the SVOC analysis were analyzed by low-resolution gas chromatography/mass spectrometry (LRGC/LRMS) per EPA Method 8270C instead of high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) per EPA Method 8290 (used in the PAH analyses reported above). The 8270C analyses typically provide poorer detection limits than 8290. PAH measurements determined by 8290 are typically more sensitive and should be used instead of PAH measurements by 8270C when, as in this case, no PAHs were detected by 8270C.

The SVOC analysis included determinations for not only the 64 listed SVOCs that the GC/MS instrument was calibrated for; the GC/MS scans were also evaluated for any additional SVOCs present in the sample, for which the instrument was not calibrated. These additional species, if detected with peak areas greater than a threshold limit, are tentatively identified (if they can be adequately matched with library compounds) and reported as “tentatively identified compounds” (TICs). The laboratory looked for the top 20 TICs, which is a common practice. No SVOC TICs were found that met the acceptance criteria for peak area and match identification.

Levels of SVOCs on the order of the detection limits observed in these tests are not expected to present any unacceptable environmental, worker, or public risk.

VOC measurements are summarized in Table 8. VOC emissions were measured in all of the reported tests. Most VOCs were not detected above the detection limits of the methods. Methylene chloride was detected in one of the propane test runs and one of the medical waste test runs, but was not detected in any of the other 15 runs of all the tests. Methylene chloride is a common laboratory contaminant. Amounts detected in those two runs may be due to such contamination. Other VOCs detected in two or more of the medical waste tests were benzene, toluene, tetrachloroethene (one run only), ortho-, meta-, and para-xylenes, 1,3,5-trimethylbenzene, and 1,2,4-trimethylbenzene. No VOCs were detected in the equivalency test, at detection limit levels about 10 times lower than those for the other tests. Only one VOC (acrylonitrile) was detected, in only one of the runs, of the Circuitboard Test.

VOC measurements made during the medical waste tests were performed using EPA Compendium Method TO-14 “Determination of Volatile Organic Compounds (VOCs) in

Ambient Air Using SUMMA Passivated Canister Sampling and Gas Chromatography Analysis.” VOC measurements made during the Equivalency and Circuitboard tests were performed using EPA Method 0031. This change was made so that the EPA-approved method (Method 0031), which can also be more sensitive than TO-14, was used in the equivalency and EvTEC-observed tests. While Method TO-14 was promulgated for ambient air sampling, it costs less than Method 0031 and was a cost-effective method used in the medical waste tests to determine VOC emissions.

Because of the use of different VOC measurement methods, the VOC analyte lists varied for the different tests. For example, Method TO-14 detected xylenes that were excluded in the Method 0031 tests, and Method 0031 detected acrylonitrile, that was excluded in the Method TO-14 tests.

The laboratory looked for three specific commonly-occurring volatile TICs (crotonaldehyde, 1,4-dioxane, and ethylene oxide) in the VOC GC/MS scans. None of these TICs were detected. No other volatile TICs were searched for.

Levels of VOCs on the order of the levels observed in these tests are not expected to present any unacceptable environmental, worker, or public risk.

Destruction and removal efficiencies (DREs) for principal organic dangerous constituents (PODCs) measured during the equivalency test are shown in Table 9. The four volatile PODCs are benzene, chlorobenzene, tetrachloroethene (perchloroethylene), and toluene. These PODCs include both aliphatic and aromatic, and chlorinated and nonchlorinated VOCs that are commonly used in incinerator trial burns to determine VOC DREs. These were spiked into the liquid methanol surrogate feed at nominal concentrations of 1.5-2.5 weight %. PCBs were also spiked into the methanol feed to indicate total PCB destruction efficiency. Total PCB homologue groups (mono-through decachlorinated PCBs) were spiked at a nominal concentration of about 0.05%.

Of the triplicate runs, the lowest measured DREs for the volatile PODCs were > 99.999939% for benzene, > 99.999963% for chlorobenzene, > 99.999968% for tetrachloroethene, and > 99.999955% for toluene. “Greater than” values are used because of the use of detection limit values in the calculations where measured concentration results were below detection limits of the measurement methods. These PODCs were not

detected in any of the triplicate runs. The measured VOC DREs were at least two orders of magnitude greater than the target DRE of 99.99% (four 9s).

The PCB DRE target of six 9s destruction efficiency could not be demonstrated based on the PCB data. The PCB DREs were calculated two different ways because some total PCB homolog groups were detected, and some were not detected. The traditionally conservative mass emission rate calculation method totals all detected and non-detected emission rates, and shows the emission rate as a “less than value”. This value, when used in DRE calculations, results in a “greater than” DRE which can be misleading when the mass emission rates of detected values considerably exceeds the detection limit values. These values range from > 99.99978% to > 99.99988%. The PCB DRE was also calculated by summing only the detected PCB values, excluding the non-detected values. These values ranged between 99.99982-99.99991%, higher than the first range, but still just under the target of 99.9999% (six 9s) DRE. Using the measured data, the true PCB DRE values are between the two ranges based on the two different calculation techniques.

Two factors that affected the inability to demonstrate at least six 9s DRE may have been due to the relatively small amount of PCBs spiked into the feed. First, the spiked PCB total homolog concentrations ranged about 40 times lower than the spiked concentrations of the volatile PODCs, which all showed over six 9s DRE. If the PCBs were spiked at a higher concentration in the feed, then an adequate PCB DRE may have been demonstrated, since the DREs for the volatile PODCs all exceeded six 9s. Second, all of the four detected total PCB homologs (di-through pentachlorinated biphenyls) were detected in the field blank at levels ranging from 40-150% of the levels detected in the offgas samples. These blank values were not subtracted from the measured values in the mass emission rate calculations, according to standard conservative practice. If they were subtracted, the DRE values would have exceeded six 9s DRE.

4.2.3 Metal Emissions

Metal emissions (Table 10) were measured at the genset offgas emission point during the Circuitboard Test and in one of the medical waste tests (March 8-9).

The offgas samples from the Circuitboard Test were analyzed for 32 metals. Some metals detected in the offgas were either not analyzed for in the feed, or were present in the feed at low

concentrations. Lead was detected in the offgas in large enough amounts that the total semivolatile metal (SVM) levels ranged from around 6-13% of the HWC MACT standard (120 ug/dscm at 7% O₂). Of the low volatility metals (LVM), As and Cr were not detected, and the detected levels of Be were low. The total LVM levels, including the As and Cr detection limits, was around 1% or less of the HWC MACT standard for LVMS of 97 ug/dscm. Mercury was not expected in this test and was not detected. Using the Hg detection limit, the Hg levels were less than 2% of the HWC MACT standard for Hg of 45 ug/dscm.

Cd, Pb, and Hg were measured for the medical waste test. Cadmium and lead were spiked into the medical waste feed, each at a concentration of 1 weight %. Any amounts of these metals already in the waste would be additive to the 1% spiked levels. As expected, the Cd and Pb levels in the offgas were very low. If regulatory or permit limits for medical waste treatment are equivalent to the HWC MACT limit for semivolatile metals, then the measured level would be under 0.4% of this limit.

Hg was not spiked into the medical waste and was not supposed to be there^{*1}, but the test results show that Hg was present in the waste. The measured offgas Hg level for the medical waste test ranged from two to five times higher than the HWC MACT limit for Hg. If Hg regulatory or permit emission limits for an actual waste treatment system are equivalent to the HWC MACT limit, then the facility may need to include mercury control such as carbon absorption in the offgas system if the waste contains levels of Hg similar to the levels in the medical waste during this test.

4.3 Feed Material Representativeness

Feeds used during tests were physically and chemically representative of a variety of candidate wastes. The feed for the Equivalency Test (Table 11) was methanol spiked with PCBs and volatile PODCs. The PCBs included both coplanar PCBs and mono-through deca-chlorinated biphenyls (CBs). The volatile

PODC mixture also contained dichlorobenzene and naphthalene. This feed mixture was prepared with these objectives:

- Provide a worst-case, most volatile feed material to challenge the capability of the melter system to process such a volatile feed. Methanol is a very volatile liquid, with a boiling point (65°C) lower than most other VOCs that are liquid at ambient conditions.
- Provide a feed media that can controllably meter spiked compounds into the melter. Methanol is a good solvent for the spiked compounds.
- Provide a feed mixture that simulates the organic liquid feed for the planned GASVIT™ low-level mixed waste melter system at ATG in Hanford, Washington
- Include PCBs and PODCs from which DREs can be determined

These objectives were accomplished with the methanol feed mixture. This mixture can also represent other volatile liquid organic feeds for other applications.

The feed mixture for the Circuitboard Test was actual circuitboard fabrication waste provided to IET for testing by a circuitboard fabrication company. The waste material is waste pieces of fiberglass circuit board, backed with copper sheet, without any added wiring, electrical components, or solder. The waste pieces (initially appearing as shown in Figure 3) were shredded to a size small enough to be bagged into approximately 1-cubic-foot bags (Figure 4). These bags were fed through the solid waste feed system into the melter.

The chemical composition of the circuitboard waste is shown in Table 12. The material is fiberglass-reinforced plastic, and is nearly one-half (by weight) organic matter. Depending on the analysis technique, the remainder is roughly one-half elemental copper that is the metal sheet backing, and roughly one-half metal oxides that comprise the glass fiber content. This material is representative of various solid wastes that contain appreciable metals and organic content, with essentially no moisture.

^{*1}The medical waste was obtained from a local hospital. No Hg was said to be present in the waste but was certainly determined to be there in the offgas analysis of these tests. The prototype system used in the demonstration tests was not configured with carbon absorption to capture mercury. Consequently, it was reported in the offgas, since the offgas system was not designed with the intent to efficiently control mercury emissions. Determinations of Hg control or Hg emissions was not an objective of this test.

The April 14, 2000 municipal solid waste test was conducted using a blended municipal solid waste with the following approximate composition:

<u>Component</u>	<u>Weight %</u>
Paper	50
Wood	30
Plastic	11
Glass	8
Metal	0
Total	100

This material, excluding metals that may comprise up to 5-10% of the total weight, represents a range of municipal solid waste.

The medical waste used in the April 14, 2000 medical waste test was actual medical waste provided by local area hospitals. The same hospitals provided the waste used in the earlier medical waste tests in the 2 ton/day prototype PEM™ system. A chemical analysis is not readily available for this material. One surprise in this waste was the unexpected presence of Hg detected in the March 8-9 test. While the actual makeup of this waste is not well known, it provides one example of medical waste processing for the PEM™ system.



Figure 3. The circuitboard fabrication waste before shredding and bagging



Figure 4. Shredded and bagged circuitboard fabrication waste

4.4 PEM™ Product Characterization

The PEM™ products produced during the verification tests included the vitrified glass, the syngas, any fly ash or dust captured in the baghouse, and any scrub solution discharged. A metal product, tapped as a separate molten phase from the molten glass, is also possible depending on the feed input, but no metal product was tapped during the verification tests. Glass was produced from the Circuitboard Test, because the circuitboard fabrication waste contained glass-forming metal oxides. No glass was produced from the Equivalency Test because the feed was 100% organic material and contained no glass-forming components.

The composition and leachability of the glass from the Circuitboard Test are shown in Table 13. This glass contains many metals, presumed in the analysis to be oxides of the forms listed in the table. The hazardous metals Ag, Ba, Cr, and Pb were detected in the glass, though the majority of the glass is oxides of Si, Al, Ca, Na, and Mg.

The glass leachability was evaluated using the Toxicity Characteristic Leachability Procedure (TCLP, 40 Code of Federal Regulations 261 Appendix II) and compared to TCLP limits (40 Code of Federal Regulations 261.23). Of the four hazardous metals detected in the glass, less than 0.8% leached into the TCLP solution, based on measured and detection limit results of the TCLP analysis. Based on measured results alone (excluding the detection limit results for Ag and Pb), only 0.01% of the Cr and 0.03% of the Ba leached into solution. The TCLP concentrations for all eight hazardous metals ranged from 0.02% of the limit (for Ba) to less than 20% of the limit (using the detection limit for Se, which was not detected in the TCLP solution).

The syngas compositions are summarized in Table 2 and discussed in Section 4.1.

The baghouse dust from the Circuitboard Test was captured and analyzed for elemental composition and particle size. The composition is shown in Table 14. The moisture content ranged between 10–45%, based on operating conditions of the baghouse. At different times, some condensation was observed in the baghouse.

The carbon content ranged between 18–53%, and total organic content ranged from 54–61%. The carbon and total organic contents depended on how effectively soot and tar compounds were gasified in the melter plenum and TRC. At times, soot buildup occurred in the system between the TRC and the baghouse in this prototype system. This amount of soot buildup represented only a small fraction of total carbon in the field. Mass balance calculations using the feed rate syngas composition and syngas flow rate show that essentially all (99.6%) of the carbon in the circuitboard feed material was gasified and converted to CO, CO₂ and CH₄.

Metals (excluding Cu) detected in the analysis at levels totaling 13–19% (wet basis) were assumed to be in the form of oxides, increasing their mass percentages to 36–43% (dry basis). Copper was assumed in its elemental form, since it was fed to the melter in its elemental form and exposed to reducing rather than oxidizing conditions in the melter system. Elemental Cu levels ranged around 2.5% (dry). These assumptions are validated by the low values (87–90%, wet basis) for the total composition when the elemental composition is used, compared to 100–106% (wet or dry) for the total composition when the oxide forms of the non-Cu metals are used.

The baghouse dust particle size distribution is shown in Table 15. About 50% of the material is less than 0.5 microns in diameter; up to 75% is less than 1 micron; and essentially all of the dust is less than 10 microns. This is fairly typical for particulate matter in offgas from melters.

Scrub solution compositions from the verification tests are shown in Tables 16–18. Levels of PCBs and the spiked PODCs in the scrub solution from the Equivalency Test are shown in Table 16. No coplanar PCBs were detected, but increasingly high total PCB homolog levels were detected in subsequent samples. The levels increased because, as in standard wet scrubber practice, the scrub solution is recycled through the scrubber system except for a small amount that is, or can be, discharged, to maintain total dissolved solids and total undissolved solids within acceptance limits. Mono-CB increased by the largest factor (over 1,000x) compared to its pre-test level. Other total PCB homologs increased by at least a 10x.

Only two of the VOCs spiked with the PODCs (benzene and naphthalene) were detected in the scrub solution. The detection limits for the EPA Method 8260 procedure used for the VOC

analysis ranged about 1,000x poorer than for the EPA Method 1668 specified for PCB analyses. Some of these VOCs may have been present, but were not detected, at levels similar to the PCB levels. Benzene and naphthalene were detected at levels up to 500x higher than the highest measured PCB levels.

