Modular Mixer-Settlers for SX Plant Sustainability

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The challenges facing the mining industry include complex ores and declining grades, together with increasing capital costs and environmental regulations. In addition, future commodity price uncertainty makes investment decisions difficult. Shorter plant lifecycles mean that new projects need shorter payback and increased net present value. With regard to solvent extraction, the introduction of an innovative modular plant design will help to address these issues. The first such modular offering is Outotec's VSF®X modular solvent-extraction plant that uses prefabricated and transportable modules.

Reuse and recyclability have underpinned the design concept. The greatest advantage of the VSF®X modular solvent-extraction plant is its relocation possibility. Additionally, it is suitable for various metals and plant capacity is adjustable through a scalable modular structure. After a dedicated plant lifecycle, the plant can be dismantled and relocated to a new site. This reuse ability offers major benefits for short-term plants, making them more feasible due to higher residual value.

A net present value analysis is made for two examples, a conventional plant with no relocation possibility and a modular movable plant with extended plant life cycle, in order to evaluate the feasibility of modular plants. Results indicate that modular plant design could offer an economical solution with the additional advantage of improved overall sustainability through its life cycle.

INTRODUCTION

The challenges facing the mining industry include complex ores and declining grades, together with increasing capital costs and environmental regulations. In addition, future commodity price uncertainty makes investment decisions difficult. Shorter plant lifecycles mean that new projects need shorter payback and increased net present value (NPV) (Mudd, 2010; Norgate & Jahanshahi, 2010) .

Awareness of sustainability issues is also rising and sustainability reporting is now a key element of many companies' public and investor relations. Major companies are now putting more effort in this area to earn legitimacy for new projects (Mudd 2010).

Sustainability can traditionally be divided into three main categories: economic, environmental and social (World Commission on Environment and Development, 1987). Outotec has recently developed a modular solvent extraction plant called VSF®X that uses prefabricated and easily transportable modules. This new development addresses many of the sustainability issues due to its positive impact on engineering, manufacturing, installation, operation and maintenance.

This paper evaluates the sustainability of a modular SX plant. Environmental sustainability is studied through analysis of the end-of-life options. The recyclability of the plant is discussed as well as the ability to relocate the plant.

Economic sustainability is evaluated through NPV analysis which compares the investment potential of conventional and modular SX plants with relocation possibility and an extended plant lifecycle. Social sustainability is strongly related to health and safety, but is not discussed in depth in this paper.

BASIC CHARACTERISTICS

Modular SX-plant Description

The new modular design, VSF®X, is based on the settler units being constructed in transportable ISO-standard container-sized preassembled modules. This gives advantages in terms of prefabrication, quality, transportation, installation, scalability and re-use of equipment. All container-sized and shaped modules are equipped with standard container fittings for locking and lifting of units. Modules can be easily installed on top of concrete foundations or pillars. The VSF®X units are gas tight, thus making the SX process resistant to organic phase oxidation. This also increases work safety by preventing the vapourisation of organic, as well as other harmful gases. This philosophy allows these SX plants to be custom designed using standard modules and hence allows faster and more economical project implementation.

The benefit of using standard designed modules is that short-term projects can be more readily justified economically. This economic justification is supported yet further when the benefits of the modular design during the whole plant life cycle are considered. SX plant end-of-life options, such as reuse of the whole plant or recycling of the materials used, are realistic alternatives.

Figure 1 illustrates the basic arrangement of a single large-scale VSF®X mixer-settler unit. This includes the DOP® pump and two SPIROK® mixers combined with the modular settler and piping units.

