New York/ New Jersey Harbor: Alternative Methods for Ex-Situ Sediment Decontamination and Environmental Manufacturing

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Compiled June-August 2002

Prepared for

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington D.C.
http://clu-in.org

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About this Report

Prepared by a MIT undergraduate student, this report is intended to provide a basic summary and current status on the New York/New Jersey Harbor Sediment Decontamination Project. The scope of the report was developed by EPA's Technology Innovation Office.

The report contains information gathered from a range of currently available sources, including project documents, reports, periodicals, Internet searches, and personal communication with involved parties. No attempts were made to independently confirm the resources used. It has been reproduced to help provide federal agencies, states, consulting engineering firms, private industries, and technology developers with information on the current status of this project.

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ACKNOWLEDGEMENTS

I would like to thank the Technology Innovation Office (TIO) of the EPA for giving me the opportunity to write this paper. I wish to extend a special thank-you to Kelly Madalinski (TIO), Mary McDonald from Triangle Labs, and Eric Stern from the Region 2 Office of the EPA.

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Abstract

The natural accumulation of sediment in the NY/NJ harbor reduces its depth and prevents ships from navigating through it. In order to allow the ships to travel in the harbor and facilitate commerce, approximately 3 to 5 million cubic yards of sediment must be dredged from the harbor annually. Until the early 1990s, this sediment was disposed of in the ocean or other areas surrounding the harbor. Throughout the 1990s, growing concern over high levels of contamination in the harbor resulted in the implication of higher costs and more stringent regulations on ocean disposal. As a result of the new standards, 70-80% of the dredged sediment was unacceptable for ocean disposal. Increased costs also partially eliminated ocean disposal as an option for the storage of the contaminated sediment. Congress addressed the situation by creating the Water Resources Development Acts (WRDA), which created steps to establish a plan to manufacture a beneficial use product from the dredged sediment. WRDA invoked the help of the Region 2 Office of the EPA and the U.S. Army Corps of Engineers. The EPA and the USACE selected the Brookhaven National Laboratory (BNL) as the managing project lead for the NY/NJ Harbor endeavor. A similar project, headed by the New Jersey Maritime Resources, took place on the state level. Both the state and federal programs conducted small-scale studies of a variety of decontamination and environmental manufacturing methods developed by several companies.

This report provides an overview of the pilot studies of five different firms considered by the state and/or federal program(s). Between the two programs, twelve firms completed pilot studies. However, due to time constraints and the availability of these reports, only five firms are discussed in this report. These five firms include Biogenesis, the Westinghouse Science and Technology Center, the Institute of Gas Technology (GTI), NUI Environmental Group (NUIEG), and Metcalf & Eddy. Descriptions of each firm's decontamination and product conditioning process, along with the process' decontamination efficiency and by-products are included in this paper. The nature of the beneficial use product and a simple economic analysis comparing the costs and credits associated with each firm are also discussed.

Background

Harbor Background

The New York/New Jersey Harbor is located between the states of New Jersey and New York and opens up into the Atlantic Ocean. The harbor consists of the Hudson River, East River, Hackensack River, Passaic River, Newark Bay, Jamaica Bay, Arthur Kill, the Kill van Kull, and the Long Island Sound. The Hudson River flows between Brooklyn and Staten Island into a larger bay area, which opens up into the New York Bight and Atlantic Ocean as shown in Figure 1.

Figure 1: Map of the New York and New Jersey Harbor (New York District of the Army Corps of Engineers. http://www.nan.usace.army.mil/harbor/ 2001)

The NY/NJ Harbor is a valuable resource for business as well as a habitat for flora and fauna and a place for recreation. The harbor is the largest port on the eastern seaboard, and the third largest in the United States (EPA, 8). Over 180,000 jobs are a result of the port's activities and over 29 billion dollars are generated by the harbor every year (Douglas, interview). The New York/ New Jersey Harbor holds a high recreational value, providing the public an opportunity to fish, sail, or take a cruise (EPA). The harbor is also home to many species of plants and animals including those that are federally endangered or threatened such as the humpback whale, the leatherback sea turtle, the piping plover, and swamp pink (www.harborestuar.org).

The Problem

Natural forces, such as fluid dynamics and transport systems, cause sedimentation to occur along the bottom of the NY/NJ Harbor. Consequently, the harbor becomes shallower each year. The decreasing depth of the port becomes a problem when ships need to travel into and out of the bay. The harbor's current average depth is approximately 19 feet (EPA, 7). In order to facilitate the unobstructed navigation of ships through the harbor, it should have a depth of about 40 feet (Clesceri, 1). To maintain this depth, 3-5 million cubic yards of sediment must be dredged from the harbor. In years prior to 1990, the sediment removed from the harbor was transported regularly to a point 6 miles out into the Atlantic Ocean where it was dumped (Mensinger). This began to change in the early 1990s when the Environmental Protection Agency conducted several studies on bioaccumulation and toxicity risks on a variety of animals and came to the conclusion that current standards were too high to sufficiently protect wildlife. Consequently, the EPA tightened regulations for ocean disposal in the *Greenbook*, a collection of ocean standards. Contaminants of concern included polychlorinated biphenyls (PCBs), metals, polyaromatic hydrocarbons (PAHs), and others (Stern, interview). As a result of the more restrictive standards, 70-80% of the sediment dredged from the New York/ New Jersey harbor is not acceptable for ocean disposal. Typical concentrations for contaminants for select locations in the NY/NJ

Harbor along with New Jersey and New York contaminant standards are shown in Figure 2.

Figure 2: Contaminant Concentrations for Select Locations in the NY/NJ Harbor and Applicable Standards (Modified from *Fast Track Dredged Material Decontamination Demonstration for the Port of New York and New Jersey* 1999.)

Contaminant	Newark Bay	Arthur Kill	Newtown Creek	NJ Non-Residential	NJ Residential	NY Residential
2,3,7,8 TCDD (ppt)	130	39	9.9		---	
OCDD (ppt)	5494	3016	15369		---	
TCDD/TCDF TEQ (ppt)	197	61	224		---	
Total PCBs (ppm)	.92	1.16	2.86	2000	480	1000
Anthracene (ppb)	1400	880	5820	10,000,000[a]	10,000,000[a]	50,000[a]
Benzo(a)anthracene (ppb)	3070	1460	6190	4,000[a]	900[a]	224,000
Chrysene (ppb)	3100	1630	6050	40000[a]	9000[a]	50,000
Total PAHs (ppb)	32550	19120	59380	4000	900	224
Total Herbicides and DDT (ppb)	145	1219	420	40,000	9000	400
Arsenic (ppm)	9-17	17-25	5-33	20[a]	20[a]	396,500
Cadmium (ppm)	1-2	1.5-3	1-20	100[a]	39[a]	N/A
Chromium (ppm)	175	161	305	N/A	N/A	7.5
Copper (ppm)	105-131	178-304	61-770	600[a]	600[a]	1
Lead (ppm)	109-136	111-261	68-554	600[a]	400[a]	10
Mercury (ppm) total	2-3	2-5	2-3	270[a]	14[a]	25
Nickel (ppm)	33-40	20-60	12-140	2400[a]	250[a]	SB
Silver (ppm)	2-4	2-5	2-3	4100[a]	110[a]	0.1
Zinc (ppm)	188-244	230-403	104-1260	1500[a]	1500[a]	20

[a] NJDEP 1996 standards from Biogenesis report
N/A not available
SB Site Background

Increasing costs have also caused ocean dumping to be almost completely eliminated as a possibility for sediment disposal. A 2.2 square mile area off of the coast of Sandy Hook, New Jersey, commonly known as the “Mud Dump” was a site that was conventionally used for sediment disposal. In the early 1990s, the cost of disposing of a cubic yard of sediment escalated from $5-10 to over $100 over the course of a few months (Stern, Inteview). This cost upsurge paired with more stringent regulations on ocean disposal forced those involved in the dredging of the NY/NJ Harbor to develop alternatives for contaminated sediment disposal.

The Search for Alternatives to Ocean Disposal of Dredged Sediment

Several groups including the United States Army Corp of Engineers (USACE), the Port Authority of New York and New Jersey (PANYNJ), the State of New Jersey, EPA, the Harbor Estuary Program (Douglas), and the New Jersey Office of Maritime Resources (NJMR) of the New Jersey Department of Transportation (NJDOT) took an interest in investigating alternative methods for contaminated sediment remediation (Jones, 127). In response to the growing concern over the status of the harbor, Congress began to take action through the Water Resources Development Acts (WRDA) and assigned the task of solving the NY/NJ Harbor problem to the Region 2 office of the U.S. EPA and the New York District of the USACE (Stern, interview)

Congress passed the first of the WRDA acts, *Phase 1: Study of Alternative Methods for Disposal of Dredged Material*, in 1990. This act fostered a demonstration project to find alternatives to disposing of the dredged sediment in the ocean. Some of the proposed alternatives included using the sediment for capping of more contaminated materials, storing it on a containment island, and cleaning it with new decontamination technologies (EPA, 2). The second phase, *Bench- and Pilot-Scale Demonstrations,* was passed in 1992. The purpose of this phase was to demonstrate the effectiveness and applicability of the variety of decontamination technologies. Issues that were to be considered in the bench and pilot studies were cost, possible manufacturing of a beneficial end-use product, decontamination efficiency, and feasibility of expanding the technology to a full-scale facility. In 1996 the last phase of WRDA, *Full-Scale Dredged-Material Decontamination Demonstration*, one or more decontamination technologies were to be selected for application in a full-scale facility that would process a minimum of 500,000 cubic yards of contaminated sediment each year. In 1999, Congress passed section 218, an amendment section to WRDA which provided for the manufacturing of “practical end-use products” from the decontaminated sediment. (Stern, interview).

In 1993, a federally funded program, involving the United States Army Corps of Engineers and the EPA was established in order to meet the goals established by WRDA. The federal government granted $20 million to the two groups involved in order to support the program efforts. After receiving funding, the USACE and Region 2 of the EPA agreed to employ the U.S. Department of Energy Brookhaven National Laboratory (BNL) to be the technical lead managing the NY/NJ Harbor project. The USACE and the EPA developed a six-step plan to establish a full-scale sediment remediation and beneficial use plant (EPA, vii).

The plan consisted of three main steps: a bench-scale study, pilot-scale study, and full scale implementation of one or more decontamination technologies. Planning and preliminary evaluations took place before each of these major steps. In the first step of the plan, the USACE and the EPA reviewed information on and sent requests for proposals to over 500 treatment technologies. Twenty-six firms responded and eight completed bench-scale studies. After the EPA and USACE reviewed the results of the bench studies, seven firms were selected to demonstrate their technologies at the pilot-scale level: Marcor, Metcalf & Eddy, Gas Technology Institute (GTI), Westinghouse Science and Technology, BioGenesis, International Technology, and BioSafe (Stern, interview).

A program parallel to the federal efforts took place at the state level. In 1996, New York and New Jersey developed the *Joint Dredging Plan for the Port of New York & New Jersey*, which proposed several possible solutions to the sediment problem. The possibilities included constructing confined disposal facilities to store the dredged sediment and implementing alternative treatment technologies to decontaminate the sediment. In support of the dredging plan, PANYNJ promised $130 million to the project. The state of New Jersey pledged an additional $205 million to the project through the Harbor Revitalization and Dredging Bond Act of 1996 (Douglas). To ensure that sufficient man-hours would be dedicated to achieve the goals of the *Joint Dredging Plan for the Port of New York & New Jersey*, Governor Christine Todd Whitman created the New Jersey Office of Maritime Resources (NJMR).