SVOC concentrations in the scrub solution from the Circuitboard Test is shown in Table 17. This test, of the two verification tests, was most likely to result in SVOC increases in the scrub solution because the feed was composed of roughly 50% complex organic material. Out of 64 SVOCs in the analytical list, 16 were detected in at least one of the triplicate samples. Of these, 13 were detected in the initial pretest sample, and all of these actually decreased in subsequent samples. No detected SVOCs increased during the duration of the test, suggesting that no net capture of SVOCs in the scrub solution occurred during the test.

The data in Table 17 is estimated data because of two factors that occurred during the scrub solution sampling and analysis for SVOCs. First, the volumes of the scrub solutions analyzed for SVOCs were not measured due to sampling and analysis error. The samples were contained in 1-L bottles, and the entire amount of sample was extracted and analyzed. A volume of 1 L was estimated for all of the samples. The concentration values reported in Table 17 are estimates of the true values, because they are based upon estimated sample volumes. Second, a few of the measured mass values are estimated because the analytical

instrument response was above the calibrated range for those measurements. The value reported is flagged (with an “E” for “estimated”) and estimated based on extrapolating the instrument calibration. These “E” values may be an underestimate of the true value.

One of the scrub solution samples was analyzed for SVOCs twice as a quality control check in the laboratory. The duplicate analysis results and the relative percent difference (RPD) of the duplicate analyses are shown in Table 17. The RPD for those compounds that were detected ranged under 20% except for acenaphthene, which had a RPD of 40%. This RPD range is within a typical acceptance limit of 50% for SVOC analyses.

Levels of total metals and total undissolved solids (UDS) in the Circuitboard Test scrub solution are shown in Table 18. Many metals were detected including the hazardous metals Ba, Cd, Cr, and Pb. Hg was not analyzed in these samples, but was not expected to be in this scrub solution. Metals with the highest concentrations included in order of decreasing concentration Na, Si, Cu, Ca, B, P, K, Mg, Zn, and Al. These metals include those that are either major constituents in the circuitboard fabrication waste (Si, Al, Ca, and Mg), major components in glass frit used in preparing the initial molten glass bath (Na, Si, Ca, B, K, Mg, and Al), or known to be relatively volatile and prone to disproportionally volatilize into the offgas system (Na, B, P, K, and Zn).

Verification Program Quality Assurance Activities



The control room for a 10 ton/day melter system

Quality control and quality assurance (QA/QC) activities for the tests were performed by IET and by independent subcontractors. These activities included (a) preparation of test plans, (b) performance of QA/QC activities according to applicable test/quality plans, and (c) reporting summary results of the QA/QC activities in the test reports.

Quality assurance activities performed by EvTEC representatives for the verification program included (a) reviewing and editing the initial verification test plan prepared by IET and Focus, (b) performing an onsite, informal systems audit during the EvTEC-observed tests, (c) validating results reported in test reports, and (d) reviewing and evaluating the results of the QA/QC activities performed by independent subcontractors.

5.1 Verification Program Test Plan

The verification plan was initially drafted by Focus and IET following the format of a traditional incinerator trial burn. In the initial panel meeting held in 1998, the panel recommended various changes to this plan to redirect the focus from a trial burn to a performance verification including identification of performance criteria and evaluation of the PEM™ based on the performance criteria. These revisions were made at the time of the verification tests. The changes included:

- Documented, detailed organization of responsible persons and organizations for the verification tests, including subcontracted independent laboratories for process sample analysis. Offgas measurements and sample collection for all of the tests was performed by AmTest Air Quality, LLC. Focus Environmental, Inc. directed the offgas measurements performed by AmTest during the equivalency and circuitboard fabrication waste tests. Sample analysis was performed by organizations shown in Table 19.
- Revisions of some of the test methods. EPA Method TO-14, used for VOC measurements in the medical waste tests, was replaced with EPA Method 0030 based on prior trial burn guidance in the original test plan. The revised test plan specified EPA Method 0031 which has been the specified methodology for VOC measurements since the late 1990's.
- Preparation of a manual data sheet for observers to use to record process and emissions data from local instrument indicators, the process data logger, and the offgas continuous emissions monitoring system (CEMS).

5.2 EvTEC Audits

The EvTEC onsite systems audit was performed during the Equivalency and Circuitboard tests to evaluate the operating and measurement systems and procedures performed by IET and the independent subcontractors. The results of the systems audits are summarized below:

PEM™ test system The entire PEM™ system was inspected. The use of specific unit operations or features in the test system were clarified. Some of these unit operations and features are subject to change (and have changed) in current and future system designs. Unit operations and features in the Equivalency and Circuitboard tests that can or have already changed include (a) the design of the thermal residence chamber (TRC), (b) the use of pure O₂ injected into the TRC to oxidize a portion of the syngas for preheating and maintaining high temperatures, (c) the design of the PM filtration upstream of the wet scrubber, (d) the wet scrubber design, and (e) the enclosed flare for the equivalency tests (instead of possible alternative syngas conversion devices such as a thermal oxidizer). As long as design or operating changes are at least as effective as those tested during the tests, the test results should indicate representative or conservative performance of modified or new unit operations or features.

The design and operation of each unit operation was reviewed, with the exception of some details of the processing chamber that were proprietary. Normal operating ranges for temperatures, pressures, and flowrates were identified, and acceptable operating limits for the tests were defined.

Continuous process monitoring system (CPMS): Key process conditions (flowrates, temperatures, pressures, etc) were monitored locally and transmitted using the data logging computer in the control room. Manual operator logs were used to record data in addition to the electronic data logger. Manually logged data included some data at local readouts that was not transmitted to the electronic data logger, along with data that was also electronically logged. Data that was manually but not electronically logged included (a) AC joule heating electrode voltage and power, which, during these tests, was not being correctly transmitted and recorded electronically, and (b) He, steam, O₂, N₂, cooling water, and scrubber water flowrates.

Field audit Results of a field audit of the different offgas sampling and analysis procedures performed during the equivalency test are summarized in Appendix A. The Appendix A tables are based on procedure summaries in EPA 1994. All offgas measurements were made according to applicable and appropriate EPA-approved procedures. High offgas temperatures, exceeding 800°F for the genset and 1,100°F for the flare, dictated the use of sample probes and equipment that can tolerate such temperatures. Sample probes used in the Equivalency and Circuitboard tests included single-piece glass probe liners and nozzles that avoided potential leakage that can occur if the probe nozzles, as separate pieces, are attached to the probe liner. Two-piece nozzle-probe liner assemblies were reported to have been used in the medical waste tests used to provide supplemental data. While two-piece assemblies are accepted according to the reference methods, these assemblies can leak at high temperatures even when they pass leak checks at lower temperatures.

Such high offgas temperatures may also result in continued reactions as the sample gas passes through the sample probe and upfront filter, before the gas is cooled in the impingers. If such reactions occur, then the sample train measurements can be less representative of true offgas conditions. Little is known about the potential, extent, or variability of such continued reactions, except that some researchers have reported the possibility of D/F formation in the sample train under similar conditions (MSE 1997). Since D/F levels were at least 10x lower than the HWC MACT limit in all tests, this potential concern does not adversely affect these measurements. If some D/F formation was in fact occurring in the sample train front half, then the reported results are conservatively high.

The low offgas velocity of the flare offgas can affect the isokinetic sample train measurements because the velocity measurement is indicated by velocity pressure head values on the order of 0.01–0.05 inches water. At such low velocity head, the measured value is subject to larger measurement error from velocity head fluctuations, condensation, or other plugging in pitot lines. According to velocity calculations, the square root of errors in velocity head readings will propagate into errors in the sampling rate (which will affect the sample isokineticity and representativeness of particulate sample collection), the measured concentrations of particle-phase species, and mass emission rates for both particle and gas-phase species. The

potential error was minimized by using a pressure transducer with digital output (Airdata Multimeter ADV-850) to provide better readability at such low velocity heads.

Testing was delayed for several hours during the Equivalency Test while the offgas testing subcontractor resolved an incompatible fitting in the Method 0031 trains. The incompatibility was caused by the last-minute change from the originally-planned use of Method 0030 to the use of Method 0031, upon recommendation from EvTEC representatives. After replacing the incompatible fitting, the Method 0031 trains were leak-checked and operated successfully.

The Method 0031 trains were run during the Equivalency Test for a nominal sample volume of 40 liters instead of the maximum volume of 20 liters specified in the method. The sample volume is limited by procedure because of the potential for some of the more volatile VOCs to elute through the Tenax resin sorbent. If appreciable amounts of some VOCs are detected, especially on the second Tenax tube or on the charcoal tube, then the data may be considered suspect. Even though the larger sample volume was used, the VOC data from this test is still valid because (a) no breakthrough of VOCs was detected in the second and third tubes, and (b) no VOCs were detected in any of the sample trains above typical detection limits.

5.3 Data Validation

The independent testing companies (Focus and AmTest) prepared reports that included the results of the offgas testing. These reports were reviewed during the EvTEC verification program, and results of these reports were incorporated into the verification report. Data in these reports was checked in several ways to assess data completeness and quality. These data checks were especially useful for validating data from the medical waste tests, which were not observed by EvTEC representatives and were not necessarily performed according to the verification test plan.

Some findings of the data validation checks are discussed in Section 4, where the results are presented. Some additional checks, results, and corrective actions are summarized as follows:

- The medical waste test reports by AmTest included all applicable offgas measurements and laboratory results, but very minimal data on process operation and no feed or product characterization information. Except for feedrate and genset power information, no process conditions (temperatures, flowrates, syngas composition, scrubber pH, etc) and no feed or product information (composition, glass properties, metals partitioning, etc) is available for use in the verification program.
- The medical waste test reports did not include descriptions of the prototype test equipment.
- The process and product information in reports for the Equivalency and Circuitboard tests was more complete. The electronic log files, operator data sheets, and operator logbook sheets that were obtained by EvTEC during these tests were also available and augmented the information in the test reports. Even so, data that could be used to evaluate the PEM™ system performance based on many of the criteria listed in the test plan were not included. These data include amounts of glass and metal products, amounts of baghouse dust and scrub solution discharged, metals partitioning results, and auxiliary fuel flowrates.
- Field data sheets, laboratory data, and data reduction calculations shown in all of the test reports was validated by limited checks of data accuracy, calculation accuracy, use of detection limits, etc. The raw data and the reduced data were generally well organized and accurate.
- Concentration data was not generally reported on a 7% O₂ basis. Calculations were made during the verification report preparation to convert, where necessary, concentration data to a 7% O₂ basis.
- Results of triplicate runs were often not averaged. In many cases, the results from a set of three runs varied by a factor of 2 or more from the average. This is common when measured results are so near their detection limits, as was the case with much of the data from these tests. The general approach used during

the verification report preparation was to provide all of the triplicate run data. Users of this report may average the triplicate data or use the worst-case result from any run in a triplicate set, in order to most conservatively present the results.

- In some cases, data reported in various units were converted to SI or other units in order to best report data in the verification report for all of the tests using equivalent units.
- Field QA/QC procedures including the collection of field blanks and reagent blanks were followed, the offgas emissions data was generally not corrected for the amounts of analytes found in blanks. Any blank corrections that were done (during only the supplemental medical waste tests) was consistent with guidance from EPA Method 0060 for metals and from EPA Method 23A for D/Fs.
- The equivalency test report indicated that the CEMS measurements were performed according to procedures in 40 CFR 266 Appendix IX for CEMS installed for monitoring hazardous waste treatment processes. The performance requirements, procedures, and calibrations from the applicable 40 CFR 60 Appendix A methods are more appropriate for these short-duration tests, were followed by the independent subcontractor.
- Manual sample train sample durations and volumes in some of the tests varied. Sample durations are shown in Table 20. These variations, including the larger (40-liter) Method 0031 sample volumes already discussed above, do not affect data quality or use.
- Various, occasional procedure or QA/QC discrepancies are listed in Table 20.

5.4 Evaluation of Independent Subcontractor QA/QC reports

QA/QC activities performed by the independent subcontractors were summarized in the test reports. The test reports included the appropriate field equipment calibration information (for sample nozzles, pitot tubes, thermocouples, dry gas meters, impinger weigh scales, etc. to show that the field measurements were under control and performed with appropriate and expected data quality.

Information about the CEMS instrumentation, calibration gases, calibration procedures, calibrations performed, and calibration results was sufficient to indicate that the applicable reference methods were strictly followed and that the CEMS measurements were under control. CEMS calibration results were available for all of the tests. Zero, mid-span, and high-span calibration error, zero and span bias, and zero and span drift values were typically less than $\pm 1\%$ of full scale. A few values were between ± 1 and $\pm 2\%$ of full scale, and a single value for SO_2 span bias for one of the equivalency test runs was 2.9% of full scale. All CEMS data was bias and drift-corrected.

Results of some of the CEMS measurements were consistently at or near the detection limit for typical CEMS monitoring. All of the SO_2 measurements were at or near the detection limit. The CO measurements from the tests that used the enclosed flare were also at or near the CO detection limit. The detection limits for both SO_2 and CO were sufficiently low that, even though the low CO and SO_2 values are too low for accurate determinations, these measurements are conclusive for indicating appropriate system operation and compliance to applicable emission standards.

Information was sufficient to show that applicable laboratory analysis procedures were observed for those measurements that were performed off-site by a second-tier laboratory subcontractor. QA/QC procedures including laboratory instrument calibrations, laboratory procedures, isotopically labeled standards, and laboratory sample custody were followed.

Recovery results for isotopically-labeled surrogates and internal standards showed that most of the time, surrogate and standard

recoveries were within acceptable ranges. Isotopic recovery results for all of the D/F, PCB, and PAH measurements for the medical waste tests and were within acceptance limits. Most recoveries were within 60–100%, with a few recoveries between 50–60% and 100–120%. Isotopic recovery results for the D/F, PCB, PAH, and VOC measurements for the Equivalency and Circuitboard tests were not available.

Results of duplicate, matrix spike, and standard reference material (SRM) analyses were reported for chloride sample analyses for the medical waste genset tests. Duplicate analyses agreed with a 5.6 relative percent difference (RPD). Matrix spike recoveries were 88.4%, 90.0%, and 106%. SRM recoveries were 101%, 109%, and 113%. Information about chloride sample duplicate and spike sample analyses was not provided in the other test reports.

