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SITE Demonstration of Bioremediation of Cyanide at the Summitville Colorado Site

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Introduction

The Summitville Mine in southern Colorado is located in the San Juan mountains at an average site altitude of 11,500 feet. Summitville was the site of mining operations that began in 1873 with the discovery and development of gold placer and lode deposits. The site was actively mined for gold, silver and copper between 1873 and 1947. From 1947 to 1986 the mine area was inactive until the Summitville Consolidated Mining Corporation, Inc. (SCMCI) a wholly-owned subsidiary of Galactic Resources, Ltd. started an open pit mine and heap leach operation at the site.

SCMCI ran a large tonnage open-pit and cyanide heap leach operation from 1986 to 1992. Gold ore (approximately 10 million tons) was mined, crushed and stacked on a lined, bowl-shaped leach pad. The mine experienced problems with water balance and unplanned solution discharges from the start of the mine life. Solution containment complications and ineffective water treatment contributed to environmental problems. Despite the production of 249,000 troy ounces of gold during the mine operation SCMCI was unable to meet remedial requirements and notified the state of Colorado of its intention to file a Chapter VII bankruptcy in December 1992. The EPA Region VIII Emergency Response Branch took over site operations on December 16, 1992 to prevent a catastrophic release of hazardous substances to the environment. The Summitville Mine site was added to the National Priority List in June 1994.

There are multiple sources of contamination at the site due to historic and SCMCI mining operations. Emergency response operations at the site have prevented releases of severely contaminated solution and studies are underway to define a permanent solution to detoxification or neutralization of the various mine waste units. This report addresses demonstration of an innovative bioremediation technology for treatment of cyanide and soluble leachable metals in the heap and heap solutions.

The heap leach pad consists of approximately 10 million tons of cyanide-leached ore and 90 to 150 million gallons of process solution. EPA Region VIII commissioned a Focused Feasibility Study (FFS) and Report of Investigation (RI) to evaluate remedial options for the Heap Leach Pad (HLP). The RI/FFS was completed by Morrison Knudsen Corporation and submitted to EPA Region VIII on August 19, 1994.

A Request for Proposal (RFP) was issued by Environmental Chemical Corporation (ECC) in October 1993 at the request of USEPA Region VIII, Department of the Interior and Bureau of Reclamation. The RFP requested interested companies to provide information on their ability to

implement innovative treatment technologies to improve treatment efficiency and reduce cost of treatment of the heap leach pad spent ore and leachate solutions. Dames & Moore and Pintail Systems, Inc. (PSI) jointly submitted a proposal suggesting application of biotreatment processes for treatment of the spent ore and process solutions in the HLP. The proposal was accepted for feasibility demonstration under the EPA Superfund Innovative Technology Demonstration Program (SITE) with additional funding from EPA Region VIII.

The primary objectives of the Dames & Moore/Pintail Systems proposal were to:

1. Demonstrate the feasibility of spent ore and process solution cyanide bio-detox.
2. Develop site-specific biotreatment processes for spent ore and process solution cyanide detox.
3. Provide treatment data for use in the RI/FS and Record of Decision (ROD) for the Spent Ore and Entrained Solutions operable units at the Summitville Mine.
4. Immobilize potentially leachable metals including zinc, copper, manganese, iron and arsenic within the heap to improve water quality.

Tests and demonstrations outlined in the proposal were conducted in PSI's Aurora, Colorado lab and pilot plant and at the mine site. Spent ore treatability testing included waste characterization, bacteria isolation and bioaugmentation, parallel column treatment tests, data evaluation and reporting.

Biotreatment processes for heap, tailings and process solution detox have been proven at other mine sites in a variety of environments. Biological processes are both site-specific and waste-specific and must be individually engineered and tested for each mine waste. Successfully adapting treatment bacteria to the spent ore environment is a key to developing successful bioremediation potential. Working with a biotreatment population that has been specifically adapted to the ore and augmented to improve cyanide metabolism insures that biotreatment will be effective.

Cyanide metabolism is known to occur in several species of bacteria. Bacteria that have the capacity for enzymatic hydrolysis of ionic cyanide or metallo-cyanide compounds use the carbon and/or nitrogen of the cyanide to meet their nutritional needs. The end-products of cyanide metabolism are natural and non-toxic.

