Separation Of Rare Earths from Uranium and Thorium
Presented by Damien Krebs
IAEA 23-27 June 2014
Greenland Minerals and Energy Ltd
ASX-listed, Greenland-focussed mineral explorer and developer

**Kvanefjeld multi-element project (REEs, uranium, zinc):**
- A mineral project of world-wide strategic importance
- One of world’s largest REE-uranium resources
- Highly accessible – able to mine all year round
- Non-refractory ore type – beneficiates and leaches well with low-technical risk
- Long-life, cost-effective production of rare earths
- Environmental and social impact risks are low and manageable
The Kvanefjeld Project – Favourable Location

Readily accessible location near existing infrastructure

- Located at a latitude lower than long established mining regions of Alaska and northern Canada
- Adjacent to deep water fjords which run directly out to the North Atlantic Ocean
  - Mine and concentrator can be built within 10kms of harbour;
  - Access to nearby hydropower, minimal infrastructure requirements
- Town of Narsaq located 10km from Kvanefjeld can provide both labour and services
The Kvanefjeld Project – Unique Geology

Location of Deposits within Northern Ilimaussaq Complex

Kvanefjeld: 619 Mt
6.50 Mt REO,
350 M lbs U₃O₈

Sorenson: 242 Mt

Zone 3: 95 Mt

Northern Ilimaussaq Complex
Alkaline Intrusion

License Boundary

Black (arfvedsonite) Lujavrite
Green (aegerine) Lujavrite

4km
The Kvanefjeld Project – Significant Resources

Exploration and Resource Estimation continuing success

- GME has invested over $75M over past 6 years in exploration and research
- Overall Project JORC-code compliant resource inventory is 956Mt containing 10.33 Mt TREO and 575 Mlbs U₃O₈

<table>
<thead>
<tr>
<th>Deposit Name</th>
<th>Tonnage (Mt)</th>
<th>U₃O₈ Grade (ppm)</th>
<th>REO Grade (%)</th>
<th>Contained U₃O₈ (Mlbs)</th>
<th>Contained REO (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvanefjeld</td>
<td>619</td>
<td>257</td>
<td>1.06</td>
<td>350</td>
<td>6.55</td>
</tr>
<tr>
<td>Sorensen</td>
<td>242</td>
<td>304</td>
<td>1.10</td>
<td>162</td>
<td>2.67</td>
</tr>
<tr>
<td>Zone 3</td>
<td>95</td>
<td>300</td>
<td>1.16</td>
<td>63</td>
<td>1.11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>956</strong></td>
<td><strong>273</strong></td>
<td><strong>1.08</strong></td>
<td><strong>575</strong></td>
<td><strong>10.33</strong></td>
</tr>
</tbody>
</table>
Rare Earths Market – Focus on Strategic Elements

Kvanefjeld’s Endowment of Critical Rare Earths

Greenland – An Important New Minerals Region

Pro-mining government looking to foreign investment and expertise

- Greenland moved from ‘Home Rule’ to ‘Self Rule’ in 2009, and assumed full authority over its mineral and hydrocarbon resources, formerly shared with Denmark
- Looking to mining as a cornerstone of its future economy; the key to economic independence
- New government elected in March 2013; three party coalition headed by Siumut Party

Why is this of particular significance??

- Greenland Government has lifted the ban on uranium mining (24 Oct 2013)
- Looking to finalise regulations and prioritise the development of the Kvanefjeld project
- This pivotal move will be a critical step in opening up one of the world’s largest resources of both rare earth metals and uranium to mine development; a move that could change the dynamics of global REE supply
Our Goal: Build Global Rare Earth Business

MOU Recently Signed with Established REE Producer – Non Ferrous China (NFC)

- **Mine and Concentrator**
- **Refractory**
- **Separation Plant**
- **REE Marketing JV**

- **U offtake**
- **REE offtake**

GMEL Market Separated REO to EU and other Western World customers

Market Separated REO into China, Japan & Korea
Comparison of REE Project with U Project

Kvanefjeld will be more complex than a uranium project

- Mine
- Concentrator
- Refinery
- Separation Plant
- Value Adding
- REO Markets

- Mine
- Refinery
- Off Take

- U Ores not typically concentrated
- U Refinery half as complex
- Technology Hurdle
- Differentiation for REO
- Limited U Customers
- Limited U Customers

U Less Complex
Kvanefjeld Multi-Element Project Flowsheet
Concentrator and Refinery in Greenland.
Rare Earth Hydrometallurgy Flowsheet

Simple Equipment and Elegant Chemistry
Sulphuric Acid Atmospheric Leaching
Two Stage Counter Current Leaching of Concentrate
• Atmospheric Leaching at 98°C
• Two stage leaching reduces acid consumption
• Steenstrupine main mineral
  – \( \text{Na}_{14}\text{REE}_6\text{Mn}_2\text{Fe}_2(\text{Zr,Th})(\text{Si}_6\text{O}_{18})_2(\text{PO}_4)_7(\text{OH})_2\text{3H}_2\text{O} \)
• Standard uranium leach chemistry
  – \( \text{UO}_2(\text{SO}_4)_3^{4-} \) formed
• REE Leach then precipitate as double salts
  – \( \text{Na}^+ + \text{REE}^{3+} + 2\text{SO}_4^{2-} + \text{xH}_2\text{O} = \text{NaREE}(\text{SO}_4)_2.\text{xH}_2\text{O} \)
  • Effectively separates REE from U
Rare Earth Recovery
Selective and High Recovery of REEs Over Metathesis and HCl Re-Leach

