

SUPPORTING DOCUMENT 12

**GIANT MINE
ARSENIC TRIOXIDE PURIFICATION**

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**GIANT MINE
ASSESSMENT OF A PROCESS FOR ARSENIC TRIOXIDE PURIFICATION**

Prepared for:

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DECEMBER 2002

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GIANT MINE

ASSESSMENT OF A PROCESS FOR ARSENIC TRIOXIDE PURIFICATION

1. INTRODUCTION

This document presents the assessment of a process to recover purified arsenic trioxide from the Giant Mine dust, for sale to large scale consumers of the material, typically manufacturers of wood preservatives. The process would also recover gold bullion for sale and would stabilize the remaining arsenic in the process residue, making it suitable for storage in a secure surface waste disposal facility.

The Giant Mine dust has an average arsenic content of about 60%, equivalent to about 80% arsenic trioxide. Large scale consumers of arsenic trioxide require a product at least 99% pure and, therefore, some kind of purification process would be required to make a marketable product. Although several types of process may be technically feasible for the purification of arsenic trioxide, the process known as “fuming” (or “selective sublimation”) is considered better proven in large scale applications and therefore most suitable for this assessment.

The following sections of this report provide details on the selection of the fuming process, the conceptual design of a plant to apply the process, and the estimation of capital and operating costs for such a plant. This assessment was a collaborative project involving Lakefield Research Limited, H.G. Engineering Limited and SRK Consulting Inc.

2. PROCESS SELECTION

Processes for the purification of arsenic trioxide fall into two major categories. These are hydrometallurgical processes, involving the leaching of arsenic into solution with a suitable solvent, and pyrometallurgical processes, involving heating the material to produce an arsenic gas (or fume) by sublimation.

Several arsenic leaching processes have been tested by numerous groups on a laboratory or pilot scale, including hot water, hot ammonium hydroxide, sodium hydroxide and methanol leaching. Each of these processes dissolve arsenic into

solution from the feed material, leaving insoluble impurities as a solid residue in the leaching pulp, followed by solution clarification and fractional crystallization, in which purified arsenic trioxide is selectively precipitated by careful control of the solution temperature. The only leaching process that has been applied to any extent at a commercial scale is the hot water leach process. This process was employed at the Con Mine, in Yellowknife, in the 1980's with limited success. The process was capable of producing a product that met market specifications, but recoveries were low.

Arsenic fuming processes have been extensively applied around the world for the production of marketable arsenic trioxide on a large scale, and have provided the majority of high-purity arsenic trioxide sold in bulk in recent years. In most cases, the arsenic fume is generated during the roasting of arsenical gold ores and fine solid impurities are separated from the arsenic fume with electrostatic precipitators. This type of process was successfully operated at the El Indio Mine, in Chile, and process data are available from this and other operations for the design of a fuming-based process at the Giant Mine.

In addition to the information available from successful large-scale fuming plants, useful data have also been provided by several laboratory and pilot scale test programs conducted on the Giant Mine material since the 1970's. Due to the significant amount of operating and test data available for process design, and the proven feasibility and efficiency of the fuming process on a large scale, this process has been selected for conceptual design and assessment.

3. PROCESS DESIGN

The following sections describe the selection of major variables for the conceptual design of a plant to apply the process.

3.1 Processing Rate

The optimum rate of material processing would be determined by the quantity of purified arsenic trioxide that could be sold on an annual basis. The storage of large quantities of arsenic trioxide product would be avoided, since an unpredicted collapse in the market could make the product unmarketable and require that it be stabilized for disposal at additional cost.

For the purpose of this assessment, it has been assumed that an arsenic purification process would operate for 15 years, producing an average of 11,400 tonnes of marketable product per year. This quantity represents about 40% of average annual North American consumption of arsenic trioxide in the period 1994 to 1999.