Results of duplicate, matrix spike, and standard reference material (SRM) analyses were reported for metals sample analyses for the medical waste genset tests. Duplicate analyses agreed within 22 RPD. Matrix spike recoveries ranged from 83.6% to 113%. SRM recoveries ranged from 88.9% to 102%. Information about metals duplicate and spike sample analyses was not provided in the other test reports.

A few laboratory analysis issues identified by the verification panel were not completely resolved based on available data. These were:

- Much of the laboratory results were near or below detection limits. When an analyte was not detected above its detection limit, then the detection limit (defined by the laboratory as the lowest value that it could accurately report based on instrument calibrations) was reported and flagged. Detection limits were not typically “method detection limits,” but were determined for a specific sample batch from laboratory detection limit studies. Detection limits for PAHs, for example, are “reporting limits,” which are those levels derived by the laboratory which the laboratory has confidence in reporting on a routine basis. Reporting limits are typically 2–3 times higher than instrument or method detection limits. Detection limit values are reported in this report with the “<” flag indicating that the analyte was not detected at this level, and that the true level is below this detection limit.

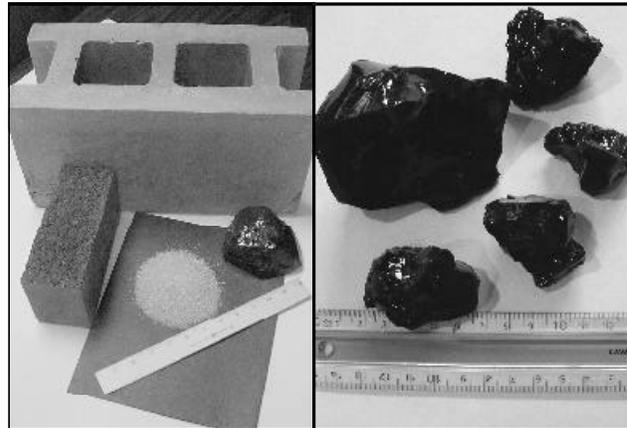
- At times detection limits for an analyte varied for different analyses in the same set of triplicate measurements; sometimes, the detection limits varied enough that a reported detection limit in one sample is in fact higher than a detected value in another sample. This can result when reported values are actually a sum of analytical results for multiple train fractions. When all of the train fractions have non-detects, then the detection limit value reported for the whole train can be quite low. When one or more train fractions have a detected value, then the sum, that includes the detection limit and detected values, can be higher. Laboratory analysis and individual train fraction information is not provided in this report. These occurrences do not impair data quality for this report, because the detection limit values are generally reported and used along with the detected values. Zeros are used in place of detection limit values only in the D/F measurements, which is allowed by Method 23 procedure.

- Other flags are commonly used as other indicators of data quality. While they are reported to the independent testing subcontractor in analytical laboratory reports, only the “E” flag, where applicable, was propagated into this verification report. The “E” flag indicates that, for that analyte, the instrument response was above the calibrated range for those measurements. The value reported is estimated based on extrapolating the instrument calibration. This occurred only in the SVOC analysis of scrub solution shown in Table 17. These “E” values may underestimate the true value.

- The PCB results may be subject to various interferences during analysis that can result in false positive values. The most recent procedure, EPA Method 1668, was used for PCB analysis. While insufficient information from the laboratory was available to clarify the presence or lack of false positive values, the PCB emission results were used in this report without any blank or other corrections. This was done to provide reasonably conservative PCB emission measurements. If false positives are present, then the reported PCB emissions are conservatively high.

CHAPTER 6

Verification Summary



Recycled Products from PEM™ system

The verification tests and the supplemental tests provide data that:

- Show how the system operates while feeding a variety of different feed materials
- Extensively characterize offgas emissions

The tests demonstrated complete system operation while (a) continuously feeding solid and liquid materials, (b) continuously heating, gasifying, and melting the feed material in the processing chamber, (c) tapping molten products as needed, (d) continuously scrubbing the syngas, and (e) continuously either flaring the syngas or producing electrical power in a gas-fired electric generator set (genset). The two prototype systems used in these tests were demonstrated at feedrates ranging from 12-68% of their nominal design capacities, which were 2 and 10 tons/day of waste feed. The range depended on specific test objectives and properties of the feed material. Operating conditions (temperatures, pressures, flowrates, and process stream compositions) were generally under control and within design operating limits.

The organic constituents in the feed materials was successfully gasified in the processing chamber and in the thermal residence chamber (TRC), with the exception of some residual unreacted char consisting of mainly “fixed carbon” left after more volatile components have been gasified.

Offgas emissions were extensively evaluated in these tests. Emission measurements were made at the outlet of an enclosed flare in some tests. Emission measurements in other tests were made at the outlet of the genset, to demonstrate emissions performance when the PEM™ system operates in a configuration that provides electrical power generation from the syngas.

The measured offgas emissions were compared to the HWC MACT standards. These standards will not apply to such applications as medical waste and municipal waste treatment, but they may apply in some applications where the PEM™ system treats hazardous waste. Any specific PEM™ application should determine what specific regulatory standards apply. The measured emissions were within all of the HWC MACT standards except for:

- Residual CO and THC in the genset offgas
- The PCB target DRE of six 9's destruction was not demonstrated, because the feedrate of PCBs was not high enough to demonstrate the target efficiency

- Hg was not spiked into any of the feed materials, and was not supposed to be in any of the feed materials, but was detected in the offgas during one of the medical waste tests. The measured offgas Hg level for this test was 5x higher than the HWC MACT limit. If Hg regulatory or permit emission limits for medical waste treatment are equivalent to the HWC MACT limit, then a medical waste treatment facility may need to include mercury control such as carbon absorption in the offgas system if the medical waste contains levels of Hg similar to the levels in waste during this test.

As a result of the equivalency test, the US EPA has concurred in writing that the PEM™ system, when operated within applicable technical requirements, performs in a manner equivalent to other thermal treatment technologies consistent with criteria set forth in the definition of CMBST found in 40CFR 268.42 (EPA 2001, Appendix A).

Test durations were typically 1-3 days long. Because of these relatively short-duration tests, test data was insufficient for such evaluation criteria as reliability, availability, and maintenance (RAM), lifecycle costs, and hazard exposures to workers from operations and maintenance. Ultimately, these criteria, and how the PEM™ system meets these criteria, depend largely on site-specific customer and regulatory requirements.

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APPENDIX A

EPA Approval of PEM/GASVT System as Equivalent to Incineration



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

FEB 15 2001

OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

Mr. Douglas E. McKinley, Jr.
Director of Administration
Integrated Environmental Technologies, LLC
1935 Butler Loop
Richland, Washington 99352

Dear Mr. McKinley

Thank you for the opportunity to assist you in clarifying certain requirements of the Environmental Protection Agency's (EPA) Land Disposal Restrictions (LDR) program. Earlier this year, you met with David Hockey and Mary Cunningham of my staff, to discuss the procedures for submitting a "Determination of Equivalent Treatment" (DET) petition under §268.42(c). Specifically, you asked about a possible DET for the treatment standard expressed as CMBST found in §268.40. As it was explained to us, your company, Integrated Environmental Technologies, has developed an electrothermal process where hazardous wastes are treated to produce syngas and glass. This system, called a Plasma Enhanced Melter (PEM) or a GASVIT (gasification and vitrification) system, uses electrical heating to create a non-combustive, oxygen-reduced, thermal treatment process. At the time, you believed a DET was necessary because your treatment technology was not specifically identified in the definition of CMBST found in 268.42. Based on subsequent telephone calls and our meeting on August 2, 2000, we have decided that in lieu of a DET petition, an interpretation of the regulatory definition of CMBST, as found in §268.42, is an appropriate response to your request. As such, this letter will serve as EPA's interpretation that your technology, known as both PEM and GASVIT, is covered under the definition of CMBST found in §268.42.

In the Phase III LDR Rule (61 FR at 15588, April 8, 1996), we modified the treatment standard for hazardous waste expressed as INCIN to CMBST. The change from INCIN to CMBST was made to make clear that thermal units other than incinerators, such as boilers and industrial furnaces, are suitable treatment technologies for treating organic hazardous constituents. In addition, we determined that certain non-combustion units, when operated properly (particularly when operated pursuant with applicable technical operating requirements), could perform as efficiently as combustion technologies and therefore, are also appropriately included under the CMBST definition. Id. col. 2. The regulatory language found in 268.42 is as follows:

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CMBST: High temperature organic destruction technologies, such as combustion in incinerators, boilers, or industrial furnaces operated in accordance with the applicable requirements of 40 CFR part 264, subpart O, or 40 CFR part 265, subpart O, or 40 CFR 266, subpart H, and in other units operated in accordance with applicable technical operations requirements; and certain non-combustive technologies, such as the Catalytic Extraction Process.

Last year, EPA Region X issued a RCRA Subpart X permit, for one of your PEM/GASVIT systems, to ATG Incorporated in Richland, Washington, for the treatment of mixed hazardous and radioactive waste. We have reviewed documents supporting that permit issuance, including selected pages of your storage and treatment permit identifying the waste feed cutoff parameters of the unit, as well as your "PEM/GASVIT Equivalency Test Report" which documents a full-scale treatment test of the unit. In these documents, we have identified information and data that support our determination that your PEM/GASVIT technology comports with the definition of CMBST found in §268.42. These documents establish that you are achieving two measures that describe parameters which are characteristic of good combustion conditions for the destruction of organic compounds in this type of unit: (1) Temperatures in the process chamber consistently are in the range of 2000°F; and (2) Temperatures in the air pollution dry particulate control devices are maintained outside the temperature window optimum for surface catalyzed dioxin/furan formation (450°F to 750°F). Furthermore, the measured destruction removal efficiencies for benzene, monochlorobenzene, tetrachloroethylene, toluene, and naphthalene, all difficult-to-treat organic hazardous constituents, exceeded 99.9999%.

Based on our review of the information and data submitted to us, we conclude that the PEM/GASVIT system, when properly operated pursuant to applicable technical requirements, performs in a manner equivalent to other thermal treatment technologies consistent with criteria set forth in the definition of CMBST found in 268.42, as well as the regulatory history to that provision. Therefore, the use of this technology to satisfy the treatment standard of CMBST found in §268.40 is appropriate and within the meaning of the present rule. If you should have any further questions, please contact Elaine Eby of my staff at (703) 308-8449.

Sincerely,



James R. Berlow, Director
Hazardous Waste Minimization and
Management Division

cc David Hockey, USEPA
Mary Cunningham, USEPA
Catherine Massimino, USEPA- Region X

Results of Field Audit

METHOD 5 AUDIT CHECKLIST

IET Equivalency Test

April 4-5, 2000

Auditor: Nick Soelberg

YES	NO	ACTIVITY
		EQUIPMENT PREPARATION AND CHECK
X		1. Sampling train assembled and leak checked.
X		2. Probe and filter box heaters checked and set for proper temperatures.
X		3. Stack gas temperature measuring system assembled and checked for proper operation.
X		4. Stack gas velocity measuring system assembled and checked for proper operation.
		PRELIMINARY MEASUREMENTS
X		6. Selection of traverse points according to Method 1 or equivalent.
X		7. Moisture content by Method 4 or equivalent.
X		8. Molecular weight by Method 3 or equivalent.
X		9. Measurement of stack dimensions.
X		10. Mark probe for sampling at traverse points.
		SAMPLE COLLECTION
X		11. Equal sampling time at each traverse point.
X		12. Probe temperature satisfactory throughout the test.
X		13. Filterbox temperature $248 \pm 25^{\circ}\text{F}$ throughout the test.
X		14. Sample gas temperature at last impinger $< 68^{\circ}\text{F}$ throughout the test.
X		15. Isokinetic sampling checked and adjusted if necessary at least every 5 minutes.
X		16. Leak check of sampling train at end of test.
X		17. Minimum sample volume and sample time achieved.
		SAMPLE RECOVERY
X		18. Satisfactory handling and movement of probe and filter to sample recovery area.
X		19. Recovery area satisfactory (i.e., space, cleanliness, etc.)
X		20. Sample recovery procedure adequate.
X		21. Proper labeling of sample containers.
X		22. Determination of moisture content procedure adequate.
		ANALYSIS
X		23. Proper equilibration of filter, probe wash residue, and acetone blank residue
X		24. Analytical balance checked before weighings.
		DOCUMENTATION
X		25. All information recorded on datasheet as obtained.
X		26. All unusual conditions recorded.
X		27. Isokinetic sampling rate ok.
X		28. Appropriate stack conditions were used in calculations.

CEMS AUDIT CHECKLIST
 IET Equivalency Test
 April 4-5, 2000
 Auditor: Nick Soelberg

YES NO

ACTIVITY

PREPARATIONS

- X 1. Used EPA Protocol 1 calibration gases.
- X 2. Used zero, mid-range, and high-range calibration gases.
- X 3. Used analyzers allowed by the analyzers allowed or specified by the reference methods.
- X 4. Prepared and calibrated the gas analyzers and data recorders. Adjusted system components as necessary.

CEMS TEST PERFORMANCE

- X 5. Selected the sampling site and sampling points as in Method 6. Set up the sampling system as in Method 6C (except use hot-wet setup per Method 25A for THC measurement).
- X 6. Conducted pretest calibration error check per EPA Method 6C.
- X 7. Conducted pretest bias check per EPA Method 6C.
- X 8. Coordinated CEMS sample period start and end times to bracket sample train time periods.
- X 9. Sampled at each measurement point using the same sampling rate as that used during the sampling system bias check. Maintain constant sampling rate during the entire run.
- X 10. Record data at 1-minute intervals for a 1-hour or shorter test, or at up to 2-minute intervals for >1-hour tests (or more frequently).

POST-TEST

- X 11. Following each run, or before adjustments made to the measurement system during the run, determined the sampling system bias per Method 6C. Do not make any adjustments to the measurement system until after the drift checks are completed.
- X 12. All bias check results were within acceptance criteria per Methods 3A, 6C, 7E, 10, and 25A.
- X 13. Calculate the zero and upscale calibration drift to determine whether the calibration error and system bias tests must be conducted before the next run.
- X 14. Performed calibration error, bias, and drift corrections for the measurement data.
- X 15. Recorded all calibration and sampling data in electronic files and on hard copies.

METHOD 23 AUDIT CHECKLIST

IET Equivalency Test

April 4-5, 2000

Auditor: Nick Soelberg

Note: This sampling procedure is basically the same as that of Method 5. Preclean components according to Method 23.

