Name of Process:
Gas-Phase Chemical Reduction (GPCR)

Applicable Pesticides and related POPs wastes:
Pesticides such as Lindane, Hexachlorobenzene, DDT, Aldrin, Dieldrin, HCBs, DDT, PCBs, dioxins and furans and other POPs.

Status:
A commercial GPCR system operated in Australia for more than 5 years, treating more than 2,500 t of PCBs, DDT and other POPs. In 1999 a full-scale test on HCB was conducted using the commercial plant.

GPCR technology licensees in Japan have built and operated a semi-mobile GPCR plant for the treatment of PCB wastes. A trial run for PCB treatment was performed in October 2006.

The technology was tested as part of the ACWA (Assembled Chemical Weapons Assessment) Program for the destruction of chemical warfare agents. Through this testing the GPCR technology was proven to be effective for treatment of chemical warfare agents.

The GPCR technology can be used in conjunction with thermal desorption technologies for treatment of soil and sediment at rates of up to 10 t per hour.

Additional approvals received:
-for PCB and dioxin waste in Japan
-for PCB's TSCA permit in USA
-for PCB's and other toxic compounds in the Province of Ontario (Canada)

Technology description:
GPCR involves the reduction of organic compounds by hydrogen and some steam (which acts as a heat transfer agent and another source of hydrogen) at temperatures of 850°C or greater. Organic compounds are ultimately reduced to methane, hydrogen chloride (if the waste is chlorinated), and minor amounts of low molecular weight hydrocarbons (benzene and ethylene). The hydrochloric acid is neutralized by addition of caustic soda during initial cooling of the process gas, or can be taken off in acid form for reuse, if desired. Cooled, scrubbed gas from the reactor ("Product Gas") is compressed and analyzed. Product gas can then be reused as a fuel for plant components, or consumed in a burner.

The GPCR technology can be broken down into three basic unit operations: the front-end system (where the contaminants are rendered into a suitable form for destruction in the reactor), the reactor (which reduces the contaminants, now in gas phase, using hydrogen and steam), and the gas scrubbing and compression system (Figure 1). The front-end units will differ depending on the waste matrix. For example, bulk solids such as drummed chemicals, electrical equipment, spent carbon, etc., are placed into a Thermal Reduction Batch Processor (TRBP), which desorbs the contaminants from the solid material, and then conveys them to the reactor for destruction. Watery wastes and high-strength oily wastes are injected into a preheater that vaporises the liquids in an indirectly fired heat exchanger. The gases are mixed with hydrogen and steam to a temperature of 600°C prior to introduction to the GPCR reactor.

In the case of soil and sediment treatment, contaminants are first desorbed from the solids using a thermal desorption device (of which there are many proven and available worldwide). The gas containing the contaminants is then condensed, the water removed, and the remaining concentrated contaminant liquid fed to the preheater and GPCR reactor as a contaminant-concentrated liquid waste feed.

Process diagram: Block Flow Schematic:

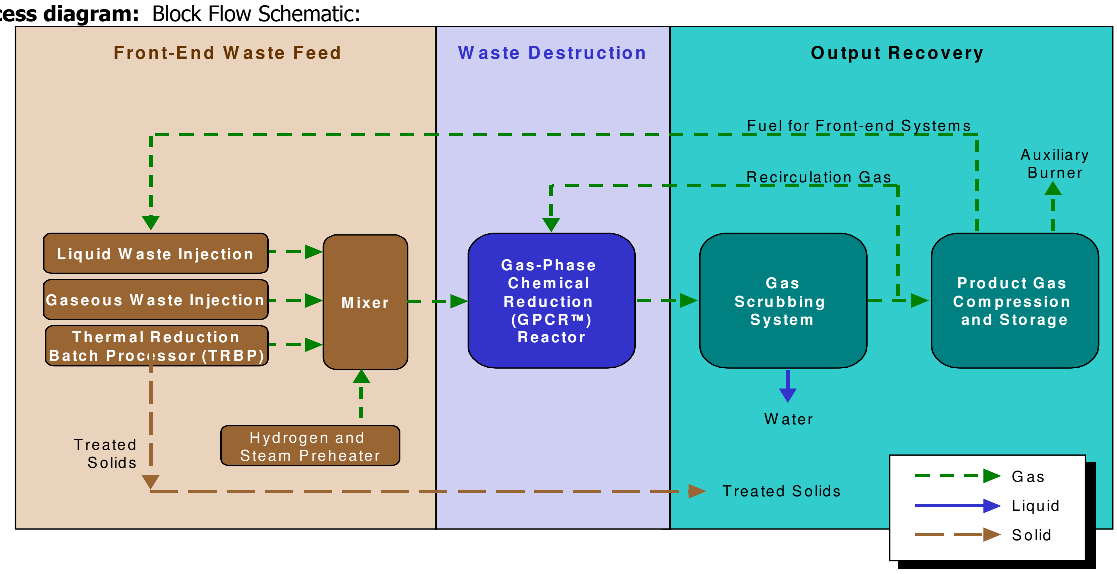

Figure 1

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PART I: Criteria on the Adaptation of the Technology to the Country

