Australian Titanium
From Ore to More

International Titanium Association, October 2011

John E. Barnes
Leader
Titanium Technologies
CSIRO today: a snapshot

Australia’s national science agency
One of the largest & most diverse in the world
6500+ staff over 55 locations
Ranked in top 1% in 14 research fields
20+ spin-off companies in six years
160+ active licences of CSIRO innovation
Building national prosperity and wellbeing
Our purpose

By igniting the creative spirit of our people…

**Great people**

…we deliver great science and innovative solutions…

**Great science**

…for industry, society and the environment

**Great impact**
Titanium - from ore to *more*

<table>
<thead>
<tr>
<th>1</th>
<th>Rank of Australian titanium ore reserves in the world</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Amount of Titanium metal produced in Australia</td>
</tr>
<tr>
<td>90</td>
<td>Number of years until known ore is depleted</td>
</tr>
<tr>
<td>100</td>
<td>The factor of economic value of metal over ore</td>
</tr>
<tr>
<td>1%</td>
<td>Resource that could be used to yield the same revenue</td>
</tr>
<tr>
<td>9,000</td>
<td>Years of resource left</td>
</tr>
</tbody>
</table>
Titanium - from ore to more

Titanium Technologies

Metal Production
- TIRO
- Alloys Process
- Inert Anodes
- Novel Alloys

Powder to Product
- Sheet
- Wire
- Extrusions
- Billet
- Powder Prep
- Blocker Forgings

Manufacturing
- Cold Spray
- Additive Manufacturing
- Machining Technologies
Titanium Technologies

Reduction of Waste

Affordable

Sustainable

Buy and Fly Figures for Aerospace Parts

<table>
<thead>
<tr>
<th>Waste</th>
<th>Buy</th>
<th>Fly</th>
</tr>
</thead>
<tbody>
<tr>
<td>91%</td>
<td>9%</td>
<td></td>
</tr>
</tbody>
</table>

Ilmenite and Titanium

- 700,000 tonnes pa
- 600,000 tonnes pa
- 500,000 tonnes pa
- 400,000 tonnes pa
- 300,000 tonnes pa
- 200,000 tonnes pa
- 100,000 tonnes pa

1% reduction in waste
Innovation the key for manufacturing

Kim Carr  
September 2, 2011

There’s no turning back for the troubled sector - just turning around, writes Kim Carr.

So why do I say Australian manufacturers are up to this fight?

We are a creative and resilient people, and we should be prepared to back ourselves. The CSIRO, for example, is working with industry to develop a viable titanium processing industry. Titanium alloys are light and strong but current production methods are too costly to expand their use beyond the aerospace market. CSIRO’s new technology is far more versatile, cutting waste and bringing down the cost by 40 to 50 per cent. That would allow Australia to open new markets in the medical and energy sectors, and get more value from our substantial titanium ore reserves.

That is a snapshot of what innovation makes possible.

It won’t happen by chance, but it can happen by choice. That is the key to everything the government has been doing for the past three years. We are implementing today the most ambitious innovation agenda in our history.
METAL PRODUCTION
TiRO™ Titanium
A continuous titanium production process

The advantages of the TiRO™ process

**Efficient** – Low use of energy per tonne of titanium produced

**Capital** – Significant reduction of Kroll capital requirement

**Continuous** – Low labour, high output continuous production

**Key Features:**
- Fluidised Bed Reactor
- Continuous Vacuum Distillation
TiRO™ Titanium
A continuous titanium metal production process

Current status of the TiRO™ project

• Solving last remaining challenges around the continuous separation stage

• Optimizing TiRO™ flowsheet for ‘sponge’ production

• Understanding morphology considerations:
  - Native powder tap density ~50% (> 2.2g/cm³)
  - Hollow irregular spheres

The future of TiRO™

• Pilot Plant

• Investigating TiRO™ potential to make alloys (i.e. Ti-6Al4V, Ti-Pd, Super-TiX, etc)

Demonstrated quality of TiRO™ powder

<table>
<thead>
<tr>
<th>Element</th>
<th>%wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>&gt; 99.7</td>
</tr>
<tr>
<td>Oxygen</td>
<td>&lt; 0.15</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Carbon</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>Sodium</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>Chlorine</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>Others (Total)</td>
<td>&lt; 0.10</td>
</tr>
</tbody>
</table>
Electrometallurgy & Recent Focus for Ti

- Inert anodes for Ti electrowinning (FFC type process)
- Studying electrode materials *in-situ* using advanced diffraction techniques
- First group in the world to *quantitatively* characterise anode corrosion using diffraction data obtained *in situ*
- Flexibility of furnace and cell design allows materials to be studied in other complex, high-temperature environments:
  - ‘Real’ anode materials and/or cathodes
  - Sintering or hydrothermal processes
  - Controlled atmosphere processing:
    - Vacuum
    - Inert atmospheres
    - Reducing atmospheres
POWDER TO PRODUCT
Continuous Extrusion Capability

**Goal** – Continuous, affordable extruded shapes
- 3 mm diameter wire

**Applications**
- Potential for weld wire
- Fastener applications

**Achievements**
- Continuous extrusion of 12, 9 & 6 mm dia
- CP and BE Ti mixtures

BE Ti64: 58%Al-42%V + CP2 H/DH:

β field anneal: Acicular 64, (99.85% TD)

6 mm DIA CP Ti
Continuous Extrusion Capability

CP2 Rod Feed

ConX CP2

ConX CP1, high Cl Sponge fines

ConX CP2, ITP

ConX CP3, H/DH

100%TD

99.4%TD

99.8%TD
Continuous Sheet Production

Powder feedstock

- Morphology
- Flow properties
- Fill/tap density
- Chemistry

Green Sheet

- Density
- Dimensional accuracy

Consolidated Strip

- Processing
- Properties
- Chemistry
- Microstructure
Continuous Ti Sheet Production

Rolled green sheet

Fully commissioned and encapsulated hot roll mill and control station

CP Ti, 0.2% O, annealed
Tensile properties in *longitudinal* direction
UTS 655 MPa, 0.2% proof stress 449 MPa, elongation to failure 18.6%
MANUFACTURING
Morphology Considerations in Cold Spray

HDH Kimet Chinese Grade 4/5 (ASTM B861)

Gas Atomised TLS German Grade 2 (ASTM B861)

ITP CP-Powder
Dendritic structure (as-received)

Near spherical shape and can be easily broken
Appears ideal for Cold spray
Cold Spray for Pre-forms
Additive Manufacturing via EBFFF

Australian Direct Manufacturing Initiative

- Allowables for Production
- Distortion Control Technologies
- Advanced Inspection Methods
- Additional Material Data
- Novel Titanium Materials

Electron beam Additive Manufacturing Technology
Callaghan Forsyth, an Honours Industrial Design student at Swinburne University in Melbourne, VIC for his concept of an advanced radiator.
TECHNOLOGY TRANSFER IS A FULL CONTACT SPORT.

“THE SECRET OF LEADERSHIP IS SIMPLE: DO WHAT YOU BELIEVE IN. PAINT A PICTURE OF THE FUTURE. GO THERE. PEOPLE WILL FOLLOW.”
- SETH GODIN
CSIRO
John Barnes
Theme Leader, Titanium Technologies
Phone: +61 3 9545 8310
Email: John.Barnes@csiro.au

Thank you

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: Enquiries@csiro.au  Web: www.csiro.au