

Disruptive Technologies for Light Metals  
Low Cost Non-Melt Processing of  
Titanium Alloys

**Dr Martin Jackson**

Royal Academy of Engineering/EPSRC  
Research Fellow

# Global Demand



Titanium

68

Nickel

234

Stainless Steel

13,307

Quality Steel

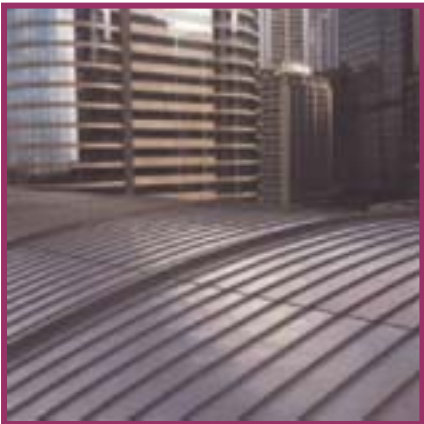
1,130,000

# A Brief History

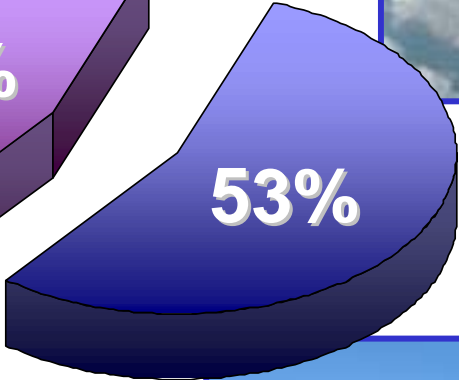
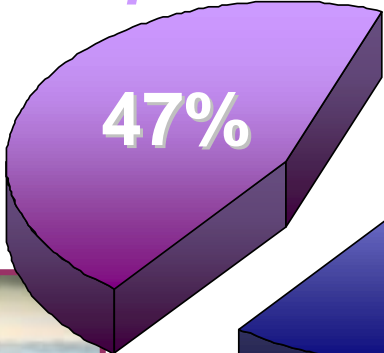
- Over 60 years ago Kroll developed method for conversion of Ti oxide ore.
- Ti-6Al-4V became available 50 years ago.