A. Performance:

1. Minimum pre-treatment:
Contaminants must be in a gaseous form in order to be reduced in the GPCR reactor. While liquid wastes can be preheated and injected directly into the reactor on a continuous basis, contaminants on solids must first be volatilized from the solid. Bulk solids and drummed chemicals are placed in a TRBP, which is then heated to approximately *650°C in a hydrogen-rich (oxygen deficient) atmosphere.* In this environment the contaminants are desorbed (leaving a hazard-free solid) and are then conveyed directly to the GPCR reactor for destruction.

Because the TRBP involves minimal handling (i.e., material need not be removed from drums and does not require sorting or segregation by type), worker exposure to the chemicals is minimal.

An evaluation for the US Department of Energy (DOE) (Schwinkendorf, 1997) noted that the front-end components for introducing solids and large equipment was a limiting factor. A more recent assessment of the applicability of GPCR for chemical weapons destruction noted that the TRBP should be "completely effective in decontaminating metal components" to the stringent requirements of the ACWA program (Bizzigotti, 1999) and that "[a]n advantage of the GPCR process with regard to solids treatment is that the solids would not have to be size-reduced or shredded before being treated. Treatment could be as simple as removing the lids from the solids waste drums and treating the drums in the TRBP."

2. Destruction efficiency (DE): (See Table 2 and 3 in separate Annex)
The GPCR has treated HCBs and PCBs and DDT, other chlorinated pesticides and POPs related wastes such as dioxins and furans. The Annex provides a complete list of contaminants treated. Generally Destruction Efficiencies (DE's) of 99.999% and mostly more have been proven.

Commercially the system operated more than 5 years at Kwinana in Western Australia, treating PCBs, HCBs and DDT. Here efficiencies of at least 99.9999 % (Kummling, Gray, et al, February 2002), (Woodland, February 1999), (Eco Logic, June 8, 1998) were demonstrated. In commercial-scale performance tests in Canada, the gas-phase reduction process achieved DE and Destruction and Removal Efficiencies (DRE) with high-strength PCB oils and chlorobenzenes as shown below in Table 2 (See Annex). Dioxins that were present as contaminants in the PCB oil were destroyed with efficiencies ranging from 99.999 to 99.9999 percent (Kummling, Festarini, et al., 1997), (Kümmling, Kornelsen, 1997).

Engineering testing on batches of 3, 9 and 27 drums (205 litre size) of HCB wastes showed that, "Results of the trials indicated that the system effectively desorbed approximately 98 percent of the waste input to the TRBP. In excess of 99.9999 percent of the HCB and chlorobenzene present in the waste was volatilized in the TRBP and swept to the reactor for destruction." Destruction efficiencies for the desorbed HCB and chlorobenzenes in the GPCR reactor were reported to be 99.99999% and 99.9999% respectively (Kümmling, Gray, et al., 2001).

3. Toxic by-products:
There are no toxic by-products produced by the technology. An evaluation for the US Department of Energy (DOE) (W. E. Schwinkendorf, 1997) noted that contaminants are "completely destroyed in the process" and that the process, "features a high degree of internal waste recycle and has no waste generating side streams."

4. Uncontrolled releases:
There have been no uncontrolled releases during use of the technology. The GPCR technology has a process control system in place that provides rigorous monitoring of all stages of the system. The necessary controls are in place such than in an upset event, the system goes into recirculation mode and no untreated waste is released

5. Capacity to treat all POPs:
The GPCR technology has treated HCBs and PCBs and DDT, other chlorinated pesticides and POPs related wastes such as dioxins and furans. In addition to more recent treatment of Lindane and 2,4-Dichlorophenyxoacetic Acid (2,4-D), the following Table provides a complete list of contaminants treated.