LABORATORY WORKPLAN

Bacteria Source - Isolation and Development

Cyanide decomposition bacteria were isolated from Summitville spent ore samples and were augmented for remediation testwork with mine ores, tailings and waste rock. Preparation for the column tests included:

1. Isolating native bacteria from the spent ore;
2. Adapting the treatment bacteria to the Summitville Mine spent ore in a series of stress and waste infusion media;
3. Characterizing growth and enhancing the new "cyanooxidans" population.
4. Demonstrating bacteria growth and cyanide decomposition in an ore leach flask test.

Column Test Design

The following workplan was used for the column tests:

1. 75-85 kg of spent ore collected by SAIC and the SITE program was loaded into each of six 6"x10' PVC columns. The columns were fitted with a perforated screen and a tapped end-cap to allow treatment solutions to percolate through the ore and be collected for analysis. The columns were set up as follows:

   Column #1: sulfide zone ore, percolation leach biotreatment;
   Column #2: oxidized ore, 25-90 ft depth, percolation leach biotreatment;
   Column #3: oxidized ore, 90-130 ft depth (saturated zone), saturated with HLP solution, percolation biotreat;
   Column #4: oxidized ore, 0-90 ft depth, rinsed zone (1993 peroxide rinse program), percolation leach biotreatment;
   Column #5: oxidized ore, 0-25 ft depth, percolation leach biotreat;
   Column #6: Control Column, oxidized ore, 90-130 ft depth (saturated zone), saturated with HLP solution, percolation leach with peroxide-treated HLP solution.

2. The Detox population of bacteria was grown to working strength and transferred to a dilute nutrient solution for application in a percolation leach.

3. Thirty gallons of barren solution supplied by SAIC and ECC were used to saturate the ore in Columns 3 and 6 to simulate treatment in a saturated ore zone.

4. The treatment solutions were applied to each column at a nominal rate of 0.004 gpm/ft^2.

5. Bio-leach or detox barren solutions from the columns were collected and analyzed for total cyanide. Total cyanide, weak acid dissociable (WAD) cyanide, gold and select metals were analyzed in column leachate solutions during the course of the test.

6. Data was collected to allow calculation of contaminant reduction related to tons of treatment solution applied per ton of ore.

7. Leachate solutions were analyzed for copper to determine metal mobilization due to bacteria processing. Metal analyses were run on an Inductively Coupled Spectrophotometer and an Atomic Absorption Spectrophotometer.

8. Split samples of spent ore and column leachate solutions were collected by SAIC and were submitted to a contract laboratory for confirmation analysis.

Pilot Test Data

The data collected from the pilot column ore treatment program is presented in Figures 1 and 2. Treatment compliance for successful cyanide detoxification was 0.2 mg/L WAD cyanide measured in column leachate solutions. The control peroxide rinse column of saturated zone ore did not achieve compliance with a WAD cyanide standard. All other column treatments reached compliance levels. Total and WAD cyanide were plotted against the tons of solution applied per ton of ore. The amount of biotreatment solution required for complete cyanide detoxification is projected to be 25-30% of the amount of solution required by conventional chemical rinse detox treatments.