YES	NO	ACTIVITY
		MAJOR EXCEPTIONS TO METHOD 5
X		Do not use sealing greases in assembling the train.
X		Use nozzle material made of nickel, nickel-plated stainless steel, quartz, or borosilicate glass.
X		Use pesticide quality for acetone, methylene chloride, and toluene.
X		As sample storage containers of washes, use amber glass bottles with leak-free Teflon lined caps.
		PRETEST PREPARATION
X		Soaked for several hours in chromic acid cleaning solution all glass components of the train upstream of and including the adsorbent module. Then cleaned the components as described in section 3A of the "Manual of Analytical Methods for the Analysis of Pesticides in Human and Environmental Samples." Especially ensured the removal of residual silicone grease sealants on ground glass connections of used glassware.
X		Loaded the adsorbent trap in a clean area (never in the field) to avoid contamination. Filled the trap with 20 to 40 g XAD- 2, followed with glass wool, and tightly capped both ends of the trap.
X		Added 100 ml of each of the five surrogate standards to each trap.
		TRAIN PREPARATION
X		Placed 100 mL water in the second and third impingers.
Not verified		Leave the first and fourth impingers empty.
X		Placed known weight of silica gel in the fifth impinger.
X		Determined sampling conditions (stack diameter, temperature, velocity, sampling rate, etc.).
X		Assembled the train as shown in Method 23.

YES	NO	ACTIVITY
SAMPLING		
X		Turned on the adsorbent module and condenser coil recirculating pump and began monitoring the adsorbent module gas entry temperature.
X		Ensured proper sorbent temperature gas entry temperature before proceeding and before initiating sampling. Never exceeded 50°C because thermal decomposition of the XAD-2 adsorbent resin will occur. During testing, did not exceed 20°C for the XAD-2 (necessary for efficient capture of PCDD and PCDF).
SAMPLE RECOVERY		
X		Followed the general procedure in Method 5.
X		Used aluminum foil or Teflon tape to close off both ends of the probe. Closed off the inlet to the train with Teflon tape, a ground glass cap, or aluminum foil. Did not smoke (possible contaminating source) in the cleanup area. Treated the samples as follows:
X		Container No.1. Carefully removed the filter from the filter holder and placed it in its identified container.
X		Adsorbent Module. Removed the module from the train, tightly capped both ends, labeled it, covered with aluminum foil, and stored on ice for transport to the laboratory .
X		Container No.2. Quantitatively recovered material deposited in the nozzle, probe transfer lines, the front half of the filter holder, and the cyclone, if used, as follows:
X		Brushed the probe while rinsing three times each with acetone and then rinse three times with methylene chloride.
X		Rinsed the back half of the filter holder and connecting line between the filter and condenser three times with acetone.
Not verified		Soaked the connecting line with three separate portions of methylene chloride for 5 minutes each.
Not verified		Rinsed the condenser in the same manner as the connecting line.
X		Marked the level of the liquid on the container and label.
X		Container No.3. Repeated front half rinsing using toluene as the rinse solvent. Marked the liquid level on the container and label.
X		Impinger Water. Treated as in Method 5, unless this solution is recovered for other analyses.
X		Silica Gel. Treated as in Method 5.

METHOD 0050 AUDIT CHECKLIST

IET Equivalency Test

April 4-5, 2000

EvTEC Auditor: Nick Soelberg

Hydrogen Halides and Halogens (Midget Impinger Procedure)

Note: This procedure is the same as that for Method 5, except for the variations noted below (see also Method 26 for variations in the sampling train). The hydrogen halides (HX) include hydrogen chloride (HCl), hydrogen bromide (HBr), and hydrogen fluoride (HF)] and the halogens (X₂) include chlorine (Cl₂) and bromine (Br₂). Ground glass stoppers, plastic caps, serum caps” Teflon tape, Parafilm, or aluminum foil may be used to close openings of train component after preparation, before sampling, during transport to and from the sampling site, and prior to sample recovery.

YES	NO	ACTIVITY
		SAMPLING
X		Added the following reagents to the impingers:
X		15 mL 0.1 N H ₂ SO ₄ in each of the next two impingers.
X		15 mL 0.1 N NaOH in each of the following two impingers.
X		Weighed silica gel in the last impinger.
X		Maintained a temperature > 248°F around the filter.
		SAMPLE RECOVERY
X		After recovery, sealed the lids of all storage containers around the circumference with Teflon tape. Recovered the samples as follows:
X		Container No.1 (Optional: Filter Catch). Same as Method 5. (not needed)
X		Container No.2 (Optional: Front Half Rinse.) Same as Method 5. (not needed)
X		Container No.3 (Knockout and Acid Impinger Catch for Moisture and Hydrogen Halide Determination). Same as Method 5 except:
X		Quantitatively transferred this liquid to a leak-free sample storage container. Rinsed these impingers and connecting glassware including the back portion of the filter holder (and flexible tubing, if used) with water and added these rinses to the storage container.
X		Sealed the container, shook to mix, and labeled. Marked the fluid level.
X		Container No.4 (Alkaline Impinger Catch for Halogen and Moisture Determination). Same as Method 5, except:

YES	NO	ACTIVITY
X		Quantitatively transferred this liquid to a leak-free sample storage container. Rinsed these two impingers and connecting glassware with water and add these rinses to the container.
X		Added 25 mg sodium thiosulfate per ppm halogen-dscm of stack gas sampled. Sealed the container, shook to mix, and labeled; marked the fluid level. Retained alkaline absorbing solution blank and analyzed with the samples.
X		Container No.5 (Silica Gel for Moisture Determination). Same as Method 5.

Table 1. Offgas measurements performed during PEM™ tests

Test	EvTEC-observed verification tests		Other EvTEC-observed tests (a)		Other supplementary tests (b)		
	Equivalency Test	Circuitboard Test	MSW Process Demonstration	Med Waste Process Demonstration	Propane Test (c)	Medical Waste Tests	
Test date	April 3-5, 2000	April 12-13, 2000	April 14, 2000		February 15-16, 2000	February 16-18, 2000	March 8-9, 2000
Nominal melter size, ton/day	10				2		
Feed material	Methanol spiked with PODCs	Circuitboard fabrication waste	Municipal solid waste	Medical waste	Propane fired in genset	Medical waste	Medical waste with Cd and Pb
Offgas measurement location	Flare stack	Genset stack	None		Genset stack	Flare stack	Genset stack
Offgas measurements:							
Semivolatile organics (Method 23/0010)	D/Fs, PAHs, PCBs	D/Fs, PAHs, SVOCs	---		---	D/Fs, PAHs, PCBs	D/Fs
PM or HCl/Cl ₂ (Methods 5, 26, 050)	PM, HCl, Cl ₂	PM and baghouse dust particle size	---		PM, HCl, Cl ₂	PM	PM, HCl, Cl ₂ , particle size (d)
Metals (Method 29)	---	X	---		---	---	Cd, Pb, Hg
VOCs (Method TO-14)	---	---	---		X	X	X
VOCs (Method 0031)	X	X	---		---	---	---
Offgas composition (CEMS)	X	X	---		X	X	X

- a. These tests were performed to demonstrate the PEM™ while processing MSW and medical waste for EvTEC representatives, since prior medical waste tests that had extensive offgas measurements were not observed by EvTEC representatives. No offgas measurements were included in these EvTEC-observed tests.
- b. Extensive offgas measurements were performed during these tests. Although not observed by EvTEC representatives, results of these tests were included in the EvTEC verification program and generally corroborate the results of the EvTEC-observed tests.
- c. This test did not indicate performance of the PEM™ system, but it provided a baseline of offgas emissions from the genset while firing propane for comparison with offgas emissions from the genset while co-firing syngas with propane.
- d. Particle size determination was inconclusive due to insufficient particles.

Table 2. Feedrates, feed compositions, and key operating conditions for the tests

	EvTEC verification tests		Other EvTEC-observed tests		Other supplementary tests			Comments
	Equivalency test, Apr 3-5	Circuit-board test, Apr 12-13	MSW test, Apr 14	Med waste test, Apr 14	Propane test, Feb 15-16	Med waste tests		
						Feb 16-18	Mar 8-9	
Melter size, ton/day	10	10	10	10	2	2	2	
Feed rate:								
lb/hr	265	100	na (a)	na	na	na	114	
ton/day (b)	3.2	1.2	na	na	na	na	1.36	
% of nom. feedrate (c)	32	12	na	na	na	na	68	
Other process inputs:								
Total added N2, scfm	na	33	33	33	Process input data is not available for these tests.			Total N2, manually recorded from multiple flowmeters, includes process chamber purge flows and baghouse pulse N2.
Total added N2, lb/hr	na	144	144	144				Steam is added at 2 locations in the process chamber. The steam flowrate was not correctly transmitted to the data logger, so it was manually recorded based on calibrated valve position.
Total added steam, lb/hr	na	75.6	92	92				Typically used only during TRC heatup, manually recorded from uncalibrated flowmeter.
TRC O2, scfm and lb/hr (d)	na	1/5	3/15	3/15				Calculated from feedrate of electrodes
Electrode consumption, lb/hr	na	na	na	na				Co-fired with the syngas in the genset, manually recorded from calibrated flowmeter. During the Mar 8-9 med waste test, propane was about 2.5 vol% of the genset fuel.
Genset auxiliary propane flowrate, lb/min	---	0.855	---	---				
Flare auxiliary gas flowrate, scfm	na	na	na	na				
Process chamber conditions (e):								
AC joule power, % of total	na	21	14	15	Process chamber data is not available for these tests.			AC voltage and power was not correctly transmitted to the data logger; AC voltage was manually recorded; AC power was manually calculated
DC arc power, % of total	na	79	86	85				Not including energy generated by the genset
Total power, kW	na	224	265	273				Including energy generated by the genset
Energy consumption, kWh/kg feed	na	4.9	na	na				From TC E (TI-0176B), which is most indicative of the melt T
Maximum refractory T,C	na	1,209	1,164	1,162				The arc shines on this TC, causing it to read higher than the bulk gas T
Plenum T C	1,170	1,335	1,155	1,230				This TC in the outlet duct is shielded from the plasma arc, but be biased low due to heat losses
Outlet gas T,C	760	966	na	na				
Plenum pressure, in. H2O	na	-2	-2	-0.2				
Thermal Residence Chamber T, C	813/799	782/875	772/790	882/901				Two different TCs sense this temperature at different locations in the TRC

Table 2. (continued) Feedrates, feed compositions, and key operating conditions for the tests

	EvTEC verification tests		Other EvTEC-observed tests		Other supplementary tests			Comments
	Equivalency test	Circuit-board test	MSW test	Med waste test	Propane test, Feb 15-16	Med waste tests		
						Feb 16-18	Mar 8-9	
Syngas treatment system:								
Partial quench column T,C	na	268	288	290	Syngas treatment system data is not available for these tests.			
Baghouse T, C	177	112	135	145				
EVS 1 pH	4.2	8.8	4.8	7.3				
EVS 2 pH	2.0	7.1	6.6	6.6				
Syngas composition (% as measured, almost dry) (f):								
N2	na	61	44.1	44.2	Syngas composition system data is not available for these tests.	na	Semicontinuous gas chromatograph (GC), manually recorded	
H2	47.1	18.3	25.6	28.1		33.3	GC	
CO	29.5	9.7	17.2	14.8		15.2	GC and nondispersive infrared (NDIR) continuous analysis	
CO2	1.6	6.2	11	11		7.3	NDIR	
H2O	2.5	5	5	5		na	Estimated assuming H2O-saturated air at the syngas temperature	
CH4	2.0	1.3	3.5	3		na	GC and NDIR	
He	na	0.07	0	0		na	GC, manually recorded	
O2	0.00	0.00	0	0		0	GC	
Total	na	101.6	106.4	106.1		na	Calculated	
Products (g):								
Syngas flowrate, scfm	141	63	Product data is not available for these tests.			Measured at the outlet of the syngas treatment system		
Syngas flowrate, lb/hr	335	236				Calculated using the volumetric flowrate and the composition		
Genset energy production, kW	---	102	---	---	65 and 130	130		

- a. na = Not available.
- b. The hourly feedrate was normalized to a ton/day basis to compare with the nominal melter design feedrate.
- c. The nominal design organics feedrate for the 10 ton/day melter is 250 lb/hr (3 ton/day), 30% of total design feedrate. The actual feedrate limit for any type of feed material is based on its composition and physical properties. The feedrate is limited based on both the capacity of the syngas processing capacity (which limits the feedrate of organic material) and the melting capacity of the process chamber (which limits the feedrate of inorganic material).
- d. A small amount of O2 is sometimes added to increase the TRC temperature for more efficient char oxidation reactions. Some error is possible in this reading due to temperature change of the O2 as it evaporates from the liquid O2 cylinder.
- e. Power, temperature, pressure, and flowrate data was taken from electronically recorded data logs unless otherwise indicated.
- f. The as-measured syngas composition is almost dry because the gas temperature where sampled is about 33°C, so the maximum H2O content is only about 5 volume %, resulting in only about 5% dilution of the true dry composition.
- g. Other products from these tests included vitrified glass, baghouse dust, and scrubber solution discharge. Flowrates of these products are not available.

