ALTA 2015

23 - 30 May

Perth, Australia

20th Anniversary Event

Proceedings

Uranium-REE Conference

Sponsored by

GBM

11th Annual Uranium Event

ALTA Metallurgical Services, Melbourne, Australia

www.altamet.com.au

PROCEEDINGS OF
ALTA URANIUM-REE SESSIONS

28-29 May 2015

Perth, Australia

ISBN: 978-0-9925094-3-9

ALTA Metallurgical Services Publications

All Rights Reserved

Publications may be printed for single use only. Additional electronic or hardcopy distribution without the express permission of ALTA Metallurgical Services is strictly prohibited.

Publications may not be reproduced in whole or in part without the express written permission of ALTA Metallurgical Services.

The content of conference papers is the sole responsibility of the authors.

To purchase a copy of this or other publications visit www.altamet.com.au

Celebrating 30 years of service to the global mining and metallurgical industry.

ALTA Metallurgical Services was established by metallurgical consultant **Alan Taylor** in 1985, to serve the worldwide mining, minerals and metallurgical industries.

Conferences: ALTA conferences are established major events on the international metallurgical industry calendar. The event is held annually in Perth, Australia. The event comprises three conferences over five days: Nickel-Cobalt-Copper, Uranium-REE and Gold-Precious Metals.

Free Library: Conference proceedings and technical papers. The library will be expanded each year, providing a major ongoing resource to the industry.

Publications: Sales of proceedings from ALTA Conferences, Seminars and Short Courses.

Short Courses: Technical Short Courses are presented by Alan Taylor, Managing Director.

Consulting: High level metallurgical and project development consulting.

THE KVANEFJELD PROJECT

By

D.G.I. Krebs

Greenland Minerals & Energy Ltd, Australia

Presenter and Corresponding Author

Damien Krebs
Damien@ggg.gl

ABSTRACT

Greenland Minerals and Energy is a junior project development company which is listed on the Australian Stock Exchange (asx:GGG). The primary project within the company is the Kvanefjeld Rare Earth project located in the southern tip of Greenland. Historically the project was known to be a low grade and medium sized uranium deposit which was discovered by a Danish government department called RISO in the 1960's. RISO performed a significant amount of metallurgical testwork with the view to extracting the uranium only, developing sulphation roast and high pressure carbonate leach processes. This work culminated in the production of a high quality prefeasibility study in 1972 after which the project was cancelled due to a lack of government support. Around this time both Denmark and Greenland government's instituted a zero tolerance policy towards the mining of uranium in Greenland/Denmark. The deposit sat idle for a number of decades with little or no development until the mineral rights were acquired by Greenland Minerals and Energy in 2007. Greenland Minerals and Energy was able to raise significant funds to continue to the exploration for uranium as the uranium price was enjoying a cyclical high at the time. Modern exploration methods were applied which analysed the ore for more than just uranium. This was performed to find other values as the zero tolerance policy was still in place. After assaying each drill core for 36 different elements it was determined that Kvanefjeld was actually much more of a rare earth deposit than a uranium deposit. Using current metal prices the in-ground value of the uranium is less than 20% with rare earths making up the vast majority of the balance.

In 2009 Greenland become more independent from Denmark which included gaining the responsibility for mineral resources. After this time the Greenland government changed the Kvanefjeld exploration licence to include radioactive elements. This was the first step forward in allowing the Kvanefjeld deposit to be mined. In 2010 extensive metallurgical studies were commenced to determine the best metallurgical treatment method to recover both the rare earths and uranium. This resulted in a change of metallurgical flowsheet to beneficiation and atmospheric leaching. A prefeasibility on this flowsheet was completed in April 2013 which presented a project which could become of the world largest and lowest cost rare earth mines. In October 2013 the Government of Greenland lifted the zero tolerance policy (ban on uranium mining) which essentially unlocked this deposit and paved the way for commercialization. This opening up of Greenland to uranium mining was reaffirmed in December 2014 when fresh government elections installed a coalition government which is pro mining and pro uranium mining. In March 2015 Greenland Minerals and Energy released a Feasibility Study for the Kvanefjeld Rare Earth project which will form the basis for a mining licence application in 2015.

Greenland Minerals and Energy looks forward to working with their project partner Non Ferrous China during the course of 2015. Non Ferrous China will be providing design, construction capability, financing and rare earth technology to the Kvanefjeld Project.

INTRODUCTION

Greenland Minerals and Energy

Greenland Minerals and Energy Ltd (The Company) is a junior project development company which is listed on the Australian Stock Exchange (asx:GGG). Greenland Minerals and Energy Ltd owns 100% of the shares in GME A/S which is a Greenlandic based company which owns the exploration licences for Kvanefjeld. The primary focus of The Company is the Kvanefjeld Rare Earth project located in the southern tip of Greenland. The Project area is located in south Greenland approximately 10km from Narsaq and approximately 35km from Narsarsuaq. The main commodities of interest in the Kvanefjeld orebody are Rare Earth Elements (REE). There are also sufficient levels of uranium and zinc in the orebody to produce commercially viable by-products.

Greenland Minerals and Energy completed a Feasibility Study on the project in 2015. This study will form part of a mining licence application in Greenland allowing the commencement of project construction.

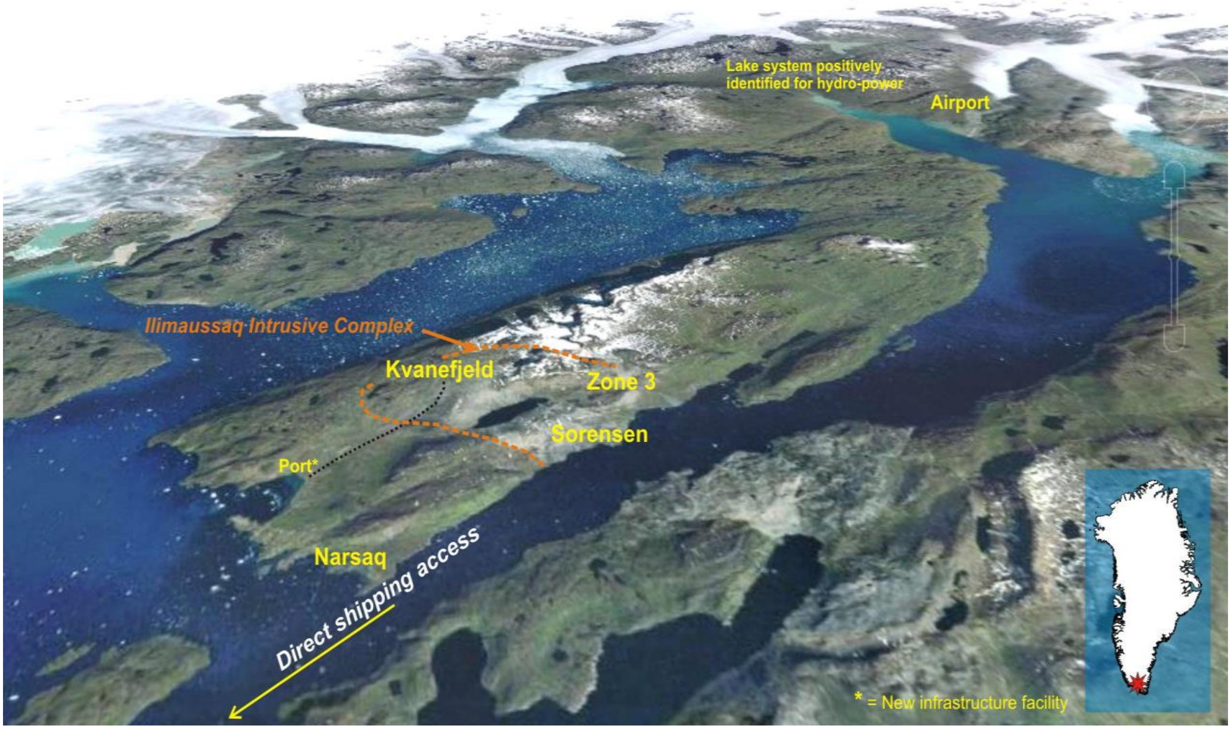

Figure 1: The Location of the Kvanefjeld Project in Southern Greenland

Historical Project Development

Historically the project was known to be a low grade and medium sized uranium deposit which was discovered by a Danish government department called RISO in the 1960's. RISO performed a significant amount of metallurgical testwork with the view to extracting the uranium only. RISO developed two different metallurgical flowsheets: sulphation roast and high pressure carbonate leach processing. This work culminated in the production of a high quality prefeasibility study in the 1970's after which the project was cancelled due to a lack of government support. Around this time both Denmark and Greenland government's instituted a zero tolerance policy towards the mining of uranium in Greenland/Denmark. The deposit sat idle for a number of decades with little or no development until the mineral rights were acquired by Greenland Minerals and Energy in 2007.