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Industrial Chemicals and Manufacturing By-products			
PCBs	Dioxin and Furans	Hexachlorinated Wastes	Pentachlorophenol
Polyaromatic Hydrocarbons			
Acenaphthene	Benzo(a)Pyrene	Chrysene	Indeno(123-cd)Pyrene
Acenaphthylene	Benzo(b)Fluoranthene	Dibenzo(ah)Anthracene	Naphthalene
Anthracene	Benzo(ghi)Perylene	Fluoranthene	Phenanthrene
Benzo(a)Anthracene	Benzo(k)Fluoranthene	Fluorene	Pyrene

Organochlorine Pesticides				
o,p'-DDE	Chlorodimeform	Endosulfan I	Mecoprop	Pirimphos ethyl
p,p'-DDE	Chlorofenviphos	Endosulphan	Metalaxyl	Procymidone
o,p'-DDD	Chloropropham	Endosulphan II	Methiocarb	Procynidone
p,p'-DDD	Chloropyrifos	Endrin	Methomyl	Propachlor
o,p'-DDT	cis-Chlordane	Endrin Ketone	Methoxychlor	Propargite
p,p'-DDT	Coumoiphos	Ethephon	Metoxuron	Propazine
2,4,5-T	Crotoxyphos	Ethion	Metribuzin	Propoxur
a-BHC	Dieldrin	Fenamiphos	Mevinphos	Quinomethionate
a-chlordane	Diazinon	Fenitrothion	Naproamide	Quintozene
Alachlor	Dicambamethyl	Fenoprop	Nicotine	Rotenone
Aldrin	Cyanthoate	Fenthion	Nornicotine	Secbumeton
Atrazine	Dacthal	Folpet	Oxydisulfoton	Simazine
Azinphos ethyl	d-BHC	g-BHC	Parathion	SWEP
b-BHC	DCPA	g-chlordane	Pendimethalin	Technazene
Bendiocarb	DDMU	Glyphosate	Permethrin I	Terbufos
Bis-2-chloroethylether	Dichlorfuanid	Heptachlor	Phenolthiazine	Terbutryn
Bupirimate	Dichlorobenil	Heptachlor Epoxide	Phorate	Tetrachloro-m-xylene
Captan	di-Chlorovos	Hexachloroethane	Phorate Sulfone	Thiabendazole
Carbaryl	Dicloran	Lindane	Phosmet	Trans-chlordane
Carbofenthion	Dicofol	Linuron	Phosphorodithioic Acid	Triadimefon
Carbophenothion	Dimethoate	Malathion	Piperonyl butoxide	Triallate
Carboxin	Disulfoton	Manoczeb	Pirimicarb	Tridimefon

Chemical Warfare Agents and other Military Wastes			
VX	HD (Distilled Sulphur Mustard)	GB (Sarin)	DPE Suit Material (Plastic, Teflon
Napalm	Chemical Agent Neutralents		
Other Compounds Treated			
Benzene	Toluene	Mineral oil	Vegetable oil

6. Throughput:

6.1 Quantity [t/day, etc]:

Throughput of the technology will depend on the scale of GPCR plant that is deployed, and the type of waste being treated. The following table gives the rough throughput estimates for different waste types. A general description of the different plant sizes follows the Table.

Waste Type	Plant	Capacity (Tonnes/yr)
PCB Oil	Semi-Mobile	840
	Full Scale	3360
CFCs and Halons	Semi-Mobile	1680
	Full Scale	6720
PCB Capacitors	Semi-Mobile	1400
	Full Scale	5600
Chlorinated Pesticides (solid and/or liquid)	Semi-Mobile	840
	Full Scale	3360

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Full-Scale Plants:

- Full-scale plants in operation since 1995 (Kwinana: 1995 to 2000; GMCL: 1996 to 1997)
- For use at sites with large waste stockpiles, or where waste can be brought in from surrounding area
- Footprint: 4,000 m^2 (approximately 8 to 10 trailers)

Semi-Mobile Plants:

- Semi-Mobile plant recently constructed in Japan
- For use at sites or in regions with smaller waste stockpiles, or where mobility is important
- Footprint: 1,000 m^2 (approximately 4 trailers)

Portable Plants

- Small size (fits into single sea container or gooseneck trailer; 800 ft^2 footprint)
- Highly mobile
- First developed as a unit for conducting treatability tests
- Commercial applications are on-site, in-process treatment of manufacturing wastes and carbon filter material
- Throughput: 50 - 250 (or greater) t/year, depending on reactor configuration, chemical concentration and waste matrix

Table 5 in the Annex provides a summary of the utility requirements per tonne of pesticide waste treated. These utility requirements can be applied to any scale of plant.

6.2 POPs throughput: [POPs waste/total waste in %]
Most GPCR experience has been with the treatment of chlorinated POPs wastes (PCBs, pesticides) and to a lesser degree fluorinated wastes (chemical warfare agents and chlorofluorocarbon refrigerants). The technology has also been used to treat a small quantity of iodic waste. In general the technology is well suited and well proven for halogenated waste streams.

