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

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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.

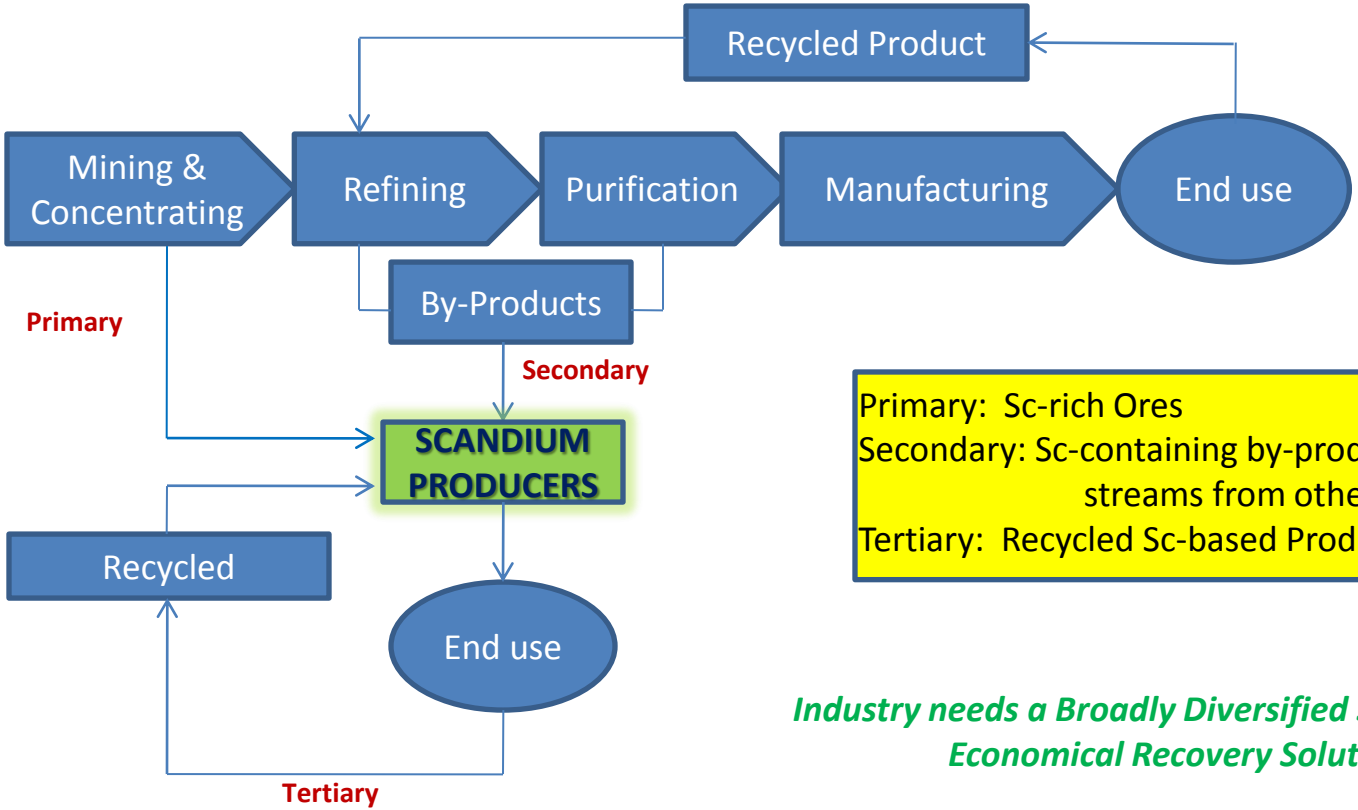
- Currently, typical methods comprise hydro- and pyro-metallurgical processes:
  - Ore pre-treatment
  - Leaching
  - Solvent Extraction
  - Precipitation
  - Calcination

Scandium Performance Vs. Cost Dilemma

For	Against
Weight Reduction	Cost
Weldability	Cost
Grain Boundary/Crystallization Modifier	Cost
High Temperature Stability	Cost
Corrosion Resistance	Cost
Ionic Conductivity	Cost
Optical Properties	Cost

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.

