Current State of the Sc Recovery Possibilities during Hydrometallurgical Treatment of Lateritic Ni-Co Ores

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META Nikel-Kobalt A.Ş.: Turkey’s 1st and Europe’s only HPAL Ni-Co concentrate facility
OUTLINE

- Current Sc Sources and Supply/Demand Issues:
- Laterite Reserve/Production Information:
- Companies Developing New Sc Projects:
- Scandium Recovery from Lateritic Ni-Co Ores:
- Sc Distribution in META HPAL Plant
- References:
Current Sc Sources and Supply/Demand Issues

No primary Sc mine production yet!
- As a by product during Iron-Uranium Production,
- As a by product during Tungsten Production,
- As a by product during Titanium Production,
- As a by product during Zirconium Production,
- As a by product during REE’s Production, [1,2]

• Supply is only ~5-12 tons/year in the form of \( \text{Sc}_2\text{O}_3 \) and the price is too high (2000-4500 $/kg 99.9 \( \text{Sc}_2\text{O}_3 \)) for commercial applications. [3]

• Currently, only used in applications where performance is much more important than the price (military/sporting goods, space appl. etc.)

However; when consistent, abundant, reliable and low cost scandium supply is achieved, commercial applications will certainly boom!

The solution for the short term promising source of the huge and urgent scandium need of the industry:

LATERITES
World Laterite Reserves

**Trend in Nickel Production from Laterites**

- In 1950’s  <10% of primary Ni was produced from lateritic ores,
- In 2003  ~42% of primary Ni was produced from lateritic ores,
- In 2012  ~50% of primary Ni was produced from lateritic ores,
- In 2020’s  It is expected that 55-60% of Ni will be produced from lateritic sources.

**Sulfides:** Russia, Canada, South Africa, Australia.

**Laterites:** Indonesia, Philippines, New Caledonia, Colombia, Madagascar, Cuba, Papua New Guinea, Brazil, Venezuela, Dominican Republic, Australia, Turkey, Greece, Albania, Serbia, etc.

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*Images and text from Europe’s CRM Data Management & The European Scandium Inventory Workshop, Berlin.*
## Companies Developing New Sc Recovery Projects

<table>
<thead>
<tr>
<th>Company &amp; Project/Deposit Name</th>
<th>Location</th>
<th>Head Grade (mg/kg)</th>
<th>Cut-off Grade (mg/kg)</th>
<th>Contained Sc₂O₃ (tons)</th>
<th>By-products</th>
<th>Production Route</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean TeQ Syerston/Sunrise Ni-Co-Sc Project (Previously Ivanhoe Mines)</td>
<td>Australia</td>
<td>583</td>
<td>300</td>
<td>18,000</td>
<td>Ni, Co</td>
<td>HPAL Sc IX (Resin in Pulp) IX-SX for Ni&amp;Co sulphate</td>
<td>DFS completed in 2018. Construction is planned in 2019.</td>
</tr>
<tr>
<td>Scandium Int.&amp; Scandium Inv. LLC. Nyngan Scandium Project</td>
<td>Australia</td>
<td>409</td>
<td>100</td>
<td>3,135</td>
<td>None</td>
<td>HPAL SX</td>
<td>DFS completed in Waiting financing</td>
</tr>
<tr>
<td>Platina Resources Ltd. (Owendale Sc-Pt Project)</td>
<td>Australia</td>
<td>384</td>
<td>300</td>
<td>16,500</td>
<td>Ni, Co, Pt</td>
<td>HPAL SX</td>
<td>PFS</td>
</tr>
<tr>
<td>Metallic/Australian Mines SCONI Project</td>
<td>Australia</td>
<td>208</td>
<td>120</td>
<td>3,000</td>
<td>Ni, Co</td>
<td>HPAL SX</td>
<td>DFS</td>
</tr>
<tr>
<td>Jervois/Australian Mines Flemington Deposit</td>
<td>Australia</td>
<td>450</td>
<td>300</td>
<td>2,085</td>
<td>Ni, Co</td>
<td>HPAL SX</td>
<td>PFS</td>
</tr>
<tr>
<td>Imperial Mining Crater Lake</td>
<td>Canada</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Nb, Ti, Zr</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Niocorp Niobium Project Elk Creek</td>
<td>USA</td>
<td>72</td>
<td>-</td>
<td>3,400</td>
<td>Nb</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RUSAL Al Corp. – From Red Mud by carbonate/bicarbonate leaching</td>
<td>Russia</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Carbonate Leaching IX</td>
<td>Currently producing Sc₂O₃ in its pilot plant facilities.</td>
</tr>
</tbody>
</table>