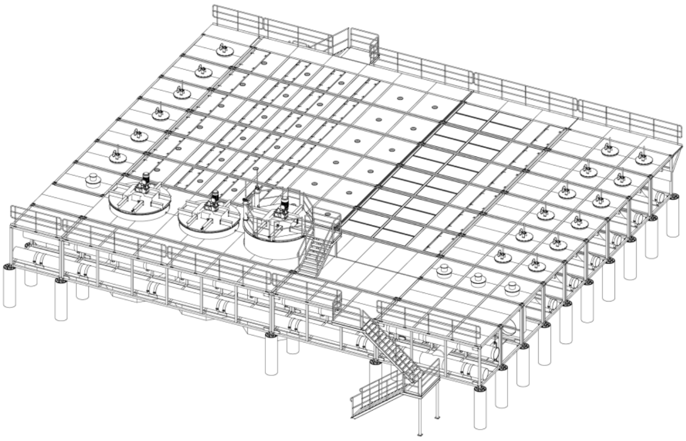

Figure 1. VSF®X modular SX plant.

The modular philosophy is shown in Figure 2. The module in the upper left corner is the coalescing module. These contain the Dispersion Depletor Gate (DDG®)-type fences and are used to coalesce the droplets of the aqueous and organic phases and to separate these two phases. The module in the upper right corner is the retention unit, which extends the residence of the two phases before they move to the next stage. The module in the lower right corner is the launder module, used for collecting and delivering the separate phases between each stage. Finally, the VSF®X tank system consisting of a DOP® pump and two SPIROK® mixers is shown n the lower left corner.

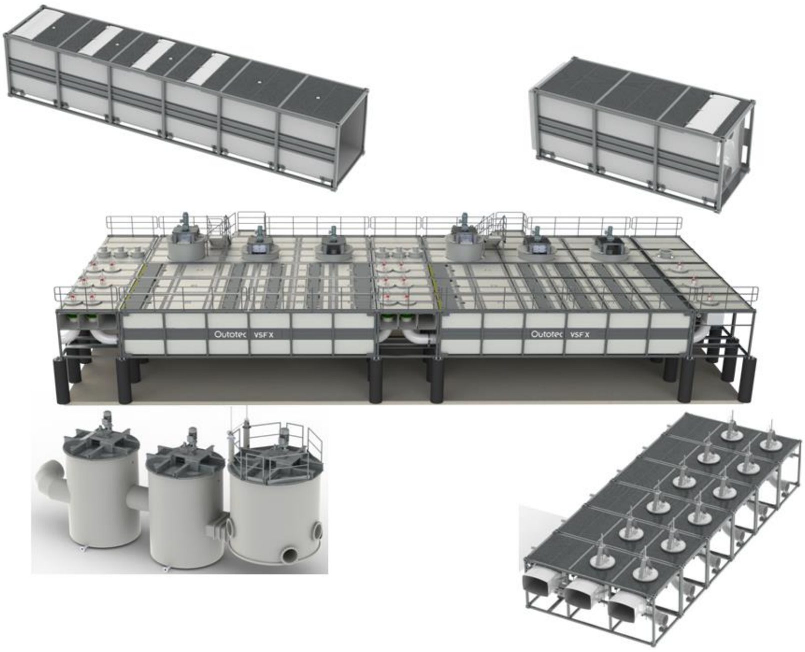

Figure 2. Settler modules.

Materials selection
Materials are selected based on suitability, availability and recyclability. Fibre-reinforced plastic (FRP) is used for all components which are in touch with the SX process solution since FRP provides good protection against various chemicals as well as protection against chlorides, such as sea water. FRP is lightweight and has very good structural properties. Additionally, it can be shaped in order to create smooth flow patterns (Broekel & Scharr, 2005).

Carbon steel is used for the supporting structures and is not in contact with the process solutions. Carbon steel ensures that the structures are rigid enough to withstand the loads during transportation and potential events such as earthquakes. Carbon steel is a cost effective material which is easily available and also fully recyclable.

There is no need for complex concrete support structures due to the use of steel in the module structure. Concrete is only used for support pillars and floor slabs. Polyethylene (PE) is used for the DDG settler fences since this material is fully recyclable, relatively inexpensive and suitable for the solvent extraction process (Hopewell et al., 2009).