The state-funded program run by the NJMR followed a similar plan to select technologies suitable for operation on the full-scale level. However, unlike the federal program, the state program did not test the technologies on the bench-scale level. Instead, it accelerated five technologies from five different firms to complete pilot-scale studies. These companies include: GTI, Biogenesis, JCI/Upcycle, NUIEG, and BEM to pilot-scale testing. Note that the federal program also selected GTI and Biogenesis to complete pilot studies.

Once the pilot study phase was finished by both the state and federal programs, the two programs formed a technical review committee consisting of representatives from Rochester Institute of Technology (RIT), the Stevens Institute, the New Jersey Institute of Technology (NJIT), Rensselaer Polytechnic Institute (RPI), and others (Stern, interview) The committee selected three technologies out of the nine different technologies that completed pilot tests to construct full-scale facilities. The technologies that have been chosen to construct full-scale facilities are BioGenesis, GTI, and JCI/Upcycle. The state and federal programs continue to keep their funds separate, although they are both funding and managing the NY/NJ project. Currently, Biogenesis is in the first stages of constructing a full-scale facility. GTI and JCI/Upcycle will begin constructing processing plants soon.

Report Information

Purpose of this Report

This report gives a summary of five of the seven technologies for which pilot-studies were performed. The information presented in this paper is based on the pilot study reports and personal interviews with representatives from each of the firms. The five firms included in this report are BioGenesis, Westinghouse Science and Technology, Gas Technology Institute, Metcalf & Eddy, and NUIEG. Each of the firms that participated in the pilot study processed between 1.5 and 500 cubic meters (approximately 2 and 654 cubic yards). (Jones, 127) The sediment that was used in the pilot study was dredged from the Stratus Petroleum Site, located in the Upper Newark Bay.

The purpose of this report is to give information on the technologies developed by these five firms. The following topics are covered in this paper: information on the process, the beneficial use product, the decontamination efficiency, waste, and economics of the technology. It is important to realize that these technologies are still developing and thus the information in this report is bound to change as the technology matures. Also, the steps of the process, cost figures, contaminant removal efficiencies, and other information from the pilot-scale study may not be directly applicable to the full-scale facility. For example, on a pilot-scale, a firm may choose to have its waste processed by an outside firm because it is a cost-effective and feasible option for an operation of a small size. However, on a full-scale, the same firm may choose to purchase the equipment to treat the waste on-site, because economies of scale make the cost of processing the waste onsite less than sending the waste off-site for treatment.

Outline of Report Components

The Process

The process section of the report explains the different components of the decontamination and product conditioning procedures. A schematic is included with each of the processes. It is recommended that one follow the schematic while reading the description of the process.

Residuals

This section addresses the issue of waste by-products resulting from the sediment decontamination and conditioning processes. This portion describes the nature of the by-products produced by the various steps in the procedure and how the waste is treated. The amount of waste produced is also provided in this portion of the report contingent on its availability.

Decontamination Efficiency

This part of the report summarizes the contaminant removal efficiency of each firm's process. The contaminants which this report focuses on are metals, PCBs, dioxins, 2,3,7,8 TCDD, and SVOCs. New York and New Jersey have separate standards for the concentration of these contaminants in permitted in soil. The standards for each contaminant are presented below in Figure 3. In this report, the New York Recommended Soil Cleanup Standards (1994) are only used for PCBs. The New Jersey Residential and Non-Residential Soil Standards (1996) were used for metals, PCBs, and SVOCs. These standards were chosen for use in this report because the Region 2 office of the EPA, USACE, and several of the firms involved in the study also used them. Although standards do not exist for 2,3,7,8 TCDD, a general standard of 1 ppb, a goal for dioxin cleanup sites, was used for comparison. No standard or general guidelines exist for dioxins.

Figure 3: Contaminants and Corresponding Standards and General Guidelines

Contaminant	New York Recommended Soil Cleanup Standards	New Jersey Residential Soil Standard	New Jersey Non-Residential Soil Standard	General Standard of 1 ppb	No Standard
Metals		**X**	**X**		
PCBs	**X**	**X**	**X**		
SVOCs		**X**	**X**		
2,3,7,8 TCDD				**X**	
Dioxins					**X**

The phrase, “regulated RCRA metals” is used throughout the report. New Jersey Residential and Non-Residential Soil Standards exist for twelve out of the thirteen RCRA metals. For simplicity these twelve metals are referred to as “regulated RCRA metals”.

The standards, along with the contaminant concentrations of the untreated and treated sediment for each firm, are present in the Appendix for each contaminant. The *Decontamination Efficiency* section states which standards, if any, the treated sediment failed to meet.

It is important to note that not all of the beneficial-use materials produced by the firms are soil-type products. As a result, the New York and New Jersey soil standards do not directly apply to products that are not soil. The specific standards, which the end-use product must meet, can be found through the American Society for Testing and Materials (ASTM), the EPA, and other sources.

Beneficial-Use Product

The nature of the end-use product is described in this section. The properties of the material are also discussed and in some cases data on product quality testing are included.

For many of the firms, the conditioning processes can be modified to manufacture different products. Variations in the processes as well as the different characteristics of the beneficial-use products are discussed in this section. In many cases, which beneficial-use product will be manufactured from the decontaminated sediment depends on many factors including the chemical composition of the dredged sediment, product marketability, production costs, and feasibility of manufacturing on a large-scale. For instance, deviations in the chemical makeup of the sediment may make one product manufacturing process extremely difficult, while it may be ideal for another process. Likewise, one product may be more saleable, easier to produce, or cheaper to manufacture than another product. The three firms chosen to construct full-scale facilities are still completing cost-analysis, market research, and sediment composition tests to determine exactly what product or products to manufacture. These variables are discussed in the *Economic Analysis* portion of the report.

Economic Analysis

The purpose of this portion of the report is to give a rough idea of the relative magnitudes of the manufacturing costs and end-use product price. This comparison is done to show that one should not discount a manufacturing process because it is cost-intensive, for the beneficial-use material may be able to be sold for a high price and offset production costs. Conversely, a firm that produces a material that will not sell on the market for a high price, may still be profitable if the processing costs are relatively low.

The tipping fee, mentioned in the report, is the amount of money that the state of New Jersey will pay the firms to dispose of the dredged sediment. $35 per cubic yard of dredged sediment is the target dollar amount that the state of New Jersey plans to pay the processing plants in the long term. This tipping fee is equal to the cost of disposing of the dredged sediment in the ocean. The tipping fee in the pilot study, $55 per cubic yard of dredged sediment, was greater than that which the State will pay in full-scale processing because of economies of scale (Stern, interview).

The figure labeled “processing cost” in the cost analysis portions of this report includes all of the materials needed for processing and conditioning the contaminated sediment (water, chemicals, electricity, etc.), labor, facility costs (construction, maintenance, property, etc), loan interest, and equipment (purchase and maintenance). Marketing costs are not taken into account in the processing cost figure.

The end-use product price is the estimated value that the material could be sold for in the NY/NJ or surrounding areas. This value was estimated differently for each of the firms. Some of the values were actual estimates made by the company while other values were obtained by researching the current market for a similar product. The way in which the end-use product price was attained for each respective firm is noted in the *Economic Analysis* section.

As mentioned in the *Beneficial-Use Product* section, determining the processing costs and market price of the product is difficult because most of the firms that participated in the pilot-study do not know which product they will manufacture. Different products can be sold on the market for different prices. Even for a single product, the product price, marketability, and even production costs can vary greatly. As a result of these uncertainties, the precise production costs and market price for the product cannot be determined. The market price and the processing cost, which are used in the economic analysis portion, are estimated values, the sources of which are explained in the end-use product section. The purpose of the figures is not to give an exact amount of profit a firm will make, but rather to give the reader an idea of how cost-intensive a process is.

Biogenesis

The Process

The BioGenesis Sediment Washing Process consists of four main steps followed by dewatering[1]. The four major steps of the process are pre-processing, aeration, sediment washing, and oxidation and cavitation. These steps are labeled in the schematic of the process in Appendix A. Pre-processing, begins by screening the sediment to remove oversized materials. The raw screened sediment is then mixed with chelating agents, select surfactants, and proprietary BioGenesis washing chemicals. The chelating agents remove the metals present in the sediment by drawing them into heterocyclic rings. The surfactants have the ability to adsorb various contaminants present in the sediment (National Research Council, 120). The affinity between the sediment and the contaminants, solids, and organic matter is reduced by the washing chemicals, which facilitates their future removal.

After the pre-processing chemicals are added to the raw sediment, high-pressure water is injected tangentially to further homogenize the mixture. This washing also causes the naturally occurring organic material (NOM) coating of the sediment to dissociate and enter into water phase and large clumps of sediment, which may hinder the process, to break apart.

During aeration, ambient air is bubbled through the sediment slurry thus causing the bonds between the sediment particles and the contaminants to be weakened. Once these bonds are sufficiently weakened, organics and other contaminants break free from the sediment and enter into the aqueous phase. Buoyant organics and other aqueous contaminants can be skimmed off of the top of the slurry. Gas that escapes from the mixture is trapped and treated with granular activated carbon (GAC) and later tested for thirty-nine volatile compounds using gas chromatography/ mass spectrometry (GC/MS).

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[1] For more information on the Biogenesis process see U.S. Patent 6,325,079B1, Apparatus and Method for Removing Contaminants from Fine Grained Soil, Clay, Silt, and Sediment Particles"

A listing of the compounds and their concentrations in the air stream can be found in Table D-11 of the Biogenesis Sediment Washing Technology Final Report. In the pilot study, the gas was determined to be in compliance with NJDEP standards for these volatile compounds.

In the sediment-washing portion of the process, high-pressure water is directed perpendicularly to the flow of the sediment to cause collisions between the sediment particles. The impact between the sediment particles causes the remaining NOM, humic contamination, and microorganisms to dissociate from the sediment. After separating from the sediment, the contaminants enter the water phase.

Hydrogen peroxide is then added to the sediment slurry to oxidize it, and then the mixture is cavitated. During cavitation, vapor bubbles are blown into the sediment mixture to facilitate the breakdown of organic molecules to weak acids, water, and carbon dioxide.

After cavitation and oxidation, the slurry is separated into two phases: decontaminated sediment in solid form and NOM, inorganic and organic contaminants, and residual sediment particles in the liquid phase. Two centrifuges are then used to separate the solids from the liquids. Although a hydrocyclone was not used in the pilot study, it may be used in order to remove larger particles that may cause the balance of the centrifuge to be disrupted.

Residuals

The waste produced by the Biogenesis process can be categorized into wastewater, solids, and gases. In this pilot study, 298,000 gallons of wastewater were produced in the decontamination of 700 cubic yards of dredged material. (Biogeneisis, 1-1 and 3-29). Biogenesis contracted an outside company, PVSC, to dispose of the wastewater. The wastewater consisted of stormwater and other residual fluids collected from the floor drain in the processing area, aqueous centrate from the liquid/solid separation process, and wash water and other cleaning fluids produced during the decontamination of the sampling and processing equipment.

Solid waste, both potentially-hazardous and non-hazardous materials, was also produced by the process. The non-hazardous construction debris and domestic trash were disposed of in a local landfill. Biogenesis contracted SK Services to properly dispose of the potentially hazardous materials which consisted of personal protective equipment (PPE), plastic sheeting, chemical containers, and other materials that may have contacted process streams (Biogenesis, 3-30).