The concentration of arsenic (and arsenic trioxide) varies in the inventory of dust stored at the mine (Royal Oak Mines, 1998). Due to significant modifications made to the roaster gas cleaning circuits over a period of several years, which were finally completed in 1963, the collected material can be classified into two distinct inventories. These are material produced before the modifications were completed, which has a lower arsenic content and higher gold content; and material produced after the modifications were completed, which has higher arsenic content and lower gold content. These two inventories consist of:

- Low grade material: 59,000 dry tonnes, average 47% As, 43 grams Au/tonne
- High grade material: 178,000 dry tonnes, average 65% As, 10 grams Au/tonne

There may be advantages in treating these material types separately. For example, by treating the lower grade material at the start of the project, the initial production of arsenic trioxide would be relatively low, allowing the marketing process to get established with lower sale volumes. Revenues from gold sales would also be maximized early in the project with this approach. Alternatively, by treating higher grade material early in the project, and producing as much arsenic trioxide as can be sold, the remaining inventory of arsenic trioxide and the associated liability would be reduced as quickly as possible.

To allow this flexibility, the plant has been designed to process either type of material at a fixed rate of 2.1 tonnes per operating hour. Assuming a plant availability of 85% (310 operating days per year), at this processing rate, the entire dust inventory would be treated over the 15 year processing phase of the project. In the case of the higher grade feed material, this flexible plant design requires arsenic trioxide conditioning and packaging circuits capable of handling larger quantities of product. In the case of the lower grade feed material, larger residue stabilization and gold recovery circuits are required.

For the purpose of estimating annual operating costs and revenues, a simple case has been assumed, in which a fully blended feed representing the average arsenic and gold

grades of the entire inventory is treated at 2.1 tonnes per hour (50.4 tonnes per day). Operating costs and revenues are discussed in Section 5.

3.2 Feed Preparation

The handling of large quantities of arsenic trioxide dust, while maintaining a safe working environment, represents a major engineering challenge. Because the material is very fine grained and easily dispersed into the air when dry, extraordinary management and engineering measures would be required to control air quality in the plant within regulated limits.

A great advantage would be realised by handling the material wet, rather than dry, as much as possible. For this reason, it has been assumed that the mining processes would either produce a slurry of the material in water directly from the extraction point underground, or that the mined material would be made into a slurry as close as possible to the extraction point. All arsenic trioxide material is therefore assumed to enter the process plant as dilute slurry pumped through a pipeline, and would be handled as a slurry in the feed preparation section of the plant.

Laboratory settling and filtration tests have been recently conducted on samples of the arsenic trioxide dust (see Supporting Document 11). The tests results indicate that, despite the fine particle size of the material, reasonable settling rates can be achieved with the application of flocculants. Although these data were not available for the initial conceptual plant design and cost estimation exercise, they indicate that the thickener originally selected would be appropriate for the required duty. Similarly, although simple laboratory tests for vacuum filtration were conducted and the plant would use pressure filtration, the results indicate reasonable filtration characteristics, and the originally selected filtration equipment would also be appropriate.

The drying characteristics of the arsenic trioxide dust are less well known. For drying purposes, a paddle type dryer has been selected, heated indirectly by steam. This type of dryer has been successfully applied in the drying of very fine precipitates, sludges and baghouse products at large-scale.

3.3 Arsenic Trioxide Production

For the purpose of this assessment, based on the results of laboratory and pilot plant test work on the Giant Mine material, it has been assumed that 90% of the arsenic in

the feed material would be recovered to the high-purity arsenic trioxide product, resulting in an average annual production of 11,418 tonnes.

Large scale consumers of arsenic trioxide typically require a product greater than 99% pure, with very low concentrations of specific impurities, including antimony and iron. Based on general industrial experience, as well as test work on the Giant Mine material, these product specifications are considered achievable. Due to the occupational health concerns associated with the product, consumers also require that the material is free-flowing and produces little dust. For this reason, a purification plant would require a product conditioning circuit, which would compact and granulate the final product.

3.4 Residue Stabilization

Solid residue from the fuming process would contain 10% of the arsenic in the original process feed, on average, and almost all of the gold. A significant portion of the arsenic in the residue is likely to be soluble in water and, therefore, some kind of stabilization process would be required before the material can be disposed of.