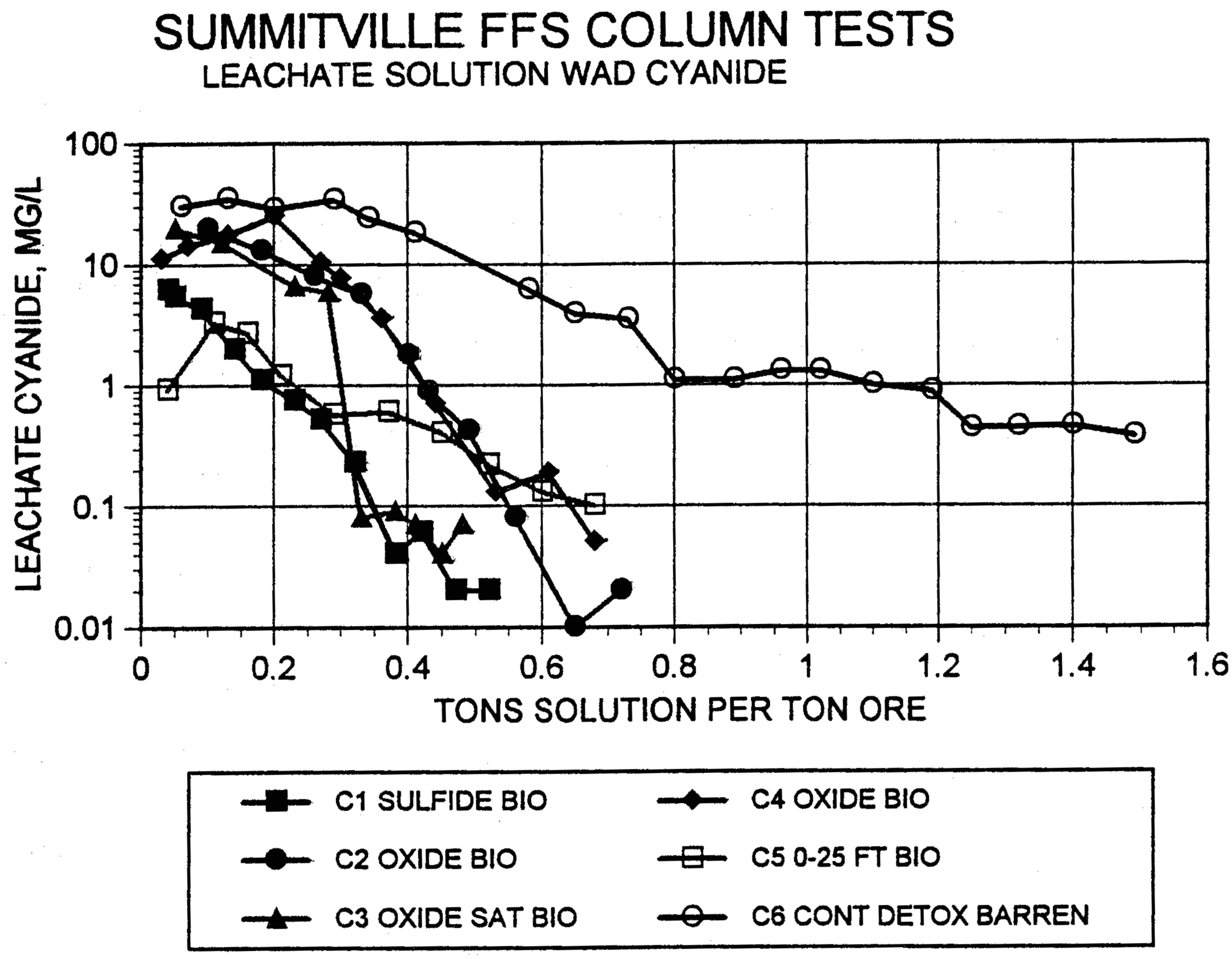

Figure 1. Column Leachate Solution WAD Cyanide

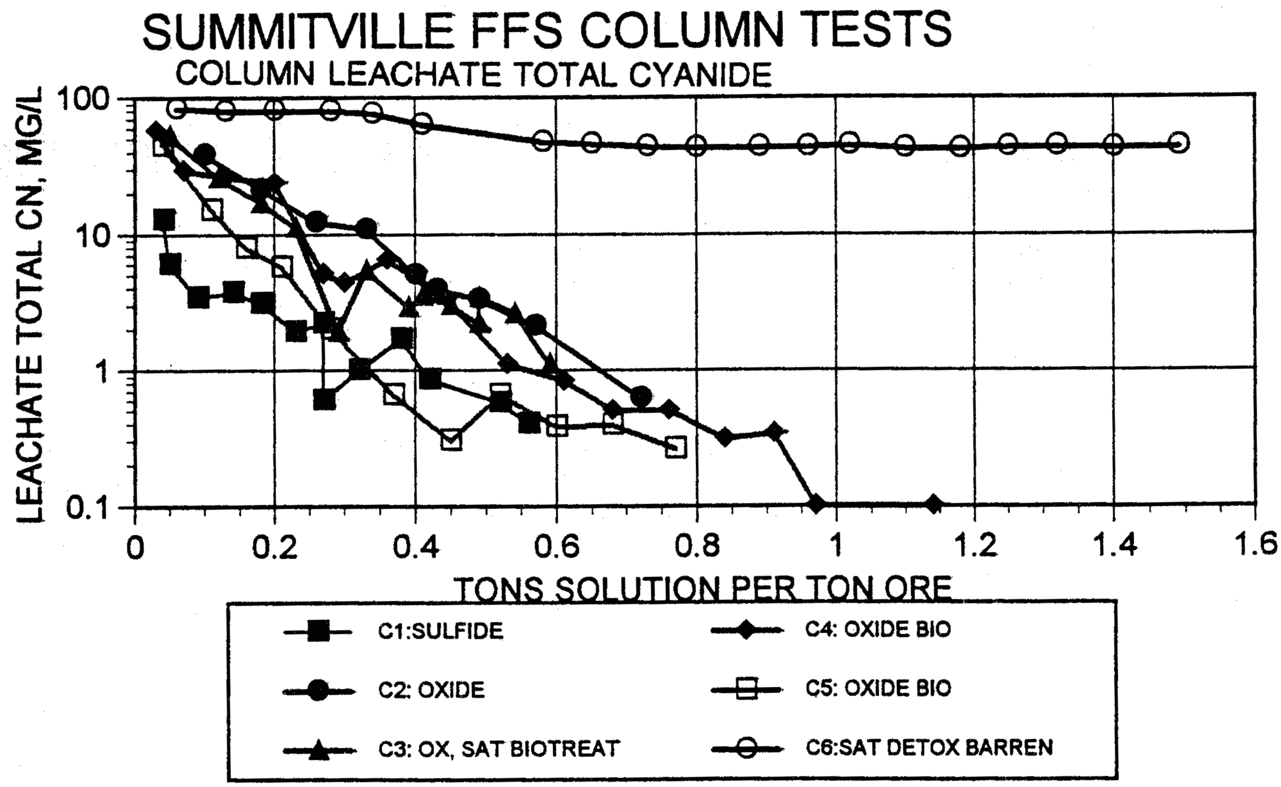

Figure 2. Column Leachate Total Cyanide

A secondary treatment goal in the Focused Feasibility Study was to reduce the amount of leachable or soluble metals in the spent ore and entrained heap leachate solution. Pintail Systems has observed a reduction of soluble metals such as copper in other pilot and field treatment applications. This test was designed to quantify reduction of metals in column leachate solution and to identify any remineralized products in the column tests. Copper in column leachate solutions is shown in Figure 3 for Column 3 and Column 6. Column 3 was the biotreatment test column run as a saturation zone sample. Column 6 was a control rinse using a barren solution detoxified with hydrogen peroxide in a saturation rinse.

Numerous species of bacteria, fungi and yeasts are capable of accumulating many times their weight in soluble metals. Both living and dead biomass are effective in removing soluble metals from waste streams containing gold, silver, chromium, cadmium, copper, lead, zinc, cobalt and others. Bacteria found in natural and extreme environments have developed a wide variety of metabolic functions to adapt to these environments. These natural microbial functions contribute to global mineral cycling that continuously forms, transforms and degrades minerals and metals in the environment. Biomineralization is described as a surface process associated with microorganism cell walls where the remineralization occurs. The biogeochemical activities initiated by microorganisms in ores, soils, surface and groundwater environments can dominate the formation and transformation of those mineral environments.