Table 3. Effluent offgas conditions measured during the tests

	EvTEC verification tests		Other supplementary tests				Comments
	Equivalency Test	Circuitboard Test	Propane tests, Feb 15-16		Med waste tests		
					Feb 16-18	Mar 8-9	
Syngas conversion stage	Flare	Genset	Genset		Flare	Genset	
Genset power output, kW	---	102	65	130	---	130	
Offgas T, F	~1,400	833	1,145	1,191	1,073	886	Offgas temperature, velocity, and flowrate from the EPA Method 5 trains only, even when other trains may also report these data. Offgas velocities ~10-20 f/s are prone to measurement error, but this potential error does not impact conclusions because of such low measured PM, HCl/Cl ₂ , D/F, PAH, and PCB levels.
Offgas velocity, f/sec	~17	134	99.6	174	11	108	
Offgas flowrate, dscfm	1,716	217	134	216	1,480	159	
Offgas composition (as measured, dry volume basis, unless otherwise indicated):							
O ₂ , %	14.4	0.0	0.0	0.0	16.5	0.0	EPA Method 3A continuous monitoring. The genset is a lean-burn engine, resulting in no excess O ₂ and low NO _x emissions.
CO ₂ , %	5.2	12.5	14.0	14.0	3.1	14.3	EPA Method 3A continuous monitoring.
CO, ppm	0.8	159	197	359	1.7	258	EPA Method 10 continuous monitoring.
Total NO _x , ppm	62	57.7	15.9	18.0	25	~125	EPA Method 7E continuous monitoring.
SO ₂ , ppm	0.05	1.2	0.3	0.3	2.3	0.4	EPA Method 6C continuous monitoring. These values are within the SO ₂ analyzer detection limit and error bounds.
THC, wet ppm	0.5	15.6	11.3	16	0.1	9.9	EPA Method 25A continuous monitoring, hot wet method
HCl, ppm	6.4	---	<0.6	<0.6	---	<0.6	EPA Method 26, 1 hour tests. For the med waste tests, no HCl and Cl ₂ were detected above the reported detection limits, and the sample detection limits were identical to the reagent blank detection limits. For the Equivalency test, higher HCl levels (up to 14 ppm during Test 2) were measured when the EVS 1 pH was 2.3 and the EVS 2 pH was 1.6.
Cl ₂ , ppm	<0.17 (b)	---	<0.6	<0.6	---	<0.6	
H ₂ O, wet %	na (a)	14.5	16.1	15.9	5.9	18.1	EPA Method 5 trains
Total PM, mg/dscm	<4	<5	<3	<2	3.5 ± 32%	<2	EPA Method 5, 1-hour tests, front half only, except for the Circuitboard Test, which had 2-hour PM tests. PM measured at such low concentrations approaches the method detection limit of about 1-3 mg/dscm for a 1-2 hour test. Standard deviation for triplicate tests at such low levels is about +50% of the average value.
Offgas composition, key species corrected to 7% O ₂ , dry basis:							
CO, ppm	1.7	107	132	241	5.3	173	HWC MACT limit is 100 ppm CO (and 10 ppm THC); genset emissions exceed limit, flare emissions ~20x less than limit.
THC, ppm	1	12.2	9.0	13	0.3	8.1	HWC MACT limit is 10 ppm; genset emissions exceed limit, flare emissions ~10-30x less than limit.
Total HCl/Cl ₂ as HCl, ppm	14	---	<1.2	<1.2	---	<1.2	HWC MACT limit is 21 ppm for new sources; emissions are >20x less than limit except for the equivalency test, when the EVS pH was 1-2, and may not have efficiently scrubbed HCl.
Total PM, mg/dscm	<8	<3	<2	<1	10	<1	HWC MACT limit is 34 mg/dscm

- a. na = Not available
- b. The “<” sign indicates that the species was not detected at a level greater than the indicated detection limit.

Table 4. D/F emissions measured during the tests

	2,3,7,8-TCDD TEF	EvTEC verification tests						Other supplementary tests					
		Equivalency Test			Circuitboard Test			Med waste test, Feb 16-18			Med waste test, Mar 8-9		
		Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Sample volume (dscm)		3.27	2.86	3.38	4.01	4.03	3.35	4.38	4.18	4.4	4.38	4.42	4.7
Stack oxygen content (% dry)		13.3	14.7	15.1	0.0	0.0	0.0	16.2	16.4	16.4	14.5	14.4	14.5
Mass of dioxins found, pg													
2,3,7,8-TCDD	1	<7.90	<4.8	<6.50	<13.5	<8.5	<12.2	<4	<4	<4	<0.9	<2	<0.9
Total TCDD		<7.90	<4.8	<6.50	<13.5	<8.5	<12.2	<4	<4	<4	26.3	92.8	14.1
1,2,3,7,8-PeCDD	0.5	<15.1	<14	<17.2	<29.7	<12	<14.0	4.38	<4	<4	<1	13.3	<0.9
Total PeCDD		<15.1	<14	<17.2	<29.7	<12	<14.0	35.0	8.36	<4	17.5	181.2	23.5
1,2,3,4,7,8-HxCDD	0.1	<13.5	<11	<14.4	<25.0	<15	<18.8	4.38	<4	<4	1.31	13.3	1.9
1,2,3,6,7,8-HxCDD	0.1	<13.3	<11	<14.3	<25.0	<15	<18.7	8.76	<4	<4	4.4	22.1	4.7
1,2,3,7,8,9-HxCDD	0.1	<12.6	<10	<13.5	<23.0	<14	<17.3	8.76	<4	<4	1.75	17.7	4.7
Total HxCDD		<13.5	<11	<14.4	<25.0	<15	<18.8	83.2	16.7	<4	56.9	309.4	47
1,2,3,4,6,7,8-HpCDD	0.01	<27.3	<23	<33.4	<47.0	<21	<26.5	35.0	12.5	8.8	17.5	110.5	18.8
Total HpCDD		<47.3	<23	<61.4	<47.0	<21	<26.5	74.5	29.2	22	52.6	221	42.3
OCDD	0.001	119	80.0	156	210	56.0	102	83.2	71.1	48.4	92.0	181.2	75.2
Total PCDDs		119	80.0	156	210	56.0	102	337.3	137.9	79.2	244.0	1069.6	218.1
Mass of furans found, pg													
2,3,7,8-TCDF	0.1	14.6	<6.8	<5.8	<11.7	<10	<12.5	8.8	4.2	<4	13.1	17.7	4.7
Total TCDF		192	<6.8	<5.8	<15.7	<10	<12.5	140.2	12.5	<4	280.3	380.1	108.1
1,2,3,7,8-PeCDF	0.05	17.1	<14	<8.4	<29.0	<15	<18.3	13.1	<4	<4	4.4	30.9	4.7
2,3,4,7,8-PeCDF	0.5	18.0	<13	<8.2	<27.9	<15	<18.1	21.9	<4	<4	4.4	35.4	9.4
Total PeCDF		153	<14	<8.4	<29.0	<15	<18.3	188.3	<4	<4	74.5	411.1	84.6
1,2,3,4,7,8-HxCDF	0.1	26.0	<9.1	<7.1	<18.5	<15	<17.6	21.9	<4	<4	4.4	35.4	9.4
1,2,3,6,7,8-HxCDF	0.1	18.6	<8.2	<6.5	<16.8	<13	<15.2	21.9	<4	<4	4.4	39.8	9.4
1,2,3,7,8,9-HxCDF	0.1	<3.80	<10	<7.9	<21.4	<16	<19.2	21.9	<4	<20	4.4	26.5	9.4
2,3,4,6,7,8-HxCDF	0.1	12.8	<7.1	<5.5	<14.5	<11	<13.4	13.1	<4	<4	1.8	13.3	4.7
Total HxCDF		115	<10	<8.2	<21.4	<16	<19.2	170.8	<4	<4	35.0	300.6	65.8
1,2,3,4,6,7,8-HpCDF	0.01	55.0	<13	<7.7	<17.3	<15	<41.6	70.1	8.4	4.4	13.1	110.5	23.5
1,2,3,4,7,8,9-HpCDF	0.01	<8.20	<8.4	<9.4	<21.0	<19	<17.2	13.1	<4	<20	4.4	17.7	4.7
Total HpCDF		55.0	<15	<9.4	<21.0	<19	<44.0	100.7	8.4	4.4	21.9	168.0	42.3
OCDF	0.001	80.0	<23	<32.1	<50.0	<35	<48.0	30.7	<8	<15	17.5	66.3	18.8
Total PCDFs		595	0	0	0	0	0	836.6	33.4	8.8	483.6	1653.1	399.5
Total PCDD/PCDF, pg		714	80.0	156	210	56.0	102	1173.8	171.4	88	727.5	2722.7	617.6
Total Toxicity Equivalent (TEQ, pg)		17.8	0.0800	0.156	0.210	0.0560	0.102	26.0	0.698	0.180	6.42	47.1	10.4
Ratio of total PCDD/PCDF to total TEQ		40.1	1,000	1,000	1,000	1,000	1,000	45	246	488	113	58	59
Total PCDD/PCDF, ng/dscm @ 7% O2		0.399	0.0628	0.110	0.0349	0.00924	0.0202	0.782	0.125	0.0609	0.358	1.31	0.283
Total Toxicity Equivalent, ng/dscm @ 7% O2		0.010	0.000063	0.00011	0.000035	0.000092	0.00002	0.0173	0.0005	0.0001	0.003	0.0226	0.00476

Notes: 1. Non-detects are treated as zero in summing per Method 23. 2. The "<" sign indicates that the species was not detected at a level greater than the indicated detection limit.

Table 5. PAH emissions measured during the tests

	EvTEC verification tests						Other supplementary tests			
	Equivalency Test			Circuitboard Test			Med waste test, Feb 16-18			Detected at x% in field blank
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
Sample Date	4/4/00	4/5/00	4/5/00	4/12/00	4/13/00	4/13/00	2/16/00	2/17/00	2/17/00	
Gas Volume Collected (dscm)	3.27	2.85	3.38	4.00	4.03	3.34	4.38	4.18	4.4	
Measured PAH concentrations, µg/dscm										
Naphthalene	0.248	1.22	0.271	0.959	<0.512	<0.479	1.37	0.55	3.18	---
2-Methylnaphthalene	<0.0833	<0.281	<0.104	<0.210	<0.117	<0.117	0.053	0.022	0.039	---
Acenaphthylene	<0.013	<0.055	<0.0199	<0.235	<0.125	<0.105	0.027	0.008	0.048	---
Acenaphthene	<0.0680	<0.120	<0.0871	<0.0780	<0.0399	<0.0347	0.032	0.016	0.006	1-6
Fluorene	<0.115	<0.118	<0.127	<0.190	<0.0806	<0.0993	0.05	0.038	0.027	---
Phenanthrene	<0.298	<0.706	<1.081	<2.02	<0.721	<0.790	0.594	0.55	0.5	8-10
Anthracene	<0.0279	<0.0555	<0.110	<0.232	<0.0691	<0.0825	0.037	0.048	0.011	15-70
Fluoranthene	<0.398	<0.386	<0.544	<1.77	0.644	<0.589	0.32	0.239	0.272	30-50
Pyrene	<0.251	<0.253	<0.343	<1.09	0.473	<0.427	0.119	0.134	0.1	5-7
Benzo(a)anthracene	<0.0346	<0.0558	<0.0675	<0.280	<0.126	<0.129	0.009	0.019	0.007	---
Chrysene	<0.123	<0.1024	<0.116	<0.345	0.245	<0.188	0.055	0.041	0.052	2-3
Benzo(b)fluoranthene	<0.0524	<0.0600	<0.0755	<0.340	0.105	<0.0993	0.032	0.038	0.036	3
Benzo(k)fluoranthene	<0.0209	<0.0194	<0.0252	<0.0338	<0.0361	<0.0431	0.005	0.009	0.009	---
Benzo(e)pyrene	<0.0243	<0.0292	<0.0347	<0.105	<0.0426	<0.0440	0.011	0.016	0.014	---
Benzo(a)pyrene	<0.0125	<0.0238	<0.0232	<0.0765	<0.0222	<0.0404	0.003	0.008	0.002	---
Perylene	<0.00314	<0.00665	<0.00579	<0.0138	<0.00362	<0.00970	<0.001	0.002	<0.001	---
Indeno(1,2,3-cd)pyrene	<0.00672	<0.0101	<0.0113	<0.0390	<0.00976	<0.0171	0.005	0.007	0.005	---
Dibenz(a,h)anthracene	<0.00229	<0.00416	<0.00304	<0.0133	<0.00370	<0.00540	<0.001	0.002	0.001	---
Benzo(g,h,i)perylene	<0.00672	<0.0115	<0.0116	<0.0323	<0.00879	<0.0153	0.003	0.006	0.004	---
Totals	<1.79	<3.52	<3.06	<8.06	<3.38	<3.31	2.73	1.75	4.31	---

Notes:

1. All results are uncorrected for field blanks.
2. The “<” sign indicates that the species was not detected at a level greater than the indicated detection limit.
3. Naphthalene was detected in the Equivalency Test field blank at levels ranging from 10-50% of the values detected in the samples.
4. Naphthalene was detected in the Circuitboard Test field blank at 66% of the value detected in Run 1.
5. The totals for the EvTEC tests include all detected and detection limit values, because the detected values are the same order of magnitude as the detection limit values. The total PAHs for the medical waste tests do not include detection limit values and are shown as actual, not less than values, because the detection limit values are three orders of magnitude less than the detected values.

Table 6. PCB emissions measured during the tests

	EvTEC verification tests						Other supplementary tests				
	Equivalency Test						Med waste test, Feb 16-18				
	Run 1	Run 2	Run 3	Detected at x% in field blank	Run 1	Run 2	Run 3	Detected at x% in field blank			
Gas Volume Collected (dscm)	3.27	2.86	3.38			4.38	4.18		4.4		
Coplanar PCB concentration, µg/dscm (Measured only in the Equivalency Test)											
PCB-77	<	3.04E-04	<	3.28E-04	<	2.76E-04	---	---	---	---	
PCB-81	<	3.97E-04	<	4.00E-04	<	2.71E-04	---	---	---	---	
PCB-105	<	5.39E-04	<	4.35E-04	<	6.10E-04	---	---	---	---	
PCB-114	<	5.85E-04	<	5.08E-04	<	6.66E-04	---	---	---	---	
PCB-118	<	5.19E-04	<	4.95E-04	<	5.74E-04	---	---	---	---	
PCB-123	<	6.49E-04	<	5.63E-04	<	7.40E-04	---	---	---	---	
PCB-126	<	5.19E-04	<	4.50E-04	<	5.87E-04	---	---	---	---	
PCB-156	<	4.22E-04	<	2.39E-04	<	2.17E-04	---	---	---	---	
PCB-157	<	3.34E-04	<	2.25E-04	<	1.47E-04	---	---	---	---	
PCB-167	<	3.51E-04	<	2.37E-04	<	1.82E-04	---	---	---	---	
PCB-169	<	3.75E-04	<	2.98E-04	<	1.77E-04	---	---	---	---	
PCB-170	<	1.33E-04	<	1.59E-04	<	1.72E-04	---	---	---	---	
PCB-180	<	3.28E-04	<	2.45E-04	<	3.67E-04	---	---	---	---	
PCB-189	<	1.42E-04	<	1.71E-04	<	1.84E-04	---	---	---	---	
Total PCB Homolog concentration, µg/dscm											
Total Monochlorobiphenyls	<	4.41E-04	<	4.73E-04	<	3.72E-04	---	<5E-04	<5E-04	<5E-04	---
Total Dichlorobiphenyls		3.89E-03		3.85E-03		2.78E-03	40-60	<5E-04	<5E-04	<5E-04	---
Total Trichlorobiphenyls		8.67E-03		9.99E-03		6.41E-03	70-95	6.00E-03	6.00E-03	1.00E-03	---
Total Tetrachlorobiphenyls		1.15E-02		1.23E-02		9.89E-03	60-70	1.20E-02	1.20E-02	2.00E-03	4-25
Total Pentachlorobiphenyls		2.88E-03	<	2.67E-03	<	2.04E-03	150	2.30E-02	1.60E-02	3.00E-03	---
Total Hexachlorobiphenyls	<	5.57E-04	<	1.12E-03	<	1.14E-03	---	2.70E-02	1.30E-02	2.00E-03	---
Total Heptachlorobiphenyls	<	3.40E-04	<	2.94E-04	<	3.77E-04	---	5.00E-03	<5E-04	5.00E-03	---
Total Octachlorobiphenyls	<	3.30E-04	<	4.41E-04	<	2.93E-04	---	<5E-04	<5E-04	<5E-04	---
Total Nonachlorobiphenyls	<	7.07E-05	<	1.52E-04	<	5.74E-05	---	<5E-04	<5E-04	<5E-04	---
Total Decachlorobiphenyl	<	1.69E-04	<	1.65E-04	<	2.63E-04	---	<5E-04	<5E-04	<5E-04	---
Total PCB homologs		2.69E-02		2.61E-02		1.91E-02		6.80E-02	4.70E-02	8.00E-03	---

- Note: 1. All results are uncorrected for field blanks. 2. The "<" sign indicates that the species was not detected at a level greater than the indicated detection limit.
 3. All of the total PCB homologs that were detected in the Equivalency Test were also detected at levels in the field blank representing much or all of the detected mass.
 4. Only one of the homologs detected in the medical waste test were found in the field blank, at a relatively low level compared to the amounts detected in the offgas.
 5. The total PCB homolog values do not include detection limit values, and are reported as actual, not less than values, because the detection limit values are at least an order of magnitude less than the detected values.