Procurement and Manufacturing
The materials used for the settler modules are procured through a predefined and audited supply chain. Manufacturing is performed in a factory environment using standardized working methods. This ensures quality manufacture and on-time delivery. The standardised design philosophy means that manufacturing can start promptly after receiving a purchase order. The finished modules can be transported to the project site easily, where they can be stored (and stacked if necessary) until installation starts.

Installation
The VSF®X settler modules are installed simply and quickly on a pre-constructed concrete foundation slab and support pillars by a mobile crane. The weight of each module is less than 10 tonnes and this allows installation with a single standard crane (or container-handling device). On-site lamination work is minimised since all lamination joints are predefined and the work procedures are

standardised. Fewer installation personnel are required and standardised working procedures allow for easier supervision on-site and an improved work safety environment.

Operation and Maintenance

A significant benefit of the VSF®X settler design is that one settler module can be shut down for service work without shutting down or by-passing the whole settler. The elevated structure on concrete pillars makes early leak detection possible before serious problems occur. The settler structure is completely enclosed for operator safety and so that fugitive emissions are minimised.

END-OF-LIFE OPTIONS

This section focuses on the SX plant end-of-life options in order to examine environmental sustainability aspects. A literature review was conducted to evaluate the end-of-life options for the different materials used in the modular SX plant.

A number of waste management options face any product at the end of its life. The 4R strategy is one method used for mapping the most suitable end-of-life option. 4R stands for reduce, reuse, recycle and recover. Options are listed in order of decreasing environmental desirability (Hopewell et al., 2009). The first R for a more sustainable end-of-life solution is to reduce the amount of materials used. This is a simple but effective method, and is illustrated in the modular SX-plant design by minimising the concrete usage, and replacing it with carbon steel which is a material with more sustainable end-of-life options.

The second R is for the reuse of the whole or part of the product. The modular SX plant is designed to be reused and this option will be discussed later. The third R is for recycling, which requires separation of the different materials and recycling them appropriately. This R is the option used when the other Rs are not applicable (e.g., when a product requires demolition). Although recycling is an end-of-life option, designing of recyclability starts from the drawing board and needs to be considered in the very beginning of product development by choosing the most appropriate materials. Recycling possibilities of modular SX plant are also discussed later.

The last R is for recover, which refers to energy recovery of the calorific value of the material by, for example, incineration. This is the least desirable waste management strategy; however it is more sustainable than dumping the material into landfill (Hopewell et al., 2009).

Re-use

Re-use is the second most favourable end of life option after material reduction. The VSF®X plant is designed to be relocatable at the end of its planned life cycle. This is due to its modular design philosophy. The modules can be dismantled according to standardised procedures and transported easily to the next project site, since the modules are sized as standard ISO freight containers.

Twist-lock mechanisms are used to fasten the settler modules for transport and may be used, if necessary, for fixing to the concrete pillars in a fast and secure manner. In addition to reducing installation time, these also allow simple and fast dismantling of the plant without destructive methods such as cutting of welds.

The settler module FRP shell is connected to the next module by bushed or bolted flanged joints. The bolted flanges can be easily installed and dismantled and are the most favoured jointing method when considering relocation. The main FRP shells are connected with adhesive bushed fittings; these offer extremely good structural properties, fast installation and allow for thermal expansion that might be an issue in extreme climate conditions.

Recycling

Recycling is the third R in the series, and, in the case of this modular SX-plant, the main materials are concrete, carbon steel, FRP and PE plastic.

The recycling of concrete has developed in recent years, whereas the typical end-of-life option for concrete used to be as landfill. However, concrete recycling is still not so common and issues such as contaminated concrete remain. Recycled concrete aggregate, such as crushed concrete or crushed brick, is used to partially replace virgin concrete aggregate, but the strength properties are often reduced if the proportion of recycled aggregate is over 20 – 30 % (Khatib 2005).

