The Albion Process™ Development Program

GLENCORE TECHNOLOGY

A GLENCORE COMPANY

“Albion Process™ exceeded expectations. Even with large swings in sulphur grade and feed rate, we maintain gold recovery in the cyanidation plant above design targets. Without Albion Process™ we would only achieve around 20% gold recovery and huge cyanide consumption, but with Albion Process™ we can achieve over 95% gold recovery and minimal cyanide consumption, giving the process plant outstanding return on investment.”

– GPM Gold

ALBION PROCESS™

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Figure 1: Las Lagunas Albion Plant

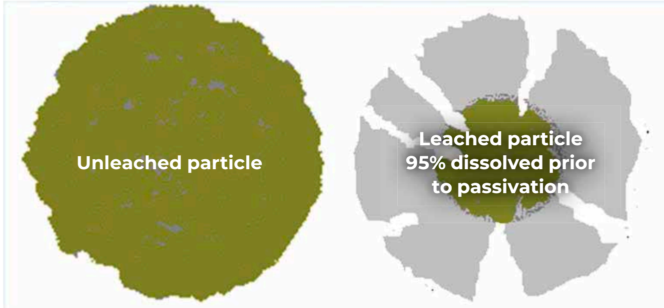


Figure 2: Mechanism of Passivation of Sulphide Minerals

Albion Process™ Description

The Albion Process™ is a combination of ultrafine grinding and oxidative leaching at atmospheric pressure. The feed to the Albion Process™ is a concentrate containing base or precious metals, and the Albion Process™ is used to oxidise the sulphide minerals in the concentrate and liberate these metals for recovery by conventional means.

The Albion Process™ technology was developed in 1994 by Glencore and is patented worldwide. There are five Albion Process™ plants currently in operation. Three plants treat a zinc sulphide concentrate and are located in Spain (4,000 tpa zinc metal) and Germany (18,000 tpa zinc metal) and Australia (250,000 tpa zinc lead). A fourth Albion Process™ plant was operating in the Dominican Republic treating a refractory gold/silver concentrate, producing 80,000 ounces of gold annually. It is now shut down due to depleted feed. A photograph of the Las Lagunas IsaMill™ and oxidative leaching circuit is shown in Figure 1. The fifth plant is the GPM Gold plant in Armenia. Running since 2014, the plant quadrupled recoveries and maintains above-target results. A sixth Albion Plant, the fifth in operation, treats chalcopyrite copper concentrate in the Sable Zinc mine in Zambia. The operation went on hold after changing hands and awaiting license renewal.

The first stage of the Albion Process™ is fine grinding of the concentrate. Most sulphide minerals cannot be leached under normal atmospheric pressure conditions. The process of ultrafine grinding results in a high degree of strain being introduced into the sulphide mineral lattice. As a result, the number of grain boundary fractures and lattice defects in the mineral increases by several orders of magnitude, relative to un-ground minerals. The introduction of strain lowers the activation energy for the oxidation of the sulphides, and enables leaching under atmospheric conditions. The rate of leaching is also enhanced, due to the increased mineral surface area.

Fine grinding also prevents passivation of the leaching mineral by products of the leach reaction. Passivation occurs when leach products, such as iron oxides and elemental sulphur, precipitate on the surface of the leaching mineral. These precipitates passivate the mineral by preventing the access of chemicals to the mineral surface.

Passivation is normally complete once the precipitated layer is 2–3 µm thick. Ultrafine grinding of a mineral to a particle size of 80% passing 10–12 µm will prevent passivation, as the leaching mineral will disintegrate prior to the precipitate layer becoming thick enough to passivate the mineral. This is illustrated in Figure 2.

After the concentrate has been finely ground, the slurry is then leached in agitated vessels, and oxygen is introduced to the leach slurry to oxidise the sulphide minerals. The agitated leaching vessels are designed by Glencore Technology and are known as the Albion Process™ Leach Reactor. The Albion Process™ Leach Reactor is agitated using dual hydrofoil impellers and oxygen is introduced to the leach slurry at supersonic velocity to improve mass transfer efficiency and ensure efficient oxidation of the sulphides. This is achieved using HyperSparge™.

