ENDESCO CLEAN HARBORS

# Sediment Decontamination Demonstration Program – Cement-Lock® Technology

## Final Report: Phase II Demonstration Tests with Stratus Petroleum and Passaic River Sediments

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# EXECUTIVE SUMMARY

Cement-Lock technology® is a thermo-chemical manufacturing process – developed by the Gas Technology Institute (formerly Institute of Gas Technology, Des Plaines, IL) and Unitel Technologies (Mount Prospect, IL) – that thoroughly decontaminates dredged sediment and converts it into Ecomelt®, a pozzolanic material, which when dried and finely ground can be used as a partial replacement for Portland cement in the production of concrete. As such, Ecomelt can be a marketable beneficial use product. When Ecomelt and Portland cement are blended together in prescribed proportions, the result is blended cement. Blended cement can be used in general construction projects at lower cost than Portland cement alone.

The Cement-Lock* technology was selected by the Office of Maritime Resources in the New Jersey Department of Transportation (NJ-DOT/OMR) to be evaluated for its applicability to the treatment of sediment dredged from navigational channels as part of the Sediment Decontamination Technology Demonstration Program. The goal of this program is to establish the ability of sediment decontamination technologies to use dredged material as a feedstock in a manufacturing process that produces a value-added product cost competitive with other management options for dredged material. A pilot test of the Cement-Lock technology was performed in 2005 at the demonstration plant located at the International Matex Tank Terminal (IMTT) site in Bayonne, NJ using material dredged from the Stratus Petroleum site in upper Newark Bay (NJ).[8] This test treated a total of 100 tons of dewatered sediment and modifiers to produce two products: Ecomelt (approximately 2 tons) and EcoAggMat (approximately 53 tons) using both slagging and non-slagging modes of operation, respectively. These products contained very low levels of contaminants, demonstrating the ability of the technology to decontaminate the dredged material at levels typical of New York/New Jersey Harbor navigational dredged material. However, continuous operations were not possible due to problems with the material feeding and slag discharging components of the demonstration plant. Because of this, the efficiency of the air pollution control equipment could not be established

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under slagging mode. Demo plant modifications were suggested and designed as part of the pilot study.[7]

At the conclusion of the Phase I pilot test, it was decided that additional information was needed on the efficiency of the air pollution control equipment as well as the ability of the plant to operate with continuous feeding under slagging mode. A Phase II demonstration study was commissioned by the NJ-DOT/OMR and U.S. Environmental Protection Agency (U.S. EPA) Region 2 to develop this information. The work described in this report covers the Phase II demonstration project. The specific objectives of this project were to: 1) develop and implement modifications to the demo plant to improve performance, 2) conduct a Confirmation Test in the modified plant with sediment dredged from the Stratus Petroleum site in Upper Newark Bay, 3) conduct an Extended Duration Test in the modified Cement-Lock demonstration plant with more highly contaminated sediment dredged from the Passaic River (NJ), 4) prepare a concrete mix design for a beneficial use demonstration with Ecomelt from Passaic River sediment, 5) update the economics of the Cement-Lock Technology for application to dredged sediment, and 6) dismantle the demo plant and restore the IMTT site.

The overall intent of the equipment modifications was to ensure that the Cement-Lock demo plant could consistently feed the sediment and modifier mixture to the Ecomelt Generator and operate in slagging mode – producing Ecomelt – over an extended period of time.

The modifications to the feeding system included using a screening bucket to mix the sediment-modifier mixture, installing a covered belt conveyor for the sediment-modifier mixture, and installing a V-Ram feeder at the charging deck. Modifications to the slag discharging equipment (drop-out box) included moving the Ecomelt quench/granulator under the rotary kiln discharge, angling the north and south walls of the drop-out box straight down, adding an access port, replacing the rotary kiln nose ring refractory, and altering the nose ring refractory configuration.

The Confirmation Test was initiated on November 29, 2006 during which time Stratus Petroleum site sediment-modifier mixture was fed to the demo plant at a rate of about 1,000 pounds per hour. The sediment had been previously mixed with modifiers in the proportions required to make Ecomelt.

The Confirmation Test was more successful than any of the previous slagging tests conducted in the demo plant. A total of 5.1 tons of sediment-modifier mixture was fed to the system, which yielded an estimated 3.3 tons of Ecomelt. The temperature of the Ecomelt Generator was varied from 2400° to 2580°F and the temperature of the Secondary Combustion Chamber (SCC) ranged from 2220° to 2500°F. Nitrogen oxide (NOx) measurements were taken from the flue gas stack periodically as required by the NJ Environmental Improvement Pilot Test (EIPT) permit. The NOx concentration in the flue gas ranged from 102 to 171 ppm during testing. Oxygen concentrations measured concurrently were 5.0 and 6.9 mole percent, respectively. The Confirmation Test was concluded due to slag buildup, weather-related difficulties, and a scheduling conflict with the EPA SITE (Superfund Innovative Technology Evaluation) program. To ensure that the air pollution control treatment efficiency would be evaluated by EPA SITE, the Confirmation Test was halted. Steps were taken to ensure that slag buildup would not hamper the ability to proceed with the emissions evaluation[9] and approval was given to proceed with the Extended Duration Test with Passaic River sediment.

The Extended Duration Test was conducted during two separate campaigns. The first was conducted from December 4 through 11, 2006. The second was conducted from May 14 through 19, 2007. The EPA SITE sampling crews took process and environmental samples (sediment feeds, modifiers, Ecomelt product, and air emission samples upstream and downstream from the Activated Carbon bed) during each campaign. In addition during the May 2007 campaign, water vapor samples were collected from the granulator discharge to determine the extent of potential contaminant emissions from that process point.

During these two separate campaigns, a total of 31.6 tons of Passaic River sediment and modifiers were processed through the Cement-Lock demo plant at rates exceeding one cubic yard (about 1 ton) per hour. The quantity of Passaic River sediment processed was equivalent to an *in situ* volume of 44.0 $yd^3$. An estimated total of 26.6 tons of Ecomelt was generated during the campaigns.

Despite the implementation of the changes to the plant suggested during the pilot study,[7] both campaigns experienced equipment-related problems, some due to the installation of new equipment and others due to freezing weather in December 2006 and rainstorms in May 2007.

In each case, the campaigns were terminated involuntarily when slag accumulated in the drop-out box and plugged the slag discharge. The plant had been modified to the maximum practicable extent to minimize this from happening. Further modifications would not be practical without dismantling and elevating the entire plant. For a commercial-scale Cement-Lock treatment facility, the plant would need to be re-designed with a drop-out box configuration consistent with industry criteria for continuous slagging mode operation.

Another important design and operational problem involved the air pollution control system. It was observed that the rate of powdered lime flowing to the duct upstream of the bag house was inconsistent during the later tests. This was manifested in inconsistent discharging of spent lime from the bag house. During testing, the bulk sample of lime in the hopper was replaced with fresh lime, but the lime continued to cake up in the feeder and not flow. Sufficient lime was fed during the December 2006 campaign to coat the bags in the bag house and keep the acid gas content of the flue gas low. However, the May 2007 campaign experienced higher than expected SOx as well as particulate emissions. Although this was not confirmed, it is possible that a bag (or bags) had torn inside the bag house that would have compromised the ability of the bag house to capture particulates containing both mercury and lead. In a commercial-scale Cement-Lock treatment facility, specific equipment to detect bag breakage (tearing) would be installed to closely monitor this potential equipment problem. Similarly, the lime feeding system would be designed to improve lime delivery and reliability.

To evaluate the treatment efficiency of the plant, samples of sediment feed materials and Ecomelt products were collected and analyzed for contaminants of concern to determine treatment efficiency (TE) of the Cement-Lock technology for Passaic River sediment. The TE results for major contaminants are presented in Table ES-1.

The Ecomelt product samples from the December 2006 and May 2007 campaigns show an average of 246 pg/g of polychlorinated biphenyls (PCBs) and <0.385 pg/g of 2,3,7,8-tetrachloro dibenzo dioxin (TCDD). The total Toxicity Equivalent (TEQ) of PCBs plus dioxins and furans (D/F) was 3.60 pg/g. Taken together with the sediment feed analysis yields a treatment efficiency (TE) of 99.991 percent for PCBs and 99.947 percent for 2,3,7,8-TCDD. On a total TEQ basis, the TE is 99.593 percent. The TE of benzo[a]pyrene averaged 99.968 percent; the

TE of naphthalene averaged 99.625 percent. The average TE of mercury was calculated to be 99.685 percent.

Table ES-1. Contaminants of Concern in Feed Passaic River Sediment and Product Ecomelt from Cement-Lock Demo Plant Campaigns

| Analyte | Campaign | Input Sediment | Product Ecomelt | Treatment Efficiency, %* |
|---|---|---|---|---|
| | | pg/g | | |
| PCBs, Congener Total | Dec 2006 | 3,297,502 | 263 | 99.991 |
| | May 2007 | 2,217,913 | 229 | 99.992 |
| 2,3,7,8-TCDD | Dec 2006 | 968.7 | <0.54 | >99.969 |
| | May 2007 | 549.5 | <1.0 | >99.926 |
| TEQ (D/F+PCB) | Dec 2006 | 1,163.1 | 1.48 | 99.855 |
| | May 2007 | 697.2 | 5.7 | 99.331 |
| | | µg/kg | | |
| Benzo[a]pyrene | Dec 2006 | 845.2 | <0.53 | >99.965 |
| | May 2007 | 2,015.0 | <1.03 | >99.971 |
| Naphthalene | Dec 2006 | 49.3 | <0.42 | >99.514 |
| | May 2007 | 276.5 | <1.28 | >99.735 |
| | | mg/kg | | |
| Mercury (Hg) | Dec 2006 | 5.23 | <0.033 | >99.64 |
| | May 2007 | 4.35 | 0.014 | 99.73 |

* If any analytical result was "Non Detect," TE was calculated using ½ the analytical detection limit.

The samples of Ecomelt show very low leachability when subjected to either the TCLP (toxicity characteristic leaching procedure) or the SPLP (synthetic precipitation leaching procedure). The TCLP results (Table ES-2) show that none of the Ecomelt samples leached any of the priority metals above regulatory limits. Most analyses were below detection limits for priority metals.

The SPLP results (Table ES-3) show most analyses were below detection limits for priority metals. However one sample exceeded the NJ Ground Water Quality Criteria limit for Mn and three exceeded the limit for Pb.

As part of the air pollution control equipment, the purpose of the activated carbon (AC) bed is to capture volatile heavy metals, specifically mercury, in the flue gas. The activated carbon pellets (RB-4C) in the AC bed were supplied by Norit Americas (Marshall, TX). During the December 2006 and May 2007 demo plant campaigns, flue gas samples were taken upstream and downstream of the AC bed and analyzed for metals, PCBs, D/Fs, and SVOCs (semi-volatile organic compounds) to characterize flue gas emissions and to determine AC bed capture efficiencies. Table ES-4 presents the AC bed capture efficiencies for heavy metals (total of As, Ba, Cd, Cr, Co, Cu, Pb, Mn, Ni, Se, Ag, Zn, and Hg) with Hg and Pb presented as separate items.

Table ES-2. Results of TCLP Tests for Metals on Ecomelt from Cement-Lock Demo Plant Campaign with Passaic River Sediment

| Metal | TCLP Limit | Ecom-1 | Ecom-2 | Ecom-3 | Ecom-4 | Ecom-5 | Ecom-6 | Average Ecomelt |
|---|---|---|---|---|---|---|---|---|
| | mg/L | | | | | | | |
| As | 5 | 0.5U** | 0.5U | 0.5U | 0.5U | 0.5U | 0.5U | 0.5U |
| Ba | 100 | 1U | 1U | 1U | 1U | 1U | 1U | 1U |
| Cd | 1 | 0.0092 | 0.005U | 0.005U | 0.005U | 0.005U | 0.005U | 0.0057 |
| Cr | 5 | 0.01 | 0.01U | 0.01U | 0.01U | 0.014 | 0.011 | 0.0108 |
| Co | --* | 0.05U | 0.05U | 0.05U | 0.05U | 0.05U | 0.05U | 0.05U |
| Cu | -- | 0.15 | 0.025U | 0.025 | 0.025U | 0.034 | 0.026 | 0.0475 |
| Pb | 5 | 0.5U | 0.5U | 0.5U | 0.5U | 0.5U | 0.5U | 0.5U |
| Mn | -- | 0.21 | 0.071 | 0.037 | 0.032 | 0.037 | 0.034 | 0.070 |
| Hg | 0.2 | 0.0002U | 0.0002U | 0.0002U | 0.0002U | 0.0002U | 0.0002U | 0.0002U |
| Ni | -- | 0.12 | 0.04 | 0.04 | 0.04 | 0.04U | 0.04 | 0.0533 |
| Se | 1 | 0.5 | 0.5 | 0.5 | 0.5U | 0.5U | 0.5U | 0.5U |
| Ag | 5 | 0.01 | 0.01 | 0.01 | 0.01U | 0.01 | 0.01U | 0.01U |
| Zn | -- | 0.7 | 0.31 | 0.16 | 0.13 | 0.22 | 0.17 | 0.282 |

* Not a TCLP priority metal.
** U = below the analytical detection limit.

Table ES-3. Results of SPLP Tests for Metals on Ecomelt from Cement-Lock Demo Plant Campaign with Passaic River Sediment

| Metal | NJ Ground Water Quality Criteria | Ecom-1 | Ecom-3 | Ecom-6 | Average Ecomelt |
|---|---|---|---|---|---|
| | mg/L | | | | |
| As | 0.003 | 0.008U* | 0.008U | 0.008U | 0.008U |
| Ba | 2 | 1U | 1U | 1U | 1U |
| Cd | 0.004 | 0.004U | 0.004U | 0.004U | 0.004U |
| Cr | 0.07 | 0.01U | 0.01U | 0.01U | 0.01U |
| Co | -- | 0.05U | 0.05U | 0.05U | 0.05U |
| Cu | 1.3 | 0.025U | 0.025U | 0.025U | 0.025U |
| Pb | 0.005 | 0.01U | 0.017 | 0.032 | 0.0197 |
| Mn | 0.05 | 0.084 | 0.021 | 0.023 | 0.04267 |
| Hg | 0.002 | 0.0002U | 0.00029 | 0.0002U | 0.00023 |
| Ni | 0.1 | 0.043 | 0.04U | 0.04U | 0.041 |
| Se | 0.04 | 0.05U | 0.05U | 0.05U | 0.05U |
| Ag | 0.04 | 0.01U | 0.01U | 0.01U | 0.01U |
| Zinc | 2 | 0.13 | 0.1U | 0.12 | 0.117 |

* U = below the analytical detection limit.

The results show that the Hg capture efficiencies were >88.8 and >98.9 percent during the December 2006 and May 2007 campaigns, respectively. The results also show that the AC bed was less efficient at capturing total metals including Pb, indicating that these metals were probably particle-bound.

Table ES-4. Activated Carbon Bed Capture Efficiency for Heavy Metals Including Hg and Pb During the Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| December 2006 Test | | | | May 2007 Test | | | |
|---|---|---|---|---|---|---|---|
| Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt | Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt |
| 1 | 6.06e-3 | 3.42e-3 | 43.5 | 1 | 3.21e-3 | 2.69e-3 | 16.3 |
| 2 | 4.56e-3 | 2.50e-3 | 45.2 | 2 | 3.89e-3 | 2.64e-3 | 32.1 |
| Total Metals Average | | | 44.2 | Total Metals Average | | | 25.0 |
| | | | | | | | |
| 1 (Hg) | 3.02e-3 | <2.58e-5 | >99.6 | 1 (Hg) | 1.50e-3 | <2.85e-5 | >99.1 |
| 2 (Hg) | 2.34e-3 | 5.89e-4 | 74.8 | 2 (Hg) | 1.43e-3 | <3.49e-5 | >98.8 |
| Average (Hg) | | | >88.8 | Average (Hg) | | | >98.9 |
| **Average Hg Capture – 2006 and 2007** | | | | | | | **93.84** |
| | | | | | | | |
| 1 (Pb) | 4.45e-4 | 4.31e-4 | 3.2 | 1 (Pb) | 2.99e-4 | 3.03e-4 | 0.0 |
| 2 (Pb) | 2.52e-4 | 2.01e-4 | 20.2 | 2 (Pb) | 3.53e-4 | 3.12e-4 | 11.1 |
| Average (Pb) | | | 9.3 | Average (Pb) | | | 5.4 |
| **Average Pb Capture – 2006 and 2007** | | | | | | | **7.35** |

The AC bed capture efficiencies for D/Fs and PCBs are presented in Table ES-5. The results show D/Fs were effectively captured by the AC bed at efficiencies of 98.7 and 99.5 percent for the December 2006 and May 2007 tests, respectively. The PCB capture efficiency was 92.1 percent for the December 2006 test, but 45.7 percent for the May 2007 test. Calculations are based on using ½ the analytical detection limit in the event that an analyte was "Non Detect."

Table ES-5. Activated Carbon Bed Capture Efficiency for Dioxins and Furans and PCBs During the Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| December 2006 Test | | | | May 2007 Test | | | |
|---|---|---|---|---|---|---|---|
| Dioxins and Furans (D/Fs) | | | | | | | |
| Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt | Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt |
| 1 | 7.77e-8 | 1.42e-9 | 98.2 | 1 | 9.40e-8 | 3.43e-10 | 99.6 |
| 2 | 6.04e-8 | 4.21e-10 | 99.3 | 2 | 4.27e-8 | 3.55e-10 | 99.2 |
| Average (D/F) | | | 98.7 | Average (D/F) | | | 99.5 |
| **Average D/Fs Capture – 2006 and 2007** | | | | | | | **99.1** |
| | | | | | | | |
| PCBs | | | | | | | |
| Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt | Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt |
| 1 | 1.91e-6 | 2.01e-7 | 89.5 | 1 | 2.19e-6 | 1.19e-6 | 45.7 |
| 2 | 1.37e-6 | 5.97e-8 | 95.6 | 2 | 1.16e-6 | 1.16e-6 | -- |
| Average (PCB) | | | 92.1 | Average (PCB) | | | 45.7 |
| **Average PCBs Capture – 2006 and 2007** | | | | | | | **68.9** |

The destruction and removal efficiency (DRE) for D/Fs and PCBs are presented in Table ES-6. DREs are based on the mass flow rate of these contaminants in the feed stream compared with the mass flow rate of these contaminants in the flue gas and Ecomelt streams.

Table ES-6. DREs for Dioxins and Furans (D/Fs) and PCBs During the Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| December 2006 Test | | | | May 2007 Test | | | |
|---|---|---|---|---|---|---|---|
| Dioxins and Furans (D/Fs) | | | | | | | |
| Feed, lb/hr | Ecomelt, lb/hr | Outlet, lb/hr | DRE, wt % | Feed, lb/hr | Ecomelt, lb/hr | Outlet, lb/hr | DRE, wt % |
| 2.49e-5 | 1.18e-8 | 9.19e-10 | 99.949 | 2.89e-5 | 3.27e-8 | 3.49e-10 | 99.886 |
| TEQ Basis | | | | | | | |
| 1.20e-6 | 1.78e-9 | 6.24e-11 | 99.846 | 1.02e-6 | 7.18e-9 | 5.76e-11 | 99.288 |
| | | | | | | | |
| PCBs (total of congeners) | | | | | | | |
| 3.62e-3 | 3.29e-7 | 1.30e-7 | 99.987 | 3.42e-3 | 2.89e-7 | 1.18e-6 | 99.957 |
| TEQ Basis | | | | | | | |
| 7.83e-8 | 6.92e-11 | 1.32e-11 | 99.895 | 5.96e-8 | 2.26e-11 | 1.94e-11 | 99.930 |

The results show that the average DRE achieved for D/Fs during the December 2006 and May 2007 tests was 99.949 and 99.886 percent, respectively. The DREs achieved for PCBs were 99.987 and 99.957 percent, respectively for the two tests. On a TEQ basis, the DREs achieved for D/Fs were 99.846 and 99.288 percent, respectively. The TEQ-based DREs for PCBs were 99.895 and 99.930 percent, respectively.

Mass balance calculations were performed on the trace elements, mercury and lead, from the sediment being processed through the Cement-Lock demo plant to confirm that the final distribution of these volatile metals was known. (Mass balance calculations were not performed for organic contaminants, since those materials are quantitatively destroyed during high-temperature thermal processing.) The trace elements could be distributed to several different process streams including: 1) Ecomelt, 2) fly slag accumulating in or coating the Secondary Combustion Chamber walls, 3) water in the Ecomelt quench/granulator, 4) particulate matter and/or water condensed at the flue gas quencher, 5) spent lime and other particulate matter collected by the bag house, 6) adsorbed on the activated carbon in the activated carbon (AC) bed, 7) coating the inside of the flue gas stack, and 8) exiting the flue gas stack. The distribution of mercury and lead to these various process streams depends upon the chemical properties of each Hg or Pb compound present.

The mass balance calculations presented in Table ES-7 are the averaged results from the December 2006 and May 2007 Cement-Lock demo plant campaigns.

Table ES-7. Mass Balance Calculations for Mercury and Lead – Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| Contaminant in Feed | In Ecomelt | In Quench / Granulator Water | In Activated Carbon (AC) Bed | In Flue Gas Exiting Stack | In Other Process Streams* |
|---|---|---|---|---|---|
| 4.79 mg/kg Hg | 0.0237 mg/kg Hg | 15.95 µg/L Hg | -- | -- | -- |
| 0.1151 lb | 5.896e-4 lb | 8.483e-5 lb | 0.03728 lb | 3.406e-3 lb | 0.07564 lb |
| 100.000% | 0.313% | 0.075% | 31.514% | 1.429% | 66.669% |
| | | | | | |
| 367.35 mg/kg Pb | 21.14 mg/kg Pb | 8,445 µg/L Pb | -- | -- | -- |
| 8.8290 lb | 0.5101 lb | 0.04491 lb | 4.914e-4 lb | 5.860e-3 lb | 8.2694 lb |
| 100.000% | 5.714% | 0.518% | 0.0055% | 0.047% | 93.715% |

* SCC walls, flue gas quencher water, spent lime (bag house), and stack walls.
** Activated carbon does not have a high affinity for Pb.

As expected, the results show that mercury was essentially volatilized from the sediment during thermal processing. Only 0.31 percent of the Hg in the feed sediment was found in the Ecomelt and about 1.429 percent exited through the flue gas stack. The rest of the mercury was distributed throughout the plant with 31.51 percent in the AC bed and 0.075 percent of Hg in the quench/granulator water. This left roughly two-thirds of the Hg in the sediment feed unaccounted for. It is assumed that the mercury condensed onto the metal in cooler parts of the plant or was associated with particles that deposited in the system. This phenomenon is assumed to be transitory – continuous long-term operation would push the mercury further into the plant where it would eventually be captured in the air pollution control equipment.

Because of mercury's high volatility, most of it is expected to pass through the high-temperature treatment units (Ecomelt Generator or Secondary Combustion Chamber). A portion of the Hg is expected to condense out in the cooler downstream sections of the process plant. The portion that does not condense out will be efficiently captured in the AC bed.

Some Hg could appear in particulate matter and/or water condensed at the flue gas quencher; however that is unlikely since the flue gas quencher was designed to operate without condensation (dry bottom). Similarly, fine particulate matter would be entrained to downstream air pollution control equipment.

The bulk of Hg is expected to condense on the powdered lime used for acid-gas capture and be collected at the bag house. This assumption would need to be tested during the shakedown phase of any new plant and prior to the treatment of any highly contaminated materials. As discussed above, none of the samples of spent lime from the bag house were analyzed because it was not operating properly.

The results show that lead was also volatilized from the sediment during thermal processing. About 5.71 percent of the Pb in the feed sediment was found in the Ecomelt, but only about 0.047 percent exited through the flue gas stack. About 0.005 percent of the Pb remained in the Activated Carbon bed, which represented an average AC bed capture efficiency of 7.35 percent (activated carbon has limited affinity for Pb). About 0.52 percent of Pb showed up in the quench/granulator water. About 94 percent of the Pb in the sediment feed was unaccounted for.

As with Hg, some Pb could appear in particulate matter and/or water condensed at the flue gas quencher; however that is unlikely since the flue gas quencher was designed to operate without condensation. Fine particulate matter would be entrained to downstream air pollution control equipment.

Because of lead's moderate volatility, some of it will remain in the high-temperature treatment units, specifically the Secondary Combustion Chamber (SCC), as fly slag accumulating in or coating the SCC walls. The balance of Pb is expected to be removed from the flue gas in the form of particulate matter in the cooler downstream sections of the process plant, specifically in the bag house. These assumptions would need to be tested during the shakedown phase of any new plant and prior to the treatment of any highly contaminated materials. None of the samples of spent lime from the bag house were analyzed because it was not operating properly.

Mass balances for non-volatile metals, chromium and barium, showed that 51 and 69 percent of these metals remained with the Ecomelt, respectively. The unaccounted for remainder of each is expected to reside in elutriated particulate matter and be captured downstream in the air pollution control equipment. Other non-volatile metals would be expected to behave similarly.

To evaluate the use of Ecomelt in the production of blended cement, tests were conducted on a sample of Ecomelt from Passaic River sediment. A batch of concrete was prepared in which

Ecomelt replaced 40 percent of the Portland cement normally required and specific tests were conducted on the concrete. The objective of these tests was to characterize the concrete and establish a mix design for a beneficial use demonstration at Montclair State University (MSU, Montclair, NJ).

As mentioned above, the batch of concrete was prepared with a mixture of 40:60 Ecomelt/Portland cement. Major tests included compressive strength, flexural strength, drying shrinkage, freeze-thaw testing, deicing-scaling, and chloride permeability. The compressive strength tests results (Table ES-8) showed that after 28 days of curing, the Ecomelt/Portland specimen achieved 5,700 psi; while the control achieved 5,950 psi. After 56 days of curing, the compressive strength results were the same (6,650 psi). These results show that concrete made with the 40:60 Ecomelt/Portland blend may require an accelerator for high early strength applications.

Table ES-8. Results of Compressive Strength Tests Conducted on Concrete Samples Made with Ecomelt/Portland (40:60 wt %) Blended Cement and Control Cement

| Days of Curing | Ecomelt/Portland Blended Cement Concrete | Control Concrete |
|---|---|---|
| | Compressive Strength, psi (MPa) | |
| 4 | 2,850 | 4,500 |
| 7 | 3,450 | 4,800 |
| 28 | 5,700 | 5,950 |
| 56 | 6,650 | 6,650 |

The results of the drying shrinkage test showed that the concrete made with the Ecomelt/Portland blend had a slightly lower shrinkage than the control. Also, after 301 freeze-thaw cycles, the Ecomelt/Portland blend specimens had a slightly higher relative dynamic modulus of elasticity of 91 percent compared to 90 percent for the control. The Ecomelt/Portland blend specimens showed lower resistance to deicer scaling than the control. The Ecomelt/Portland blend specimens showed "Very Low" chloride permeability compared to "Moderate" chloride permeability for the control, where a lower result is preferred. These results indicate that the Ecomelt blended concrete is likely to perform favorably in a general construction application.

A concrete mix design was prepared for a general construction application at Montclair State University (MSU, Montclair, NJ). For the beneficial use demonstration, about one ton of

Ecomelt from Passaic River sediment was ground to cement fineness (<50 µm). The ground Ecomelt will be used as a partial replacement for Portland cement in a batch of concrete for a length of sidewalk (165 feet long and 6 feet wide) at MSU. The sidewalk is situated in a "high use" area of MSU's campus and will be monitored long-term for evidence of wear, cracking, spalling, weathering and leachability underneath the new sidewalk. An Acceptable Use Determination (AUD) for the beneficial use demonstration was issued to Endesco Clean Harbors (ECH) by the NJ Department of Environmental Protection (NJ-DEP). One ton of finely ground Ecomelt in five 55-gallon drums was shipped to MSU on May 1, 2008.

The economics of a commercial-scale Cement-Lock facility were determined for both enterprise- (permanent) and project-based (temporary) scenarios. The enterprise-based calculation was based on a 500,000 $yd^3$/yr operation, whereas the project-based calculations were based on several potential treatment options for restoration of the lower Passaic River (NJ). For an enterprise-based, sustainable industry scenario, the break-even tipping fee for a commercial-scale Cement-Lock facility processing 500,000 $yd^3$/year of sediment dredged from the NY/NJ Harbor was estimated to be \$40.05/$yd^3$. The economics include revenues from the sale of pulverized Ecomelt, export of electric power to the grid generated from waste heat recovery, 75:25 debt-to-equity ratio, 20-year period of depreciation and capital recovery, and a natural gas cost of \$9.33/million Btu. Estimated capital and operating costs for on-site sediment storage, screening, and handling were also included in the economic evaluation. In this enterprise-based scenario, co-processing of supplementary feedstocks with calorific value was not considered.

The sensitivities of the break-even tipping fee to plant capacity, plant utilization efficiency, natural gas cost, Ecomelt selling price, and electric power generation (plant use and export) were also determined. As expected, the break-even tipping fee increases with increasing natural gas cost, decreasing sediment processing rate (% of rated capacity), decreasing credit for electric power for export, decreasing plant throughput capacity, and deceasing Ecomelt selling price. The cost of natural gas has the most effect on break-even tipping fee as it represents about 48 percent of the operating and capital expenses.

The economics of the Cement-Lock Technology were also evaluated under specific project-based criteria for the Focused Feasibility Study (FFS) being conducted by Malcolm Pirnie Inc.

(MPI) for early action on restoration of the Lower Passaic River. The project-based economics were estimated for the three alternative cases developed by MPI and presented in Table ES-9.

Table ES-9. Environmental Remediation Cases Developed by MPI for the Passaic River Restoration Project and Break-Even Tipping Fee Required for Cement-Lock Technology

| Alternative No. | Sediment to be Treated, $yd^3$ (55 wt % solids) | Project Duration, years | Alternative Type | Analysis | Break-Even Tipping Fee Cement-Lock, $\$/yd^3$ |
|---|---|---|---|---|---|
| 3 | 7,600,000 | 9 (10 processing) | Dredging | Subsurface | $78.70 |
| 6 | 3,000,000 | 6 | Capping | Surface | $105.06 |
| 9 | 2,000,000 | 4 | Capping | Surface | $140.94 |

The results of the economic assessment show that the required break-even tipping fee can be significantly higher than the enterprise-based scenario primarily due to the short duration over which capital costs and depreciation expenses are recovered. Further, for these scenarios, the demo plant air emissions rates were scaled up proportionately to estimate the plant capacity and by contaminant concentration of the Passaic River sediment at the surface or subsurface. Case 3 is based on processing subsurface sediment at a rate of 760,000 $yd^3$/year, which includes 50 percent additional operating cost to cover residual mercury capture. At this rate, the processing of 7,600,000 $yd^3$ of Passaic River sediment will require 10 years. Cases 6 and 9 are based on surface sediment processing rates of 500,000 $yd^3$/year amortized over the dredging project time of 6 and 4 years, respectively. The break-even tipping fees were estimated to be $78.70, $105.06 and $140.94/$yd^3$ for Alternatives 3, 6 and 9, respectively.

**Commercial Plant Design Consideration:** The following addresses the potential situation in which a batch of sediment with significantly elevated mercury level is received at a commercial-scale Cement-Lock treatment facility. First, the air pollution control equipment for a commercial-scale facility will be conservatively designed to accommodate a fairly broad range of mercury concentrations expected in sediment. For example, the average mercury concentration of Passaic River subsurface sediment is 7.7 mg/kg.[17] The maximum Passaic River surface sediment mercury concentration is 12.4 mg/kg. Designing for the higher value should provide considerable leeway in sediment processing. Second, each batch of sediment delivered to a commercial-scale Cement-Lock facility will be characterized for mineral matter as well as for trace element concentrations. The mineral matter content is needed to establish modifier requirements. Third, any batch of sediment with elevated mercury concentration will be segregated from the bulk of the dredged sediment and stored under cover pending processing. Fourth, the highly contaminated sediment will be mixed with sediment (ratio to be determined) with much lower mercury concentration prior to feeding to the system. The net effect would be to dilute the Hg concentration in the sediment to the range for which the pollution control equipment was designed. This will enable more levelized treatment of the sediment. Fifth, mixing the highly contaminated sediment with less contaminated sediment will be done under cover to minimize/prevent volatilization of organic contaminants. Taken together, these design and operating protocols will enable a commercial-scale Cement-Lock plant to successfully treat a broad range of contaminated levels in sediment.

The Cement-Lock Technology is flexible regarding co-processing of other materials with sediment, some of which may have significant calorific value. For example, supplemental or alternate fuels, such as waste petroleum oils and sludges, tanker bottoms, municipal solid wastes, municipal sewage sludges, and shredded tires are candidates for reducing energy-related costs. Some of these materials have tipping fees associated with their use, which would increase revenues and enhance the Cement-Lock economics.

It should be noted that no supplemental or alternate fuels were tested under this current program. However, GTI has conducted small pilot-scale tests in which Ecomelt was produced from oil-contaminated soil co-processed with paper and plastics as surrogate for municipal solid wastes. GTI has conducted several laboratory-scale tests each with river sediment, recycled concrete, PCB (surrogate) contaminated soil, coal fly and bottom ash as well as uranium oxide to produce Ecomelt. Many waste-to-energy projects have successfully burned municipal solid wastes to ash and converted the thermal energy into electric power. Further, the cement industry has a long history of using waste oils and rubber tires as supplemental energy sources for producing Portland cement. Although not every combination of waste or alternate fuel has been tested, the developers of the Cement-Lock Technology are confident that suitable Ecomelt can be produced from these materials provided the proper mix of modifiers is included.

After the demonstration project was concluded, the demo plant equipment was removed from the site and the site was restored per the lease agreement with IMTT.

An AUD was also issued to ECH by NJ-DEP for the remaining Stratus Petroleum sediment and Ecomelt on the Cement-Lock demo plant site. The Ecomelt (about 16.9 tons) and remaining Stratus Petroleum sediment (about 105.4 tons) were beneficially used as geotechnical fill at the ProLogis Elizabeth Seaport Business Park (Elizabeth, NJ).

The remaining Passaic River sediment could not be beneficially used without further treatment or processing, because its dioxin/furan concentration exceeded the land-disposal limit of 1 ppb and its PCB concentration exceeded the land-disposal limit of 2 ppm. Therefore, all 146.2 tons of Passaic River sediment remaining were transported off site and disposed at a secure landfill at the Wayne Disposal, Inc., Site #2 Landfill, 49350 N. I-94 Service Drive, Belleville, MI 48211.

The work described in this report was conducted from June 19, 2006 through December 31, 2007.

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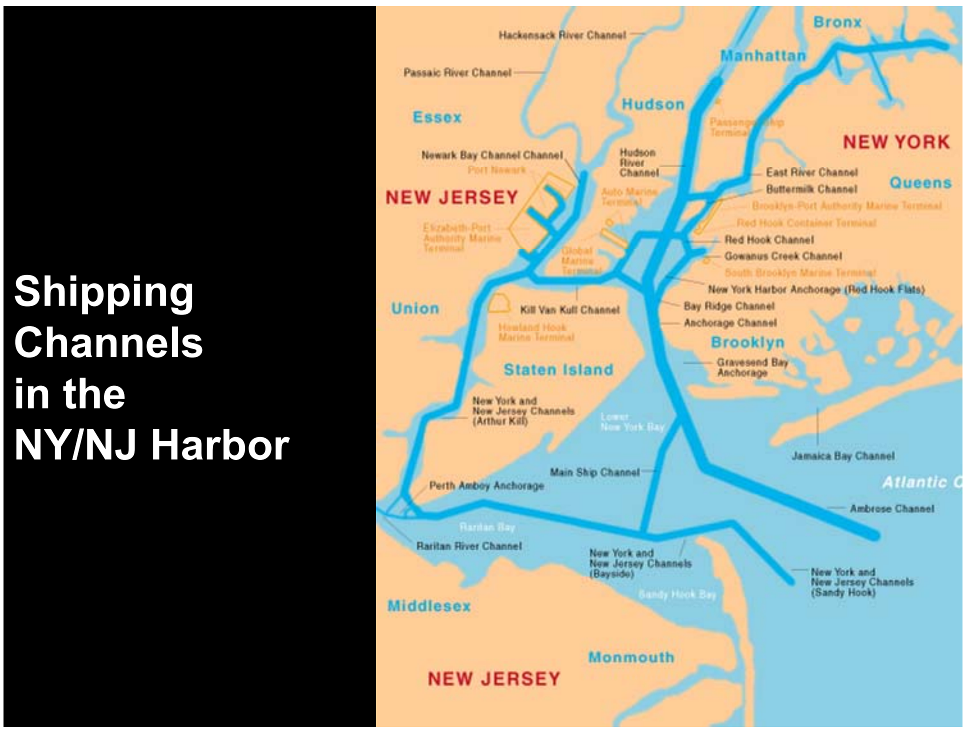
# I. INTRODUCTION

The New York/New Jersey Harbor has a natural depth of about 19 feet. Because of this, as a major regional shipping hub, the harbor is laced with about 240 miles of navigation shipping channels (see diagram below) that must be periodically dredged to maintain the required depths for ocean-going cargo vessels. Due to unacceptably high levels of contaminants – both organic and inorganic – most of the sediment dredged from the harbor is no longer suitable for ocean disposal and must be treated as necessary and beneficially used or disposed of elsewhere.