Greenland Minerals and Energy was able to raise significant funds to continue the exploration for uranium as the uranium price was enjoying a cyclical high at the time. Modern exploration methods were applied which analysed the ore for more than just uranium. This was performed to find other values, as the zero tolerance policy was still in place. After assaying each drill core for 36 different elements it was determined that Kvanefjeld was actually much more of a rare earth deposit than a uranium deposit. Using current metal prices the in-ground value of the uranium is less than 20% with rare earths making up the vast majority of the balance. The rare earths and the uranium both occuring within the same mineral making their co-recovery essential for production of either.

In 2009 Greenland become more independent from Denmark which included gaining the responsibility for mineral resources. After this time the Greenland government changed the Kvanefjeld exploration licence to include radioactive elements. This was the first step forward in allowing the Kvanefjeld deposit to be mined. In 2010 extensive metallurgical studies were commenced to determine the best metallurgical treatment method to recover both the rare earths and uranium. This resulted in a change of metallurgical flowsheet to beneficiation and atmospheric leaching. A prefeasibility on this flowsheet was completed in April 2013 which presented a project which could become one of the world largest and lowest cost rare earth mines. In October 2013 the Government of Greenland lifted the zero tolerance policy (ban on uranium mining) which essentially unlocked this deposit and paved the way for commercialization.. This opening up of Greenland to uranium mining was reaffirmed in December 2014 when fresh government elections installed a coalition government which is pro development and pro uranium mining. In April 2015 Greenland Minerals and Energy released a Feasibility Study for the Kvanefjeld Rare Earth project which will form the basis for a mining licence application in 2015.

In March 2014 the company singed a non binding Memorandum Of Understanding (MOU) with Non Ferrous China (NFC) to investigate project co-operation. NFC are a large diversified mining company with significant zinc industry assets and a high quality rare earth separation plant located in China.The relationhip to jointly develop the Kvanefjeld deposit was strenghtened with the signing of another MOU in March 2015 which is more specific about the project scope and partner participation. Greenland Minerals and Energy looks forward to working with their project partner Non Ferrous China during the course of 2015 as it looks to formalise this relationship through a strategic co-operation agreement. NFC has already provided capital cost estimes for the Feasibility Study. In the future they will be providing design, construction capability, financing and rare earth technology to the Kvanefjeld Project according to a recently extended Memorandum Of Understanding.

PROJECT SETTING

Location in Greenland

The landscape in south Greenland is characterised by relatively high and steep mountains and by low islands and peninsulas in the coastal areas. This landscape is largely formed through the action of ice, which has carved the long, narrow and deep fjords. Kvanefjeld is a 690m high mountain, which is situated on the Erik Aappalaartup Nunaa peninsula. South of Kvanefjeld is the Narsaq Valley and Narsaq River, which drains the valley and surrounding mountains into the Narsaq Ilua Bay. The Figure 2 below show the Narsaq River in the Valley area of the project site.

Figure 2: South West View Looking Down the Narsaq Valley in Greenland

At a regional scale the weather in south Greenland is mainly influenced by the North American continent and the north atlantic ocean. However the local climate is also heavily influenced by the Greenland Inland Ice. Another key factor is the year round low sea surface temperature, which causes the south Greenland waters and coastal areas to be part of the arctic climatic zone.

Foehn winds are quite common in southern Greenland, including the Kvanefjeld area. Foehn winds are outbursts of dry and relatively warm air. Such winds arise through adiabatic compression of the air sweeping down from the inland ice cap. Its relative humidity drops to 30-40%, and the temperature rises by up to 15-20^{o}C within an hour, remaining elevated for a day or two. The effect of the foehn wind is particularly marked in winter, when it can result in rapid melting of the snow.

Local climate data is collected from a climate station on Kvanefjeld. Monthly average temperatures range from minus 8^{o}C in January and February, to plus 6^{o}C in July and August. Long term time series data for precipitation gives monthly averages of 73 mm during March, up to 131 mm during the month of September. Annual average precipitation for the area is approximately 1200 mm.

The Kvanefjeld region is located inside the northwest margin of the Illimaussaq Complex. The region represents the remains of lava which formed 1.2 billion years ago . Black lujavrite is the rock that hosts REE's, uranium, and zinc multi-element mineralisation.

Geology

Geology of Ilimaussaq Complex

The Ilimaussaq Complex is one of the intrusive complexes of the Gardar igneous province in South Greenland. The layered nature of the complex is attributed to four successive pulses of magma. The first pulse produced an augite syenite, which now forms a marginal shell. This was followed by intrusion of a sheet of peralkaline granite that is mostly preserved in the roof of the complex. The third and fourth stages make up the bulk of the intrusion. Stage four produced the agpaitic lujavrites and kakortokites that formed from volatile-rich alkaline magmas that were extremely enriched in incompatible elements such as rare earth elements, lithium, beryllium, uranium, and high-field-strength elements such as niobium and tantalum. Minerals containing the incompatible elements are chemically unstable and suitable for mild metallurgical processes such as atmospheric leaching.

Black lujavrite is the unit that hosts REEs, uranium, and zinc multi-element mineralisation. Kakortokite units host zirconium mineralisation that also contains REEs and tantalum and niobium. The lujavrite series within the Ilimaussaq Complex is at least 500 m thick and are generally fine-grained and laminated but there are locally some medium to coarse-grained pegmatoidal varieties.

Kvanefjeld Geology

The Kvanefjeld region is located inside the northwest margin of the Ilimaussaq Complex. The region represents a lujavrite-rich area that has been unroofed by erosion. Other rock types that outcrop include basalt, gabbro and sandstone of the Ericsfjord Formation, and augite syenite and naujaite.
Steenstrupine is the dominant host to rare earth elements and uranium in all mineralisation styles. It is a complex sodic phospho-silicate mineral and mineralogical studies suggest that it commonly contains between 0.2 and 1% U_3O_8, and likely hosts approximately 50% of the uranium at Kvanefjeld. Other minerals that are important hosts to REEs include the phosphate mineral vitusite, and to a lesser extent, cerite and monazite. Aside from steenstrupine, uranium is also hosted in unusual sodic silicate minerals that are rich in yttrium, heavy REEs, zirconium and tin. Minor uranium is also hosted in uranothorite and monazite. Zinc is exclusively hosted in sphalerite, which is the dominant sulphide throughout the deposit.

Mineral Resources

The current mineral resources were estimated by SRK Consulting (Australasia) Pty Ltd, and categorised in accordance with the JORC Code (2012). The latest Project mineral resource estimate was publicly released in February 2015, and was based on drilling completed to the end of the 2011 field season. The Project consists of three deposits of differing exploration development. The main deposit is the Kvanefjeld deposit which has the most historical and modern drilling. The other two current satellite deposits (Sorensen and Zone 3) are less developed. The maiden

Sorensen and Zone 3 estimates were publicly released in March and June of 2012 respectively, and were based on drilling completed to the end of the 2011 field season.