Some of the gold could probably be leached with cyanide directly from the fuming residue, and an encapsulation type process, such as cement stabilization, could then be applied to the leach tailings. However, high concentrations of dissolved arsenic in gold leaching pulps can result in poor gold recovery, and an efficient process could require the chemical conversion of arsenic to an insoluble form, in advance of a gold recovery circuit. For this reason, the conceptual plant design includes a batch autoclave for treating the fuming residue, in which arsenic and added iron would be oxidized and combined to form insoluble, crystalline ferric arsenate compounds. This type of stabilization process would allow for efficient recovery of gold in a subsequent cyanide leaching process.

A batch process was chosen in this case because the amount of material to be treated would be relatively small and the dry feed material could be easily stored in bins between batch treatments. Batch autoclaves are significantly cheaper and easier to operate than continuously fed autoclaves.

A discussion of alternative iron sources for autoclave stabilization is presented in Supporting Document 13. For this assessment, it has been assumed that the iron would be provided as a pyrite concentrate, obtained from mining operations outside of

the Northwest Territories. Other design criteria for the batch autoclave process would be similar to those presented in Supporting Document 13.

Metallurgical test work would be required to determine the gold recovery that could be achieved without prior conversion of the arsenic to ferric arsenate. A lower gold recovery could be acceptable, if a less costly stabilization process could then be applied to the leach residue.

3.5 Gold Recovery

Gold would be recovered from the stabilized autoclave residue by conventional methods, involving cyanide leaching, activated carbon adsorption, and electrowinning. High recoveries of gold from autoclave products have been well demonstrated. A gold recovery of 90% has been assumed for the assessment of this process, resulting in an average annual gold production of 8,170 troy ounces.

3.6 Water Treatment

The process would produce an excess of water, with different streams contaminated either with arsenic or cyanide. The major source of arsenic contaminated water would be the various air scrubbers, which must be fed with fresh water to minimize the release of arsenic. This water would be sent to the conventional hydrogen peroxide oxidation and iron precipitation treatment plant described in Supporting Document 8.

A small volume of cyanide contaminated water would be produced from the filtering of gold leaching residue. This water would also be treated in the hydrogen peroxide treatment plant, where the cyanide would be oxidized to cyanate and detoxified.

4. PLANT DESCRIPTION

Based on the major process variables discussed above, a conceptual plant design has been prepared. Process flow diagrams are provided in Figures 1 and 2, and the plant operation is described below.

The arsenic trioxide bearing feed material would be received at the processing plant as a dilute slurry. Two stages of screening would separate trash (metal, wood, plastic) and rock chips from the fine material. Steel trash would be recovered with a magnetic separator, and the rock chips would be ground in a ball mill and returned to the screening circuit.

The slurry would be thickened in a conventional thickener with the aid of a chemical flocculant. Clear overflow water from the thickener would be recycled back to the mining process. The underflow pulp from the thickener would be delivered to a series of agitated tanks, providing a storage capacity equivalent to 20 days of plant feed. The feed preparation section of the plant would operate for 35% of total time, processing material at a higher rate than the following plant circuits. This would allow the mining operation greater flexibility with respect to production schedules.

The fuming and gold recovery circuits would be available to operate for 85% of total time. Feed slurry for the fuming circuit would be drawn from the storage tanks, filtered in a pressure filtration circuit, dried in a steam-heated paddle dryer, and discharged to a storage bin. Air vented from the dryer and storage bin would be cleaned in a wet scrubber, to minimize the release of arsenic to the atmosphere, and contaminated scrubber water would be sent to water treatment facilities.

Dried material would be fed to a fluidized-bed fuming reactor via a screw feeder. The fuming reactor would be fed with air heated by a propane-fired furnace and inert sand would be added in small quantities to stabilize the bed. The fuming reactor would operate at a temperature of about 500°C and arsenic in the feed material would be driven off in gaseous form. Fine dust and gases leaving the reactor would be fed to cyclone classifiers, followed by an electrostatic precipitator (ESP). The cyclones and ESP would recover fine particulates from the reactor off-gas and deliver them to a storage bin for further processing. This material would comprise the main waste residue from the process.

