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Talvivaara Nickel Mine – from a project to a mine and beyond

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Abstract

The first commercial application of bioleaching in Europe is the Talvivaara Sotkamo Mine in Finland. The ore contains low grade sulphide minerals. Utilization of the deposit has been extensively studied for over 20 years. Bioheapleaching technology was chosen for the extraction of nickel from the ore based on its favorable capital, operational costs and good performance data obtained in a large on-site pilot trial.

Building of the industrial scale plant was started in 2007 and metals recovery started in 2008. In full production the annual nickel production will be approximately 50,000tpa. In addition, the mine will also produce zinc, copper and cobalt.

Talvivaara will start to recover uranium from the PLS solution. A novel solvent extraction process will be used to extract uranium for the yellowcake production.

An update of the existing operation, uranium extraction and the plans for the production expansion and upgrading beyond the 50,000tpa will be discussed.

Introduction

The Talvivaara Deposits are located approximately 350 km south of the Arctic Circle. The climate is characterized by extreme seasonal changes in temperature and light. Average daylight hours in summer (June to August) are 20 hours whereas in winter (November to March) this is reduced to seven hours. Winter temperatures range from 0 to minus 20 °C with exceptional short-lived cold spells of below 30 °C. The average annual snowfall is 0.7 m. Talvivaara deposits, Kuusilampi and Kolmisoppi comprise one of the largest sulphide nickel resources in the world with 1121 Mt in measured and indicated resource categories (Table 1).

Table I: Total mineral resources at 0.07% nickel cut-off in 2010.

Category	Mt	Nickel %	Zinc %	Cobalt %	Copper %
Measured	432	0.23	0.50	0.02	0.13
Indicated	689	0.23	0.50	0.02	0.13
Subtotal	1,121	0.23	0.50	0.02	0.13
Inferred	429	0.20	0.47	0.02	0.12
Total	1,550	0.22	0.49	0.02	0.13

Talvivaara's extraction technology is bioheapleaching, which is widely used for other metals, notably copper and gold. The company has demonstrated the viability of bioheapleaching technology for the extraction of nickel on site using Talvivaara ore (Riekkola-Vanhanen, 2007; Riekkola-Vanhanen, 2010). The leaching process generates heat and is therefore suitable in subarctic conditions. The planned annual nickel production of 50,000 tonnes is anticipated to be reached in 2014 – 2015. As by-products the mine will also produce approximately 90,000 tonnes of zinc, 15,000 tonnes of copper and 1,800 tonnes of cobalt.

Deposit Geology

Talvivaara is situated in the southern part of the Early Proterozoic Kainuu Schist belt. The Ni-Cu-Co-Zn mineralisations are hosted almost entirely by high-grade metamorphosed and intensively folded black schist. About 90 % of the ore is hosted by black schist and the rest by metacarbonate rocks. The main mineral assemblage in the black schist is quartz, micas, graphite and sulphides. The valuable metal containing sulphides are pyrrhotite, pyrite, sphalerite, pentlandite, violarite and chalcopyrite. The average content of the ore using the cut-off of 0.07% of nickel is 0.23% Ni, 0.50% Zn, 0.13% Cu, 0.02% Co, 10.3% Fe and 8.4% S. The distribution of nickel in different sulphides is pentlandite 66%, pyrrhotite 33% and pyrite 1%. The distribution of cobalt is pentlandite 11%, pyrrhotite 26% and pyrite 63%. All copper is in chalcopyrite and zinc in sphalerite.

The Talvivaara deposit consists of two ore bodies, Kuusilampi and Kolmisoppi, about 3 km apart. Known dimensions for the Kuusilampi deposit are length 2600 m, width 40 – 1000 m and depth 600 m, and for Kolmisoppi 1500 m, 30 – 350 m and 300 m respectively. The metal distribution in the deposits is homogeneous.

Project History

Geological work in Talvivaara area commenced in the early 1900's when geological mapping of bedrock was conducted by Geological Survey of Finland (GSF) and continued through 1951. Between 1951 and 1962, various Finnish companies carried out exploration activities in the area. The result of this phase led GSF to commence detailed exploration in the area in 1977. As a result of the work done by GSF, two polymetallic deposits, Kuusilampi and Kolmisoppi, were established. Outokumpu acquired the deposits from the Finnish State in 1985 and the mining license covering the Talvivaara Deposits was granted to Outokumpu in 1986. Between 1989 and 1992, Outokumpu focused on further geological and metallurgical work on the Talvivaara Deposits.