**New Jersey Sediment Decontamination Demonstration Project**

In 1998, the State of New Jersey Department of Commerce and Economic Development Office of Maritime Resources issued an RFP (Request for Proposals) for technologies that could effectively and economically decontaminate sediment dredged from the navigation channels in the NY/NJ Harbor. It was also necessary to demonstrate that the decontaminated sediment could be beneficially used and sold in the marketplace. The processing cost (exclusive of dredging costs) of decontaminating the sediment must also be less than \$35 cubic yard ($yd^3$) dredged for a large-scale project.

Fifteen proposals were submitted in response to the RFP. The Institute of Gas Technology (predecessor to Gas Technology Institute) and ENDESCO Services, Inc. (wholly owned subsidiary of GTI) submitted a proposal offering the Cement-Lock Technology as a means of accomplishing the stated objectives. After a detailed technical evaluation, the Cement-Lock Technology was one of five technologies selected by the New Jersey Dredging Project Facilitation Task Force (appointed by then New Jersey Governor Christine Todd Whitman) to participate in a two-phased program to evaluate and demonstrate technologies for decontaminating dredged sediment. The sediment for the Phase I Pilot test and the Phase II demonstration test was to be dredged from the navigation channels in the NY/NJ Harbor. Subsequently, a contract was awarded from the New Jersey Department of Transportation Office of Maritime Resources (NJ-DOT/OMR) to ENDESCO Clean Harbors, L.L.C. (ECH), a subsidiary of ENDESCO Services and Gas Research Institute formed to demonstrate and commercialize the Cement-Lock Technology in the NY/NJ Harbor area.

## Cement-Lock® Technology

The Cement-Lock®[*] Technology is a thermo-chemical remediation technology that converts contaminated sediment and other wastes into Ecomelt® – a pozzolanic material, which when dried and finely ground can be used as a partial replacement for Portland cement in the production of concrete. According to ASTM (American Society for Testing and Materials) standard C-595, the pozzolanic Ecomelt can replace from 15 to 40 weight percent of Portland cement in the production of concrete. As such, Ecomelt is a marketable product for beneficial use similar to granulated blast furnace slag. If the Ecomelt and Portland cement are blended and packaged together in the above prescribed proportions, the result is blended cement.

Cement-Lock was developed by the Gas Technology Institute (GTI, formerly the Institute of Gas Technology, Des Plaines, IL) and Unitel Technologies (Mount Prospect, IL) in response to the need identified by the U.S. Environmental Protection Agency Region 2 and the U.S. Army Corps of Engineers (New York District) under the federal Water Resources Development Act (WRDA). An objective of the WRDA Sediment Decontamination Program was to foster the

[*] Inquiries regarding commercial application of Cement-Lock Technology may be directed to the technology owner, Volcano Group LLC, 557 North Wymore Road, Suite 100, Maitland, FL 32751, phone (877) 326-6358 / (877) ECOMELT.

development of sediment decontamination technologies and bring them to commercial readiness for utilization in the NY/NJ harbor area and to find beneficial uses for these sediments.

Under the WRDA Program, GTI conducted tests in bench-scale as well as continuously operating pilot-scale equipment using Newtown Creek (New York) sediment to prove the concept of the technology. The results of these tests were very encouraging and have been published elsewhere.[10,13] All the organic contaminants present in the sediment were destroyed; the inorganic contaminants were immobilized in the cement matrix; and the compressive strength of the blended cement produced from these tests surpassed the requirements for Portland cement as required by ASTM standard C 150.

In the Cement-Lock process, a mixture of sediment and modifiers is charged to a rotary kiln melter (Ecomelt® Generator). The Ecomelt Generator is maintained at a temperature in the range of 2400° to 2600°F by combustion of natural gas or other fuels with air. This temperature yields a melt with a manageable viscosity and causes the minerals in the sediment and modifier mixture to react together. During processing, the sediment-modifier mixture is thermo-chemically transformed from the recognizable feed materials to a homogeneous, lava-like melt. All nonvolatile heavy metals originally present in the sediment are incorporated into the melt matrix via an ionic replacement mechanism. The melt flows like lava through the Ecomelt Generator as the kiln rotates. The melt then falls by gravity through a plenum into water, which immediately quenches and granulates the melt. The quenched and granulated material, called Ecomelt® is removed from the quench granulator by a drag conveyor, which also partially dewaters it.

Flue gas from the Ecomelt Generator flows into the Secondary Combustion Chamber (SCC), which provides an additional 2 seconds of residence time at a minimum temperature of 2200°F to ensure complete destruction of any organic compounds that survive the severe thermal conditions in the Ecomelt Generator. Flue gas exiting the SCC is rapidly cooled via direct water injection to prevent the formation or recombination of dioxin or furan precursors. In the commercial concept, the thermal energy of the flue gas can be used to raise steam in a heat recovery steam generator to generate electric power for plant use or for export.

Powdered lime (CaO) is injected into the cooled gas to capture sulfur oxides and hydrogen chloride from sulfur and chlorine in the sediment as well as sodium and potassium chlorides from seawater. The sulfur/salt/spent lime mixture is removed from the flue gas stream by a bag house. The spent lime from the bag house is containerized and shipped to a landfill. In a commercial Cement-Lock Technology application, a portion of this spent lime may be recycled to the front of the plant for use as a modifier. Volatile heavy metals, such as mercury, are removed from the flue gas as it passes through a fixed bed of activated carbon pellets. Alternatively, in a commercial application, powdered activated carbon could be injected into the flue gas to capture volatile metals, which would be collected in another bag house. Cleaned flue gas is vented to the atmosphere at about 350°F via an induced draft fan.

**Cement-Lock Demonstration Plant**

ENDESCO Clean Harbors, L.L.C. (ECH) installed a Cement-Lock demonstration plant on a 2-acre parcel of land at the International Matex Tank Terminal (IMTT) in Bayonne, NJ. The demo plant incorporates the major equipment components needed to demonstrate and characterize the process (Figure 1). The final step in producing Cement-Lock construction-grade blended cement (grinding and blending the Ecomelt with Portland cement or another lime source) can be accomplished at an off-site facility. The demo plant has a nominal throughput capacity of 10,000 $yd^3$ of sediment per year, or about 1 ton per hour. With process enhancements, such as oxygen enrichment, its estimated throughput could be increased to 30,000 $yd^3$/year.

Figure 2 shows the Ecomelt Generator and Secondary Combustion Chamber (SCC) from the South. The Ecomelt Generator is a 30-foot long by 10-foot diameter rotary kiln at right. The kiln is connected to the SCC at left via the drop-out box. The drop-out box and Ecomelt Granulator are at center. Visible at the back left is the Flue Gas Quencher.

Figure 3 shows the overall Cement-Lock demo plant from the Northeast. At far left is the 100-$yd^3$ sediment storage hopper. To the right of the sediment storage hopper is the 25-$yd^3$ alternate feed hopper. An inclined screw conveyor connects the feed hoppers to the charging deck. The large vessel at center is the Modifier 1 hopper. The much smaller Modifier 2 hopper is immediately to the left of the Modifier 1 hopper. The Flue Gas Quencher and the quench water storage tank are also shown at the right.

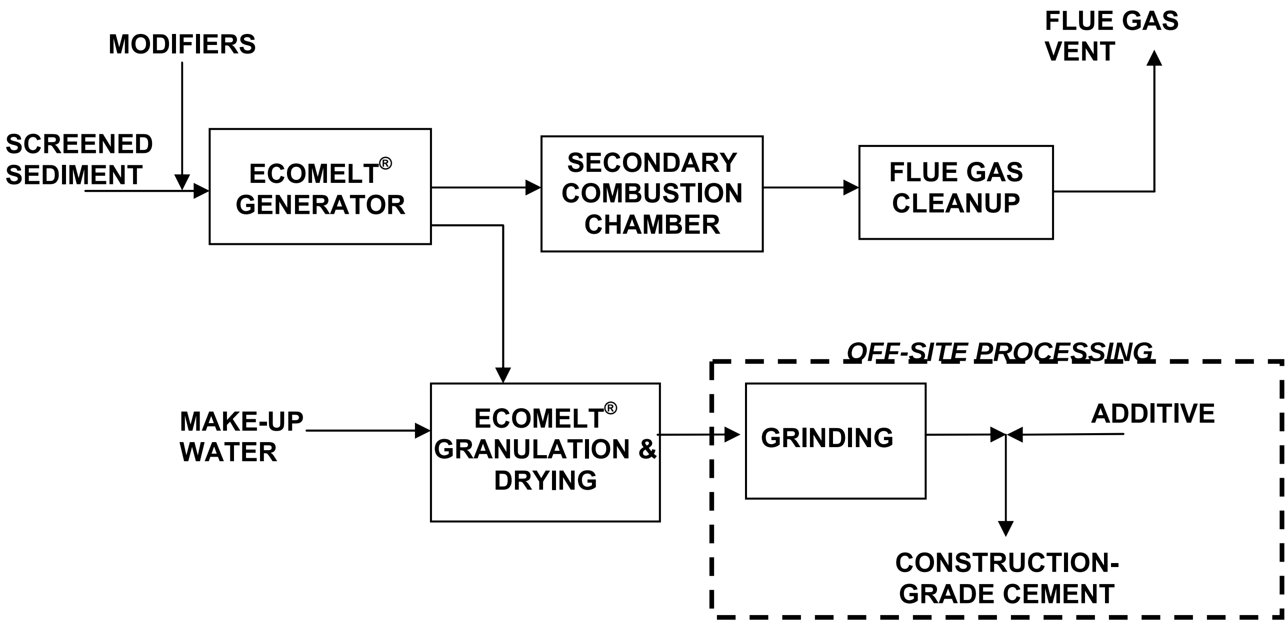



Figure 1. Process Flow Diagram for Cement-Lock Demonstration Plant

Figure 2. The Cement-Lock Demonstration Plant from the South

Figure 3. The Cement-Lock Demonstration Plant from the Northeast

Plant construction was initiated in mid 2002. The plant was mechanically complete by the end of July 2003 and shakedown and commissioning was initiated subsequently. The initial testing of the demo plant took place in December 2003 and culminated in the first large-scale production of Ecomelt from Stratus Petroleum sediment. Shakedown and commissioning activities (July 28, 2003 through December 24, 2003) and Cement-Lock demo plant Operations (December 2003 through March 2005) are described in detail in separate project reports.[5,6]

During the initial start up of the demo plant, several problems were encountered in the sediment and modifier feeding systems as well as the slag discharging system. The sticky nature of the mechanically dewatered sediment caused it to adhere to the flights of the screw conveyors in the sediment storage hopper and in the transfer screws leading to the charging deck. The sediment also stuck in the weigh feeder rendering it useless for monitoring sediment being fed.

To remedy the feeding problems, the sediment was air-dried under a tent and modifiers were premixed in the sediment storage area. Also, instead of screw conveyors, belt conveyors were installed to move the sediment-modifier mixture to the charging deck.

Once the sediment-modifier mixture was charged to the Ecomelt Generator, it was readily converted to molten lava-like material; however, as the molten material exited the rotary kiln it solidified on the ceramic distributors and on the walls of the drop-out box. After enough slag accumulated in the drop-out box, the discharge was essentially plugged.

To remedy the slag discharging problem, several different approaches were considered and equipment modifications were designed and implemented during 2004. Additional burners were installed in the drop-out box to keep the molten material in a fluid state. Also, different geometries of the drop-out box discharge were tested. Mechanical slag breakers were also installed to disrupt accumulated slag. However, slag continued to accumulate in the drop-out box leading to involuntary shut-downs. At the end of 2004, an agreement was made between the sponsors, ECH, and GTI to operate the demo plant in non-slagging mode to process sediment through the system and generate air emission data for permitting.

### Phase I Pilot Test Summary

ECH conducted a pilot test with Stratus Petroleum sediment mixed with modifiers during March 2005. The objectives of the Phase I Pilot Test were to: 1) process a bulk quantity of sediment dredged from a harbor navigation channel through the Cement-Lock demo plant, 2) demonstrate the effectiveness of the technology for treating organic as well as inorganic contaminants in the sediment, 3) show that the organic contaminants were actually destroyed and not just transferred to another medium, 4) determine the leachability of the treated sediment by subjecting it to the TCLP (Toxicity Characteristic Leaching Procedure, EPA Method 1311) and MEP (Multiple Extraction Procedure, EPA Method 1320) protocols, 5) show that the treated material qualifies for a beneficial use application, and 6) show that the sediment processing cost can be $35 per cubic yard ($yd^3$) or less.

The project objectives were achieved. The results of the Cement-Lock Technology Phase I Pilot Test have been published previously[8] and are briefly summarized below:

**Sediment:** For the Phase I Pilot Test, sediment dredged from the Stratus Petroleum site in Upper Newark Bay was provided to ECH by NJ-DOT/OMR. The bulk quantity of sediment (about 500 $yd^3$) was screened to -¼ inch to remove oversized debris and then dewatered to about 55 weight percent water in a belt press. The dewatered sediment was brought to the site in twenty 20-$yd^3$ lined and tarped roll-off containers.

**Demo Plant Operating Modes:** During the Phase I Pilot Test, the Cement-Lock demo plant was operated in both slagging and non-slagging modes. In the tests conducted under slagging mode, the sediment was converted to Ecomelt, which is the non-crystalline remediated product from Cement-Lock processing. Ecomelt can be ground to cement fineness and then blended with a lime source, such as ordinary Portland cement, to yield construction-grade cement.

In the test conducted under non-slagging mode, the sediment was converted to EcoAggMat (Ecological Aggregate Material). EcoAggMat can be beneficially used without further treatment, as fill or as a partial replacement for sand in mortar.

**Sediment Treatment Capacity:** The demo plant was operated at a sediment processing rate of about 1,000 pounds per hour (about ½ $yd^3$/hour) during both the slagging and non-slagging test campaigns. The nominal throughput capacity of the demo plant without any process enhancements is about 10,000 $yd^3$/year or a little more than 1⅓ $yd^3$/hour. A commercial-scale Cement-Lock plant would be designed to treat up to 500,000 $yd^3$/year of sediment using multiple processing modules. From this quantity of sediment, a commercial plant would produce about 243,000 ton/year of Ecomelt for incorporation in construction-grade cement.

**Sediment Treated/Beneficial Use Product Generated:** Approximately 20 $yd^3$ (about 20 tons) of sediment was processed through the plant during slagging-mode testing. In total, about 2 tons of Ecomelt were generated – the balance (about 8 tons) was in the form of large clinkers or slag. Approximately 80 $yd^3$ (about 80 tons) of sediment were processed through the plant in non-slagging mode. About 53 tons of EcoAggMat were produced from the sediment.

**Ecomelt – Suitable for Beneficial Use:** The initial sample of Ecomelt was subjected to the EPA TCLP test. The sample was essentially non-leachable as none of the priority metals was detected in the leachate above the analytical detection limits. The Ecomelt was then converted to construction-grade cement and tested for compressive strength. The compressive strength of the construction-grade blended cement was 5,190 psi after 28 days of curing. This exceeds the

ASTM (American Society for Testing and Materials) C 150 requirement for Portland cement (4,060 psi) and the ASTM C 595 requirement for blended cement (3,480 psi).

**EcoAggMat – Suitable for Beneficial Use:** The EcoAggMat was essentially devoid of any organic contamination. After treatment, the level of polychlorinated biphenyls (PCBs) in the sediment was reduced by 99.97 percent to 0.22 µg/kg in the EcoAggMat. Further, the concentrations of non-volatile metals in the EcoAggMat were also suitable for beneficial use.

The EcoAggMat was also subjected to the TCLP, SPLP (Synthetic Precipitation Leaching Procedure), and MEP tests to determine its aqueous leaching potential. In the TCLP, the sample is leached for 18±2 hours in a solution of acetic acid (pH of 4.93). In the SPLP, the sample is leached for 18±2 hours in a solution of sulfuric and nitric acids (pH of 4.20). As shown in Table 1, chromium was detected in the EcoAggMat leachate from both the TCLP and SPLP tests at 29.0 and 13.3 µg/L, respectively. These values are well below the TCLP limit of 5,000 µg/L and the NJ GWQC limit of 70 µg/L.

Table 1. Results of Leachability Tests Conducted on EcoAggMat from Cement-Lock Phase I Pilot Test with Stratus Petroleum Sediment

| EcoAggMat (thermally treated sediment) Leachability Results | | | | | | |
|---|---|---|---|---|---|---|
| Contaminant | TCLP 1311* | TCLP Limits | SPLP 1312 | MEP 1320* Highest | MEP 1320* Last† | NJ GWQC Limits |
| | µg/L | | | | | |
| Arsenic | <500 | 5,000 | <500 | 9.06 | 9.06 | 3 |
| Barium | <1000 | 100,000 | <1000 | 133 | <100 | 2,000 |
| Cadmium | <5 | 1,000 | <5 | <4 | <4 | 4 |
| Chromium | 29.0 | 5,000 | 13.3 | 29.3 | <10 | 70 |
| Copper | <25 | NA | <25 | <10 | <10 | 1,300 |
| Lead | <500 | 5,000 | <500 | 6.28 | <5 | 5 |
| Manganese | NA | NA | NA | <10 | <10 | 50 |
| Mercury | <0.2 | 200 | <0.2 | <0.285 | <0.285 | 2 |
| Nickel | <40 | NA | <40 | <40 | <40 | 100 |
| Selenium | <500 | 1,000 | <500 | <20 | <20 | 40 |
| Silver | <10 | 5,000 | <10 | <10 | <10 | 40 |
| Zinc | <20 | NA | <20 | <20 | <20 | 2,000 |

* EPA Leachability method number.
** < = Less than the analytical detection limit.
† Concentration of leachate on last day of MEP.

The MEP test consists of a series of sequential extractions of the sample first in a solution of acetic acid (pH maintained at 5, EPA Method 1310) followed by nine extractions in a sulfuric and nitric acid solution (pH of 3.0). The highest leachate concentration and the leachate concentration on the final day of leaching are presented in the table. Arsenic, barium, chromium, and lead were detected during the MEP testing. Arsenic was detected in several extractions, but was highest (9.06 µg/L) on the last day of leaching. Lead was detected at 6.28 µg/L on the first day of leaching, but was below the detection limit on the last day. Chromium was detected on the first day of leaching and on several subsequent leaching days, but not on the last day. The concentrations of arsenic and lead in the leachate exceeded the NJ GWQC. The concentration of barium and chromium were well below the NJ GWQC.

The EcoAggMat was approved by the NJ Department of Environmental Protection for placement at the former BASF site in Kearny, NJ, which was undergoing remediation. The EcoAggMat was placed at the BASF site in early May 2006 and was beneficially used as geotechnical fill.

**Environmental Sampling**: The emissions from the Ecomelt Generator were sampled to determine the efficiency of the equipment for capturing and/or destroying organic or inorganic contaminants. The emissions of potential air pollutants from the demo plant were assessed during the non-slagging campaign in March 2005. The EPA SITE (Superfund Innovative Technology Evaluation) Program provided the stack sampling, environmental sampling and analytical work for the Phase I Pilot test.

The air data collected under the EPA SITE program showed emission rates of $SO_2$ of < 0.024 lb/hr (< 0.8 ppmdv at 7% $O_2$), NOx of 1.53 lb/hr (76 ppmdv at 7% $O_2$), carbon monoxide of 0.02 lb/hr (1.7 ppmdv at 7% $O_2$), and total hydrocarbons (as methane) of < 0.01 lb/hr (< 1.4 ppmdv at 7% $O_2$). These are well within the NJ-DEP Air Quality Permit limits.

The concentration of PCBs in the stack was measured at 0.13 µg/dscm (at 7% $O_2$), which corresponds to an emission rate of 1.42 x $10^{-6}$ lb/hr. Of the PCBs fed to the system, 99.49 percent was destroyed, 0.03 percent appeared in the EcoAggMat, and 0.48 percent appeared in the flue gas. The emission rate of specific SVOCs (semi-volatile organic compounds) analyzed in the stack was below the analytical detection limit of 3.53 x $10^{-6}$ lb/hr each. Bis(2-ethylhexyl) phthalate (a common laboratory contaminant) was also detected in the flue gas.

The concentration of polychlorinated dioxin (PCDD) and furan (PCDF) congeners in the stack was measured at 0.35 ng/dscm (at 7% $O_2$). For comparison, the EPA New Source Performance

Standard for PCDDs and PCDFs emitted from large municipal waste incinerators is 30 ng/dscm (at 7% $O_2$: ref. 40 CFR 60.52b). The emission rate of PCDDs and PCDFs from the stack totaled 2.86 x $10^{-9}$ lb/hour. Overall, 99.84 percent of the dioxins and furans fed to the system were destroyed, 0.10 percent appeared in the EcoAggMat, and 0.06 percent appeared in the flue gas.

On a toxicity equivalent (TEQ) basis (including full detection-limit accounting for non-detected species), 99.02 percent of the TEQ from PCDD, PCDF, and PCB congeners in the sediment-modifier mixture fed to the Cement-Lock demo plant was destroyed. The balance appeared in the flue gas (0.23 percent) and the EcoAggMat (0.75 percent). The TEQ of the EcoAggMat itself was 2.08 pg/g from PCDD and PCDF congeners and 0.03 pg/g from PCBs.

Samples of spent lime and granulator quench water also showed trace levels of PCDD and PCDF congeners and PCBs. These samples were taken near the mid-point of the 17-day campaign in March 2005 and the contaminant accumulation rate could not be accurately determined. If the rate of contaminant accumulation is assumed to be constant up to the sampling time, then the estimated TEQ of the PCDD and PCDF congeners and PCBs in the spent lime and granulator quench water represents less than 0.0015 percent of the total contaminant TEQ load.

The concentration of mercury entering the activated carbon bed was 14.6 μg/acm (6.79 x $10^{-4}$ lb/hr) while that exiting the stack measured 0.14 μg/acm (5.61 x $10^{-6}$ lb/hr or 0.049 lb/year). This represents 99.2 percent collection efficiency across the activated carbon bed. The NJ-DEP Air Quality Permit required a minimum of 70 percent mercury collection efficiency and a maximum emission of 0.64 lb/year.

The samples of spent lime collected from the bag house did not have any specific SVOCs above the analytical detection limit, which ranged from 1.2 to 9.6 ng/g. The common laboratory contaminant, bis(2-ethylhexyl) phthalate, was also detected in these samples. Samples of water from the quencher/granulator also did not contain any SVOCs above the analytical detection limit, which ranged from 0.0053 to 0.083 μg/L. These samples did contain trace metal contaminants at low levels, but no mercury was detected.

These results show that the organic contaminants in the sediment were destroyed and not merely transferred to other media or the flue gas. Some of the more volatile trace metal contaminants were removed from the sediment and transferred to the spent lime and quench water (with the exception of mercury noted above). In a commercial Cement-Lock plant, most of these process streams will be recycled to the feed section for ultimate incorporation into the Ecomelt, so that the spent lime and granulator quench water will not contain the trace metal contaminants.

**Economic Evaluation and Assessment (2005):** The preliminary economics of the Cement-Lock technology for treating sediment from navigation channels were evaluated for the Phase I project. Per the assumptions made, the break-even tipping fee for a commercial-scale Cement-Lock facility processing 500,000 $yd^3$/year of sediment dredged from navigation channels in the NY/NJ Harbor was \$34.97/$yd^3$ (\$2005). The economics include revenues from the sale of pulverized Ecomelt valued at \$80/ton and the export of electric power to the grid generated from waste heat recovery. The economics were based on a total installed cost of \$81,626,000 for the plant, 75:25 debt-to-equity ratio, 20-year period of depreciation and capital recovery, and a natural gas cost of \$9/million Btu. Estimated capital and operating costs for on-site sediment storage, screening, and handling were also included in the economic evaluation.

The sensitivities of the break-even tipping fee to variations in natural gas cost, plant throughput capacity, processing rate, and Ecomelt product price were also determined. As expected, the tipping fee increased with increasing natural gas cost, decreasing sediment processing rate (% of rated capacity), decreasing plant throughput capacity, and decreasing Ecomelt selling price. The cost of natural gas has the most effect on break-even tipping fee as it represented about 50 percent of the total operating and capital expense.

Cement-Lock is an energy intensive technology and, its economics are sensitive to the cost of fuel. However, the Cement-Lock Technology is flexible regarding co-processing of other materials with sediment, some of which have significant calorific value. For example, supplemental or alternate fuels, such as waste petroleum oils and sludges, tanker bottoms, municipal solid wastes, municipal sewage sludges, and shredded tires can be used to reduce energy-related costs. Some of these materials have tipping fees associated with their use, which increase revenues and enhance the Cement-Lock economics.

**Equipment Modification Design Study:** ECH conducted an equipment modification design study as part of the NJ-DOT/OMR project. The objectives of this study were to develop equipment modifications, and estimate costs and schedule to remedy the problems described above. The study was conducted from August through December 2005. Based on the results of this study, it was recommended that the existing feeding system be replaced by ground-level sediment-modifier mixer, screening the sediment-modifier mixture through an ALLU-type screening bucket to feed a covered belt conveyor, and using a V-Ram feeder to feed the kiln. It was further recommended that the auxiliary burners be removed from drop-out box, the walls of the drop-out box be made vertical, and space be opened in front of the kiln nose allowing slag to flow directly into the quencher below. The complete results of the study have been submitted to NJ-DOT/OMR and published separately.[7] A summary of the Equipment Modification Design Study and the implementation of equipment modifications are included in Appendix A.

**Phase I Pilot Test Conclusions:** The Cement-Lock Technology successfully achieved the objectives of the Phase I Pilot Test of the NJ Sediment Decontamination Demonstration Project. Dredged sediment has been remediated and converted to two beneficial use products – Ecomelt (slagging mode) and EcoAggMat (non-slagging mode). The EcoAggMat satisfies New Jersey Residential Direct Contact Soil Cleanup Criteria and was determined to be suitable for use as geotechnical fill. All of the EcoAggMat produced during the pilot test has been beneficially used at the BASF site in Kearny, NJ. The Ecomelt also can be used as a partial replacement for Portland cement in concrete. The required break-even tipping fee for sediment dredged from navigational channels in a commercial-scale Cement-Lock facility was estimated at $\$34.97/yd^3$.

### Objectives of the Phase II Demonstration Project

The overall objectives of the Phase II Demonstration Tests with Stratus Petroleum and Passaic River sediments were to: 1) develop modifications for and implement the modifications to the demo plant, 2) conduct a Confirmation Test in the modified plant with sediment dredged from the Stratus Petroleum site in Upper Newark Bay – as much as 100 tons of sediment were to be processed during this test over a 72-hour period, 3) conduct an Extended Duration Test in the modified Cement-Lock demonstration plant with sediment dredged from the Passaic River – as much as 200 tons of sediment were to be processed during this test, 4) conduct a beneficial use project with Ecomelt from Passaic River sediment, 5) update the economics of the Cement-Lock Technology for application to dredged sediment, and 6) dismantle the demo plant and restore the IMTT site.

The work described in this report was conducted from June 19, 2006 through December 31, 2007.

# II. PROCESS DEMONSTRATION

The following summarizes the Cement-Lock technology demonstration with Passaic River sediment and includes discussion on sediment handling, delivery, and on-site storage, pre-test planning and air permitting, Confirmation Test Operations, and Extended Duration Test Operations. Chronological details of the Confirmation Test and the two Extended Duration Test campaigns are included in Appendix B.

### Passaic River Sediment Handling, Delivery, and On-Site Storage

During March 2006, BioGenesis Enterprises mechanically dewatered some 619.15 cubic yards (125,052 gallons) of Passaic River sediment using a batch plate-and-frame filter press. The sediment had been in storage in the former Great Lakes ore carrier Valgocen at Bayshore Recycling Corporation (Keasbey, NJ). By mechanical dewatering, the water content of the sediment was reduced from 81.6 to 38.5 weight percent (the solids content was increased from 18.4 to 61.5 wt %). The resulting mechanically dewatered sediment had a volume of about 168.8 cubic yards and weighed 201.45 tons as-delivered to the sediment storage area at the Cement-Lock demo plant. Based on the *in situ* bulk density of sediment of 81.3 lb/ft$^3$, and the *in situ* solids content of 42.5 weight percent, the volume of sediment delivered to the plant represented about 264.4 cubic yards of *in situ* sediment.

The mechanically dewatered sediment was covered by tarps (Figure 4) waiting to be processed through the Cement-Lock demo plant. During storage, the water content of the sediment decreased over time by air drying. The water content of grab samples of sediment was determined to be about 27.5 weight percent.

### Pre-Test Planning and Air Permitting

**Air Quality Permitting, November – December 2006 Campaign:** In preparation for submitting a modified Environmental Improvement Pilot Test (EIPT) permit application to NJ-DEP, a meeting was held at the NJ-DEP on May 19, 2006 with Mr. Patrick Sanders (NJ-DEP Enforcement), Mr. Joel Leon and Dr. Negib Harfouche (Air Quality Permitting), Mr. Scott Douglas (NJ-DOT/OMR), and GTI to discuss Phase II project permitting requirements. NJ-DEP suggested that new Operating Scenarios be incorporated into the existing EIPT permit that would include the Confirmation Test with Stratus Petroleum sediment and the Extended Duration Test with Passaic River sediment. This suggestion was incorporated into the EIPT application.

Figure 4. Mechanically Dewatered Passaic River Sediment
in Storage at the Cement-Lock Demo Plant

The analytical requirements for the Confirmation Test included measurement of nitrogen oxide (NOx) emissions during the test. Other analytical requirements for the Confirmation Test included using the continuous emission monitoring system (CEMS) in the stack for oxygen (must be greater than 2 volume percent, dry basis), carbon monoxide (must be less than 50 ppm, dry volume basis corrected to 7 volume percent $O_2$), and opacity (must be less than 5 percent).

NJ-DEP also suggested that ECH analyze a sample of the mechanically dewatered Passaic River sediment that was in storage for trace elements, PCBs, dioxins and furans, semi-volatile organic contaminants (SVOCs), and pesticides. RPMS took a grab sample of the Passaic River sediment. The sample was submitted to SGS Environmental Services (SGS) for major and minor oxides, trace elements, PCBs, dioxins and furans, SVOCs, pesticides, calorific value, proximate and ultimate analyses. The analysis of this grab sample of Passaic River sediment is presented in Table 2.

The Potential to Emit (PTE) calculations for each of the Operating Scenarios in the EIPT permit application utilized the analysis of the mechanically dewatered Passaic River sediment on site as

Table 2. Analysis of Grab Sample of Mechanically Dewatered Passaic River Sediment (May 3, 2006)

| Contaminant | Quantity | TEQ |
|---|---|---|
| **Dioxins – Furans** | pg/g | |
| 2,3,7,8-TetraCDD | 270 | 270 |
| 1,2,3,7,8-PentaCDD | 5.1 | 5.1 |
| 1,2,3,4,7,8-HexaCDD | 3.6 | 0.4 |
| 1,2,3,6,7,8-HexaCDD | 20 | 2.0 |
| 1,2,3,7,8,9-HexaCDD | 11 | 1.1 |
| 1,2,3,4,6,7,8-HeptaCDD | 370 | 3.7 |
| 2,3,7,8-TetraCDF | 14 | 1.4 |
| 1,2,3,7,8-PentaCDF | 14 | 0.4 |
| 2,3,4,7,8-PentaCDF | 32 | 9.6 |
| 1,2,3,4,7,8-HexaCDF | 150 | 15.0 |
| 1,2,3,6,7,8-HexaCDF | 35 | 3.5 |
| 1,2,3,7,8,9-HexaCDF | 5.6 | 0.6 |
| 2,3,4,6,7,8-HexaCDF | 19 | 1.9 |
| 1,2,3,4,7,8,9-HeptaCDF | 18 | 0.2 |
| 1,2,3,4,6,7,8-HeptaCDF | 600 | 6.0 |
| TetraCDDs (total) | 340 | -- |
| PentaCDDs (total) | 61 | -- |
| HexaCDDs (total) | 210 | -- |
| HeptaCDDs (total) | 890 | -- |
| OctaCDD | 3700 | 1.1 |
| TetraCDFs (total) | 430 | -- |
| PentaCDFs (total) | 420 | -- |
| HexaCDFs (total) | 480 | -- |
| HeptaCDFs (total) | 790 | -- |
| OctaCDF | 870 | 0.3 |
| Total TEQ | | 322.3 |
| **Proximate Analysis** (as received) | wt % | dry |
| Moisture Content | 27.50 | -- |
| Ash | 66.70 | 92.0 |
| Volatile Matter | 5.51 | 7.4 |
| Fixed Carbon | 0.29 | 0.6 |
| Total | 100.00 | 100.0 |
| | | |
| **Ultimate Analysis (dry basis)** | wt % | |
| Carbon | 4.16 | |
| Hydrogen | 0.16 | |
| Nitrogen | 0.05 | |
| Sulfur | 0.83 | |
| Oxygen (by difference) | 2.80 | |
| Ash | 92.00 | |
| Total | 100.00 | |
| | | |
| Chlorine (dry basis) | 0.01 | |
| Calorific Value, Btu/lb (dry basis) | 448 | |

| **SVOCs** | µg/kg | |
|---|---|---|
| Acenaphthene | <540 | |
| Acenaphthylene | <540 | |
| Anthracene | <540 | |
| Benzo[a]anthracene | <540 | |
| Benzo[a]pyrene | 680 | |
| Benzo[b]fluoranthene | 570 | |
| Benzo[(g,h,i]perylene | <540 | |
| Benzo[k]fluoranthene | <540 | |
| Chrysene | <540 | |
| Dibenzo[a,h]anthracene | <540 | |
| Fluoranthene | <540 | |
| Fluorene | <540 | |
| Indeno[1,2,3-c,d]pyrene | <540 | |
| 1-Methylnaphthalene | <540 | |
| 2-Methylnaphthalene | <540 | |
| Naphthalene | <540 | |
| Phenanthrene | <540 | |
| Pyrene | <540 | |
| | | |
| **Pesticides** | µg/kg | |
| alpha-BHC | <17 | |
| beta-BHC | <17 | |
| delta-BHC | <17 | |
| gamma-BHC (Lindane) | <17 | |
| Heptachlor | <17 | |
| Aldrin | <17 | |
| Heptachlor epoxide | <17 | |
| Endosulfan I | <17 | |
| Dieldrin | <17 | |
| 4,4'-DDE (p,p'-DDX) | <17 | |
| Endrin | <17 | |
| 4,4'-DDD (p,p'-TDE) | <17 | |
| Endosulfan II | <17 | |
| Endosulfan sulfate | <17 | |
| 4,4'-DDT | 54 | |
| Methoxychlor | <17 | |
| Toxaphene | <17 | |
| alpha-Chlordane | <17 | |
| gamma-Chlordane | <17 | |
| Chlordane, total | <17 | |
| Endrin aldehyde | 17 | |
| Endrin ketone | <17 | |
| | | |
| **PCBs/Aroclors** | µg/kg | |
| Aroclor 1016 | <54 | |
| Aroclor 1221 | <54 | |

| | | |
|---|---|---|
| Aroclor 1232 | <54 | |
| Aroclor 1242 | <54 | |
| Aroclor 1248 | <54 | |
| Aroclor 1254 | <54 | |
| Aroclor 1260 | 92 | |
| | | |
| **Metals** | mg/kg | |
| Arsenic | 13 | |
| Barium | 89 | |
| Cadmium | <1.6 | |
| Chromium | 110 | |
| Cobalt | 14 | |
| Copper | 140 | |
| Lead | 220 | |
| Manganese | 1100 | |
| Mercury | 0.4 | |
| Nickel | 28 | |
| Selenium | <3.1 | |
| Silver | <1.6 | |

| | | |
|---|---|---|
| Zinc | 180 | |
| | | |
| **Major & Minor Oxides** | wt % | |
| $SiO_2$ | 62.68 | |
| $Al_2O_3$ | 12.45 | |
| $TiO_2$ | 0.84 | |
| $Fe_2O_3$ | 5.88 | |
| CaO | 1.19 | |
| MgO | 2.00 | |
| $K_2O$ | 2.33 | |
| $Na_2O$ | 2.31 | |
| $SO_3$ | 1.52 | |
| $P_2O_5$ | 0.22 | |
| $SrO_2$ | 0.02 | |
| BaO | 0.05 | |
| $MnO_2$ | 0.07 | |
| Loss on Ignition | 8.44 | |
| Total | 100.00 | |

well as the air emission data in the report prepared by TRC Environmental from the March 2005 non-slagging campaign.

The major and minor oxides analyses were also used by GTI to establish the modifiers required for the target Ecomelt composition. The recipe was not significantly different from that for the Stratus Petroleum sediment.

GTI submitted the EIPT permit application along with necessary additional support documentation to NJ-DEP on September 26, 2006. Upon consideration of the Operating Scenario with Stratus Petroleum sediment-modifier mixture, another separate Operating Scenario was added as described below. Therefore, a total of three new Operating Scenarios were included in the EIPT permit application.

1. The first Operating Scenario is for the Confirmation Test in which the Stratus Petroleum sediment-modifier mixture will be fed to the system at 1,000 lb/hour for up to 12 hours.
2. The second Operating Scenario is for the Confirmation Test in which the Stratus Petroleum sediment-modifier mixture will be fed to the system at 4,000 lb/hour for up to 60 hours (the total of these two Operating Scenarios is 72 hours or 3 days).
3. The third Operating Scenario is for the Extended Duration Test in which the Passaic River sediment-modifier mixture will be fed to the system at 4,000 lb/hour for 200 to 450 hours.