The gas vented from the ESP, containing most of the arsenic in the original feed material, would be cooled in order to condense the gaseous arsenic as particulate arsenic trioxide. High-purity, particulate arsenic trioxide would be filtered from the gas in a baghouse and delivered to the arsenic trioxide product conditioning and packaging circuit. Air vented from the baghouse would be cleaned in a wet scrubbing system to minimize the release of arsenic to the atmosphere. Contaminated scrubber water would be sent to water treatment facilities.

High-purity arsenic trioxide, discharged from the baghouse in very fine particulate form, would be drawn from the storage bin and fed to a compactor, which would compress the material into a dense 'cake'. The compactor product would be broken into granules in a granulator and the conditioned product would be discharged to a

storage bin. Steel drums would be filled with weighed quantities of the granulated product. The drums would be sealed and the exterior of the drums would be washed. Drums of purified arsenic trioxide product would be loaded into covered trucks for transport to consumers.

Particulate material collected in the cyclones and ESP would comprise the main waste residue from the process and residual arsenic in this material would require stabilization. Weighed batches of this material would be mixed with water in an agitated tank to form a slurry, and pyrite concentrate and magnesium oxide would be added to the slurry. The tank contents would be transferred to a batch autoclave. In each batch treatment, the autoclave would be sealed and the pulp would be pre-heated with steam. When the pulp reaches the process initiation temperature, oxygen would be fed to the autoclave under pressure. The steam supply would be cut off and the heat required for reaction would be generated by the oxidation of pyrite.

At the end of the autoclave treatment cycle, the hot pulp would be discharged through a pressure let down system into a flash cooling tank, operating at atmospheric pressure. Steam released from the flash tank would be collected in a wet scrubber, to minimize the release of arsenic bearing water vapour to the atmosphere. Contaminated scrubber water would be sent to water treatment facilities.

The cooled slurry would be delivered to a series of three thickeners, operating in counter-current decantation (CCD) mode, in which the solids are separated from the liquor, and the solids are washed to minimize acid residue. The acid liquor would be neutralized with lime in an agitated tank to form gypsum. The gypsum would be recovered from the liquor by pressure filtration and the filter cake would be transported to an on-site stabilized waste disposal facility. The clear neutralized liquor would be returned to the process, or sent to water treatment facilities.

The solids from the CCD circuit would be neutralized with lime in an agitated tank. Additional lime would be added to make the pulp alkaline in preparation for cyanide leaching. The solids pulp would be mixed with cyanide solution in a conditioning tank, and then fed to a series of six carbon-in-leach (CIL) agitated tanks, containing coarse granular activated carbon. Compressed air would be bubbled into the tanks to dissolve oxygen in the pulp. Gold would be leached into solution from the autoclave residue and concentrated by adsorption on the surfaces of the carbon granules. The leach pulp would be allowed to flow freely through the CIL tanks, and on to a pressure

filtration circuit. The leached autoclave residue, containing arsenic in a stable chemical form, would be filtered from the pulp and transported to the on-site stabilized waste disposal facility. The filtrate would be sent to water treatment facilities for detoxification of the contained cyanide.

Carbon would be retained in the CIL tanks by inter-tank screens. Carbon loaded with gold would be removed from the CIL circuit in batches, and gold would be stripped from the carbon in a small pressure vessel, producing a concentrated gold cyanide solution. Gold would be recovered from the stripping liquor in an electrowinning circuit. Gold deposits would be washed from the electrowinning cathodes in batches, filtered, dried, and then smelted in a refining furnace. The plant would produce gold bullion for sale.

5. ESTIMATION OF COSTS & REVENUES

5.1 Capital Costs

The capital costs for the installation of the processing plant described above, in Yellowknife, have been estimated by H.G. Engineering Limited and are presented in detail in HGE 2001. These costs are summarized in Appendix A.

The estimated capital costs for the plant amount to a total of \$66,900,000. The estimated capital costs are considered accurate within the range of plus or minus 25%. The costs include engineering, construction management, commissioning and transportation, as well as standard contingencies.