Despite extensive exploration in the Talvivaara area that established the presence of large deposits, it was concluded at the time that exploitation of the relatively low-grade deposits would not be economically viable using conventional techniques. Therefore, the Talvivaara deposits remained unexploited until the Talvivaara Project acquired the rights to the deposits in February 2004 and continued the work by focusing on sampling for metallurgical purposes and investigating areas for the pilot trial.

With the deposits Talvivaara was assigned the right to use all exploration data and research documentation relating to various process options studied. Bioheapleaching seemed to be the most economical option. Construction of a 17,000 tonnes on-site pilot heap was started in May 2005 and initial bioheapleaching in August that year. A metals recovery pilot using the PLS (pregnant leaching solution) from the process was run in 2006 at the OMG plant in Kokkola. The environmental permit was granted in March 2007 followed by the commencement of the construction phase of the project. In April 2008 ore mining started at Kuusilampi open pit and in July 2008 bioheapleaching was initiated. The first metal sulphides were produced at the plant in October 2008.

Talvivaara Black Schist Ore Bioleaching Tests

Talvivaara's application of the bioheapleaching technology has its origins at Outokumpu Research, where it has been developed in conjunction with Talvivaara ore since 1987. All the rights relating to the accumulated research and development data on bioheapleaching were transferred to Talvivaara in connection with the acquisition of the mining licenses in February 2004.

In order to validate the bioheapleaching process on a larger scale, an on-site pilot study was commenced at Talvivaara in May 2005 (Riekkola-Vanhanen, 2007; Puhakka et al., 2007). Heap irrigation was started in August 2005 and metals recovery in November 2005. The pilot heap was constructed of 17,000 tons of Talvivaara ore. The particle size used was 80% < 8 mm. In laboratory tests the temperature remained at the room temperature level. The size of the pilot was large enough to generate heat and the rise of temperature could be observed. The rise was due to the oxidation of the large quantity of pyrrhotite and pyrite in the ore. The temperatures measured inside the heap varied from 30 °C to nearly 90 °C.

The primary leaching of the 8 meters high pilot heap (heap pad of 50 x 100 m) took one and a half years and yielded nickel and zinc recoveries of about 90%. The heap was reclaimed during the coldest time in winter 2007 and moved to a new leaching pad. The temperature of the ore was under 0 °C when irrigation of the secondary heap was started at the end of February. The temperature started to rise immediately and was at the level of 80 °C in April and started to decrease gradually after that to the level of 20 – 40 °C, where it remained to the end of November 2008.

The main reason to install a secondary leaching phase is to get better recoveries of copper and cobalt. Copper is in chalcopyrite and the main part of cobalt in pyrite. As sulphide minerals have semiconductor properties, galvanic interactions appear when there is an electrical contact among mineralogical phases. During dissolution of a mineral assembly of different sulphides, those minerals that have the highest rest potentials behave as cathodes which means that they are galvanically protected and their leaching is hindered until the minerals with lower rest potentials have been leached. The electrochemical potentials of chalcopyrite and pyrite are higher than the ones of pyrrhotite, pentlandite and sphalerite (Riekkola-Vanhanen and Heimala, 1993). The leaching recoveries from the pilot plant were substantially better than anticipated based on laboratory and other smaller pilot results and confirmed the viability of the bioheapleaching of the Talvivaara ore. It was assumed that most of nickel and zinc will be leached in the primary heap within one and one-half years. Nickel recovery reached 80% within 400 days. The corresponding zinc recovery was 80% in 480 days. After secondary leaching the recoveries of nickel and zinc were 99%, the ones of copper and cobalt 22 and 35%. The pilot plant showed that the assumed recoveries for nickel and zinc can be reached (Puhakka et al., 2007).

Production Process

Overview

The mining method selected for use is large scale open pit mining. The crushed (80% < 8mm) ore is agglomerated and conveyed to the heap pad. After 13 to 14 months of bioleaching on the primary pad, the leached ore is reclaimed, conveyed and re-stacked onto the secondary heap pad. After secondary leaching, the barren ore will remain permanently in the secondary heaps. In the metals recovery process, metals are precipitated as sulphides from the PLS using gaseous hydrogen sulphide (Figure 1). The resulting products are intermediates to be transported for further processing in refineries operated by the company's customers.

