INFINIUM Aluminum
August 24 – 25, 2016
Detroit, MI

METALS Annual Meeting
Agenda

- Team Intro
- Motivation
- Technical Concept
- Technical Progress to date
- TEA Highlights
- Demo Requirements
- Future Goals/Closing Thoughts
- Q&A
The INFINIUM Team

Clean Metal Production for Clean Energy

Aluminum Team Members
- Adam Powell, PI
- Salvador Barriga, Experimental Lead
- Uday Pal group, Supporting Experiments

Project Summary
- Developed new inert anode technology for aluminum production
- Significant projected energy reduction from 18-19 kWh/kg to 12-13
- Pivoted to low-cost production of Al-Sc master alloy for high performance alloys and products
- Significant flow sheet simplification and cost reduction

Project goals
- Produce at least 10 kg Al-2 wt% Sc master alloy
- Cell/plant design for Al-Sc master alloy production scale-up
Al-Sc Motivation

- **Sintered powder metallurgy parts:**
  - **AlSi10Mg (10% Si 0.5% Mg):** 240-270 MPa $\sigma_y$, 460 MPa UTS, 6-9% ductility
  - **Scalmalloy (3.6% Mg 1% Sc):** $\sigma_y$ 525 MPa, 575-720 MPa UTS, 10% ductility
  - **Ti-6-4 (6% Al 4% Mg):** $\sigma_y$ 620 MPa, 724 MPa UTS, 6% ductility

- **Welding:** 2219 alloy (T87 strength 365 MPa 19.8% ductility)
  - Standard 2319 filler alloy → weld strength 136 MPa, ductility 4.9%
  - 2319 + 0.25% Sc → strength 162 MPa, ductility 8.4% — **20% and 70% higher**
  - 2319 + 0.75% Sc → strength 268 MPa, ductility 9.7% — **both ~100% higher**

- **New mines:** World production will increase 2-20x within 5 years

<table>
<thead>
<tr>
<th>Company</th>
<th>Project type (location)</th>
<th>Volume</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUSAL</td>
<td>Sc from red mud</td>
<td>Unknown</td>
<td>Construction</td>
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<tr>
<td>Sumitomo Metal Mining</td>
<td>Ni-Co mine/plant (Philippines)</td>
<td>7.5 TPY</td>
<td>Construction</td>
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<td>NioCorp</td>
<td>Nb-Ti-Sc (Nebraska)</td>
<td>97 TPY</td>
<td>Fundraising</td>
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<tr>
<td>Scandium International</td>
<td>Sc primary (NSW Australia)</td>
<td>37 TPY</td>
<td>Fundraising</td>
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<tr>
<td>Platina Resources</td>
<td>Pt-Sc (NSW Australia)</td>
<td>30 TPY</td>
<td>Fundraising</td>
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<tr>
<td>CleanTeq</td>
<td>Sc primary (NSW Australia)</td>
<td>~30 TPY</td>
<td>Fundraising</td>
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**Technical Concept**

### Al-Sc Master Alloy Production Today:

- **Sc$_2$O$_3$**
  - $1700/kg
  - $2600/kg
  - $5.20/kg
- **Ca metal, welded Ta retorts**
- **ScF$_3$**
  - $2050/kg
  - $4650/kg
  - $9.30/kg
- **Al$_2$O$_3$**
- **Electrolysis**
- **Al metal**
  - $1.50/kg
- **Distill**
- **Pure Sc metal**
  - >$5000/kg
  - >$10/kg
- **Pure metal**
  - >$5000/kg
  - >$10/kg

Even if new mines cause the price of Sc$_2$O$_3$ to fall to $600/kg →$920/kg → $1.84/kg →

**INFINIUM Solution:**

- **Al$_2$O$_3$**
- **Direct Oxide Electrolysis**
- **Al-2%Sc Master Alloy**
  - Low Cost

Low-cost Sc$_2$O$_3$ + Low-cost process → Total cost is very low Enables broad adoption

Single step, no HF, no reductants, no refractory metal welds
Technical Progress to Date

- **Inert Anodes:**
  - New tube geometry and anode material
  - Lower temperature (700°C), lower anode resistance
  - Significant improvement in lifetime and current density

- **Al-Sc Master Alloy:**
  - Can repeatably make product exceeding composition specs
  - Next: optimize process parameters
  - Project end goal: scale up production to multi-kg quantity

- **Biggest successes to date:**
  - Inert anodes: two orders of magnitude improvement in charge/area in the past year
  - Production of Al-Sc alloy directly from oxides
TEA Highlights

- **Partner engagement**: developing relationship with a company opening a new scandium oxide mine/production facility
  - Received a large Sc₂O₃ sample with more to come
  - Partner is marketing to aerospace and automotive industries

- **Price range**: will make final alloy very competitive with titanium

- **Energy/emissions**:
  - Self-heated cell energy comparable to primary aluminum
  - Direct emissions below primary aluminum

- **Benefits**:
  - Much lower cost than today’s process due to simplified flow sheet
  - Continuous production → high yield

- **Typical plant scale**:
  - Aiming for 200-500 TPY Al-2Sc master alloy
Demo Requirements

▶ If this project succeeds, the Demonstration phase will build and test a small pilot production cell
  – Scale: 2-10 TPY
  – Cost Range: relatively small compared with scandia cost
  – Projected Outcomes:
    • Large samples for customer trials
    • Design for full-scale production cell
    • More accurate cost model for full production

▶ Partnership requirements
  – Scale-up will require funding for larger cells and scandium oxide material
  – Supply agreement(s), customer off-take
Future Goals/Closing Thoughts

- **Project end goals:**
  - At least 10 kg product to sample to partner and other customers
  - Design for the Demo phase pilot production cell

- **5-10 year vision:**
  - 200-500 TPY production
  - Scale-up of other master alloy systems which are difficult to produce by melting alone or have other challenges

- **Prospective impact:**
  - Dramatically reduce costs in a key Al-Sc value chain step
  - Enable low-cost mines to produce for new lower-cost markets
  - Expand the use of this outstanding alloy system
Aluminum-Cerium Alloys

- **Motivation:**
  - Very good castability, high-T creep
  - Potential engine applications

- **Challenge:**
  - Nearly all Ce metal production is in China

- **INFINIUM Solution:**
  - Directly produce alloy from oxides