# Current Titanium Market



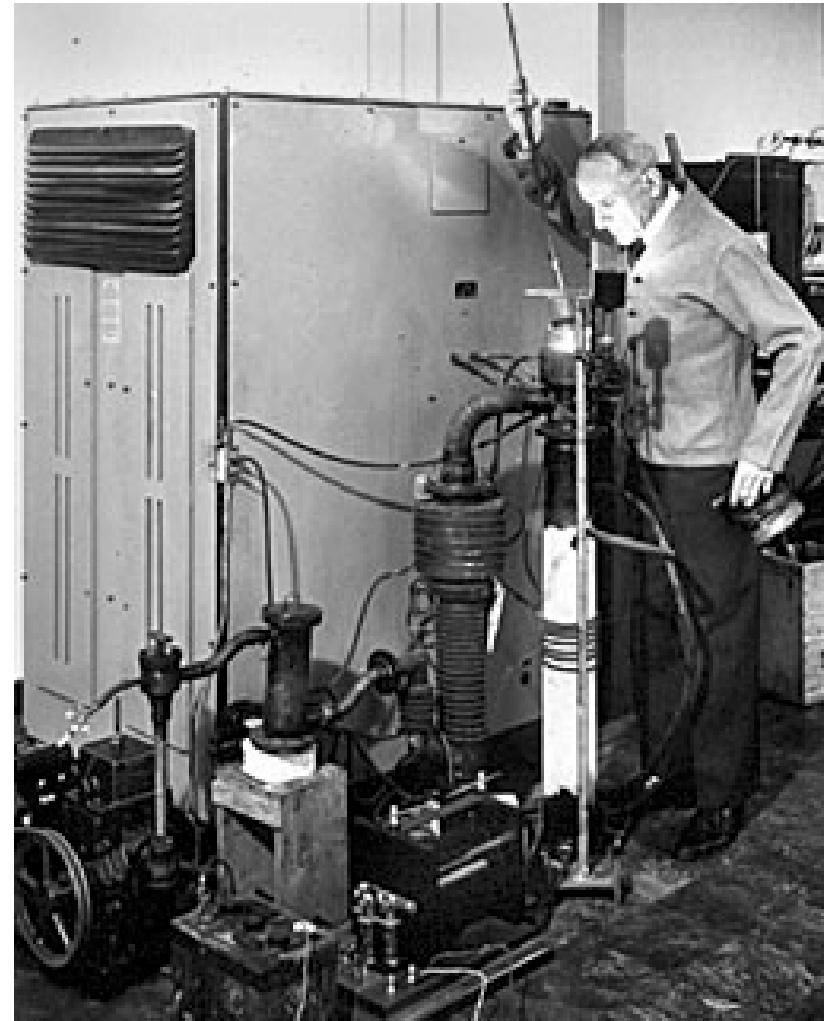
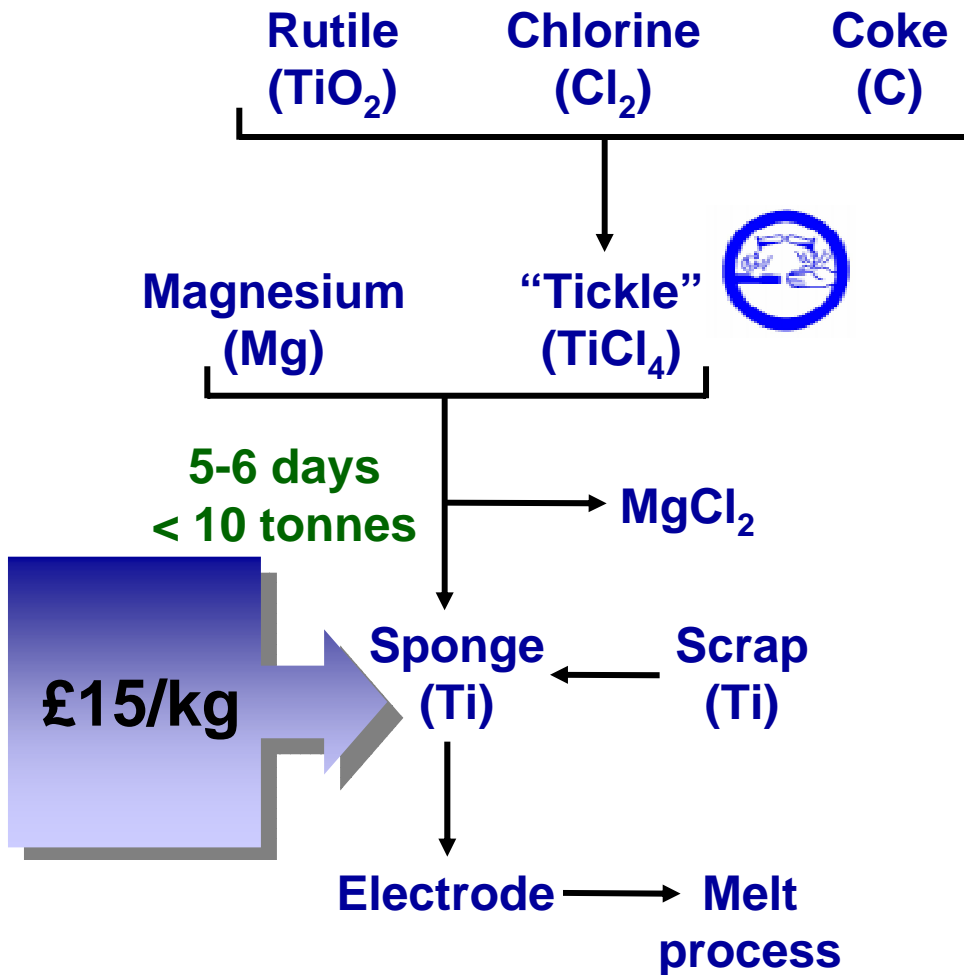
**Non-aerospace**