Other solid waste materials were also produced in the decontamination process. Most of the oversized material, which was removed during preprocessing, could be disposed of in a non-hazardous landfill. If the oversized material did in fact contain significant levels of contamination, it was first rinsed with water before it was sent it to a non-hazardous landfill (Wilde, interview). Organic materials skimmed off of the sediment after the aeration step were transported to an on-site filter press, where they were dewatered. After dewatering, the solid was tested and then sent to an appropriate landfill.

The gas component of the waste by-products was that which was emitted from the aeration step and other holding and processing containers. These offgases were filtered through a granulated activated carbon filter (GAC) before they were released into the atmosphere.

Decontamination Efficiency

The removal efficiency analysis was completed by using the average inlet sediment, listed in the report as RAW-SD, as the untreated sediment, and the average treated sediment, PSD-SL, as the treated sediment. Biogenesis treated 700 cubic yards of dredged sediment. The decontaminated sediment or end-use product resulting from the Biogenesis' decontamination process passed all of the standards and general guidelines considered in this report with the exception of the New Jersey standards for five SVOCs.

The soil or fill product passed all of the metal and PCB standards and general guidelines for dioxins and 2,3,7,8 TCDD.

The decontamination analysis for 2,3,7,8 TCDD and dioxins is in Appendix F. The average removal efficiency for three dioxins: PeCDD, HxCDD, HpCDD, was about 51%. The removal efficiency for TCDD was roughly 5%. The removal efficiency for 2,3,7,8 TCDD was approximately 61%. The concentration of 2,3,7,8 TCDD in the treated sediment was 35.3 ppt, which is below the general standard of 1 ppb.

The decontaminated sediment passed all of the New Jersey Residential and Non-Residential Standards for metals, as shown in Appendix G. On average, the metal concentrations in the treated sediment were more than 89% below the New Jersey Residential and Non-Residential Standard.

As shown in Appendix H, the PCB concentration of the treated sediment was found to be 203 ppb, which is below the New York Recommended Soil Standard, 1000 ppb, and the New Jersey Residential and Non-Residential Soil Standards, 480 and 2000 ppb, respectively.

The standards that the end-product did not pass were the New Jersey Residential Soil Standards for benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, and indeno(1,2,3-cd)pyrene. The soil or fill also did not pass the New Jersey Non-Residential Soil Standard for benzo(a)pyrene[2]. Data was missing for three of the nine SVOCs considered in this study: N-Nitrosodiphenylamine, bis-2-ethylhexylphthlate, and di-n-butyl phthalate. The remaining six SVOC concentrations of the untreated sediment were an average of 42% above the New Jersey Residential Soil Standards and 36% below the New Jersey Non-Residential Soil Standards. The concentrations of these five out of these six SVOCs were below the detection limit in the untreated sediment. These data can be found in Appendix I.

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[2] The New Jersey Non-Residential and Residential Soil Standards are the same.

End-Use Product

After the contaminated sediment goes through the Biogenesis process, the decontaminated sediment is used to produce a beneficial-use product. Biogenesis has chosen to manufacture a soil or fill product (Biogenesis, 3-17).

New York and New Jersey have an annual demand for approximately 15-18 million bags of soil and as much as 6 million cubic yards of wholesale bulk soil (Biogenesis, 4-63). It is estimated that the current market price of the end-use soil or fill product is between $2-$4 per cubic yard, although future estimate that the value may climb as high as $10 per cubic yard (Wilde, interview).

The more "contaminant-free" the processed sediment is, the more valuable it is on the market. However, removing a larger proportion of the contaminants from the sediment costs more. As a result, Biogenesis must complete a cost-benefit analysis of the treatment cost against the market price to determine the extent to which the sediment should be decontaminated (Biogenesis, 5-4). The level of decontamination that will yield the largest profit-margin, where the market price for the treated sediment excedes the processing costs by the largest amount, will be selected for production.

Economic Analysis

The full-scale processing facility, built to decontaminate the sediment in the NY/NJ Harbor, will treat approximately 500,000 cubic yards of material each year. The tipping fee paid to the firm by the state is $35 per cubic yard. The Biogenesis sediment washing treatment costs approximately $32, as shown in Figure 4. According to a Biogenesis representative, the approximate product price of the end-use material is between $2 and

$4 per cubic yard. For analysis purposes, an average product price of $3 cubic yard was used (Wilde, interview). Due to the fact that the sediment is approximately 50% water, two cubic yards of dredged sediment will yield one cubic yard of end-use product. As a result, the revenue that is generated by processing one yard of dredged sediment will be approximately $1.50. Taking into account the tipping fee, the processing costs, and the market price of the end-use product, Biogenesis will earn a net profit of roughly $4.50 per cubic yard, as shown below Figure 4.

Figure 4: Economic Analysis of the Biogenesis Process

	Cost/Credit (per yd^3 of dredged sediment)
Tipping Fee	+$35
Processing Cost	-$32
End-use Product Price	+$1.50
Net Profit/Loss	**+$4.50**

Westinghouse

The Process

The Integrated Plasma Gasification and Combine Cycle (IPGCC) devised by the Solena Group, Westinghouse's strategic partner, for the decontamination of sediment consists of three major steps: preprocessing, vitrification, and offgas treatment. Preprocessing consists mostly of sediment sorting and dewatering. The actual decontamination of the sediment takes place through vitrification, or heating the sediment to sufficiently high temperatures to transform it into a glass-like product.

As shown in the schematic in Appendix B, pre-processing begins with screening the contaminated sediment twice: the first time to remove oversized materials and the second to remove larger pieces of sediment. The oversized material can be disposed of in a non-hazardous landfill while the larger sediment particles can be broken down and processed. The purpose of screening the sediment is to create a finer mix of sediment, which can be pressed and processed more easily and efficiently (Miller, interview). Large materials may clog the equipment, whereas smaller particles pass through without difficulty.

Once the sediment has passed through the second one millimeter grid screen, the sediment enters a mixing tank to which dilution water and hydrated lime are added. Lime is added to dry out the sediment, in order to increase the efficiency of vitrification. In some instances, water can be decanted from the sediment, however, this process was not used in this pilot study.

After screening, the sediment is then transferred into a filter press, where more water is removed from the sediment. The filter press blows air through the sediment, driving off excess water and leaving behind a sediment filter cake. The filtrate is captured in a storage container, labeled "frac tank" in the schematic, and is later analyzed and disposed of properly.

The filter cake then enters a delumper hopper, where lime and soda ash are mixed with the cake in order to achieve a metal oxide loading of 83% in the final glass melt (Westinghouse, 5-11). Sufficient water is added so that this dewatered sediment can be fed into the Plasma Melter via a vitrification tuyere. If the water content of the sediment is too low, it will be unable to flow into the Plasma Melter.

In the Plasma Melter, rapid mixing of the sediment with the 5000°C plasma torch flame occurs as a result of sediment moisture flashing from the sediment and to brisk air circulation from the tuyere. PCBs, dioxin, and other refractory organic carbon compounds volatalize, and leave the sediment. This offgas is trapped and later treated.

Vitrification transforms the sediment into a molten product. This molten material can be conditioned in preparation for manufacturing into a beneficial use product. To prepare the molten glass for rock wool fabrication, it is put into a centrifuge with glass fibers

(Westinghouse, 4-3). In order to produce uniform roofing granules, the molten material is granulated. The molten glass may also be shattered by quenching it with water to form aggregate.

The offgas produced by the vitrification process is treated through a system of scrubbers, a demister/separator, and exhauster. The Venturi scrubber first cools the gas stream, eliminates sulfur oxides, and condenses volatile salts. Condensed particulates are removed from the stream by the scrubber. The separator/demister then performs two major tasks: removing additional aerosols and solid particulates and treating exhaust. The separator/demister scrubs the stream from the exhaust, then traps and sends water soluble offgas products to a holding tank. The offgas then goes to one of two places. The majority of the stream is composed of of innocuous offgases such as N_2, O_2, and CO_2 which are allowed to escape into ambient air. The gas, that does not meet the standards to be released into the atmosphere, is sent back to the scrubber for further processing.

Residuals

Six residuals are produced by the Westinghouse Plasma Vitrification Process. Three of the six by-products are solid waste, two are clean water, and one is clean offgases. 2200 tons of gypsum (calcium sulfate), 400 tons of oversized material, 90 tons of precipitated metals (from the scrubber water), 52 million gallons of filtrate and rinse water, 700,000 gallons of scrubber water bleed, and 2.4 billion standard cubic feet of clean offgases are estimated to be produced from processing 100,000 cubic yards of contaminated sediment each year.

The three solid waste by-products: gypsum, oversized material, and precipitated metals, can be disposed of in a non-hazardous landfill. Precipitated metals must first be encapsulated before they are put in a landfill. Alternatives to disposal in a landfill also exist for each of the three forms of solid waste. Gypsum can be used, oversized material can be plasma vitrified to produce a slag, and precipitated metals can be further processed to recover heavy metals.

Both wastewater products, the scrubber water bleed and the filtrate and rinse water, can be disposed of in a regular sewer, although the scrubber water bleed must first be treated for heavy metals.

Decontamination Efficiency

Two samples, one untreated (WP-R1-01-01B) and one treated (WV-03-02-01B), were used for removal efficiency analysis for the specific contaminants considered in this report.

The sediment treated with the Westinghouse Plasma Vitrification passed the SVOC, PCB, 2,3,7,8 TCDD, and metal standards with the exception of the New Jersey Residential and Non-Residential Soil Standards for copper and thallium.

The PCB concentration of the decontaminated sediment was 0.83 ppt which falls below the New York Recommended Soil Cleanup Standard, and both the New Jersey Residential and Non-Residential Soil Cleanup Standards, as shown in Appendix H. The levels of 2,3,7,8 TCDD in the treated sediment, 0.9 ppt, was less than that of the general standard, 1 ppb.

The average reduction in the concentrations of TCDD and three different dioxins: PeCDD, HxCDD, HpCDD, was 100%, as shown in Appendix F.

Six of the nine SVOC concentrations were below the detection limit of 333 ppb. The remaining three SVOC concentration were an average of 98% and 100% below the New Jersey Residential and Non-Residential Soil Standards, respectively. The concentration of N-Nitrosodiphenylamine, was greater in the treated sediment than in the untreated sediment. This data is in Appendix I.

The treated sediment passed ten standards out of the twelve standards set for the RCRA metals. The copper and thallium concentrations in the decontaminated sediment both exceeded the standard. The copper concentration was approximately 1000 ppm, which is roughly 67% greater than the standard New Jersey Residential and Non-Residential Standard of 600 ppm. The treated sediment also contained a thallium concentration of approximately 4.97 ppm, nearly two and a half times the New Jersey standard of 2 ppm. The other metal concentrations, however, were an average of 66% and 77% below the New Jersey Residential and Non-Residential Standards respectively.

When comparing the contaminant concentration of the treated sediment to the standard, one must take into account that the decontaminated material produced by the Westinghouse Plasma Vitrification is a glass product not soil. As a result, the New Jersey soil standards do not directly apply to the treated sediment, although they do provide a rough basis of comparison between the technologies. The actual standards that apply to the glass material will vary by the product which Westinghouse chooses to manufacture. These standards are available through the EPA and American Society for Testing and Materials (ASTM).

End-Use Product

The molten glass material produced by the Westinghouse Plasma Vitrification Process can be used to make a variety of products including, but not limited to, glass fiber, glass tiles, rock wool, aggregates, solar glass, and roofing granules. The preliminary phases for creating aggregate, roofing granules, and rock wool are listed in *The Process* section.