[9-10 and corporate webpages]
Sc from Lateritic Ni-Co Ores and Residues

- When compared to NaOH leaching of Bauxite ores in Al production, Sc does not dissolve during leaching and remain in the Leach Residue-Red Mud.
- Depending on the ore mineralogy 80-95% of Sc in lateritic ores dissolves during HPAL. [11,12]
- At META-Gördes HPAL Plant, Sc leach recovery is ~80%.

Main Ni-Co Recovery Options

1-MSP (Mixed Ni-Co Sulfide Ppt.)
- Coral Bay (Philippines)
- Taganito (Philippines)
- Ambatovy (Madagascar)
- Moa Nickel (Cuba)
- Murrin Murrin (Australia)

2-MHP (Mixed Ni-Co Hydroxide Ppt.)
- Ramu Nickel (Papua New Guinea)
- Ravensthorpe (Australia)
- Cawse (Australia)
- META Nikel-Kobalt A.Ş. (Turkey)

3-Direct Solvent Extraction
- Bulong (Australia)
- Goro Nickel (New Caledonia)

Europe’s CRM Data Management & The European Scandium Inventory Workshop, Berlin
Sc from Lateritic Ni-Co Ores and Residues

Companies Developing New Sc Projects

Sumitomo Metal Mining Co.

- Coral Bay & Taganito MSP HPAL Plants (Philippines)
- In 2013, Pilot Plant constructed in Coral Bay 10 kg/month Sc₂O₃ capacity, and the industrial plant in Taganito HPAL and Harima Refinery (Japan) having 7.5 ton/year Sc₂O₃ capacity was completed in 2017.
- Sc concentration by IX and purification by SX.
- Product Portfolio: Sc₂O₃

META Nikel-Kobalt A.Ş.

- Gördes MHP HPAL Plant-Eskişehir Yunusemre Deposit (40-120 g/ton Sc)
- Patent Applications for IP.
- Scandium fluoride chemicals are targeted [13, 14].
- Lab. scale process chemistry was proved in bench and semi-pilot scale.
- Product Portfolio: (NH₄)₂NaScF₆, (NH₄)₂KScF₆, (NH₄)₃ScF₆, ScF₃ and mixture of (NaScF₄ - Na₃ScF₆), (K₃ScF₆ - KSc₂F₇)

Companies Already Operating HPAL Plants for Ni-Co Production
Sc from Lateritic Ni-Co Ores and Residues

1-MSP (Mixed Ni-Co Sulfide Ppt.) Method

Laterite Ore → HPAL-Autoclave → Primary Neut. and S/L Separation → Leach Residue + Hydrolyzed Impurities

H₂S → Ni-Co Sulfide ppt. → Ni-Co Sulfide

Sc containing soln. → Sc Upgrading by IX → Sc Recovery by SX

Sc Precipitation → Re-leaching → Sc Recovery by IX or SX
Sc from Lateritic Ni-Co Ores and Residues

2-MHP (Mixed Ni-Co Hydroxide Ppt.) Method

Laterite Ore

HPAL-Autoclave

Primary Neut. and S/L Separation

pH 2.75-3.0

Impurity Removal and Sc ppt.

pH 4.75-5.0

Ni-Co Hydroxide ppt.

pH 7.0-8.0

Leach Residue

4-7 times Sc enrichment

Re-leaching

Sc Recovery by IX or SX

[15, 16]
Sc from Lateritic Ni-Co Ores and Residues

Behaviour of Sc in Gördes HPAL Plant during HPAL during 250 days of operation

Average 36 ppm Sc in from feed

~80% Leach Recovery during HPAL!