The Kvanefjeld deposit only has a total resource of 673 Mt, and is characterised by thick, mostly sub-horizontal slabs of lujavrite. The highest grades occur near surface, with grades of REEs, uranium and zinc decreasing with depth. Features of the Kvanefjeld resource include:

Kvanefjeld Deposit - global resource for all delineated deposits:

- Resources of 673 Mt containing 368 Mlbs U_3O_8, 7.4 Mt TREO
- Measured resources of 143 Mt @ 303 ppm U_3O_8, 1.2% TREO and 0.24% Zn.
- 54 million tonnes @ 403 ppm U_3O_8 and 1.4% TREO.

Global Resources – Across all three deposits:

- 1.01 billion tonnes of ore containing 593 Mlbs U_3O_8 and 11.13 Mt TREO.

Of the global resources 240 Mt of inferred resources have been established at Sorensen, with another 95 Mt at Zone 3. Sorensen features many similarities to the Kvanefjeld deposit, including a higher grade upper section.

Sørensen Deposit- higher grade upper lens:

- 119 Mt @ 400 ppm U_3O_8, 414 ppm HREO, 940 ppm Y_2O_3, 1.2% TREO, 0.3% Zn

The mineral resources have been delineated by diamond core drilling from surface. The majority of grade information is based on chemical assaying of half-core, although 15% of the Kvanefjeld assay data is based on historical spectral assays. Chemical assays were performed by NATA-certified laboratories in Australia, using multi-acid-digest and ICP-OES and ICP-MS instruments. For the samples with only spectral assay data, REE grades were estimated from uranium grades using linear models, based on linear regression parameters calculated from the more extensive set of chemical assays.

The resource definition drilling has been by diamond coring from surface, either NQ or BQ diameter, with HQ diameter holes utilised for geotechnical assessments and metallurgical sampling. Drill hole spacing is approximately 70 m x 70 m over the northeast of Kvanefjeld, widening to 140 m x 140 m in the southwest. Sorensen has a wider hole spacing of between 150 m and 300 m. Drill hole locations are partially constrained by locally rugged topography, which inhibits drilling on an exact grid spacing. The majority of holes are oriented vertical, or near vertical, to achieve intercepts that are close to true thickness given the sub-horizontal orientation of the lujavrite sills. Recovery is generally 100%, or close to 100%.

Kvanefjeld has a long exploration history, with 65 holes drilled by Danish institutions in the period 1958-1977, and 156 holes completed by the Company in the period 2007-2010, as summarised in Table 2.3.3. Drilling completed at Kvanefjeld by the end of 2010 totalled 45 000 m of drill core and 23 000 assays.

Sorensen has a recent exploration history, with all but one hole drilled by the Company in the 2010/2011 field campaigns. The discovery hole was drilled by the Company near the close of the 2008 field season. A total of 23 holes, 10,351 m of core and 4,600 assay samples have been completed to date at Sorensen.

Zone 3 was drilled initially in 2008 (5 holes) and then completed to its current status in 2011 (23 holes). A total of 6,499 m was drilled in 28 drill holes with the holes going to depths of around 200 m where possible.

Table 1: Summary of Exploration Drilling

Drill Program	Holes	Metres
GMEL resource definition (2007 -2010)	130	31,436
GMEL Geotechnical (2009)	12	1,870
GMEL Metallurgical (2009)	14	2,254
Historical (1958-1977)	65	9,830

Mineral resources were estimated using industry best-practice geological modelling techniques to constrain the lujavrite volume together with geostatistical modelling to constrain the distribution of grades within the lujavrite volumes. Leapfrog software was used to model lujavrite and sub-domain volumes directly from drill hole intercepts using a 3D-splining technique. Isatis and Surpac software was used to model the distribution of grades using ordinary kriging.

MINING

Mining studies indicate the suitability of a medium sized, open pit mine at Kvanefjeld. The mine will have a low strip ratio and, as the highest grades present near-surface, will generate higher grade run of mine ore in the early years of production.

A number of mining rate studies have been performed from 3 to 10.8 million tonnes per annum. The Feasibility Study is based on an initial mining rate of 3.0 million tonnes per year of ore treated.

With a crusher feed target of 3.0 Mt/a and an average waste to ore strip ratio of 1:1, the average total material movement from the mine is ~6 Mt/a.

The mining study is based on owner mining, with the mining fleet being leased as an operating expense. It is assumed that the maintenance of all mobile equipment will be carried out by the original equipment manufacturer (OEM) as part of their supply and maintain contract.

Mining Fleet

At this stage of the Project, a standard drill/blast/truck/shovel operation would be considered the lowest operating risk mining method, both in terms of cost and productivity. Therefore this configuration has been selected as the base case for the mining study.

Equipment selection has determined that 6 x 150 tonne mining trucks and one excavator would be required for the project.

Manning Levels

Based on mining equipment proposed and the nature, complexity and location of the Project, it is estimated that the mining workforce directly involved with the earthmoving component would consist of 44 management and supervision personnel, 62 operators, 18 maintenance and service personnel with blast and mine service crew estimated at 12. This is a total of 136 employees.

Pit Optimisation

Pit optimisation and mine design studies were completed by SRK in April 2015. In the early years of mine life the grade is expected to be >350 ppm U_3O_8, >1.4% REO and >0.25% Zn. Based on the ore reserve only the mine can provide 37 years of feed.

An Ore Reserve estimate developed to JORC 2012 standards has been produced. The contained mineral inventory is shown in the table below.

Table 1: Ore Reserve Estimate

Classification (JORC)	Inventory (Mt)	REO (ppm)	U_3O_8 (ppm)	Zn (ppm)
Proven	43	14,700	352	2,700
Probable	64	14,000	368	2,500
Total	108	14,300	362	2,600

Mine Design

Higher grade portions of Kvanefjeld (>300 ppm U_3O_8) the phosphate bearing minerals (e.g. steenstrupine) are the dominant hosts to REEs and uranium. Mine development is planned in four main stages, with all of the ore scheduled from the greater than 300 ppm U_3O_8 resource material that dominates the upper level of the Kvanefjeld deposit.

Figure 3 shows a long section through the Kvanefjeld resource model, with drill strings coloured by REO grade. The model generally follows the lujavrite contact. The northern half features zones of black lujavrite over 200 m thick that outcrop at surface. To the south, the lujavrite forms a series of thinner lenses. Highest REO, uranium and zinc grades occur together in the upper parts of the deposit. Grades begin to decrease below 200 m.

