Beneficiation of South Africa’s Titanium Resource
A Long Term Vision is the Key to Success

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Acknowledgements

- DST and the Titanium Centre of Competence network
- The CSIR Light Metals Competence Area
- CUT Centre for Rapid Prototyping and Manufacturing
- The Additive Manufacturing Collaborators Network
Overview

• Introduction
• Sasol: A Beneficiation Success
• The South African Titanium Metal Industry Strategy
• Role of the Titanium Centre of Competence
• Government Support for Titanium Beneficiation
• Success Factors
• Impact of Successful Beneficiation
• Concluding Remarks
• Beneficiation has been on the agenda of South African governments over the past century
• We have some good successes of beneficiation of local resources in our history
• However, more so than in the past, beneficiation has become a national imperative for sustained growth of our economy
• We can draw inspiration from the past and take up the current challenges with confidence
Sasol: A Beneficiation Success

- Beneficiation of SA’s coal resource through commercialising the Fischer-Tropsch process – largest scale in the world
- Anglovaal started exploring the technology in the 1930s
- Sasol was established as government controlled company in 1950
- It produced the first synthetic petrol in 1955
- Sasol is listed on the Johannesburg Stock Exchange and the New York Stock Exchange
- One of the largest multi-national companies originating in SA
  - Employs 34 000 people worldwide
  - Operates in 38 countries
  - Exports to more than 100 countries

The South African Titanium Metal Industry Strategy
We recommend improvement in mineral processing technologies to enable the more cost-effective and wider exploitation of our mineral resources taking environmental requirements into account.

Government and industry should jointly support research and development in the following fields:

- Titanium and titanium oxide production from local raw materials

Ref: Mining and Metallurgy Foresight, The National Research and Technology Foresight Project, DACST 1999
The South African Titanium Opportunity

2nd largest Ti mineral producer
3rd largest V producer

Primary Metal and Mill Products
Components and Manufactured Products

Processes & technologies

Aerospace
Medical
Marine
Chemical
Automotive
Recreational
Industrial
Power

Market

Raw material
Key Properties of Titanium

- Titanium’s strength compares favourably to stainless steels and superalloys, but its density is only about 56% that of steel
  - It has the highest Specific Strength (strength/density) of all metals
- Commercial alloys of titanium are useful up to temperatures of about 540°C to 600°C. Some alloy systems (titanium aluminides) may have useful strengths well above this temperature.
- Titanium is exceptionally corrosion resistant - outstanding in seawater and in the human body (used for implants)
- Since the 1950s Ti has been an aircraft metal; first for military, later for commercial aircraft
The SR-71 Blackbird

Designed & built in 1959 - 1963
• Fuselage skin temperature could reach 370ºC
• Needed to be lightweight, strong and corrosion-resistant
• Constructed 90%+ from Ti alloys

Fastest airplane ever:
• Mach 3.2 (3700 km/h) at 80 000ft (~ 24 km)
• New York to London: 1h 55min
Need for Titanium in the South African Industry

The dti’s IPAP 2014/15 – 2016/17: Key Action Programmes (p131) Development of a Titanium Production Capability Roadmap with the focus on downstream manufacturing technologies and products

Economic rationale

- To position South Africa as a lead supply chain participant within the global titanium manufacturing industry, concentrating on aerospace and defence products and new technologies.
- To increase the spill-over effects of these new technologies into related activities and adjacent industries such as medical, energy, automotive, chemical processing, marine, oil and gas.
Cheaper Titanium Powder – Changing the Industry

Typical prices

- Ti Powder: 10 USD/kg Ti
- Ti Sponge: 10 USD/kg Ti
- Ti Ingot: 20 USD/kg Ti
- Ti Mill Products: 50 USD/kg Ti
- Ti Cl₄: 4.4 USD/kg Ti
- TiO₂ Slag: 1.45 USD/kg Ti
- Ilmenite: 1 USD/kg Ti
- TiO₂ Pigment: 5.3 USD/kg Ti
- Current SA industry
  Market failure?

Final Products/Components: USD/kg 150 - 20,000
A new Titanium Metal Industry sector in South Africa
A New South African Titanium Industry
Economic and Job Creation Opportunities

Primary Titanium Metal Industry

Titanium Metal Powder
- Newco 300 - 400

Powder consolidation
- Titanium Mill Products
  - Bar
  - Sheet
  - Tube
  - Newco 140 - 180

Ferrotitanium

Additive Manufacturing Products
- Medical
- Aerospace
- Newco 40 - 70

Near-net & Net Shape Products
- Conventional Powder Metallurgy
- Newco 20 - 50

Fabricated Products
- Forming
- Machining
- Joining
- Co/Newco 180 - 220

Cast Products
- Investment Casting
- Foundry 15 - 20

Steel Making

Downstream Titanium Manufacturing Industry

Titanium Metal

Powder spheroidisation
- Alloying

CSIR-Ti Process
- Pilot Plant
- Semi-Commercial (Demo) Plant
- Full Commercial Plant

Estimated initial direct jobs
- 700 - 950

CSIR Light Metals 2013
Role of the Titanium Centre of Competence
Pursuing the South African Beneficiation Opportunity