Average 8 ppm Sc unleached in LR
Sc from Lateritic Ni-Co Ores and Residues

Behaviour of Sc in Gördes HPAL Plant during HPAL during 250 days of operation

~15 times Sc concentration in the residue!!!

>95% Sc leach recovery within just 15 min. with 100 g/L H₂SO₄ !!!
<table>
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<tr>
<th>PLS</th>
<th>Strip Liquor</th>
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</thead>
<tbody>
<tr>
<td>Ag ppm</td>
<td>Ag ppm</td>
</tr>
<tr>
<td>Al ppm</td>
<td>Al ppm</td>
</tr>
<tr>
<td>As ppm</td>
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<tr>
<td>Ca ppm</td>
<td>Ca ppm</td>
</tr>
<tr>
<td>Cd ppm</td>
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</tr>
<tr>
<td>Co ppm</td>
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<td>Cr ppm</td>
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<td>Fe ppm</td>
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<td>Mg ppm</td>
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<td>Mn ppm</td>
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<tr>
<td>Ni ppm</td>
<td>Ni ppm</td>
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<tr>
<td>Pb ppm</td>
<td>Pb ppm</td>
</tr>
<tr>
<td>Sc ppm</td>
<td>Sc ppm</td>
</tr>
<tr>
<td>Zn ppm</td>
<td>Zn ppm</td>
</tr>
</tbody>
</table>

High Purity $\text{(NH}_4\text{)}_2\text{ScF}_6$ Product

High purity $\text{ScF}_3$ can be obtained after calcination.
Sc Recovery Possibility from Laterites - Worst Case Scenario!

- 1) Coral Bay – MSP ................. 24 000 ton Ni,
- 2) Taganito – MSP .................. 36 000 ton Ni,
- 3) Murrin Murrin – MSP .......... 40 000 ton Ni,
- 4) Ambatovy – MSP ................ 40 000 ton Ni,
- 5) Moa Bay – MSP ................. 30 000 ton Ni,
- 6) Ramu – MHP ..................... 35 000 ton Ni,
- 7) Ravensthorpe – MHP ........... 40 000 ton Ni,
- 8) META Nikel-Kobalt – MHP ... 10 000 ton Ni,

USGS, 2018 Price Data

<table>
<thead>
<tr>
<th></th>
<th>Purity (%)</th>
<th>Sample Size</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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</thead>
<tbody>
<tr>
<td>Scandium Acetate, US$/per gram</td>
<td>99.9</td>
<td>5 gr</td>
<td>51.90</td>
<td>43.00</td>
<td>43.00</td>
<td>44.00</td>
<td>44.00</td>
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<tr>
<td>Scandium Chloride, US$/per gram</td>
<td>99.9</td>
<td>5 gr</td>
<td>148.00</td>
<td>123.00</td>
<td>123.00</td>
<td>126.00</td>
<td>124.00</td>
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<tr>
<td>Scandium Iodide, US$/per gram</td>
<td>99.999</td>
<td>5 gr</td>
<td>228.00</td>
<td>187.00</td>
<td>187.00</td>
<td>149.00</td>
<td>183.00</td>
</tr>
<tr>
<td>Scandium Oxide, US$/per gram</td>
<td>99.99</td>
<td>5000 gr</td>
<td>5.00</td>
<td>5.00</td>
<td>5.10</td>
<td>4.60</td>
<td>4.60</td>
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<tr>
<td>Scandium Fluoride, US$/per gram</td>
<td>99.9</td>
<td>5 gr</td>
<td>253.00</td>
<td>263.00</td>
<td>263.00</td>
<td>270.00</td>
<td>277.00</td>
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<tr>
<td>Scandium Ingot, US$/per gram</td>
<td>-</td>
<td>5 gr</td>
<td>175.00</td>
<td>134.00</td>
<td>134.00</td>
<td>107.00</td>
<td>132.00</td>
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</tbody>
</table>