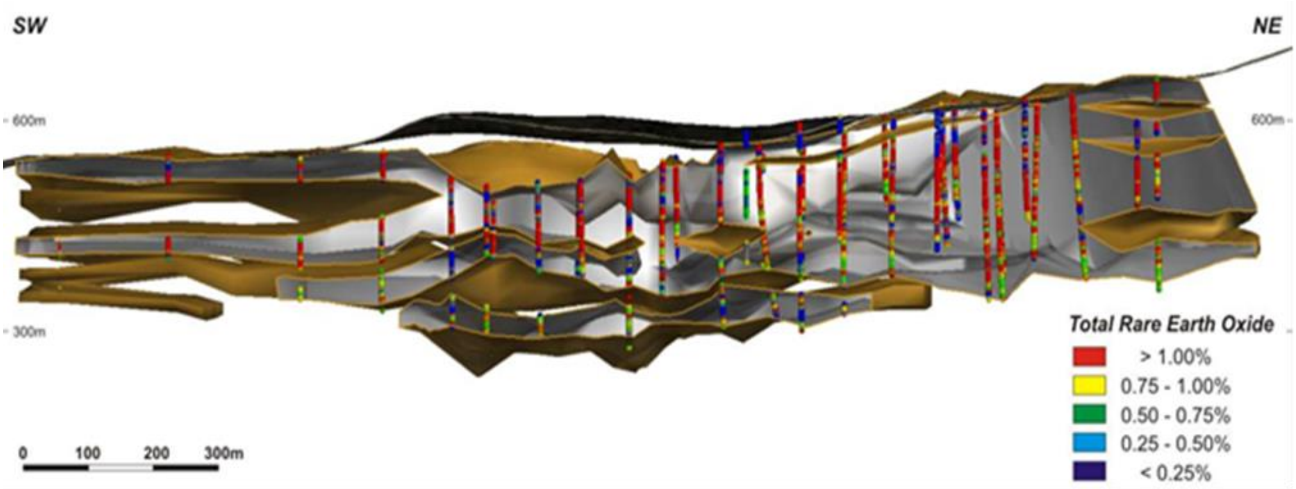

Figure 3: Long Section Through the Orebody

The fact that Kvanefjeld is essentially a plateau, with the orebody outcropping at surface and the highest grade material occurring in the upper zones, means that the waste material moved per tonne of ore (strip ratio) is low. The expected strip ratio is only 1 tonne waste per 1 tonne ore over the first 39 years of operation, and as a consequence the mining costs are favourable.

METALLURGY

Flowsheet Selection

Due to the unique nature of the deposit a customised metallurgical flowsheet was developed by the GMEL in-house metallurgical team. This flowsheet was selected after a rigorous selection process in which 6 different metallurgical flowsheets were assessed in detail.

The selected flowsheet involves beneficiation, atmospheric sulphuric acid leaching, uranium solvent extraction, caustic conversion, hydrochloric atmospheric re-leaching, lanthanum and cerium separation and production of a mixed high value rare earth oxide. The flowsheet has been extensively tested at bench scale, continuous and pilot plant scale.

Beneficiation

Ore mined from the open pit is trucked to the concentrator at a rate of 3 million tonnes per year where beneficiation is performed. The ore is crushed and ground to a particle size of 80% passing 75 microns. Flotation is used as the beneficiation method to concentrate the value minerals. Flotation of the zinc mineral sphalerite from the rest of the ore produces the first product for the project. The zinc concentrate contains 0.5% of the total ore mass and 78% of the mined zinc.

The next flotation stage concentrates the rare earth phosphate minerals into 8% of the original ore mass. Approximately 80% of the rare earths are recovered into the Rare Earth Phosphate (REP) mineral concentrate. This typically produces 250,000 tonnes of REP mineral concentrate which is sent to the refinery for further processing.

Water is treated by the concentrator before placement into the fjord to the north of the concentrator site. The water treatment removes fluoride and solids from the water and recycles most of the water back into the concentrator. Fluorspar is produced by the water treatment plant as a by-product of the beneficiation process.

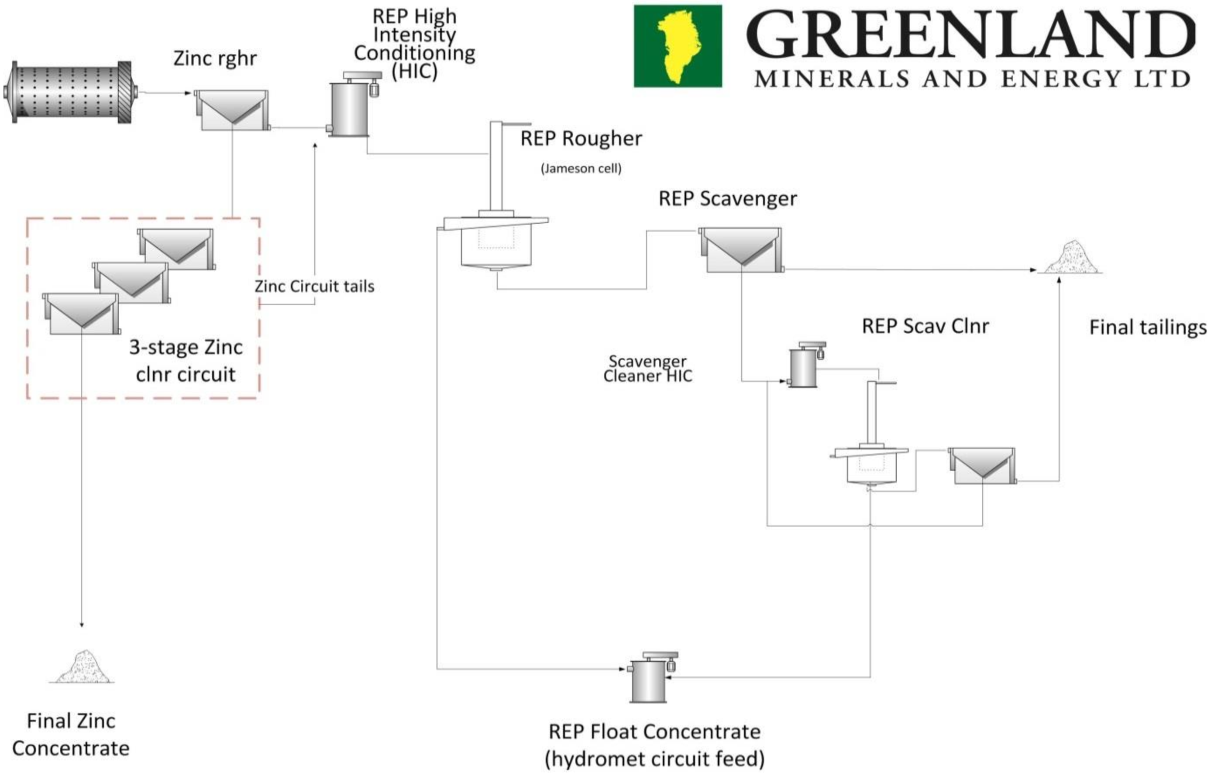

Figure 4: Simplified Beneficiation Process Diagram

Refinery

REP concentrate from the concentrator is pumped via a pipeline to the refinery which is located approximately 1 km away. Here the concentrate is leached atmospherically in a counter current sulphuric acid leaching circuit. The solution produced by the atmospheric leaching is sent to the uranium circuit for recovery. The leach residue is treated atmospherically with caustic to condition the solids prior to re-leaching. The solids are re-leached in hydrochloric acid at cool atmospheric conditions to produce rare earth chloride solution.

Lanthanum and cerium are removed from the rare earth chloride solution using solvent extraction to produce four different rare earth products. These products are:

- Lanthanum Oxide 99% grade = 4,500 tonnes per year
- Cerium Hydroxide 99% grade = 7,600 tonnes per year
- Mixed Lanthanum and Cerium Oxide = 3,700 tonnes per year
- Mixed Critical Rare Earth Oxide (Pr to Lu) = 7,900 tonnes per year

All products are transported to Europe for sales apart from the Mixed Critical Rare Earth Oxide which is transported to NFC in China for separation into 14 different rare earth oxides at >99.95% purity.

A Uranium by-product is produced from the solution produced from the sulphuric atmospheric leaching. Industry standard solvent extraction is used to recovery the uranium selectively from the sulphate solution. Two stages of precipitation are then performed on the uranium solution to further purify the uranium. The final product is uranium peroxide UO_4 which is directly saleable to power utilities.