Of particular benefit is the fact that the waste streams do not require dilution prior to destruction using GPCR. For example, in April 1999 the technology was used to treat almost 84 percent pure hexachlorobenzene crystals using the commercial-scale GPCR plant in Kwinana; no dilution or specialized pre-treatment was required. Similarly, the refrigerant R-12 (dichlorodifluoromethane) was treated in pure form (100% strength) using the GPCR demonstration plant. This robustness is an advantage over other technologies that may require dilution of the material to accommodate the high halogen content.

Summary of high-strength POPs treated**:**

- Commercial testing at Kwinana, Australia: 30.3% DDT, 5.6% DDT, 96% PCBs (1995/1996)
- Commercial testing at General motors with 50% PCBs and 30% Chlorobenzenes (1996)
- Commercial demonstration at Kwinana, Australia: 84% Hexachlorobenzene crystals (April 1999)
- Demonstration with portable plant at Rockwood, Canada: 100% dichlorofluoromethane gas (2002)
- Demonstration with portable plant at Rockwood, Canada: 100% Lindane powder (2003)

7. Wastes/Residuals:

7.1 Secondary waste stream volumes:
System outputs generated during waste treatment activities are treated solids, water and product gas, all of which are clean, reusable or disposal products. All process and waste residuals are contained and can be tested and reprocessed as necessary. No uncontrolled releases in normal operation. The USEPA recently noted that, "All outputs are stored and analyzed for regulatory compliance prior to off-site disposal or reuse." and that "The principal waste stream is the scrubber residuals which include decant water (which is recycled into the process) and scrubber particulate (which is stored and analyzed and then retreated or shipped off-site for disposal)" (US EPA, 2000). An evaluation for the US Department of Energy (DOE) (W. E. Schwinkendorf, 1997) noted that contaminants are "completely destroyed in the process" and that the process, "features a high degree of internal waste recycle and has no waste generating side streams."

The system does not produce slag or ash – the only solid process residual (other than the treated steel and other treated waste inputs) is carbon filter media, which are not a system output. When the filters are "spent", they are placed in the TRBP, which heats them to desorb contaminants, and the contaminated gas goes to the GPCR reactor for destruction. The carbon is now ready for reuse, as is common practice at GPCR commercial operations (Kümmling, 2004)

For Approximately 500 t pesticides and 1500 t PCBs in Kwinana; no PCBs or DDT detected in gaseous, liquid and solid outputs. Further during Regulatory testing Waste-specific compounds non-detect in air, solid and liquid outputs; no slag created (See Table 2 and 3 of Annex).

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7.2 Off gas treatment:
Contaminants entering the GPCR reactor are reduced using hydrogen, heat and steam, resulting in a gas that is comprised of primarily methane, acid gases and hydrogen. This gas leaving the GPCR reactor is scrubbed in two caustic scrubber towers to cool the gas and to remove acid, water, heat and fine particulate. The acid in the gas (HCl, in the case of chlorinated wastes) can be neutralized with a caustic solution (to create a salty scrubber water), or recovered for subsequent refinement/concentration to recyclable specifications for industrial reuse.
The cooled and scrubbed product gas is a mixture of hydrogen, methane, carbon monoxide and other light hydrocarbons. Some of the product gas is reheated and recirculated back to the reactor, or through the TRBP as sweep gas. Excess product gas is removed from the system, compressed and temporarily stored. This stored product gas is chemically tested with on-line instruments and then used as fuel to heat system components such as the boiler, and as an input stream to a catalytic steam reformer as heating fuel for hydrogen generation (in situations where piped hydrogen gas is not readily available at the site). This gas meets the BIF standards for use as a fuel in the United States.

7.3 Water treatment:
During conventional hazardous waste treatment operations (PCBs, pesticides, etc.), it was permitted to dispose of scrubber water. After carbonfiltering removing any residual organics, the water could be disposed in a variety of ways, including discharge to a local irrigation system, discharge to a surface water body, and discharge to a municipal sewer. Alternatively the water can be reused as cooling water.

7.4 Complete elimination:
An evaluation for the US Department of Energy (DOE) (Schwinkendorf, et al, 1997) noted that contaminants are "completely destroyed in the process". The technology has been subjected to regulatory testing during treatment of high-strength PCB oil at a General Motors of Canada facility in Ontario, Canada. Data from this testing (provided below) was audited by the Provincial Government (the Ministry of the Environment). Data from other projects in the accompanying table has also been verified by third-party review, such as cognizant regulatory authorities in Australia and the US National Research Council. All of the data demonstrates complete destruction of the contaminants in the wastes, and safe disposal of the byproducts.