The Albion Process™ Leach Reactor is designed to operate at close to the boiling point of the slurry, and no cooling is required. Leaching is carried out autothermally, and the temperature of the leach slurry is set by the amount of heat released by the leaching reaction. Heat is not added to the leaching vessel from external sources, and excess heat generated from the oxidation process is removed through humidification of the vessel off gases.

Albion Process™ Installations

PLANT	YEAR	CAPACITY (TPA)	FLOWSHEET	STATUS
San Juan de Neiva	2010	8,056	Integrated with an Roast-Leach-Electrowin refinery	Operating
Nordenham	2011	76,100	Integrated with an Roast-Leach-Electrowin refinery	Operating
MRM	2011	250,000	Partial oxidation of galena	Operating
Las Lagunas	2012	322,240	Oxidation of pyrite/arsenopyrite to CIL	Depleted
GPM Gold	2014	110,000	Oxidation of pyrite/arsenopyrite to CIL	Operating
Sable	2018	9,000	Oxidation of chalcopyrite feeding to SX/EW and cobalt precipitation	On hold

Ultrafine Grinding and the IsaMill™ Technology

Ultrafine grinding requires a different milling action than found in a conventional ball mill, due to the fine nature of the grinding media required.

In most ultrafine grinding mills, an impeller is used to impart momentum to the media charge. Media is agitated through stirring, and the resulting turbulent mixing overcomes the tendency of fine media to centrifuge. Abrasion is the major breakage mechanism in a stirred mill. The common aspects of a stirred mill are a central shaft and a series of impellers attached to the shaft. These impellers can be pins, spirals, or discs.

In stirred mills, two configurations are common. In the first, the mill shaft and grinding elements are set up vertically within the mill. This type of configuration is limited in size to typically 750 kW of installed power or less. This limitation is brought about by the large break out torque imposed on the impeller located at the base of the media charge, due to the compressive load of media sitting vertically on the impeller.

In the second configuration the mill shaft is aligned horizontally within the mill chamber. This configuration, which is used in Glencore Technology's IsaMill™, is more cost efficient at motor sizes in excess of 500 kW. There is very little break out torque required to begin to agitate the media charge, which limits the motor size to that required for grinding only.

The IsaMill™ is a large-scale energy efficient continuous grinding technology specifically developed for rugged metalliferous applications. Glencore Technology supplies the IsaMill™ technology to mining operations around the world, with over 130 mills installed in 21 countries worldwide. The IsaMill™ uses a very high energy intensity of 300 kW/m³ in the grinding chamber, resulting in a small footprint and simple installation. The IsaMill™ can be scaled up directly from small scale laboratory tests. Glencore's IsaMill™, is installed in more than two-thirds of the world's metalliferous ultrafine grinding applications. The grinding media size for the IsaMill™ is within the size range 1.5–3.5 mm. Media can come from various sources, such as an autogenous media screened from the feed ore, silica sands or ceramic beads.

Glencore Technology will provide the IsaMill™ as a packaged Grinding Plant, consisting of the mill, slurry feed and discharge systems, media handling system, all instrumentation and control and all structural steel and platforms. Some of the IsaMill™ Grinding Plant components are shown in Figure 3 and 4. The IsaMill™ Grinding Plant incorporates all of Glencore Technology's operational and design experience gained from over 130 IsaMill™ installations, ensuring a trouble free commissioning.