Rock wool can be made by shooting a stream of air at a revolving wheel covered in molten glass product to produce wool fibers. Steel mill slag is usually used to make rock wool. However, new sulfur emission limits have deterred steel mills from producing rock wool. The supply of rock wool has decreased, but the demand for rock wool has remained relatively constant. As a result, where the demand used to be met by the supply, the demand now excedes the supply. Westinghouse hopes to fill this gap between the supply and demand for rock wool because its product does not contain or emit high levels of sulfur in its production. The market density of rock wool in the NY/NJ is also sufficiently low so that shipping rock wool produced by Westinghouse distances of more than 100 to 200 miles would be profitable (Westinghouse, 9-3).

The molten slag produced by the Westinghouse Plasma Vitrification Process can also be used to produce roofing granules, which can serve as a barrier against ultraviolet degradation on asphalt roofs and shingles. The production of roofing granules is slightly more difficult than that of rock wool, because specific oxidation-reduction potentials must be retained to ensure ultraviolet absorption by the roofing granules. The high Fe^{3+}/Fe^{2+} ratio in the sediment product is desirable because it allows for high levels of ultraviolet absorption.

Westinghouse would have to complete a cost-benefit analysis to determine which end-use product it should manufacture. The chemical composition of the decontaminated sediment must be analyzed to determine which additives are needed to create a beneficial end-use product. The cost of the additives and product conditioning must be weighed against the revenue generated by the sale of the beneficial-use material to determine which product will produce the greatest margin of profit. The Solena Group is considering the possibility of partnering with a tile company to produce tiles from the sediment (Miller, interview).

Economic Analysis

Approximately 177,000 tons or 79,300 cubic yards[3] of molten glass material are expected to be produced from the vitrification of 500,000 cubic yards of sediment. As mentioned before, this molten product can be used to manufacture a variety of products. It is estimated that both glass fiber and glass tiles could be sold for on the order of hundreds

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[3] Using a standard density of 2650 kg/m3 for sediment

of dollars per ton. The market price for rock wool is roughly $200 per ton. The price and market for aggregates, solar glass and roofing granules has not been researched.

Due to the fact that Westinghouse could produce a variety of products from the molten glass product, the beneficial-use product price is difficult to determine. According to Westinghouse estimates, the range of revenue generated by the sale of the end-use product may vary from $7 to $180 per cubic yard (Westinghouse, 12-17). The processing cost per cubic yard of contaminated sediment is approximated to be between $99 to $126. The processing cost depends on several factors including the level of contamination of the sediment and the variable costs associated with building a new processing plant. For economic analysis, the averages of the upper and lower bounds of the processing costs and end-use product price were used for simplicity sake. Consequently, the estimated beneficial use product price is approximately $93.50 per cubic yard. One must also take into account that the dredged sediment is approximately 50% water, which is not used in the manufacturing of the final product. As a result, two cubic yards of contaminated sediment are used to make one cubic yard of product. Therefore, the revenue generated by the sale of the beneficial use product per cubic yard of contaminated sediment is about $47 per cubic yard.

Figure 5: Economic Analysis of the Westinghouse Process

	Cost/Credit (per yd^3 of dredged sediment)
Tipping Fee	+$35
Processing Cost	-$112.5
End-use Product Price	+$47
Net Profit/Loss	**-$3**

As shown in Figure 5, Westinghouse would lose roughly $3 per cubic yard of contaminated sediment processed. According to the range of costs and product prices, this number could vary from approximately -$87.5 to $26 per cubic yard of dredged sediment.

GTI

The Process

The four main steps of GTI's Cement-Lock^R Technology process are pre-treatment, sediment melting, end-product processing, and offgas treatment. A schematic of the process can be found in Appendix C. The contaminated sediment is first sifted through a vibrating screen to remove any oversized material. Propietary modifiers, used to enhance the cementitious characteristics of the sediment, are added to the screened sediment. The mixture is then fed into a rotary kiln melter.

The melter exposes the sediment and modifier mix to temperatures between 1200° and 1400°C. At these temperatures, the sediment and proprietary modifiers are melted completely and form a matrix melt. Organic contaminants and volatile compounds in the sediment, including sodium and potassium chlorides, vaporize as a result of the elevated temperatures of the melter. The organic compounds, which are released from melting the sediment, are naturally converted by heat to environmentally acceptable gases, carbon dioxide (CO_2) and water (H_2O). To ensure that all of the organic compounds are destroyed, the flue gas enters a secondary combustion chamber (SCC) where it is exposed to the same temperatures of the melter for two periods of two seconds each.

The flue gas, containing the SVOCs and other volatile contaminants, leaves the SCC and is cooled by a 204°C direct water injection to prevent the formation of furan and dioxin precursors. Hydrogen chloride, formed by the heating of any chlorines which may have been originally in the sediment, also must be treated. Powdered lime is injected to capture the hydrogen chloride, sulfur dioxide (SO_2), and other acid gases. Not all of the chlorine is trapped by this process; some of it is locked into the matrix of the melt. Sodium and potassium chlorides, which transpired out of the sediment, along with spent lime and fine particulates are captured in a bag house, sent through a carbon column, and then released into the atmosphere.

Metal contaminants present in the dredged sediment, however, are not removed by the melting process. Instead, the metals remain in the cement mixture. When the cement product is made into concrete, the metals are locked into place. The concrete made with GTI's cement product must pass specific leachability tests, such as the toxicity characteristic leaching procedure (TCLP), before it can be marketed.

In the product-conditioning portion of the Cement-Lock™ Technology, the matrix melt is either diffused into micrometer-sized fibers or pulverized into granules by freezing it with a stream of quench water or high-velocity air. Special additives can be combined with granulated fibers or pulverized matrix melt to create construction-grade cement.

Residuals

The residuals resulting from the GTI process can be categorized into two types: metals and organic compounds. Most of the metal components are locked into the end-product, the Ecomelt, while the majority of the organic compounds leave are converted to innocuous gases, water, or salts.

Nine out of the thirteen RCRA metals, barium, cadmium, chromium, copper, lead, nickel, silver, selenium, and zinc are locked into the end-use product (32). Two of the remaining RCRA metals, arsenic and mercury are adsorbed into activated carbon, solidified, and immobilized.

The organic contaminants, which may or may not be present in the sediment, include polyaromatic hydrocarbons (PAHs), organochlorine pesticides, PCBs, and 2,3,7,8-chlorine substituted PCDD/PCDF isomers. These compounds are transformed into hydrogen, chloride, SO_2, nitrogen, and organic carbon by the GTI process. These waste components are then altered so that they can be released into the environment. All of the modified forms of the waste components are innocuous, with two exceptions. These two exceptions, SO_2 and NO_x, are released within regulatory limits. A table of the waste components and their modified forms can be found in Figure 6.

Figure 6: GTI Waste Components and Their Modified Forms

Waste Component	**Modified Form**
Organic Hydrogen	Demineralized water
Chlorine, SO_2	Salts, solidified, stable,
	some SO_2 in the off-gas
Organic Nitrogen	Oxides of Nitrogen,
	N_2 (off-gas)
Organic Carbon	CO_2 (off-gas)

Removal Efficiency

The sediment treated by the GTI process passed all of the standards for metals, semi-volatile organic compounds, dioxins, and 2,3,7,8 TCDD. Note that two samples, one for untreated sediment, sample GTI-37, and one for the treated sediment, sample GTI-15, were used in the following analysis of removal efficiencies for these select contaminants.

On average, the concentrations of twelve of the regulated RCRA metals in the decontaminated sediment were 85% and 89% below that of the New Jersey Residential and Non-Residential Recommended Soil Standards, respectively.

The concentrations of four of the nine SVOCs in the treated sediment were below the detection limit of 333 ppb. The untreated sediment also contained a concentration of N-Nitrodiphenylamine below the detection limits. The concentrations of the five SVOCs that were not below the detection limit in the decontaminated sediment, were an average of 99% below the both the New Jersey Residential and Non-Residential Recommended Soil Standards.

The GTI process removed an average of 100% of PeCDD, HxCDD, HpCDD, and TCDD as shown in Appendix F. The treated sediment also contained levels of 2,3,7,8 TCDD below the detection limit of 1 ppt, which is below the recommended standard of 1ppb.

End-Use Product

The end-use material produced by GTI is not portland cement, rather it is a cement product with properties similar to those of portland cement, to which sand, gravel, and water must be added in order to create concrete (25). The cement product resulting from the sediment decontamination is coined Ecomelt by GTI. Compressive strength tests were performed on the Cement-lock cement to determine whether it met ASTM standards C-595 for blended cement and C-150 for Portland cement. Water and Ottawa sand were blended with the cement in a standard ratio specified by ASTM. In accordance with the ASTM standard testing method, the samples were allowed to cure for 3, 7, and 28 days. A summary of the results are shown in Figure 7. The Cement-Lock Cement passed all of the standards for both blended and Portland cement, with the exception of the blended cement seven day test period requirement, which it missed by 0.1 Mpa.

Figure 7: Comparison of Cement-Lock Cement Strength v. ASTM Cement Requirements

		ASTM Cement Requirements	
Test Period (days)	**GTI Cement-Lock Cement**	**C-595 Blended**	**C-150 Portland**
3	15.4	13	12
7	19.9	20	19
28	36.3	24	28

Economic Analysis

The United States uses approximately 105 million metric tons of powdered cement each year. Roughly 25 million tons of the powdered cement are imported. GTI hopes to fill part of the gap between the supply of domestically-produced powdered cement and the domestic demand for powdered cement.

At full-scale, the approximate processing cost is $60 per cubic yard, as shown in Figure 8. This cost includes the treatment and conditioning of the raw dredged sediment to produce a material similar to portland cement.

Figure 8: Economic Analysis of the GTI Process

	Cost/Credit (per yd^3 of dredged sediment)
Tipping Fee	+$35
Processing Cost	-$60
End-use Product Price	+$27.50
Net Profit/Loss	**+$2.50**

The price of portland cement is $82.34 per ton, according to the July 2002 issue of the Engineering News Record. The estimated market price for the cement material produced by GTI is expected to be between $50 and $60 per ton. The difference between the market prices of portland cement and the GTI cement product is due to the fact that the latter will not be as marketable because of public resistance to purchase a product made from previously contaminated materials. For the purpose of developing a rough economic analysis, the average expected market price, $55 per ton of Ecomelt ($22 per cubic yard[4]) of was used as the end-use product price. The revenue generated by the sale of the end-use material produced by processing one cubic yard of dredged sediment was estimated to be $27.50. This estimated figure is half the market price of one cubic yard

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[4] Note: 3.00 g/cm^3 was used as the specific gravity of powdered Portland cement as well as the powdered cement made from the sediment decontaminated by GTI

of end-product because approximately 50% of the dredged sediment is water and thus will not be used in the actual manufacturing of the end-use product. Taking into account the processing fee, the tipping fee, and the market price for the end-use product, the estimated profit, per cubic yard of dredged sediment is \$2.50, as shown in Figure 8.

NUIEG

The Process

The NUIEG sediment processing procedure consists of three core steps: pre-processing, oxidation, and end-use product conditioning. A schematic of the NUIEG process can be found in Appendix D. The first step in pre-processing is screening the sediment for materials over ¼" in size. The isolated oversized material is then disposed of in a landfill. Although not used in the pilot-scale, recycled filtrate water would be added to the sediment to aid in the screening process in a full-scale facility.