Efficiency of Halogenated Waste Treatment using GPCR

Project	***Contaminant***	***Destruction Efficiency (%)****	***Target Criteria (%)***
Bay City (oily water – 3 tests)	Tetrachloroethene	> 99.99	99.99
Bay City (oil – 3 tests)	Tetrachloroethene	> 99.99	99.99
General Motors of Canada Limited (PCB Oil - 3 tests)	PCBs	99.9999996	99.9999
	PCBs	99.9999985	
	PCBs	99.9999808	
	Chlorobenzenes	99.9999836	None
	Chlorobenzenes	99.9999972	
	Chlorobenzenes	99.9999971	
PCB Oil (Kwinana Regulatory Testing)	PCBs	99.999998	99.9999
DDT in Toluene (Kwinana Regulatory Testing)	DDT	99.999984	99.9999
PCB Oil (Japanese Regulatory Testing)	PCBs	99.99998098	99.9999
	PCBs	99.99999977	99.9999
HCB Treatment Trials (HCB crystals - 3 Tests)	HCB	99.999999	99.9999
	HCB	99.999999	99.9999
	HCB	99.99999	99.9999
Refrigerant Treatment (CFC R-12 - 1 Test)	Dichlorodifluoromethane	> 99.999	99.99

**Note that these destruction efficiencies take into account contaminants in the solid and liquid outputs in addition to the stack gas. The exception may be the Japanese Regulatory Testing where we are unsure of whether solid and liquid outputs were included in the calculation.*

Detailed information and treatment examples:

In the separate Annex the following information is given:

Table 1: Technology overview-Summary Technical Details
Table 2: Overview of Project Experience per Technology Supplier
Table 3: Overview detailed Project Information per Project – Project Name (from Table 2)
Table 4: Client References for GCPR Plant in Australia
Table 5: Utilities required for High-strength Pesticides Waste Treatment
Table 6: Comparison of Worldwide Incinerator Air Emission Standards with GCPR-Results

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PART II: Criteria on the Adaptation of the country to the Technology

Note: This part has to be filled in every time the "suitability" of the technology has to be examined for a certain country situation!!

Example on basis of pesticide waste treatment at 840 t per year (semi-mobile plant) and 3,360 t per year (full-scale plant). Quantities are provided per tonne of waste treated, so that utility requirements at different scales and throughput rates can be more easily calculated. A table of utility requirements is provided in Table 5 of the Annex.

A. Resource needs:

1. Power requirement :

Power (peak) demand: 1,000 kW
2.5 MWh required per tonne of waste input to plant

2. Water requirements (per tonne of waste input to plant):

Steam: 1,500 kg
Cooling water: 500 m^3

3. Gas volumes (per tonne of waste input to plant):

Natural gas: 600 Nm^3

4. Reagents volumes (per tonne of waste input to plant):

Nitrogen: 75 Nm^3
Carbon Dioxide: 20 kg
Caustic: 1.4 t
Hydrogen: 1,000 Nm^3

5. Weather tight buildings:
GPCR plants have been run effectively in out-door environments (e.g. GMCL and Kwinana). Nevertheless, installing the equipment inside a building or portable structure is preferred, so as to minimize the amount of pad water (from rain or snow) that would require monitoring and possible treatment, and to make the working conditions more comfortable for site employees.

6. Hazardous waste personnel requirement:
For all GPCR projects to date, plant workers have been required to be trained in hazardous waste operations (e.g. 40-hour HAZWOPER training).

7. Sampling requirements/facilities:
Dependent on the specific country's regulatory requirements. For the Kwinana and GMCL full-scale operations, a portable laboratory trailer was installed on site so that rapid analysis of process samples could be carried out. Regular subsamples (e.g. 1 in 10) were sent to the regulatory authority's laboratory for confirmatory analysis.

8. Peer sampling:
See 7.

9. Laboratory requirements:
Dependent on the specific country's regulatory requirements. See 7 above.

10. Communication systems:
Dependent on the specific country's regulatory requirements. The GPCR process control system can be accessed remotely, for monitoring and troubleshooting purposes. For example, head office personnel in Canada are able to monitor systems operating in other locations, through internet access.