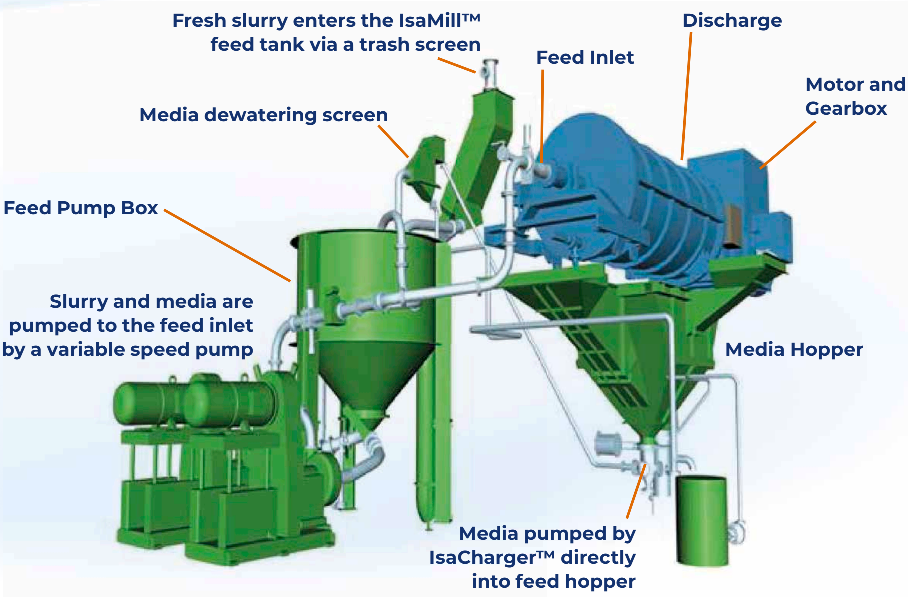


Figure 3: IsaMill™ Feed and Media Systems

The IsaMill™ will contain up to eight discs on the shaft, with each disc acting as a separate grinding element. The operating mechanism for the IsaMill™ is shown in Figure 5. This allows the IsaMill™ to be operated in open circuit without the need for cyclones. The IsaMill™ produces a sharp size distribution in open circuit, as the feed must pass through multiple distinct grinding zones in series before reaching the Product Separator. This plug flow action ensures no short circuiting, and efficiently directs energy to the coarser feed particles.

The Product Separator is a centrifugal separator at the end of the mill shaft that spins at sufficient rpm to generate over 20 'g' forces, and this action is responsible for the sharp classification within the mill. The IsaMill™ can be operated in open circuit at high slurry density, which is a key advantage for the leaching circuit, as the entry of water to the leach is limited, simplifying the water balance.

The IsaMill™ uses inert grinding media that produces clean, polished mineral surfaces resulting in improved leaching kinetics. A steep particle size distribution is produced in the mill. The 98% passing size in the mill is typically less than 2.5 times the 80% passing size, and very little coarse material enters the leaching circuit, resulting in very high leach recoveries.

The IsaMill™ is the highest intensity grinding technology available (>300 kW/m³), meaning it is also the most compact, with a small footprint and low profile. The IsaMill™ is oriented horizontally, with the grinding plant accessed by a single platform at an elevation of approximately three metres. Access to the mill and maintenance is simplified by the low operating aspect of the IsaMill™ and the associated grinding plant. Maintenance of the IsaMill™ is similar to routine maintenance for a slurry pump.

The internal rotating shaft in the IsaMill™ is counter-levered at the feed inlet end so the discharge end flange and grinding chamber can be simply unbolted and slid off using hydraulic rams. A shut down for inspection and replacement of internal wear parts takes less than eight hours. Availability of 99% and utilisation of 96% are typical of the IsaMill™.

Scale-up of the IsaMill™ is straight forward. Laboratory test results are directly scaled to commercial size with 100% accuracy. The IsaMill™ has a proven 1:1 direct scale-up to reduce project risk

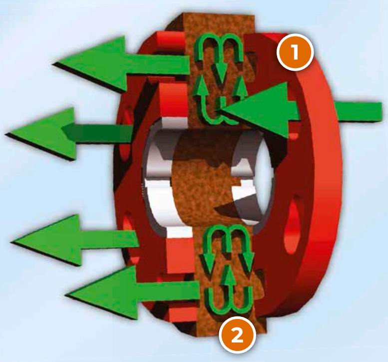
Figure 4: IsaMill™ Grinding Plant Layout

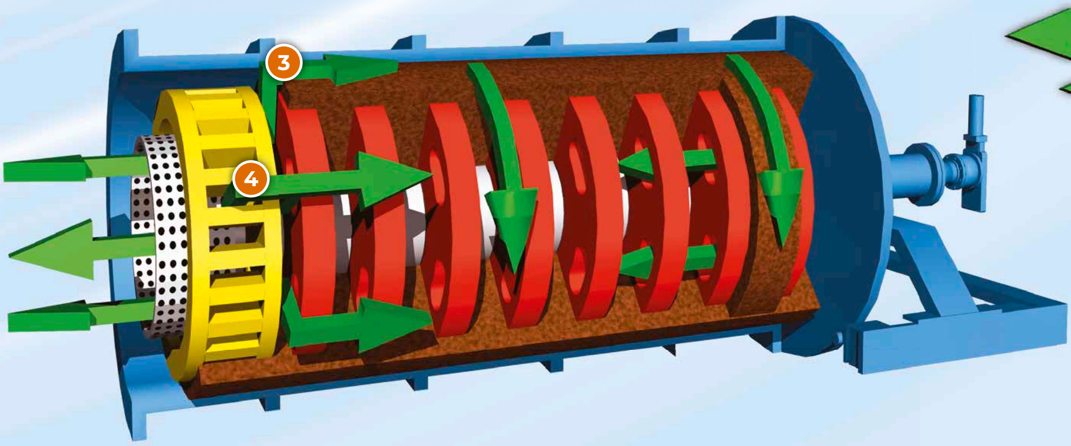
The IsaMill™ is available in the following models:

- **M500 (200 kW):** capable of max flowrate of 30 tonnes per hour
- **M1000 (500 kW):** capable of max flowrate of 90 tonnes per hour
- **M5000 (1200 and 1500 kW):** capable of max flowrate of 200 tonnes per hour
- **M7500 (2200 kW):** capable of max flowrate of 275 tonnes per hour
- **M10000 (3000 kW):** capable of max flowrate of 350 tonnes per hour
- **M15000 (3800 kW):** capable of max flowrate of 600 tonnes per hour

Figure 5: IsaMill™ Operating Mechanism

1. The shaft rotating at high speeds generates disc tip speeds of 19–22 m/s.
2. Recirculation of media occurs between discs due to variation in velocity profile across discs.
3. Media centrifuged to outside of grinding chamber by high centrifugal force generated inside mill.
4. Rotor pumps liquid back into chamber to retain media.





Oxidative Leaching

After the sulphide concentrate has been finely ground, it is then leached under atmospheric conditions in an oxidative leach consisting of interconnected Albion Process™ Leach Reactors. Each Reactor is an atmospheric leaching vessel that has been designed by Glencore Technology to achieve the oxygen mass transfer required for oxidation of the sulphide minerals at low capital and operating cost.

Oxygen is injected into the base of the Albion Process™ Leach Reactors using Glencore's HyperSparge™ supersonic injection lances. The design of the HyperSparge™ injection system is carried out in conjunction with the design of the agitation system to ensure high oxygen mass transfer rates are achieved in the reactor. The agitator unit power is moderate, and the impeller tip speed is chosen in combination with the HyperSparge™ injection velocity to provide the required mass transfer rates.

The Albion Process™ Leach Reactor has a corrosion resistant alloy steel shell and base, supported on a ring beam or raft foundation. The tank aspect ratio is designed to achieve high oxygen transfer rates and capture efficiencies. Glencore Technology has developed fully modular tank shell systems, which can be rapidly installed on site in one third the time of a field welded tank and at much lower costs. The Glencore modular reactor designs require no site welding. The modular Albion Process™ Leach Reactor is shown in Figure 6.

The reactor is fitted with a centrally mounted agitator consisting of one or more hydrofoil impellers. The agitator sizing and impeller geometry is chosen by Glencore Technology using in house correlations and testwork data to provide sufficient power to meet the oxygen mass transfer requirements in the leach vessel, as well as provide adequate solids suspension and gas dispersal. Impeller arrangements and spacing are also designed to assist in foam control within the vessel. The agitator is mounted off the tank shell, and modular maintenance platforms and structural supports are provided as part of the Albion Process™ Leach Reactor.

Key design aspects of the agitator, such as the solidity ratio, the impeller diameters and tip speeds and the overall pumping rate are determined in combination with the design of the oxygen delivery system to provide the optimum mass transfer rates in the reactor.

HyperSparge™ supersonic oxygen injection lances are mounted circumferentially around the reactor, close to the base. The HyperSparge™ is mounted externally to the tank, and penetrates through the tank wall using a series of sealing assemblies. This design ensures that no downtime is incurred for maintenance of the oxygen delivery system, as all HyperSparge™ units can be removed live for inspection.

The HyperSparge™ injects oxygen at supersonic velocities in the range 450–550 $m.s^{-1}$. The supersonic injection velocities result in a compressed gas jet at the tip of the sparger that incorporates slurry via shear resulting in very high mass transfer rates within the Reactors.