Compared with conventional solvent-extraction settler structures, VSF®X settlers' concrete use is minimised. Only the supporting pillars and the floor slab are made from concrete. If a leak occurs it is easily visible and repairable. Additionally, the concrete support pillars are protected with FRP shells. The minimal concrete use and innovative settler design significantly improve the ability to recycle the concrete material.

Steel is one of the most recycled metals in the world and secondary steelmaking using mainly electric arc furnaces has used recycled steel as its raw material for decades. Currently, more than 32% of the world's steel is produced through the electric arc furnace (EAF) route. The EAF process consumes approximately one third of the energy per metric tonne compared to basic oxygen steel production from iron ore (Yellishetty et al., 2011). The amount of recyclable carbon steel is maximised in this settler structure.

Recyclability of FRP structures varies, with most ending up in landfill. This can be seen as a major environmental hazard in the long term. Incineration is also used for disposal of the thermoset resin-filled FRP (Asokan et al., 2009).

Luckily, new end of life options for FRP structures and recyclability exist as follows:

- Primary recycling – conversion of waste into material having same properties to those of the original material. This is not possible yet.
- Secondary recycling – conversion of waste into material having inferior properties. Grinding of fibre-reinforced thermoset polymers is effective way of reducing the size of composites so that it can be used as a filler material or as secondary raw material for SMC (sheet moulding compound) and BMC (bulk moulding compound). Before grinding, the FRP needs to be separated from other material such as metals (Halliwell, 2006). Additional recycling methods include using FRP recyclates in polyester-based mortars (Meira Castro et al., 2013). However, the low price of common filler materials (such as glass) has made it economically less feasible so far.
- Tertiary recycling – conversion of waste into chemicals and fuels. Fluidised-bed processing is one such method for recovering chemicals and other compounds from used FRP material (Halliwell, 2006).
- Quaternary recycling – conversion of waste into energy (according to the 4R principles, not a recycling but a recovery method). Incineration is one method, such as co-incineration of FRP in cement kilns in order to provide energy (from resin) and improve the structural properties of cement with glass fibre (Halliwell, 2006).

The modular plant design offers a benefit since settler modules can be transported independently to a suitable recycling facility. It should be noted that, in this case, the recycling facility needs to be able to process the carbon steel frame as well (Halliwell, 2006).

ECONOMIC SUSTAINABILITY

This section presents the methodology for evaluating the economic feasibility and sustainability of a modular solvent-extraction plant. Two financial calculation methods were used for analysing the investment feasibility: net present value and sensitivity analysis. The values used in the calculations are based on industrial standards and evaluations made in-house. The analysis does not represent a real-life case, but offers a representative evaluation of a typical solvent-extraction plant investment calculation.

CAPEX Benefit of a Modular Structure

The main cost benefit of the modular settler philosophy is achieved during site implementation. Saario et al. (2013) argued that overall capital expenditure (CAPEX) savings of up to 24 % are achievable when modular technology is used. These savings arise mainly during the construction and installation phases of the project. The cost breakdown of the conventional and modular settler solutions are shown in Figures 3 and 4. It can be seen that equipment manufacturing is the major cost for modular VSF®X settlers and site work (construction and installation) is the major cost for the conventional settler philosophy (Saario et al., 2013).

In addition to overall CAPEX savings, the project site work schedule can be shortened during the equipment installation phase since on-site work, such as lamination, has been reduced significantly. Saario et al. (2013) state that a 25 % saving in overall SX project lead time is achievable. This reduced lead time not only improves project CAPEX as indicated above, but additionally reduces site risks including the risk of schedule overrun.

The CAPEX and lead time savings are included in the net-present-value analysis presented next.