On October 19, 2006 NJ-DEP forwarded a draft EIPT Compliance Plan to GTI for review. NJ-DEP had combined Operating Scenarios 1 and 2 into one Operating Scenario. GTI completed its review of the draft EIPT and forwarded comments to NJ-DEP on November 1, 2006.

As part of the EIPT process, ECH was required to obtain a general permit for the rental diesel-powered Emergency Generator (EmGen). The general permit for the EmGen was granted by NJ-DEP. The general permit allows for the EmGen to be operated for a period not-to-exceed 50 hours at a thermal input of no more than 3 million Btu/hr. According to Foley Power (rental company), the thermal input to the EmGen is about 1.4 million Btu/hr. In the event of a power outage at the plant, the EmGen automatically energizes. The EmGen allows the rotary kiln to continue to be rotated while it cools from elevated temperature to prevent going "out-of-round."

When operated for the 50-hour maximum duration, the estimated emissions from the EmGen represent a significant fraction of the total plant emissions for CO, $SO_2$, VOCs (volatile organic compounds), and particulates. The EmGen emissions were not included in the EIPT.

The EIPT permit was issued by NJ-DEP to ECH for a 90-day operating period. The EIPT including the PTE calculations and specific permit requirements are included in Appendix C.

**Air Quality Permitting, May 2007 Campaign:** Because of the delay experienced in initiating the additional Cement-Lock demo plant campaign, the 90-day EIPT issued to ECH in November 2006 expired. NJ-DEP required that ECH submit another air quality permit application for the balance of the testing. Other requirements for the EIPT included 1) submitting revised PTE calculations based on the December 2006 results, 2) completing a risk screening worksheet for long- and short-term risks, and 3) measuring the vapor emissions from the granulator discharge during subsequent testing.

During previous plant operation, the NJ-DEP permitting representative had noticed water vapor emanating from the discharge of the quencher granulator. He asked if emissions from this source had ever been measured before. As this had never been considered an emission source, no sampling had ever been conducted. Therefore, NJ-DEP included the requirement for collecting and analyzing a sample of the vapors being emitted from that point in the EIPT. In support of the EIPT application, GTI performed detailed calculations to estimate the potential-to-emit from the granulator discharge based on the estimated heat input to the granulator, the rate of evaporation of water from the granulator, the fraction of water vapor that would not pass through the Secondary Combustion Chamber, and the mole fraction of different contaminants in the granulator water and their corresponding vapor pressures.

The risk screening worksheet was prepared by GTI and submitted to NJ-DEP. The risk screening worksheet provides an indication of the potential long-term and short-term risks associated with the planned operation of a facility. GTI prepared several risk screening scenarios for submission to the NJ-DEP. The one that was finally submitted included maximum operation of the demo plant of 120 hours (5 days of continuous operation) with Passaic River sediment.

The NJ-DEP issued a 90-day EIPT to ECH for the continuation of the Extended Duration Test effective May 14, 2007. The EIPT permit, PTE calculations, Risk Screening Worksheet, and vapor pressure calculations submitted in support of the EIPT application are included in Appendix D.

**Project Planning:** In August 2006 ECH held a meeting with IMTT and RPMS at IMTT offices to discuss the overall project scope and to keep communications with IMTT up to date. Another objective of this meeting was to discuss IMTT site rules and safety requirements so that expectations on both sides were fully understood by all.

In September 2006, GTI updated and revised the Health and Safety Plan (HASP) for the Phase II project based on the existing plant and environmental conditions. Copies of the revised HASP were distributed to the project sponsors.

Representatives from the EPA SITE Program visited the demo plant on November 29, 2006 (Wednesday) to assess the stack and activated carbon bed inlet scaffolding, available equipment, and operations in anticipation of the Passaic River sediment testing scheduled to begin during the first week of December 2006.

### Confirmation Test Operations

The Confirmation Test was initiated on November 27. The Ecomelt Generator was heated to its nominal operating temperature of 2400°F at the prescribed rate of 100°F/hour. The Secondary

Combustion Chamber (SCC) was not fired during the test as the SCC exceeded the Air Quality Permit minimum temperature requirement of 2100°F. Feeding the sediment-modifier mixture was initiated on November 29. During the overnight hours, feeding was halted and the system temperature was reduced to 1700° or 1800°F to conserve natural gas. The average rate of sediment-modifier mixture fed to the system was 1904.3 lb/hr. A total of 5.1 tons of Stratus Petroleum sediment-modifier mixture was processed through the Cement-Lock demo plant yielding about 3.3 tons of Ecomelt.

Although the modifications made to the drop-out box enabled more slag to be discharged from the system, slag continued to accumulate on the walls of the drop-out box, specifically the opposite wall. Slag accumulating in the drop-out box discharge resulted in an involuntary shutdown.

Overall, the Confirmation Test achieved improved and more consistent feeding via the V-Ram feeder than previous tests. Ecomelt was discharged from the granulator at a fairly uniform rate (Figure 5 shows Ecomelt filling a dump hopper). The temperature of the Ecomelt Generator was varied from 2400° to 2580°F and the temperature of the SCC ranged from 2220° to 2500°F. The test was concluded on December 2, 2006.

Figure 5. Ecomelt Product Accumulating in a Dump Hopper

The operating conditions during the Confirmation Test are summarized in Table 3. The time-temperature histories of the Ecomelt Generator and SCC during the Confirmation Test are presented in Figure 6. The natural gas flow to the system during the test is presented in Figure 7. A summary of the sediment-modifier mixture fed is presented in Table 4. A detailed chronological summary of the Confirmation Test is included in Appendix B.

Table 3. Summary of Operating Conditions for Cement-Lock Demo Plant Confirmation Test

| **Test No.** | **7** |
|---|---|
| Test Dates | 11/27 – 12/2/06 |
| Ecomelt Generator (rotary kiln) | |
| Temperature, °F | 2200 – 2580 |
| Pressure, inches (water gauge) | -0.3 |
| Kiln Speed, rpm | 0.25 – 0.3 |
| Solids Residence Time, min. | 129 – 107 |
| Secondary Combustion Chamber | |
| SCC Burner | Low fire |
| Temperature, °F | 2220 – 2500 |
| Process Temperatures, °F | |
| Granulator | 195 |
| Quencher Outlet, average (min – max) | 325 (289 – 375) |
| Bag House Outlet, average (min – max) | 295 (275 – 314) |
| Activated Carbon Bed Outlet, average (min – max) | 245 (225 – 268) |
| Stack Gas, average (min – max) | 280 (257 – 296) |
| Flue Gas Components | |
| $O_2$, vol % (dry basis) | 5.0 – 6.86 |
| NOx, ppm (dry basis) | 102 – 171 |

* N/A = Not measured.

**NOx Analysis**

Nitrogen oxides (NOx) analysis of the flue gases in the stack during the Confirmation Test are summarized in Table 5. The NOx analysis ranged from 102 to 171 ppm (dry basis) during the Confirmation Test. The corresponding oxygen concentrations were 5.00 and 6.86 mole percent, respectively. Sediment was fed to the system on November 29 and December 1, 2006. A NOx sample was taken on November 30, 2006 but no sediment was fed on that day.

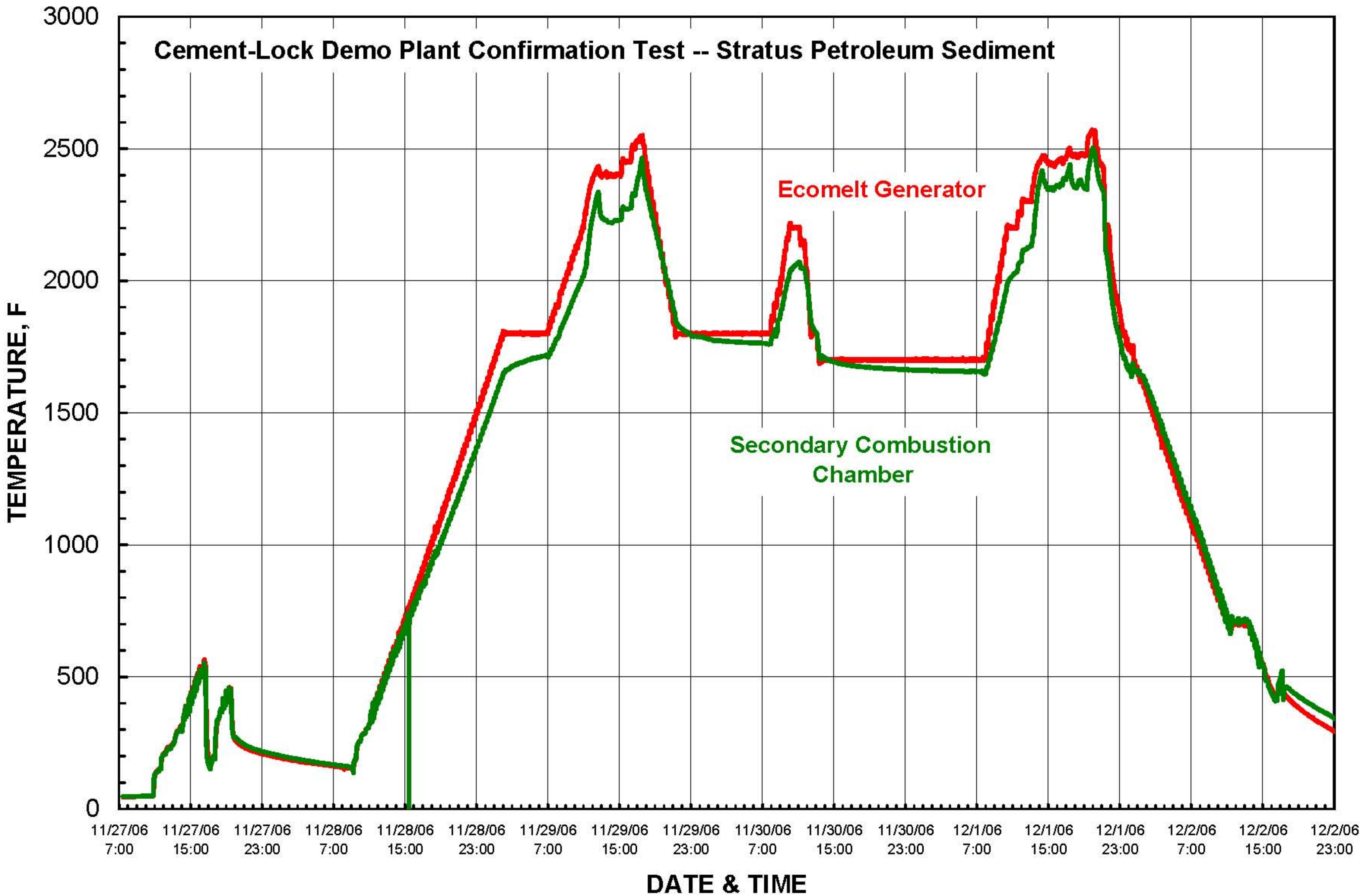



Figure 6. Time-Temperature History of the Confirmation Test with Sediment Dredged from the Stratus Petroleum Site (sediment-modifier mixture)

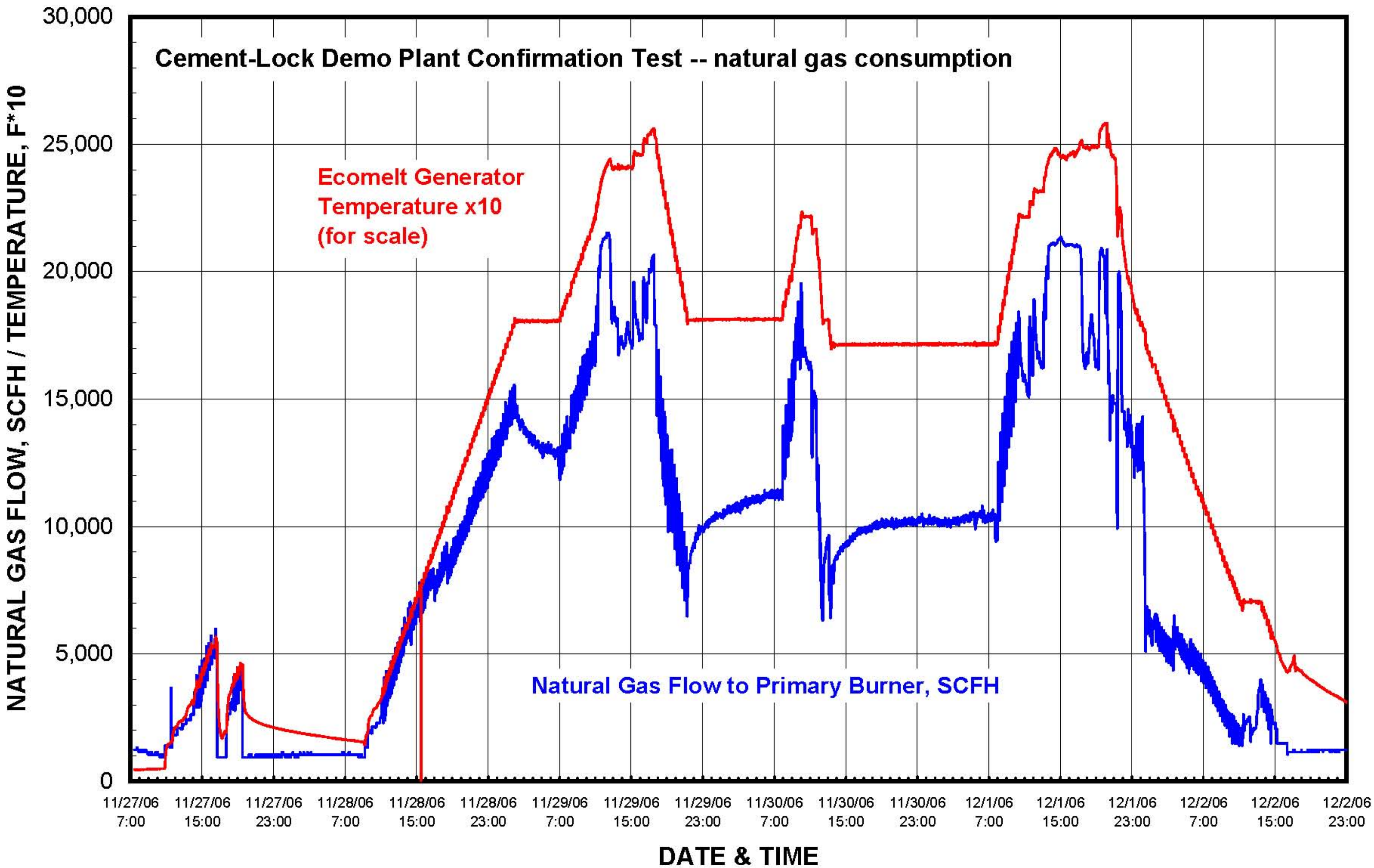



Figure 7. Natural Gas Consumption During the Confirmation Test (November 27 – December 2, 2006)

Table 4. Chronology of Sediment-Modifier Mixture Feeding Episodes During the Cement-Lock Confirmation Test (November 29 – December 1, 2006)

| **STRATUS PETROLEUM SEDIMENT** | | | | | | | | Cumulative | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Feeding Time | | Weights, lb | | | | Sed/mod Fed | | Daily |
| Batch No. | Date / Time | Start | End | Gross | Tare | Net | Tons | Total, lb | Tons | |
| 1 | 11/29/06 1:30 PM | 1:30 PM | 2:15 PM | -- | -- | 1,156 | 0.58 | 1,156 | 0.58 | |
| 2 | 11/29/06 2:15 PM | 2:15 PM | 3:00 PM | -- | -- | 958 | 0.48 | 2,114 | 1.06 | |
| 3 | 11/29/06 3:00 PM | 3:00 PM | 3:30 PM | -- | -- | 481 | 0.24 | 2,595 | 1.30 | 1.30 |
| | | 3:30 PM | V-Ram jammed, stopped feeding | | | | | | | |
| | | | | | | | | | | |
| 1 | 12/1/06 1:45 PM | 1:45 PM | 2:15 PM | 6 5-gal pails | | 240 | 0.12 | 2,835 | 1.42 | |
| 2 | 12/1/06 2:15 PM | 2:15 PM | 2:56 PM | 9,054 | 7,888 | 1,166 | 0.58 | 4,001 | 2.00 | |
| 3 | 12/1/06 3:15 PM | 3:15 PM | 3:40 PM | 8,672 | 7,932 | 740 | 0.37 | 4,741 | 2.37 | |
| 4 | 12/1/06 3:46 PM | | | 8,810 | 7,846 | 964 | 0.48 | 5,705 | 2.85 | |
| 5 | 12/1/06 4:17 PM | 4:17 PM | 4:45 PM | 8,816 | 7,814 | 1,002 | 0.50 | 6,707 | 3.35 | |
| 6 | 12/1/06 4:45 PM | 4:45 PM | 5:30 PM | 8,166 | 7,460 | 706 | 0.35 | 7,413 | 3.71 | |
| 7 | 12/1/06 5:30 PM | 5:30 PM | 5:41 PM | 8,690 | 7,810 | 880 | 0.44 | 8,293 | 4.15 | |
| 8 | 12/1/06 6:11 PM | 6:11 PM | 6:13 PM | 9,194 | 7,846 | 1,348 | 0.67 | 9,641 | 4.82 | |
| 9 | 12/1/06 6:25 PM | 6:25 PM | -- | 9,598 | 8,498 | 550 (½ load) | 0.28 | 10,191 | 5.10 | 3.80 |
| | | Feeding stopped in anticipation of large slag chunk dropping | | | | | | | | |
| | | 8:15 PM | granulator jammed – large slag chunk dropped | | | | | | | **5.10** |
| | | Total Stratus Petroleum Sediment-Modifier Mixture fed | | | | | | 5.10 tons | | |
| | | Average Sediment-Modifier Feed Rate | | | | | | 1,904.3 lb/hr (0.952 ton/hr) | | |
| | | Average Ecomelt Rate | | | | | | 1,241.6 lb/hr (0.621 ton/hr) | | |

Table 5. Summary of Nitrogen Oxide (NOx) Measurements Taken from the Vent Stack During the Confirmation Test

| Date and time | $O_2$ Content mol % | NO, ppm | $NO_2$, ppm | NOx ($NO+NO_2$) ppm |
|---|---|---|---|---|
| 11/29/06, 10:32 am | 7.48 | 118.6 | 0.0 | 118.6 |
| 11/29/06, 11:35 am | 4.65 | 91.3 | 0.2 | 91.5 |
| 11/29/06, 1:42 pm | 6.86 | 170.7 | 0.6 | 171.3 |
| 11/29/06, 3:11 pm | 6.92 | 154.8 | 0.2 | 155.1 |
| 11/29/06, 3:13 pm | 5.00 | 102.1 | 0.0 | 102.1 |
| 11/30/06, 9:35 am | 8.05 | 110.5 | 0.0 | 110.5 |
| 12/1/06, 2:44 pm | 2.37 | 35.5 | 0.0 | 35.5 |

NOx can be formed from nitrogen in sediment (nitrogen content of Passaic River sediment was about 0.05 wt % – Table 2), from nitrogen in the natural gas (<3 volume %), and from nitrogen in the air (20.9 mol %). NOx formation in combustion systems increases with increasing temperature due to oxidation of atmospheric nitrogen. Therefore, it would be beneficial to operate a Cement-Lock plant (either demo or commercial) at the lowest practical temperature to minimize NOx formation without jeopardizing technology performance.

The design of a commercial-scale (500,000 $yd^3$ of sediment per year capacity) Cement-Lock facility will include Selective Catalytic NOx Reduction (SCR) equipment to reduce the emission of NOx to the maximum practical extent as well as to comply with local permit requirements. Low-NOx burners will also be included in the design.

**Extended Duration Test Operations**

There were two separate Extended Duration Test campaigns: The first was conducted in December 2006; the second in May 2007. During both campaigns, the EPA SITE (Superfund Innovative Technology Evaluation) Program provided stack emission and environmental sampling and analysis of process streams.

The first Extended Duration Test was initiated on December 4, 2006. The Ecomelt Generator was heated to its nominal operating temperature of 2500°F at the prescribed rate of 100°F/hour. The Secondary Combustion Chamber (SCC) was also not fired during the test as the SCC exceeded the Air Quality Permit minimum temperature requirement of 2100°F.

Feeding the Passaic River sediment was initiated on December 6, 2006. In this campaign, modifiers were fed into the system via the modifier hoppers and feeders at the prescribed rate. During the overnight hours, feeding was halted and the system temperature was reduced to 1700° or 1800°F to conserve natural gas. The average rate of Passaic River sediment fed to the system was 1513.1 lb/hr. The average rate of modifiers fed to the system was about 400 lb/hr. A total of 16.5 tons of Passaic River sediment was processed through the Cement-Lock demo plant yielding about 13.4 tons of Ecomelt. This quantity of Passaic River sediment processed was equivalent to 25.65 $yd^3$ of *in situ* sediment. The test was concluded on December 9, 2006. Slag accumulating in the drop-out box caused an involuntary shutdown of the system. A photograph of the "devil's tongue" formed in the drop-out box is shown in Figure 8.

The operating conditions during the first Extended Duration Test are summarized in Table 6. The time-temperature histories of the Ecomelt Generator and SCC during the Extended Duration Test are presented in Figure 9. The natural gas flow to the system during the test is presented in Figure 10. A summary of the Passaic River sediment fed is presented in Table 7.

Table 6. Summary of Operating Conditions for Cement-Lock Demo Plant Extended Duration Test (December 4 – 9, 2006)

| **Test No.** | **8** |
|---|---|
| Test Dates | 12/4/06 – 12/9/06 |
| Ecomelt Generator (rotary kiln) | |
| Temperature, °F | 2300 – 2650 |
| Pressure, inches (water gauge) | -0.2 |
| Kiln Speed, rpm | 0.25 – 0.3 |
| Solids Residence Time, min. | 129 – 107 |
| Secondary Combustion Chamber | |
| SCC Burner | Low fire |
| Temperature, °F | 2245 – 2530 |
| Process Temperatures, °F | |
| Granulator | 195 |
| Quencher Outlet, average (min – max) | 325 (267 – 425) |
| Bag House Outlet, average (min – max) | 290 (240 – 318) |
| Activated Carbon Bed Outlet, average (min – max) | 270 (220 – 290) |
| Stack Gas, average (min – max) | 280 (245 – 316) |

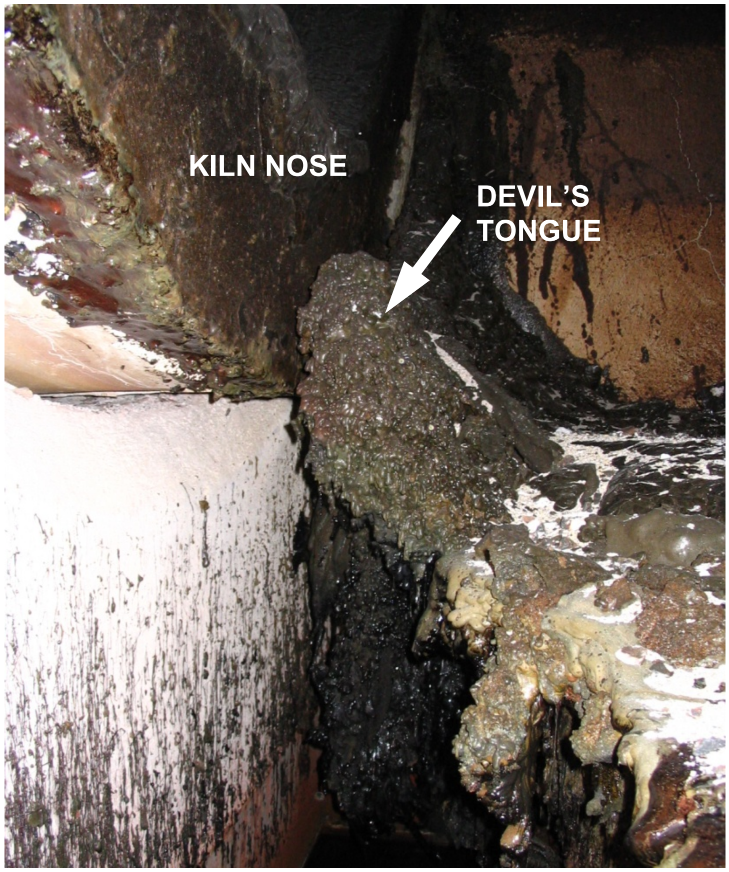



Figure 8. Devil's Tongue Extending from West Wall to Near the Kiln Nose

Significant milestones were achieved during the Cement-Lock demo plant campaigns in November and December 2006. The equipment modifications extended the slagging mode operating time. Sizable quantities of Ecomelt were generated from both Stratus Petroleum as well as Passaic River sediment. The feed system performed well. The conveyor belts effectively conveyed material from the sediment storage area to the pug mill on the charging deck. Slag accumulation in the drop-out box was slowed – but not stopped.

The second Extended Duration Test campaign was inaugurated on April 26, 2007 (Wednesday) when all RPMS operating staff remobilized to the demo plant site. Several days later, the Ecomelt Generator was heated to its nominal operating temperature of 2500°F at the prescribed rate of 100°F/hour. The Secondary Combustion Chamber (SCC) was not fired during the test as the SCC exceeded the Air Quality Permit minimum temperature requirement of 2100°F.

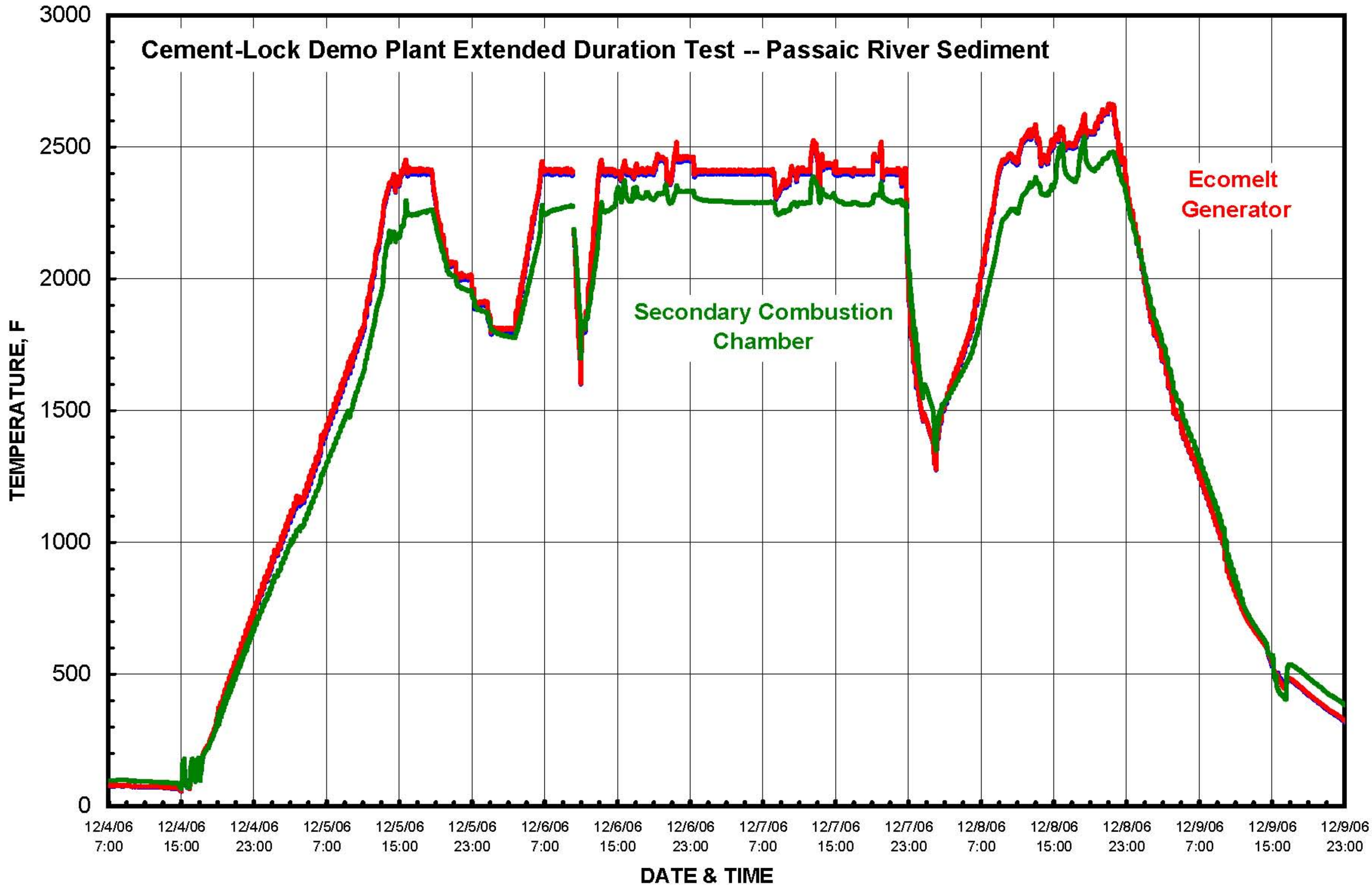



Figure 9. Time-Temperature History of the Extended Duration Test with Sediment Dredged from the Passaic River (December 4 – 9, 2006)

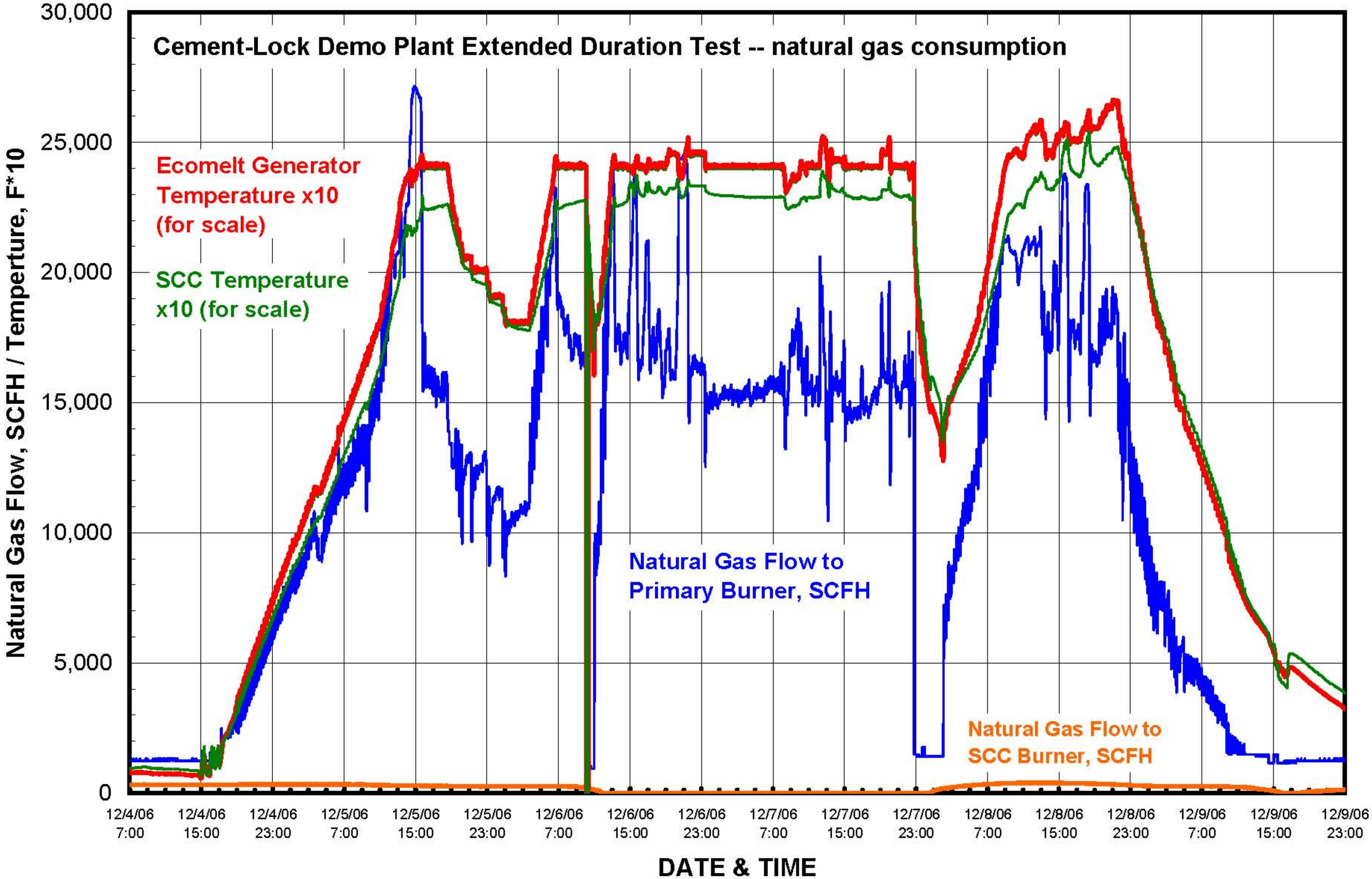



Figure 10. Natural Gas Consumption During the Extended Duration Test (December 4 – 9, 2006)

Table 7. Chronology of Sediment Feeding Episodes During the Cement-Lock Extended Duration Test (December 4 – 9, 2006)

| **PASSAIC RIVER SEDIMENT – MODIFIERS ADDED BY MOD HOPPER** | | | | | | | | | CUMULATIVE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feeding Time | | Weights, lb | | | | Sediment Fed | | DAILY |
| Batch No. | Day | Date | Start | End* | Gross | Tare | Net | lb/hr | pounds | tons | tons |
| 1 | Wednesday | 12/06/06 | 8:22 AM | 9:12 AM | 8,756 | 7,558 | 1,198 | 1,438 | 1,198 | 0.60 | |
| 2 | | 12/06/06 | 1:50 PM | 2:35 PM | 8,816 | 7,896 | 920 | 1,227 | 2,118 | 1.06 | |
| 3 | | 12/06/06 | 2:35 PM | 2:50 PM | 10,664 | 9,512 | 1,152 | 4,608 | 3,270 | 1.64 | |
| 4 | | 12/06/06 | 2:50 PM | 3:50 PM | 10,654 | 9,458 | 1,196 | 1,196 | 4,466 | 2.23 | |
| 5 | | 12/06/06 | 3:50 PM | 4:52 PM | 10,360 | 9,496 | 864 | 836 | 5,330 | 2.67 | |
| 6 | | 12/06/06 | 4:52 PM | 5:34 PM | 10,750 | 9,510 | 1,240 | 1,771 | 6,570 | 3.29 | |
| 7 | | 12/06/06 | 5:34 PM | 6:10 PM | 10,620 | 9,514 | 1,106 | 1,843 | 7,676 | 3.84 | |
| 8 | | 12/06/06 | 6:10 PM | 7:00 PM | 10,560 | 9,234 | 1,326 | 1,591 | 9,002 | 4.50 | |
| 9 | | 12/06/06 | 7:50 PM | 8:21 PM | 10,648 | 9,066 | 1,582 | 3,062 | 10,584 | 5.29 | |
| 10 | | 12/06/06 | 8:21 PM | 9:11 PM | 10,864 | 9,508 | 1,356 | 1,627 | 11,940 | 5.97 | 5.97 |
| 11 | Thursday | 12/07/06 | 7:40 AM | 8:35 AM | 10,514 | 9,472 | 1,042 | 1,137 | 12,982 | 6.49 | |
| 12 | | 12/07/06 | 8:35 AM | 9:19 AM | 10,686 | 9,550 | 1,136 | 1,549 | 14,118 | 7.06 | |
| 13 | | 12/07/06 | 9:19 AM | 10:06 AM | 10,548 | 9,574 | 974 | 1,243 | 15,092 | 7.55 | |
| 14 | | 12/07/06 | 10:06 AM | 10:42 AM | 10,844 | 9,560 | 1,284 | 2,140 | 16,376 | 8.19 | |
| 15 | | 12/07/06 | 10:42 AM | 11:25 AM | 10,454 | 9,536 | 918 | 1,281 | 17,294 | 8.65 | |
| 16 | | 12/07/06 | 11:25 AM | 12:03 PM | 10,480 | 9,562 | 918 | 1,449 | 18,212 | 9.11 | |
| 17 | | 12/07/06 | 12:03 PM | 12:53 PM | 10,688 | 9,536 | 1,152 | 1,382 | 19,364 | 9.68 | |
| 18 | | 12/07/06 | 1:13 PM | 2:03 PM | 10,682 | 9,532 | 1,150 | 1,380 | 20,514 | 10.26 | |
| 19 | | 12/07/06 | 2:21 PM | 3:12 PM | 10,730 | 9,490 | 1,240 | 1,459 | 21,754 | 10.88 | |
| 20 | | 12/07/06 | 4:22 PM | 5:11 PM | 10,512 | 9,482 | 1,030 | 1,261 | 22,784 | 11.39 | |
| 21 | | 12/07/06 | 5:11 PM | 6:01 PM | 10,370 | 9,488 | 882 | 1,058 | 23,666 | 11.83 | |
| 22 | | 12/07/06 | 6:30 PM | 7:07 PM | 10,544 | 9,506 | 1,038 | 1,683 | 24,704 | 12.35 | |
| 23 | | 12/07/06 | 7:07 PM | 7:57 PM | 10,712 | 9,403 | 1,309 | 1,571 | 26,013 | 13.01 | 7.04 |
| 24 | Friday | 12/08/06 | 2:03 PM | 2:55 PM | 10,642 | 9,490 | 1,152 | 1,329 | 27,165 | 13.58 | |
| 25 | | 12/08/06 | 2:55 PM | 3:45 PM | 10,844 | 9,522 | 1,322 | 1,586 | 28,487 | 14.24 | |
| 26 | | 12/08/06 | 4:05 PM | 4:55 PM | 10,732 | 9,228 | 1,504 | 1,805 | 29,991 | 15.00 | |
| 27 | | 12/08/06 | 5:20 PM | 6:08 PM | 10,714 | 9,608 | 1,106 | 1,383 | 31,097 | 15.55 | |
| 28 | | 12/08/06 | 6:08 PM | 6:58 PM | 10,870 | 9,410 | 1,460 | 1,752 | 32,557 | 16.28 | |
| 29 | | 12/08/06 | 7:03 PM | Late night – no modifiers | | | 444 | | 33,001 | 16.50 | 3.49 |
| | | | Average Sediment Feed Rate | | | 1,513.1 wet lb/hr | 0.757 wet ton/hr | | | 16.50 Total tons | |
| | | | Average Ecomelt Rate | | | 1,247.0 lb/hr | 0.624 ton/hr | | | | |

* End time data estimated from average feeding time and maximum feed interval. Modifiers were fed at a rate of about 400 lb/hour.