5.2 Operating Costs

The annual operating costs for this processing plant, including labour, spare parts, supplies, energy and reagents, have been estimated, amounting to a total of \$8,341,000 per year. A table summarizing annual operating costs is provided in Appendix A.

5.3 Revenues

Revenues originate from the sale of purified arsenic trioxide and gold bullion. Prices paid in the U.S.A. for arsenic trioxide concentrates of greater than 99% purity, with low levels of problematic impurities, were at a minimum of about \$780 (US\$500) per tonne in the late 1990's. In the light of recently announced changes to the regulation of arsenic-based wood preservatives in the U.S.A., it is unlikely that similar prices

would be paid in the future, and it is very difficult to predict a stable future price over the project life.

The economics of this project would obviously be highly dependant on the revenues from arsenic trioxide sales. The cost of transporting the arsenic trioxide product to markets in the U.S.A. has been estimated at \$330 per tonne, and the average annual production is estimated to be 11,418 tonnes. At a market price of \$600 (US\$385) per tonne, the annual revenue would be \$3,083,000 (after transportation costs). At a price of \$450 (US\$290) per tonne, the revenue would be \$1,370,000 per year. At a market price of \$330 (US\$210) or less, there would be no revenue from arsenic trioxide sales to off-set the plant operating or capital costs.

An average future price of \$470 per ounce of gold (about US\$300) has been assumed. With an annual production of 8,170 ounces, the sale of gold would provide an estimated \$3,840,000 of revenue per year.

5.4 Cost and Revenue Summary

Estimated capital and operating costs, and estimated revenues, are summarized in Table 5.1. It is important to note that these are the costs of just one component of a complete arsenic trioxide management alternative. The costs of dust extraction, water treatment, and waste disposal, for example, are not included here. The estimated revenue must be applied against total project costs, in order to calculate net project costs.

TABLE 5.1
Cost and Revenue Summary

Capital Cost	\$66,900,000
Operating Cost (per year)	\$8,341,000
Arsenic Trioxide Revenues (per year)	unknown
Gold Revenues (per year)	\$3,840,000
Plant Operating Phase	15 years

Prepared by: SRS
Checked by: DBM

6. ACKNOWLEDGEMENTS AND AUTHOR

The process selection and conceptual plant design presented in this report was developed by Grant Feasby, P.Eng., and Dr. Cesar (Jo) Ferron of Lakefield Research Limited, working in collaboration with SRK Consulting. Capital costs and rates of energy consumption for the conceptual plant design were estimated by Ernie Burga, P.Eng., and Daryl Purdie, P.Eng., of H.G. Engineering Limited (HGE). Operating costs were estimated by HGE and SRK.

This report, **Giant Mine – Assessment of a Process for Arsenic Trioxide Purification**, has been prepared by:

STEFFEN, ROBERTSON AND KIRSTEN (CANADA) INC.