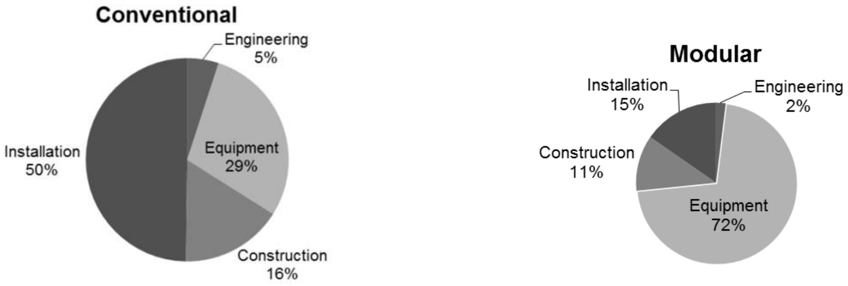

Figure 3. Cost structure comparison of conventional & modular settlers (Saario et al., 2013).

NPV Analysis

NPV analysis was chosen to evaluate both conventional and modular solvent-extraction plants. NPV analysis is widely used for evaluating project feasibility and is considered to be suitable for this purpose. NPVs are calculated for both conventional and modular cases in order to form clear comparison and identify possible benefits. The analysis consists of two different scenarios. The first case compares the NPV of a typical short-term project using both conventional and modular SX technology. The second case compares relocation costs of existing modular and conventional SX plants. In addition, the internal rate of return and payback period was calculated for the cases.

Case 1: Typical SX project

The project life cycle (building phase, operation and plant closure) for comparison was chosen as eight years. The building phase of the modular plant was set to one year and the conventional plant to one and a half years since 25 % percent project lead time reduction is possible using modular technology (Saario et al., 2013).

The base case was a comparison for a plant of 15 000 tonnes annual production output capacity, a copper solvent extraction–electrowinning plant extracting copper from 0.5% oxide ore through heap leaching. Many such plants exist in the world so this was seen as a typical example for hydrometallurgical copper production. The analysis was limited to the solvent-extraction plant.

Closure of each plant is assumed to be one year, and this is added at the end of each project life cycle. Thus, the total project lifetime for modular plant is 10 years and 10.5 years for the conventional plant. A fixed price of US$ 3.00 per pound or US$ 6623 per metric tonne was used for calculating the base-case revenue stream. This copper price choice was based on future forecasts for copper market development at the date of this paper. Analysts presently expect a slight decrease in copper price in future years because of stable demand but increasing production (Hopwood, 2012: Phillips & Morton, 2013). A sensitivity analysis with varying copper price was conducted and is presented in its own sub-section. A tax rate of 25 % was used to simulate annual revenue taxes. An 8 % annual discount rate for both cases was used in the calculations.

Project CAPEX

CAPEX was evaluated based on annual production capacity of the plant. Conventional plant evaluation was based on figures presented by Schlesinger et al. (2011), which suggest a CAPEX of US$ 500 per annual metric tonne of produced copper. This equals, in total, US$ 7.5 million CAPEX for the example 15 000 t/a plant.

As discussed earlier, estimation for CAPEX of the modular plant is based on evaluations that approximately 24 % savings can be achieved through the modular structure (Saario et al., 2013). By this evaluation method, the CAPEX of modular plant was set at US$ 5.7 million.

Both CAPEX evaluations include mixer-settlers, pumps, piping, storage tanks and initial first fillof extractant and diluent. Mine investment costs or other process steps are not included in analysis.

SX plant OPEX

SX plant operating expenditures (OPEX) was set to US$ 0.05/kg, equalling US$ 1.5 million of total annual OPEX. Annual OPEX does not include ore cost (Schlesinger et al., 2011).