Feeding the Passaic River sediment was initiated on May 15, 2007. In this campaign, the mixture of Passaic River sediment and modifiers was fed into the system via the V-Ram feeder at the prescribed rate. During the overnight hours, feeding was halted and the system temperature was reduced to 1700° or 1800°F to conserve natural gas. The average rate of Passaic River sediment-modifier mixture fed to the system was 1929.1 lb/hr. A total of 15.1 tons of Passaic River sediment-modifier mixture was processed through the Cement-Lock demo plant yielding about 9.85 tons of Ecomelt. On a modifier-free basis, the quantity of Passaic River fed totaled 11.6 tons. This quantity of Passaic River sediment processed was equivalent to 18.36 $yd^3$ of *in situ* sediment. The test was concluded on December 9, 2006. During this test, different flame management techniques were employed to prevent slag accumulation in the drop-out box as well as "devil's tongues." At one point the Ecomelt Generator temperature was increased to a maximum of 2775°F in an attempt to clear slag from the discharge; however, slag accumulation in the drop-out box caused an involuntary shutdown of the system.

The accumulation of slag in the drop-out box continued to hinder operations during the Confirmation Test as well as the two Extended Duration tests even though flame management techniques were employed. The need for designing the drop-out box to reduce/eliminate slag accumulation is imperative for any further commercial applications of Cement-Lock technology. Any new plant design must be developed according to generally accepted criteria for slagging kiln construction and operation, including accommodations for fly slag accumulation and the anticipated formation of "devil's tongues."

Potential modifications to the slag discharging system include increasing clearance around the kiln discharge, increasing the width of the granulator and drag conveyor, improving access to dislodge accumulated slag, and installing the Secondary Combustion Chamber vertically, among other considerations.

For a commercial-scale installation, the front end system for metering, blending, and feeding sediment and modifiers must be made more robust. The system should be capable of handling, screening, scalping, etc. the sticky sediment prior to its being dried. The sediment and modifiers should be pre-mixed before being conveyed to the charging deck. Low-level waste heat from the flue gas quencher could be captured and utilized for drying the sediment prior to mixing.

Heavily contaminated sediment can be readily blended with lightly contaminated sediment to levelize treatment and reduce the potential effects of contaminant spikes on processing efficiency. Once the blended feed material reaches the charging deck, a V-Ram (or similar feeder) will be able to inject the material into the Ecomelt Generator as was done during the Cement-Lock demo plant testing.

The operating conditions during the second Extended Duration Test are summarized in Table 8. The time-temperature histories of the Ecomelt Generator and SCC during the Extended Duration Test are presented in Figure 11. The natural gas flow to the system during the test is presented in Figure 12. A summary of the Passaic River sediment-modifier mixture fed is presented in Table 9. Detailed chronological summaries of the two Extended Duration Tests are included in Appendix B.

Table 8. Summary of Operating Conditions for Cement-Lock Demo Plant Extended Duration Test (May 14 – 19, 2007)

| **Test No.** | **9** |
|---|---|
| Test Dates | 5/14/07 – 5/19/07 |
| Ecomelt Generator (rotary kiln) | |
| Temperature, °F | 2300 – 2775 |
| Pressure, inches (water gauge) | -0.2 |
| Kiln Speed, rpm | 0.25 – 0.3 |
| Solids Residence Time, min. | 129 – 107 |
| Secondary Combustion Chamber | |
| SCC Burner | Low fire |
| Temperature, °F | 2175 – 2700 |
| Process Temperatures, °F | |
| Granulator | 195 |
| Quencher Outlet, average (min – max) | 300 (230 – 380) |
| Bag House Outlet, average (min – max) | 275 (250 – 330) |
| Activated Carbon Bed Outlet, average (min – max) | 260 (220 – 290) |
| Stack Gas, average (min – max) | 275 (240 – 315) |

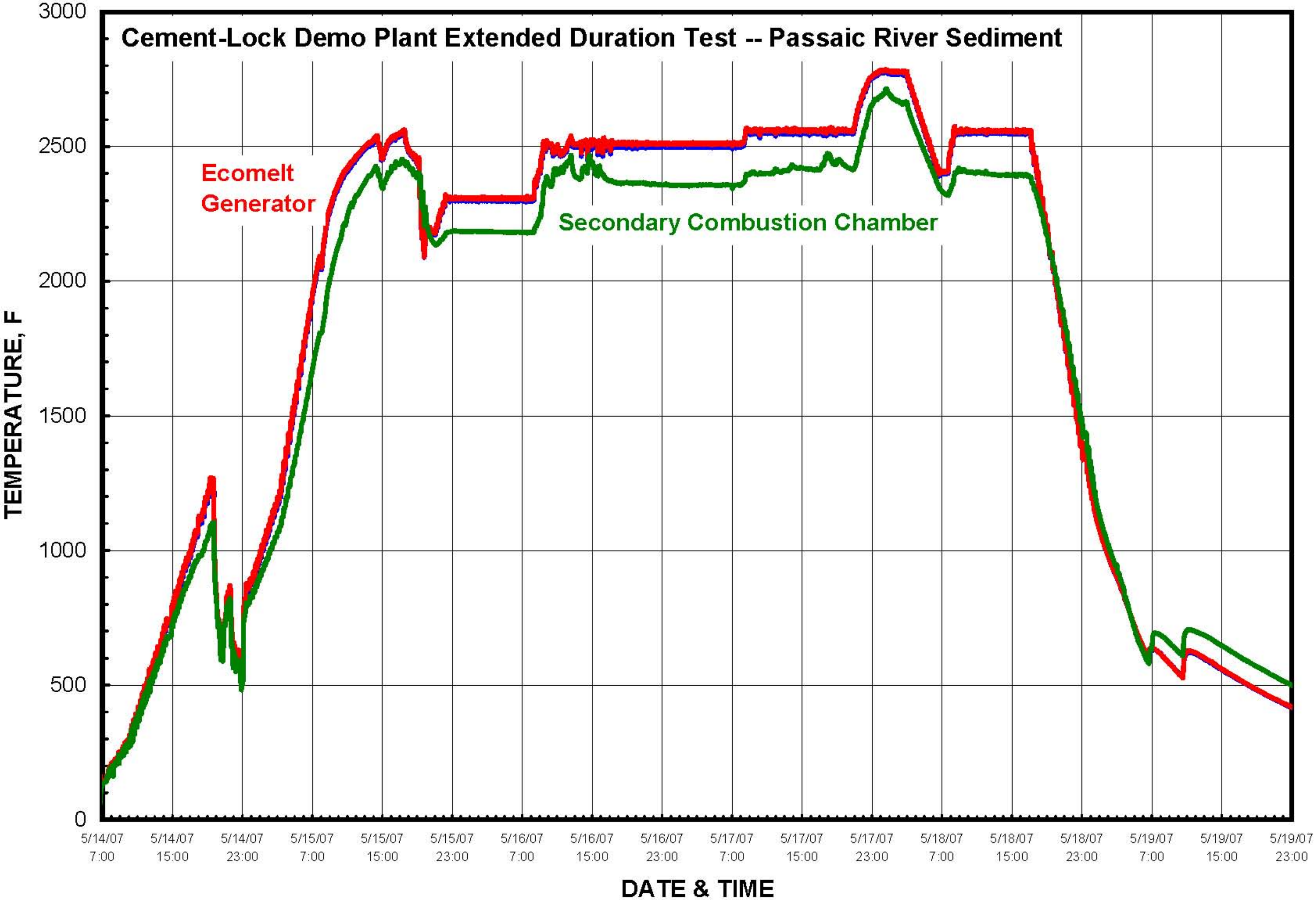



Figure 11. Time-Temperature History of the Extended Duration Test with Sediment Dredged from the Passaic River (sediment-modifier mixture, May 14 – 19, 2007)

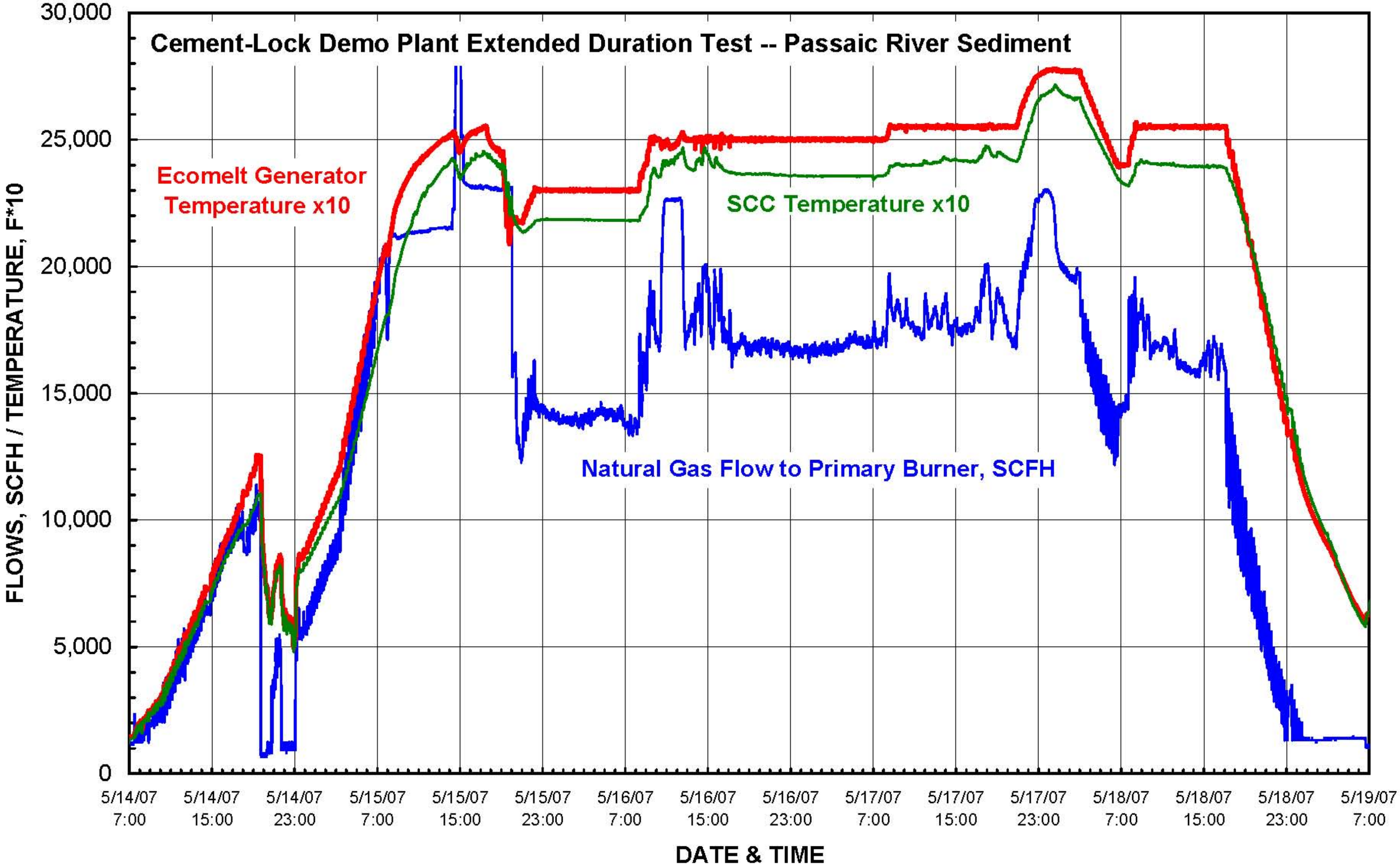



Figure 12. Natural Gas Consumption During the Extended Duration Test (December 4 – December 11, 2006)

Table 9. Chronology of Sediment-Modifier Mixture Feeding Episodes During Extended Duration Test (May 14 – 19, 2007)

| **PASSAIC RIVER SEDIMENT-MODIFIER MIXTURE** | | | | | | | | | CUMULATIVE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feeding Time | | Weights, lb | | | | Sediment-Modifier Fed | | DAILY |
| Batch No. | Day | Date | Start | End | Gross | Tare | Net | lb/hr | pounds | tons | tons |
| 1 | Tuesday | 5/15/07 | 5:22 PM | 5:55 PM | 10,052 | 9,006 | 1,046 | 1,902 | 1,046 | 0.52 | |
| 2 | | 5/15/07 | 5:58 PM | 6:16 PM | 9,888 | 9,020 | 868 | 2,893 | 1,914 | 0.96 | |
| 3 | | 5/15/07 | 6:20 PM | 6:28 PM | 9,604 | 9,064 | 540 | 4,050 | 2,454 | 1.23 | |
| 4 | | 5/15/07 | 6:32 PM | 6:50 PM | 10,098 | 9,046 | 1,052 | 3,507 | 3,506 | 1.75 | 1.75 |
| 5 | Wednesday | 5/16/07 | 9:55 AM | 10:44 AM | 10,416 | 9,176 | 1,240 | 1,518 | 4,746 | 2.37 | |
| 6 | | 5/16/07 | 10:48 AM | 11:38 AM | 10,486 | 9,194 | 1,292 | 1,550 | 6,038 | 3.02 | |
| 7 | | 5/16/07 | 11:42 AM | 1:15 PM | 10,264 | 9,176 | 1,088 | 1,518 | 7,126 | 3.56 | Stop 12:00 pm/start 12:50 pm |
| 8 | | 5/16/07 | 1:23 PM | 2:00 PM | 10,506 | 9,208 | 1,298 | 2,105 | 8,424 | 4.21 | |
| 9 | | 5/16/07 | 2:10 PM | 2:38 PM | 10,216 | 9,140 | 1,076 | 2,306 | 9,500 | 4.75 | |
| 10 | | 5/16/07 | 3:12 PM | 3:42 PM | 10,132 | 9,154 | 978 | 1,956 | 10,478 | 5.24 | |
| 11 | | 5/16/07 | 3:52 PM | 4:08 PM | 10,350 | 9,136 | 1,214 | 4,553 | 11,692 | 5.85 | 4.09 |
| 12 | Thursday | 5/17/07 | 7:59 AM | 8:39 AM | 9,046 | 7,676 | 1,370 | 2,055 | 13,062 | 6.53 | |
| 13 | | 5/17/07 | 8:44 AM | 9:16 AM | 9,866 | 8,130 | 1,736 | 3,255 | 14,798 | 7.40 | 9:16 Conveyor shut off |
| 14 | | 5/17/07 | 3:25 PM | 4:05 PM | 8,552 | 7,908 | 644 | 966 | 15,442 | 7.72 | |
| 15 | | 5/17/07 | 4:15 PM | 4:45 PM | 8,776 | 7,382 | 1,394 | 2,788 | 16,836 | 8.42 | |
| 16 | | 5/17/07 | 5:00 PM | 5:30 PM | 8,976 | 7,796 | 1,180 | 2,360 | 18,016 | 9.01 | |
| 17 | | 5/17/07 | 5:40 PM | 6:05 PM | 8,990 | 7,910 | 1,080 | 2,592 | 19,096 | 9.55 | |
| 18 | | 5/17/07 | 6:20 PM | 6:52 PM | 9,194 | 7,898 | 1,296 | 2,430 | 20,392 | 10.20 | 4.35 |
| 19 | Friday | 5/18/07 | 7:35 AM | 8:10 AM | 8,446 | 7,996 | 450 | 771 | 20,842 | 10.42 | |
| 20 | | 5/18/07 | 8:20 AM | 8:55 AM | 9,426 | 7,848 | 1,578 | 2,705 | 22,420 | 11.21 | |
| 21 | | 5/18/07 | 9:10 AM | 9:40 AM | 9,002 | 7,936 | 1,066 | 2,132 | 23,486 | 11.74 | |
| 22 | | 5/18/07 | 9:57 AM | 10:35 AM | 8,642 | 7,956 | 686 | 1,083 | 24,172 | 12.09 | |
| 23 | | 5/18/07 | 10:43 AM | 11:25 AM | 8,832 | 7,362 | 1,470 | 2,100 | 25,642 | 12.82 | |
| 24 | | 5/18/07 | 11:30 AM | 12:00 PM | 8,660 | 7,880 | 780 | 1,560 | 26,422 | 13.21 | |
| 25 | | 5/18/07 | 1:30 PM | 2:40 PM | 8,686 | 7,760 | 926 | 794 | 27,348 | 13.67 | |
| 26 | | 5/18/07 | 2:53 PM | 3:23 PM | 8,574 | 7,640 | 934 | 1,868 | 28,282 | 14.14 | |
| 27 | | 5/18/07 | 3:30 PM | 4:00 PM | 8,820 | 7,940 | 880 | 1,760 | 29,162 | 14.58 | |
| 28 | | 5/18/07 | 4:10 PM | 4:50 PM | 8,868 | 7,840 | 1,028 | 1,542 | 30,190 | 15.10 | 4.90 |
| | | | Average Sediment Feed Rate | | 1,929.1 lb/hr | | 0.757 ton/hr | | | | Total tons |
| | | | Average Ecomelt Rate | | 1,258.3 lb/hr | | 0.629 ton/hr | | | | 15.10 |

# III. DISCUSSION OF DEMO PROJECT RESULTS

This section discusses the results of chemical analyses conducted on environmental samples taken during the Cement-Lock demonstration project with sediment dredged from the Harrison Reach of the Passaic River, New Jersey. As mentioned above, the demonstration project was conducted in two separate campaigns – the first in December 2006, the second in May 2007.

The EPA SITE Program and subcontractor personnel took samples for environmental and process characterization during both campaigns. AirNova, Inc. (Pennsauken, NJ) took samples to characterize air emissions from the demo plant during both campaigns. AirNova was under subcontract to Tetra Tech EMI (EPA SITE subcontractor) during the December 2006 campaign; AirNova was under subcontract to GTI during the May 2007 campaign. Based on the air emission testing results, AirNova prepared Emission Evaluation Test Reports, which are included in Appendices E (December 2006) and F (May 2007).

Tetra Tech EMI performed the data validations for the environmental and air emission samples for the EPA SITE and GTI contracted work.

The environmental sampling and analytical results are discussed in the following sections: Feed Sediment, Process Samples, Ecomelt Product, Characterization of Demo Plant Air Emissions, and Characterization of Granulator Vapor Emissions.

**Feed Sediment, Process Samples, Ecomelt Product**

Samples of Passaic River sediment feed and Ecomelt product as well as other process samples were collected by Tetra Tech personnel during the December 2006 and May 2007 campaigns. Analyses of these samples were conducted by Accutest Laboratories (Dayton, NJ), SGS Environmental Services (Wilmington, NC), and Element One (Wilmington, NC). A summary of the chemical analyses conducted on the Passaic River sediment and Ecomelt product samples including a calculation of sediment treatment efficiency (TE) is presented in Table 10. The samples of feed sediment were taken as material was loaded onto the belt conveyor at the sediment storage area. The samples of Ecomelt were taken at the discharge from the granulator. In the event that the analytical result was "Non Detect" the TE was calculated based on the ½ the analytical method detection limit. The detailed chemical analyses of the Passaic River feed and Ecomelt product samples for PCBs, dioxins and furans, selected pesticides, metals, and selected SVOCs for both campaigns are included in Appendix G. The grab sample of sediment analyzed in Table 2 was taken from the pile of Passaic River sediment after delivery to the site. A comparison of the tables shows the variability of the contaminants in the sediment.

Table 10. Contaminants of Concern in Feed Passaic River Sediment and Product Ecomelt from Cement-Lock Demo Plant Campaigns

| Analyte | Campaign | Input Sediment | Product Ecomelt | Treatment Efficiency (TE), % |
|---|---|---|---|---|
| | | pg/g | | |
| PCBs, Congener Total | Dec 2006 | 3,297,502 | 263.5 | 99.991 |
| | May 2007 | 2,217,913 | 229.3 | 99.992 |
| | | | | |
| 2,3,7,8-TCDD | Dec 2006 | 968.7 | <0.54 | >99.969 |
| | May 2007 | 549.5 | <1.0 | >99.926 |
| Total D/Fs | Dec 2006 | 22,686.0 | 9.46 | 99.953 |
| | May 2007 | 18,749.2 | 26.0 | 99.887 |
| | | | | |
| TEQ (D/F+PCB) | Dec 2006 | 1,163.1 | 1.43 | 99.855 |
| | May 2007 | 697.2 | 5.70 | 99.331 |
| | | µg/kg | | |
| Benzo[a]pyrene | Dec 2006 | 845.2 | <0.53 | >99.965 |
| | May 2007 | 2,015.0 | <1.03 | >99.971 |
| | | | | |
| Naphthalene | Dec 2006 | 49.3 | <0.42 | >99.514 |
| | May 2007 | 276.5 | <1.28 | >99.735 |
| | | | | |
| Bis(2-Ethylhexyl) phthalate | Dec 2006 | 18,683.3 | <23.0 | >99.930 |
| | May 2007 | 35,500.0 | 6.08 | 99.980 |
| | | | | |
| | | mg/kg | | |
| Mercury (Hg) | Dec 2006 | 5.23 | <0.033 | >99.64 |
| | May 2007 | 4.35 | 0.014 | 99.73 |
| | | | | |
| Lead (Pb) | Dec 2006 | 382.7 | 25.0 | 92.57 |
| | May 2007 | 352.0 | 17.3 | 96.00 |

The analyses of the Passaic River sediment samples show an average of about 3,297,502 and 2,217,913 pg/g of total PCBs for the December 2006 and May 2006 tests, respectively. The dioxin and furan (D/F) concentration of the Passaic River sediment samples averaged 22,686 and 18,749 pg/g, respectively.

The Ecomelt product samples from the December 2006 and May 2007 campaigns showed an average of 246 pg/g of PCBs, <0.385 pg/g of 2,3,7,8-tetrachloro dibenzo dioxin (TCDD), and 17.73 pg/g of D/Fs. The total Toxicity Equivalent (TEQ) of PCBs plus D/F was 3.60 pg/g. Taken together with the sediment feed analysis yields a treatment efficiency (TE) of 99.991

percent for PCBs, 99.947 percent for 2,3,7,8-TCDD, and 99.920 percent for D/Fs. On a total TEQ basis, the TE is 99.593 percent.

Samples from the December 2006 and May 2007 tests show various levels of SVOCs. The TE of benzoic[a]pyrene averaged 99.968 percent; that for naphthalene averaged 99.624 percent. The concentration of bis(2-ethylhexyl) phthalate (BEHP) averaged 18,683 and 35,500 µg/kg, respectively, in samples from the December 2006 and May 2007 tests. The average TE for BEHP was 99.955 percent.

The December 2006 and May 2007 sediment feed samples contained an average of 5.23 and 4.35 mg/kg mercury, respectively. The lead concentration of the feed samples averaged 382.7 and 352.0 mg/kg, respectively for the December 2006 and May 2007 tests. The TE for mercury averaged 99.685 percent for the two tests. The TE for lead was 92.57 percent for the December 2006 test and 96.00 percent for the May 2007 test.

Leaching tests [Toxicity Characteristic Leaching Procedure (TCLP, EPA Method 1311) and Synthetic Precipitation Leaching Procedure (SPLP, EPA Method 1312)] were conducted on samples of Ecomelt product from the December 2006 campaign. The TCLP is applied when a waste generator needs to determine if a material qualifies for disposal in an ordinary landfill or a hazardous waste landfill. The SPLP is applied when a waste generator needs to determine if a material qualifies for a beneficial use, such as geotechnical fill. The results of the TCLP and SPLP leaching tests are presented in Table 11 (Ecomelt samples are labeled “Ecom”).

The results show that none of the Ecomelt samples leached any of the priority metals above the TCLP regulatory limits. The SPLP results show most analyses were below detection limits for priority metals. However, one sample exceeded the NJ Ground Water Quality Criteria limit for Mn and three exceeded the limit for Pb.

### Characterization of Cement-Lock Demo Plant Air Emissions

**Extended Duration Test – December 2006:** As specified by the project Quality Assurance Project Plan, AirNova took samples of the flue gas in the duct upstream of the Activated Carbon bed adsorber and downstream in the stack. The flue gas in the stack was analyzed for $SO_2$, NOx, CO, and VOCs. The results of these analyses are presented in Table 12.

Table 11. Results of Leaching Tests Conducted on Samples of Ecomelt from Passaic River Sediment

| **Compound** | Ecom-01 | | Ecom-02 | | Ecom-03 | | Ecom-04 | | Ecom-05 | | Ecom-06 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SPLP Metals** | SPLP Leachate, mg/L | | | | | | | | | | | | | |
| Arsenic | 0.008 | U | - | | 0.008 | U | - | | - | | 0.008 | U | 0.00800 | U |
| Barium | 1 | U | - | | 1 | U | - | | - | | 1 | U | 1.00000 | U |
| Cadmium | 0.004 | U | - | | 0.004 | U | - | | - | | 0.004 | U | 0.00400 | U |
| Chromium | 0.01 | U | - | | 0.01 | U | - | | - | | 0.01 | U | 0.01000 | U |
| Cobalt | 0.05 | U | - | | 0.05 | U | - | | - | | 0.05 | U | 0.05000 | U |
| Copper | 0.025 | U | - | | 0.025 | U | - | | - | | 0.025 | U | 0.02500 | U |
| Lead | 0.01 | U | - | | 0.017 | | - | | - | | 0.032 | | 0.01967 | |
| Manganese | 0.084 | | - | | 0.021 | | - | | - | | 0.023 | | 0.04267 | |
| Mercury | 0.0002 | U | - | | 0.00029 | | - | | - | | 0.0002 | U | 0.00023 | |
| Nickel | 0.043 | | - | | 0.04 | U | - | | - | | 0.04 | U | 0.04100 | |
| Selenium | 0.05 | U | - | | 0.05 | U | - | | - | | 0.05 | U | 0.05000 | U |
| Silver | 0.01 | U | - | | 0.01 | U | - | | - | | 0.01 | U | 0.01000 | U |
| Zinc | 0.13 | | - | | 0.1 | U | - | | - | | 0.12 | | 0.11667 | |
| | | | | | | | | | | | | | | |
| **SPLP Pesticides** | SPLP Leachate, mg/L | | | | | | | | | | | | | |
| 4,4’-DDD | 0.000017 | U | - | | 0.000017 | U | - | | - | | 0.000017 | U | 0.00002 | U |
| 4,4’-DDE | 0.0000041 | U | - | | 0.0000041 | U | - | | - | | 0.0000041 | U | 0.00000 | U |
| 4,4’-DDT | 0.000018 | U | - | | 0.000018 | U | - | | - | | 0.000018 | U | 0.00002 | U |
| Dieldrin | 0.000013 | U | - | | 0.000013 | U | - | | - | | 0.000013 | U | 0.00001 | U |
| | | | | | | | | | | | | | | |
| **SPLP SVOCs** | SPLP Leachate, mg/L | | | | | | | | | | | | | |
| Benzo[a]anthracene | 0.000019 | U | - | | 0.000019 | U | - | | - | | 0.000019 | U | 0.00002 | U |
| Benzo[a]pyrene | 0.0000039 | U | - | | 0.0000039 | U | - | | - | | 0.0000039 | U | 0.00000 | U |
| Benzo[b]fluoranthene | 0.000017 | U | - | | 0.000017 | U | - | | - | | 0.000017 | U | 0.00002 | U |
| Benzo[k]fluoranthene | 0.000021 | U | - | | 0.000021 | U | - | | - | | 0.000021 | U | 0.00002 | U |
| Bis(2-ethylhexyl) phthalate | 0.00013 | U | - | | 0.00013 | U | - | | - | | 0.00013 | U | 0.00013 | U |
| Chrysene | 0.0000093 | U | - | | 0.0000093 | U | - | | - | | 0.0000093 | U | 0.00001 | U |
| Indeno[1,2,3-cd]pyrene | 0.0000085 | U | - | | 0.0000085 | U | - | | - | | 0.0000085 | U | 0.00001 | U |
| | | | | | | | | | | | | | | |
| **TCLP Metals** | TCLP Leachate, mg/L | | | | | | | | | | | | | |
| Arsenic | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U |
| Barium | 1 | U | 1 | U | 1 | U | 1 | U | 1 | | 1 | U | 1.0 | |
| Cadmium | 0.0092 | | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.005 | U | 0.0 | |
| Chromium | 0.01 | | 0.01 | U | 0.01 | U | 0.01 | U | 0.014 | | 0.011 | | 0.0 | |
| Cobalt | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | 0.1 | U |
| Copper | 0.15 | | 0.025 | U | 0.025 | | 0.025 | U | 0.034 | | 0.026 | | 0.0 | |
| Lead | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U |

| Compound | Ecom-01 | | Ecom-02 | | Ecom-03 | | Ecom-04 | | Ecom-05 | | Ecom-06 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manganese | 0.21 | | 0.071 | | 0.037 | | 0.032 | | 0.037 | | 0.034 | | 0.1 | |
| Mercury | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0 | U |
| Nickel | 0.12 | | 0.04 | | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.1 | |
| Selenium | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U | 0.5 | U |
| Silver | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.0 | U |
| Zinc | 0.7 | | 0.31 | | 0.16 | | 0.13 | | 0.22 | | 0.17 | | 0.3 | |
| | | | | | | | | | | | | | | |
| **TCLP Pesticides** | TCLP Leachate, mg/L | | | | | | | | | | | | | |
| 4,4'-DDD | 0.00017 | U | 0.00017 | U | 0.000017 | UJ | 0.00017 | U | 0.00017 | U | 0.00017 | U | 0.000145 | U |
| 4,4'-DDE | 0.000041 | U | 0.000041 | U | 0.000041 | U | 0.000041 | U | 0.000041 | U | 0.000041 | U | 0.000041 | U |
| 4,4'-DDT | 0.00018 | U | 0.00018 | U | 0.00018 | U | 0.00018 | U | 0.00018 | U | 0.00018 | U | 0.000180 | U |
| Dieldrin | 0.000013 | U | 0.00013 | U | 0.00013 | U | 0.00013 | U | 0.00013 | U | 0.00013 | U | 0.000111 | U |
| | | | | | | | | | | | | | | |
| **TCLP SVOCs** | TCLP Leachate, mg/L | | | | | | | | | | | | | |
| Acenaphthene | 0.000054 | U | 0.000054 | U | 0.000054 | U | 0.000054 | U | 0.000054 | U | 0.000054 | U | 0.0000540 | U |
| Acenaphthylene | 0.000021 | U | 0.000021 | U | 0.000021 | U | 0.000021 | U | 0.000021 | U | 0.000021 | U | 0.0000210 | U |
| Anthracene | 0.000029 | U | 0.000029 | U | 0.000029 | U | 0.000029 | U | 0.000029 | U | 0.000029 | U | 0.0000290 | U |
| Benzo[a]anthracene | 0.00019 | U | 0.00019 | U | 0.00019 | U | 0.00019 | U | 0.00019 | U | 0.00019 | U | 0.0001900 | U |
| Benzo[a]pyrene | 0.000039 | U | 0.000039 | U | 0.000039 | U | 0.000039 | U | 0.000039 | U | 0.000039 | U | 0.0000390 | U |
| Benzo[b]fluoranthene | 0.00017 | U | 0.00017 | U | 0.00017 | U | 0.00017 | U | 0.00017 | U | 0.00017 | U | 0.0001700 | U |
| Benzo[g,h,i]perylene | 0.000088 | U | 0.000088 | U | 0.000088 | U | 0.000088 | U | 0.000088 | U | 0.000088 | U | 0.0000880 | U |
| Benzo[k]fluoranthene | 0.00021 | U | 0.00021 | U | 0.00021 | U | 0.00021 | U | 0.00021 | U | 0.00021 | U | 0.0002100 | U |
| Bis(2-ethylhexyl) phthalate | 0.0013 | U | 0.0013 | U | 0.0013 | U | 0.0013 | U | 0.0013 | U | 0.0013 | U | 0.0013000 | U |
| Chrysene | 0.000093 | U | 0.000093 | U | 0.000093 | U | 0.000093 | U | 0.000093 | U | 0.000093 | U | 0.0000930 | U |
| Dibenzo[a,h]anthracene | 0.00012 | U | 0.00012 | U | 0.00012 | U | 0.00012 | U | 0.00012 | U | 0.00012 | U | 0.0001200 | U |
| Di-n-octyl phthalate | 0.002 | U | 0.002 | U | 0.002 | U | 0.002 | U | 0.002 | U | 0.002 | U | 0.0020000 | U |
| Fluoranthene | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002 | U | 0.0002000 | U |
| Fluorene | 0.000077 | U | 0.000077 | U | 0.000077 | U | 0.000077 | U | 0.000077 | U | 0.000077 | U | 0.0000770 | U |
| Indeno[1,2,3-cd]pyrene | 0.000085 | U | 0.000085 | U | 0.000085 | U | 0.000085 | U | 0.000085 | U | 0.000085 | U | 0.0000850 | U |
| Naphthalene | 0.000082 | U | 0.000082 | U | 0.000082 | U | 0.000082 | U | 0.000082 | U | 0.000082 | U | 0.0000820 | U |
| Phenanthrene | 0.000099 | U | 0.000099 | U | 0.000099 | U | 0.000099 | U | 0.000099 | U | 0.000099 | U | 0.0000990 | U |
| Pyrene | 0.00011 | U | 0.00011 | U | 0.00011 | U | 0.00011 | U | 0.00011 | U | 0.00011 | U | 0.0001100 | U |

"Ecom" refers to "Ecomelt" sample.

U – Analyte was not detected. The associated value is the estimated detection limit.

J – The analyte is present, but the concentration is below the quantitation limit. The concentration is estimated.

UJ – The detection limit is estimated.

C – The isomer co-eluted with another of its homologue group. If followed by a number, the number indicates the lowest numbered congener among the co-elution set.

"-" The sample was not analyzed for that analyte.

Table 12. Cement Lock Demonstration Plant – Activated Carbon Bed Outlet: $SO_2$, NOx, CO, and VOCs Test Results

| Run No. | 1 | 2 | 3 | Average |
|---|---|---|---|---|
| Date | 12/06/06 | 12/06/06 | 12/07/06 | |
| Time Period | 1625-1725 | 1812- | 0934-1034 | |
| **Exhaust Gas Characteristics** | | | | |
| Oxygen, % (dry) | 3.99 | 5.13 | 6.19 | 5.10 |
| Carbon Dioxide, % (dry) | 9.83 | 10.47 | 9.41 | 9.90 |
| Temperature, °F | 287 | 286 | 304 | 292 |
| Moisture, % | 51.1 | 54.4 | 53.1 | 52.9 |
| Velocity, ft/s | 36.4 | 36.4 | 35.9 | 36.2 |
| Flow Rate, ACFM | 14,983 | 15,002 | 14,795 | 14,927 |
| Flow Rate, DSCFM | 5,230 | 4,898 | 4,830 | 4,986 |
| **Carbon Monoxide*** | | | | |
| Concentration, ppmvd | >100 | 17.3 | 4.2 | >40.5 |
| Concentration, ppmvd @ 7% $O_2$ | >82.2 | 15.2 | 4.0 | >33.8 |
| Emission Rate, lb/hr | >2.27 | 0.37 | 0.09 | >0.91 |
| **Volatile Organic Compounds** | | | | |
| Concentration, ppmvd | 4.7 | 4.6 | 0.9 | 3.4 |
| Concentration, ppmvd @ 7% $O_2$ | 3.9 | 4.1 | 0.8 | 2.9 |
| Emission Rate, lb/hr | 0.06 | 0.06 | 0.01 | 0.04 |
| **Nitrogen Oxides (as $NO_2$)** | | | | |
| Concentration, ppmvd | 94.0 | 134 | 149 | 126 |
| Concentration, ppmvd @ 7% $O_2$ | 77.3 | 118 | 141 | 112 |
| Emission Rate, lb/hr | 3.51 | 4.69 | 5.13 | 4.44 |
| **Sulfur Dioxide** | | | | |
| Concentration, ppmvd | 42.2 | 16.5 | 8.8 | 22.5 |
| Concentration, ppmvd @ 7% $O_2$ | 34.7 | 14.5 | 8.3 | 19.2 |
| Emission Rate, lb/hr | 2.19 | 0.80 | 0.42 | 1.14 |

Standard Conditions: 70°F, 29.92 inches Hg
* CO emissions during Run No. 1 were out of the calibration range of the analyzer which was operated in the 0-100 ppmv range. Therefore, CO emissions could not be quantified for this test run, and were reported as greater than the detectable quantity of 100 ppmv.