The unique design of the HyperSparge™ means that the agitator power required for the Albion Process™ Leach Reactors is much lower than is required in a conventional system. Oxygen capture efficiencies of 85% or higher are achieved in Albion Plants within Glencore Technology using the HyperSparge™ system. A typical HyperSparge™ assembly is shown in Figure 7. The high jet velocities at the tip of the HyperSparge™ keep the nozzle clean and eliminate blockages.

The HyperSparge™ is incorporated in an overall oxygen addition and control system developed by Glencore Technology, consisting of in stack off gas monitoring and control of the HyperSparge™ delivery pressure. The oxygen control system is used to maintain high oxygen capture efficiencies within the Albion Process™ Leach Reactor.

Exhaust gas from the oxidative leach is inert, and so the Reactor is fitted with sectional lids and an off gas stack to vent steam from the vessel to a safe working height. As the Albion Process™ Leach Reactors operate at close to the boiling point of the slurry, significant water vapour is released from the vessel with the exhaust gas, which assists in overall process water balance. The off gas stack is designed as a natural chimney to vent this exhaust gas to a safe working height. The exhaust gas it typically vented, however condensers can be fitted if required to recover the evaporated water. The Reactor has a modular lid assembly, incorporating an agitator moat seal and sliding roof section to allow easy removal of the agitation mechanism for maintenance. This is shown in Figure 8.

Each Albion Process™ Leach Reactor has modular Internal baffles to assist mixing and prevent slurry vortexing, as well as a modular slurry riser to prevent slurry short-circuiting and assist in transport of coarser material through the leaching train.

The Reactors are connected in series with a launder system that allows gravity flow of the slurry through the leach train. All Albion Process™ Leach Reactors are fitted with bypass launders to allow any reactor to be removed from service for periodic maintenance. This is a low cost leaching system that is simple and flexible to operate, and the overall availability of the oxidative leach train is 99%. Glencore Technology's launder design accommodates froth, preventing a build-up of foam in the leach train. The Launder Assembly is shown in Figure 9.

No internal heating or cooling systems are required in the Albion Process™ Leach Reactors. The vessel is allowed to operate at its equilibrium temperature, which is typically in the range 90–95°C. Heat is provided by the oxidation of the sulphide minerals, with heat lost from the vessel by humidification of off gas. No direct or indirect temperature control is required, simplifying tank construction and maintenance. No external cooling towers or flash vessels are required.

The Albion Process™ Leach Reactor has a corrosion resistant alloy steel shell and base, supported on a ring beam or raft foundation.

Figure 6: Albion Process™ Leach Reactor

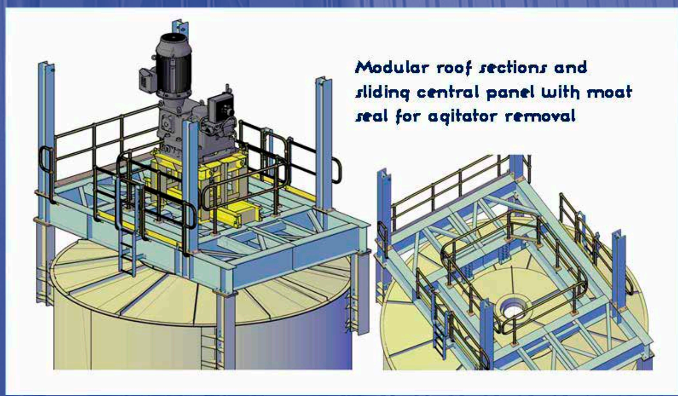


Figure 8: Albion Process™ Leach Reactor Roof Section

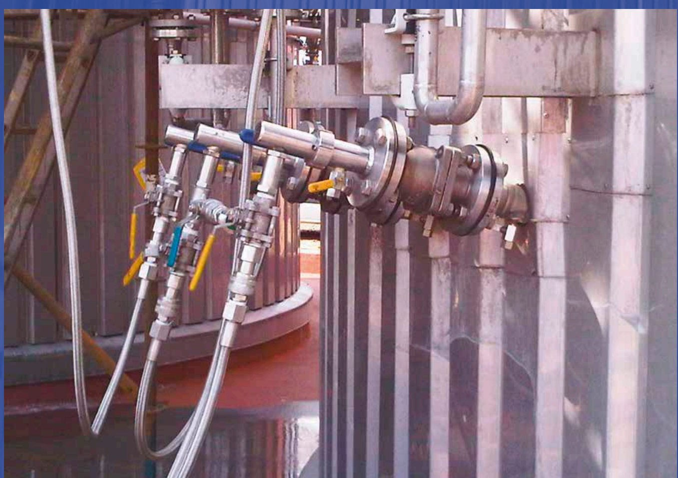


Figure 7: HyperSparge

Glencore Technology's launder design accommodates froth, preventing a build-up of foam in the leach train.