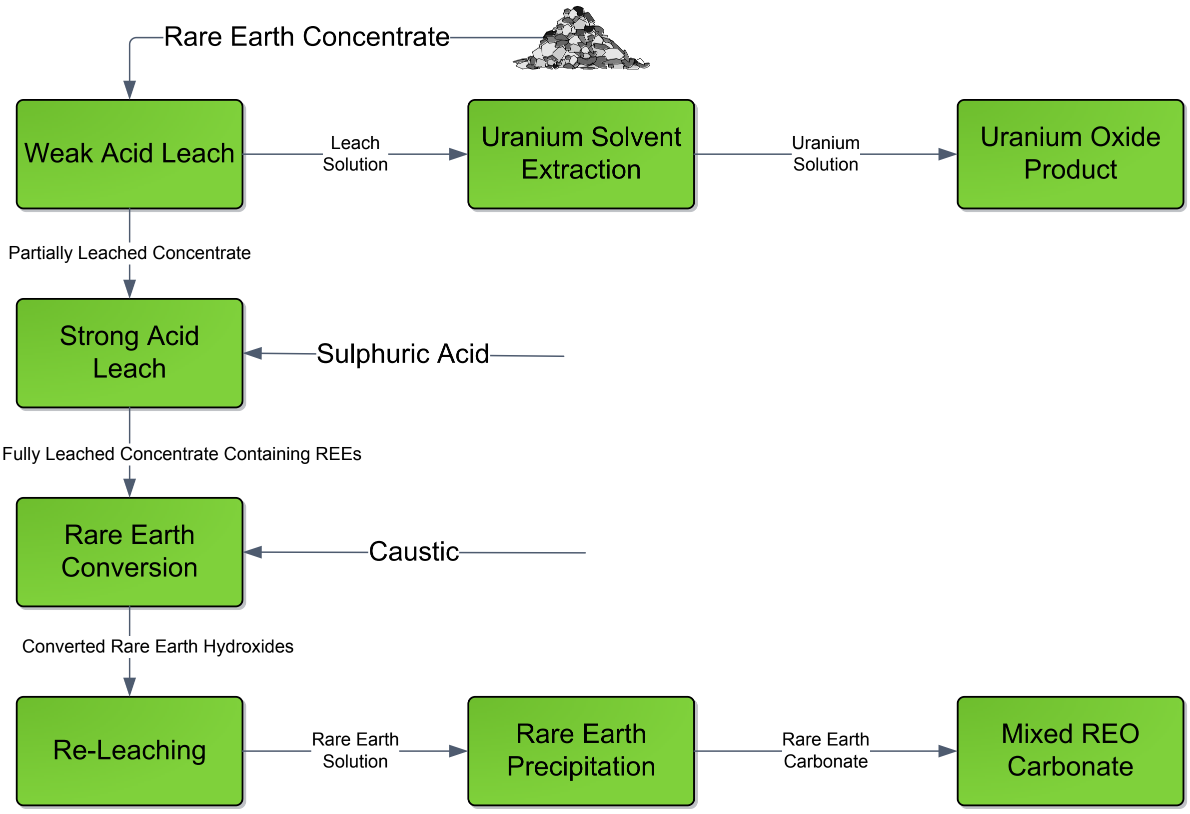

Figure 5: Simplified Refinery Process Diagram

Process Plant Design

Key Design information for the processing plants are summarises in the Table 2. Figure 6 shows the overall simplified blockflow diagram for the metallurgical plant.

Table 2: Process Design Basis

	Units	Value
Operating Schedule		
- Operating Days/Annum	#	365
- Operating Hours/Day	h	24
- Operating Hours	h	7 884
Plant Feed, solids	t/a Ore	3 000 000
	t/h	380.5
Nominal Plant Feed Grade		
- U_3O_8 equivalent	ppm	380
- REO	%	1.352
Overall Plant Recovery		
- Uranium	%	45.0
- Rare Earth Elements	%	56.9

	Units	Value
Nominal Plant Production		
- U_3O_8 equivalent	t/a	512
- Lanthanum Oxide	t/a	4 266
- Lanthanum-Cerium Oxide	t/a	3 895
- Cerium Hydroxide	t/a	6 931

Water is recycled within both the concentrator and refinery to minimise water consumption. This includes recovering decant water from each of the tailings facilities and re-using in the process plants. Excess water produced from the processing plants is treated and pumped into the northern fjord as Treated Water Placement (TWP).

Raw water is provided by the raw water dam which is located near the Refinery. This dam provides 4 weeks of water supply of fresh high quality water from the Narsaq river.

Due to the large quantity of hydrochloric acid consumed by the REE plant, a chlor-alkali plant has been incorporated into the process design for on-site acid production. This has the added benefit of producing a caustic soda by-product, another major REE plant reagent.

Sulphuric acid is also produced on site by treating elemental sulphur which is imported to site. The production of concentrated sulphuric acid also produces excess energy which is captured to produce electricity and building heating.

Power generation is provisionally based on use of heavy fuel oil fired multiple reciprocating machines. The heavy fuel oil power station is located at the concentrator site. This is done to capture excess energy from the off-gases for process and building heating.

The concept of implementing hydro-power for Kvanefjeld is provided as a development option as part of the mining licence application