Approximately: ~250 000 ton Ni/year comes from laterites

If ores contain ~1% Ni → ~25 million tons of lateritic ore processed annually!

If lateritic ores contain ~40 g/ton Sc (worst case) ~(25 million tons * 40 g/ton = 1000 tons Sc) enter into the HPAL process annually.

If ~50% of Sc recovered overall during HPAL → ~500 tons Sc production (worst case) is possible with the current scenario.

By taking long term (2000 $/ton for Sc₂O₃) and (3000 $/ton for ScF₃)

500 tons Sc → 750 tons Sc₂O₃, Economic Value: (750 tons * 1000 $/kg) = 0.75 Billion USD/year

500 tons Sc → 1100 tons ScF₃, Economic Value: (1100 tons * 1500 $/kg) = 1.65 Billion USD/year
For the widening of Sc market and applications in a sustainable manner:

- Reliable,
- Secure,
- Long-term,
- Open to collaborations,

As META, we are ready and confident about producing:

- \((\text{NH}_4)_2\text{NaScF}_6\), \((\text{NH}_4)_2\text{KScF}_6\),
- Mixture of \((\text{NaScF}_4 - \text{Na}_3\text{ScF}_6)\) or \((\text{K}_3\text{ScF}_6 - \text{KSc}_2\text{F}_7)\)
- \((\text{NH}_4)_3\text{ScF}_6\),
- And, \(\text{ScF}_3\) if collaborated with serious partners.
REFERENCES

6. Sudol, S., The thunder from down under: Everything you wanted to know about laterites but we were afraid to ask. Canadian Mining Journal, (2005).
Additional Slides
Laterites are mainly composed of:
• Fe rich, Mg, Si poor **Limonitic (Fe oxide dominant)**, and (more amenable to HPAL)
• Fe poor, Mg, Si, rich **Saprolitic (Mg silicate dominant)** zones (more amenable to FeNi and NPI)
APPLICATIONS of Sc

Al-Sc & Al-Sc-Mg Alloys

Solid Oxide Fuel Cells

Lasers & Lighting

3D Printing Tech.

In the Near Future
Clean TeQ Sc Recovery Circuit
Clean TeQ Sc Recovery Circuit
The changing face of nickel – stagnation in sulphide production as laterites take off – mine production basis

Sulphide ore production stops growing

Laterite nickel mine production takes off

Source: INSG, Macquarie Research, July 2013

New Caledonia has not participated in the laterite ore surge
PATH OF LATERISATION

All compositions are shown in terms of the three oxides.

- SiO2
- MgO
- FeO or F2O3

- Bedrock
- Hard Saprolite
- Soft Saprolite
- Limonite
Sc from Bauxite Residues (Red Mud)

Environmental concerns and huge economic potential, force the exploitation of Red Mud for Sc recovery.

Hydrometallurgical Approaches
• Selective Leaching
  ✓ (mineral acids: $\text{H}_2\text{SO}_4$, $\text{HCl}$, $\text{HNO}_3$),
  ✓ (carbonate leaching),
  ✓ (Ionic liquids),
• IX - Solvent Extraction (Recovery & Purification)

Pyro-Hydrometallurgical Approach
• Reductive Roasting & Magn. Separation
• Reductive Smelting of BR for Fe rec. (Pig Iron)
  ✓ > 98% Sc reported in the slag
• Leaching & Recovery by IX-SX
Worldwide there is an annual bauxite residue production of 120 million tonnes (dry matter) and a total inventory of 3 billion tonnes, stored in huge tailing ponds. Sc is enriched ~2 times in the BR and represents >95% of the economic value of rare earth elements in red mud.