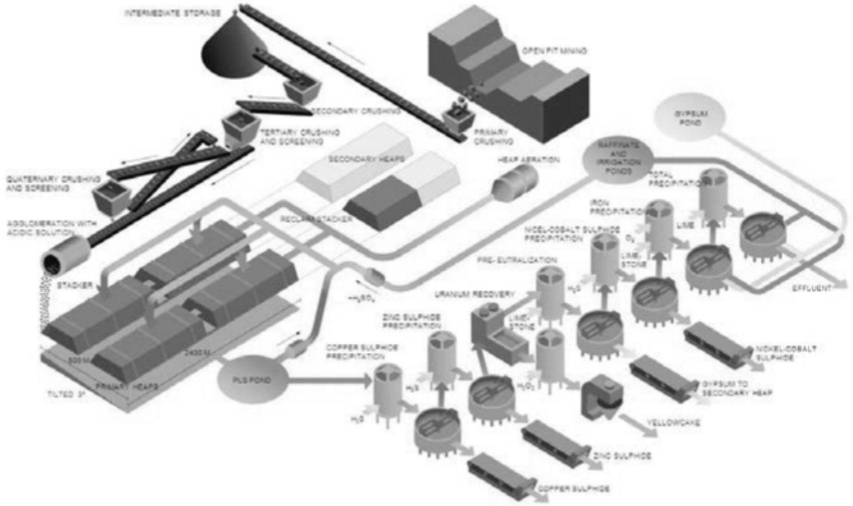

Figure 1. Process flow sheet of Talvivaara Sotkamo process.

Open Pit Mining

Planned annual ore production is approximately 24 million tonnes. Sufficient areas to extend the pit will be prepared in subsequent years, normally a year prior to when mining is scheduled to commence. Any overburden or moraine not required for road, perimeter wall or other construction, is stockpiled for later use in rehabilitation. Ore and waste are extracted using conventional large scale open pit drill and blast methods. A fleet of self-propelled diesel hydraulic track drill rigs is used. Fragmentation by blasting is preferred to crushing because of lower costs. It is also beneficial to create more fracturing at blasting stage which increases the surface area and therefore improves leaching solution entry and consequently leaching efficiency.

Materials Handling

During the process, the ore is crushed and screened in four stages into p80<8mm. After primary crushing, the ore is conveyed to the fine crushing station where it is crushed and screened in three phases. All material <10 mm continues to agglomeration. It takes place in a rotating drum, where PLS is added to the ore in order to consolidate the fine particles with coarser particles. This preconditioning step makes the ore permeable to air and water for bioheapleaching. After agglomeration, the ore is conveyed and stacked from eight to ten meters high on the primary heap pad. After 13 – 14 months of bioleaching on the primary pad, the leached ore is reclaimed, conveyed and re-stacked onto the secondary heap pad, where it is leached further in order to recover metals from those parts of the primary heaps, where leaching solution has had poor contact. Such areas include, for example, the slopes of the heaps and areas between channels formed by the circulating leaching solution. Also the leaching of copper from chalcopyrite and cobalt from pyrite continue in the secondary leaching. After secondary leaching, the barren ore is expected to remain permanently in the secondary heaps. The heaps will be covered air- and water-tight and revegetated.

Bioleaching

The bacteria used in the Talvivaara process grow naturally in the ore and the bioleaching process is technically viable by creating optimal conditions for growth of the bacteria. The designed parameters for bioheapleaching are based on laboratory test work, experience from other mine sites and pilot heap operation.

The primary heap comprises of two heap pads, a lower section and an upper section and a 40 m wide corridor between them reserved for a service area, pipelines and two fixed conveyor lines. The heap pads are 2400 m long and 400 m wide, the entire surface area is 210 hectares. Each section is further divided into two sectors. The heap pads are designed so that in the longitudinal direction they are horizontal and in the cross direction they slope toward the PLS ponds. The cross slopes vary from 2% to 3.5 %. The heap pad is equipped with piping, laid about 1.5 meters from the bottom of the pad, through which low-pressure fans supply air to the stacked ore. From the top, the heap is irrigated with leaching solution, which is collected from the bottom of the heap. Primary heap is irrigated at a rate of 5 l/m^2xh. The pH value of the irrigation solution is adjusted to 1.7 – 2.0 and the solution is circulated evenly on the heap surface. PLS is collected with a drainage system and discharged to the PLS collection ponds. About 10 – 20 % of the solution is pumped to the metals recovery plant and the rest of the solution is circulated back to the heap. The amount of solution is kept constant by adding process water and the pH value is adjusted. Several physico-chemical and microbiological process parameters, such as the pH of the irrigation solution, the rate of irrigation, the rate of removal of the PLS, and the rate of aeration are continuously monitored and modified in order to enhance and speed up the metals recovery to the solution.