Stephen Schultz
Project Engineer

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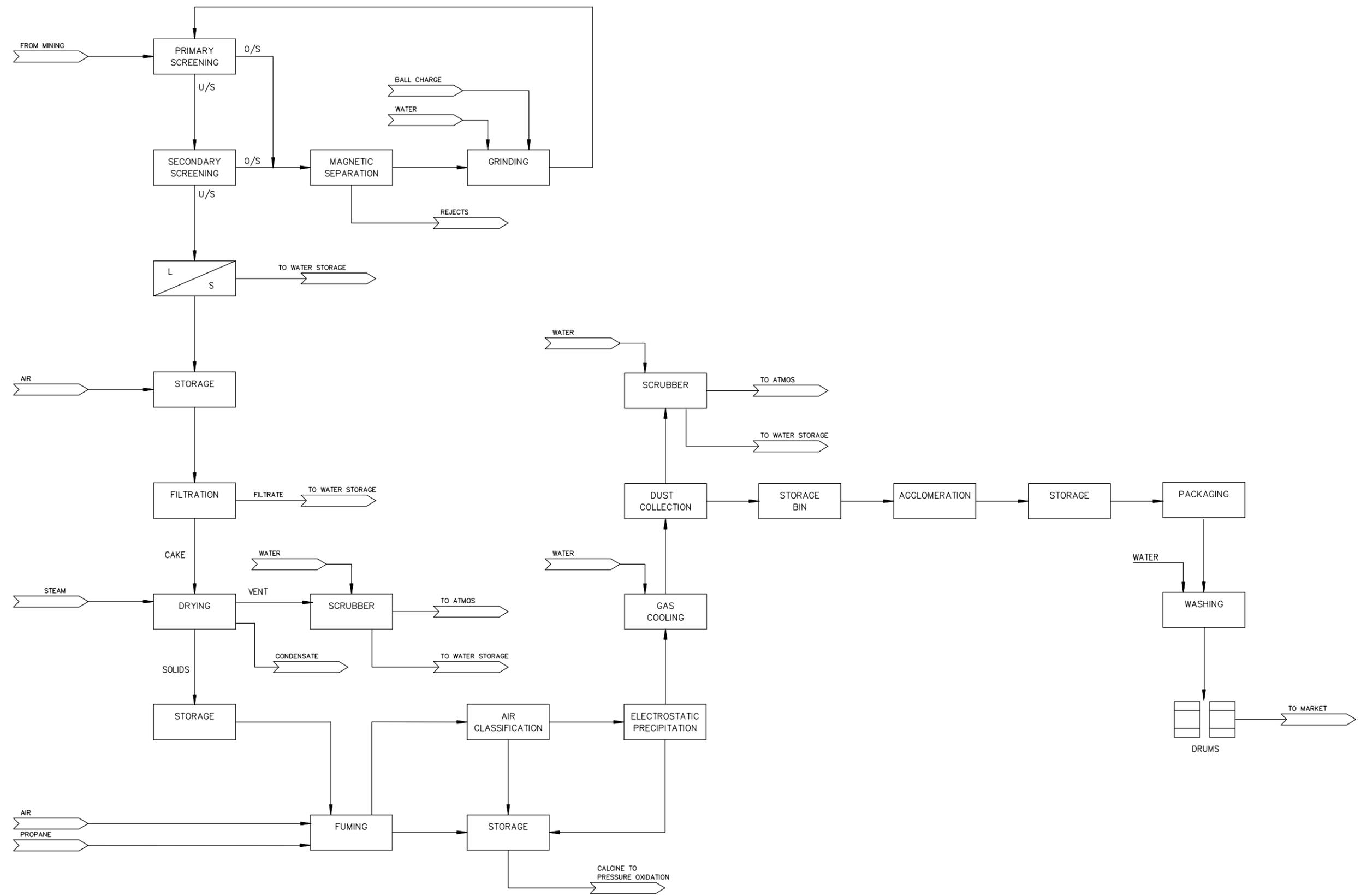
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FIGURES