11. Number of personnel required:

Solids Feed (2 TRBPs)

Semi-mobile Plant:	4 people per shift
Full-Scale Plant	6 people per shift

Liquid/Gas Feed (1 TRBP)

Semi-mobile Plant:	3 people per shift
Full-Scale Plant:	5 people per shift

11.1 Number of Technicians required (skilled labour):

Solids Feed (2 TRBPs)

Semi-mobile Plant:	2 people per shift
Full-Scale Plant	3 people per shift

Liquid/Gas Feed (1 TRBP)

Semi-mobile Plant:	2 people per shift
Full-Scale Plant:	3 people per shift

11.2 Number of Labourers required (unskilled labour):

Solids Feed (2 TRBPs)

Semi-mobile Plant:	2 people per shift
Full-Scale Plant	3 people per shift

Liquid/Gas Feed (1 TRBP)

Semi-mobile Plant:	1 people per shift
Full-Scale Plant:	2 people per shift

B. Costs:

1. Installation and commissioning costs [US Dollars]:

2. Site preparation costs [US Dollars]:

Estimated Capital Costs (unburdened design labour, no licensing/royalties, includes installation and commissioning, site preparation)

Two-TRBP Plant Estimate (solid feed)

Full-Scale	$10,800,000
Semi-Mobile	$ 5,000,000

One-TRBP Plant Estimate (liquid and gaseous feed)

Full-Scale	$10,300,000
Semi-Mobile	$ 4,750,000

3. Energy & Telecom installation costs:
Unknown

4. Monitoring costs:
Amount of monitoring dependent on regulatory requirements

5. Complying costs:
Amount of compliance testing, oversight, etc., will depend on regulatory requirements

6. Reporting costs:
Amount of reporting dependent on regulatory requirements

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7. Running costs with no waste:
If system were to remain running but no waste input to the system, then the major cost would be that of natural gas and labour for monitoring the system (see the Annex Table 5 for a list of utility requirements – if no waste is run, then hydrogen and caustic are not needed). If waste were unavailable over a long period of time, the system would be shut down. Costs would therefore vary depending on how many staff are retained, etc.

8. Running costs with waste:

Estimate of Utility and Labour Costs for Pesticide Treatment (estimates based on 2004 US utility prices)

Waste Type	Plant	Capacity (Tonnes/yr)	Estimated GPCR cost per tonne of waste feed (US$)*	
			Utilities	Labour
Chlorinated Pesticides (solid or liquid)	Semi-Mobile	840	$1,317	$593
	Full Scale	3360	$1,317	$222

* Utility and Labour costs are marginal only; no allocation has been made for overhead or profit

9. Decommissioning costs:
Estimated at $750,000

10. Landfill costs:
Depending on the local situation – Should be filled in by the concerned country

11. Transport costs of residues:
Depending on the local situation – Should be filled in by the concerned country

<u>C. Impact:</u>

1. Discharges to air: Estimate of stack gas generated
Semi-mobile Plant (70 t/month waste treated): 1.75 million m^3/month
Full-scale Plant (280 t/month waste treated): 7 million m^3/month

Stack gas is comprised of 16% H_20, 4% CO_2, 72% N_2 and 8% O_2. Stack gas is the result of the burning of product gas; product gas is tested to ensure compliance before it is burned.

2. Discharges to water: Estimate of scrubber water generated
Semi-mobile Plant (70 t/month waste treated): 140,000 kg/month
Full-scale Plant (280 t/month waste treated): 560,000 kg/month

Scrubber water is carbon filtered to remove any residual organics, and then tested prior to discharge or reuse as cooling water. In the past, GPCR plants have been permitted to discharge scrubber water to open water bodies, municipal sewers, and irrigation systems.

3. Discharges to land:
There are no uncontrolled discharges to land. All site-generated waste is treated in the TRBP to ensure it is free of waste-specific contaminants.

Small amounts of residual carbon that may remain in the TRBP are tested and then disposed of in a landfill. During full-scale HCB treatability testing in Kwinana, full drums of HCB crystals were treated in the TRBP. Only 2% of the input mass was present following treatment. This material was tested and found to be silicon and carbon residue.

Carbon filter media is used at various locations throughout the plant, including the effluent water treatment system. Once saturated with organics, the carbon filter media is treated in the TRBP and then reused as part of regular operations. Internal and third-party testing has confirmed the viability of the TRBP for carbon regeneration.

4. Soil impact (noise etc):

<u>D. Risks:</u>

1. Risks of reagents applied:
GPCR reactor must be operated in a closed, contained environment. As a result, fugitive hydrogen emissions can be a serious hazard (National Research Council, 1999). The monitoring and control system on the GPCR units must ensure that no oxygen or other oxidants are present before oxygen is admitted into the system (National Research Council, 1999).