After the sediment is screened, it must be dewatered in order for the decontamination process to run smoothly. The water content of the sediment is reduced by a recycling drying procedure. In this process, a portion of the sediment is dried by normal exposure to air and manual mixing. This dried sediment is then added to wet sediment. The two portions are mixed together, dried, and then added to more wet sediment. The purpose of using this recycling process is to accelerate drying (NUIEG, 10). In the full-scale facility, the water that evaporates from the wet sediment will be salvaged and used as filtrate water in the screening process.

Once the sediment is dewatered, the sediment is transferred to a mortar mixer where it is oxidized through the addition of an oxidant, potassium permanganate ($KMnO_4$). Potassium permanganate reacts with the contaminants in the soil to produce non-hazardous compounds. In the pilot study, $KMnO_4$ was added to the weight of the dried sediment until a concentration of approximately 6,000 ppm was achieved.

After sediment decontamination, the additives, including fly ash and cement, can be mixed in with the treated sediment to create a variety of products. Pozzolanic additives can also be added to the decontaminated sediment in order to stabilize it, although they were not added in this pilot study.

NUIEG is concerned that using $KMnO_4$ as the oxidant may result in unacceptably high levels of magnesium in the benficial-use product. As a result, they are researching alternative oxidants, including hydrogen peroxide (H_2O_2).

Residuals

The only waste produced by the NUIEG process is wastewater generated by the dewatering process of the sediment. A fraction of this water is recycled and used to ease the initial screening of the sediment. The remainder of the water can either be transported to a Public-Owned Treatment Works (POTW) or discharged under a point source discharge permit (NJPDES) (NUIEG, 56). On a full-scale, NUIEG may chose to construct an on-site facility to treat the wastewater. However, on a pilot-scale, it is more cost-effective to send the wastewater to a POTW.

Decontamination Efficiency

Missing data make this analysis of the decontamination efficiency of the NUIEG process incomplete. The treated and untreated sediment contaminant concentrations are averaged over two runs, which contained nine samples each. This data can be found in the "Analytical Qualifiers" section of NUIEG's pilot study report.

From the data that is provided, the treated sediment met all but the New Jersey standards for benzo(a)pyrene. The decontaminated sediment met the standards and general safety guidelines for PCBs, eight out of the twelve RCRA regulated metals, and seven out of the nine SVOCs considered in this analysis. Data is missing for three RCRA regulated metals: beryllium, selenium, and thallium. The concentration for the remaining regulated RCRA metal, silver, was found to be indeterminable. The concentration for di-n-butyl phthalate, a SVOC, is also missing. No data exists for dioxin or 2,3,7,8 TCDD.

As shown in Appendix I, the treated sediment did not meet the standard for one SVOC, benzo(a)pyrene. The concentration in the decontaminated sediment was found to be 3820 ppb, nearly five times the New Jersey Residential and Non-Residential Soil Standard[5] of 600 ppb. Overall, the treated sediment contained SVOC concentrations approximately 68% and 88% below the New Jersey Residential and Non-Residential Soil Standards, respectively.

The metal concentrations in the treated sediment were an average of 32% and 83% below the New Jersey Residential and Non-Residential Soil Standards, respectively. These averages are calculated from the eight metals for which data existed. The data used to compute these averages can be found in Appendix G.

The NUIEG process removed approximately 24% of the PCBs present in the untreated sediment. The treated sediment contained 358 ppb of PCBs, which meets the New York and New Jersey standards, which are listed in Appendix H.

End-Use Product

As mentioned in *The Process* section of this report, the treated sediment produced by the NUIEG decontamination process can be used to create a variety of products. Which material NUIEG actually chooses to manufacture depends on the production costs and marketability of the potential product. Different ratios and amounts of ash, cement, and other additives can be added to the treated sediment in order to create a wide range of products, including a material similar to portland cement. Without the addition of these chemicals, the treated sediment alone can be used as fill or capping material.

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[5] The New Jersey Residential and Non-residential Soil Standards are both 600 ppb for benzo(a)pyrene

Economic Analysis

The cost of the NUIEG process is approximately $30 per cubic yard. This processing cost is compensated for by the tipping fee of $35.

Due to the fact that NUIEG was unsure of which product it would manufacture, the average between the estimated market prices of soil and fill was used as the end-use product price. The estimated market prices for fill and soil were obtained by averaging the cost of soil and aggregate from seven different wholesalers of each product. These wholesalers were located in the area surrounding the NY/NJ Harbor. The market prices for fill and cement were roughly $6 and $11 per cubic yard, respectively. The average between these two figures, or $8.50 per cubic yard, was taken to be the end-use product price.

Figure 9: Economic Analysis of the NUIEG Process

	Cost/Credit (per yd^3 of dredged sediment)
Tipping Fee	+$35
Processing Cost	-$30
End-use Product Price	+$4.25
Net Profit/Loss	**+$9.25**

This figure was then divided by two, to account for the fact that about half of the dredged sediment is water. The water in the sediment is removed by the process, and thus is not used in the manufacturing of the beneficial-use product. Taking into account the tipping fee, processing cost, and end-use product price, the revenue generated by processing one cubic yard of contaminated sediment is roughly $9.25, as shown in Figure 9.

Metcalf & Eddy

The Process

The approach that Metcalf & Eddy took in the pilot-study was different from the other firms, in that it tested three variations of a single process, whereas the other firms tested a single process. A schematic of the combination of these procedures is shown in Appendix E. The main components of the decontamination and end-use product conditioning process are pre-processing (HYDRO-SEP), organic extraction (ORG-X), and solidification and stabilization (SOLFIX). Different combinations of these three processes were used to form the three variations that were tested in the pilot study. The three variations of the process are HYDRO-SEP and ORG-X, HYDRO-SEP and SOLFIX, and HYDRO-SEP, ORG-X, and SOLFIX. HYDRO-SEP and ORG-X can be used to produce a fill material, while the other two combinations, HYDRO-SEP and SOLFIX and HYDRO-SEP, ORG-X, and SOLFIX produce a cement product. The specific required materials and end-use product associated with each of the process combinations are shown in Figure 10.

Figure 10: Metcalf & Eddy Process Combinations and Specific Required Materials and End-Use Materials

	Required Materials	End-Use Product
HYDRO-SEP and ORG-X	ORG-X extraction chemicals	Fill
HYDRO-SEP and SOLFIX	Portland cement	Cement Product
HYDRO-SEP, ORG-X, and SOLFIX	ORG-X extraction chemicals and Portland cement	Cement Product

Pre-processing begins with the screening of the raw sediment through a ¼” screen. The screened sediment continues through the decontamination process; materials that do not make it through the screen are set aside and are later treated by the HYDRO-SEP washing process. HYDRO-SEP uses water to rinse away the contaminants on the oversized material, thus making it acceptable for disposal in a non-hazardous landfill. The washwater used in the HYDRO-SEP procedure can be recycled and used again.

The screened sediment, meanwhile, is cleansed by ORG-X solvent extraction. Both batch and continuous extraction processes of the ORG-X procedure were tested in this pilot study. In the batch procedure, the screened sediment is transferred to a mixer-settler extractor tank containing new solvent or solvent which has been recycled from a previous batch. The mixer-settler tank is equipped with a three-blade impeller and a two-bar bottom scrapper propeller mixer (Metcalf & Eddy, 2-6). After the addition of the screened sediment to the mixer-settler extractor, nitrogen is flushed through the vessel in order to clean it. Extraction solvent heated to between 100° and 140°F is then added to the tank until the ratio between the screened sediment and the extraction solvent is 1:1. After fifteen minutes of agitation with the mixer and ten minutes of settling, the tank consists of a bottom layer of solvent-saturated sediment, and a top layer of solvent containing organic contaminants. The contaminated solvent layer is decanted from the tank and treated. A bag filter is used to trap the small amount of sediment that is present in the solvent layer. The extraction process is repeated on the bottom layer of solvent-saturated sediment until the desired amount of the various organic compounds have been removed from the sediment.

The treated sediment layer is dried using a steam jacket. The propeller mixer is kept rotating in order to increase heat transfer through the sediment, which in turn accelerates the drying process. The solvent and water azeotrope is trapped, condensed, and returned to the extractor where it is used for future extractions. The decontaminated sediment is then exposed to the vapor temperature of water, 212°F, to ensure that all of the solvent has been removed from the sediment.

The second layer from the extraction, the azeotrope water and solvent mixture, is separated into its aqueous and solvent components using distillation. The solvent and water mixture is heated to 172 to 185°F, a span of temperatures which corresponds to the range of boiling points of typical azeotrope solvent-water mixtures (2-8). As a result, when the azeotrope is heated to these temperatures, it volatilizes. The azeotrope vapor is then condensed into waste oil and a 2-layer liquid, which consists of a top layer of solvent and an aqueous bottom layer. An oil polisher is used to remove the residual solvent present in the waste oil. The polished waste oil is sent to an off-site facility to be incinerated or disposed of in some other manner (Cardoni, interview). The solvent layer of the azeotrope can be decanted off of the aqueous layer and used in the extraction process. The water layer is drained from the vessel and is steam stripped to remove residual solvents (Metcalf & Eddy, 2-9).

The wastewater layer is transported to a stripper column where any residual solvents are removed by steam stripping. Organic compounds with lower boiling points can be isolated by injecting steam into the sediment. Other organic compounds can be removed from the wastewater or condensate by feeding water, just below the azeotropic boiling point through the feed preheater. A portion of this feedwater vaporizes upon entering the top of the column, and the remainder is stripped of residual solvents by upflowing steam (2-10). The vapors produced by the stripping process are condensed and used again as solvent in the extraction process.

The continuous solvent extraction process is identical to the batch solvent extraction process, with a few modifications. The sediment must be screened to 1/8" instead of 1/4". Also, instead of periodically decanting the solvent and water azeotropic layer from the sediment after extraction, the continuous process separates the two layers without interruption during extraction. In the continuous process, the sediment is allowed to escape through the bottom of the column, and the solvent is removed through the top of the column. The solvent recovery, organic separation, and water stripping steps are the same for both extraction processes.

The final step in the process, the SOLFIX solidification and stabilization step, involves the addition of Portland cement to the sediment. As mentioned in *The Process* portion of this section, the SOLFIX process was performed on both the raw dredged sediment and ORG-X extracted sediment. Due to the high water content of the raw sediment, excess water had to be decanted from it in order to ensure the production of a quality product. Portland cement was added to the raw sediment in 1:10, 1:5, and 1:2.5 ratios and to the treated sediment in 1:6.67 and 1:3.33 ratios. The sediment and Portland cement mixture can then be poured into desired molds to make solid concrete.

Residuals

The waste by-products resulting from the Metcalf & Eddy process fall into four categories: spent solvent, organic waste oil, gas mixtures, and water. The used solvent and the organic waste oil are shipped to an outside source to be processed by a fuel-blend incinerator and regular incinerator, respectively. The gas that is discharged from the batch and continuous extractions consists of mostly nitrogen purge gas, small amounts of oxygen, other atmospheric gases, and traces of solvents and water. Although only small amounts of solvent exist in the vent gas, an activated carbon scavenger downstream of the vent destroys any remaining organic vapors before the gas is released into the atmosphere. Before the wastewater is sent to a public-owned treatment works (POTW) for disposal, it is tested to ensure that it does not contain concentrations of organic solvents in excess of the POTW's standard for acceptance. In the pilot-study, the wastewater was found to contain less than 0.1 percent organic solvents, a level acceptable for disposal in a POTW.