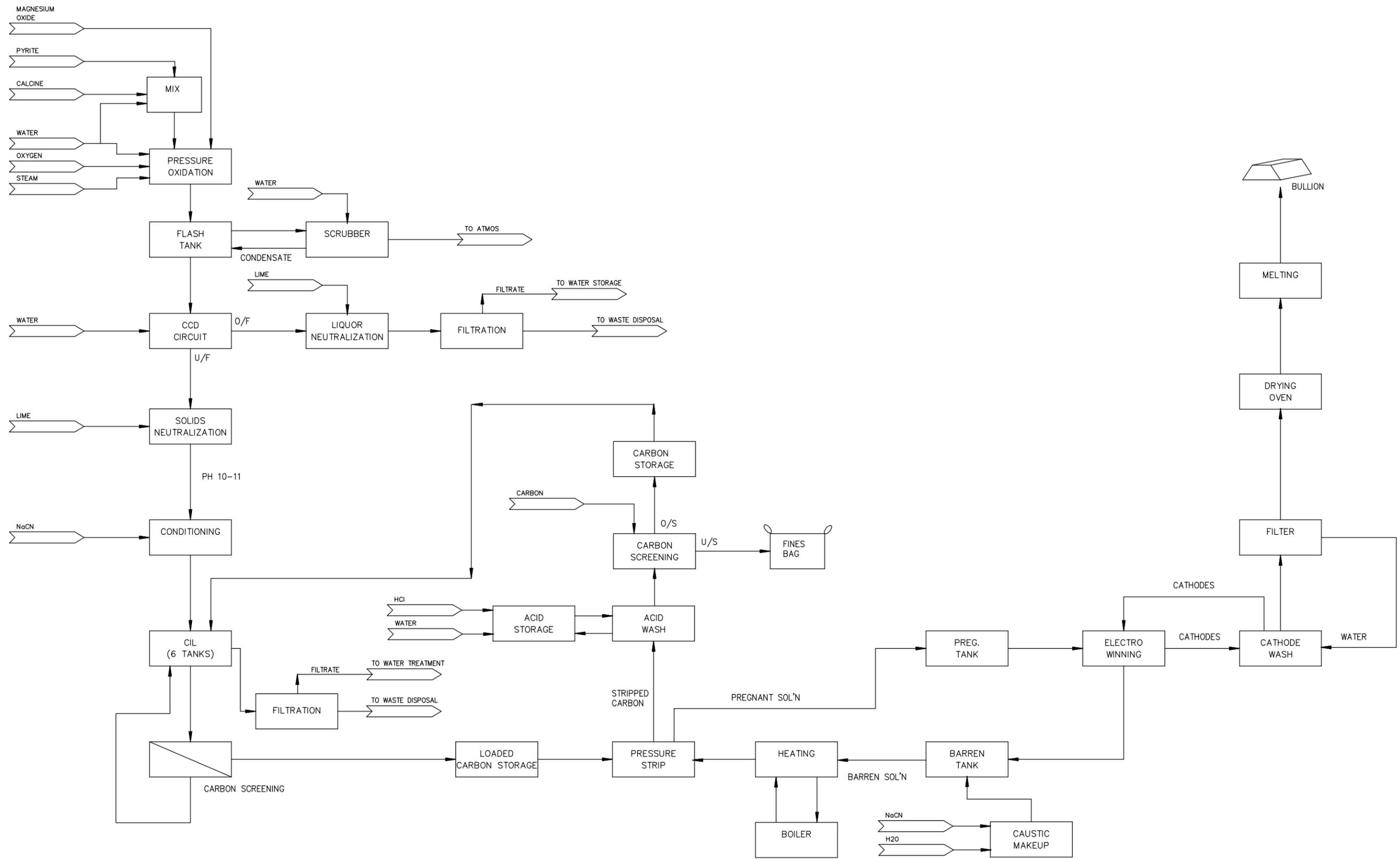
Source: Arsenic Trioxide Treatment – Capital Cost Estimates,
H.G. Engineering Ltd, Revision 2, April 2001



Giant Mine – Assessment of Fuming Process

PROCESS FLOW DIAGRAM
Feed Preparation and Fuming

PROJECT NO. 1CI001.07	DATE Dec. 2002	APPROVED	FIGURE 1
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Source: Arsenic Trioxide Treatment – Capital Cost Estimates,
H.G. Engineering Ltd, Revision 2, April 2001



Giant Mine – Assessment of Fuming Process

PROCESS FLOW DIAGRAM
Waste Stabilization and Gold Recovery

PROJECT NO. 1CI001.07	DATE Dec. 2002	APPROVED	FIGURE 2
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APPENDIX A
Capital and Operating Cost Summaries

Cost Estimate Summary sorted by area code

Date *17-Apr-01*
 Estimate no 55901-Case 1:FUMING
 Plant
 Building

55901
 Giant Mine Arsenic Trioxide Dust Management
 SRK Consultants

			<u>Total price Supply</u>	<u>Total price Install</u>	<u>Total cost</u>
Area code	000	General	\$2,751,240	\$799,120	\$3,550,360
Area code	100	Conditioning and Storage	\$3,950,300	\$1,147,000	\$5,097,300
Area code	200	Filtration Drying and Fuming Area	\$11,574,200	\$2,319,240	\$13,893,440
Area code	500	Pressure Oxidation, CCD, and Neutralization	\$13,197,530	\$3,679,382	\$16,876,912
Area code	600	Gold Recovery	\$1,509,900	\$431,400	\$1,941,300
Area code	700	Reagents	\$1,119,560	\$299,360	\$1,418,920
Area code	800	Services	\$2,157,120	\$816,320	\$2,973,440
Area code	900	Buildings	\$1,181,200	\$770,200	\$1,951,400
Sub - total direct costs			\$37,441,050	\$10,262,022	\$47,703,072