Annual revenues

The revenue that may be allocated to the SX plant alone is difficult to evaluate. Since this analysis focuses only on the SX plant, the annual revenue cannot be calculated straight from the annual copper production. Certain revenue allocation is required in order to be able to analyse the SX plant alone. According to Schlesinger et al. (2011), the ratio of OPEX of the SX plant to that of the total heap leach–SX–EW plant is roughly 6.25 %; the corresponding CAPEX ratio is roughly 16 %. In this light, it was assumed that 5 % allocation of total revenue would be used to calculate the net present value for the SX plant, which equals approximately US$ 5 million annual revenue.

Shutdown costs

Plant closure costs are also challenging to evaluate. Closure costs of whole plant have been evaluated to exceed couple of million dollars in some previous feasibility studies. It was decided to use a shutdown cost comprising 10 % of initial CAPEX investment for the conventional plant and 7 % for the modular plant, because modular plant allows for fast and efficient plant closure since the modules can be easily transported to the recycling facility. Thus, plant closure costs were US$ 750 000 and US$ 420 000, respectively.

Case 2: Relocation

Relocation ability is one of the main benefits of the modular plant; however relocation is a multiphase process, requiring appropriate inspection, module dismantling and transport, as well as installation at the new location. Concrete structures need to be demolished at the old site and new concrete foundations constructed at the new site. Outotec's in house approximations were used for evaluating the relocation cost comprising 40 % of original project CAPEX, equalling US$ 2.3 million. A benefit of the modular plant is convenient storage due to the container-sized modules. The plant can be dismantled after the first plant shutdown and stored for later use.

Relocation of a conventional plant is also possible, but is more expensive since conventional settlers often consist of a concrete frame for which relocation is not feasible. However the FRP-lining can be used in the next settler installation and tanks are typically relocatable. In this study, the conventional plant relocation was evaluated to equal 60 % of original project CAPEX, equalling US$ 4.5 million.

A one-year implementation time for the plant relocation was used. The plant lifetime was chosen to be 4 years. Other initial values (plant capacity, opex, etc.) were the same as the previous project.

NPV was calculated for the relocation project and the result was discounted to present value. This shows the current residual value of each plant.

Sensitivity Analysis

Three different sensitivity analyses for NPV were conducted for the Case 1 project to examine its sensitivity towards changes in copper price, as well as capital and operating expenditures. Sensitivity with ±50 % variance to the base case values was simulated. Sensitivity analysis was not conducted for Case 2, because the results would be relatively similar when compared with Case 1.

RESULTS

In this section, the results of the NPV analysis for economic sustainability are presented.

NPV Analysis – Case 1

The NPV analysis reveals that the modular SX-plant has significant economic benefit compared to a conventional SX plant. Figure 4 illustrates the discounted cumulative cash flow during the project lifecycle. It can be seen that cash flow turns positive earlier in modular plant case. The discounted total cash flow is 21.1 % higher for the modular SX plant after the plant life cycle. This is achieved mainly due to lower CAPEX and shorter implementation time, which allow earlier positive cash flow and shorter payback period. Additionally, plant closure costs are lower since the modular plant can be dismantled and transported more conveniently.

The key financial ratios and their percentage differences are presented in Table I. It can be seen that the NPV for the conventional SX plant is significantly lower and has a longer payback period.

Sensitivity Analyses

The sensitivity analyses focussed on the most common variable, such as copper price, capital and operation expenditures. Results show that modular SX plant is less sensitive to variances in each of these cases.

Table I. Key financial figures, Case 1.
Total project lifecycle of 12 years

Description	Conventional	Modular	Difference (%)
Net Present Value (NPV)	US$ 7 844 624	US$ 9 998 733	24.1
Internal Rate of Return (IRR)	23 %	35 %	42.6
Payback period	4.6 yr	3.4 yr	30.2

