Evolution of Scandium Recovery Technology to Increase Supply from Ultra-low Concentration Streams

Presented at the Scandium Inventory Workshop- BAM, November 27\textsuperscript{th}, 2018

Shailesh Patkar, Leigh Dahl, Wen-Qing Xu, Gomer Abrenica, Louie Bedes, Martin Benzing
II-VI’s Scandium Interests

- Vertically Integrated Engineered Rare Materials Producer
- Refining/Production Capabilities with extensive experience in Scandia
- Emerging Processing Technology Leader (Laser Welding, 3D Printing)
- End-Use Markets (Automotive, Aerospace, Lasers, Batteries, SOFC’s)
Scandium Recovery Sources & Technology

- Scandium is mainly recovered as a by-product from residues, tailings and waste liquors in the production of other metals:
  - rare earths, uranium, titanium, tungsten, aluminum, nickel, tantalum and niobium.

- Bauxite and nickel laterite ores are also proposed as promising scandium resources.

- Currently, typical methods comprise hydro- and pyro-metallurgical processes:
  - Ore pre-treatment
  - Leaching
  - Solvent Extraction
  - Precipitation
  - Calcination
### Scandium Performance Vs. Cost Dilemma

<table>
<thead>
<tr>
<th>For</th>
<th>Against</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Reduction</td>
<td>Cost</td>
</tr>
<tr>
<td>Weldability</td>
<td>Cost</td>
</tr>
<tr>
<td>Grain Boundary/Crystallization Modifier</td>
<td>Cost</td>
</tr>
<tr>
<td>High Temperature Stability</td>
<td>Cost</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>Cost</td>
</tr>
<tr>
<td>Ionic Conductivity</td>
<td>Cost</td>
</tr>
<tr>
<td>Optical Properties</td>
<td>Cost</td>
</tr>
</tbody>
</table>

All Emerging Commercial Applications are Price-Sensitive!
Diversification of Scandium Raw Material Supply Chain

Primary: Sc-rich Ores
Secondary: Sc-containing by-product streams from other metals/products
Tertiary: Recycled Sc-based Products

Industry needs a Broadly Diversified Supply Chain & Economical Recovery Solutions!
Scandium Cost/Supply Considerations

- Primary Source (Mines): Upfront Capital Cost: €100M-1B
  - Sc concentrations: 200 ppm-400 ppm
  - Capital Cost + Processing Cost can result in cost of >€2000/kg

- Secondary Source (Tailings, By-Products): Capital Cost: €10M-50M
  - Sc concentrations: 10 ppm-100 ppm
  - Capital Cost + Processing Cost may result in cost <€1000/kg

- Tertiary Source (Recycled End Products): No Steady Source Currently Available
  - Future availability of higher Scandium containing products (>10,000 ppm) could result in long-term cost <€800/kg
Challenges of Solvent Extraction and Ion Exchange Techniques for Separation of Rare Earths

- Solvent Loss, Incomplete Aqueous-Organic Phase Separation, Emulsion & Crud Formation, Mixing Intensity & Rheology-Dependence, Large Volumes of Solution/Slurry to handle small concentrations of Valuable Metals.
  - II-VI invented a Direct Solvent Extraction (DSX) Process to extract RE’s from aqueous acid-leached ore slurries.

- Strong Competition in Recovery of RE$^{3+}$ Ions from Other Multivalent Cations makes Selective Uptake of Target Ions quite challenging.
Challenges in $\text{Sc}^{3+}$ Recovery from an Acid-Leaching Solutions

- Difficulty in Filtration and Washing of a Low pH Acid-Leaching Slurry.
- Strong Competition in Recovery of $\text{Sc}^{3+}$ Ions from Multivalent Cations, particularly, from:
  - $\text{Fe}^{3+}$, $\text{Ti}^{4+}$, $\text{Zr}^{4+}$, $\text{Cr}^{3+}$, $\text{Al}^{3+}$, $\text{Ca}^{2+}$, $\text{Mg}^{2+}$, $\text{Ni}^{2+}$, $\text{Co}^{2+}$, $\text{Zn}^{2+}$, $\text{Cu}^{2+}$, $\text{Mn}^{3+/2+}$, $\text{Si}^{4+}$, etc.
- Reduction of $\text{Fe}^{3+}$ to $\text{Fe}^{2+}$ & $\text{Mn}^{3+}$ to $\text{Mn}^{2+}$: Very Expensive.
- Economically-Prohibitive: for Low-$[\text{Sc}^{3+}]$-Contained Acid-Leaching Solution or Slurry that Contains a high $[\text{Fe}^{3+}]$.

II-VI developed SIR Technology to Address these Challenges!
Evolution of II-VI Scandium Extraction Technology

SX/IE  DSX  SIR
II-VI Selective Ion Recovery Technology (SIR) for Low-[Sc$^{3+}$]-Acid-Leaching Solution or Slurry

- Selectively Recover Sc from Acid-Leaching-Solutions
- Demonstrated for 8-23 ppm Sc Streams
- Tolerate high [Fe$^{3+}$] and other Cations
- No Ferric Reduction Required
- Batch or Continuous Process
- Patent-Pending Technology
SIR Basic Concept

Sc$^{3+}$ ALS
Or HPAL Feed
10-20 ppm

Stripping Agent

Regeneration

Raffinate or HPAL Return

Spent Regeneration solution

Stripped Sc$^{3+}$
Current Status

- Confirmed Process Viability (lab-scale) with EU produced Al and Ti acid leached slurries under Horizon 2020 SCALE (Scandium Aluminium Europe) consortium initiative.

- Construction and Installation of Pilot Plant to Demonstrate Technology in partnership with AoG (and other SCALE consortium partners) in 2019.
Summary

- Scandium’s value in enabling high Energy Efficiency applications will drive demand across a range of markets.

- The rate of adoption of these applications will be cost-dependent.

- Multiple sources of Scandium (primary, secondary and tertiary) needed to create a robust Supply Chain that reassures new adopters of Scandium-based products.

- Secondary (by-product) streams provide the largest availability and biggest cost reduction potential in the near-term.

- II-VI’s portfolio of existing SX, IE, DSX and next generation SIR Scandium recovery technology offer an evolutionary path to Cost Reduction Options.