The Titanium Centre of Competence integrates and coordinates R&D and commercialisation across the value chain.
Titanium Centre of Competence

Developing and commercialising technology building blocks for the South African Titanium Industry

SA Ti Industry

SA Supplier Development

Industrialisation & Commercialisation

Technology Development

- Primary Metal Production
- Powder Consolidation
- Additive Manufacturing
- Investment Casting
- High Performance Machining
- Friction Welding
- Sheet Forming

Physical Metallurgy and Characterisation

Design, Simulation and Modelling

Laboratories and R&D Facilities

Supportive Platforms

Modification of the TiCoC Model
<table>
<thead>
<tr>
<th>Programme Phase</th>
<th>Level</th>
<th>State of Development</th>
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<tbody>
<tr>
<td>Phase 1 Technology Assessment</td>
<td>1</td>
<td>Process concept proposed with scientific foundation</td>
</tr>
<tr>
<td>and Proving</td>
<td>2</td>
<td>Applicability and validity of concept described and vetted or demonstrated</td>
</tr>
<tr>
<td>Phase 2 Pre-production</td>
<td>3</td>
<td>Experimental proof of concept completed</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Process validated in laboratory using representative development equipment</td>
</tr>
<tr>
<td>Phase 3 Production &amp; Implementation</td>
<td>5</td>
<td>Basic capability demonstrated using production equipment</td>
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<tr>
<td></td>
<td>6</td>
<td>Process optimised for capability and rate using production equipment</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Capability and rate confirmed via economic run lengths on production parts</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Full production capable process qualified on full range of parts for significant run lengths</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Full production capable process qualified on full range of parts over extended period (all business case metrics achieved)</td>
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Titanium Centre of Competence

Developing and commercialising technology building blocks for the South African Titanium Industry

SA Ti Industry

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Modification of the TiCoC Model
The South African TiCoC Resource Pool

International R&D Institutions:
- CSIRO (Australia)
- NIMS (Japan)
- ESRF (France)
- Fraunhofer IWU (Germany)
- Univ of Plymouth (UK)
- TiDA (New Zealand)

Companies:
- Airbus (Europe)
- Boeing (USA)
- Snecma (France)
- ALD (Germany)

Mobilisation and alignment of the national expertise:
- Permanent researchers: 80+
- Post graduate students: 20+
Primary Titanium Industrialisation Plan

Primary Ti Production (CSIR-Ti Process)


Basic Development
Pilot Phase (2kg/h)
Feasibility Phase
Demonstration Plant 500 tpa Commerically Pure (CP) Ti
World-Class Plant Production: 20 000 tpa first: CP Ti; then Ti Alloy

Completed
CSIR-Ti Pilot Plant (current)
Commercial partners

TRL 2-4
Concept, Proof of concept, Lab validation

TRL 5
Validation in relevant environment

TRL 6
Demonstration in relevant environment

TRL 7
Demonstration in operational environment

TRL 8
System complete and qualified

TRL 9
Deployment
The Power of the Titanium Centre of Competence

• Constitutes a national Titanium R&D “business”
• It embodies the national vision – the collaborators and stakeholders can identify with it
• The participants in different focus areas can share their learning
• It demonstrates the government’s long term sustained commitment
• Opportunities for industry involvement becomes clear
A Titanium Inter-departmental Task Team was established, representing the following departments:

- Department of Science and Technology
- Department of Trade and Industry
- Industrial Development Corporation
- Department of Mineral Resources
- Department of Public Enterprises

It meets regularly to facilitate cooperation of the departments.
Success Factors

- Agreement on the national strategy by all key role players
- Secure a mandate to implement the strategy
- A Champion in Government
- A Champion in each collaborating unit
- Industry involvement early on
- Share the Vision and continuously promote it
- Sustained communication
- Recognition of each contribution (ongoing buy-in)
- Remain focused and persevere
Impact of Beneficiation: Changing Lives through Additive Manufacturing
Additive Manufacturing/3D Printing Process

Titanium Powder → Laser Sintering → Part

Courtesy EOS
Customised Lower Jaw Implant
UP – CUT Collaboration
Customised Lower Jaw Implant
UP – CUT Collaboration
Custom Designed Titanium Implant
Custom Designed Titanium Implant
Custom Designed Titanium Implant
Potential Future Impact of Successful Local Ti Beneficiation

• Titanium powder production through the CSIR-Ti process
• Alloying and spheroidisation of the locally produced Ti powder
• More affordable production of customised medical implants through Additive Manufacturing of local Ti6Al4V powder
• Large numbers of South Africans experience vastly improved quality of life
Concluding Remarks and Recommendations

- A shared long term vision is the key to success
- Establish national support for the vision
- It does not happen overnight – persevere when unforeseen stumbling blocks are encountered
- Put SA’s best resources, expertise and experience to the task
- We have examples of successful beneficiation, such as Sasol
- We have proven models, such as the Centre of Competence
- Two areas with most potential for titanium beneficiation:
  - Primary titanium powder production
  - Additive manufacturing of titanium components
Thank you

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