Indirect Costs

	Owner's costs	\$2,250,000
Consultant services and Construction Management (15%)		\$7,155,000
	Commissioning (1%)	\$477,000
	Escalation (5%)	\$2,385,154
	Capital Spares (5%)	\$1,872,000
	Transportation (5%)	\$1,872,000
Total indirect cost		\$16,011,154
Total direct and indirect cost		\$63,714,226
Project contingencies (5%)		\$3,185,774
Total project costs		\$66,900,000

Arsenic Trioxide Dust Treatment

Arsenic and Gold Recovery by Fuming
(Blended Dust Feed, 15 Year Processing Phase)

By: D. Purdie (HGE) 17-Apr-01
Revised: S. Schultz (SRK) 31-May-01
Revised: S. Schultz (SRK) 12-Aug-02
Revised: S. Schultz (SRK) 6-Dec-02

Plant Operating Cost Summary

Plant capacity	50.40 dry tonnes per operating day	
Operating time	310 days per year	
Plant Through-put	15,624 tonnes per year of raw dust	
Arsenic Trioxide Production	11,418 tonnes per year	
Revenue - Arsenic Sales (after transportation)	? Cdn\$/tonne	? Cdn\$/year
Gold Production	8,170 troy ounces per year	
Revenue - Gold Sales	470 Cdn\$/ounce	\$3,839,900 Cdn\$/year

PLANT OPERATING COST

Annual Cost Cost/tonne

1 OPERATING LABOUR

Number

Labour Cost

Operators (12 hr shifts)	24	\$85,000	\$ 2,040,000	\$ 130.57
Supervisors	6	\$110,000	\$ 660,000	\$ 42.24
Maintenance	8	\$105,000	\$ 840,000	\$ 53.76
Staff (management, technical, admin)	3	\$110,000	\$ 330,000	\$ 21.12

Sub-total Cost

Cdn \$ 3,870,000 \$ 247.70

2 OPERATING SUPPLIES & SPARES

Spare parts
Operating supplies

Sub-total Cost (1% of capital cost per year)

Cdn \$ 670,000 \$ 42.88

3 UTILITIES

Electric Power	\$ 0.120	per kWh	8,547,444 kWh/yr	\$ 1,025,693	\$ 65.65
Propane Gas	\$ 0.380	per Litre	8,558 L/d	\$ 1,008,132	

Sub-total Cost

Cdn \$ 2,033,826 \$ 65.65

4 REAGENTS

Cost per unit

4.1 Grinding Balls	1 \$/kg	2 kg/d	\$ 625	\$ 0.04
4.2 Quick Lime	250 \$/tonne	5.8 mtpd	\$ 451,143	\$ 28.88
4.3 Magensium Oxide	600 \$/tonne	2.8 mtpd	\$ 514,655	\$ 32.94
4.4 Pyrite Concentrate	176 \$/tonne	6.6 mtpd	\$ 359,677	\$ 23.02
4.5 Oxygen	100 \$/tonne	10.1 mtpd	\$ 312,480	\$ 20.00
4.6 Flocculant	2.5 \$/kg	12 kg/d	\$ 9,374	\$ 0.60
4.7 Sodium Cyanide	3 \$/kg	48 kg/d	\$ 44,692	\$ 2.86
4.8 Activated Carbon	1000 \$/tonne	0.22 mtpd	\$ 67,183	\$ 4.30
4.9 Hydrogen Peroxide (50%)	0.9 \$/kg	27 kg/d	\$ 7,533	\$ 0.48

Sub-total Cost

Cdn \$ 1,767,363 \$ 113.12

TOTAL ANNUAL OPERATING COST

Cdn \$ 8,341,188 \$ 469.35