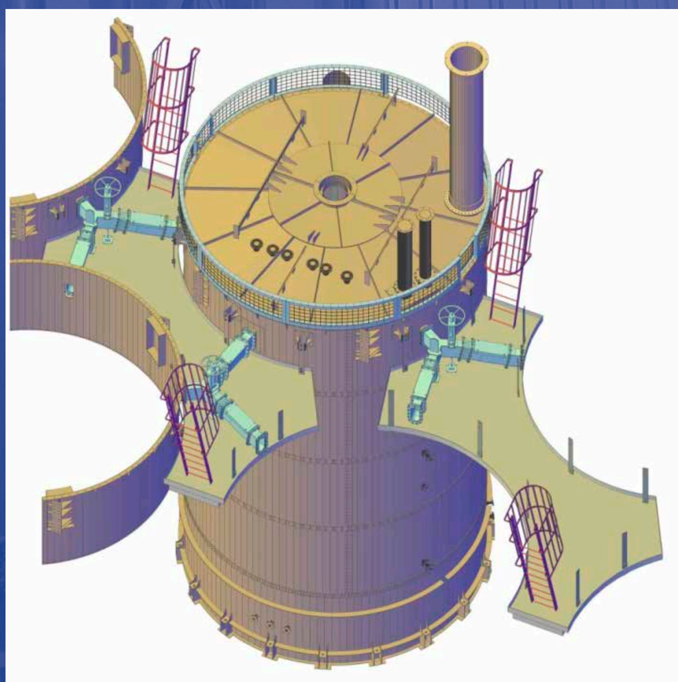


Figure 9: Launder System

Development Program Overview

A typical development program for an Albion Process™ project would proceed in five Phases:

Phase 1: Proof of Concept Class 5 (AACE) Engineering Study

Phase 2: Scoping Level Evaluation Testwork Program and Class 4 (AACE) Engineering Study

Phase 3: Pre-Feasibility Level Evaluation and Class 3 (AACE) Engineering Study

Phase 4: Feasibility Level Evaluation and Class 2 (AACE) Definitive Feasibility Study

Phase 5: Project Implementation as a Lump Sum Plant Design and supply package from Glencore Technology

Phase 1 – Amenability Test + Class 5

The Phase 1 Proof of Concept program consists of a Class 5 (AACE Guidelines) order of magnitude capital and operating cost estimate for an Albion Process™ plant based on a preliminary concentrate throughput and analysis provided by the client. Limited testwork is required as part of Phase 1, and all data is based on the Glencore Technology database. It is possible to generate a Phase 1 Class 5 Engineering Study based on a client's concentrate analysis only if insufficient sample is available for testwork.

Phase 2 – Parameterization + Class 4

The Phase 2 Scoping Level Evaluation Testwork Program would evaluate the IsaMill ultrafine grinding and oxidative leach unit operations only, as these are the heart of the Albion Process™. Downstream unit operations are not normally tested as part of this level of evaluation.

This stage of testwork normally requires 10–20 kg of concentrate over a duration of 12–16 weeks to complete. On completion of this testwork program, Glencore Technology can then complete a Class 4 (AACE Guidelines) Engineering Study on the Albion Process™ Plant to an accuracy of + 35%, with additional costing of the fully integrated flowsheet to a lower level of accuracy. This Engineering Study could be used for detailed project evaluation as is and for comparison of various technologies or flowsheet options.

Phase 3 – Variability Test + Class 3

The Phase 3 Pre-Feasibility level work program expands on the scoping study. Additional concentrate types can be evaluated to provide data on the process for each defined concentrate type within the life cycle of the project. Testwork would also be carried out on downstream impurity control, such as iron and arsenic precipitation, as well as solid/liquid separation. Where metal recovery options are to be investigated, then testwork to define the preferred flowsheet is carried out at this stage. The Pre-Feasibility stage of testwork normally requires 20–50 kg of each concentrate type over a duration of 12–18 weeks. The aim of the Pre-Feasibility level testwork is to finalise a flowsheet from concentrate through to metal or final product production, as well as to provide sufficient data to support a Pre-Feasibility level capital and operating cost estimate for the Albion Process™ plant. On completion of this testwork program, Glencore Technology are then in a position to complete a Class 3 (AACE Guidelines) Engineering Study on the Albion Process™ Plant and integrated flowsheet to an accuracy of + 25%.