Measures to counter hydrogen risks:

In order to ensure safe use of hydrogen the company has several procedures to avoid that hydrogen becomes explosive. These procedures are carried out during waste processing to ensure safe operation:

1. Prior to any hydrogen being introduced into the system, all vessels that may contain hydrogen-rich gas are pressure tested to well above normal operating pressure, to ensure they are leak-proof. This testing includes a final test of the entire system with all vessels connected

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2. All vessels which might contain hydrogen-rich gas are electrically grounded through the main power transformer on site. This ensures that even in the unlikely event that the hydrogen combines with oxygen and becomes explosive; there is no potential for spark ignition.

3. All gasketed pipeline joints that may contain hydrogen-rich gas are connected by conducting straps or structural conductors, and grounded.

4. The technology operates as a sealed, close loop system, at nominal atmospheric pressure (less than 0.4 psig). Therefore, the possibility of the system rupturing due to over-pressure is extremely unlikely. Also, the low system operating pressure means that any small leaks which may occur would release very small amounts of hydrogen – too small to become explosive.

5. Rigorous procedures are followed for plant operations to ensure that hydrogen-rich gas never mixes with oxygen or air. For example, all sealed vessels in the system are completely purged and filled with nitrogen before any hydrogen enters the vessel. The vessels are monitored and hydrogen is only introduced when the levels of oxygen are well below the safe limit for a hydrogen/oxygen mixture.

6. The procedure described under 5. is also followed at the end of each waste processing cycle, when vessels full of hydrogen-rich gas need to be opened. Nitrogen gas is used in the system as a "buffer" gas between hydrogen and oxygen.

7. Once a sealed vessel is filled with hydrogen-rich gas, the system is continuously monitored for oxygen content by process operators, to ensure that any increase of oxygen in the system is immediately detected. Special actions are taken by the system operators which will correct the condition well before an explosive mixture is created. The special actions are detailed in a rigorous response procedure for operators that forms part of the Standard Operating Procedures.

8. As part of standard system operations, the air around the system is continuously monitored at numerous strategic locations for explosive conditions due to hydrogen release. Warning alarms will sound at levels well below an explosive mixture, which gives the system operators ample time to take the appropriate corrective actions

9. No open flames are permitted

2. Risks of technology:
A primary design criteria of GPCR plants is the prevention of any releases of hazardous materials that would put environmental and public safety at risk. It is for this reason that Product Gas is compressed and stored prior to test and release to the Product Gas Burner. Product Gas must meet specific contaminant level criteria otherwise it is re-circulated back to the reactor for reprocessing or further reduction. Another example is that the entire system is designed to be a low pressure (2-8 kPa normal operating pressure) system. Operating at slightly above atmospheric pressure ensures that any potential leaks have a minimal impact.

The design features that protect against the release of hazardous materials can be divided into three categories: physical systems, procedural systems and process control systems. Physical systems are actual physical controls or barriers that prevent final release to the environment (i.e. the pad). The procedural systems are standard industry practices for both operators and management that ensure that environmental and public safety are an integral part of operations and design (i.e. HAZOPs). The process control systems are the instrumentation and interlocks that ensure that process limits are not exceeded (i.e. ESD routine).

3. Operational risks:

Operational risks are minimized by the process control system. The process control system that forms part of the general system safety and control for GPCR plants includes all the instrumentation, measurement devices, computers and software that are used to observe and control the operation of the facility. The entire system that consists of the electronic eyes, ears and fingers of the facility contribute greatly to the general safety and control of each facility. In the following section the Process Control Systems currently in place to ensure that the system operates with the critical ranges is described. Conditions outside the ranges will cause the process control system to alert the operator, so that corrective action can be taken. These are the standard operating conditions of the full-scale unit, and have been fully evaluated and tested as part of routine operations over the past 9 operating years.

In addition, Hazards and Operability reviews of the system have been conducted on GPCR plants during their development to identify areas that require redundancy for safety purposes. Redundant instrumentation is in place to measure temperature and pressure for key components (e.g. oxygen analyzer, process gas monitoring). The gas scrubbing system is equipped with redundant pumps to ensure that there is adequate cooling water at all times. Throughout the system there are isolation valves, block and bleed valves as well as several redundant valves and pipes. These valves and pipes allow facility operators to change equipment while on-line, drain lines, fix measurement devices and conduct regular maintenance activities without risk. Process controlled valves have "back-up" hand valves that can be manually operated in the event of a process control problem. Valve and pipe redundancies allow operators to re-route product gas should a blockage or equipment failure require it.

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In the event of a fire, all sources of flammable gas to the process (i.e. hydrogen, propane, etc.) are shut off via the Emergency Shutdown Devices (ESDs), and the process is put into automatic shutdown mode. ESDs are located at key positions throughout the site.