The primary heap pad is constructed as a dynamic pad. This means that after the first stacking cycle, the ore is reclaimed and conveyed to the secondary leach pad for further leaching. While the reclaimer moves ahead reclaiming the ore, the stacker follows behind it, stacking new ore from agglomeration. This cycle goes on continuously.

The secondary leaching pads are constructed on top of waste rock dumps. The benefit of the arrangement is multiple lining systems and reduced earthwork quantities. It also reduces the final footprint of the operation and final rehabilitation costs. Both heap pads and waste dumps are lined with bentonite and plastic layers to prevent leakages.

Metals Recovery

In the metals recovery process, metals are precipitated from the PLS using gaseous hydrogen sulphide and pH adjustment (Figure 2). Solid waste is formed in pre-neutralisation, iron removal and total precipitation. In pre-neutralisation the acidity in the feed and the acid formed in copper and zinc sulphide precipitation are neutralized. At the same time a considerable part of aluminium in the solution is precipitated. The underflow from the thickeners is filtrated on belt filters. The inert precipitate is transported to the waste rock area as a filter dry product. Iron is removed from the solution as goethite and/or hydroxide which are pumped to the gypsum pond. The final precipitation is the outlet for manganese and magnesium in the process. Remaining iron and gypsum also precipitate in this step. After iron removal the solution goes to the final precipitation where the pH value is raised to a value of 10 with slaked lime. The remaining metals precipitate as hydroxides. The underflow from the thickeners is pumped to the gypsum pond. The slurry has to be carefully analyzed to ensure its suitability for the gypsum pond. The overflow from the thickener is recycled back to the heap leaching circuit.

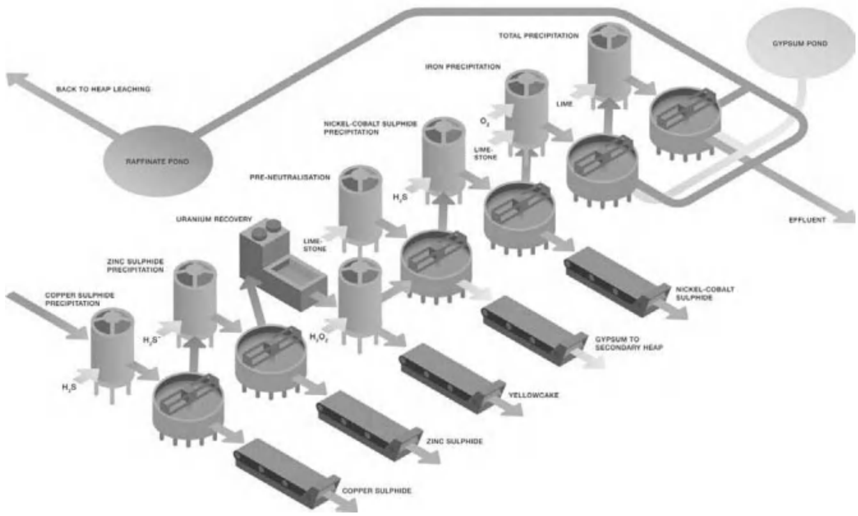

Figure 2. Schematic flow sheet of the metal recovery plant.

The resulting products of metals recovery are intermediates, copper and zinc sulphides and a mixed nickel cobalt sulphide. These intermediates are transported for further processing in refineries operated by Talvivaara's customers.

<u>Water Management</u>

The water management includes all relevant pipelines, ponds and pump stations related to the processes outside the metals recovery plant area. It also includes surface water management, effluent treatment and other surface water construction projects.

Water management plays an important role at the operation. The most important component is the recycling of the leaching solution from the irrigation pond to the heap and thereafter to the PLS pond. From the PLS pond, approximately 90 per cent of the solution is recycled back to irrigation to increase the metal grade, while about 10 – 20 percent is lead to metals recovery. After metals precipitation, the remaining solution goes into the raffinate pond for pH adjustment and is reused to irrigate the heaps.

Production Ramp-up

Year 2008 marked the transformation of Talvivaara from a project to an operating mine. During the year, the construction project went through its most intensive periods, providing work for some 2,000 contractor employees during the peak installation months in late summer and early autumn. As a result of this sizeable and multidimensional effort, the project reached all its operational milestones on time enabling start-up of production processes in stages beginning with the first blast of ore in April. Some final construction and installation work remained to be completed in the following years. In total the amount of work required to bring the mine into full operation was approximately 3,500 man-years.