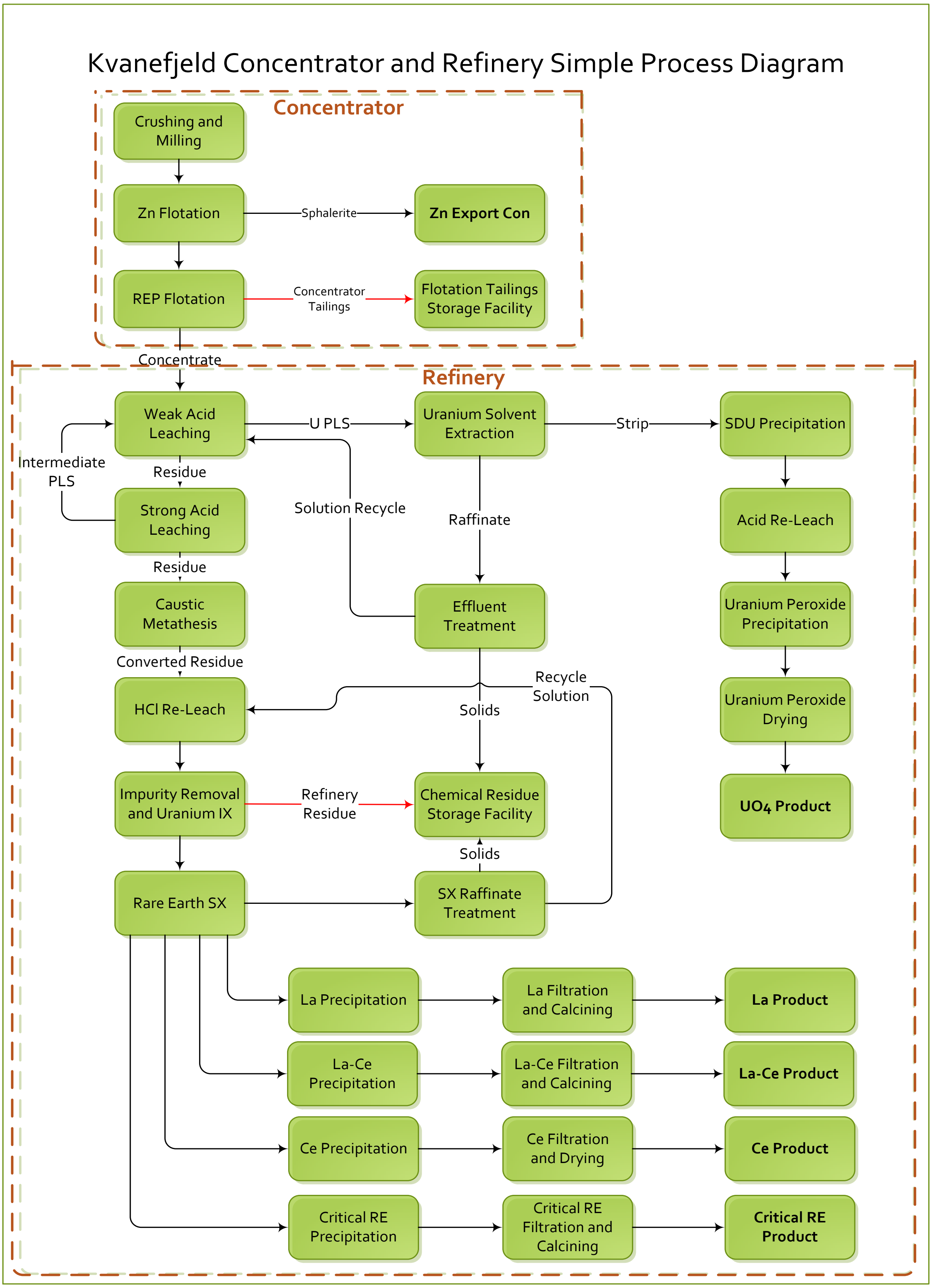

Figure 6: Overall Kvanefjeld Process Diagram

TAILINGS MANAGEMENT

The tailings, or residues, arising from the processing plants are fully managed to ensure a negligable impact on the environment. The tailings management includes the design, operating and closure concepts. The tailings management design was performed by the independent consultant AMEC Foster Wheeler to Feasibility level standard.

Three sources of tailings that will require management are as follows:

1. The major source is produced by the concentrator and stored in the Western end of the Taseq basin located ~1 km to the south of the Refinery. This tailings facility is called the Flotation Tailings Storage Facility (FTSF).
2. The second source of tailings, from the Refinery, is potentially recoverable for further processing and is stored in the Chemical Residue Storage Facility (CRSF).
3. Excess water from the facilities is treated and then placed back into the environment. This release is placed into the fjord to the north of the project site. This stream is called the Treated Water Placement (TWP).

For FTSF, the tailings storage concept involves pumping thickened tailings from the plant via a pipeline and discharging below water into a natural basin. To store the estimated volume of tailings generated over the life of mine, an embankment will be constructed at the outlet using rock quarried from adjacent slopes. The key advantages of subaqueous tailings storage include mitigation of radon gas release and mitigation of dust generation. Based on the information provided, there is sufficient storage in FTSF for the design life of mine production.

For CRSF, the concept involves pumping slurry from the Refinery, with reclaim water recycled. The CRSF is a fully lined tailings dam to prevent migration of mildly radioactive solid tailings.

INFRASTRUCTURE

Regional Communities and Infrastructure

The district and municipality of Narsaq has a total population of more than 2,000, of whom ~1,300 live in the town itself. The majority of inhabitants are employed in fishing or government/administration. Narsaq is a port of call for the Arctic Umiaq Line, a passenger and freight shipping line. The sea connection provided by Arctic Umiaq is a lifeline for the entire western Greenland.

Narsaq Heliport operates year-round, linking Narsaq with Qaqortoq on the shores of the Labrador Sea and also linking Narsaq with the nearby Narsarsuaq Airport. Narsarsuaq is a small community with approximately 200 people mainly employed at the airport or the associated hotel. Narsarsuaq has air connections to Nuuk (capital of Greenland) and to Copenhagen with Boeing 757s. Nuuk has a population of over 17,000.

The Fly In – Fly Out (FIFO) workforce is expected to utilise the Narsarsuaq airport as the Greenland entry point. This is likely to be the case for the imported construction workforce in addition to the operations FIFO workforce.

Accommodation

It is predicted that a total 787 personnel will be required for the project operation and approximately 325 of these personnel will be recruited locally from within the Southern Greenland municipality. The remaining project personnel will be accommodated on a temporary FIFO basis in a custom built village to be located to the North West of Narsaq.

An accommodation village will be provided with an access road off a new road connecting the mine and plant to the harbour. The village will be supplied with power (from the process plant power station), water and sewage treatment. A large centre is envisaged, with recreation facilities, meeting rooms, canteen and internet connections.

Harbour Facilities

Dedicated new port facilities will be installed at the Tunu peninsula at Ilua Bay for the Kvanefjeld Project. The new port will handle materials and equipment for the construction of the mine and plant. During the operational phase the port will handle the ongoing import of fuel, reagents, consumables, and the export of products. The new facilities will be designed to handle handymax vessels.

The port is designed with a 200 m quay front with conveyors for bulk cargo, and mobile stackers for containers. Adjacent to the quay, an area will be prepared for container stacking and covered bulk storage for both imports and exports.

Other Transport Facilities

A new 7 m wide road, approximately 13 km long, will be built to connect the harbour at Ilua Bay, the process plant, the mine and accommodation village. The new road will follow an existing gravel road along the Narsaq River. The new road will be for all imports and exports transport between port, plant and mine, as well as ore transportation from the mine to the plant. Specialised fuel trucks will transport heavy fuel oil (HFO) from the port to the power plant at the concentrator site.

Personnel will generally commute by bus between the accommodation village and the work sites at the mine, concentrator and refinery. The existing heliport at Narsaq is considered to require an extension to passenger facilities, but the airport at Narsarsuaq is considered adequate to handle additional passenger loads resulting from the Kvanefjeld construction and operation. A chartered flight from southern England will be used on a twice weekly basis to transport FIFO workers during the operations phase. Additional commercial and chartered flights between Narsarsuaq and Nuuk, Reykjavik and Copenhagen may be necessary for the increased volume of passengers.

Water Supply

The process plant can access raw water from the mine area, Narsaq river, and water resulting from tailings displacement in Lake Taseq. This engineering study assumes that mine water is not required for processing and that excess water is discharged to the environment without any contact with the process plant.

Water will be recovered from Lake Taseq, which will perform the dual function of tailings and water reservoir. It is estimated that a proportion of the recycle decant water will require basic water treatment and filtration for use in the process plant. Diversion and segregation of a portion of the precipitation run-off into the lake is required to satisfy the demand for uncontaminated water.

A preliminary water balance indicates that there will be a net placement of treated water to the Bredefjord to the north of the concentrator site.

Hydropower

Although the engineering studies are based on importing and burning HFO to meet the total project energy requirements, Greenland is well suited for hydro electric power development from both a topographical and a hydrological point viewpoint. An existing hydropower facility is located in the area north of Narsarsuaq called Johan Dahl Land. Istak and Verkis of Iceland have completed a study which has evaluated and costed the establishment of hydropower for the project. There is adequate hydropower capacity to supply the 38.3 MW electrical requirement for the project.