The metal remineralization process is catalyzed by biological processes alone and by biological processes initiating physical and chemical processes causing an alteration of the micro-environment. During the course of the column tests a series of observations were made on the changing surfaces in the test column. These observations are the basis of the following hypothesis for formation of bio-minerals.

1. Bacteria added to the ore columns attach to the ore surfaces forming a "bio-slime" layer,

2. Soluble metals bind to cell walls and extra-cellular products excreted by the microorganisms (exopolymers, pigments, waste organics, etc.),

3. Metal hydroxides, oxides and carbonates are formed in the primary "bio-slime" layer as amorphous mineral pre-cursors. Curing or maturation of the amorphous slimes suggests that a molecular rearrangement of the hydroxy-metals to more stable forms occurs,

4. Stabilization of the amorphous precipitates forms a remineralization nucleation crystal template for further mineralization to occur. The micro-environment alteration and bacteria metabolism continue to catalyze the remineralization by on-going formation of organometallic compounds, precipitates and transformation of metal oxidation states. The biomineralization appears to follow a sequential and "layered" development on many of the surfaces. Some of the possible minerals formed include calcite, gypsum, bornite, pyrite and covellite.

CONCLUSIONS

Cyanide detox in spent ore is a function of solution application efficiency and bacterial use of cyanide. The ore biotreatment in this test gave similar results and comparable detox time to prior PSI experiences. The treatment bacteria adapted well to the spent ore environment and effected a rapid detoxification of cyanide in spent ore and ore solutions. The Summitville ore is a suitable candidate for a field biotreatment.