Talvivaara's focus has remained firmly on production ramp-up throughout the years 2009 - 2012. Optimization of the already operating equipment and processes continued, and pre-requisites for full-scale production were fulfilled through the commissioning of the second production lines.

The scalability of the production processes and progress in ramp-up were confirmed by the production volumes achieved in 2011: 16,087 t of nickel (2010: 10,382 t, 2009: 735 t) and 31,815 t of zinc (2010: 26,462 t, 2009: 3,133 t). Although the production fell short of the originally budgeted figures, the ramp-up trend seen has been encouraging with a relatively steady increase in nickel production.

The metal plant operations have faced a series of technical challenges, ranging from a hydrogen plant failure to insufficient hydrogen sulphide capacity caused by installation faults in the hydrogen sulphide generator. Also, hydrogen sulphide emissions forced production levels to be restricted for several months because of the odour discharges. A break-through in controlling the odours was made through the use of hydrogen peroxide as the odour controlling chemical.

Mining has performed well. The crushing processes in materials handling have caused the biggest problems in the process. The primary crusher had to be fitted with a new mantle. The fine crushing circuit had to be redesigned and more crushers had to be added.

The installation and commissioning of the primary heap reclaiming and secondary heap stacking systems have represented a major challenge. Both systems were started up in autumn 2010 and the secondary stacker has since then been in production with good results. Commissioning of the primary heap reclaiming equipment has however been slower, resulting in reduced overall crushing and stacking output.

In bioheapleaching the building of the first heap sector proceeded much too slowly due to difficulties in crushing. Irrigation and aeration could only be started when about 25m of heap had been built. The agglomerates started to break apart during that time. The particle size was also smaller than planned. When irrigation and aeration were started, there were difficulties in getting an even airflow through the heap. With improved crushing systems the bioheapleaching started to progress according to expectations. The primary heap was fully stacked for the first time in November 2010, and secondary leaching started with good results. In process development, particular attention has been paid to improve aeration. As a result, nickel grades in leach solution have increased especially in the newer heap sections, reaching levels well above 3 g/l.

The quality of zinc and nickel/cobalt sulphides has been very good. Nickel/cobalt sulphide contains about 50% of nickel and 1.5% of cobalt, the moisture content is under 20%. Zinc sulphide contains about 64% of zinc and its moisture content is about 10%. The impurity levels in both sulphides are very low. Copper concentrations have just started to rise in the PLS and saleable amounts of copper sulphide production started in 2012.

Personnel

The total number of employees at Talvivaara is about 500. The personnel are mostly recruited locally from the Kainuu region, where Talvivaara is the largest provider of new job opportunities. In its recruitment process, Talvivaara has sought to maintain a representative staff age structure, in spite of the exceptionally vigorous rate of recruitment. Although the mining industry has conventionally been male dominated, Talvivaara seeks to hire employees representing both genders. This has however proven difficult due to the limited number of female applicants.

Sustainable Development

Talvivaara has continued to develop its operations in line with its sustainable development policy which emphasizes continuous improvement and operational excellence. With respect to safety issues Talvivaara’s goal is a safe and healthy working environment. The company has continued to develop its safety culture based on zero accident philosophy. The company is also committed to continuous improvement in environmental efficiency, operational risk management and reduction of environmental impact.

Open and frequent communication is of outmost importance when building a long-term, trusting relationship with the nearby residents and communities, and Talvivaara has focused increasingly emphasis on its community programme during the last years. Open days for visitors and meetings with the local residents have been continued. A new, locally focused internet site was launched in the beginning of this year to provide up-to-date environmental information and a discussion and feedback channel for the local residents (http://paikanpaalla.fi/).

Business Development

Extraction of Uranium as a By-product

Talvivaara ore contains a low concentration of uranium which will be recovered from the existing production process as a uranium yellow cake by-product. The pregnant leach solution (PLS) from the existing metals recovery plant will enter the uranium plant with a uranium concentration of approximately 20 ppm. A novel solvent-extraction process will be used to selectively extract the uranium from the PLS into an organic solution. Sodium carbonate will be used to strip the uranium from the organic phase back into an aqueous phase. The yellowcake will be precipitated from the aqueous phase with hydrogen peroxide, settled in a thickener and then dried before being packaged in steel drums.

