UTRS Method of Extracting Binary and Tertiary Titanium Alloy from Natural Ores
UTRS – Who We Are

• Universal Technical Resource Services, Inc. (UTRS, established in 1985) is a small business that provides a wide range of leading-edge scientific, engineering, management, and information technology to the public and private sectors.
• Our mission is to consistently deliver creative, high-quality, technology-based services and solutions to our customers on time and within budget. This includes various engineering services in diverse technical areas.
• Our customer base includes clients such as the Department of Defense, the Federal Aviation Administration, the Federal Laboratory Consortium for Technology Transfer, NASA, IBM, General Electric and AT&T.
• As a part of our service to US army, UTRS has developed a more energy efficient and environmentally friendly process to produce titanium metal.
Goal:
• Develop a more energy efficient and environmentally friendly process to produce titanium metal

Accomplishments:
• Designed a Ti production method – two major processing steps: 1) Extraction and 2) Refining/Recycling
• Diversity of input ores and output products
• Low production costs
• Fewer production steps to Ti-6Al-4V, powder, ingot, Ti aluminides, Ferro-Ti and more
• No hazardous chemicals are used and no greenhouse gas (CO₂) is produced in any part of the process.

Limited by Current Laboratory Equipment
• Need better equipment for next phase - process scale-up
The UTRS Ti Process can utilize a variety of Ti ores.
Step 1 – Extraction: Titanium metal is extracted from Ti ores and is easily separated from the slag.
Step 2 – Refining: Extracted titanium alloy is further refined to a dendritic metal product called “Titanium wool”
UTRS Titanium Process

Titanium Ore → Reduction → Unrefined Ti alloy

Purified Ti-wool ← Vacuum Evaporation ← Ti-wool & electrolyte Separation ← Ti-wool in frozen electrolyte ← Electro-refining
Ingot Production for Bulk Titanium Applications

Titanium ingots can be pressed directly from Ti wool without a binder. Incorporation of master alloy prior to pressing followed by melting (e.g., in a VAR furnace) provides a path to desired alloy composition.

- Green: 85-88% relative density
- Sintered: 95-97% relative density
Direct Route to Additive Manufacturing

It has been demonstrated that UTRS Ti wool is well suited to produce Ti rod or wire by using a novel Spark Plasma Extrusion technique. These products can be used in Additive Manufacturing equipment to directly produce titanium parts.
Powder from Titanium Wool

By gentle grinding of titanium wool, titanium powder can be produced.

UTRS Ti wool  →  Ti powder
Titanium Recycling:

Off grade or scrap Ti can be recycled to high purity Ti with the UTRS process.

Off-Grade Ti Sponge → Purified Ti-wool → Pressed & Sintered Ti Piece
Analytical Results of Selected Samples from UTRS Process

- UTRS Titanium Alloy, Ti-5Al: 95 % Ti, 3.8 % Al
- CP Titanium: 99 % Ti, 0.2 % Al
- TiAl: 61 % Ti, 38 % Al
- Ti-6Al-4V from conventional alloying: 89 % Ti, 6.3 % Al, 3.8 % V
- Ti-6Al-4V Direct from process: 89 % Ti, 6.0 % Al, 3.9 % V
## Raw Materials and Energy Cost: Kroll vs. UTRS (Ti-5Al)

<table>
<thead>
<tr>
<th>Raw Materials</th>
<th>Unit Cost/Kg</th>
<th>Kroll Process</th>
<th>UTRS Process</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Materials/ kg of Ti</td>
<td>Cost, US$/ kg of Ti</td>
</tr>
<tr>
<td>Ti Ore and Other Chemicals</td>
<td>6.95</td>
<td>4.25</td>
<td>4.29</td>
</tr>
<tr>
<td>Energy (kWh)</td>
<td>0.07</td>
<td>100</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Total Cost ($)</strong></td>
<td><strong>11.25</strong></td>
<td><em>(8.70)</em></td>
<td><strong>4.86</strong></td>
</tr>
</tbody>
</table>

*Cost assumption based on Mg & Cl₂ recycle; if purchase, add 2.55 $/kg
### Raw Material and Energy Cost for UTRS Ti-6Al-4V:

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Cost, US$/kg</th>
<th>Materials/kg of Ti64</th>
<th>Cost, US$/kg Ti64</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiO2</td>
<td>0.77</td>
<td>2.85</td>
<td>2.20</td>
</tr>
<tr>
<td>V, Al, Other</td>
<td>1.60</td>
<td>3.88</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>0.07</td>
<td>12kWh</td>
<td>0.84</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>6.92</td>
</tr>
</tbody>
</table>

**Average price for Ti-6Al-4V is ~$17.0/kg.**

Sources: metalprices.com, InvestmentMine and Largo Resources ltd.
Comparison of UTRS (Ti-5Al) and Kroll Process with Future US Targets (for 1kg of Ti)

<table>
<thead>
<tr>
<th></th>
<th>Kroll Process</th>
<th>UTRS Process</th>
<th>US Future Targets¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>100kWh</td>
<td>12kWh</td>
<td>35kwh</td>
</tr>
<tr>
<td>CO₂ emission</td>
<td>36kg</td>
<td>0.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Production Cost ($)</td>
<td>9.0</td>
<td>5.0-6.0²</td>
<td>4.0</td>
</tr>
</tbody>
</table>

1. Targets based on ARPA-e Metals Program
2. Price range from materials/energy ($5) and engineering analysis with CapEx ($6)
### Lower Capital and Production Expenses

<table>
<thead>
<tr>
<th></th>
<th>Kroll</th>
<th>UTRS</th>
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</thead>
<tbody>
<tr>
<td>CapEx</td>
<td>$400MM</td>
<td>$216MM</td>
</tr>
<tr>
<td>OpEx</td>
<td>$9/kg</td>
<td>$5-6/kg</td>
</tr>
</tbody>
</table>

Based on a 10,000 MT production plant

- **Anticipated additional cash flow for a UTRS plant: $30MM***

  *Based on a selling price of $9/kg and subtracting the max estimated production cost of $6/kg.*
UTRS, an Open Architecture Process

OPEN, UTRS Ti PROCESS

UTRS PROCESS

\[ \text{TiO}_2 \rightarrow \text{UTRS Process} \rightarrow \text{Ti Wool} \rightarrow \text{Ti64} \rightarrow \text{Direct to Additive} \rightarrow \text{Ti Rod & Wire} \rightarrow \text{Ti Spherical Powder} \]

\[ \text{Non-traditional ores: } \text{limonite, rutile, perovskite} \]

\[ \text{Scrap Ti} \]

\[ \text{Rare Earth Halides} \]

CLOSED, KROLL Ti PROCESS

UTRS PROCESS

\[ \text{TiO}_2 \rightarrow \text{KROLL Process} \rightarrow \text{Ti Sponge} \]

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Thank you for Your Consideration

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