The biological treatment column achieved a >99% removal of weak acid dissociable cyanide with

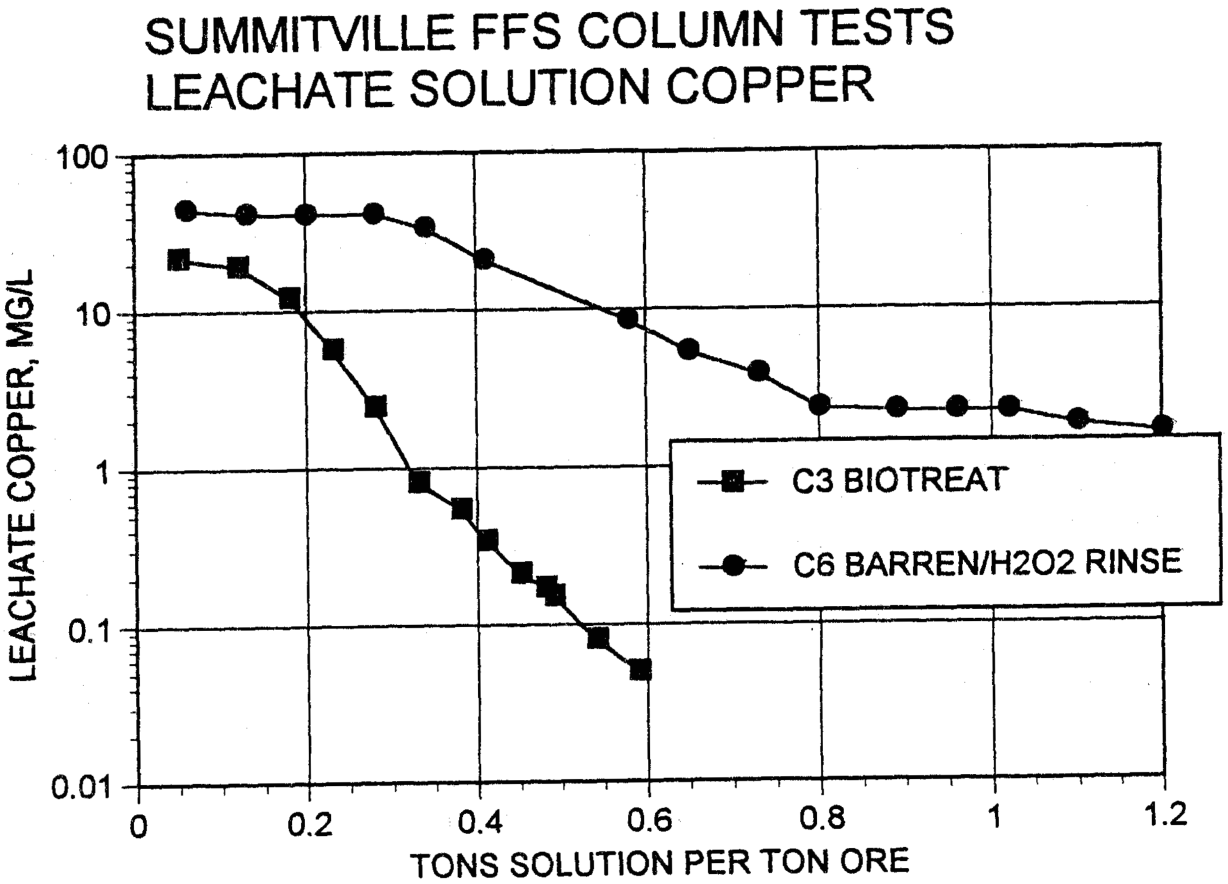

Figure 3. Column Leachate Solution Copper

application less than an average of 0.5 tons of solution per ton of ore. Total cyanide in column leachate solutions at the end of the test was <0.5 mg/L indicating that bacterial action in the treatment solution will metabolize strong metal-cyanide compounds. A field treatment of a leach pad cell or other division of spent ore could be planned for a treatment program using less than 0.5 tons of solution per ton of ore.

Biotreatment in this study achieved a greater reduction in total cyanide in a shorter application than chemical treatments can achieve. In Situ biotreatment is the most efficient heap cyanide detox as compared to peroxide rinse treatments. The data generated in this study indicate that the biotreatment processes have the potential to operate as an effective field treatment. Biological treatments are projected to be cost and time competitive with chemical rinse treatments.