Environmental concerns and huge economic potential, force the exploitation of Red Mud for Sc recovery.
Sc from Bauxite Residues (Red Mud)

**ORBITE Alumina Flowsheet** [6]

- **Red Mud**
  - HCl Leaching
  - S/L Separation
  - AlCl$_3$.6H$_2$O Crystallization
  - AlCl$_3$.6H$_2$O Calcination
  - Al$_2$O$_3$
  - Impurity Hydrolysis
  - Impurities
  - Sc/REE Recovery

**RUSAL Flowsheet** [7]

- **Red Mud**
  - Carbonate Leaching (NaHCO$_3$ + CO$_2$)
  - S/L Separation
  - Impurity Hydrolysis I
  - Ti, Zr
  - Hydrolysis II
  - NaOH
  - Sc Concentrate
  - Further Purification
  - > 99% Sc$_2$O$_3$

*Pilot Plant in Urals Al Smelter
~95 kg Sc$_2$O$_3$ per year*
Sc from Lateritic Ni-Co Ores and Residues

Companies Developing New Sc Projects

<table>
<thead>
<tr>
<th>Project Characteristic</th>
<th>Nyngan</th>
<th>Syerston</th>
<th>Owendale</th>
<th>ScONi</th>
<th>Flemington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proponent</td>
<td>Scandium International Mining Corp</td>
<td>Clean TeQ</td>
<td>Platina Resources</td>
<td>Metallica/ Australian Mines</td>
<td>Jervois/ Australian Mines</td>
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<tr>
<td>Study Status</td>
<td>DFS Completed</td>
<td>PFS (Sc only)</td>
<td>Scoping/ PFS underway</td>
<td>PFS by Metallica/ DFS by Auz</td>
<td>Scoping Completed by Auz</td>
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<td>Next Steps</td>
<td>Financing</td>
<td>DFS</td>
<td>PFS</td>
<td>DFS</td>
<td>PFS</td>
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<td>300 ppm</td>
<td>120 ppm</td>
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<td>Head Grade</td>
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<td>583 ppm</td>
<td>384 ppm</td>
<td>208 ppm</td>
<td>450 ppm</td>
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<td>By-products</td>
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<td>Co, Ni</td>
<td>Co, Ni, Pt</td>
<td>Co, Ni</td>
<td>Co, Ni</td>
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<tr>
<td>Resource (t Sc₂O₃)</td>
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<td>11,819</td>
<td>16,500</td>
<td>1,950</td>
<td>2,085</td>
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<tr>
<td>Recovery</td>
<td>83.7%</td>
<td>88%</td>
<td>86%</td>
<td>81.5%</td>
<td>76.2%</td>
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<tr>
<td>Product %</td>
<td>99.8%</td>
<td>99.9%</td>
<td>99.9%</td>
<td>99.99%</td>
<td>99.9%</td>
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<tr>
<td>Capacity (tpa)</td>
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<td>49.2</td>
<td>30</td>
<td>68</td>
<td>50</td>
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<td>Process</td>
<td>HPAL/SX</td>
<td>HPAL/RIP IX</td>
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<td>HPAL/SX</td>
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<td>CAPEX</td>
<td>US$77.8M</td>
<td>US$75M</td>
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<td>OPEX</td>
<td>US$556/kg</td>
<td>US$444/kg</td>
<td>US$598/kg</td>
<td>US$853</td>
<td>AUD$531</td>
</tr>
</tbody>
</table>

Lateritic Ni-Co resources seem highly advantageous;

- Urgent,
- Reliable/secure,
- Sufficient,
- Long-term/stable,
- Reasonably priced,
- Sustainable,

Sc Production in the near future!