Phase 4 – Class 2

The Phase 4 Definitive Feasibility Study involves testwork and further engineering. Phase 4 level testwork involves continuous operation of a fully integrated pilot plant with the flowsheet identified in the Pre- Feasibility work program. This pilot involves all unit operations from concentrate ultrafine grinding through to metal or final product production, and has a closed water balance. This stage of testwork normally requires 500–2,000 kg of concentrate to complete, with a duration of 12–16 weeks of continuous operation. All unit operations would be tested by vendors where possible. The aim of the Feasibility level testwork is to provide all process data necessary to support a feasibility level capital and operating cost estimate to be compiled for the Albion Process™ plant.

In parallel to the pilot plant program, Glencore Technology also issues a complete Class 2 (AACE Guidelines) Engineering Study on the Albion Process™ Plant and integrated flowsheet to an accuracy of +10%. This study involves bringing the level of engineering in the project to a completion level in the range 45–55%.

On completion of Phase 4 of the project, Glencore Technology offers to the client a Lump Sum design and supply package to supply all plant and equipment for the project, as well as all engineering.

Phase 5

Phase 5 of the project involves the Implementation of the project, including completion of all engineering, procurement of all equipment, piping, valves, instruments, control systems and structural steel and supply of entire plant as modular sections to the project site for construction.

More detail on the Scope of Work for each development stage is outlined in Section 2. A description of the Classes of Engineering Study carried out by Glencore Technology as part of the development program is outlined below. All Engineering Studies follow the guidelines outlined in the AACE International Recommended Practice No 18R-97 Cost Estimate Classification System.

Classes of Engineering Study

TESTWORK LEVEL	CLASS OF ESTIMATE	PURPOSE	ACCURACY	PROJECT COMPLETION LEVEL
Phase 1	Class 5 Order of Magnitude Estimate	Concept Screening	Low Range = -20 to -50% High Range = 30 to 100%	0–2%
Phase 2	Class 4 Study Estimate	Concept Study	Low Range = -15 to -30% High Range = 20 to 50%	1–15%
Phase 3	Class 3 Definitive Estimate	Budgeting	Low Range = -10 to -20% High Range = 10 to 30%	10–40%
Phase 4	Class 2 Detailed Estimate	Control Estimate or Bid Preparation	Low Range = -5 to -15% High Range = 5 to 20%	30–70%
	Class 1 Check Estimate	Tender	Low Range = -3 to -10% High Range = 3 to 15%	50–100%

Engineering and Project Development Services

Glencore Technology is the developer and owner of the Albion Process™ technology and offers the technology to clients worldwide.

Glencore Technology provides lump sum equipment design and supply packages to all Albion Process™ clients. The scope of supply includes the full Albion Process™ plant, inclusive of all structural steel, piping and launders, platforms, stairways and support structures. Full civil and foundation design can be included in the Glencore Technology scope of work. Construction is supplied by the client, with supervisory labour provided by Glencore.

The Albion Process™ plant package provided by Glencore Technology is low cost and low risk, and incorporates all of Glencore's know-how in the 20 year development history of the IsaMill™ and Albion Process™ technologies. Glencore Technology can work with our client's EPCM contractor to ensure that the Albion Process™ plant interfaces with all other plant areas in an efficient manner

Glencore Technology involvement in a project usually begins at the testwork stage, with a testwork and project development program designed for the client by Glencore Technology and our marketing partner Core Resources. All testwork is carried out at an approved testing facility. Glencore Technology can provide a range of Engineering Studies in support of the testwork programs to provide capital and operating cost data for the Albion Process™ plant. Glencore Technology can also provide Feasibility Study services, ultimately leading to a lump sum equipment design and supply package, which is fully guaranteed.

As an introduction to the Albion Process™ technology, Glencore Technology can provide desktop capital and operating cost estimates for an Albion Process™ plant at no cost to our clients, once provided

For more information on the Albion Process™, please refer all enquiries to:

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