The objectives of the pilot column tests were met in this biotreatment demonstration.

1. Existing strains of cyanide-oxidizing bacteria were adapted to grow in the ore environment and to use cyanide as a carbon and/or nitrogen source.

2. Flask and column tests of the adapted, augmented treatment population verified that bacteria would grow and metabolize soluble cyanide in the Summitville spent ore.

3. Cyanide was detoxified in biotreatment tests in spent ore and column leachate solutions with application of less than an average of 0.5 tons of solutions per ton of ore. Cyanide levels did not reach a 0.2 mg/L discharge criteria with the peroxide kill, saturated, barren rinse test column with application of more than 1.5 tons of treatment solution per ton of ore.

REDUCTIVE PHOTO-DECHLORINATION (RPD) PROCESS FOR SAFE CONVERSION OF HAZARDOUS CHLOROCARBON WASTE STREAMS

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INTRODUCTION

A novel technology designated "Reductive Photo-Dechlorination" (RPD) has been developed and successfully tested for environmentally safe treatment of waste streams containing hazardous chlorinated hydrocarbons. This RPD process employs ultraviolet (UV) light in a reducing atmosphere and at moderate temperatures to efficiently convert chlorocarbon contaminants into valuable hydrocarbons such as methane, ethane, ethylene, acetylene and hydrogen chloride. The UV light promotes carbon-chlorine bond cleavage and long-chain radical reactions with the hydrogenous bath gas leading to the thermodynamically and kinetically favored hydrocarbon products at a conversion of +99%.

The RPD process is schematically shown in Figure 1. The pilot-scale prototype consists of five main units: (1) Input/Mixer; (2) Photo-thermal Reactor; (3) Scrubber; (4) Separator/Storage; and (5) Recycling. Chlorinated waste streams can be introduced in one of three ways: liquid, vapor or adsorbates (to activated carbon). Chlorocarbon solvents are fed into a vaporizer, mixed with a reducing gas and passed into the Photo-thermal Reactor. Air laden with chlorocarbon vapors is first passed through a separator (condenser) which removes chlorinated materials as liquid. Chlorinated contaminants adsorbed onto activated carbon are removed as vapors by purging with a mildly heated reducing gas. Then, the vapors are passed into the Photo-thermal Reactor.

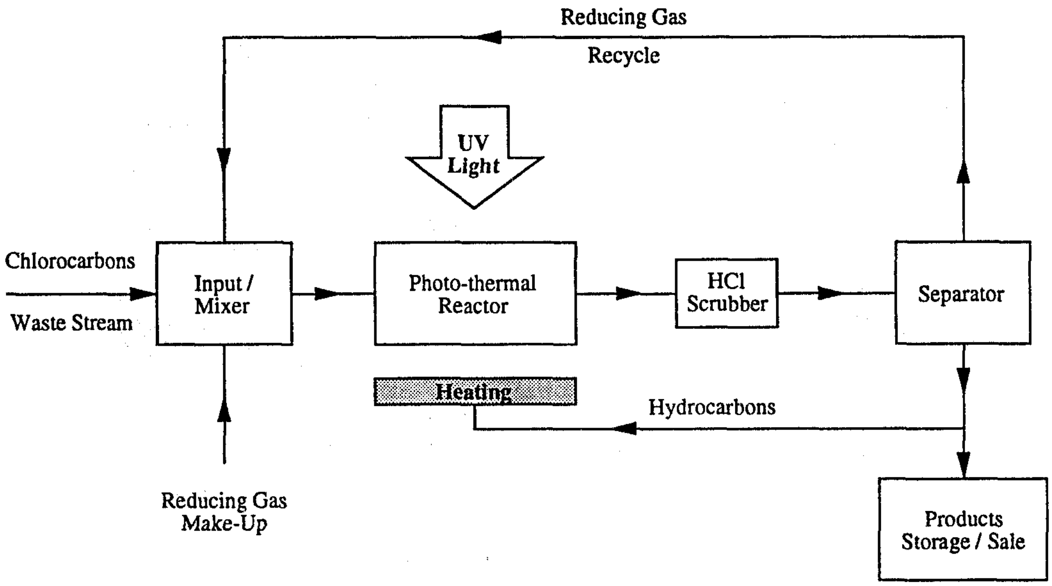

Figure 1. ENERGIA's Reductive Photo-Dechlorination (RPD) Process.