The condensate from the steam stripping traps does not come in contact with any contaminated substances or waste streams, so it can be disposed of a sewer. The city water, which is used in the vent condenser, can also be discharged into the sewer. In the pilot-study, the city water flow into the sewer was less than .5 gallons per minute.

Decontamination Efficiency

To complete the decontamination efficiency evaluation, two samples were considered. One of these samples, MEP-1-1, was an “as-dredged” sediment sample, which was used as the untreated sediment. The other sample, MEPP-10-1, which was treated using the continuous ORG-X decontamination process, was used as the treated sediment. As mentioned in *The Process* portion of this report, Portland cement was added to the treated sediment in ratios of 1:3.33 and 1:6.67. Because the beneficial use end-product consists of both decontaminated sediment and Portland cement, adjustments to the data had to be made. A Portland cement to treated sediment ratio of 1:3.33 was assumed. Using this ratio, approximately 76.9% of the end-product is actually treated sediment. The concentrations of the treated sediment, MEPP-10-1, were multiplied times a factor of .76905 to reflect the actual contaminant concentrations in the beneficial-use material.

The treated sediment did not meet the standards for three of the twelve RCRA metal standards: arsenic, copper, and lead. The arsenic concentration was 53.2 ppm and the New Jersey Residential and Non-Residential Standards is 20 ppm. The copper concentration of the treated sediment, 823 ppm, exceeded the residential and non-residential standard, which are both 600 ppm. In this case, the copper concentration of the untreated sediment, 1410 ppm, was higher than that of the treated sediment. The treated sediment contained concentrations of lead greater than the New Jersey Residential Standard. The standard is 400 ppm and the treated sediment had a concentration of 461 ppm. The concentrations for the nine metals that did meet the standards were an average of 53.3% and 75.4% below the New Jersey Residential and Non-Residential Soil Standards, respectively.

The treated sediment contained PCB concentrations below the New York Recommended Soil Cleanup Standard and the New Jersey Residential and Non-Residential Standards, as shown in Appendix H. The Metcalf & Eddy process reduced the PCB concentration in the sediment by nearly 98%, reducing it from 5,440 to 109 ppb.

The average removal efficiencies for TCDD and three dioxins: PeCDD, HxCDD, and HpCDD were 96% and 99% respectively. The concentration of 2,3,7,8 TCDD was found to be 7.29 ppt, which is below the general standard of 1 ppb. This data can be found in Appendix F.

As shown in Appendix I, the treated sediment contained SVOC concentrations below the New Jersey Standards, though it should be noted that the concentrations of two contaminants, benzo(b)flouranthene and benzo(a)anthracene were both within 2% of the standard. On average, the SVOC concentrations of the treated sediment were 59.3% and 82.7% below the New Jersey Residential and Non-Residential Standards, respectively.

End-Use Product

The Metcalf & Eddy sediment treatment process can either be used to produce a cement product or a fill material depending on the specific processes used. HYDRO-SEP will be used regardless of which material is chosen for production. This washing process is necessary for the disposal of oversized materials. HYDRO-SEP and SOLFIX with or without ORG-X can be used to produce a cement product. Fill can be produced by using a combination of the HYDRO-SEP and SOLFIX technologies. In the production of the cement material, to determine the exact ratio of treated sediment to Portland cement in the final product an economic analysis must be done of the production costs and the expected revenue generated by the end-use product. As in any cost-benefit analysis, the ratio that provides the most profit will be selected. The choice between using screened raw sediment or ORG-X treated sediment in the SOLFIX procedure must also be made.

Unconfined Compressive Strength (UCS) tests were performed by both Metcalf & Eddy and the Brookhaven National Laboratory (BNL) on the concrete made with the two different SOLFIX products. As shown in Figure 11, the concrete made from the SOLFIX-treated raw sediment was found to express strengths of 728 and 102 psi by Metcalf & Eddy and BNL respectively. The Brookhaven National Laboratory and Metcalf & Eddy measured the strength of SOLFIX performed on the ORG-X treated sediment to be 600 and 487 psi.

Figure 11: Unconfined Compressive Strength (UCS) Test on SOLFIX Final Products

Product	UCS by Metcalf & Eddy (psi)	UCS by BNL (psi)
SOLFIX on raw screened sediment	728	102
SOLIFIX on ORG-X treated sediment	600	487

Economic Analysis

The processing cost depends on which combination of the three processes: HYDRO-SEP, ORG-X, and SOLFIX are used. The cost in Table 12 below gives the cost analysis for three viable production options. The end-use product prices are derived from the same source as those used in the NUIEG economic analysis. The average market price for fill and cement are roughly \$6 and \$11 per cubic yard respectively. Taking into account that about half of the dredged sediment is water, the revenue that would be generated by each cubic yard of dredged sediment is approximately \$3 and \$5.50 for the production of fill and cement respectively.

The estimated processing costs of the HYDRO-SEP and SOLFIX is \$44 per cubic yard of dredged sediment . The material produced by performing this process on one yard of dredged sediment is worth approximately \$3. As a result, Metcalf and Eddy would lose roughly \$6 per cubic yard of dredged sediment by using these processes. The HYDRO-SEP and ORG-X processes cost \$45 and generate approximately \$5.50 of revenue per cubic yard of dredged sediment. Factoring in the tipping fee, processing costs, and end-product revenue, Metcalf & Eddy would lose about \$4.50 per cubic yard of dredged sediment. The processing costs associated with HDRO-SEP, ORG-X, and SOLFIX is \$67 per cubic yard of dredged sediment. The cement material produced by this combination of processes is worth approximately $5.50 per cubic yard of dredged sediment. Using all three of these procedures, Metcalf & Eddy would lose about $26.50 for each yard of dredged sediment that it processed.

Figure 12: Economic Analysis of Three Production Options for Metcalf & Eddy

	Cost/Credit (per yd^3 of dredged sediment)		
	HYDRO-SEP and SOLFIX	HYDRO-SEP and ORG-X	HYDRO-SEP, ORG-X, and SOLFIX
Tipping Fee	+$35	+$35	+$35
Processing Cost	-$44	-$45	-$67
End-use Product Price	+$3	+$5.50	+$5.50
Net Profit/Loss	-$6	-$4.50	-$26.50