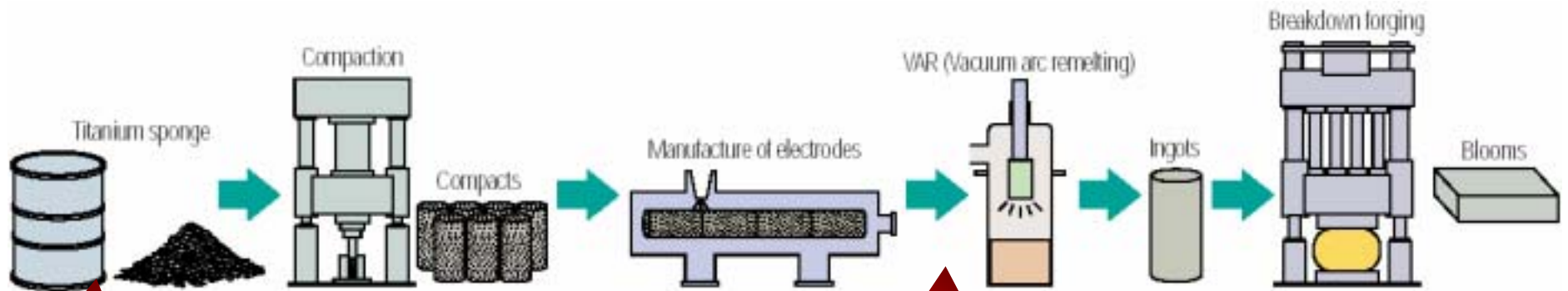
**Aerospace**



# Kroll Process



# Vacuum Arc Remelting



# Advances to Improve the Prospects of Titanium

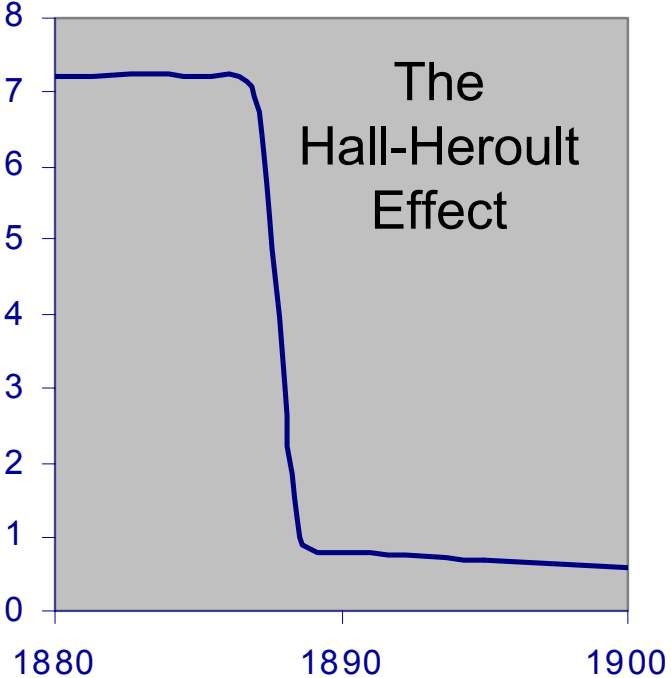
1. Improve the utilisation of current titanium process.
2. Develop intrinsically lower cost titanium and processing routes.

Disruptive Technologies

# Step Change in the Economics (akin to Aluminium)



Aluminium Price (£/Kg)



## Emerging Reduction Processes (2004)

FFC Cambridge Process

OS Process

MER Corp

SRI International

ITP Armstrong Process

BHP Billiton

Millenium Chemicals

GTT (Ginatta)

MIR Chem

Idaho Titanium Tech

CSIR

Preform Reduction

Vartech

and more.....