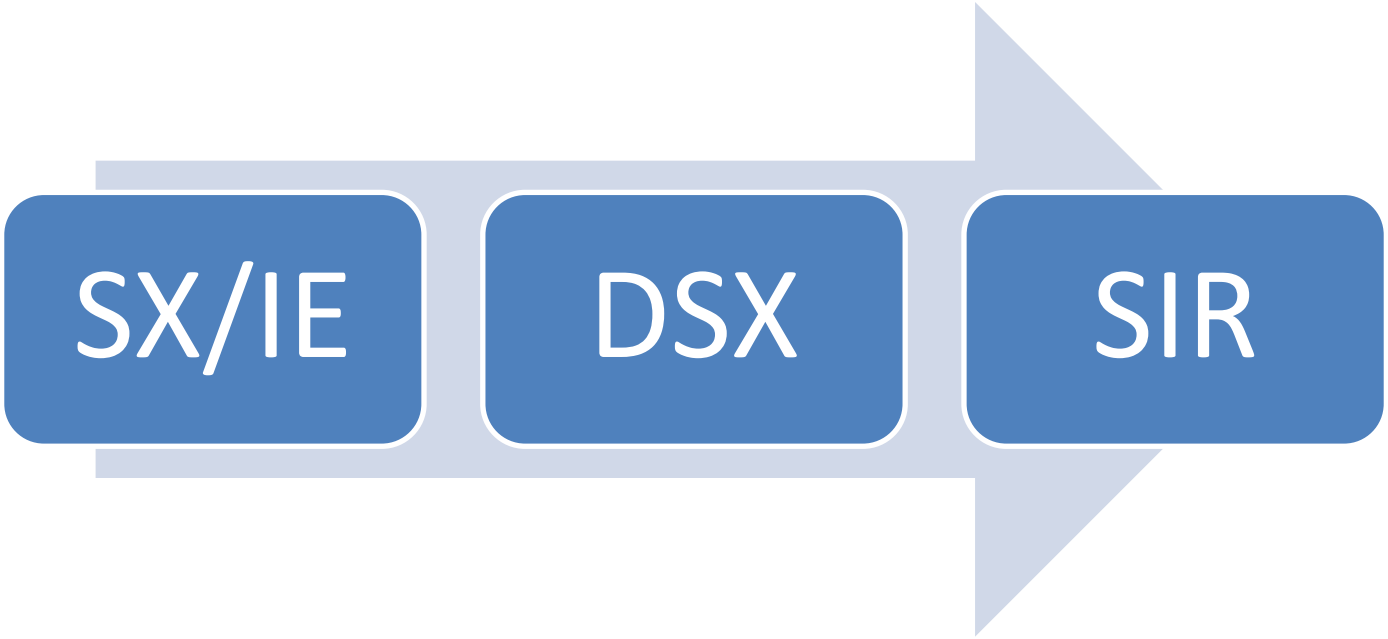
- Strong Competition in Recovery of RE^{3+} Ions from Other Multivalent Cations makes Selective Uptake of Target Ions quite challenging.

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

II-VI developed SIR Technology to Address these Challenges!

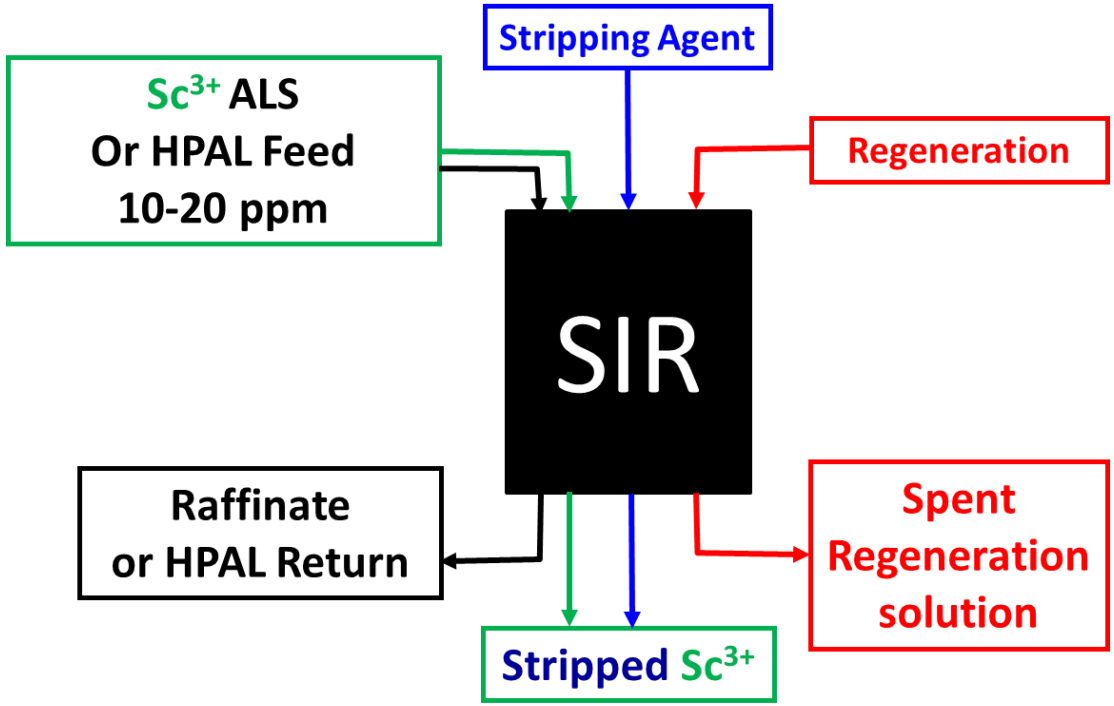
Evolution of II-VI Scandium Extraction Technology



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



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.

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