The results show that the level of CO in the flue gas during the first test exceeded the calibration limit of the analyzer. This indicates that the demo plant system was being operated at a less than optimum condition regarding excess air. The oxygen concentration in the first test was 3.99 percent, which represents about 20 percent excess air for stoichiometric combustion of natural gas. This level of excess air was expected to provide sufficient oxygen to keep the CO levels low as achieved during the second and third tests. It is apparent from the results that the oxygen concentration in the flue gas should be maintained at about 5 percent for these process conditions to reduce CO emissions.

The concentration of volatile organic compounds (VOCs) in the three tests was quite low, quite consistent, and averaged 0.04 lb/hour. The emission of NOx in the flue gas averaged 4.44 lb/hour. This was higher than the 1.53 lb/hour measured during the non-slagging test conducted in March 2005. The December 2006 test was operated at a higher temperature (2400° compared with 1835°F) than the non-slagging test and additional NOx formation was expected.

NOx reduction equipment will be incorporated into any commercial-scale Cement-Lock sediment processing plant to maintain NOx emissions within local regulatory limits.

The emission of $SO_2$ averaged 1.14 lb/hour during the three tests. There was considerable variation in the three samples. The concentration in the first test was 42.2 ppm compared with 16.5 and 8.8 ppm during the second and third tests, respectively. The sulfur capture efficiency of the lime injected into the duct upstream of the bag house appears to have increased somewhat as plant operation progressed. The emission limit was within the range allowed by the EIPT permit.

The results of tests to measure hydrogen chloride and chlorine are presented in Table 13. $Cl_2$ was not detectable in either run. The HCl emission rate averaged 1.52 lb/hour for the two tests. The results are within the permitted emission limits for HCl per the EIPT permit.

Table 13. Cement Lock Demonstration Plant – Activated Carbon Bed Outlet (Stack), HCl and $Cl_2$ Test Results

| Run No. | 1 | 2 | Average |
|---|---|---|---|
| Date | 12/06/06 | 12/07/06 | |
| Time Period | 1700-1832 | 0959-1110 | |
| **Exhaust Gas Characteristics** | | | |
| Oxygen, % (dry) | 5.1 | 6.3 | 5.7 |
| Carbon Dioxide, % (dry) | 10.5 | 9.2 | 9.9 |
| Temperature, °F | 286 | 307 | 297 |
| Moisture, % | 54.3 | 52.6 | 53.5 |
| Velocity, ft/s | 36.4 | 35.8 | 36.1 |
| Flow Rate, ACFM | 15,001 | 14,761 | 14,881 |
| Flow Rate, DSCFM | 4,901 | 4,843 | 4,872 |
| **Hydrogen Chloride** | | | |
| Concentration, ppmv | 59.3 | 51.2 | 55.3 |
| Emission Rate, lb/hr | 1.64 | 1.40 | 1.52 |

Standard Conditions: 70°F, 29.92 inches Hg
Detailed analysis of $Cl_2$ quantities can be found in Appendix E (2006 AirNova test report).

**Extended Duration Test – May 2007:** AirNova conducted air emission sampling at the plant on May 16, 17, and 18, 2007. The results of continuous emission monitoring of flue gases for CO, VOCs, and NOx are presented in Table 14.

Table 14. Cement-Lock Demonstration Plant – Activated Carbon Bed Outlet: NOx, CO, and VOCs Test Results

| Run No. | 1 | 2 | 3 | 4 | Average |
|---|---|---|---|---|---|
| Date | 05/16/07 | 05/17/07 | 05/17/07 | 05/18/07 | |
| Time Period | 1155-1600 | 0835-1307 | 1545-1915 | 0827-1149 | |
| **Exhaust Gas Characteristics** | | | | | |
| Oxygen, % (dry) | 4.61 | 5.18 | 5.04 | 6.07 | 5.23 |
| Carbon Dioxide, % (dry) | 9.79 | 9.41 | 9.49 | 8.71 | 9.35 |
| Temperature, °F | 277 | 278 | 288 | 265 | 277 |
| Moisture, % | 53.6 | 54.1 | 54.4 | 53.2 | 53.8 |
| Velocity, ft/s | 35.1 | 34.9 | 36.0 | 34.0 | 35.0 |
| Flow Rate, ACFM | 14,872 | 14,818 | 15,257 | 14,409 | 14,839 |
| Flow Rate, DSCFM | 4,960 | 4,911 | 4,963 | 4,994 | 4,957 |
| **Carbon Monoxide*** | | | | | |
| Concentration, ppmvd | >41.5 | 5.4 | 10.1 | 2.8 | >15.0 |
| Concentration, ppmvd @ 7% $O_2$ | >35.4 | 4.8 | 8.9 | 2.6 | >12.9 |
| Emission Rate, lb/hr | >0.89 | 0.12 | 0.22 | 0.06 | >0.32 |
| **Volatile Organic Compounds** | | | | | |
| Concentration, ppmvd | 20.5 | 7.0 | 17.1 | 4.7 | 12.3 |
| Concentration, ppmvd @ 7% $O_2$ | 17.5 | 6.2 | 15.0 | 4.4 | 10.8 |
| Emission Rate, lb/hr | 0.25 | 0.09 | 0.21 | 0.06 | 0.15 |
| **Nitrogen Oxides (as $NO_2$)** | | | | | |
| Concentration, ppmvd | 112 | 225 | 181 | 195 | 178 |
| Concentration, ppmvd @ 7% $O_2$ | 95.4 | 199 | 159 | 183 | 159 |
| Emission Rate, lb/hr | 3.96 | 7.89 | 6.41 | 6.95 | 6.30 |

Standard Conditions: 70°F, 29.92 inches Hg

* CO emissions during Run No. 1 were out of the calibration range of the analyzer which was operated in the 0-200 ppmv range. Therefore, CO emissions could not be totally quantified for this test run, and were reported as greater than the average quantified CO concentration.

The results show that the level of CO in the flue gas during the first test exceeded the calibration limit of the analyzer. This indicates that the demo plant system was being operated at a less than optimum condition regarding excess air. The oxygen concentration in the first test was 4.61

percent, which represents about 25 percent excess air for stoichiometric combustion of natural gas. This level of excess air was expected to provide sufficient oxygen to keep the CO levels low as achieved during the second and third tests. As mentioned above, the oxygen concentration in the flue gas should be maintained at about 5 percent for these process conditions to reduce CO emissions.

The concentration of volatile organic compounds (VOCs) in the four tests ranged from 0.06 to 0.25 lb/hour and averaged 0.15 lb/hour. The NOx emission rate averaged 6.30 lb/hour.

The results of flue gas analyses upstream and downstream of the Activated Carbon bed for SOx are presented in Table 15. The reduction in SOx emissions achieved through the Activated Carbon Bed is presented in Table 16. The results show that the SOx emission decreased by 98.8 and 90.9 percent, respectively, during the two tests (average of 94.9 percent). This was unexpected in that the principal method for acid gas (SOx and HCl) capture is by reacting with lime (CaO) injected into the flue gas duct upstream of the bag house. The resulting spent lime (with CaSOx and $CaCl_2$) is to be captured and removed from the flue gas stream by the bag house filters. That a considerable amount of SOx capture was achieved across the Activate Carbon bed indicates that some of the lime may have passed through the filter bags in the bag house and was deposited on the activated carbon pellets.

As part of the air pollution control equipment, the purpose of the Activated Carbon (AC) bed is to capture volatile heavy metals, specifically mercury, from the flue gas. The activated carbon pellets (RB-4C) in the AC bed were supplied by Norit Americas (Marshall, TX). During the December 2006 and May 2007 demo plant campaigns, flue gas samples were taken upstream and downstream of the AC bed and analyzed for metals, PCBs, D/Fs, and semi-volatile organic compounds (SVOCs) to characterize flue gas emissions and to determine AC bed capture efficiencies. Table 17 presents the AC bed capture efficiencies for total heavy metals (sum of As, Ba, Cd, Cr, Co, Cu, Pb, Mn, Ni, Se, Ag, Zn, and Hg) with Hg and Pb presented as separate items. The results show that the Hg capture efficiencies were >88.8 and >98.9 percent during the December 2006 and May 2007 campaigns, respectively. The results also show that the activated carbon in the AC bed was less efficient at capturing total metals including Pb, indicating that these metals were probably particle-bound.

Table 15. Cement-Lock Demonstration Plant – Activated Carbon Bed Inlet and Outlet: SOx Test Results

| Run No. | 1 | 2 | Average |
|---|---|---|---|
| Date | 05/18/07 | 05/18/07 | |
| Time Period | 1330-1503 | 1540-1643 | |
| **Exhaust Gas Characteristics** | | | |
| Oxygen, % (dry) | 5.9 | 5.8 | 5.9 |
| Carbon Dioxide, % (dry) | 8.7 | 8.9 | 8.8 |
| Temperature, °F | 320 | 320 | 320 |
| Moisture, % | 50.6 | 54.1 | 52.4 |
| Velocity, ft/s | 34.7 | 35.0 | 34.9 |
| Flow Rate, ACFM | 14,697 | 14,848 | 14,773 |
| Flow Rate, DSCFM | 4,911 | 4,607 | 4,759 |
| **Sulfur Oxides in Inlet to AC Bed** | | | |
| Concentration, ppmv | 118 | 246 | 182 |
| Emission Rate, lb/hr | 6.00 | 11.34 | 8.67 |
| | | | |
| Run No. | 1 | 2 | Average |
| Date | 05/18/07 | 05/18/07 | |
| Time Period | 1337-1442 | 1543-1646 | |
| **Exhaust Gas Characteristics** | | | |
| Oxygen, % (dry) | 5.8 | 5.8 | 5.8 |
| Carbon Dioxide, % (dry) | 8.8 | 8.9 | 8.9 |
| Temperature, °F | 263 | 265 | 264 |
| Moisture, % | 52.5 | 52.9 | 52.7 |
| Velocity, ft/s | 34.0 | 33.8 | 33.9 |
| Flow Rate, ACFM | 14,391 | 14,318 | 14,355 |
| Flow Rate, DSCFM | 5,068 | 4,982 | 5,025 |
| **Sulfur Oxides in Outlet from AC Bed (Stack)** | | | |
| Concentration, ppmv | 1.2 | 14.1 | 7.7 |
| Emission Rate, lb/hr | 0.07 | 1.03 | 0.55 |

Standard Conditions: 70°F, 29.92 inches Hg

Table 16. Cement-Lock Demonstration Plant – Activated Carbon Bed Capture Efficiency of SOx Test Results

| Run No. | Inlet, lb/hr | Outlet, lb/hr | SOx Capture Efficiency, wt % |
|---|---|---|---|
| 1 | 6.00 | 0.07 | 98.8 |
| 2 | 11.34 | 1.03 | 90.9 |
| | | Average | 94.9 |

$$\text{Capture Efficiency (\%)} = \left[\frac{(\text{lb/hr})\ SOx_{in} - (\text{lb/hr})\ SOx_{out}}{(\text{lb/hr})\ SOx_{in}}\right] \times 100$$

The AC bed capture efficiencies for D/Fs and PCBs are presented in Table 18. The results show D/Fs were effectively captured by the AC bed at efficiencies of 98.7 and 99.5 percent, respectively, for the December 2006 and May 2007 tests. The PCB capture efficiency was 92.1 percent for the December 2006 test, but only 45.7 percent for the May 2007 test. The calculations are based on using ½ the analytical method detection limit in the event that an analyte was "Not Detected."

Table 17. Activated Carbon Bed Capture Efficiency for Heavy Metals Including Hg and Pb During the Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| December 2006 Test | | | | May 2007 Test | | | |
|---|---|---|---|---|---|---|---|
| Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt | Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt |
| 1 | 6.06e-3 | 3.42e-3 | 43.5 | 1 | 3.21e-3 | 2.69e-3 | 16.3 |
| 2 | 4.56e-3 | 2.50e-3 | 45.2 | 2 | 3.89e-3 | 2.64e-3 | 32.1 |
| Total Metals Average | | | 44.2 | Total Metals Average | | | 25.0 |
| | | | | | | | |
| 1 (Hg) | 3.02e-3 | <2.58e-5 | >99.6 | 1 (Hg) | 1.50e-3 | <2.85e-5 | >99.1 |
| 2 (Hg) | 2.34e-3 | 5.89e-4 | 74.8 | 2 (Hg) | 1.43e-3 | <3.49e-5 | >98.8 |
| Average (Hg) | | | >88.8 | Average (Hg) | | | >98.9 |
| **Average Hg Capture – 2006 and 2007** | | | | | | | **93.84** |
| | | | | | | | |
| 1 (Pb) | 4.45e-4 | 4.31e-4 | 3.2 | 1 (Pb) | 2.99e-4 | 3.03e-4 | 0.0 |
| 2 (Pb) | 2.52e-4 | 2.01e-4 | 20.2 | 2 (Pb) | 3.53e-4 | 3.12e-4 | 11.1 |
| Average (Pb) | | | 9.3 | Average (Pb) | | | 5.4 |
| **Average Pb Capture – 2006 and 2007** | | | | | | | **7.35** |

$$\text{Capture Efficiency (\%)} = \frac{\text{(lb/hr) Toxic Metal}_{in} - \text{(lb/hr) Toxic Metal}_{out}}{\text{(lb/hr) Toxic Metal}_{in}} \times 100$$

Table 18. Activated Carbon Bed Capture Efficiency for Dioxins and Furans and PCBs During the Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| December 2006 Test | | | | May 2007 Test | | | |
|---|---|---|---|---|---|---|---|
| Dioxins and Furan (D/Fs) | | | | | | | |
| Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt | Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt |
| 1 | 7.77e-8 | 1.42e-9 | 98.2 | 1 | 9.40e-8 | 3.43e-10 | 99.6 |
| 2 | 6.04e-8 | 4.21e-10 | 99.3 | 2 | 4.27e-8 | 3.55e-10 | 99.2 |
| Average (D/F) | | | 98.7 | Average (D/F) | | | 99.5 |
| **Average D/Fs Capture – 2006 and 2007** | | | | | | | **99.1** |
| | | | | | | | |
| PCBs | | | | | | | |
| Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt | Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt |
| 1 | 1.91e-6 | 2.01e-7 | 89.5 | 1 | 2.19e-6 | 1.19e-6 | 45.7 |
| 2 | 1.37e-6 | 5.97e-8 | 95.6 | 2 | 1.16e-6 | 1.16e-6 | -- |
| Average (PCB) | | | 92.1 | Average (PCB) | | | 45.7 |
| **Average PCBs Capture – 2006 and 2007** | | | | | | | **68.9** |

The destruction and removal efficiency (DRE) for dioxins and furans and PCBs are presented in Table 19. DREs are based on the mass flow rate of each of these contaminants in the feed stream compared with the mass flow rate of these contaminants in the flue gas and Ecomelt streams.

Table 19. DREs for Dioxins and Furans and PCBs During the Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| December 2006 Test | | | | May 2007 Test | | | |
|---|---|---|---|---|---|---|---|
| Dioxins and Furans (D/Fs) | | | | | | | |
| Feed, lb/hr | Ecomelt, lb/hr | Outlet, lb/hr | DRE, wt % | Feed, lb/hr | Ecomelt, lb/hr | Outlet, lb/hr | DRE, wt % |
| 2.49e-5 | 1.18e-8 | 9.19e-10 | 99.949 | 2.89e-5 | 3.27e-8 | 3.49-10 | 99.886 |
| TEQ Basis | | | | | | | |
| 1.20e-6 | 1.78e-9 | 6.24e-11 | 99.846 | 1.02e-6 | 7.18e-9 | 5.76e-11 | 99.288 |
| | | | | | | | |
| PCBs (total of congeners) | | | | | | | |
| 3.62e-3 | 3.29e-7 | 1.30e-7 | 99.987 | 3.42e-3 | 2.89e-7 | 1.18e-6 | 99.957 |
| TEQ Basis | | | | | | | |
| 7.83e-8 | 6.92e-11 | 1.32e-11 | 99.895 | 5.96e-8 | 2.26e-11 | 1.94e-11 | 99.930 |

The results show that the average DRE achieved for dioxins and furans during the December 2006 and May 2007 tests was 99.949 and 99.886 percent, respectively. The DREs achieved for PCBs were 99.987 and 99.957 percent, respectively for the two tests. On a TEQ basis, the DREs achieved for dioxins and furans were 99.846 and 99.288 percent, respectively. The TEQ-based DREs for PCBs were 99.895 and 99.930 percent, respectively.

**Mass Balance**

Mass balance calculations were performed to determine the distribution of trace elements, mercury and lead, from the sediment being processed through the Cement-Lock demo plant. These trace elements could be distributed from the feed sediment to several different process streams including: 1) Ecomelt, 2) fly slag accumulating in or coating the Secondary Combustion Chamber walls, 3) water in the Ecomelt quench/granulator, 4) particulate matter and/or water condensed at the flue gas quencher, 5) spent lime and other particulate matter collected by the bag house, 6) adsorbed on the activated carbon in the activated carbon (AC) bed, 7) coating the inside of the flue gas stack, and 8) exiting the flue gas stack. The distribution of mercury and lead to these various process streams depends upon the chemical properties of each Hg or Pb compound present.

Mass balance calculations were not performed for organic contaminants, since those materials are quantitatively destroyed during high-temperature thermal processing.

The mass balance calculations were based on chemical analyses of samples and flow rates of Passaic River sediment into the demo plant, Ecomelt from the plant, and the flue gas (stack) emission rates. Samples of Ecomelt quench/granulator water were also analyzed for trace elements. It should be noted that during the campaigns to process Passaic River sediment, the feeding of powdered lime to the flue gas duct upstream of the bag house was observed to be inconsistent. The discharge of spent lime from the bag house was similarly inconsistent. Although we attempted to take samples of spent lime from the bag house, none were analyzed since they were not taken under steady-state conditions.

The mass balance calculations presented in Table 20 are the averaged results from the December 2006 and May 2007 Cement-Lock demo plant campaigns.

Table 20. Mass Balance Calculations for Mercury and Lead – Cement-Lock Demo Plant Campaigns with Passaic River Sediment

| Contaminant in Feed | In Ecomelt | In Quench / Granulator Water | In Other Process Streams* | In Activated Carbon (AC) Bed | AC Bed Capture Efficiency, % | In Flue Gas Exiting Stack |
|---|---|---|---|---|---|---|
| Mercury (Hg) | | | | | | |
| 4.79 mg/kg Hg | 0.0237 mg/kg Hg | 15.95 µg/L Hg | -- | -- | -- | -- |
| 0.1151 lb | 5.896e-4 lb | 8.483e-5 lb | 0.07564 lb | 0.03728 lb | -- | 3.406e-3 lb |
| 100.000% | 0.313% | 0.075% | 66.669% | 31.514% | 93.84% | 1.429% |
| Lead (Pb) | | | | | | |
| 367.35 mg/kg Pb | 21.14 mg/kg Pb | 8,445 µg/L Pb | -- | -- | -- | -- |
| 8.8290 lb | 0.5101 lb | 0.04491 lb | 8.2694 lb | 4.914e-4 lb | -- | 5.860e-3 lb |
| 100.000% | 5.714% | 0.518% | 93.715% | 0.0055% | 7.35%** | 0.047% |

* SCC walls, flue gas quencher water, spent lime (bag house), and stack walls.
** Activated carbon does not have a high affinity for Pb.

**Mercury:** As expected, the results show that mercury was essentially volatilized from the sediment during thermal processing. Only 0.31 percent of the Hg in the feed sediment was found in the Ecomelt. About 31.51 percent of the Hg remained in the Activated Carbon bed, which represented an average AC bed capture efficiency of 93.84 percent. About 0.075 percent of Hg showed up in the quench/granulator water and about 1.429 percent exited through the flue gas stack. As shown in the table, this left roughly two-thirds of the Hg in the sediment feed unaccounted for. It is assumed that the mercury condensed onto the metal in cooler parts of the plant or was associated with particles that deposited in the system. This phenomenon is assumed to be transitory – continuous long-term operation would push the mercury further into the plant where it would eventually be captured in the air pollution control equipment.

Because of mercury's high volatility, most of it is expected to pass through the high-temperature treatment units (Ecomelt Generator or Secondary Combustion Chamber). A portion of the Hg is expected to condense out in the cooler downstream sections of the process plant. The portion that does not condense out will be efficiently captured in the Activated Carbon bed.

Some Hg could appear in particulate matter and/or water condensed at the flue gas quencher; however that is unlikely since the flue gas quencher is designed to operate without condensation (dry bottom). Similarly, fine particulate matter would be entrained to downstream processing units.

The bulk of Hg is expected to condense on the powdered lime used for acid-gas capture and be collected at the bag house. This assumption would need to be tested during the shakedown phase of any new plant and prior to the treatment of any highly contaminated materials. As discussed above, none of the samples of spent lime from the bag house were analyzed because it was not operating properly.

**Lead:** The results show that lead was also volatilized from the sediment during thermal processing. About 5.71 percent of the Pb in the feed sediment was found in the Ecomelt. About 0.005 percent of the Pb remained in the Activated Carbon bed, which represented an average AC bed capture efficiency of 7.35 percent (activated carbon has limited affinity for Pb). About 0.52 percent of Pb showed up in the quench/granulator water and about 0.047 percent exited through the flue gas stack. Much (about 94 percent) of the Pb in the sediment feed was distributed to other process streams.

As with Hg, some Pb could appear in particulate matter and/or water condensed at the flue gas quencher; however that is unlikely since the flue gas quencher is designed to operate without condensation. Fine particulate matter would be entrained to downstream air pollution control equipment.

Because of lead's moderate volatility, some of it will remain in the high-temperature treatment units, specifically the Secondary Combustion Chamber, as fly slag accumulating in or coating the SCC walls. The balance of Pb is expected to be removed from the flue gas in the form of particulate matter in the cooler downstream sections of the process plant, specifically in the bag house. These assumptions would need to be tested during the shakedown phase of any new plant and prior to the treatment of any highly contaminated materials. None of the samples of spent lime from the bag house were analyzed because it was not operating properly.

Mass balances for non-volatile metals, chromium and barium, showed that 51 and 69 percent of these metals remained with the Ecomelt, respectively. The unaccounted for remainder of each is expected to reside in elutriated particulate matter and be captured downstream in the air pollution control equipment. Although other non-volatile metals would be expected to behave similarly, this assumption needs to be tested during the shakedown phase of any new plant.

The results in Table 21 show the concentration of HCl in the flue gas at the inlet and the outlet of the AC bed. The average flow rate of HCl at the inlet was 0.34 lb/hour. The average flow rate of HCl at the outlet was determined to be 0.21 lb/hour. The reduction in HCl emissions achieved through the AC bed for these tests are presented in Table 22. The results show that the HCl concentration decreased by 29.2 and 45.5 percent for an average of 37.4 percent.

As mentioned above, the principal method for acid gas (SOx and HCl) capture is by reacting with lime (CaO) injected into the flue gas duct upstream of the bag house. That a considerable amount of HCl capture was achieved across the AC bed indicates that some of the lime may have passed through the filter bags in the bag house and was deposited on the activated carbon pellets.

During the May 2007 test campaign AirNova sampled the flue gas in the stack for total suspended particulates (TSP) and PM-10 (particulate matter <10 micrometers). The results of these analyses, presented in Table 23, show that the emission rate of TSP was 2.03 lb/hour in the first test and 0.21 lb/hour in the second test. The emission rate of PM-10 was 5.70 lb/hour in the first test and 1.81 lb/hour in the second test. These results are higher than expected based on the use of a fine particle bag house filtering system. It is possible that one or more of the bags in the bag house filter had developed rips or holes over the course of operations.

Table 21. Cement-Lock Demonstration Plant – Activated Carbon Bed
Inlet and Outlet: HCl and $Cl_2$ Test Results

| Run No. | 1 | 2 | Average |
|---|---|---|---|
| Date | 05/18/07 | 05/18/07 | |
| Time Period | 1330-1503 | 1540-1643 | |
| **Exhaust Gas Characteristics** | | | |
| Oxygen, % (dry) | 5.8 | 5.8 | 5.8 |
| Carbon Dioxide, % (dry) | 8.9 | 8.9 | 8.9 |
| Temperature, °F | 319 | 319 | 319 |
| Moisture, % | 48.5 | 51.9 | 50.2 |
| Velocity, ft/s | 35.4 | 36.3 | 35.9 |
| Flow Rate, ACFM | 15,005 | 15,393 | 15,199 |
| Flow Rate, DSCFM | 5,234 | 5,012 | 5,123 |
| **Hydrogen Chloride** | | | |
| Concentration, ppmv | 8.1 | 15.4 | 11.8 |
| Emission Rate, lb/hr | 0.24 | 0.44 | 0.34 |
| Run No. | 1 | 2 | Average |
| Date | 05/18/07 | 05/18/07 | |
| Time Period | 1337-1442 | 1543-1646 | |
| **Exhaust Gas Characteristics** | | | |
| Oxygen, % (dry) | 5.8 | 5.8 | 5.8 |
| Carbon Dioxide, % (dry) | 8.8 | 8.9 | 8.9 |
| Temperature, °F | 262 | 265 | 264 |
| Moisture, % | 50.1 | 51.0 | 50.6 |
| Velocity, fps | 33.7 | 34.1 | 33.9 |
| Flow Rate, ACFM | 14,300 | 14,442 | 14,371 |
| Flow Rate, DSCFM | 5,300 | 5,231 | 5,266 |
| **Hydrogen Chloride** | | | |
| Concentration, ppmv | 5.6 | 8.1 | 6.9 |
| Emission Rate, lb/hr | 0.17 | 0.24 | 0.21 |

Standard Conditions: 70°F, 29.92 inches Hg.
Note: Detailed analysis of $Cl_2$ quantities can be found in Appendix F (2007 AirNova Report).

Table 22. Cement-Lock Demonstration Plant – Activated Carbon Bed
Capture Efficiency of HCl and $Cl_2$ Test Results

| Run No. | Inlet, lb/hr | Outlet, lb/hr | Capture Efficiency, % wt |
|---|---|---|---|
| 1 | 0.24 | 0.17 | 29.2 |
| 2 | 0.44 | 0.24 | 45.5 |
| | | Average | 37.4 |

$$\text{Capture Efficiency (\%)} = \left[\frac{(\text{lb/hr})\ HCl_{in} - (\text{lb/hr})\ HCl_{out}}{(\text{lb/hr})\ HCl_{in}}\right] \times 100$$

## Characterization of Granulator Vapor Air Emissions

As part of the Environment Improvement Pilot Test permit for the May 2007 campaign, the NJ-DEP requested that a sample of vapor emanating from the granulator discharge be sampled and analyzed for dioxins, furans, PCBs, SVOCs, Total Petroleum Hydrocarbons (TPH), and mercury.

Table 23. Cement-Lock Demonstration Plant – Activated Carbon Bed Outlet: TSP and PM-10 Test Results

| Run No. | 1 | 2 | Average |
|---|---|---|---|
| Date | 05/16/07 | 05/17/07 | |
| Test Period | 1155-1600 | 0835-1307 | |
| Temperature, °F | 273 | 279 | 276 |
| Moisture Content, % | 53.3 | 53.9 | 53.6 |
| Velocity, ft/s | 34.7 | 35.6 | 35.2 |
| Flow Rate, ACFM | 14,706 | 15,105 | 14,906 |
| Flow Rate, DSCFM | 4,934 | 5,023 | 4,979 |
| Oxygen, % (dry) | 4.61 | 5.18 | 4.90 |
| Carbon Dioxide, % (dry) | 9.79 | 9.41 | 9.60 |
| **Total Suspended Particulate Matter (TSP)** | | | |
| Concentration, grain/DSCF | 0.0481 | 0.0048 | 0.026 |
| Emission Rate, lb/hr | 2.032 | 0.207 | 1.13 |
| **Particulate Matter [<10 µm (PM-10)]** | | | |
| Concentration, grain/DSCF | 0.135 | 0.042 | 0.089 |
| Emission Rate, lb/hr | 5.696 | 1.813 | 3.78 |

Standard Conditions; 70°F, 29.92 in. Hg

In a commercial-scale Cement-Lock facility, the discharge from the granulator will be tied directly into the conveyor system to the Ecomelt dryer without any exposure to the atmosphere. This apparent emission source at the Cement-Lock demo plant would not be part of a commercial system.

This sampling task was a challenge because there was no actual flow of air or flue gas from the granulator discharge. The discharge is separated from the hot flowing kiln flue gases by a water seal (the granulator water). Vapors emanating from the granulator discharge are due to the evaporation of water from the granulator itself.

The rate of vapor evaporation is directly proportional to the thermal input to the granulator by radiation heat transfer from the kiln or from molten slag being quenched. Granulator water evaporated inside the water seal exits through the SCC. Water evaporated outside the water seal exits through the granulator discharge.

NJ-DEP also requested that GTI provide estimates of the expected emissions based on Henry's Law constants for PCBs, dioxins and furans. The objective was to estimate the quantity of contaminants emitted. Similarly, as the heat input to the granulator directly affects the evaporation rate, GTI also estimated the rate of water evaporation from the granulator. The rate of water vapor emanating from the granulator discharge was estimated to be 421.6 lb/hour (the volumetric flow rate of vapor was estimated at 8,860 $ft^3$/hour or 250.8 $m^3$/hour). The calculations are included in Appendix D along with the application for the EIPT.

Two samples of vapor from the granulator headspace were collected by AirNova during the May 2007 campaign. Each sample was collected variously over the course of about 4 hours. The sample was collected using a vacuum pump to draw the vapors and intrusion air (from the atmosphere) through a chilled water condenser. Once the water vapor had condensed out of the sample stream, the intrusion air (from the atmosphere) was drawn through the dry test meter. The condensate sample was collected until about 100 $ft^3$ of "dried" air had passed through the dry test meter. The samples of condensate collected were sent for component analyses.

A summary of the analyses is presented in Table 24. The complete analyses are included in Appendix F (2007 AirNova report). The results show that the estimated total of dioxin-like contaminants present in the samples was $8.348 \times 10^{-3}$ ng/SCM (TEQ basis) of water vapor. Assuming the calculated rate of water being evaporated per hour, the rate of TEQ emanating from the granulator discharge was 1.987 ng TEQ/hour. Given that the TEQ content of the flue gas exiting the stack averaged about 35 ng TEQ/hour, the TEQ emanating from the granulator discharge represents about 5 percent of the total. The calculation is based on the quantities of contaminants measured in the condensate samples related back to the volume of vapor emitted through the granulator discharge.

Mercury was not detected in either of the samples above the detection limit. Small quantities of hydrocarbons (Diesel Range Organics) were detected, but Gasoline Range Organics were below the analytical detection limit of 0.5 mg/L. Bis(2-ethylhexyl) phthalate was detected in both samples at 5.0 and 3.05 μg/L, respectively. Fluoranthene was also detected in the condensate at 0.19 and 18.50 μg/L, respectively.

Overall, the entrainment of contaminants in the granulator vapor was determined to be low. As mentioned above, in a commercial-scale Cement-Lock facility, the discharge from the granulator will be tied directly into the conveyor system to the Ecomelt dryer without exposure to the atmosphere. Water carried with the Ecomelt to the dryer will be vaporized and directed either to the Secondary Combustion Chamber or to a bag house-type filter.

Table 24. Cement-Lock Demonstration Plant – Granulator Outlet Test Results

| **Run No.** | 1 | 2 | Average |
|---|---|---|---|
| Date | 05/16/07 | 05/17/07 | |
| Test Period | 1153-1553 | 0831-1304 | |
| Moisture Content of Vapor, % | 44.2 | 41.9 | 43.1 |
| | | | |
| **Dioxins and Furans TEQ Concentration** | Estimated TEQ Values for D/Fs & PCBs | | |
| Dioxins TEQ Concentration, ng/SCM | 5.957e-3 | 4.027e-3 | 4.992e-3 |
| Furans TEQ Concentration, ng/SCM | 2.592e-3 | 2.989e-3 | 2.791e-3 |
| **PCB TEQ Concentration, ng/SCM** | 2.623e-4 | 8.679e-4 | 5.651e-4 |
| Total D/F+PCB TEQ Concentration, ng/SCM | 8.811e-3 | 7.884e-3 | 8.348e-3 |
| Estimated Total TEQ Emission Rate, ng/hour | 2.097 | 1.876 | 1.987 |
| **PCBs** | | | |
| Total Vapor Phase Concentration, ng/SCM | 40.25 | 4.404 | 22.327 |
| PCB Emission Rate, lb/hr | 2.111e-8 | 2.310e-9 | 1.171e-8 |
| **Mercury** | | | |
| Condensate Concentration, mg/L | <2.85e-04 | <2.85e-04 | <2.85e-04 |
| Hg Emission Rate, lb/hr | <6.008e-8 | <6.009e-8 | <6.008e-8 |
| **SVOCs in Condensate** | | | |
| Bis(2-ethylhexyl) phthalate, µg/L | 5.00 | 3.05 | 4.03 |
| Chrysene, µg/L | 0.097 | ND** | 0.097 |
| Fluoranthene, µg/L | 0.188 | 18.50 | 9.344 |
| Phenanthrene, µg/L | 0.105 | 0.254 | 0.180 |
| Pyrene, µg/L | 0.184 | ND | 0.184 |
| Total SVOCs, µg/L | 5.574 | 21.804 | 13.689 |
| SVOCs Emission Rate [w/o Bis(2-EH) P], lb/hr | 5.543e-7 | 8.247e-6 | 4.401e-6 |
| Bis(2-EH) P Emission Rate, lb/hr | 2.108e-6 | 1.286e-6 | 1.697e-6 |
| **Total Hydrocarbons (Diesel Range Organics) in Condensate** | | | |
| Concentration, mg/L | 0.873 | 1.48 | 1.18 |
| DRO Emission Rate, lb/hr | 3.680e-4 | 6.241e-4 | 4.961e-4 |
| **Total Hydrocarbons (Gasoline Range Organics) in Condensate** | | | |
| Concentration, mg/L | <0.5 | <0.5 | <0.5 |
| GRO Emission Rate, lb/hr | <1.054e-4 | <1.054e-4 | <1.054e-4 |

The emission calculations for dioxins and furans and PCBs can be found in Appendix F (2007 AirNova report)
* ND = Not detected
** If any component was ND then ½ DL (detection limit) was used in calculations
*** Includes other SVOCs not detected at ½ DL.