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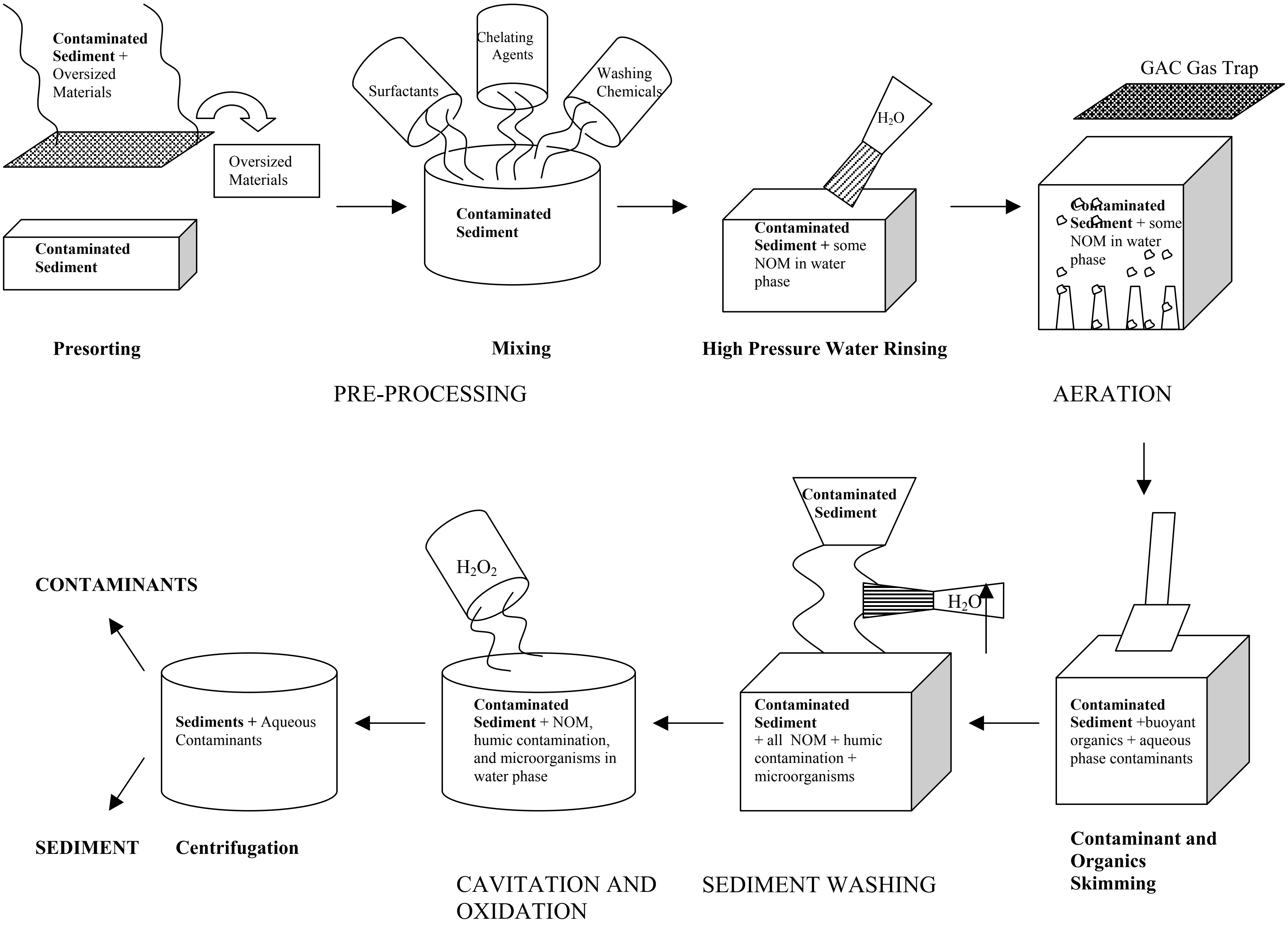
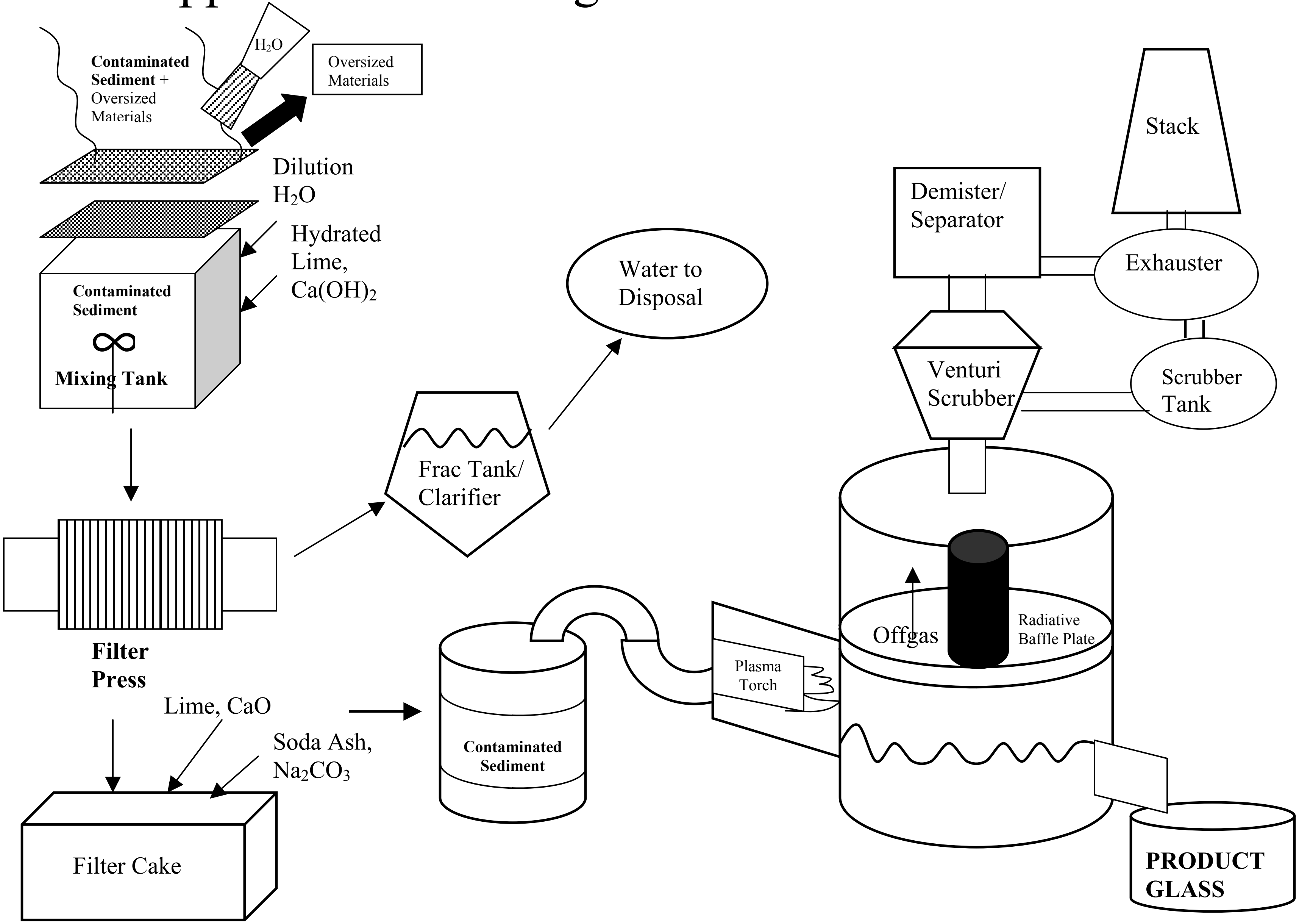
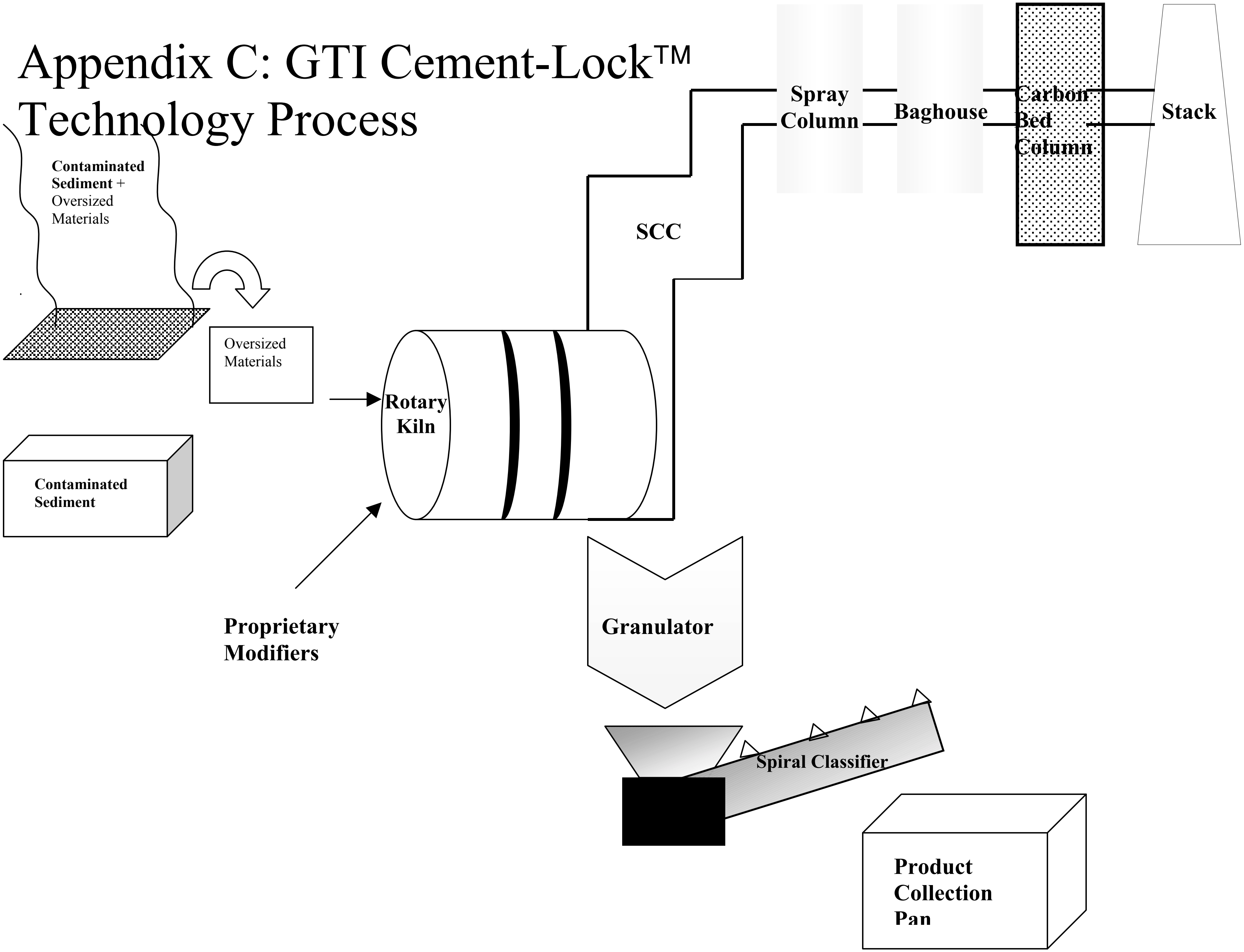
Appendix A: Biogenesis Sediment Washing Process



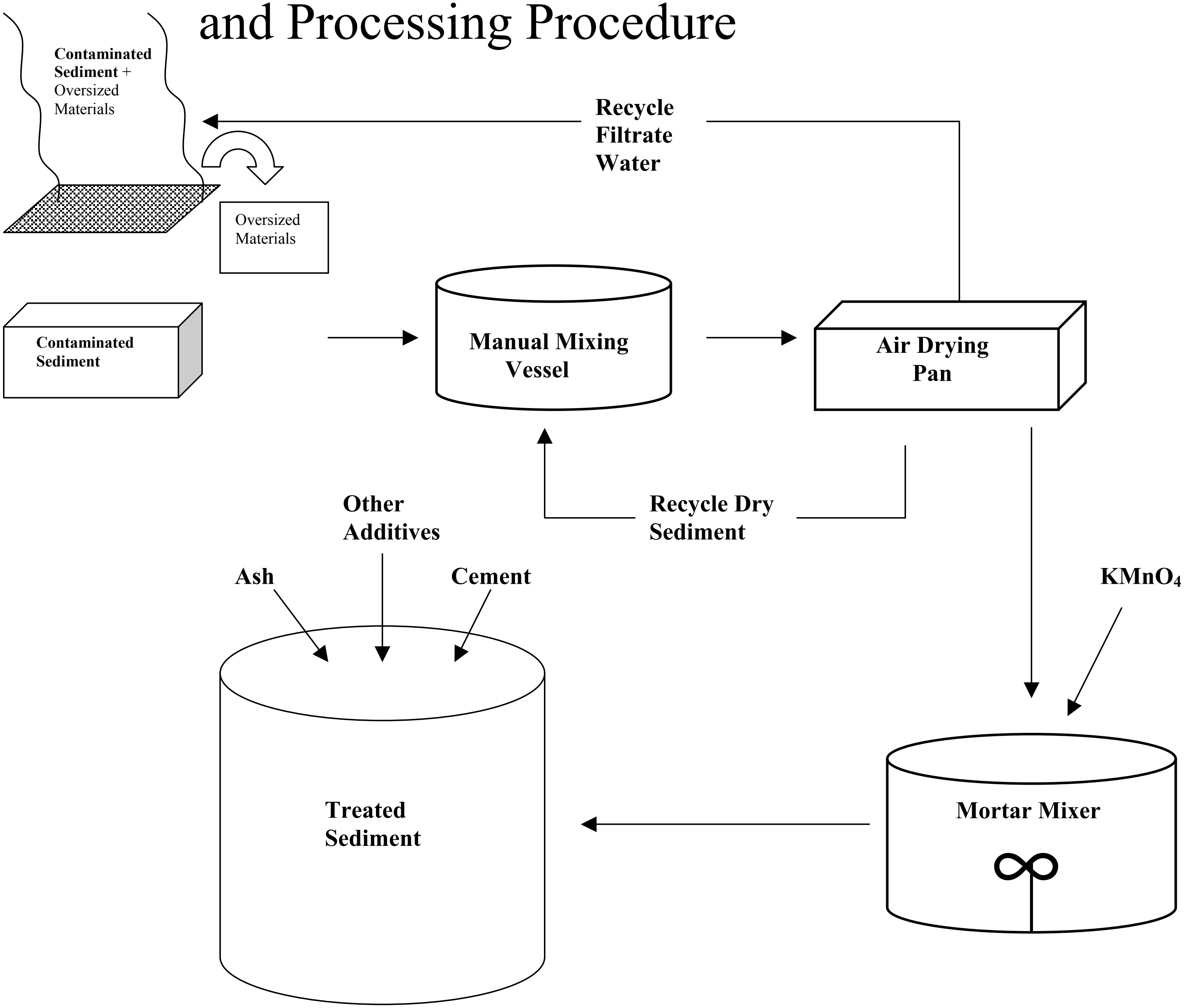
Appendix B: Westinghouse PlasmaVitrification Process