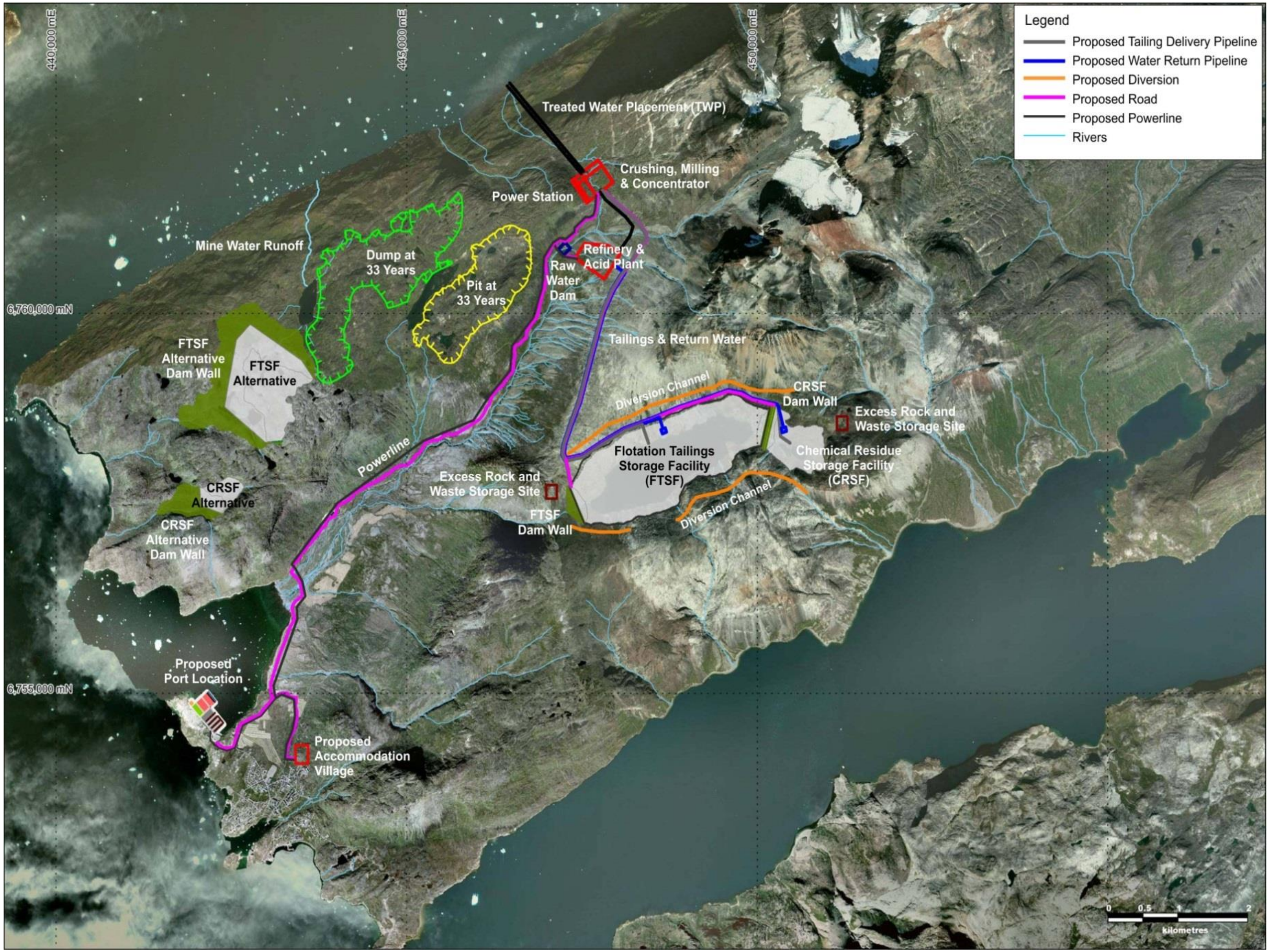

Figure 7: Overall Layout of Project Facilities

COST ESTIMATION

Cost Estimation Contributors

Capital and operating costs were developed to Feasibility Study standard for the Kvanefjeld Project. The cost estimates were provided by a range of independent consultants who specialise in particularly areas of construction and design. The following list shows the main consultants and constractors involved in the cost estimation.

1. Tetra Tech Proteus – Civil Design, Accomodation Village, Process plants and power plant design.
2. Non Ferrous China – Capital Cost Estimates for Process Plants and Power Plant installation
3. Ramboll Engineering Consultant, Denmark – Port design and cost estimation
4. MacMahon Mining Services Contractor – Civil construction costs and contract mining costs
5. SNC Lavalin – Acid plant design and equipment supply cost
6. Shedden Uhde – Chloralkali cell and hydrochloric acid plant supply design and equipment supply cost
7. Verkis/Istak Iceland – Mine facilities and Hydropower capital cost estimate
8. Blue Water Shipping Denmark – Logistics
9. Sarens – Modularisation logistics
10. AMEC Foster Wheeler – Tailings Management Design and specialist equipment supply

Capital Costs

The capital cost estimate covers the following facilities:

- Mining Infrastructure
- Run of Mine (ROM) Pad
- Concentrator Plant
- Refinery Plant
- Flotation Residue Storage Facility (FTSF)
- Chemical Residue Storage Facility (CRSF)
- Raw Water Dam
- Area/Regional Infrastructure, including roads and overland pipelines
- Port
- Accommodation Village
- Power Supply.

The total project capital cost estimate inclusive of mine infrastructure, process plants, residue storage facilities and area/regional infrastructure is summarised and tabulated in Table 2. The capital cost estimate as summarised in this section is current as of the first quarter 2015, and is presented in United States dollars.

Table 2: Capital Cost Estimate

	Area	US$M
Direct Costs	Area 1000 – Mining	32.5
	Area 2000 – Concentrator Process Plant	269.3
	Area 3000 – Refinery Process Plant	371.2
	Area 5000 – Regional Infrastructure	109.9
	Area 6000 – Major Off-site Infrastructure	154.7
	Direct Cost Subtotal	937.5
	First Fill Reagents and Consumables	14.9
	Start-up Spares	8.8
	Mobilisation/Demobilisation	35.1
	Commissioning Assistance	2.4
	Total Direct Cost	998.7
Indirect Costs	Temporary Construction Facilities	25.3
	Engineering, Procurement and Construction Management	149.6
	Total Indirect Costs	174.8
Total Costs	**Total Project Costs (Net)**	1 173.5
	Contingency (Growth Allowance)	187.6
	Total Project Costs (Overall)	1 361.1

The capital cost presented here is exclusive of:

- the cost of the mining fleet, which will be supplied by the mining contractor
- owner's costs
- escalation
- currency exchange rate fluctuations

The capital cost of US$1.36 billion is equivalent to a capital cost intensity of $59 of capex per kilogram of separated rare earth oxide produced. This compares favourable to other aspiring rare earth projects being considered around the world. This capital cost forms the part of phase 1 of the project with subsequent expansions offering significantly improved capital intensity.

Operating Costs

Table 3 summarises the total operating cost for the mine, concentrator and refinery, at a nominal plant throughput of 3.0 million tonnes of ore per year, resulting in the production of:

- 7,821 tpa of TREO as a critical rare earth oxide
- 4,266 tpa of TREO as a lanthanum oxide
- 3,895 tpa of TREO as a mixed lanthanum/cerium oxide
- 6,927 tpa of TREO as a cerium hydroxide
- 557 tpa of uranium oxide (UO_4, equivalent to 512 tpa U_3O_8)
- 14,501 tpa of zinc concentrate
- 16,198 tpa of calcium chloride (fluorspar), and
- 16,960 tpa of sodium hypochlorite solution (at 12%vol).

Costs are inclusive of mining, process plant, and area and regional infrastructure, and represent the average expected operating cost for the first five years of plant operation. Separated Lanthanuma and Cerium products will be produced in Greenland and be delivered to mainland Europe. The mixed critical rare earth oxide will be delivered to the new Xinfeng separation plant in Guangdong, China. Here the critical rare earths (Praseodymium through to Lutetium including Yttrium) will be separated into high purity individual oxides. The technology and processing plant for this part of the project is being supplied by NFC. Lanthanum, cerium, uranium oxide, zinc concentrate, fluorspar and hypochlorite are all supplied directly to mainland Europe. Each of these products is produced in Greenland by the project metallurgical facilities. The operating costs include the freight component for the delivery of all products to their final markets.

The Unit Cost – Total is inclusive of the costs to produce the rare earths including uranium, zinc, fluorspar and hydrochloric by-product credits. The Unit Cost – Net represents the cost to produce one kilogram of mixed critical rare earth oxide inclusive of by-product credits. All products other than the mixed critical rare earth oxide (CREO) are considered by-products for this cost breakdown. The revenue from by-product revenue is subtracted from the total costs as a positive credit to the overall operating costs.