Table 7. SVOC emissions measured during the Circuitboard Test

	Field Blank	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Gas Volume Collected (dscf)	---	141.5	142.3	118.3						
Flow Rate (dscfm)	---	218.9	219	212.4						
Measured SVOCs		Mass found, ug			Concentration, ug/dscf			Emission rate, g/hr		
Phenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
bis(2-Chloroethyl) Ether	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
2-Chlorophenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
1,3-Dichlorobenzene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
1,4-Dichlorobenzene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
1,2-Dichlorobenzene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
2-Methylphenol (o-Cresol)	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
bis(2-Chloroisopropyl) Ether	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
N-Nitroso-di-n-propylamine	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
4-Methylphenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
Hexachloroethane	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Nitrobenzene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Isophorone	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
2-Nitrophenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
2,4-Dimethylphenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
Benzoic Acid	<120	<180	<180	<180	<1.3	<1.3	<1.5	<0.017	<0.017	<0.019
bis(2-Chloroethoxy) Methane	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
2,4-Dichlorophenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
1,2,4-Trichlorobenzene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Naphthalene	<4.0	<6.7	<6.0	<6.0	<0.047	<0.042	<0.051	<0.00062	<0.00055	<0.00065
4-Chloroaniline	<40	<60	<60	<60	<0.42	<0.42	<0.51	<0.0056	<0.0055	<0.0065
Hexachlorobutadiene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
4-Chloro-3-methylphenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
2-Methylnaphthalene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Hexachlorocyclopentadiene	<80	<120	<120	<120	<0.85	<0.84	<1.0	<0.011	<0.011	<0.013
2,4,6-Trichlorophenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
2,4,5-Trichlorophenol	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
2-Chloronaphthalene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
2-Nitroaniline	<40	<60	<60	<60	<0.42	<0.42	<0.51	<0.0056	<0.0055	<0.0065
Dimethylphthalate	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
Acenaphthylene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
2,6-Dinitrotoluene	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
3-Nitroaniline	<40	<60	<60	<60	<0.42	<0.42	<0.51	<0.0056	<0.0055	<0.0065
Acenaphthene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
2,4-Dinitrophenol	<80	<120	<120	<120	<0.85	<0.84	<1.0	<0.011	<0.011	<0.013
4-Nitrophenol	<80	<120	<120	<120	<0.85	<0.84	<1.0	<0.011	<0.011	<0.013
2,4-Dinitrotoluene	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
Dibenzofuran	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Diethylphthalate	<20	<30	<30	<34	<0.21	<0.21	<0.29	<0.0028	<0.0028	<0.0037
Fluorene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
4-Chlorophenyl-phenyl Ether	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
4-Nitroaniline	<40	<60	<60	<60	<0.42	<0.42	<0.51	<0.0056	<0.0055	<0.0065
4,6-Dinitro-2-methylphenol	<40	<60	<60	<60	<0.42	<0.42	<0.51	<0.0056	<0.0055	<0.0065
N-Nitrosodiphenylamine	<40	<60	<60	<60	<0.42	<0.42	<0.51	<0.0056	<0.0055	<0.0065
4-Bromophenyl-phenyl Ether	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Hexachlorobenzene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Pentachlorophenol	<80	<120	<120	<120	<0.85	<0.84	<1.0	<0.011	<0.011	<0.013
Phenanthrene	<4.0	<9.8	<6.0	<6.0	<0.069	<0.042	<0.051	<0.00091	<0.00055	<0.00065
Anthracene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
di-n-Butylphthalate	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
Fluoranthene	<4.0	<9.0	<6.0	<6.0	<0.064	<0.042	<0.051	<0.00084	<0.00055	<0.00065
Pyrene	<4.0	<7.5	<6.0	<6.0	<0.053	<0.042	<0.051	<0.00070	<0.00055	<0.00065
Butylbenzylphthalate	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
3,3'-Dichlorobenzidine	<80	<120	<120	<120	<0.85	<0.84	<1.0	<0.011	<0.011	<0.013
Chrysene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Benzo(a)anthracene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
bis(2-Ethylhexyl)phthalate	<24	<47	<30	<30	<0.33	<0.21	<0.25	<0.0044	<0.0028	<0.0032
Di-n-Octylphthalate	<20	<30	<30	<30	<0.21	<0.21	<0.25	<0.0028	<0.0028	<0.0032
Benzo(b)fluoranthene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Benzo(k)fluoranthene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Benzo(a)pyrene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Indeno(1,2,3-c,d)pyrene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Dibenz(a,h)anthracene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065
Benzo(g,h,i)perylene	<4.0	<6.0	<6.0	<6.0	<0.042	<0.042	<0.051	<0.00056	<0.00055	<0.00065

Notes: 1. Results are uncorrected for field blanks. 2. If there is a single non-zero result from multiple fractions of a sample train, averages treat nondetects as 1/2 of the detection limit value. If all results are non-detects, the largest detection limit value is used as the average.

Table 8. Summarized VOC emission measurements from the EvTEC and other tests

	EvTEC verification tests		Other supplementary tests			
	Equivalency Test	Circuitboard Test	Propane only		Medical waste tests	
			Feb 15-16 (a)	Feb 15-16	Feb 16-18	Mar 8-9
Syngas conversion stage	Flare	Genset	genset	Genset	Flare	Genset
Genset power, kW	---	102	65	130	---	130
Sampling/analysis method	0031	0031	TO-14	TO-14	TO-14	TO-14
VOCs detected, µg/dscm (b, c)						
Methylene chloride	<0.29	<3.9	900 (d)	<4.0	275 (e)	<4.0
Acrylonitrile	<0.29	3.0	---	---	---	---
Benzene (f)	<0.46	<11	40	8.6	18	663
Toluene (f)	<0.29	<12	332	135	32	16
Tetrachloroethene (f)	<0.29	<0.64	<6.8	<6.8	12	<6.8
Chlorobenzene (f)	<0.29	<0.64	<4.6	<4.6	<4.6	<4.6
Ethylbenzene	---	---	6.8	26	22	<4.3
m,p-Xylenes	---	---	15	118	42	<4.3
o-Xylene	---	---	<4.3	10	27	43
1,3,5-Trimethylbenzene	---	---	<4.9	17	30	<4.9
1,2,4-trimethylbenzene	---	---	27	32	81	<4.9
Range of detection limits for other VOCs not detected	<0.28-1.4	<0.57-3.5	<2.1-11	<2.1-11	<2.1-11	<2.1-11
Total VOCs (g)	nd (h)	nd except acrylonitrile	1,321	203	527	722

Note: Bolded values are detected values.

- a. Only 2 runs, not triplicate were performed during this test.
- b. Non-detected species are indicated by < "detection limit value." No blank corrections are made.
- c. The highest value from any run in a set of 3 triplicate runs is shown here, to indicate a more conservative value than an average of each triplicate set, since there is often variability of a factor of 2 or more in triplicate measurements.
- d. Methylene chloride is a ubiquitous laboratory contaminant. Of the 2 VOC tests, methylene chloride was not detected at a detection limit of 4 mg/dscm in the other test, but the high value is reported here.
- e. Methylene chloride is a ubiquitous laboratory contaminant. Of the 3 VOC tests, methylene chloride was not detected at a detection limit of 4 mg/dscm in the other 2 tests, but the high value is reported here.
- f. Compounds spiked into the feed in the equivalency test.
- g. Total VOCs is the sum of the detected concentrations. The detection limit values are excluded because they are at least an order of magnitude less than the detected values.
- h. nd = Not detected

Table 9. Destruction and removal efficiency from the Equivalency Test for spiked PODCs

Run Number	PODC	Total PODC in, lb/hr	Total PODC out, lb/hr	DRE, %
1	Benzene	3.55	<2.16E-06	>99.999939
	Monochlorobenzene	5.45	<1.85E-06	>99.999966
	Tetrachloroethene	7.21	<1.85E-06	>99.999974
	Toluene	4.50	<1.85E-06	>99.999958
	PCBs	0.16	<1.88E-7 (a)	>99.99988 (a)
	PCBs	0.16	1.76E-07 (b)	99.99989 (b)
2	Benzene	4.71	<2.65E-06	>99.999944
	Monochlorobenzene	4.51	<1.68E-06	>99.999963
	Tetrachloroethene	5.28	<1.68E-06	>99.999968
	Toluene	3.70	<1.68E-06	>99.999955
	PCBs	0.09	<1.88E-07 (a)	>99.99978 (a)
	PCBs	0.09	1.56E-07 (b)	99.99983 (b)
3	Benzene	4.64	<2.05E-06	>99.999956
	Monochlorobenzene	6.03	<2.05E-06	>99.999966
	Tetrachloroethene	7.99	<2.05E-06	>99.999974
	Toluene	4.80	<2.05E-06	>99.999957
	PCBs	0.15	<1.70E-07 (a)	>99.999887 (a)
	PCBs	0.15	1.37E-07 (b)	99.999908(b)

- a. From Focus 2002. Based on summing mass emission rates of detected total PCB homologs and also detection limit mass emission rates for those total PCB homologs not detected in the offgas. Because non-detect values are included in the summation, the total mass emission rate is a "less than" value, and the DRE is a "greater than" value.
- b. Recalculated based on summing mass emission rates of detected total PCB homologs, and excluding any non-detected total PCB homologs from the calculation. Because non-detect values are not included in the summation, the total mass emission rate and the DRE are shown as actual values based on detected values. This calculation approach is consistent with the approach allowed by EPA Method 23 for summing different D/F congeners that are detected, and excluding any nondetected congeners from the sum.

Table 10. Metal emissions measured during the tests

	EvTEC verification tests						Other supplementary tests					
	Circuitboard Test (a)						Medical waste test, March 8-9 (a)					
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3			
Volume Collected (dscm)	2.57	2.66	2.12				1.92	1.89	1.91			
Stack Gas Flow Rate (dscfm)	221.6	221.0	207.4				163.9	154.9	158			
Element	Mass Found (ug)			Concentration, ug/dscm (b)								
Aluminum	<1.0	<1.0	<1.0	<	0.39	<	0.39	<	0.46	---	---	---
Antimony	27.0	31.0	34.0		10.49		11.66		16.01	---	---	---
Arsenic	<1.0	<1.0	<1.0	<	0.39	<	0.39	<	0.46	---	---	---
Boron	77.0	98.0	86.0		29.89		36.75		40.64	---	---	---
Barium	77.0	98.0	86.0		29.89		36.75		40.64	---	---	---
Beryllium	1.32	2.65	2.89		0.51		1.00		1.36	---	---	---
Cadmium	<0.050	<0.050	<0.050	<	0.02	<	0.02	<	0.02	0.182	0.085	0.052
Calcium	87.0	117	110		33.78		44.17		51.94	---	---	---
Chromium	<0.050	<0.050	<0.050	<	0.02	<	0.02	<	0.02	---	---	---
Cobalt	1.10	5.70	0.800		0.43		2.14		0.38	---	---	---
Copper	1.50	3.90	3.80		0.58		1.47		1.79	---	---	---
Iron	4.60	4.60	3.00		1.79		1.73		1.41	---	---	---
Lead	28.3	37.0	47.0		10.99		13.92		22.16	0.365	0.53	0.157
Lithium	<14	<14	<13	<	5.30	<	4.95	<	6.01	---	---	---
Magnesium	0.600	1.14	1.22		0.23		0.43		0.58	---	---	---
Manganese	1.90	1.20	2.10		0.74		0.45		0.99	---	---	---
Mercury	<2.0	<2.1	<2.2	<	0.74	<	0.78	<	1.02	125	233	346
Molybdenum	54.0	116	115		20.99		43.82		54.06	---	---	---
Nickel	<1.5	<1.0	<1.0	<	0.57	<	0.39	<	0.46	---	---	---
Phosphorus	<1.0	<1.0	<1.0	<	0.39	<	0.39	<	0.46	---	---	---
Potassium	<1.0	<1.0	<4.5	<	0.39	<	0.39	<	2.12	---	---	---
Selenium	5,480	430	370		2,127.21		161.84		174.20	---	---	---
Silicon	7.70	19.4	21.6		2.99		7.31		10.18	---	---	---
Silver	<0.16	0.290	0.240	<	0.06		0.11		0.11	---	---	---
Sodium	<0.055	2.20	2.10	<	0.02		0.83		0.99	---	---	---
Strontium	<1.0	<1.0	<1.0	<	0.39	<	0.39	<	0.46	---	---	---
Thallium	<0.50	<0.95	<0.50	<	0.19	<	0.35	<	0.24	---	---	---
Tin	<0.050	<0.050	<0.050	<	0.02	<	0.02	<	0.02	---	---	---
Titanium	12.7	18.2	23.7		4.95		6.86		11.17	---	---	---
Vanadium	318	401	365		123.67		150.88		172.08	---	---	---
Yttrium	55.0	36.0	51.0		21.38		13.53		24.03	---	---	---
Zinc	<0.50	<0.50	<0.50	<	0.19	<	0.19	<	0.24	---	---	---
Total semivolatile metals (SVMs) and low volatility metals (LVM)												
SVM (Cd, Pb) including all non-detect values, at 7% O2					7.38	9.34	14.86	0.366	0.412	0.140		
LVM (As, Be, Cr) including all non-detect values, at 7% O2					0.62	0.94	1.24	---	---	---		
Hg including all non-detect values, at 7% O2					0.50	0.52	0.69	83.8	156	232		

- a. The Circuitboard Test results are uncorrected for field blanks. The blanks for the medical waste test were all non-detects, and so none of the medical waste test data is blank-corrected.
- b. Detected values are shown in bold. Non-detected species are indicated by < "detection limit value." If any metal is not detected (at or above the detection limit) in any train fraction, then the amount of that metal in that fraction is counted as zero in train total, and the train total for that metal is flagged as an approximation (~).