## Comparison of Air Emissions with New Jersey Regulations

Table 25 summarizes the air emissions from the Cement-Lock demonstration plant during processing campaigns with Passaic River sediment in December 2006 and May 2007. The emission results are presented on a pound per hour basis followed by a calculation of the total emission had the demo plant operated for a full year (8,760 hours per year). The emission results are also presented on a pound per ton of dry sediment fed basis to account for the differences in average sediment feed rates and moisture contents during the two campaigns. During the 2006 campaign, Passaic River sediment was fed to the plant via the belt conveyor and blended with modifiers at the pug mill on the charging deck. During the 2007 campaign, the mixture of

Table 25. Comparison of Air Emissions from Cement-Lock Demo Plant Operation with Passaic River Sediment with New Jersey Regulations (N.J.A.C. 7:27-8)

| Air Contaminant | Cement-Lock Demonstration Plant[1] December 2006 lb/hr | December 2006 x 8760 hr ton/yr | December 2006 lb/ton of dry sediment fed | May 2007 lb/hour | May 2007 x 8760 hr ton/yr | May 2007 lb/ton of dry sediment fed | NJ Reporting Threshold, Table A lb/hr | NJ SOTA[2] Threshold, Table A ton/yr | NJ Major Facility Threshold Level, ton/yr |
|---|---|---|---|---|---|---|---|---|---|
| Total VOC | 0.04 | 0.175 | 0.073 | 0.15 | 0.66 | 0.274 | 0.05 | 5.0 | 25 |
| Total Suspended Particulates | --[3] | -- | -- | 1.12 | 4.91 | 2.05 | 0.05 | 5.0 | 100 |
| PM-10 | -- | -- | -- | 3.76 | 16.47 | 6.87 | 0.05 | 5.0 | 100 |
| NOx | 4.44 | 19.4 | 8.09 | 6.30 | 27.6 | 11.51 | 0.05 | 5.0 | 25 |
| CO | 0.23[4] | 1.01 | 0.42 | 0.32 | 1.40 | 0.58 | 0.05 | 5.0 | 100 |
| $SO_2$ | 0.61[4] | 2.67 | 1.11 | 0.55 | 2.41 | 1.01 | 0.05 | 5.0 | 100 |
| Each HAP[5] | -- | -- | -- | -- | -- | -- | -- | -- | 10 |
| All HAPs Collectively | -- | -- | -- | -- | -- | -- | -- | -- | 25 |
| Others (ex. $CO_2$) | -- | -- | -- | -- | -- | -- | -- | -- | 100 |
| | | | | | | | | | |
| | lb/hr | lb/yr | lb/dry ton fed | lb/hr | lb/yr | lb/dry ton fed | Table B[6] lb/yr | | |
| Cadmium (Cd) | 1.35e-5 | 0.12 | 2.45e-5 | 3.77e-5 | 0.33 | 6.88e-5 | 2 | 20 | -- |
| Cobalt (Co) | 6.02e-6 | 0.05 | 1.10e-05 | 9.08e-6 | 0.08 | 1.66e-5 | 20 | 200 | -- |
| Lead (Pb) | 3.16e-4 | 2.77 | 5.76e-04 | 3.09e-4 | 2.70 | 5.64e-4 | 2 | 20 | 10 (20,000 lb/yr) |
| Manganese (Mn) | 9.17e-4 | 8.03 | 1.67e-03 | 1.01e-3 | 8.84 | 1.84e-3 | 160 | 1,600 | -- |
| Mercury (Hg) | 3.01e-4 | 2.64 | 5.49e-04 | 3.17e-5 | 0.28 | 5.79e-5 | 2 | 20 | -- |
| Nickel (Ni) | 1.27e-4 | 1.11 | 2.32e-04 | 8.40e-5 | 0.74 | 1.53e-4 | 200 | 2,000 | -- |
| Selenium (Se) | 1.92e-5 | 0.17 | 3.49e-05 | 1.77e-6 | 0.02 | 3.23e-6 | 20 | 200 | -- |
| 2,3,7,8-TCDD | 1.37e-11 | 1.20e-7 | 2.50e-11 | 2.20e-11 | 1.92e-7 | 4.01e-11 | 1.2e-4 | 1.2e-3 | -- |
| Dioxins/Furans (If "U" use ½ DL) | 9.19e-10 | 8.05e-6 | 1.67e-9 | 3.49e-10 | 3.06e-6 | 6.38e-10 | 1.2e-4 | 1.2e-3 | -- |
| TEQ Basis | 6.24e-11 | 5.46e-7 | 1.14e-10 | 5.76e-11 | 5.04e-7 | 1.05e-10 | -- | -- | |
| PCBs (If "U" use ½ DL) | 1.30e-7 | 1.14e-3 | 2.38e-7 | 1.17e-6 | 1.03e-2 | 2.15e-6 | 1.8 | 18 | -- |
| TEQ Basis | 1.32e-11 | 1.16e-7 | 2.40e-11 | 1.94e-11 | 1.70e-7 | 3.53e-11 | -- | -- | |
| HCl | 1.52 | 13,315 | 2.77 | 0.21 | 1,840 | 0.38 | 2,000 | 10,000 | -- |
| Benzo[a]pyrene[7] | 2.20e-10 | 1.93e-6 | 4.01e-10 | 5.20e-7 | 4.56e-3 | 9.50e-7 | 2 | 20 | -- |
| Naphthalene | 4.60e-9 | 4.03e-5 | 8.39e-9 | ND[8] | ND | ND | 2 | 20 | -- |

1. Excludes emissions from granulator
2. SOTA = State-of-the-Art
3. "--" Not analyzed
4. Excludes out value
5. HAP = Hazardous Air Pollutant
6. Table B, N.J.A.C. 7:27-8, Appendix 1
7. Same threshold limits for polycyclic organic matter
8. ND – Not Detected

Passaic River sediment and modifiers was fed to the plant via the belt conveyor. The State of New Jersey Air Quality Regulations (N.J.A.C. Title 7, Chapter 27, Subchapter 8) are included in Table 25 for comparison.

The NJ Reporting Threshold is the emission rate that requires notification by the emitter to the NJ-DEP in the appropriate report. The NJ SOTA Threshold is the emission rate that can be achieved by the state-of-the-art pollution control technologies. The NJ Major Facility Threshold Level applies to a facility that has the potential to emit any of the air contaminants in an amount that equals or exceeds the applicable Major Facility Threshold Level.

The table shows that if the Cement-Lock demo plant were to be operated for a full year (8,760 hours per year) then NOx, HCl, and PM-10 emissions would exceed the NJ SOTA Threshold limits. These emissions would need to be controlled to a higher degree than achieved with the existing demo plant air pollution control equipment.

During the 2006 campaign, NOx was emitted from the demo plant at a rate that put the yearly emission (19.4 tons) just below the Major Facility Threshold Level (25 tons of NOx). During the 2007 campaign, NOx was emitted at a rate that put the yearly emission (27.6 tons) over the Major Facility Threshold Level. On a per ton of sediment fed basis, the NOx emission rate from the 2007 campaign was 42.3 percent higher than that of the 2006 campaign. Part of this increase was due to the higher operating temperature during the May 2007 compared with that of the December 2006 test. As mentioned above, the demo plant did not have NOx reduction equipment installed.

From a process improvement standpoint, there are several commercially available NOx reduction technologies, including some developed by GTI that can achieve 90+ percent emission reductions. These include staged combustion, burner modifications for NOx reduction, and selective catalytic (SCR) as well as non-catalytic (SNCR) NOx reduction processes. Selective non-catalytic NOx reduction can achieve NOx reductions in the range of 35 to 50 percent (worldbank.org). Selective catalytic NOx reduction technologies can reduce NOx emissions in the range of 70 to 95 percent (worldbank.org). One manufacturer touts being able to achieve NOx reductions of 90 to 97 percent with their technology (www.csmworldwide.com).

Emissions of HCl and $SO_2$ can be significantly reduced by improving the efficiency of injecting powdered lime into the flue gas duct upstream of the bag house. During the demo plant campaigns, it was observed that the lime feeder did not function properly at all times and lime addition to the flue gas stream was inconsistent and dosing was inadequate, which resulted in elevated emissions of HCl as well as $SO_2$ from the stack.

The elevated emission of particulates (TSP and PM-10) from the stack indicates the possibility of partial bag rupture or failure. This could be a simple maintenance issue or it may involve the selection of another type of filter bag material. The emission of CO can be reduced by increasing process excess air – an operating parameter. Overall, stringent air pollution control requirements for a commercial-scale Cement-Lock plant facility can be achieved through engineered solutions and best operating practices.

### Implications for Commercial Operations

The results of air emission tests presented above show that the severe temperatures employed during Cement-Lock processing are very effective in destroying organic contaminants present in Passaic River sediment. The results also show that the elevated temperatures necessary to destroy organic contaminants form nitrogen oxides (NOx), which are precursors to acid rain and subject to environmental restrictions. Priority inorganic air pollutants, such as mercury and lead, must be carefully monitored and controlled. Operation of any sediment treatment facility must also demonstrate the ability to operate for extended periods without downtime. Issues of process availability are also discussed below.

In the following discussion, the emissions measured during the Cement-Lock demo plant campaigns were used to scale up to estimated commercial operations assuming that air emissions are directly proportional to the Passaic River sediment feed rate and its trace element concentrations. The Hg and Pb concentrations measured in the Passaic River sediment processed through the Cement-Lock demo plant were used to determine the estimated emissions proportional to the historic Passaic River surface and subsurface sediment analyses provided by Malcolm Pirnie Inc.[17] Per Table 25, the NJ Major Facility Threshold Level was used for NOx-related calculations; the NJ SOTA (State of the Art) Threshold limits were use for Hg, Pb, and particulates calculations.

**NOx Emissions:** The following calculations are based on the average NOx emission rate from demo plant operations in 2006 of 8.1 lb NOx/dry ton sediment fed. This value was selected because in a commercial Cement-Lock facility, the Ecomelt Generator will be operated at the lowest practical temperature without jeopardizing process performance. Using this NOx emission value, the NJ Major Facility Threshold Level of 25 tons NOx per year, and correcting for solids content differences, the corresponding plant processing rate would be 13,180 $yd^3$/year. Clearly, this sediment processing capacity would not be economically viable. If it is assumed that commercially available NOx reduction technologies can achieve 90 percent NOx reduction, then the plant treatment capacity would be boosted to about 131,800 $yd^3$/year. Achieving a NOx emission reduction of 95 percent would permit a treatment capacity of 263,600 $yd^3$/year. To reach a sediment treatment capacity of 500,000 $yd^3$/year would require a NOx reduction of 97.4 percent. This would require a combination of low-NOx burner, SCR, and staged combustion to achieve.

**Hg Emissions:** The Cement-Lock demo plant incorporated a fixed bed of activated carbon pellets installed specifically for mercury capture. The Hg capture efficiencies measured upstream and downstream of the activated carbon bed during the 2006 and 2007 campaigns were >88.8 and >98.9 percent, respectively. For comparison, during the 2005 non-slagging test, during which time Stratus Petroleum sediment was being processed, the Hg capture efficiency across the activated carbon bed was 99.2 percent. The Hg concentration of samples of the Stratus Petroleum sediment averaged 1.78 mg/kg.[8]

The Hg concentration of samples of Passaic River sediment processed during the 2006 and 2007 campaigns averaged 5.23 and 4.35 mg/kg, respectively. On a per ton of dry sediment basis, the Hg emission rate (flue gas stack) during the 2006 and 2007 campaigns was determined to be $5.49 \times 10^{-4}$ and $5.79 \times 10^{-5}$ lb Hg/dry ton fed, respectively.

Combining the average Hg emission rates from the demo plant above, the ratios of the historic Passaic River surface and subsurface sediment mercury concentrations (surface sediment average 3.0 mg/kg Hg; subsurface sediment average 7.7 mg/kg Hg), those measured in the sediment processed through the Ecomelt Generator (above), adjusting for the solids content of the feed materials, and using the Hg SOTA (State-of-the-Art) Threshold limit of 20 pounds per year

(Table 25) yields potential sediment processing capacities. For example, a Cement-Lock plant processing Passaic River sediment dredged from the surface layer could process up to 601,300 $yd^3$/year without exceeding the SOTA Threshold limit. A Cement-Lock plant processing Passaic River sediment dredged from the subsurface could process up to 234,300 $yd^3$/year without exceeding the SOTA Threshold limit.

According to data provided by Malcolm Pirnie, the maximum Hg concentration measured in samples of Passaic River sediment was 29.6 mg/kg. This was part of the subsurface sediment characterization work.[17] This is roughly 6 times higher than the material processed through the demo plant and 10 times higher than the average surface sediment Hg concentration.

**Commercial Plant Design Considerations:** The following addresses the situation in which a batch of sediment with significantly elevated mercury concentration is received at a commercial-scale Cement-Lock treatment facility. First, the commercial Cement-Lock process flow scheme incorporates powdered activated carbon (PAC) injection upstream of a separate bag house for mercury capture instead of the fixed bed of carbon used in the demo plant. In conjunction with PAC injection, a continuous emission monitoring system (CEMS) specific for mercury will be installed to monitor variations in flue gas Hg concentration so that the rate of PAC injection can be adjusted to insure proper dosing. Second, the air pollution control equipment will be conservatively designed to accommodate a fairly broad range of mercury concentrations expected in Passaic River sediment. For example per MPI,[17] the average mercury concentration of Passaic River subsurface sediment is 7.7 mg/kg. The maximum Passaic River surface sediment mercury concentration is 12.4 mg/kg. Designing for the higher value should provide considerable leeway in sediment processing. Third, each batch of sediment delivered to a commercial Cement-Lock facility will be characterized for mineral matter as well as for trace element concentrations. This will be *standard procedure* to establish modifier requirements and identify special environmental situations such as elevated Hg or Pb concentrations. Fourth, any batch of sediment with elevated mercury concentration will be segregated from the bulk of the dredged sediment and stored under cover pending processing. Fifth, the highly contaminated sediment will be mixed with sediment (ratio to be determined) with much lower mercury concentration prior to feeding to the system. The net effect would be to dilute the mercury concentration in the sediment to the range for which the pollution control equipment was designed. This will enable more levelized treatment of the sediment. Sixth, mixing the highly contaminated sediment with less contaminated sediment will be done under cover to minimize/prevent volatilization of contaminants. Finally, an affinity metal filter could be used as a polishing step to capture mercury as an amalgam. An affinity metal, such as copper, gold, or silver, could be deposited thinly over an appropriate high-surface area substrate and the filter structure placed in the flue gas flow. The affinity metal filter would be periodically recycled and replaced. Although the initial cost of the affinity metal filter could be high, the amalgamated mercury-metal would be returned to the processor for significant credit.

Taken together, these design and operating protocols will enable a commercial-scale Cement-Lock plant to successfully treat a broad range of contamination levels in sediment.

Cost implications of processing elevated mercury concentration sediment have been considered in the Section V – Economic Evaluation and Assessment.

**Pb Emissions:** Based on the average lead emission rates from demo plant operations during 2006 and 2007 ($5.76 \times 10^{-4}$ and $5.64 \times 10^{-4}$ lb Pb/dry ton sediment fed, respectively), the ratios of the historic Passaic River surface and subsurface sediment Pb concentrations, those measured in the sediment processed through the Ecomelt Generator, and adjusting for the solids content of the feed materials, yields potential sediment processing capacities of 106,700 and 51,020 $yd^3$/year, respectively.

From previous WRDA/BNL-sponsored Cement-Lock pilot-scale testing at Hazen Research[13] (Golden, CO), the majority of Pb was determined to be associated with the particulate phase of flue gas emissions as opposed to the vapor phase. In the flue gas sample taken downstream of the Secondary Combustion Chamber (but upstream of the wet scrubber, bag house, and activated carbon bed), the Pb in the particulate phase accounted for 99.8 percent of the total Pb in that sample (0.2 percent Pb in the gas phase).

The emission rate of particulates measured in the outlet (stack) – after the wet scrubber, bag house, and activated carbon bed – was $<2.0 \times 10^{-4}$ lb/hour ($8.79 \times 10^{-3}$ lb particulates/dry ton sediment fed). Across the Hazen Research pilot-scale air pollution control equipment, the particulate emission rate was reduced by 99.86 percent. The Pb emission rate measured at the outlet (stack) was reduced by 99.71 percent to 2.75 x $10^{-5}$ lb Pb/hr [total of Pb measured in the particulates plus ½ the Pb measured in the gas phase (below the detection limit)] or 1.2 x $10^{-3}$ lb Pb/dry ton sediment fed.

The particulate emissions from the Cement-Lock demo plant were measured during the 2007 campaign. The total suspended particulates (TSP) and PM-10 (<10 micrometer) particles were 2.05 lb TSP/dry ton sediment fed and 6.87 lb PM-10/dry ton sediment fed, respectively. These results were significantly higher than the total particulate emissions recorded during the pilot-scale test at Hazen Research in 1996.[13] Controlling particulate emissions from a commercial-scale Cement-Lock facility is expected to reduce Pb emissions significantly. For example, a 90 percent reduction in the TSP and PM-10 emission rates is expected to reduce the Pb emission rate by 90 percent. Following this assumption, the potential sediment processing capacities become 1,067,000 and 510,200 $yd^3$/year [ = 106,700/(0.1) and = 51,020/(0.1)], respectively, for surface and subsurface Passaic River sediment.

Clearly, the emissions of Hg, Pb, and particulates from large-scale commercial Cement-Lock treatment facilities must be strictly controlled. The Cement-Lock technology must be able to operate at a treatment capacity that enables it to achieve economies of scale without contravening the environmental benefits of sediment remediation.

### Engineering Requirements

Based on the measured air emissions from the 2006 and 2007 Cement-Lock campaigns, scaling up from the demo plant equipment to commercial-scale equipment will require detailed attention to environmental contaminants such as NOx, Hg, Pb, and particulate emissions. Additional equipment will be needed in a commercial facility that was not included in the demo plant, such as Selective Catalytic NOx Reduction (SCR) system, powdered activated carbon injection system, separate bag house for spent carbon capture, CEMS for measuring Hg in the flue gas, consistent/reliable powdered lime injection and feeding system, instrumentation to detect bag house bag leakage/breakage, etc.

An engineered solution to reduce Hg emissions could be to use sulfur-impregnated activated carbon, which would improve mercury capture efficiency significantly compared with neat activated carbon. However, because of the real concern for possible carbon bag house fires, the flue gas temperature would need to be reduced to about 150° to 170°F. Water vapor that condensed from the flue gas would need to be treated before being recycling to the process and/or possibly disposed. As another step (mentioned above), an affinity metal filter could be used as a polishing step to capture mercury as an amalgam. An affinity metal, such as gold or silver, could be deposited thinly over an appropriate high-surface area substrate and the filter structure placed in the flue gas flow. The affinity metal filter would be periodically recycled and replaced. Although the initial cost of the affinity metal filter could be high, the amalgamated mercury-metal would be returned to the processor for significant credit.

Other air emission factors not addressed above include acid gases – $SO_2$ and HCl. These pollutants were measured at elevated emission levels indicating possible inadequacies in or problems with the air pollution control equipment.

Although this was not confirmed, it is possible that a bag (or bags) had torn or ruptured in the bag house that would have compromised the ability of the bag house to capture particulates containing both mercury and lead. In a commercial Cement-Lock treatment facility, specific equipment to detect bag breakage (tear/rupture) would be installed to closely monitor this potential equipment problem. The lime feeding system would be similarly designed to improve lime delivery, consistency, and reliability.

Insuring the consistent feeding of powdered lime or hydrated lime into the flue gas upstream of the bag house will significantly improve the capture efficiency of $SO_2$ and HCl.

# IV. BENEFICIAL USE DEMONSTRATION OF CEMENT-LOCK ECOMELT

The beneficial use project with Ecomelt produced from Passaic River sediment at the Cement-Lock demonstration plant (Bayonne, NJ), and chemical and physical characterization of Ecomelt for the beneficial use project are described below.

**Beneficial Use Project**

The objective of the beneficial use project is to demonstrate that the Ecomelt produced from Passaic River sediment can be used successfully and in an environmentally acceptable manner in a general construction project. For this beneficial use project, Ecomelt will be used as a partial replacement for Portland cement in the production of a batch of concrete. The concrete will be used to pour a length of sidewalk (165 feet long and 6 feet wide) at Montclair State University, Montclair, NJ. The sidewalk is situated in a "high use" area of MSU's campus and will be monitored long-term for evidence of wear, cracking, spalling, weathering and leachability underneath the new sidewalk.

To this end, about one ton of Ecomelt from Passaic River sediment was dried and ground to cement fineness (<50 μm) in a batch ball mill. The batch grinding work was performed at the laboratories of CTLGroup (formerly Construction Technology Laboratories, Skokie, IL). CTLGroup also conducted the Ecomelt characterization testing described below.

As part of their work, CTLGroup developed a mix design for the Ecomelt that can be used for the beneficial use project. The mix design (Table 26) specifies the amounts of Ecomelt, Portland cement, sand, gravel, water, and admixtures that must be mixed together to yield concrete with the desired properties for the beneficial use application. Ecomelt is used as a 40 percent (by weight) replacement for Portland cement in the mix design.

A formal application for Acceptable Use Determination (AUD) was submitted to New Jersey Department of Environmental Protection (NJ-DEP) for the beneficial use project. The AUD application, supporting documentation, and AUD issued by NJ-DEP are included in Appendix H. The one ton of finely ground Ecomelt in five 55-gallon drums was shipped to MSU on May 1, 2008.

Table 26. Mix Design for Ecomelt/Portland Cement Concrete Batching

| Mixes | Control | Ecomelt/Portland |
|---|---|---|
| Type I cement (Portland), wt % | 100 | 60 |
| Ecomelt, wt % | 0 | 40 |
| **Mix Design** | | |
| Cement (Continental), lb | 564 | 338.4 |
| Ecomelt (GTI), lb | 0 | 225.6 |
| 1" Coarse Aggregate (Vulcan), lb | 1875 | 1875 |
| Fine Aggregate (McHenry Sand), lb | 1256 | 1222 |
| Water (City), lb | 255 | 255 |
| Air Entraining Agent (Daravair), oz/cwt | 1.00 | 2.55 |
| Water Reducing Agent (WRDA 64), oz/cwt | 4.25 | 5.00 |
| **Fresh Properties** | | |
| Fresh Density, $lb/ft^3$ | 145.4 | 145.4 |
| Slump, inches | 4.00 | 4.00 |
| Air content, % | 6.2 | 5.7 |
| Yield, $ft^3/yd^3$ | 27.2 | 26.9 |
| **Time of Setting** | | |
| Initial, hr:min | 6:21 | 6:33 |
| Final, hr:min | 7:37 | 8:19 |

An AUD was issued to ECH by NJ-DEP for the remaining Stratus Petroleum sediment and Ecomelt on the Cement-Lock demo plant site. The Ecomelt (about 16.9 tons) and Stratus Petroleum sediment (about 105.4 tons) were beneficially used as geotechnical fill at the ProLogis Elizabeth Seaport Business Park (Elizabeth, NJ). The remaining Passaic River sediment could not be beneficially used without further treatment or processing, because its dioxin/furan concentration exceeded the land-disposal limit of 1 ppb and its PCB concentration exceeded the land-disposal limit of 2 ppm. Therefore, all 146.2 tons of Passaic River sediment remaining were transported off site and disposed at a secure landfill at the Wayne Disposal, Inc., Site #2 Landfill, 49350 N. I-94 Service Drive, Belleville, MI 48211. Details are included in Appendix I.

### Characterization of Ecomelt from Passaic River Sediment

CTLGroup conducted tests on samples of Ecomelt from Passaic River sediment to determine suitability as a partial replacement for Portland cement in concrete. The objective of these tests was to characterize the concrete and establish a mix design for the beneficial use project at Montclair State University. The results of these tests are summarized below.

The initial sample of Ecomelt was finely ground and blended with ordinary Portland cement at a 40:60 Ecomelt/Portland cement weight ratio. Forty percent was selected because it represents the maximum replacement of Portland cement by a pozzolanic material allowed under ASTM C 595 (Standard Specification for Blended Hydraulic Cements). The blended cement was subjected to compressive strength tests according to ASTM C 109 (mortar samples) and the results compared with C 595 specifications. The results (Table 27) showed that after 7 and 28 days of curing, the mortar samples made with 40:60 Ecomelt/Portland cement exceeded the compressive strength of the control mortar specimens as well as the ASTM C 595 specifications for blended cement.

Table 27. Results of Compressive Strength Tests Conducted on Mortar Samples Made with Ecomelt/Portland (40:60 wt %) Blended Cement and Control Cement

| Days of Curing | Ecomelt/Portland Blended Cement Mortar | Control Mortar | ASTM C 595 Specification |
|---|---|---|---|
| | Compressive Strength, psi (MPa) | | |
| 1 | 1,800 (12.4) | -- | -- |
| 3 | 3,680 (25.4) | 3,690 (25.5) | 1,890 (13.0) |
| 7 | 5,300 (36.5) | 4,860 (33.6) | 2,900 (20.0) |
| 28 | 7,550 (52.1) | 6,900 (47.8) | 3,620 (25.0) |

In their report, CTLGroup concluded that "the Ecomelt appears to be potentially suitable as a 40% replacement for Portland cement in concrete for use in general construction and/or where high early strength is required." CTLGroup further recommended that additional tests be conducted on a larger batch of Ecomelt so that an appropriate concrete mix design can be developed for a specific application.

Subsequently, ECH provided several hundred pounds of Ecomelt from Passaic River sediment to CTLGroup to conduct the recommended larger-scale tests. The tests are standard methods from the American Society for Testing and Materials (ASTM) and include:

- Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance (ASTM C-403)
- Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C-39)
- Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (ASTM C-78)
- Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete (AST C-157)
- Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (ASTM C-666)

- Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals (ASTM C-672)
- Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration [ASTM C-1202 (AASHTO T 277)]

The results of these tests are discussed in detail below. The complete reports prepared by CTLGroup for EPA SITE and GTI are included in Appendix J.

**Time of Setting of Concrete:** The initial and final setting times for the Ecomelt/Portland cement concrete and Portland cement concrete control were determined according to ASTM C 403. The initial setting times (refer to Table 26) were similar for the control and test mix at 6:21 and 6:33 (hr:min), respectively. The final setting times were 7:37 and 8:19 (hr:min) for the control and test mix, respectively. Pozzolanic materials such as Ecomelt are typically slow to react, but eventually achieve characteristics similar to those of ordinary Portland cement. In the event that a quicker setting time is required, an accelerator such as calcium chloride ($CaCl_2$) could be added to the concrete mix.

**Compressive Strength:** The compressive strengths of cylindrical concrete specimens (4 inches in diameter by 8 inches long) were determined after 4, 7, 28, and 56 days of curing. The results presented in Table 28, show that the compressive strengths of the Ecomelt/Portland specimens were 2,850 psi, 3,450 psi, 5,700 psi, and 6,650 psi, respectively. The compressive strengths measured were 63 percent, 72 percent, 96, and 100 percent of the control after 4, 7, 28, and 56 days, respectively. The Ecomelt-based blended cement achieved compressive strength at a slower rate than the control. However, it did gain strength with time. Figure 13 shows a specimen of Ecomelt-based blended cement concrete ready for compressive strength testing. Figure 14 shows the specimen after testing. It showed a typical conical break.

Table 28. Results of Compressive Strength Tests Conducted on Concrete Samples Made with Ecomelt/Portland (40:60 wt %) Blended Cement and Control Cement

| Days of Curing | Ecomelt/Portland Blended Cement Concrete | Control Concrete |
|---|---|---|
| | Compressive Strength, psi (MPa) | |
| 4 | 2,850 | 4,500 |
| 7 | 3,450 | 4,800 |
| 28 | 5,700 | 5,950 |
| 56 | 6,650 | 6,650 |

Figure 13. Concrete Cylinder of Ecomelt-Based Blended Cement in Position for Compressive Strength Testing at CTLGroup Laboratories

Figure 14. Concrete Cylinder of Ecomelt-Based Blended Cement After Compressive Strength Testing at CTLGroup Laboratories

**Flexural Strength:** The flexural strengths (modulus of rupture) of concrete block specimens were determined after 4, 7, and 28 days of curing to be 510 psi, 660 psi, and 910 psi, respectively. The flexural strengths measured were 74 percent, 89 percent, and 99 percent of the control after 4, 7, and 28 days, respectively. Figure 15 shows a specimen of Ecomelt-based blended cement concrete ready for flexural strength testing. Figure 16 shows the specimen after testing. The specimen fractured at the tension surface at the middle one-third of the span length.

**Drying Shrinkage:** The drying shrinkage characteristics of the control and test mix concrete specimens were determined according to ASTM C 157. After 56 days of curing, the control specimen showed a shrinkage value of -0.038 percent. The Ecomelt test specimen showed a shrinkage value of -0.031 percent. As less shrinkage is preferred, this indicates that the Ecomelt-based specimen has a slightly lower shrinkage characteristic than that of the control.

**Freeze-Thaw Testing:** In the freeze-thaw test (ASTM C 666), concrete block samples are cyclically cooled from 40° to 0°F and then heated to 40°F over the course of 2 to 5 hours (1 cycle). The freeze-thaw apparatus is usually automated and can be operated around the clock. The test samples are subjected to up 300 freeze-thaw cycles or until the relative dynamic modulus of elasticity falls below 60 percent. The test samples are periodically weighed and measured. After 301 freeze-thaw cycles, the concrete blocks made with Ecomelt/Portland cement showed a relative dynamic modulus of elasticity of 91 percent; whereas the control specimens showed a relative dynamic modulus of elasticity of 90 percent. The freeze-thaw resistance characteristic of the Ecomelt-based blended cement was similar to that of the control. Figure 17 shows the concrete test specimens in the freeze-thaw apparatus (cover open).

**Scaling Resistance to Deicer Chemicals:** Concrete test specimens were subjected to ASTM C 672 to determine resistance of the concrete surface to scaling due to exposure to deicer chemicals, specifically calcium chloride ($CaCl_2$). The results showed that the deicer chemical attacked the Ecomelt/Portland cement concrete samples more aggressively than the control samples. After 50 cycles, the Ecomelt/Portland cement samples showed a cumulative mass loss of 0.4 $lb/ft^2$, while the control showed a cumulative mass loss of 0.04 $lb/ft^2$.

**Chloride Ion Penetration:** Concrete test specimens were subjected to ASTM C 1202 (AASHTO T 277) to determine the concrete ability to resist chloride ion penetration. The

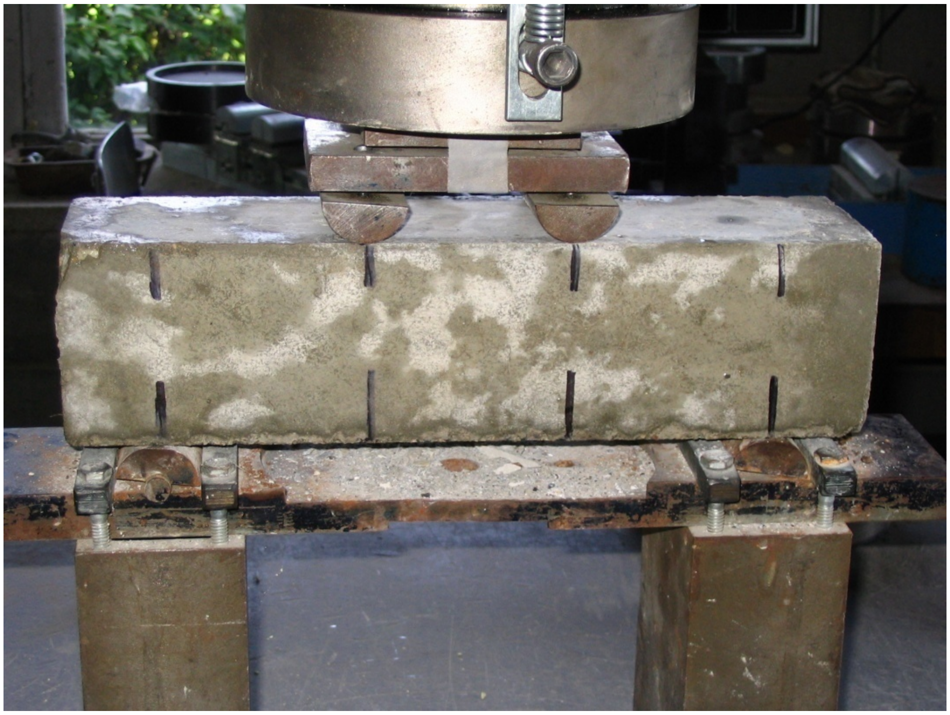


Figure 15. Concrete Block of Ecomelt-Based Blended Cement in Position for Flexural Strength Testing at CTLGroup Laboratories

Figure 16. Concrete Block of Ecomelt-Based Blended Cement After Flexural Strength Testing at CTLGroup Laboratories

Ecomelt/Portland cement blend specimens showed “Very Low” chloride ion permeability compared to “Moderate” chloride ion permeability for the control, where a lower result is preferred.


Figure 17. Concrete Blocks of Ecomelt-Based Blended Cement Being Subjected to Freeze-Thaw Cycles at CTLGroup Laboratories

**Summary:** A mix design for concrete using Ecomelt as a partial replacement for Portland cement has been developed for the beneficial use project. The major chemical and physical characteristics of concrete made with Ecomelt/Portland cement blend have been determined.

The time of setting for the Ecomelt/Portland cement blend was slower than that of the control. The compressive and flexural strengths were similar to those of the control, but typical of pozzolanic materials took longer to achieve. Drying shrinkage and freeze-thaw results were similar to those of the control.

Resistance to deicer scaling was lower for the Ecomelt/Portland cement specimen compared to the control. CTLGroup offered several explanations for this result: The test sample may have lower entrained air content than the control, which would result in lower resistance to the deicer salt. Pore water bleeding to the concrete specimen surface may evaporate leaving calcium hydroxide [$Ca(OH)_2$] to react with $CO_2$ in the atmosphere generating calcium carbonate

($CaCO_3$), which is fairly weak.  Also, finishing the concrete sample may have disturbed the air entrained at the surface.  CTLGroup suggested that reducing the Ecomelt replacement from 40 to 30 percent of the Portland cement requirement could reduce scaling.  They also suggested that using a curing compound on the concrete surface after pouring could reduce scaling.

Resistance to chloride ion penetration was better with the Ecomelt/Portland cement specimen than the control.

**Plant Demolition and Site Restoration:**  As part of the overall Cement-Lock demonstration project, the plant was removed from the site and the site was restored per the lease agreement between IMTT and ECH.  Details of the plant demolition, site restoration, and materials disposal are included in Appendix K.

# V. ECONOMIC EVALUATION AND ASSESSMENT

A preliminary economic evaluation of the Cement-Lock Technology for remediating contaminated sediments was presented in the Final Report for Phase I submitted to the NJ-DOT/OMR.[8] In that assessment, natural gas alone was considered for fueling the process. No co-processing of other wastes with or without calorific value was considered. The enterprise-based cost estimate considered a sustainable Cement-Lock industry in which capital costs were amortized and depreciation expensed over 20 years.

In 2006, Malcolm Pirnie Inc. (MPI) requested that GTI provide project-based estimates of sediment processing costs utilizing the Cement-Lock technology. MPI was preparing a Focused Feasibility Study (FFS) for early action restoration of the lower Passaic River for the U.S. EPA under the Superfund Program (the Lower Passaic River is a part of the Diamond Alkali Superfund Site); by the U.S. Army Corps of Engineers; NJ-DOT under the Water Resources Development Act; and by the U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, and NJ-DEP as Natural Resource Trustees.

Under the conditions imposed by MPI on GTI for the FFS response, capital costs were to be amortized over the life of the project ranging from 4 to 9 years with the quantity of sediment being processed ranging from 2 to 7.6 million $yd^3$. If sufficient heat were available in the flue gases, then power generation could be considered as another process by-product and included in the economic assessment.

What follows is 1) a revised and updated economic assessment for the Cement-Lock Technology and 2) the project-based economic assessment for the FFS.

**Economic Evaluation and Assessment (2007):** A major objective of the overall Sediment Decontamination Demonstration Project was to demonstrate that the treatment technology can be economically viable in the NY/NJ Harbor marketplace. Specifically, the technology must be able to demonstrate that the required tipping fee for sediment dredged from harbor navigation channels does not exceed $35/$yd^3$. The following discussion provides an evaluation and assessment of the enterprise-based economics of processing dredged sediment through a commercial-scale (500,000 $yd^3$/year capacity) Cement-Lock plant.

As Cement-Lock is a high-temperature thermal technology, it is energy intensive and its economics are sensitive to the cost of the fuel used. When the Cement-Lock Technology was proposed for the NJ Sediment Decontamination Demonstration Project, the natural gas cost was $4 per million Btu. For this economic evaluation, the natural gas cost of $9.33/million Btu has been based on the average cost of natural gas during the previous 12-month span (April 2007 to March 2008) for interruptible gas service in Public Service Electric & Gas' service area.

The Cement-Lock Technology is flexible regarding co-processing of other materials with sediment, some of which may have significant calorific value. For example, supplemental or alternate fuels, such as waste petroleum oils, sludges, tanker bottoms, municipal solid wastes, municipal sewage sludges, medical wastes, and shredded tires can be used to reduce energy-related costs. Some of these materials have tipping fees associated with their use, which increase revenues and enhance the Cement-Lock economics. All economic projections shown here assume no benefit from co-processing other materials and are therefore conservative.

Although no supplemental or alternate fuels were tested under this current program, GTI has conducted small pilot-scale tests in which Ecomelt was produced from oil-contaminated soil co-processed with paper and plastics as surrogate for municipal solids waste.[3] Similarly, GTI has conducted several laboratory-scale tests with river sediment,[11] recycled concrete,[12] PCB (surrogate) contaminated soil,[14] coal fly and bottom ash[15] as well as uranium oxide[4] to produce Ecomelt.

Many waste-to-energy projects have successfully burned municipal solid wastes to ash and converted the thermal energy into electric power.[16] The cement industry has a long history of using waste oils and rubber tires as supplemental energy sources for producing Portland cement.[19] Although not every combination of waste or alternate fuel has been tested, the developers of the Cement-Lock Technology are confident that suitable Ecomelt can be made from these materials provided the proper mix of modifiers is included.

The economic evaluation includes base case, basis of design, plant description, equipment summary, equipment cost estimate, total installed cost, and estimated operating cost. Costs for on-site sediment storage, screening, and handling are included as operating expense. The sensitivity of the break-even tipping fee to several process and economic parameters was also assessed.

**Base Case**

The Base Case is a preliminary design and cost estimate of a commercial-scale Cement-Lock plant to decontaminate and convert 500,000 $yd^3$/year of dredged sediment to 243,000 ton/year of dry and pulverized Ecomelt product. The Ecomelt is shipped to an off-site location, blended with Portland cement, and used as construction-grade cement. The plant also generates 9.55 MW of electricity for export.

The estimated purchased major equipment cost and the total installed cost are $30,409,600 and $88,100,420, respectively, which includes 8 acres of on-site sediment storage. A natural gas cost of $9.33/million Btu was based on the averaged natural gas cost for the 12-month span (12/06 - 11/07) in PSE&G's service area. Using these conditions and assumptions, the break-even tipping fee for the dredged sediment is $40.05/$yd^3$ of dredged sediment.

The capital and operating costs can be reduced by further optimizing the design and operations including but not limited to co-processing of waste materials containing calorific value; mechanical dewatering combined with thermal drying of dredged sediment; combustion of oxygen-enriched-air or oxygen with natural gas/other fuels in the Ecomelt Generator; and improved process and equipment design and costing.