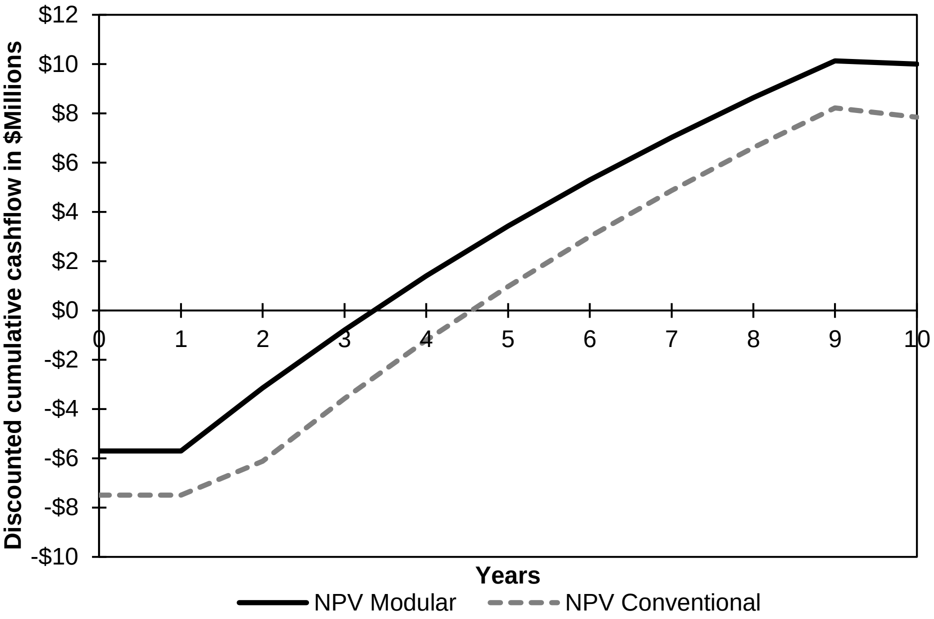

Figure 4. Discounted cumulative cash flow during project life cycle.

Copper price

Figure 5shows the effect of copper price fluctuation (horizontal axis) to the project NPV for both cases. As can be seen, the conventional plant is more sensitive to copper price or other revenue factor fluctuation. The modular plant is less sensitive to price fluctuation and, even with a 50% decrease in copper price, maintains a positive NPV.

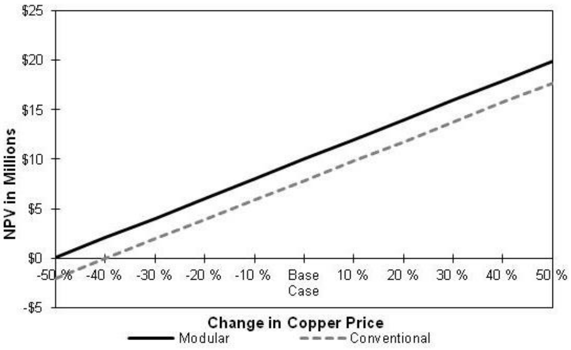

Figure 5. Sensitivity to copper price fluctuation.

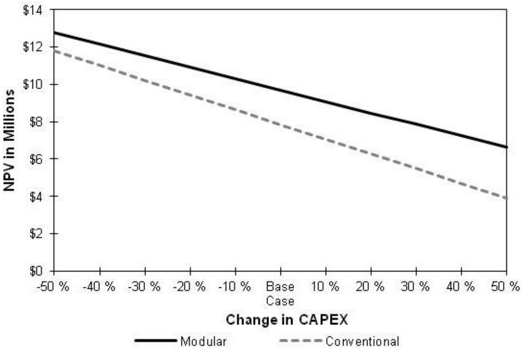

Figure 6. NPV sensitivity to CAPEX changes.

CAPEX

It can be seen from Figure65 that CAPEX increases are not very critical in projects of this size, however the conventional plant is clearly more sensitive to CAPEX increases than the modular plant.

OPEX

Figure 7 shows limited sensitivity to OPEX fluctuations for both plants. The graphs indicate that, generally, the annual OPEX does not play an important role for initial investment feasibility, although this result can be little bit distorted since SX plants have low operating costs in general. If the OPEX of the complete copper extraction plant including the electrowinning plant and the mine is examined, the role of OPEX could be higher.