The low uranium concentration in the PLS, the high volume throughput and environmental considerations were the primary factors in designing the processes and selecting the major equipment.

The uranium recovery plant is under final construction stage and commissioning of the new plant will start in early 2013. The plant will produce 350 tonnes of uranium per year, when the full nickel production is reached.

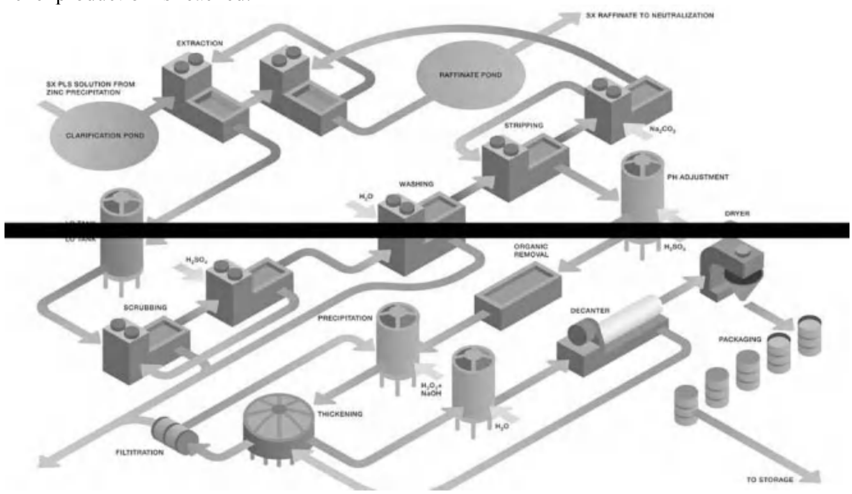

Figure 3. Schematic of the uranium recovery plant process flow sheet

Expansion Beyond 50,000 tpa Nickel
Following the announcement of upgrade of mineral resources in 2010 Talvivaara announced the plans for expansion of the mine and production up to approximately 100,000 tpa nickel. Further plans are to upgrade the nickel production from nickel sulphide to metallic nickel, where the nickel cathode production would account for a substantial part of the expanded production. The production expansion would also increase the zinc, cobalt, copper and uranium production, where the option is to produce also cobalt cathodes.

The mine and production expansion and new refinery process is currently under focus on the Environmental Impact Assessment program which is expected to be ready in the beginning of 2013. Conceptual, basic and detail designs for the new refinery process has been under work for the last 2 years.

The new process would include the pressure leaching of the nickel sulphide, cobalt solvent-extraction plant for separation of the nickel, solution purification and neutralizing plants, and nickel electrowinning tankhouse. Cobalt can be shipped out as cobalt salt solution from solvent extraction solution or optionally as cobalt cathodes from cobalt electrowinning plant. The expansion is designed to be build and commissioned in modular stages.

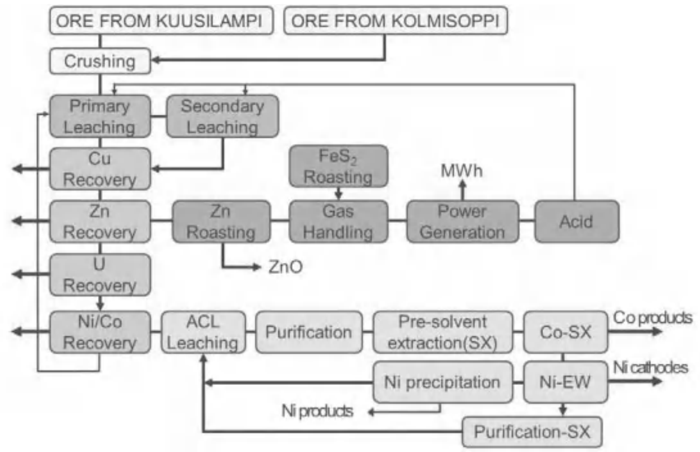

Figure 4. Block diagram of the Talvivaara Sotkamo process with the options for the production expansion.

Energy Strategy

Talvivaara has announced its new energy strategy that is to be self-sufficient for energy in the long term to cope the increased energy demands of the production expansions. The energy strategy focuses on environmental sound energy production including 60MW ownership of the new nuclear plant project and on-site energy production using local bioenergy, wind power and utilization of the energy generated from the new process plants.

Environment

Along with the present production and for the expansion projects extensive work and efforts has been put to environmental issues to minimize and improved effluent and emission levels.

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