Process Control System
Safety and Control Benefit

Process Control Computer

Each GPCR facility is automatically controlled through a process control system and computer. This system ensures that the operators can control the plant from a computer in the Process Control trailer. Facility instrumentation and measuring equipment are directly linked to the process control computer and allow the operator to view the performance of the plant in its entirety. Process control valves and "enable" switches throughout the facility as well as the burner control systems allow the operators to adjust flows, motor speeds, burner settings, pressures and temperatures directly from the process control computer. All automatic systems have back-up manual valves. The process control computer is linked to the alarm system described below.

In the event of an emergency shutdown, the process computer automatically activates a shutdown routine by means of the Emergency Shutdown Devices (ESD) located throughout the facility.

Facility instrumentation
Throughout each facility, temperature, pressure and flow elements are linked directly to the process control computer. This instrumentation provides the operators and the process control computer with the raw data necessary to run the facility safely and effectively. This data is stored historically within the process control computer for future analysis and review.

Many facility instruments have a redundant, "stand alone" instrument not connected to the process computer. This allows for system verification and safe facility shutdown in the event of process control computer failure.

System measuring equipment
Product Gas is measured in two key locations: after the scrubber system and off the product gas storage tank. Measurement is done by on-line micro GCs that are linked to the process control computer. This allows for continuous monitoring of product gas (both immediately after processing and in compressed storage) for specific compounds indicative of incomplete destruction of waste. Product gas that is outside normal operating maximums is re-routed to the reactor for reprocessing.

Measurement data is stored historically within the process control computer for future analysis and review.

Alarm system
Automatic process alarm for pressure outside pre-set normal operating range, oxygen content in system gas outside normal operating range, temperatures outside of normal operating ranges, concentration of indicator compound in exceedance of normal operating maximum.

All alarms are recorded both within the process control computer and on an on-line printer. In this way, all alarm situations can be reviewed and compared with the trend and recording system.

E. Constructability:

1. Ease of installation/construction of plant:

2. Ease of shipping/transit:
See also under Throughput under Semi mobile and portable plants. The DOE review of the full-scale plant (Schwinkendorf, 1997) noted that, "The process is offered commercially as an integrated transportable (7-10 trailers) system for on-site hazardous waste treatment." And Bizzigotti et al commented, "The GPCR is a robust system that should be able to withstand transportation and other motion- or vibration-induced stresses. In addition, system integrity checks that will be performed prior to operation should detect leaks and other minor damage caused by transportation." (Schwinkendorf, 1997).

3. Ease of operation:
The GPCR technology is not very different than any other chemical process. The process design includes many parameters that must be measured and controlled and the process control computer ensures that all parameters stay within their appropriate ranges. From the operators point of view the system is easy to operate because the actual control of the system occurs seamlessly in the background.

4. Ease of processing:
Processing of the waste is very straightforward but the pre and post processing can vary depending on the type of waste. Liquid wastes are easily handled and often no post processing is required. For bulk solids such as capacitors, they must be punched, drained, and loaded into the TRBP. After processing they must be unloaded and sampled to prove they are clean before final disposal.

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F. Output/generation waste

1. Generated waste (% of input waste):
System outputs generated during waste treatment activities are treated solids, water and product gas, all of which are clean, reusable or disposal products. All of the solid wastes are suitable for landfill and this amounts to about 2% of the organic waste input.

2. Deposited waste at landfill (% of input waste):
The deposited waste at landfill amounts to about 2% of the organic waste input. If solid wastes are treated than 100% of the inorganic portion of the waste will also be a residual and must be deposited at landfill or recycled.

3. Waste quality properties (pH, TCLP):
All wastes generated by the GPCR process in the past have met local regulatory requirements for discharge.
-Liquid effluents were permitted to discharge to open water, municipal sewers, and to irrigation systems. Typical analysis: pH 7-9, TDS<1000, Temp<35C
-Solid effluents met criteria for TCLP

**Note: This Technology Specification and Data Sheet (TSDS) does not certify any particular technology, but tries to summarise the state of the art of the concerned technology on the basis of data delivered by the companies and technology suppliers or other sources, which have been made available to the author and refers the reader to original documents for further evaluation. Without the efforts below listed technology suppliers it would not have been possible to set up this TSDS. Date: 01.09.2008*

Technology suppliers that have contributed to this TSDS:

Bennett Environmental, Canada
Hallett Environmental and Technology Group, Canada
Dr. Yukio Noma, National Institute for Environmental Studies, Japan

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