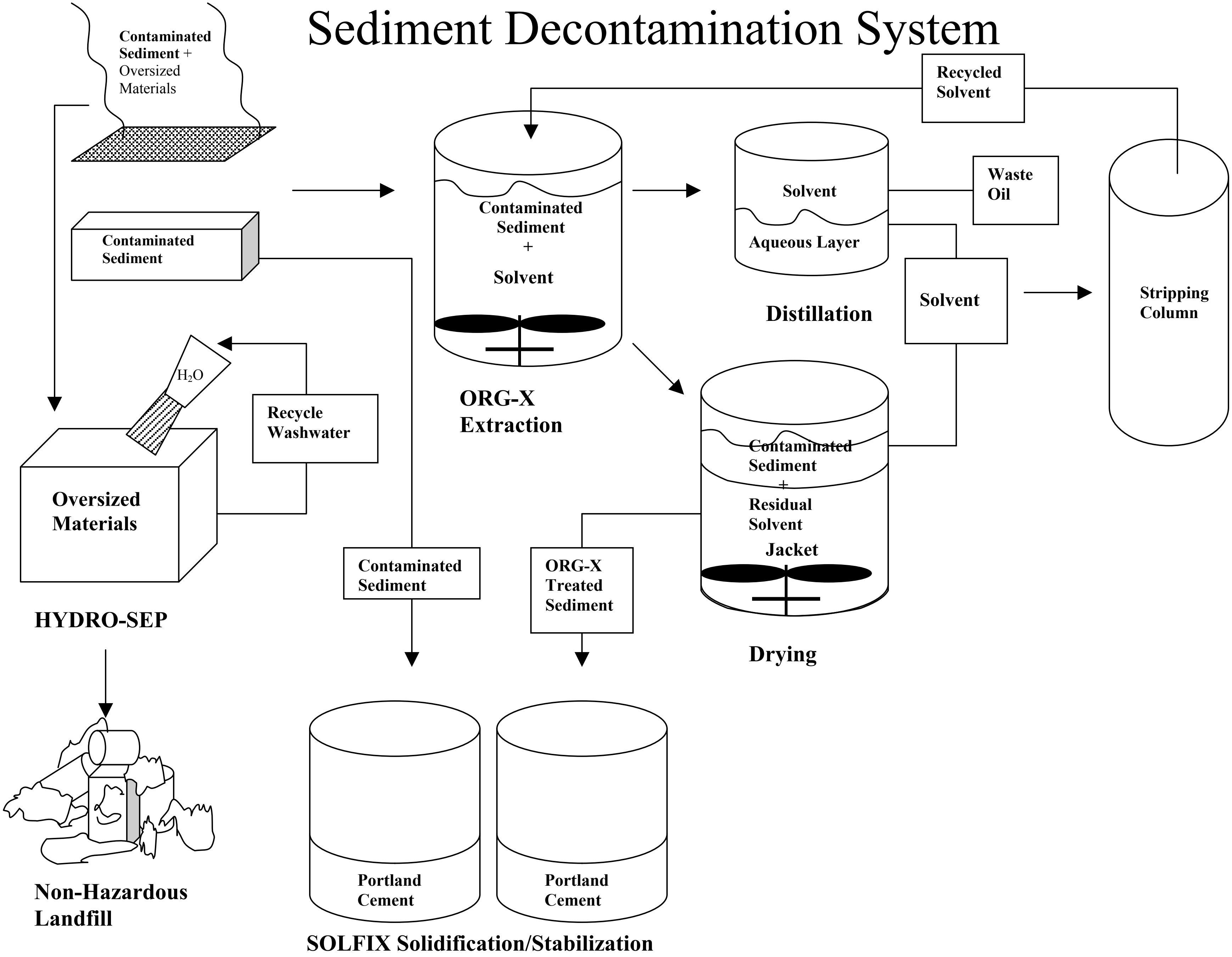
Appendix C: GTI Cement-Lock™ Technology Process



Appendix D: NUIEG Sediment Decontamination and Processing Procedure



Appendix E: Metcalf & Eddy Integrated Sediment Decontamination System



Appendix F: 2,3,7,8 TCDD and Dioxin Decontamination Analysis

2,3,7,8 TCDD	Untreated Sediment (ppt)	Treated Sediment (ppt)	Removal Efficiency (%)
Biogenesis***	91.3	35.3	61.3
GTI	262	<DL	>99.6
Metcalf & Eddy	80.6	7.29	91.0
NUIEG* (tef)	245	N/A	N/A
Westinghouse	19	.9	>95.2
NY Recommended Soil Cleanup Standard		NONE	
NJ Residential Soil Cleanup Standards		NONE	

*<DL Below detection limit. The detection limit under EPA Method sw846 8290 is 1.0 ppt for a 10g sediment sample

Dioxins (ppb)	Westinghouse	NUIEG	Biogenesis	Metcalf & Eddy	GTI
PeCDD Untreated Sediment	187		64000	5570	277
Treated Sediment	1.8		12000	60.3	0.6
Removal Efficiency	99.0		81.3	98.9	99.8
HxCDD Untreated Sediment	791		140000	23200	871
Treated Sediment	1.3		94000	210	0.8
Removal Efficiency	99.8		32. 9	99.1	99.9
HpCDD Untreated Sediment	2690		400000	42300	1810
Treated Sediment	1.9		250000	501	1.5
Removal Efficiency	99.9		37.5	98.8	100
TCDD Untreated Sediment	191		88000	1240	225
Treated Sediment	0.9		84000	45.8	0.3
Removal Efficiency	99.5		4.55	96.3	99.9

Blank entries indicate missing data.

Appendix G: Metal Decontamination Analysis

METALS (ppm)		Biogenesis	GTI	Metcalf & Eddy	NUIEG	Westinghouse	NJ Residential Soil Standard	NJ Non-Residential Soil Standard
Antimony	Untreated Sediment	0.62	1.08	4.93	1.35	2.1		
	Treated Sediment	0.081	0.9	4.41	2.45	0.808	14	340
	Removal Efficiency	SB		10.6	-81.5	61.5		
Arsenic	Untreated Sediment	11.4	5.7	42.4	5.45	30.6		
	Treated Sediment	7.8	3.8	53.2	5.55	5.34	20	20
	Removal Efficiency	SB		-25.5	-1.83	82.5		
Beryllium	Untreated Sediment	0.81	.584	0.5	0.228	0.53		
	Treated Sediment	0.41	.568	0.395		1.92	2	2
	Removal Efficiency	52	2.74	21.1		-262		
Cadmium	Untreated Sediment	3.1	21.2	47.1	1.45	33		
	Treated Sediment	1.23	.245	19.1	1.95	0.906	39	100
	Removal Efficiency	61	98.8	59.3	-34.5	97.3		
Chromium	Untreated Sediment	132	260	432	313	342		
	Treated Sediment	49.5	258	228		932	None	None
	Removal Efficiency	71	.615	47.1		-173		
Copper	Untreated Sediment	128.2	853	1410	133	160		
	Treated Sediment	56.6	.23	823	99.5	1000	600	600
	Removal Efficiency	66	85.6	41.6	25.3	----------------525		
Lead	Untreated Sediment	157	473	631	99.5	587		
	Treated Sediment	67.9	11.0	461	88.5	108	400	600
	Removal Efficiency	57	98.7	27	11	81.6		
Mercury	Untreated Sediment	3.9	3.03	3.67	3.35	2.08		
	Treated Sediment	0.3	.0388	3.97	3.4	0.092	14	270
	Removal Efficiency	92	41.6	-8.13	-1.49	95.6		
Nickel	Untreated Sediment	32.4	226	440	23.5	252		
	Treated Sediment	24.6	1.32	245	22.7	238	250	2400
	Removal Efficiency	24	93.8	44.4	3.4	5.56		
Selenium	Untreated Sediment	1.2	6.76	4.42	2.92	4.92		
	Treated Sediment	0.624	.420	8.46		1.72	63	3100
	Removal Efficiency	52	97.0	-91.4		65		
Silver	Untreated Sediment	3.3	11.3	17.2	ID	16		
	Treated Sediment	0.93	.340	10.3	ID	2.62	110	4100
	Removal Efficiency	72	93.8	40.1	ID	83.6		
Thallium	Untreated Sediment	0.22	2.24	2.5	2.42	2.63		
	Treated Sediment	0.19	1.04	1.97		4.97	2	2
	Removal Efficiency	8	53.8	21.2		-89		
Zinc	Untreated Sediment	279	1430	2070	170	1690		
	Treated Sediment	131	108	1080	162	1180	1500	1500
	Removal Efficiency	53	92.4	48	4.56	30.2		

Blank entries indicate missing data.

ID indeterminant concentration

SB site background

Appendix H: PCB Decontamination Analysis

PCBs	**Untreated Sediment (ppb)**	**Treated Sediment (ppb)**	**Removal Efficiency (%)**
Biogenesis	26	203	87.2
GTI	8585	<DL	100
Metcalf & Eddy	5,440 [a]	109	98.0
NUIEG*	471	358	24
Westinghouse	7000	.83	100
NY Recommended Soil Cleanup Standard		1000	
NJ Residential Soil Standards		480	
NJ Non-Residential Soil Standards		2000	

[a] serious interference and analytical problems for mono, di, and tri PCBs, no data for these congeners

Appendix I: Semi-Volatile Organic Compound (SVOC) Decontamination Analysis

SEMI-VOLATILE ORGANIC COMPOUND (ppb)		**Biogenesis**	**GTI**	**Metcalf & Eddy***	**NUIEG**	**Westinghouse**	**NJ Residential Soil Standards**	**NJ Non-Residential Soil Standards**
N-Nitrosodiphenylamine	**Untreated Sediment**	ND*	<DL	376	<DL	<DL		
	Treated Sediment	ND	<DL	56.4	N/A	17.2J	140000	600000
	Removal Efficiency	N/A	N/A	85.0	N/A	N/A		
bis-2-ethylhexylphthlate	Untreated Sediment	ND	57400	49300	9240	123000B		
	Treated Sediment	ND	8.72	674	3020	2580B	49000	210000
	Removal Efficiency	N/A	100	100	67.4	97.9		
di-n-butyl phthalate	Untreated Sediment	ND	<DL	85.6	341	462bj		
	Treated Sediment	ND	15.0	59.1		48.9BJ	5700000	10000000
	Removal Efficiency	N/A	N/A	31.0		89.2		
Chrysene	Untreated Sediment	<DL	17600	9770	1050	8760J		
	Treated Sediment	1770	<DL	970	458	<DL	9000	40000
	Removal Efficiency	N/A	>98.1	90.1	56.6	>96.2		
Benzo(b)fluoranthene	Untreated Sediment	<DL	12400	7700	1020	7210J		
	Treated Sediment	1400	6.01	900	412	<DL	900	4000
	Removal Efficiency	N/A	100	88.3	59.8	>95.4		
Benzo(k)fluoranthene	Untreated Sediment	<DL	5420	2760	753	3100J		
	Treated Sediment	1270	<DL	400	275	<DL	900	4000
	Removal Efficiency	N/A	>93.9	85.5	63.4	>89.3		
Benzo(a)anthracene	Untreated Sediment	<DL	18000	8970	2960	7190J		
	Treated Sediment	1600	<DL	873	3.72	<DL	900	4000
	Removal Efficiency	N/A	>98.1	90.3		>95.4		
Benzo(a)pyrene	Untreated Sediment	<DL	10600	5820	922	5290J		
	Treated Sediment	1630	9.22	626	3820	<DL	660	660
	Removal Efficiency	N/A	100	89.2	58.9	>93.7		
Indeno (1,2,3-cd) pyrene	Untreated Sediment	135	2960	131	309	584J		
	Treated Sediment	977	3.72	162	148	<DL	900	4000
	Removal Efficiency	41.8	99.9	-23.7	51.25	>43.0		

Blank entries indicate missing data

N/A	not applicable
ND	non-detect
J	below Westinghouse detection Limits
B	analyte was found in blank sample
>DL	below detection limit. The detection limit for a 30g sample was determined to be 333 ppb
*	calculations made on the basis that portland cement is added to the ORG-X treated sediment in a 1:3.33 ratio

Appendix J: Comprehensive Cost-Analysis

	Processing Cost[1]	End-use Product Price	Net Profit/Loss[2]
Biogenesis	-$32	+$1.50	+$4.50
GTI	-$60	+$27.50	-$2.50
Metcalf & Eddy (HYDRO-SEP and SOLFIX)	-$44	+$3	-$6
Metcalf & Eddy (HYDRO-SEP and ORG-X)	-$45	+$5.50	-$4.50
Metcalf & Eddy (HYDRO-SEP, ORG-X, and SOLFIX)	-$67	+$5.50	-$26.50
NUIEG	-$30	+$4.25	+$9.25
Westinghouse	-$112.50	+$47	-$3

1 This figures in this chart are average costs or credits per cubic yard of dredged sediment.

2 This assumes a fixed tipping fee of $35 per cubic yard of dredged sediment.