• Caustic Metathesis occurs at pH 11.5

• $\text{NaREE(SO}_4\text{)}_2.x\text{H}_2\text{O} + 3\text{NaOH} = \text{REE(OH)}_3 + 2\text{Na}_2\text{SO}_4 + x\text{H}_2\text{O}$

• Caustic Converted Residue Leached with HCl
  – Under mild conditions
    • 25 deg C and pH 2.0.
  – $\text{REE(OH)}_3 + 3\text{HCl} = \text{REECl}_3 + 3\text{H}_2\text{O}$
Simplified Hydrometallurgy Flowsheet

Rare Earth Purification and Recovery
High Purity Mixed Rare Earth Intermediate Produced

Rare Earth Carbonate is 97% REO after calcining

- Impurities Removed in two stages
  - pH adjustment with lime to remove Fe, Al and Th
  - Barium added to remove radium
  - Sulphide added to remove Pb, Zn, Po, Bi
- Ion Exchange
  - To remove U
- REE Precipitation
  - $\text{REE}_2(\text{CO}_3)_3.x\text{H}_2\text{O}$
Radionuclide Control in the Flowsheet

Near Complete Radionuclide Removal from REO product

- Near complete removal of radionuclides from REO product
- Little interfering contaminants in the uranium SX feed
  - Low V, Mo, Fe, Zr
- Actinium removed in the next stage of refining
Greenland Minerals and Energy  
Key Highlights – A unique world class mining project

<table>
<thead>
<tr>
<th>World-class, large scale development project</th>
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<tbody>
<tr>
<td>▪ Economically robust, proven technology, large-scale, long life production of rare earths concentrate and uranium</td>
</tr>
<tr>
<td>▪ Large JORC resource base to produce ~7kt HREO, 37kt LREO &amp; 3Mlbs U₃O₈ per annum over 30 year mine life</td>
</tr>
<tr>
<td>▪ Ideally located near international airport, existing towns and potential hydro-electric power source</td>
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<table>
<thead>
<tr>
<th>Very attractive commodity portfolio</th>
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<tbody>
<tr>
<td>▪ Heavy rare earths and uranium are both recognised as strategically important commodities for the future</td>
</tr>
<tr>
<td>▪ Rare earths market characterised by limited capacity and increasing demand (particularly Dy, Nd, Tb, Eu and Y)</td>
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<th>Strong management and technical team</th>
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<tbody>
<tr>
<td>▪ Experienced management team with proven track record</td>
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<tr>
<td>▪ Well-respected and knowledgeable technical/project team in place with exceptional local expertise</td>
</tr>
</tbody>
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<tr>
<th>Highly advantageous ore-type, makes for simple cost-effective processing, highly scalable production</th>
</tr>
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<tbody>
<tr>
<td>▪ High upgrade through beneficiation brings OPTIONALITY to Kvanefjeld project</td>
</tr>
<tr>
<td>▪ Leaching can be done in Greenland, or owing to the high-grade concentrate, can be shipped to other locations</td>
</tr>
<tr>
<td>▪ Allows to single concentrator in Greenland, multiple refineries/partners globally</td>
</tr>
</tbody>
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<tr>
<th>Globally significant, long life, low cost, multi-commodity asset</th>
</tr>
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<tbody>
<tr>
<td>▪ Company to become one of the largest producers of rare earths globally and a significant U₃O₈ mine</td>
</tr>
<tr>
<td>▪ Potential to supply &gt;20% of global critical (including heavy) rare earth element demand</td>
</tr>
<tr>
<td>▪ Company has low cost of production due to multiple by-product opportunities</td>
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<tr>
<th>Low political risk</th>
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<tbody>
<tr>
<td>▪ Stable, low-risk operating environment with government looking to develop new industries and employment</td>
</tr>
<tr>
<td>▪ GME fully permitted to evaluate the project, exploration licence now includes radioactive elements</td>
</tr>
<tr>
<td>▪ Management and board have a solid working relationship with the government and are socially aware</td>
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Back Up Slides
## Greenland Minerals and Energy

**Achievements to date – Key milestones moving forward**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Timing</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration and Resource Definition - Kvanefjeld</td>
<td>2007-2010</td>
<td>A$25M spent</td>
</tr>
<tr>
<td>Preliminary Technical Studies</td>
<td>2008-2011</td>
<td>A$10M spent</td>
</tr>
<tr>
<td>Exploration and Resource Definition - satellite deposits</td>
<td>2011-2012</td>
<td>A$7M spent</td>
</tr>
<tr>
<td>Carry out Pre Feasibility Studies</td>
<td>2008-2012</td>
<td>A$16M spent</td>
</tr>
<tr>
<td>Acquire full ownership of Kvanefjeld</td>
<td>2012</td>
<td>A$5M (plus shares/options)</td>
</tr>
<tr>
<td>Batch test work and Concentrator Piloting</td>
<td>2012</td>
<td>A$4M spent</td>
</tr>
<tr>
<td>Finalise design criteria for Concentrator and Refinery</td>
<td>2013</td>
<td>A$1M spent</td>
</tr>
<tr>
<td>Zero tolerance policy abolished</td>
<td>2013</td>
<td></td>
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<tr>
<td>REE Separation JV and Refinery location established</td>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>Finalise EIA, SIA and FS</td>
<td>2014-2015</td>
<td>A$20M Funded</td>
</tr>
<tr>
<td>Application for Exploitation Licence</td>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>Refinery Piloting and Detailed Engineering</td>
<td>2014-2016</td>
<td>A$30M</td>
</tr>
<tr>
<td>Construction (Mine &amp; Concentrator)</td>
<td>2017-2018</td>
<td>A$TBA</td>
</tr>
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**Completed ✓ Pending ★**