**Basis of Design**

The basis of design and assumptions used in design calculations are summarized below:

1. The proposed plant operates on a 24 hour/day and 7 day/week basis with an on-line factor of 90 percent.
2. The plant consists of multiple operating trains with no spare equipment.
3. The proximate, ultimate, and ash analyses of "as-dredged" sediment are given in Table 29 below. The sediment is screened to a particle size of less than 2 inches.
4. Depending upon the plant location, dredged sediment is unloaded from barges or supply trucks, screened to remove oversized debris and stored in the on-site sediment storage area. For the base case, the sediment storage area is 8 acres. The sediment is then transferred to the sediment dryers by crane unlade equipped with clamshell buckets.

Table 29. Chemical Characterization of Dredged Sediment for Commercial Process Design

| **Proximate Analysis, wt %** | | | **Ash Analysis, wt % (dry)** | |
|---|---|---|---|---|
| Moisture | 60.00 | | $SiO_2$ | 66.67 |
| Ash | 36.52 | | $Al_2O_3$ | 13.71 |
| Volatile Matter | 3.43 | | $TiO_2$ | 0.87 |
| Fixed Carbon | 0.05 | | $Fe_2O_3$ | 6.83 |
| Total | 100.00 | | CaO | 1.78 |
| | | | MgO | 2.15 |
| **Ultimate Analysis, wt % (dry)** | | | $K_2O$ | 2.59 |
| Ash | 91.31 | | $Na_2O$ | 2.24 |
| Carbon | 3.53 | | $SO_3$ | 1.06 |
| Hydrogen | 0.66 | | $P_2O_5$ | 0.48 |
| Nitrogen | 0.33 | | So | 0.02 |
| Sulfur | 0.83 | | BaO | 0.06 |
| Oxygen (by diff.) | 3.34 | | $Mn_3O_4$ | 0.12 |
| Total | 100.00 | | Others (by diff.) | 1.42 |
| | | | Total | 100.00 |
| Sediment Calorific Value (HHV), Btu/lb (dry) | | | | 700 |
| Dredged Sediment Bulk Density, lb/ft$^3$ (wet) | | | | 77 |

5. Dredged sediment is dried in indirect-contact, rotary steam-tube dryers where the sediment moisture content is reduced from 60 to 15 percent. Much of the sediment free water could be removed using mechanical dewatering equipment as was done for the demo plant project. The sediment solids in the dryers are maintained at a temperature of <220°F to prevent volatilization of contaminants during drying. Effluent gases from the sediment dryers are fed to the Gas Cleanup Section for treatment before being discharged to the atmosphere. Superheated low-pressure steam generated from the heat recovery boilers is used for sediment drying.
6. Dried sediment is blended with a predetermined amount of modifier solids in the mixers before being fed to the Ecomelt Generators. The sediment storage pit, sediment dryers and mixers are located inside of the sediment receiving building.
7. The feed materials are melted in the rotary kiln Ecomelt Generators at 2400°F in the presence of excess oxygen. Superficial gas velocity in the kiln and oxygen concentration at the kiln outlet are maintained at less than 15 ft/s and greater than 2 volume percent (dry basis), respectively, to ensure complete destruction of contaminants and to minimize the carryover of fly ash/slag.
8. The temperature and gas residence time in the secondary combustion chambers (SCC) are maintained at >2200°F and 2 seconds, respectively. Oversized vertical SCCs are used to facilitate the settling of fly ash/slag carried over from the Ecomelt Generators and to minimize the entrainment of fly ash/slag to the heat recovery boilers.
9. Hot off-gases from the SCCs are cooled to 300°F in the heat recovery boilers where superheated, high-pressure steam at 600 Pisa and 900°F is generated. A slip stream of the steam generated is depressurized and fed to the sediment and Ecomelt dryers for drying of

dredged sediment and Ecomelt. The remaining steam is fed to steam turbine generators to generate electric power.

10. Powdered lime and activated carbon sorbents are injected separately into the cooled off-gases exiting the heat recovery boilers where acid gases and volatile metal species are removed. Spent lime and carbon sorbents are then removed from the off-gas stream in separate lime and carbon bag houses. Spent sorbents are collected for disposal. Conventional dosage rates are used for the sorbents. CEMS are used to monitor flue gas contaminants so that dosage adjustments can be made rapidly. Cleaned off-gas is then vented to the atmosphere through the exhaust fans and an exhaust stack.
11. Ecomelt is dewatered by inclined conveyors of the Ecomelt granulators and then dried in the Ecomelt dryer by indirect contact with superheated, low-pressure steam generated from the heat recovery boilers. The off-gas from the Ecomelt dryer passes through a bag house prior to being discharged to the atmosphere. Dried Ecomelt is pulverized in a pulverizer system. Dried and pulverized Ecomelt product is stored in a hopper.
12. Ecomelt is shipped to an off-site location for blending with Portland cement to yield construction-grade blended cement. The Ecomelt could also be sent to ready-mix plants where it would be used as a partial replacement for Portland cement in the production of concrete. The off-site processing is outside the battery limits of the Cement-Lock plant.

## Plant Description

A schematic flow diagram of the proposed plant is shown in Figure 18. The plant consists of Feed Handling, Sediment Treatment, Gas Cleanup, and Power Generation sections. A brief description of each section is given below.

### Section 100: Feed Handling

Dredged sediment is received at the plant site, off-loaded from barges or trucks using clamshell buckets into the on-site (long-term) sediment storage area. The sediment is screened to remove oversized debris in two stages: Grizzly screens remove large, oversized debris, then finer (-2 inches) screens remove smaller debris. From the long-term storage, sediment is delivered to the process plant by trucks and weighed by truck scales near the receiving building (RB-101). The trucks are lined with membranes to prevent spilling and dripping during shipping. The truck scales can weigh the largest supply trucks allowed on the road. Sediment is then dumped into a storage pit inside the receiving building. The receiving building is under a slight negative pressure and has a large floor area to allow quick and easy maneuvering of several supply trucks unloading at the same time.

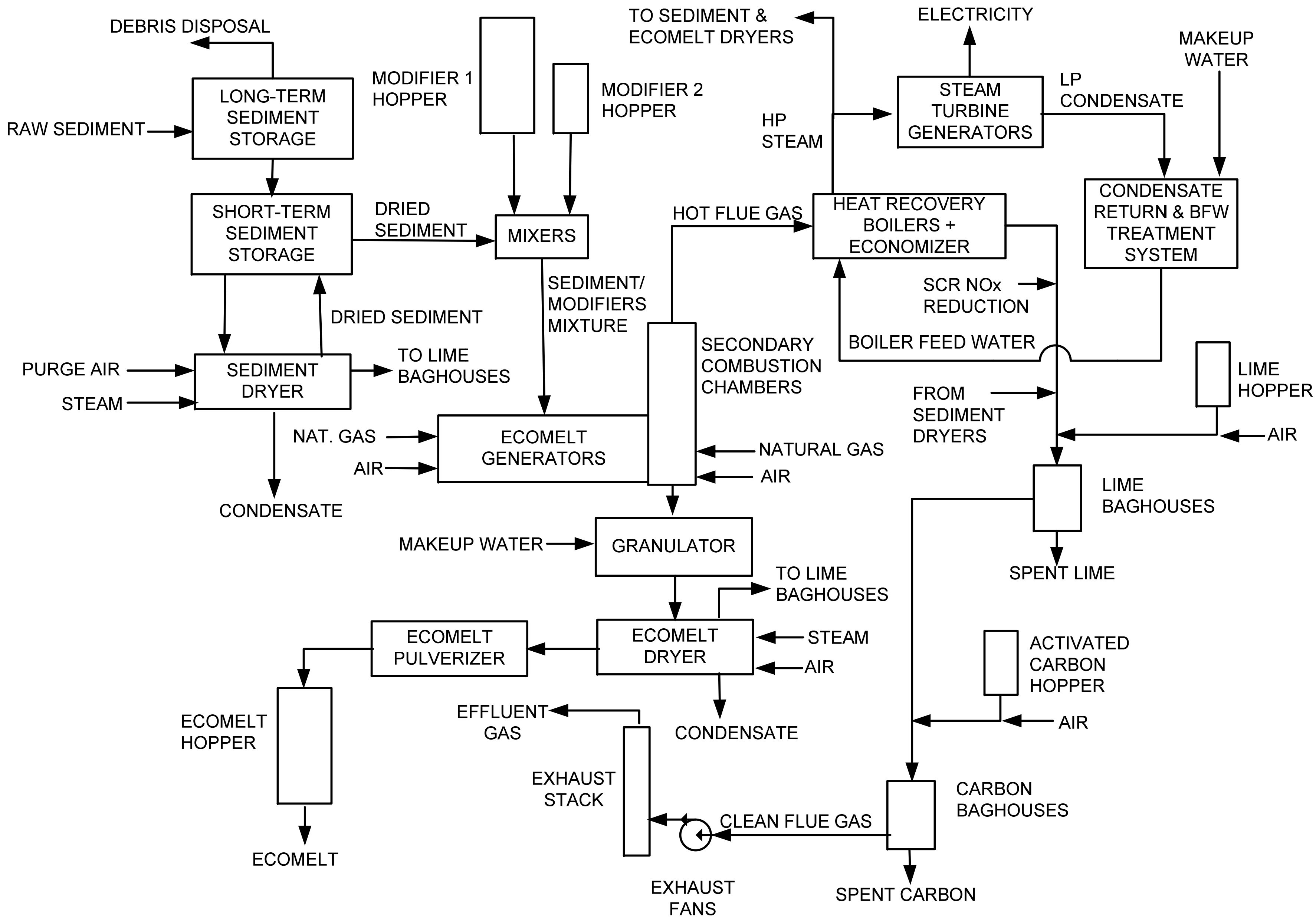



Figure 18. Schematic Flow Diagram of a Commercial-Scale Cement-Lock Plant (Base Case)

The sediment storage pit consists of two compartments: one for wet sediment and one for dried sediment. Each compartment provides two days of plant capacity. Wet sediment is transferred from the storage pit to Sediment Dryers (SD-101) by Crane Unloaders (CU-101) equipped with clamshell buckets. Two 100 percent capacity crane unloaders are used to ensure continuous operation. Wet sediment is dried in two 50 percent capacity Sediment Dryers (SD-101). The Sediment Dryers are indirect-contact, rotary steam-tube dryers. Dried sediment is returned to the storage pit by Dried Sediment Conveyors (BC-101). The temperature of sediment solids in the dryers is maintained at <220°F to prevent volatilization of contaminants from dredged sediment during drying. Superheated low-pressure steam generated in the Heat Recovery Boilers (HR-301) is used for drying. Condensate from the sediment dryers is collected and returned to the Heat Recovery Boilers by Condensate Pumps (CP-401) and Boiler Feed Water Pumps (WP-401). Off-gas from the sediment dryers is fed to the Gas Cleanup Section for treatment before discharge to the atmosphere.

Modifier solids are pneumatically transferred from supply trucks to Modifier 1 and Modifier 2 Hoppers (TK-101 and TK-102). The hoppers are equipped with discharge cones, rotary feeders and discharge conveyors. Modifier solids are fed from the hoppers to two 50 percent capacity Mixers (MX-101) by Modifier Conveyors (SC-101 and SC-102). Dried sediment is fed from the storage pit to the mixers by Dried Sediment Conveyors (BC-102).

The sediment storage pit, sediment dryers and mixers are located inside the receiving building.

### Section 200: Sediment Treatment

The dried sediment and modifiers mixture is fed from the Mixers (MX-101) to four 25 percent capacity Ecomelt Generators (EG-201). The Ecomelt Generators are rotary kilns where the feed solids are melted at 2400°F in the presence of excess oxygen with sufficient solids and gas residence time so that the organic contaminants contained in the sediment are destroyed and converted to carbon dioxide and water. Superficial gas velocity in the kilns and oxygen concentration at the kiln outlets are maintained at <15 ft/s and >2 volume percent (dry basis), respectively, to ensure complete destruction of contaminant species and to minimize the carryover of fly ash.

The molten slag discharged from the Ecomelt Generators (EG-201) is quenched with water, solidified and converted to Ecomelt granules in four 25 percent capacity Granulators (GR-202). Any non-volatile inorganic contaminants contained in the sediment are immobilized in the matrix of the resultant Ecomelt granules. Ecomelt granules are then dewatered in the granulators and conveyed to the Ecomelt Dryer (ED-201). The Ecomelt dryer is a rotary steam-tube dryer where the Ecomelt granules are indirectly dried with low-pressure steam generated from the Heat Recovery Boilers (HR-301). Dry Ecomelt is pulverized in the Ecomelt Pulverizer (EP-201), stored in the Ecomelt Hopper (TK-201), and then hauled away by trucks for off-site processing.

Flue gases from the Ecomelt Generators are fed to four 25 percent capacity Secondary Combustion Chambers (SCC, SC-202) where the flue gases are further combusted with natural gas and air, if necessary, to ensure complete destruction of contaminants contained in the flue gases.

**Section 300: Gas Clean-Up**

Hot flue gas from the SCCs is cooled to 300°F in four 25 percent capacity Heat Recovery Boilers (HR-301) where superheated high pressure steam is generated at 600 psia and 900°F. A slip stream of steam is depressurized to 150 psia and fed to the sediment dryers and Ecomelt dryer. The remaining steam is fed to four 25 percent capacity Steam Turbine Generators (ST-401) where electricity is generated.

Selective Catalytic NOx Reduction (SCR) is used to reduce the emission of NOx from the flue gas stream prior to the slip stream being taken. Ammonia or urea is injected at the appropriate rate determined from CEMS output to achieve 95 percent NOx reduction and minimize ammonia slip. Because the ammonia or urea must be injected into the flue gas stream at the proper temperature prior to the flue gas contacting the SCR catalyst, heat recovery for steam generation must be staged accordingly.

Cooled flue gases exiting the Heat Recovery Boilers is combined with the off-gases from the Sediment Dryers (SD-101) and Ecomelt dryer and fed to two 50 percent capacity gas clean-up systems. Powdered lime sorbent is injected into the cooled flue gases where acid gases are removed. The flue gases are then fed to lime bag houses (BH-301) where spent lime sorbent is collected for disposal. Powdered activated carbon sorbent is then injected into the flue gases exiting the lime bag houses where volatile metal species are removed. The flue gases are then fed to carbon bag houses (BH-302) where the spent carbon sorbent is collected for disposal.

Cleaned flue gases from the carbon bag houses are fed to two 100 percent capacity Exhaust Fans (B-301) and discharged to the atmosphere through one 100 percent Exhaust Stack (ST-301).

### Section 400: Power Generation

Superheated high-pressure steam generated in Heat Recovery Boilers (HR-301) is fed to four 25 percent capacity Steam Turbine Generators (ST-401) where electricity is generated. A portion of the generated electricity is used to supply the power required to operate the entire plant equipment. The remaining power is exported to the grid.

The exhaust steam from the steam turbine generators is condensed and recycled to the heat recovery boilers through four 25 percent capacity condensate return system trains. The condensate return system consists of Condensers (CD-401), Condensate Pumps (CP-401), and Boiler Feed Water Pumps (WP-401). The Boiler Feed Water Pumps raise the pressure of the returned condensate and makeup boiler feed water to the operating pressure level of the heat recovery boilers. Makeup water is treated in one 100 percent capacity Boiler Feed Water Treatment System (WT-401) before it is fed to the condensate return system. The requirements for boiler feed water are quite stringent regarding hardness and dissolved air. Therefore, the makeup water must be softened and deaerated prior to being fed to the condensate return system.

Cooling water to Condensers (CD-401) is provided by one 100 percent capacity Cooling Tower (CT-401) and four 25 percent capacity Cooling Water Pumps (CP-402).

## Mass Balance

The plant-wide mass balance is given below in Table 30.

## Utility Requirements

The estimated requirements for electricity, natural gas and water for the plant are presented in Table 31. A total of 12.25 MW is generated in Steam Turbine Generators (ST-401). The electric power requirement for the plant is 2.7 MW. The net power generated for export is 9.55 MW. Power requirement includes Ecomelt pulverization.

Table 30. Plant-Wide Mass Balance for Commercial-Scale Cement-Lock Process Design

| Input Streams | lb/hr | Output Streams | lb/hr |
|---|---|---|---|
| Dredged sediment (wet) | 131,849 | Dry Ecomelt | 61,613 |
| Modifier 1 | 21,600 | Exhaust gas (flue) | 562,150 |
| Modifier 2 | 1,360 | Spent lime | 2,403 |
| Purge air to sediment dryers | 111,839 | Spent carbon | 124 |
| Natural gas to Ecomelt Generators | 14,124 | Ecomelt dryer off-gas | 17,814 |
| Air to Ecomelt Generators | 286,707 | | |
| Makeup water to granulators | 60,003 | | |
| Lime sorbent (acid-gas capture) | 1,529 | | |
| Activated carbon sorbent (Hg capture) | 124 | | |
| Conveying air for lime | 2,000 | | |
| Conveying air for activated carbon | 2,000 | | |
| Purge air to Ecomelt dryers | 10,969 | | |
| **Total In** | 644,104 | **Total Out** | 644,104 |

Table 31. Plant Utility Requirements

| | |
|---|---|
| Electricity, kW-hr/day (includes Ecomelt grinding) | 64,895 |
| kW-hr/ton Dredged Sediment | 41.02 |
| Plant Electrical Requirement, MW | 2.70 |
| Natural Gas, Btu/day | 7,815,723,787 |
| Btu/ton Dredged Sediment | 4,939,808 |
| Water, gal/day | 397,654 |
| gal/ton Dredged Sediment | 251 |

## Equipment Summary

Brief summaries of the major process equipment items for the Feed Handling, Sediment Treatment, Gas Cleanup, and Power Generation sections including key design and operating parameters are included in Table 32.

Table 32. Equipment Summary for 500,000 $yd^3$/year Sediment Cement-Lock Plant

| Equip. No. | Equipment Name | Qty | Equipment Description |
|---|---|---|---|
| **Section 100: Feed Handling** | | | |
| RB-101 | Sediment Receiving Building | 1 | Enclosed building houses a Sediment Storage Pit with two compartments – one for dredged sediment and one for dried sediment, Crane Unloaders (CU-101), Sediment Dryers (SD-101) and Mixers (MX-101). Equipped with multiple bay doors to allow easy maneuvering of sediment supply trucks and unloading operation. |
| CU-101 | Crane Unloader | 2 | Overhead bridge crane equipped with clamshell bucket rated to transfer 70 ton/hr of dredged sediment from Sediment Storage Pit to Sediment Dryer (SD-101). Equipped with 350 HP motor. |

| Equip. No. | Equipment Name | Qty | Equipment Description |
|---|---|---|---|
| SD-101 | Sediment Dryer | 2 | Rotary steam-tube dryer rated to dry 33 ton/hr dredged sediment from 60 to 15% water content by condensing 150 psig supersaturated steam. Sediment temperature is maintained below 220°F. Equipped with carbon steel shell, internal steam tubes, and 125 HP motor and drive. |
| SF-101 | Sediment Dryer Fan | 2 | Induced draft exhaust fan rated to discharge 25,000 SCFM off gas from Sediment Dryers (SD-101) at 220°F and -6 inch (water gauge) to the atmosphere. Carbon steel structure, complete with damper, 40 HP motor and drive. |
| TK-101 | Modifier 1 Hopper | 1 | Storage hopper rated for 1000 tons granulated Modifier 1 solids. Equipped with multiple discharge cones, rotary feeders and discharge screw conveyors. |
| TK-102 | Modifier 2 Hopper | 1 | Storage hopper rated for 130 tons granulated Modifier 2 solids. Equipped with multiple discharge cones, rotary feeders and discharge screw conveyors. |
| BC-101 | Dried Sediment Conveyor | 2 | Enclosed belt conveyor rated to convey 20 ton/hr dried sediment containing 15% water and 85% solids from Sediment Dryers (SD-101) to Storage Pit. Carbon steel construction, complete with motor and drive. |
| BC-102 | Dried Sediment Conveyor | 2 | Enclosed belt conveyor rated to convey 20 ton/hr dried sediment containing 15% water and 85% solids from Storage Pit to Mixers (MX-101). Carbon steel construction, complete with motor and drive. |
| SC-101 | Modifier 1 Conveyor | 2 | Screw conveyor rated to convey 6 ton/hr granulated Modifier 1 solids from Modifier 1 Hopper (TK-101) to Mixers (MX-101). Carbon steel construction, complete with motor and drive. |
| SC-102 | Modifier 2 Conveyor | 2 | Screw conveyor rated to convey 2 ton/hr granulated Modifier 2 solids from Modifier 2 Hopper (TK-102) to Mixers (MX-101). Carbon steel construction, complete with motor and drive. |
| MX-101 | Sediment-Modifier Mixer | 2 | Continuous horizontal solids mixer rated to mix 16 ton/hr dried sediment and 6 ton/hr granulated modifier solids. Carbon steel construction, complete with 100 HP motor and drive. |
| BC-103 | Mixed Feed Conveyor | 4 | Enclosed belt conveyor rated to convey 11 ton/hr mixture of dried sediment and modifier solids from Mixers (MX-101) to Ecomelt Generators (EG-201). Carbon steel construction, complete with 15 HP motor and drive. |
| **Section 200: Sediment Treatment** | | | |
| EG-201 | Ecomelt Generator | 4 | Direct gas-fired, slagging rotary kiln system rated to melt 8 ton/hr dried sediment and 4 ton/hr modifier solids at a nominal temperature of 2400°F with excess air at over one hour solids residence time. Equipped with refractory-lined carbon steel shell, dropout box, gas-fired burner systems located on both ends, combustion and cooling air blowers, riding assemblies, and variable speed 100 HP motor and drive. |
| SC-201 | Secondary Combustion Chamber | 4 | Vertical combustion chamber to provide 2 seconds gas residence time at 2200°F for 19,000 SCFM flue gas exiting Ecomelt Generators (EG-201). Includes refractory-lined carbon steel vessel and gas-fired burner system. |

| Equip. No. | Equipment Name | Qty | Equipment Description |
|---|---|---|---|
| GR-201 | Granulator | 4 | Wet slag drag conveyor system rated to quench 8 ton/hr molten slag discharged from Ecomelt Generators (EG-201) at a nominal temperature of 2400°F with water. Equipped with water-filled tank, dewatering drag conveyor, and motor and drive. |
| BC-201 | Ecomelt Conveyor | 4 | Enclosed belt conveyor rated to discharge 8 ton/hr wet Ecomelt granules containing 90% solids and 10% water from Granulators (GR-201). Carbon steel, complete with variable speed motor and drive. |
| ED-201 | Ecomelt Dryer | 1 | Rotary steam-tube dryer rated to dry 34 ton/hr granulated solids containing 10% water by condensing 150 psia supersaturated steam. Equipped with carbon steel shell, internal steam tubes, and 125 HP motor and drive. |
| EP-201 | Ecomelt Pulverizer | 1 | Complete pulverizer system rated to pulverize 31 ton/hr dry granulated Ecomelt solids from minus ¼ inch to 95% minus 20 µm. Complete with grinding mill and motor, classifier system, cyclone separator, bag filter, product conveyor, exhaust fan and motor. |
| TK-201 | Ecomelt Hopper | 1 | Storage hopper rated for 1000 tons dry and pulverized Ecomelt solids. Equipped with discharge cone, rotary feeder and discharge screw conveyor. |
| **Section 300: Gas Cleanup** | | | |
| HR-301 | Heat Recovery Boiler | 4 | Packaged waste heat recovery boiler system rated to generate 38,000 lb/hr superheated high pressure steam at 600 psia and 900°F by cooling 19,000 SCFM hot flue gas exiting Secondary Combustion Chambers (SC-201) from 2400° to 300°F at 14.7 psia. Boiler system can handle dust laden flue gas with minimum fines buildup and gas pressure drop. Boiler is designed to allow easy cleaning of tube bundles and removal of fines. Boiler must also have included means of ammonia or urea injection at the proper location upstream of the SCR catalyst bed for NOx reduction. |
| TK-301 | Lime Hopper | 1 | Carbon steel storage hopper rated for 130 tons pulverized lime sorbent. Equipped with multiple aerated discharge cones and rotary feeders. |
| LB-301 | Lime Air Blower | 2 | Packaged air blower system rated to compress 300 SCFM ambient air to 25 psia, all carbon steel, complete with motor and drive. |
| BH-301 | Lime Bag house | 2 | Bag house rated to remove and collect ½ ton/hr pulverized spent lime from 110,000 ACFM flue gas at 300°F and -14 inch (water gauge) Equipped with fabric filters, support structure, insulation, platform and ladder, rotary feeder, discharge screw feeder, and motors and drives. |
| SC-301 | Spent Lime Conveyor | 2 | Screw conveyor rated to convey 1 ton/hr pulverized spent lime from lime Bag house (BH-301) to dumpster. All carbon steel, complete with motor and drive. |
| TK-302 | Activated Carbon Hopper | 1 | Carbon steel storage hopper rated for 20 tons pulverized activated carbon sorbent. Equipped with aerated discharge cone and rotary feeder. |
| CB-301 | Carbon Air Blower | 2 | Packaged air blower system rated to compress 300 SCFM ambient air to 25 psia, all carbon steel, complete with motor and drive. |

| Equip. No. | Equipment Name | Qty | Equipment Description |
|---|---|---|---|
| BH-302 | Carbon Bag house | 2 | Bag house rated to remove and collect 200 lb/hr pulverized spent carbon from 110,000 ACFM flue gas at 350°F and -20 inch (water gauge) Equipped with fabric filters, support structure, insulation, platform and ladder, rotary feeder, discharge screw feeder, and motors and drives. |
| SC-302 | Spent Carbon Conveyor | 2 | Screw conveyor rated to convey 200 lb/hr pulverized spent carbon from Carbon Bag house (BH-302) to dumpster. Carbon steel, complete with motor and drive. |
| EF-301 | Exhaust Fan | 2 | Induced draft exhaust fan rated to discharge 150,000 SCFM effluent gas from Carbon Bag houses (BH-302) at 300°F and -20 inch (water gauge) to atmosphere. All carbon steel structure, complete with damper, 400 HP motor and drive. |
| NR-101 | NOx Reduction | 1 | Selective Catalytic NOx Reduction (SCR) equipment including $NH_3$ or urea injection for removing minimum 95 percent of NOx emissions from natural gas combustion system. Injection of reductant must be at a temperature suitable for the SCR catalyst. |
| ST-301 | Exhaust Stack | 1 | Carbon steel vent stack rated to discharge 210,000 ACFM cleaned effluent gas at 300°F to atmosphere. |
| **Section 400: Power Generation** | | | |
| WT-401 | Boiler Feed Water Treatment | 1 | Packaged boiler feed water treatment system rated to deliver 310 gpm feed water for heat recovery boilers to generate superheated high-pressure steam at 600 psia and 900°F. Equipped with storage tank, water softener system, deaerator system and feed water pump. |
| ST-401 | Steam Turbine Generator | 4 | High-efficient steam turbine generator rated to generate 3 MW electricity from 21,100 lb/hr superheated high pressure steam generated from Heat Recovery Boilers (HR-301), fed to turbine generator at 600 psia and 900°F. |
| CD-401 | Condenser | 4 | Tube and shell heat exchanger rated to condense exhaust steam from Steam Turbine Generators (ST-401) at 90°F and 1½ in. Hg by contacting with cooling water. 20 x $10^6$ Btu/hr heat duty. Carbon steel construction. |
| CP-401 | Condensate Pump | 4 | Centrifugal pump rated for 80 gpm condensate at 90°F and 10 psi differential pressure. Carbon steel, complete with motor and drive. |
| WP-401 | Boiler Feed Water Pump | 4 | Reciprocating pump rated for 80 gpm boiler feed water and 635 psi differential pressure. All carbon steel, complete with 50 HP motor and drive. |
| CT-401 | Cooling Tower | 1 | Conventional cooling tower rated for 1,300 gpm cooling water. |
| CP-401 | Cooling Water Pump | 4 | Centrifugal pump rated for 1,300 gpm cooling water and 30 psi differential pressure. Carbon steel, complete with 25 HP motor and drive. |

## Base Case Cost Estimate

The purchased cost for major process equipment items totals $30,409,600, which represents an escalation of 4 percent since the previous cost estimate (2005). Also, additional costs have been added to the base case to accommodate Selective Catalytic NOx Removal (SCR) equipment. The equipment costs are based on previous vendor quotations for similar equipment, published cost estimating correlations and charts, and standard engineering estimates. The SCR equipment costs and operating expenses were estimated using costing methodology developed for retrofitting coal-fired steam boilers.[2]

The total installed cost of the plant is $88,100,420. The total installed cost is estimated using a factored method based on purchased equipment costs. Conventional cost estimating factors commonly used for preliminary designs are used for this design. Costs of building and services, installed utilities and service facilities, and working capital are not included, but allowance is made for home office engineering support, field office, and contingency. The accuracy of the cost estimate is ±30 percent. Equipments costs are presented in Table 33.

The capital and operating costs can be further reduced by design and operational optimizations, including but not limited to co-processing of waste materials containing heating value; mechanical dewatering combined with thermal drying for dredged sediment; combustion of oxygen-enriched-air or oxygen with natural gas in the Ecomelt Generators, and improved process and equipment design and costing.

Although ECH and GTI did not specifically conduct any co-processing of waste materials in the Cement-Lock demo plant, it is well known that these types of materials have been used in other waste-to-energy applications. GTI has conducted small-scale laboratory and pilot-scale tests on several potential feedstocks (mentioned previously) that demonstrate that the Ecomelt produced is suitable for partial replacement of Portland cement in producing concrete.

Table 33. Estimated Purchased Equipment Costs by Plant Section

| Item No. | Item Name | Qty | Purchased Cost, 2007 $ |
|---|---|---|---|
| **Section 100: Feed Handling** | | | |
| SS-100 | On-Site Sediment Storage (8 acres) | 1 | 1,040,000 |
| RB-101 | Sediment Receiving Building | 1 | 728,000 |

| Item No. | Item Name | Qty | Purchased Cost, 2007 $ |
|---|---|---|---|
| CU-101 | Crane Unloader | 2 | 1,570,400 |
| SD-101 | Sediment Dryer | 2 | 89,440 |
| SF-401 | Sediment Dryer Fan | 2 | 208,000 |
| TK-101 | Modifier 1 Silo | 1 | 41,600 |
| TK-102 | Modifier 2 Silo | 1 | 74,880 |
| BC-101 | Dried Sediment Conveyor | 2 | 74,880 |
| BC-102 | Dried Sediment Conveyor | 2 | 20,800 |
| SC-101 | Modifier 1 Conveyor | 2 | 20,800 |
| SC-102 | Modifier 2 Conveyor | 2 | 208,000 |
| MX-101 | Mixer | 2 | 156,000 |
| BC-103 | Mixed Feed Conveyor | 4 | 2,496,000 |
| | **Subtotal** | | **6,728,800** |
| **Section 200: Sediment Treatment** | | | |
| EG-201 | Ecomelt Generator | 4 | 6,240,000 |
| SC-201 | Secondary Combustion Chamber | 4 | 2,912,000 |
| GR-201 | Granulator | 4 | 718,640 |
| BC-201 | Ecomelt Conveyor | 4 | 160,160 |
| ED-201 | Ecomelt Dryer | 1 | 437,840 |
| EP-201 | Ecomelt Pulverizer | 1 | 2,080,000 |
| TK-201 | Ecomelt Hopper | 1 | 208,000 |
| | **Subtotal** | | **12,756,640** |
| **Section 300: Gas Cleanup** | | | |
| HR-301 | Heat Recovery Boiler | 4 | 3,165,760 |
| TK-301 | Lime Hopper | 1 | 31,200 |
| LB-301 | Lime Blower | 2 | 31,200 |
| BH-301 | Lime Bag house | 2 | 524,160 |
| SC-301 | Spent Lime Conveyor | 2 | 20,800 |
| TK-302 | Activated Carbon Hopper | 1 | 20,800 |
| CB-301 | Activated Carbon blower | 2 | 20,800 |
| BH-302 | Carbon Bag house | 2 | 524,160 |
| SC-302 | Spent Carbon Conveyor | 2 | 20,800 |
| EF-301 | Exhaust Fan | 2 | 362,960 |
| NR-101 | Selective Catalytic NOx Reduction Equipment | 1 | 1,107,600 |
| ST-301 | Stack | 1 | 104,000 |
| | **Subtotal** | | **5,934,240** |
| **Section 400: Power Generation** | | | |
| WT-401 | Boiler Feed Water Treatment | 1 | 263,120 |
| ST-401 | Steam Turbine Generator | 4 | 3,843,840 |
| CD-401 | Condenser | 4 | 550,160 |

| Item No. | Item Name | Qty | Purchased Cost, 2007 $ |
|---|---|---|---|
| CP-401 | Condensate Pump | 4 | 20,800 |
| WP-401 | Boiler Feed Water Pump | 4 | 185,120 |
| CT-401 | Cooling Tower | 1 | 74,880 |
| CP-402 | Cooling Water Pump | 4 | 52,000 |
| | **Subtotal** | | **4,989,920** |

| **Summary of Equipment Costs by Section** | **2007 $** |
|---|---|
| Section 100: Feed Handling | 6,728,800 |
| Section 200: Sediment Treatment | 12,756,640 |
| Section 300: Gas Clean-Up | 5,934,240 |
| Section 400: Power Generation | 4,989,920 |
| **Total** | **30,409,600** |
| **Total Installed Costs (TIC)** | |
| **Direct Cost** | |
| Purchased Equipment | 30,409,600 |
| Equipment Installation | 6,081,920 |
| Installed Instrumentation & Controls | 6,081,920 |
| Installed Electrical | 3,040,960 |
| Installed Piping | 9,122,880 |
| Site Development/Yard Improvement | 3,040,960 |
| Foundations/Concrete | 3,040,960 |
| Structural Steel | 3,040,960 |
| Insulation | 1,520,480 |
| **Total Direct Cost** | **65,380,640** |
| | |
| **Indirect Cost** | |
| Home Office Engineering Support | 9,807,100 |
| Field Engineering and Management | 4,903,550 |
| Contingency | 8,009,130 |
| **Total Indirect Cost** | **22,719,780** |
| | |
| **Total Installed Cost (Direct + Indirect)** | **88,100,420** |

### Sediment Treatment Cost

The estimated treatment cost for sediment dredged from navigational channels is presented below. Revenue streams include the sale of finely ground Ecomelt as a component of construction-grade cement and the sale of export electric power to the grid. The Ecomelt can be mixed with Portland cement yielding construction-grade blended cement or utilized directly in the production of concrete (as a partial replacement for Portland cement). For the present evaluation, the selling price for dry, pulverized Ecomelt has been assigned a value of $85 per ton, which represents roughly 85 percent of the cost of neat Portland cement. Per the Engineering News Record website: http://enr.construction.com/features/coneco/recent_indexes.asp (March 3, 2008), the cost of Portland cement was $101.28 per ton (March 10, 2007).[1] The revenue for electric power generation is estimated at $100/MW-hr, which is the same cost for in-plant electricity use.

A 20-year period for depreciation was assumed for the commercial plant in a sustainable enterprise-based industry. The raw materials required by the plant are shown in Table 34. The utilities required by the plant and modifier costs are shown in Table 35. The costs for all utilities and consumables are based on current prevailing rates or estimates. In Table 36 labor costs cover the man-power required for plant operation and plant management only. Labor costs include benefits to the workers and NJ Prevailing Wage guidelines were considered. Maintenance and interest expenses are assumed to be 1.5 and 7.25 percent, respectively. A debt-to-equity ratio of 75:25 was assumed for amortizing the borrowed capital over a 20-year period. Land required for the plant is estimated at 25 acres, which will be leased at a rate of $64,400 per year ($5,367 per acre per month[18]). The land usage comprises approximately 1½ acre for each Cement-Lock processing train, 3 acres of active storage, 8 acres of long-term storage, and 8 acres of access roads, parking, and storage and maintenance facilities.

Table 34. Raw Material Input and Material Output for a 500,000 $yd^3$/year Capacity Cement-Lock Plant Using Dredged Sediment as Feed Material

| **Raw Material Input** | ton/day |
|---|---|
| Dredged Sediment | 1,582 |
| Modifier 1 | 260.4 |
| Modifier 2 | 16.5 |
| Lime | 18.4 |
| Activated Carbon | 2.52 |
| **Material Output** | |
| Ecomelt | 822.4 |
| Spent Lime | 28.9 |
| Spent Activated Carbon | 2.52 |

Table 35. Utility Requirements and Costs (Credits) for a 500,000 $yd^3$/year Capacity Cement-Lock Plant Using Dredged Sediment as Feed Material

| **Component** | **Unit Cost (Credit)** |
|---|---|
| Modifier 1 | $50/ton |
| Modifier 2 | $200/ton |
| Lime | $100/ton |
| Activated Carbon | $2,000/ton |
| Natural Gas | $9.33/million Btu |
| Electricity, purchase | $100/MW-hr |
| Electricity, sale to grid | ($100/MW-hr) |
| Water | $4/1000 gallons |
| Ecomelt | ($85/ton) |

Table 36. Labor Requirements and Costs and Other Expenses for a 500,000 $yd^3$/year Capacity Cement-Lock Plant Using Dredged Sediment as Feed Material

| Labor Requirements & Costs (NJ Prevailing Wage Considered) | | | |
|---|---|---|---|
| Labor Category | Daytime or Shift | Number of Personnel | Salary (including benefits) |
| Plant Manager | Day | 1 | $112,000 |
| Plant Supervisors | Shift | 5 | $520,000 |
| Plant Operators | Shift | 20 | $1,920,000 |
| Accountant | Day | 1 | $77,000 |
| Clerk | Day | 1 | $52,500 |
| Secretary | Day | 1 | $42,000 |
| Total | -- | 29 | $2,723,500 |

| Maintenance Expense, Depreciation, Interest, and Financing | |
|---|---|
| Maintenance | 1.5% of Total Installed Cost |
| Depreciation | 20 year, Straight-line |
| Interest rate | 7.25% |
| Financing | 75:25 debt / equity ratio |

Subtracting the total expenses from the total revenues gives the revenue shortfall that must be made up by the "break-even" tipping fee from the sediment. In this scenario, the required tipping fee is $40.05/$yd^3$ of sediment. The cost components are summarized in Table 37.