Table 11. Additives in the methanol feed used in the Equivalency Test

Sample ID	Run 1			Run 2				Run 3				
	T1-R1- FEED-A	T1-R1- FEED-B	Average	T1-R2- FEED-A	T1-R2- FEED-B	T1-R2- FEED-C	Average	T1-R3- FEED-A	T1-R3- FEED-B	T1-R3- FEED-C	T1-R3- FEED-D	Average
Sample Frequency	per batch	per batch	per batch	per batch	per batch	per batch	per batch	per batch	per batch	per batch	per batch	per batch
Feed Rate (lbs/hr)	263	263	263	242	242	242	242	289	289	289	289	289
Coplanar PCBs, lb/hr												
PCB-77	0.000277	0.000445	0.000361	0.000291	0.000181	0.0000881	0.000187	0.000372	0.000276	0.000356	0.000333	0.000322
PCB-81	0.0000262	0.0000346	0.0000304	0.0000173	0.0000144	0.00000792	0.0000132	0.0000273	0.0000199	0.0000225	0.0000242	0.0000222
PCB-105	0.000298	0.000548	0.000423	0.000333	0.000236	0.000102	0.000224	0.000464	0.000323	0.000431	0.000391	0.000381
PCB-114	<0.0000031	0.0000389	<0.0000060	0.0000242	0.0000192	<0.0000043	<0.0000059	0.0000314	0.0000111	0.0000298	0.0000273	0.0000227
PCB-118	0.000412	0.000671	0.000542	0.000437	0.000261	0.000124	0.000274	0.000555	0.000409	0.000537	0.000482	0.000476
PCB-123	0.00000914	0.0000190	0.0000141	0.0000147	0.0000110	<0.0000055	<0.0000037	0.0000188	0.00000756	0.0000135	0.0000119	0.0000110
PCB-126	0.00000294	<0.0000049	<0.0000029	<0.0000032	0.00000224	<0.0000048	<0.0000027	0.00000380	<0.0000097	<0.0000073	0.00000427	<0.0000045
PCB-156	0.0000162	0.0000241	0.0000202	0.0000170	0.00000939	<0.0000032	<0.0000036	0.0000208	0.00000344	0.0000196	0.0000187	0.0000139
PCB-157	0.00000230	0.00000329	0.00000279	0.00000268	<0.0000015	<0.0000027	<0.0000016	0.00000290	<0.0000029	<0.0000067	<0.0000015	<0.0000015
PCB-167	0.00000385	0.00000764	0.00000575	0.00000449	0.00000321	<0.0000029	<0.0000012	0.00000639	<0.0000031	0.00000610	0.00000581	<0.0000011
PCB-169	<0.0000032	<0.0000013	<0.0000023	<0.0000013	<0.0000017	0.000000951	<0.0000010	<0.0000028	<0.0000035	<0.0000080	0.0000265	<0.0000034
PCB-170	0.0000781	0.000124	0.000101	0.0000265	0.0000462	0.0000224	0.0000317	0.0000968	0.0000697	0.0000931	0.0000280	0.0000636
PCB-180	0.000242	0.000389	0.000315	0.0000154	0.000160	0.0000722	0.0000825	0.000319	0.000232	0.000313	0.0000171	0.000188
PCB-189	<0.0000034	0.00000678	<0.0000021	<0.0000025	<0.0000024	0.00000135	<0.0000018	0.00000475	0.00000398	0.00000478	<0.0000032	<0.0000014
Total PCB Homologs, lb/hr												
Total Mono-CB	0.000542	0.000814	0.000678	0.000556	0.000349	0.000172	0.000359	0.000723	0.000529	0.000697	0.000624	0.000617
Total Di-CB	0.00960	0.0152	0.0124	0.0102	0.00596	0.00301	0.00639	0.0133	0.00960	0.0130	0.0118	0.0115
Total Tri-CB	0.0864	0.133	0.110	0.0948	0.0581	0.0269	0.0599	0.110	0.0807	0.124	0.110	0.105
Total Tetra-CB	0.0209	0.0366	0.0287	0.0215	0.0139	0.00663	0.0140	0.0302	0.0225	0.0290	0.0260	0.0258
Total Penta-CB	0.00581	0.0104	0.00812	0.00691	0.00504	0.00186	0.00460	0.00916	0.00672	0.00902	0.00807	0.00794
Total Hexa-CB	0.000980	0.00166	0.00132	0.00110	0.000618	0.000349	0.000688	0.00141	0.00114	0.00144	0.00126	0.00128
Total Hepta-CB	0.000900	0.00143	0.00117	0.000933	0.000581	0.000257	0.000590	0.00117	0.000865	0.00114	0.00104	0.00102
Total Octa-CB	0.000162	0.000261	0.000211	0.000171	0.0000942	0.0000394	0.000102	0.000207	0.000142	0.000188	0.000181	0.000170
Total Nona-CB	0.0000125	0.0000148	0.0000136	0.0000122	0.00000538	0.00000342	0.00000700	0.0000153	0.00000362	0.0000150	0.0000135	0.0000107
Total Deca-CB	0.00000136	0.00000197	0.00000167	0.00000131	<0.0000012	<0.00000094	<0.00000082	0.00000174	0.00000132	<0.0000014	0.00000116	<0.00000065
Total PCB Homologs (a)			0.16				0.09					0.15
PODC mixture, lb/hr												
Benzene	4.17	2.93	3.55	5.05	3.70	5.39	4.71	4.18	4.99	4.34	4.58	4.64
Toluene	4.25	4.76	4.50	3.91	3.43	3.77	3.70	4.66	4.66	4.58	5.15	4.80
Tetrachloroethene	5.64	8.78	7.21	6.47	5.25	4.11	5.28	8.04	7.08	8.04	8.85	7.99
Chlorobenzene	5.20	5.71	5.45	4.98	4.11	4.45	4.51	5.79	5.95	5.79	6.35	6.03
1,2-Dichlorobenzene	3.51	8.78	6.15	5.12	3.17	0.673	2.99	7.64	5.63	7.56	7.80	7.00
1,3-Dichlorobenzene	<0.059	<0.059	<0.059	<0.088	<0.067	<0.11	<0.088	<0.13	<0.080	<0.13	<0.13	<0.12
1,4-Dichlorobenzene	0.0236	0.0644	0.0440	0.0317	0.0212	<0.11	<0.054	0.0495	0.0418	0.0549	0.0554	0.0507
Naphthalene	0.549	0.527	0.538	0.478	0.370	0.405	0.418	0.478	0.475	<0.64	0.535	<0.53

a. Total PCB homologs includes mono- through deca-CBs. Non-detects are treated as zero for purposes of determining PCB feed rate.

Table 12. Composition of the circuitboard fabrication waste

	Weight % from ICP (a)	Weight % from XRF (b)
Metal oxides (not including Cu)		
SiO ₂	14.290	18.250
Al ₂ O ₃	3.690	2.450
CaO	5.010	7.930
MgO	0.050	0.780
BaO	0.080	0.080
SrO	0.030	0.040
Na ₂ O	0.340	0.440
K ₂ O	0.160	0.080
Pb ₂ O ₃	0.030	0.000
TiO ₂	0.110	0.140
B ₂ O ₃	1.820	0.000
ZnO	0.220	0.000
Fe ₂ O ₃	0.110	0.180
Total metals, %	25.940	30.370
Ultimate analysis:		
Carbon (%)	38.950	
Organic (%)	40.160	47.390
Copper as metal (%)	33.900	22.230
Total composition (sum of copper, organic, and total metals), %	100.000	99.990

a. From inductively coupled argon plasma (ICP) analysis.

b. From x-ray fluorescence (XRF) analysis.

Table 13. Composition and leachability of glass from the Circuitboard Test

Total Metals as oxides	Oxide composition (average of ICP/XRF measurement, %)	Normalized to ARG-1 Reference Material %	
Ag ₂ O	0.024	0.024	
Al ₂ O ₃	11.700	13.600	
B ₂ O ₃	0.260	0.280	
BaO	0.173	0.179	
CaO	9.670	9.800	
CoO	0.021	0.021	
Cr ₂ O ₃	0.680	0.700	
Fe ₂ O ₃	0.130	0.150	
K ₂ O	0.410	0.300	
Li ₂ O	0.008	0.009	
MgO	3.200	4.150	
MnO ₂	0.082	0.097	
Na ₂ O	5.580	5.270	
NiO	0.054	0.061	
PbO ₂	0.028	0.028	
SO ₃	0.160	0.160	
SiO ₂	64.000	64.800	
SrO	0.058	0.040	
TiO ₂	0.430	0.450	
ZrO ₂	0.029	0.041	
Totals	96.697	100.160	
TCLP Metals (mg/L)	Concentration, mg/L	% dissolved (a)	TCLP limit, mg/L
Arsenic	<0.2	---	5
Barium	0.020	0.03	100
Cadmium	<0.01	---	1
Chromium	0.030	0.01	5
Lead	<0.1	<0.8	5
Mercury	<0.0001	---	0.2
Selenium	<0.2	---	1
Silver	<0.02	<0.2	5
Total Carbon (wt%)	0.0152		

a. The % dissolved was calculated based on a ratio of 1 gm of glass per 20 ml of TCLP solution.

Table 14. Composition of baghouse dust from the Circuitboard Test

		Run 1			Run 2			Run 3		
Total Metals (a)		Element %	Oxide %	Oxide %	Element %	Oxide %	Oxide %	Element %	Oxide %	Oxide %
Element	Oxide	basis	wet	Oxide %, dry	basis	Oxide %, wet	Oxide %, dry	basis	wet	Oxide %, dry
Silicon	SiO ₂	8.680	18.570	20.280	10.204	21.830	26.290	7.280	15.570	28.130
Aluminum	Al ₂ O ₃	0.170	0.320	0.350	0.150	0.280	0.340	0.110	0.210	0.380
Sodium	Na ₂ O	7.350	9.910	10.820	6.970	9.400	11.320	3.950	5.320	9.620
Potassium	K ₂ O	0.400	0.480	0.530	0.380	0.460	0.550	0.250	0.300	0.540
Lithium	Li ₂ O	0.006	0.010	0.010	0.005	0.010	0.010	0.003	0.010	0.010
Calcium	CaO	0.440	0.620	0.670	0.400	0.560	0.670	0.250	0.350	0.630
Magnesium	MgO	0.180	0.300	0.330	0.160	0.270	0.320	0.110	0.180	0.330
Boron	B ₂ O ₃	0.480	1.550	1.690	0.320	1.030	1.240	0.300	0.970	1.750
Iron	Fe ₂ O ₃	0.241	0.340	0.380	0.240	0.340	0.410	0.390	0.560	1.010
Barium	BaO	0.003	0.000	0.000	0.003	0.000	0.000	0.003	0.003	0.010
Strontium	SrO	0.017	0.020	0.020	0.004	0.000	0.010	0.002	0.002	0.000
Chromium	Cr ₂ O ₃	0.076	0.110	0.120	0.069	0.100	0.120	0.094	0.140	0.250
Lead	PbO ₂	0.048	0.060	0.060	0.052	0.060	0.070	0.039	0.050	0.080
Zinc	ZnO	0.390	0.490	0.530	0.290	0.360	0.430	0.210	0.260	0.470
Cadmium	CdO	0.005	0.010	0.010	0.005	0.010	0.010	0.005	0.010	0.010
Manganese	MnO ₂	0.031	0.050	0.050	0.030	0.050	0.060	0.023	0.040	0.070
Nickel	NiO	0.027	0.030	0.040	0.031	0.040	0.050	0.038	0.050	0.090
Sulfur	-	0.095	0.100	0.100	0.079	0.080	0.100	0.059	0.080	0.110
Total metals/oxides	-	18.638	32.970	35.990	19.392	34.880	42.000	13.116	24.105	43.490
Other Components		%	%		%	%		%	%	
		wet	dry		wet	dry		wet	dry	
Total carbon		25.92	25.92	28.31	15.52	15.52	18.69	29.19	29.19	52.73
Water		10.19	10.19	0	22.66	22.66	0	44.82	44.82	0
Organic		56.22	56.22	61.40	46	46	55.41	29.94	29.94	54.09
Copper (b)		2.39	2.39	2.61	2.140	2.140	2.580	1.350	1.350	2.440
Totals		87.44	101.77	100.00	90.19	105.68	99.99	89.23	100.22	100.02

- a. Metals not including Cu are presumed to be primarily glass dust and the elemental composition is converted to oxides.
- b. The Cu enters the melter in elemental form, and is in the presence of syngas through the scrubber. It is, therefore, assumed to be metallic in the sample and is not included in the oxide conversion section.