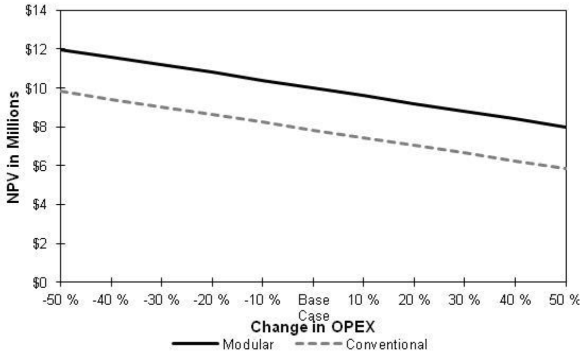

Figure 7. NPV sensitivity to OPEX changes.

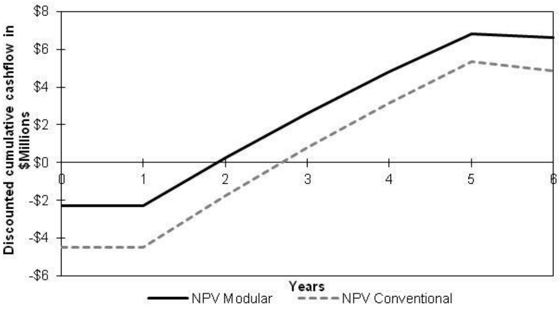

Figure 8. Discounted cash flow for Case 2.

NPV Analysis – Case 2

The NPV analysis in Case 2 shows that relocation of modular and conventional plant could be feasible if the plants were operational for at least two and two and a half years, respectively. NPV of the modular plant is 30 % higher compared to the conventional plant. The results of the NPV analysis are shown in Table II..

Table II. Key financial figures, Case 2.
Total project life cycle of 6 years

Description	Conventional	Modular	Difference (%)
Net Present Value (NPV)	US$ 4 843 688	US$ 6 635 140	31.2
Internal Rate of Return (IRR)	33 %	67 %	68.7
Payback period	2.7 yr	1.9 yr	34.1

A discounted cash flow for the relocation case can be seen in Figure 8. Once again, the modular plant results are significantly better when compared with the conventional plant. It should be noted that relocating a conventional plant is a complicated process in the first place and sometimes not even possible. Modular plants use standard modules which are scalable for various sized plants, so that relocated plant can even have greater or lesser capacity than the old plant. In both cases, plant relocation seems to have shorter payback time compared with a greenfield project. In the future, modular plant could make plant relocation a more attractive option which could decrease CAPEX of new projects. Of course, relocating just the SXplant has relatively minimal effect, since it likely comprises a fraction of the total CAPEX, but at least has a positive impact on the project economics.

CONCLUSIONS

Analysis of end-of-life options shows that modular SX plants improve the economic and environmental sustainability of solvent extraction. Modular construction provides economic benefits that are illustrated in the economic analysis. These are in the capital investment cost and the residual or reuse value due to the ability to effectively relocate the modular SX plant for use at another location.

Short life (<5 years) deposits may become economically feasible if a modular plant can be relocated and used. Modular plants are less sensitive to fluctuations in the copper price and plant CAPEX and OPEX, and can aid project development in times when global market uncertainties increase the risks to the economic feasibility of projects.

The evaluations of this hypothetical scenario provide a strong argument for the benefits that modular plants bring. The real benefits could be even more favourable for modular-type plants as maintenance advantages exist which will decrease annual operating costs. Presently, the OPEX for both modular and conventional cases were set the same. This is an area for further research.

Tighter environmental regulations, declining ore grades and shorter plant life cycles are serious future challenges. Modular SX plants have features that can give significant economic and environmental benefits compared with conventional SX-plants and therefore provide a more sustainable solvent-extraction solution.

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