Co-processing of other wastes with dredged sediment offers a significant benefit for reducing the cost of sediment treatment. Depending upon the availability of these other wastes (e.g., fly ash, petroleum sludges, tank bottoms, municipal solid wastes, and scrap tires), the cost for processing sediment by the Cement-Lock Technology can be reduced even further. Additional revenues or cost reductions can be generated by substituting alternate materials for modifiers.

Table 37. Economics of 500,000 $yd^3$/year Capacity Commercial-Scale Cement-Lock Plant Using Dredged Sediment as Feed Material – Enterprise-Based Industry

| | |
|---|---|
| Sediment Processed, $yd^3$/yr | 500,000 |
| | |
| **Annual Revenues** | |
| Sale of Ecomelt ($85/ton) | $20,644,668 |
| Electric Power Generation ($100/MW-hr) | $9,657,900 |
| Total Revenues | $30,302,568 |
| | |
| **Annual Expenses** | |
| Labor (NJ Prevailing Wage as guideline) | $2,723,500 |
| On-Site Sediment Handling, Screening ($0.50/$yd^3$) | $250,000 |
| Raw Materials | |
| Modifier 1 | $4,257,360 |
| Modifier 2 | $1,072,224 |
| Lime | $602,732 |
| Activated Carbon | $1,075,378 |
| Utilities | |
| Natural Gas | $23,954,451 |
| Electricity | $2,131,801 |
| Water | $522,517 |
| SCR (NOx reduction) Costs | $132,825 |
| Maintenance Expenses (1.5% of TIC) | $1,321,506 |
| | ========== |
| **Total Expenses** | $38,044,294 |
| | |
| Provision for Lease | $1,610,100 |
| Depreciation (straight-line) | $4,405,021 |
| Capital Recovery Charges | $6,266,921 |
| | ========== |
| **Total Operating Expenses** | $50,326,336 |
| | |
| **Revenues – Expenses** | -$20,023,768 |
| | |
| **Break-Even Tipping Fee, $/$yd^3$** | **$40.05** |

It should be noted that the natural gas consumption can be significantly reduced by thermal drying or mechanical dewatering the sediment prior to processing. Also, using oxygen enrichment in the rotary kiln will also reduce natural gas consumption.

As mentioned above, the Cement-Lock Technology is flexible regarding co-processing of other materials with sediment, some of which may have significant calorific value. For example, supplemental or alternate fuels, such as waste petroleum oils and sludges, tanker bottoms, municipal solid wastes, municipal sewage sludges, and shredded tires are candidates for reducing energy-related costs. Some of these materials have tipping fees associated with their use, which would increase revenues and enhance the Cement-Lock economics.

**Sensitivity**

The sensitivity of the break-even tipping fee to changes in plant throughput capacity (500,000 $yd^3$/year base case ±50% ), Ecomelt product selling price ($85/ton base case ±25%), natural gas cost ($9.33/million Btu base case ±25%), electric power cost ($100/MW-hr base case +25%/-50%), and processing rate (100% base case -25%/-50%) were also estimated. The break-even tipping fee <u>increases</u> with increasing natural gas cost, decreasing sediment processing rate (% of rated plant capacity), decreasing plant throughput capacity, decreasing electric power cost (credit), and decreasing Ecomelt selling price. The results of the sensitivity study are presented in graphical form in Figures 19 through 23.

Figure 19 shows that increasing the plant capacity from 500,000 to 750,000 $yd^3$/year decreases the break-even tipping fee from $40.05 to $34.22/$yd^3$. Reducing the plant capacity from 500,000 to 250,000 $yd^3$/year increases the break-even tipping fee from $40.05 to $54.35/$yd^3$.

Figure 20 shows that increasing the Ecomelt selling price from $85 to $106.25/ton decreases the break-even tipping fee from $40.05 to $29.73/$yd^3$. Reducing the Ecomelt selling price from $85 to $63.75 increases the break-even tipping fee from $40.05 to $50.37/$yd^3$.

Figure 21 shows that increasing the cost of natural gas from $9.33 to $11.66/million Btu increases the break-even tipping fee from $40.05 to $52.02/million Btu. Reducing the natural gas cost from $9.33 to $7.00/million Btu decreases the break-even tipping fee from $40.05 to $28.07/$yd^3$.

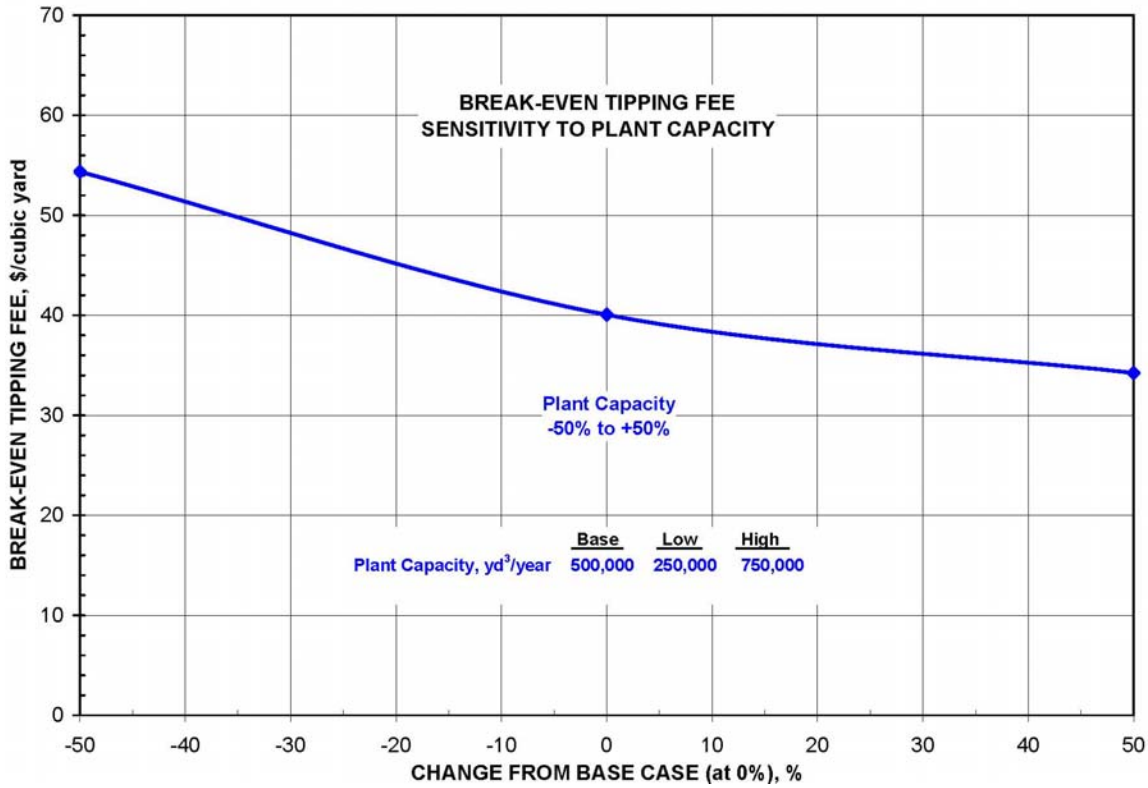



Figure 19. Sensitivity of Required Break-Even Tipping Fee to Plant Processing Capacity for a Commercial-Scale Cement-Lock Plant

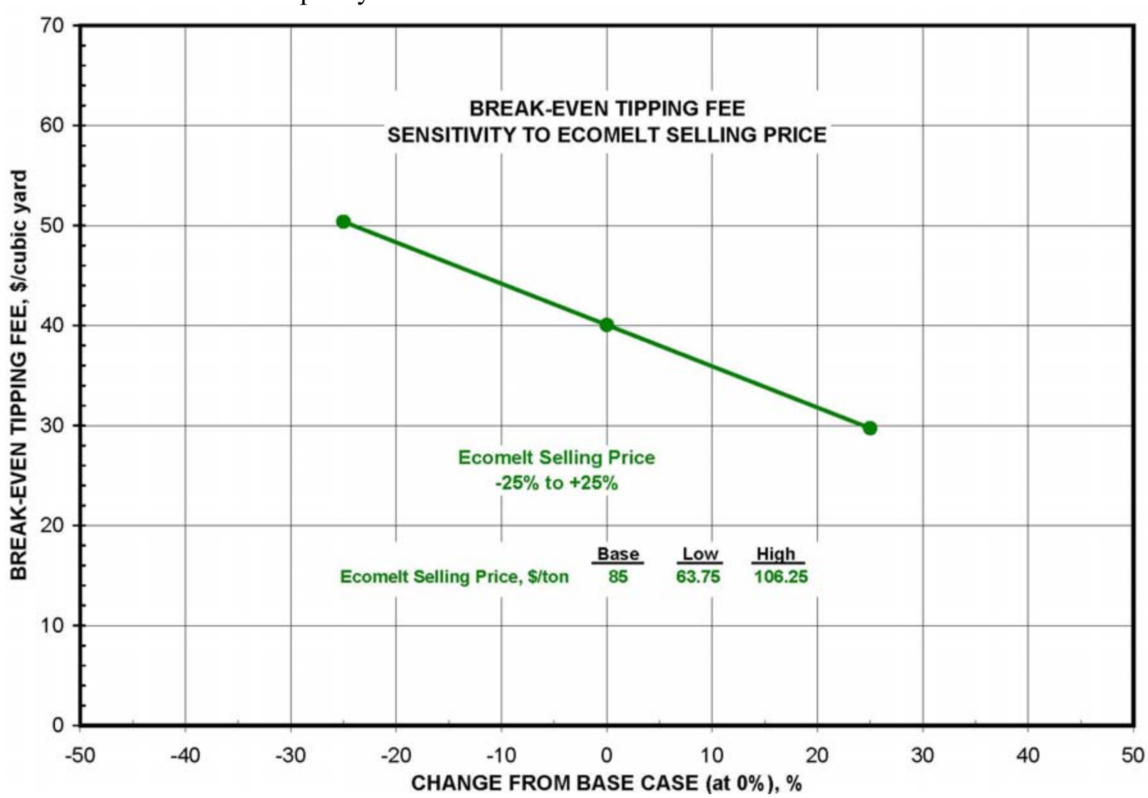



Figure 20. Sensitivity of Required Break-Even Tipping Fee to Ecomelt Selling Price for a Commercial-Scale Cement-Lock Plant

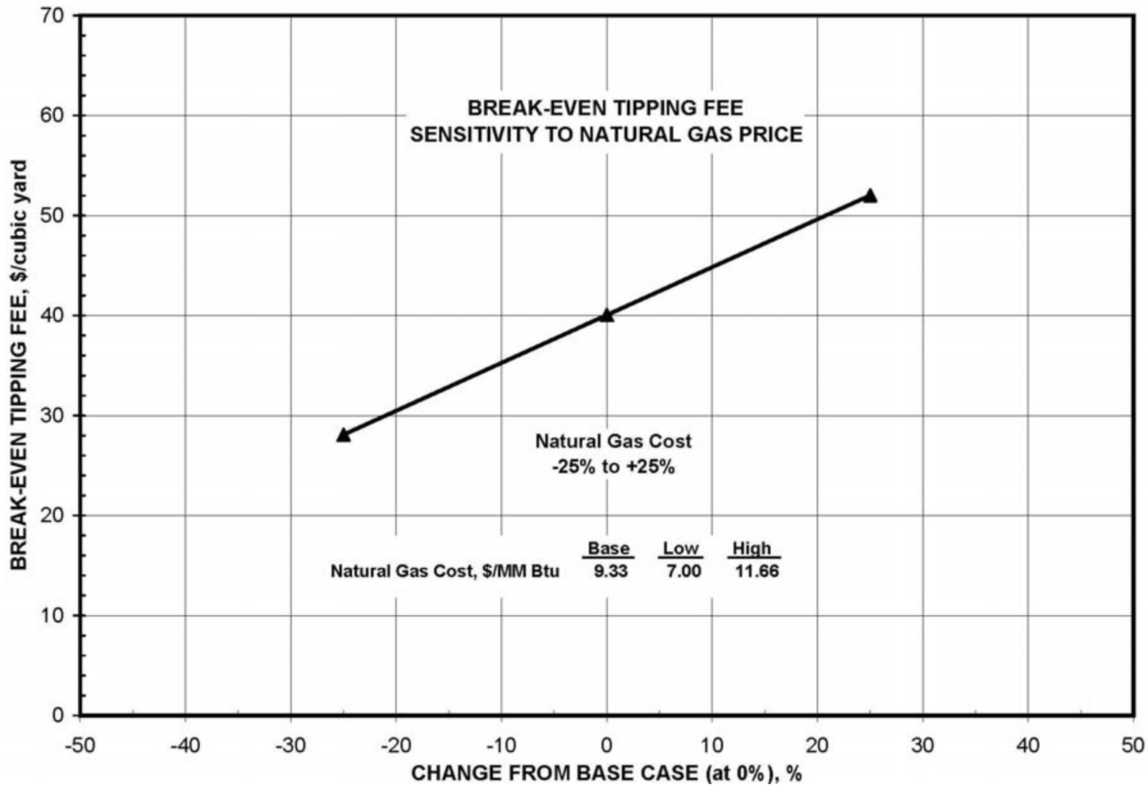



Figure 21. Sensitivity of Required Break-Even Tipping Fee to Natural Gas Cost for a Commercial-Scale Cement-Lock Plant

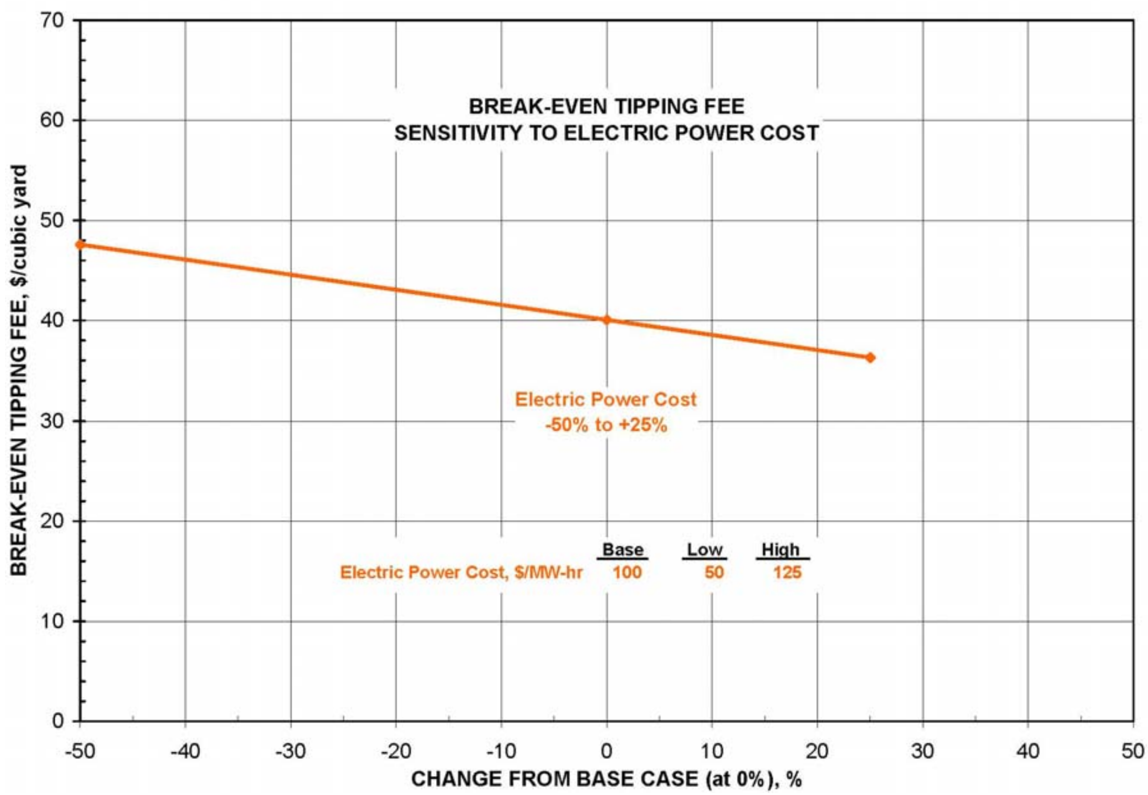



Figure 22. Sensitivity of Required Break-Even Tipping Fee to Electric Power Cost for a Commercial-Scale Cement-Lock Plant

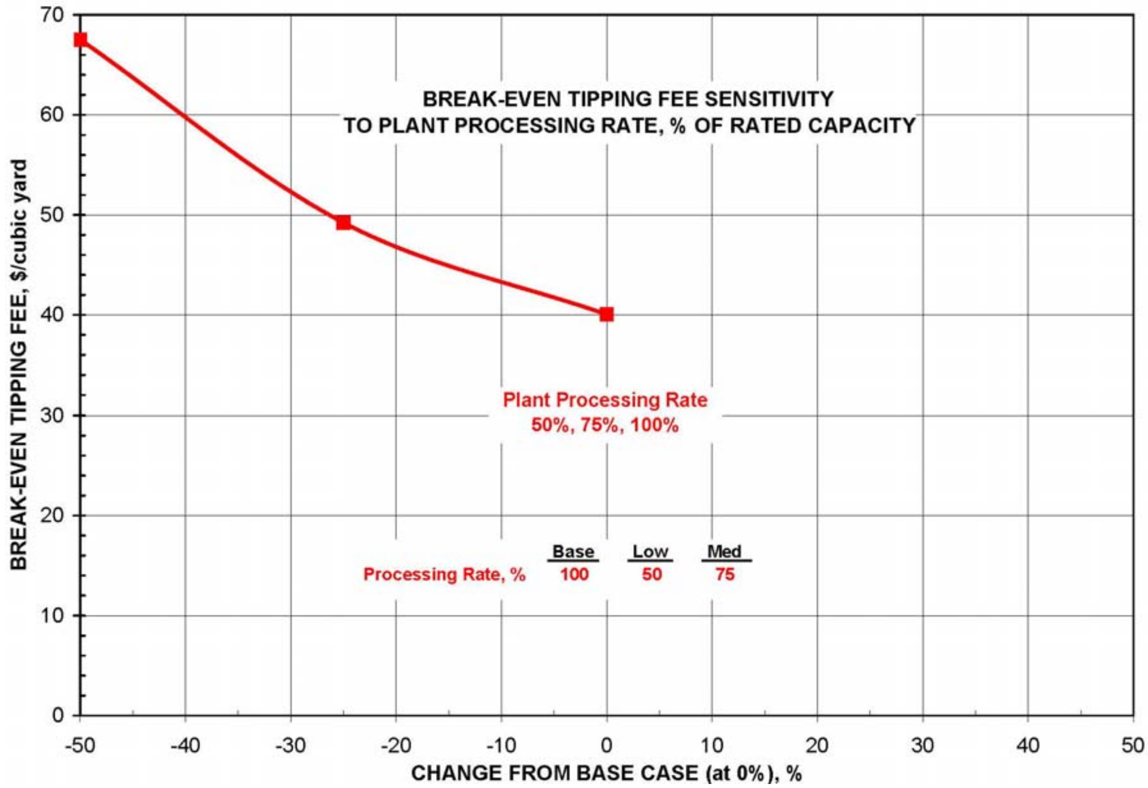


Figure 23. Sensitivity of Required Break-Even Tipping Fee to Plant Processing Rate for a Commercial-Scale Cement-Lock Plant

Figure 22 shows that increasing electric power cost (credit) from \$100 to \$125/MW-hr decreases the break-even tipping fee from \$40.05 to \$36.28/yd$^3$. Reducing electric power cost from \$100 to \$50/MW-hr increases the break-even tipping fee from \$40.05 to \$47.57/yd$^3$.

Figure 23 shows that decreasing the plant processing rate from 100 percent (500,000 yd$^3$/year) to 75 percent (375,000 yd$^3$/year) increases the break-even tipping fee from \$40.05 to \$49.21/yd$^3$. Decreasing the processing rate to 50 percent of capacity increases the break-even tipping fee to \$67.52/yd$^3$.

## Economic Estimates for Malcolm Pirnie Inc. Focused Feasibility Study

At the request of Malcolm Pirnie Inc. (MPI), GTI prepared several project-based break-even cost estimates for different quantities of Passaic River sediment to be processed through Cement-Lock plants over different project periods. The quantities of sediment and project periods were from a list of Passaic River remedial alternatives developed by MPI that has since been revised and shortened. There are currently three remediation alternatives for evaluation regarding the Cement-Lock technology as presented in Table 38.

Table 38. Environmental Remediation Cases Developed by MPI for the Passaic River Restoration Project

| Alternative No. | Sediment to be Treated, $yd^3$ (55 wt % solids) | Project Duration, years | Alternative Type | Analysis | Break-Even Tipping Fee Cement-Lock, $\$/yd^3$ |
|---|---|---|---|---|---|
| 3 | 7,600,000 | 9 (10 processing) | Dredging | Subsurface | $78.70 |
| 6 | 3,000,000 | 6 | Capping | Surface | $105.06 |
| 9 | 2,000,000 | 4 | Capping | Surface | $140.94 |

In remediation alternative 3, 7.6 million $yd^3$ of sediment would be dredged from the historically more contaminated subsurface sediment layers and remediated. In remediation alternatives 6 and 9, sediment would be dredged from the surface sediment, which is historically less contaminated and remediated. In alternatives 6 and 9, the area would eventually be capped with clean fill.

To compare the economics of Cement-Lock with other technologies, MPI imposed the following restrictions and assumptions on the cost estimates:

1. Only Passaic River sediment be treated – No co-processing of other waste feedstocks
2. The life of the plant equaled the project duration – No long-term amortization/capital recovery
3. Break out cost of beneficial use products
4. Provide costs with and without electric power co-generation

The cost estimates were based on the revised commercial-scale Cement-Lock plant economics presented above. However, there were some specific additions and assumptions made for the MPI cases as discussed below.

A fifth Cement-Lock processing train was included in the overall process flow scheme to serve as a spare. Other equipment items were included in the equipment list representing backups or spares (as discussed in the previous section, the Cement-Lock economic assessment did not include any spare equipment). Operating expense was increased to accommodate the increased need for polishing the flue gas for mercury.

Also, field-related and contingency costs were increased to 10 percent (up from 7.5 percent) and 15 percent (up from 10 percent), respectively, as fractions of the Total Investment Cost (TIC). Maintenance expense was increased to 3 percent (up from 1.5 percent). Home office expense, which includes engineering support, was maintained at 15 percent of TIC. As a result of these revisions to the overall processing scheme, the TIC was estimated at $123,998,000.

Costs related to dismantling the plant after the project, match-marking the parts, loading, and shipping the plant equipment to another location to be reassembled for another project were not included.

**Project-Based Industry for MPI Focused Feasibility Study:** The break-even tipping fees for the remediation alternative 6 and 9 were estimated based on a Cement-Lock commercial plant with a sediment processing capacity of 500,000 $yd^3$/year. The break-even tipping fees for remediation alternative 6 and 9 were estimated to be 105.06 and 140.94/$yd^3$. For remediation alternative 3, the plant capacity was increased to 760,000 $yd^3$/year to approximately match the 9-year dredging project duration for that alternative. At 760,000 $yd^3$/year, it still takes 10 years to process the 7.6 million $yd^3$ of dredged sediment. The break-even tipping fee for this case was estimated to be $78.70/$yd^3$. The break-even tipping fees for the three remediation alternatives developed by MPI are included in Table 37 above. The summary of revenues and expenses for the break-even tipping fees are presented in Table 39.

The impact of the selling price of Ecomelt on the break-event tipping fee was calculated based on an Ecomelt selling price ranging from $25 to 85/ton. The project duration was varied from 1 to 10 years to determine the effect on the required break-even tipping fee. During that time period from 500,000 to 5,000,000 $yd^3$ of sediment would have been processed through the system.

The results of this project-based economic assessment, presented in Figure 24, show that as the project duration decreases, the break-even cost increases significantly. This is a direct result of amortizing the capital cost recovery expense over a shorter and shorter time.

At the 5-year project duration time, increasing the Ecomelt selling price from $25 to $85/ton decreases the break-even tipping fee from $148.76/$yd^3$ to $119.62/$yd^3$.

Table 39. Economics of Cement-Lock Plants Processing Passaic River Sediment Under MPI Alternatives – Project-Based Industry

| **MPI Remediation Alternative** | **3** | **6** | **9** |
|---|---|---|---|
| Sediment Processing Rate $yd^3$/year | 760,000 | 500,000 | 500,000 |
| Project Duration, years | 10 | 6 | 4 |
| Sediment Processed, $yd^3$ | 7,600,000 | 3,000,000 | 2,000,000 |
| | | | |
| **Revenues** | | | |
| Sale of Ecomelt ($85/ton) | $31,379,895 | $20,644,668 | $20,644,668 |
| Electric Power Generation ($100/MW-hr) | $14,680,008 | $9,657,900 | $9,657,900 |
| Total Revenues | $46,059,903 | $30,302,568 | $30,302,568 |
| | | | |
| **Operating Expenses** | | | |
| Labor (NJ Prevailing Wage consideration) | $4,139,720 | $2,723,500 | $2,723,500 |
| On-site sediment handling, screening ($0.50/$yd^3$) | $380,000 | $250,000 | $250,000 |
| Raw Materials | | | |
| Modifier 1 | $6,471,187 | $4,257,360 | $4,257,360 |
| Modifier 2 | $1,629,780 | $1,072,224 | $1,072,224 |
| Lime | $916,152 | $602,732 | $602,732 |
| Activated Carbon (includes reprocessing cost) | $4,903,722 | $2,150,755 | $2,150,755 |
| Utilities | | | |
| Natural Gas | $36,410,765 | $23,954,451 | $23,954,451 |
| Electricity | $3,240,337 | $2,131,801 | $2,131,801 |
| Water | $925,274 | $608,733 | $608,733 |
| SCR (NOx reduction) costs | $201,894 | $132,825 | $132,825 |
| Maintenance Expenses (3.0% of TIC) | $5,627,181 | $3,702,093 | $3,702,093 |
| **Total Operating Expenses** | $64,846,013 | $41,586,473 | $41,586,473 |
| | | | |
| **Other Expenses** | | | |
| Lease (25 acres) | $2,447,352 | $1,610,100 | $1,610,100 |
| Depreciation (straight-line) | $18,757,270 | $20,567,182 | $30,850,773 |
| Capital Recovery Charges (project-based) | $19,819,107 | $19,068,709 | $26,724,374 |
| **Total Operating Expenses** | $105,869,743 | $82,832,465 | $100,771,721 |
| | | | |
| **Revenues – Expenses** | -$59,809,840 | -$52,529,897 | -$70,469,153 |
| | | | |
| **Break-even Tipping Fee, $/$yd^3$** | $78.70 | $105.06 | $140.94 |

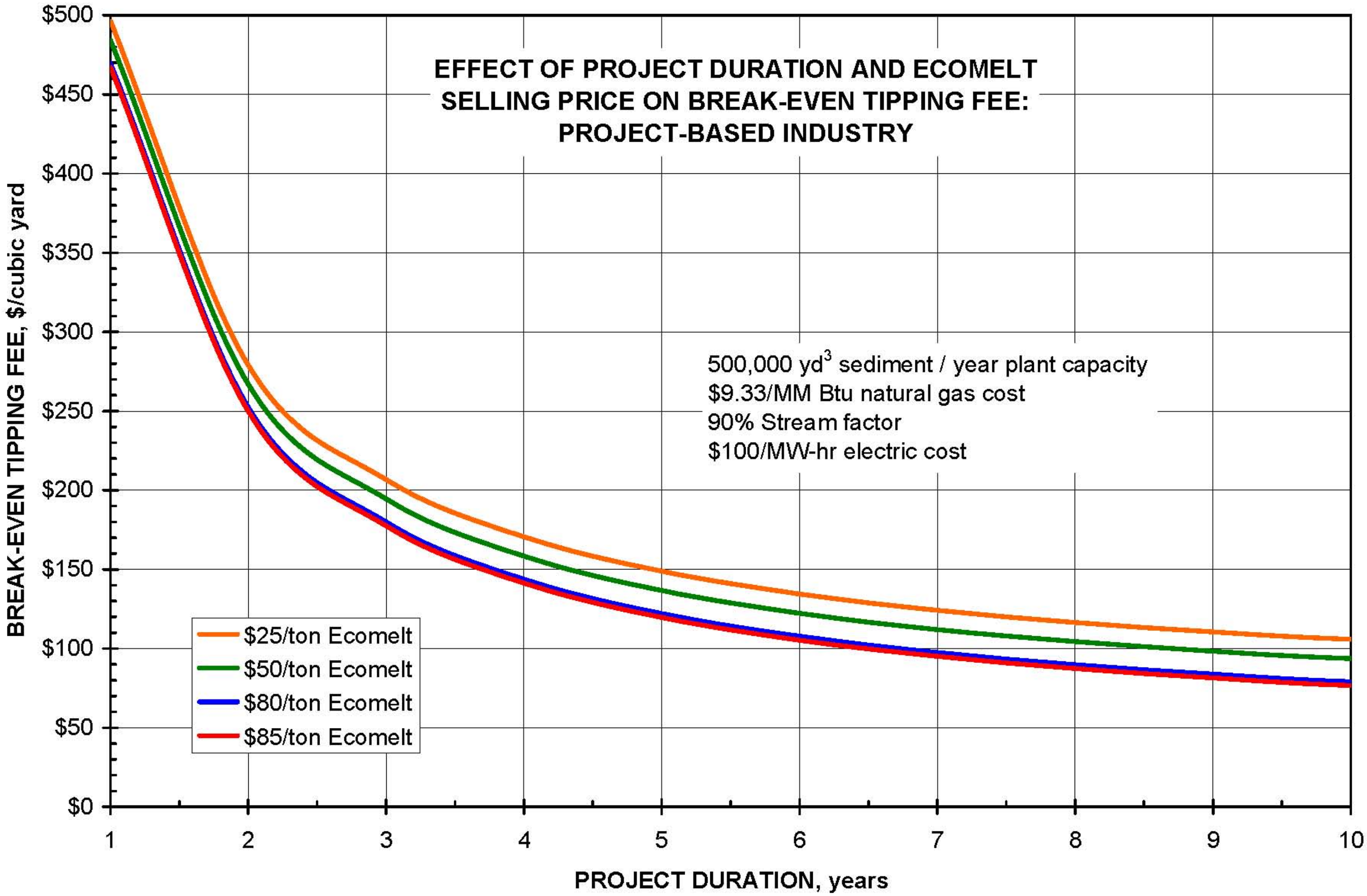



Figure 24. Effect of Project Duration and Ecomelt Selling Price on the Break-Even Tipping Fee Required for a 500,000 $yd^3$/year Cement-Lock Commercial Plant Processing Sediment – Project-Based Industry

# VI. SUMMARY AND CONCLUSIONS

In summary, based on the results of the Confirmation Test and Extended Duration Test campaigns, it can be concluded that:

- The feeding system modifications – including premixing the feeds and modifiers, using a belt conveyor, and ram feeder – enabled feeding of the premixed sediment-modifier mixture from the sediment storage area.
- About 5.1 tons of Stratus Petroleum sediment plus modifiers were processed through the Cement-Lock demo plant during the Confirmation Test.
- Approximately 31.6 tons of Passaic River sediment plus modifiers were processed through the demo plant during the Extended Duration tests.
- The physical and chemical properties of Ecomelt samples from Passaic River sediment have been evaluated by CTLGroup. The results show that Ecomelt can be used as a partial replacement (up to 40 wt %) for Portland cement in a general construction project.
- The Ecomelt/Portland cement blend achieved compressive strength at a lower rate than did the control sample. However, after 56 days of curing, the compressive strengths of both Ecomelt/Portland cement blend and control specimens were the same.
- Time of setting was longer for the Ecomelt/Portland cement blend than that of the control – typical of pozzolanic materials.
- CTLGroup prepared a mix design for the beneficial use of the dried and ground Ecomelt to be incorporated into a batch of concrete.
- About 1 ton of Ecomelt from Passaic River sediment was dried and ground to cement fineness (<50 μm) by CTLGroup. It has been shipped to Montclair State University for a beneficial use demonstration.

The EPA SITE program sampling crews conducted environmental and stack sampling during both Extended Duration test campaigns to obtain samples for process and environmental characterization.

The results show that the Cement-Lock technology – when operated under slagging mode – can achieve high destruction and removal efficiencies for contaminants of concern, specifically dioxins and furans and PCBs.

The Activated Carbon Bed Adsorber, the purpose of which is to capture volatile heavy metals (specifically, mercury), captured >88.8 percent of the mercury entering it during the December 2006 campaign and >98.9 percent of the mercury entering it during the May 2007 campaign.

The results showed that the levels of NOx produced during slagging-mode operation will require the addition of NOx reduction equipment to the overall Cement-Lock commercial plant process scheme to achieve local regulatory limits. Best management practices will be followed to enable selection of appropriate catalytic or non-catalytic NOx reduction equipment for the application.

The powdered lime storage and injection system for acid gas capture and removal did not perform as expected. Feeding of lime to the system was inconsistent and unreliable. For future commercial applications, the design of the lime storage and injection system needs to be reviewed and revised to insure proper operation. Also, elevated emissions of particulate matter from the plant indicated that some of the bags in the bag house may have torn or ruptured during operation. The design of a commercial plant needs to include instrumentation to monitor the condition of filter bags in the bag house. Torn or ruptured bags compromise bag house performance and enable elevated levels of acid gases and particulates (with condensed or adsorbed trace elements, such as mercury or lead) to by-pass the air pollution control equipment.

Sediments with mercury concentrations that exceed the design limits of the air pollution control equipment could still be treated effectively and in an environmentally sound manner at a commercial-scale Cement-Lock plant. In this case, a batch of highly contaminated sediment would be mixed with sediment (ratio to be determined) with much lower mercury concentration prior to treatment. The net effect will be to dilute the mercury concentration in the sediment to the range for which the pollution control equipment was designed. This will enable more levelized treatment of the sediment.

The economics of the Cement-Lock technology were re-evaluated based on large-scale enterprise-based as well as project-based project scenarios. The use of co-processing other materials with calorific values was not included in the economic assessments:

- Based on stated assumptions for a 500,000 $yd^3$/year enterprise-based commercial-scale Cement-Lock plant, the required tipping fee for processing sediment dredged from navigation channels was estimated to be \$40.05/$yd^3$.

- For project-based cost estimates, the required tipping fee varies significantly depending upon the quantity of sediment to be processed and the duration of the project.
- Sensitivities of break-even tipping fee requirements were evaluated for the enterprise-based industrial scenario.

There are areas of additional development that would enhance the Cement-Lock Technology:

- The engineering design of the overall sediment and modifier feeding system and the slag discharging system should be re-evaluated based on the experiences of the Cement-Lock demo plant.
- Specific large-scale tests should be conducted to demonstrate co-processing of feedstocks, such as shredded rubber tires and sediment, electronic wastes and sediment, municipal solid waste and sediment, among others.
- Steam generation equipment (for electric power production) should be incorporated into the downstream processing equipment to determine the effects on downstream air pollution control equipment efficiency and other requirements
- Provision for incorporating NOx reduction equipment into the overall Cement-Lock process flow sheet should be made
- Tests to evaluate the long-term endurance properties of concrete made with Ecomelt should be conducted (will be done by MSU under the Earth and Environmental Studies Department).
- Tests to determine the compressive strength of Ecomelt made outside the “target” composition (within the patent scope) should be conducted.
- Specific large-scale tests should be conducted with feedstock previously tested only as surrogates, i.e., PCB-contaminated soils or sediment.

# VII. ACKNOWLEDGMENT

This work was performed by the Gas Technology Institute (GTI, Des Plaines, IL) and its wholly owned subsidiary, ENDESCO Clean Harbors (ECH, Des Plaines, IL), for the New Jersey Department of Transportation Office of Maritime Resources (NJ-DOT/OMR) under a modification to an existing contract (NJ Agency Order #9345380) with ECH. Funding for this contract was provided through the Dredging and Harbor Revitalization Bond Act of 1996. Additional support was provided by the U.S. Environmental Protection Agency Region 2 with technical and contractual support through Brookhaven National Laboratory (Contract No. 725043) with funding through the Water Resources Development Act and the U.S. EPA Region 2 Superfund Program. Other funding for the overall Cement-Lock Technology demonstration has been provided by the Gas Research Institute (GRI, Des Plaines, IL).

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