Table15. Particle size distribution of the baghouse dust from the Circuitboard Test

Size (µm)	Volume % under particle size		
	Run 1	Run 2	Run 3
0.055	0.18	0.14	0.14
0.090	2.89	2.36	2.23
0.147	9.66	8.5	7.33
0.239	22.35	22.4	16.87
0.389	39.42	44.49	30.37
0.635	53.15	63.78	43.29
1.03	62.14	77.02	55.01
1.69	69.21	86.56	66.69
2.75	75.89	93.44	77.42
4.48	82.7	97.56	85.75
7.31	89.68	99.55	91.6
11.91	95.43	100	95.62
19.42	98.85	100	98.3
31.66	100	100	99.74
42.45	100	100	100

Table 16. PCB and VOC content in Equivalency test scrub solution

	Before test	Run 1	Run 2	Run 3
Sample Date	4/4/2000	4/4/2000	4/5/2000	4/5/2000
Sample Times (start/stop)		1250-1626	1030-1428	1705-2107
Coplanar PCB (ng/L)				
PCB-77	<2.5	<2.5	<2.5	4.2
PCB-81	<2.5	<2.5	<2.5	<2.5
PCB-105	<2.5	<2.5	<2.5	3.4
PCB-114	<2.5	<2.5	<2.5	<2.5
PCB-118	<2.5	<2.5	<2.5	3.6
PCB-123	<2.5	<2.5	<2.5	<2.5
PCB-126	<2.5	<2.5	<2.5	<2.5
PCB-156	<2.5	<2.5	<2.5	3.6
PCB-157	<2.5	<2.5	<2.5	<2.5
PCB-167	<2.5	<2.5	<2.5	<2.5
PCB-169	<2.5	<2.5	<2.5	<2.5
PCB-170	<2.5	<2.5	13.0	28
PCB-180	<2.5	<2.5	5.50	13
PCB-189	<2.5	<2.5	<2.5	4.2
Total Mono-CB	16.0	4,600	30,000	62,000
Total Di-CB	6.00	390	3,000	7,900
Total Tri-CB	20.0	61.0	520	930
Total Tetra-CB	<2.5	<2.5	6.10	53
Total Penta-CB	<2.5	4.60	11.0	72
Total Hexa-CB	<2.5	2.60	17.0	56
Total Hepta-CB	<2.5	7.50	28.0	100
Total Octa-CB	<2.5	3.00	13.0	32
Total Nona-CB	<2.5	<2.5	4.10	18
Total Deca-CB	<2.5	<2.5	4.80	16
Volatile Organics (mg/L)				
Benzene	0.0145	33	0.33	17.8
Toluene	<0.00200	<0.40	<0.100	<0.200
Tetrachloroethene	<0.00200	<0.40	<0.100	<0.200
Chlorobenzene	<0.00200	<0.40	<0.100	<0.200
1,2-Dichlorobenzene	<0.00200	<0.40	<0.100	<0.200
1,3-Dichlorobenzene	<0.00200	<0.40	<0.100	<0.200
1,4-Dichlorobenzene	<0.00200	<0.40	<0.100	<0.200
Naphthalene	0.050	18.5	6.0	35

Note: Bolded values are detected values.

Table 17. SVOCs in the scrub solution from the Circuitboard Test

Compound	Estimated concentrations, ug/L (a)						Run 2 RPD, % (b)
	Initial	Run 1	Run 2	Run 2 duplicate	Run 3		
Phenol	< 50	14	110	110	56	0.0	
bis(2-Chloroethyl) Ether	< 10	< 5	< 4	< 1	< 5	---	
2-Chlorophenol	< 50	< 25	< 20	< 5	< 25	---	
1,3-Dichlorobenzene	< 10	< 5	< 4	< 1	< 5	---	
1,4-Dichlorobenzene	< 10	< 5	< 4	< 1	< 5	---	
1,2-Dichlorobenzene	< 10	< 5	< 4	< 1	< 5	---	
2-Methylphenol (o-Cresol)	< 50	< 25	< 20	< 5	< 25	---	
bis(2-Chloroisopropyl) Ether	< 10	< 5	< 4	< 1	< 5	---	
N-Nitroso-di-n-propylamine	< 10	< 5	< 4	< 1	< 5	---	
4-Methylphenol	< 50	< 25	< 20	< 5	< 25	---	
Hexachloroethane	< 10	< 5	< 4	< 1	< 5	---	
Nitrobenzene	< 10	< 5	< 4	< 1	< 5	---	
Isophorone	< 10	< 5	< 4	< 1	< 5	---	
2-Nitrophenol	< 50	< 25	< 20	< 5	< 25	---	
2,4-Dimethylphenol	< 50	< 25	< 20	< 5	< 25	---	
Benzoic Acid	< 300	< 150	< 120	< 30	< 150	---	
bis(2-Chloroethoxy) Methane	< 10	< 5	< 4	< 1	< 5	---	
2,4-Dichlorophenol	< 50	< 25	< 20	< 5	< 25	---	
1,2,4-Trichlorobenzene	< 10	< 5	< 4	< 1	< 5	---	
Naphthalene	120	76	50	48	33	4.1	
4-Chloroaniline	< 100	< 50	< 40	< 10	< 50	---	
Hexachlorobutadiene	< 10	< 5	< 4	< 1	< 5	---	
4-Chloro-3-methylphenol	< 50	< 25	< 20	< 5	< 25	---	
2-Methylnaphthalene	< 10	< 5	< 4	< 1	< 5	---	
Hexachlorocyclopentadiene	< 200	< 100	< 80	< 20	< 100	---	
2,4,6-Trichlorophenol	< 50	< 25	< 20	< 5	< 25	---	
2,4,5-Trichlorophenol	< 50	< 25	< 20	< 5	< 25	---	
2-Chloronaphthalene	< 10	< 5	< 4	< 1	< 5	---	
2-Nitroaniline	< 100	< 50	< 40	< 10	< 50	---	
Dimethylphthalate	< 50	< 25	< 20	< 5	< 25	---	
Acenaphthylene	1600	610	10	15	370	40.0	
2,6-Dinitrotoluene	< 50	< 25	< 20	< 5	< 25	---	
3-Nitroaniline	< 100	< 50	< 40	< 10	< 50	---	
Acenaphthene	43	31	24	24	20	0.0	
2,4-Dinitrophenol	< 200	< 100	< 80	< 20	< 100	---	
4-Nitrophenol	< 200	< 100	< 80	< 20	< 100	---	
2,4-Dinitrotoluene	< 50	< 25	< 20	< 5	< 25	---	
Dibenzofuran	< 10	8.1	7	7	5	0.0	
Diethylphthalate	< 50	< 25	< 20	< 5	< 25	---	
Fluorene	73	61	53	62	44	15.7	
4-Chlorophenyl-phenyl Ether	< 10	< 5	< 4	< 1	< 5	---	
4-Nitroaniline	< 100	< 50	< 40	< 10	< 50	---	
4,6-Dinitro-2-methylphenol	< 100	< 50	< 40	< 10	< 50	---	
N-Nitrosodiphenylamine	< 100	< 50	< 40	< 10	< 50	---	

Table 17. (continued) SVOCs in the scrub solution from the Circuitboard Test

Compound	Estimated concentrations, ug/L (a)					Run 2 RPD, % (b)
	Initial	Run 1	Run 2	Run 2 duplicate	Run 3	
4-Bromophenyl-phenyl Ether	< 10	< 5	< 4	< 1	< 5	---
Hexachlorobenzene	< 10	< 5	< 4	< 1	< 5	---
Pentachlorophenol	< 200	< 100	< 80	< 20	< 100	---
Phenanthrene	590	480	440	410 E (c)	420	---
Anthracene	< 43	20	15	15	33	0.0
di-n-Butylphthalate	< 50	< 25	< 20	< 5	< 25	---
Fluoranthene	320	250	260	260 E	320	---
Pyrene	410	320	340	300 E	430	---
Butylbenzylphthalate	< 50	< 25	< 20	< 5	< 25	---
3,3'-Dichlorobenzidine	< 200	< 100	< 80	< 20	< 100	---
Chrysene	18	14	16	16	18	0.0
Benzo(a)anthracene	10	8.2	9.1	9.1	10	0.0
bis(2-Ethylhexyl)phthalate	< 50	< 25	< 20	< 5	< 25	---
Di-n-Octylphthalate	< 50	< 25	< 20	< 5	< 25	---
Benzo(b)fluoranthene	16	9.3	13	12	12	8.0
Benzo(k)fluoranthene	< 10	< 5	< 4	2.1	< 5	---
Benzo(a)pyrene	14	9.4	11	11	9.7	0.0
Indeno(1,2,3-c,d)pyrene	18	12	13	14	6.3	7.4
Dibenz(a,h)anthracene	< 10	< 5	< 4	< 1	< 5	---
Benzo(g,h,i)perylene	29	20	21	23	11	9.1

- The sample volumes were not measured due to sampling and analysis error. The samples were contained in 1-L bottles, and the entire amount of sample was extracted and analyzed. A volume of 1 L was estimated for all of the samples. The concentration values reported in this table should be considered estimates of the true values, because they are based upon estimated sample volumes.
- RPD = Relative Percent Difference = $2 \times \text{abs}(\text{Value 1} - \text{Value 2}) / (\text{Value 1} + \text{Value 2}) \times 100\%$.
- E = Flag indicating that the analytical instrument response was above the calibrated range. The value reported is an estimated value based on extrapolating the instrument calibration, and may be an underestimate of the true value.

Table 18. Metal and undissolved solids concentrations in the Circuitboard Test scrub solution

Metal (mg/L)	Initial	Run 1	Run 2	Run 3
Aluminum (Al)	0.43	0.64	0.9	1.8
Antimony (Sb)	0.02	0.02	0.04	0.04
Arsenic (As)	< 0.01	< 0.01	< 0.01	< 0.01
Boron (B)	2.7	8.8	20	24
Barium (Ba)	0.011	0.014	0.02	0.036
Beryllium (Be)	< 0.0005	< 0.0005	0.0046	< 0.0005
Calcium (Ca)	18	18	16	18
Cadmium (Cd)	0.12	0.1	0.11	0.17
Cobalt (Co)	0.002	0.004	0.01	0.007
Chromium (Cr)	0.14	0.16	0.16	0.26
Copper (Cu)	12	19	34	61
Iron (Fe)	0.32	0.62	0.81	1.6
Potassium (K)	2.7	3.7	5.7	8.4
Lithium (Li)	< 0.005	0.007	0.011	0.014
Magnesium (Mg)	4.9	4.9	6.1	6.4
Manganese (Mn)	0.13	0.24	0.29	0.34
Molybdenum (Mo)	0.018	0.029	0.066	0.054
Sodium (Na)	38	53	77	96
Nickel (Ni)	0.072	0.19	0.41	0.44
Phosphorus (P)	0.32	3.6	12	12
Lead (Pb)	0.24	0.25	0.25	0.46
Selenium (Se)	< 0.01	0.01	0.01	< 0.01
Silicon (Si)	30	25	31	28
Silver (Ag)	< 0.01	< 0.01	< 0.01	0.01
Tin (Sn)	0.019	0.028	0.04	0.069
Strontium (Sr)	0.064	0.067	0.069	0.087
Titanium (Ti)	0.008	0.059	0.006	0.009
Thallium (Tl)	< 0.01	< 0.01	< 0.01	< 0.01
Vanadium (V)	0.008	0.013	0.017	0.019
Yttrium (Y)	< 0.0005	< 0.0005	0.0099	< 0.0005
Zinc (Zn)	1.1	1.3	1.6	3.3
Total elemental metals	111	140	207	263
Total undissolved solids (mg/L)	100	120	200	880

Table 19. Subcontractors that performed offgas sample laboratory analyses for the EvTEC tests and supplementary tests

	EvTEC-observed verification tests		Other EvTEC-observed tests		Other supplementary tests		
	Equivalency Test	Circuitboard Test	MSW Process Demonstration	Med Waste Process Demonstration	Propane Test (c)	Medical Waste Tests	
Test date	April 3-5, 2000	April 12-13, 2000	April 14, 2000		February 15-16, 2000	February 16-18, 2000	March 8-9, 2000
Semivolatile organics (Method 23/0010)	Alta Analytical Laboratory, El Dorado Hills, CA		---		---	Alta Analytical Laboratory, El Dorado Hills, CA	
PM or HCl/Cl ₂ (Methods 5, 26, 050)	AmTest Air Quality, LLC		---		AmTest Air Quality, LLC		AmTest Air Quality, LLC and Particle Technology Labs, Limited, Downers Grove, IL
Metals (Method 29)	---	AmTest Air Quality, LLC	---		---	---	AmTest Air Quality, LLC
VOCs (Method TO-14)	---	---	---		Atmospheric Analysis & Consulting, Ventura, CA		
VOCs (Method 0031)	Air Toxics Limited, Folsom, CA		---		---	---	---
Offgas composition (CEMS)	AmTest Air Quality, LLC		---		AmTest Air Quality, LLC		
Composition of the feed, glass, and baghouse dust	Air Toxics Limited, Folsom, CA (volatiles only)	Battelle Environmental Materials Science Laboratory, Richland, WA	---	---	---	---	---
Scrub solution composition and glass TCLP analyses	Analytical Resources, Inc, Seattle, WA and Air Toxics Limited, Folsom, CA (volatiles only)		---	---	---	---	---

Table 20. Manual sample train runs and sample durations

	Number of runs and duration of each run				
	EvTEC-observed verification tests		Other supplementary tests		
	Equivalency Test	Circuitboard Test	Propane Tests	Medical Waste Tests	
Test date	April 3-5, 2000	April 12-13, 2000	February 15-16, 2000	February 16-18, 2000	March 8-9, 2000
Semivolatile organics (Method 23/0010)	3-200 min each	3 runs - 240, 240, 200 min	---	3-240 min each	3-240 min each
PM or HCl/Cl ₂ (Methods 5, 26, 050)	3 runs 160, 107, and 161 min	3 runs - 120, 120, 101 min	2-60 min each at 65 kW; 3-60 min each at 130 kW	3-60 min each	3-60 min each
Metals (Method 29)	---	AmTest Air Quality, LLC	---	---	3-80 min each
VOCs (Method TO-14)	---	---	2-60 min each at 65 kW; 3-60 min each at 130 kW	3-60 min each	3-60 min each
VOCs (Method 0031)	3 runs, 4 tube sets per run, 40 min per set	3 runs, 4 tube sets per run, 20 min per set	---	---	---
Comments	---	---	No field blanks for Methods 5 or TO-14	-6-liter Summa cans for TO-14; -No blanks for any of the samples	- No blanks for Methods 5, 29, or TO-14, although metals are reported as blank-corrected; -NO _x exceeded analyzer range of 1,000 ppm during 1 of 3 tests, so the reported average is estimated.

CERF

IIEC

2131 K Street NW Suite 700
Washington DC 20037-1810
Tel 202.785.6420
Fax 202.833.2604
Web www.cerf.org
Email hitec@cerf.org

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