Table 3: Operating Cost Estimate

	Proportion of Cost (%)	**Annual Cost (US$'000/a)**	**Unit Cost – Total** [2]	**Unit Cost – Net** [3,4]
			US$/kg TREO	**US$/kg CREO**
Mining and Haulage	7.5	17 878	0.81	0.65
Labour	19.0	45 022	2.03	1.63
Power	13.3	31 691	1.43	1.14
Reagents	22.9	54 429	2.45	1.96
Consumables	4.6	10 888	0.49	0.39
Maintenance Materials	12.9	30 509	1.38	1.10
Freight Costs	13.0	30 805	1.39	1.11
General and Administration	6.8	16 132	0.73	0.58
Total	**100**	**237 354**	**10.71**	**8.56**

Notes:

1. The nominal operating cost presented in this table is the average of the first ten years of plant operation. The actual operating cost will vary slightly from year to year with variations in ore head grade.
2. Total unit cost per kg of TREO produced at Kvanefjeld
3. Net unit cost per kg of CREO delivered to the Rare Earth separation plant, net of by-product credits for yellow cake (uranium), zinc concentrate, fluorspar, lanthanum oxide, mixed lanthanum/cerium oxide, and cerium hydroxide.
4. Byproduct credits based on US$70/lb U_3O_8, US$6.50/kg La_2O_3, US$5/kg CeO_2, US$1000/t Zn, US$350/t CaF_2.

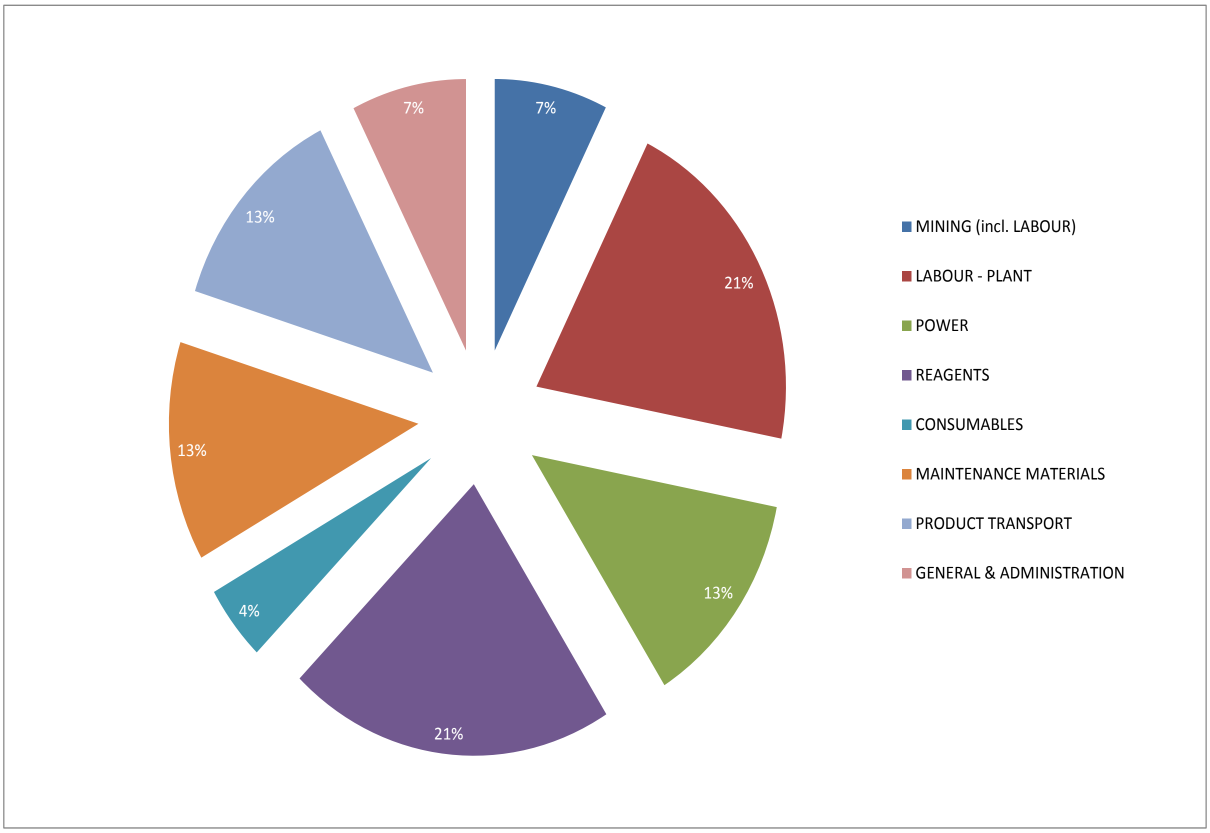

Figure 8: Total Operating Cost Breakdown

CONCLUSION

The Kvanefjeld project is a very large and globally significant project for rare earths and uranium. The scale of the deposit provides greater than 100 years of mining operations with potential for multiple expansions.

The operating cost estimate shows the operation will produce siginificant quanities of all rare earth products at one of the lowest operating costs in the world. This will allow the operation to be cash cost profitable during all economic cycles.

The metallurgical flowsheet is simple and well proven through a range of laboratory tests and studies. The use of atmospheric leaching and application of previously commercialised rare earth recovery methods, operating at mild conditions allows for easier operations. This will contribute to a faster ramp up to design rates and mitigate the risks currently experienced by aspiring western world rare earth producers.

Lanthanum and cerium, as well as the by-product materials being uranium oxide, zinc concentrate and fluorspar will be separated in Greenland and sold directly as products of Greenland.

The separation of medium to heavy rare earths into high-purity marketable products will take place offshore because of technical issues, and is a focal point of the relationship with NFC. The processing of the uranium, lanthanum and cerium in Greenland, in accordance with Greenland's Mining Act is a signficant commitment to finalising the mining license application for Kvanefjeld. Importantly, it allows for all radioactive components to be managed in the broader mine-site environment, which conforms with international best-practice in mine operations.

Non Ferrous China has recognised the potential of the project as it will allow them to have a consistent high quality feed of critical rare earths to feed their new world class separation plant. This should see NFC become one of the world's major rare earth producers in partnership with Greenland Minerals and Energy.

The Kvanefjeld project will be a major project for Greenland contributing significantly to the economy. Greenland aspires to become a mining economy and with continued government support the jewel in Greenland's mining crown can be brought to fruition.

REFERENCES

1. GMEL, 2012, "Kvanefjeld Multi Element Project – Pre Feasibility Study", Greenland Minerals and Energy. KV84-PM-RP-0000-0001

2. GMEL. 2013. Mine and Concentrator Study. Greenland Minerals and Energy Ltd. KV45-PM-RP-0000-0004.01.

3. GMEL 2015. Kvanefjeld Project - Feasibility Study. Greenland Minerals and Energy Ltd. KV55-PM-RP-0000-0005.14

4. Istak/Verkis. 2014. Kvanefjeld Rare Earth and Uranium Project – Johan Dahl Land Hydroelectric Project Prefeasibility Study. Istak Report no 14158-001

5. SRK Consulting. 2015. Kvanefjeld Project Mining Study. SRK Consulting (Australasia) Pty Ltd. GRE005.

6. Furfaro, D and Krebs, DGI. 2014. Continuous Leaching of Kvanefjeld Concentrate. Greenland Minerals and Energy. ALTA Conference 2014.

7. Furfaro, D and Krebs, DGI, . 2013. The Kvanefjeld Process. Greenland Minerals and Energy. ALTA Conference 2013.

8. Furfaro, D and Krebs, DGI. 2012. Leaching of Kvanefjeld Concentrate. Greenland Minerals and Energy. ALTA Conference 2012.

9. Greenland Minerals and Energy Ltd. 2011. Greenland Minerals Releases an Upgraded Resouces Estimate of the Kvanefjeld Muli-Element Project. ASX Announcement.
   Greenland Minerals and Energy Ltd. 2015. Kvanefjeld Project – Mineral Resource Update. ASX Announcement.