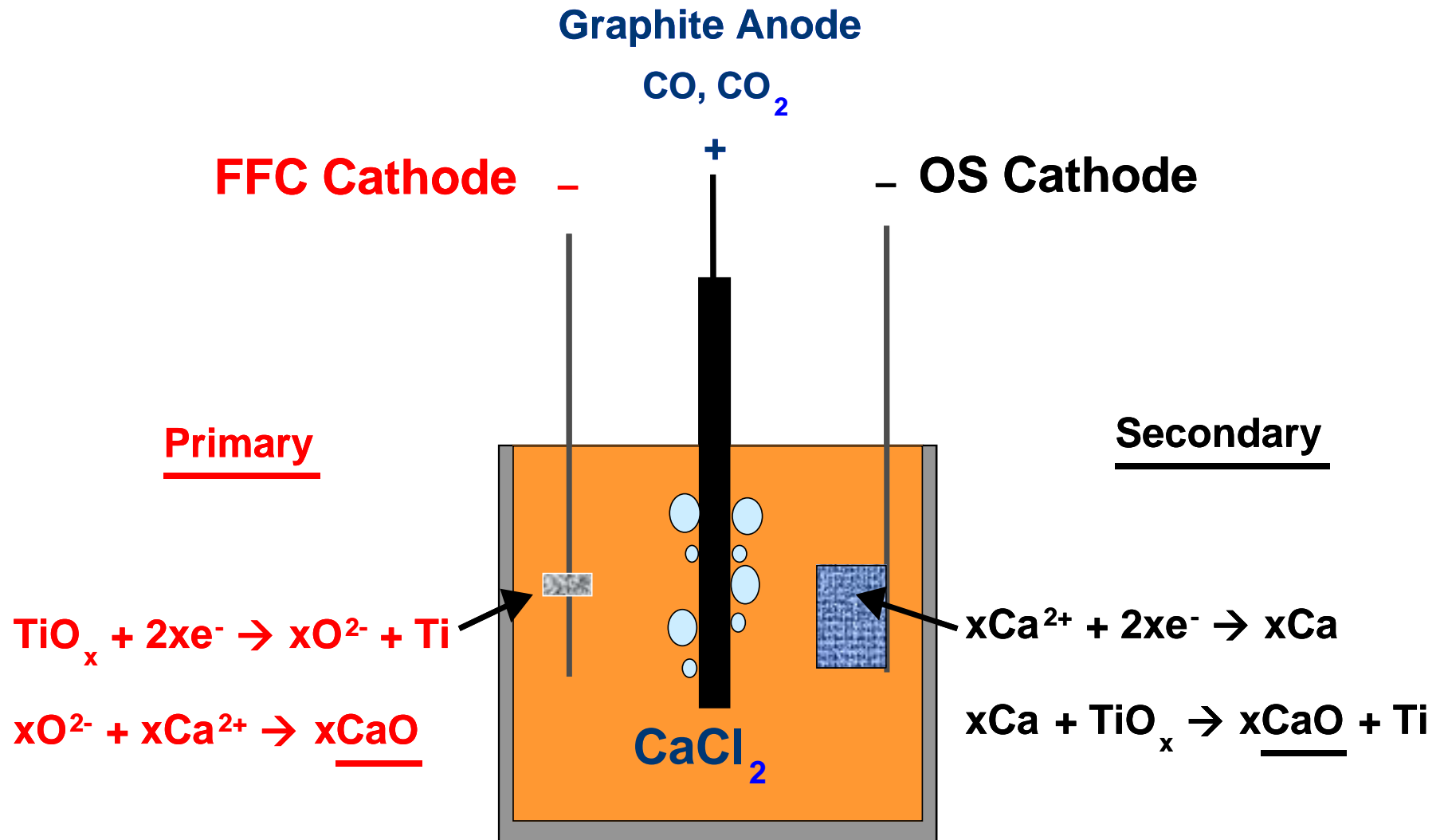
***Ed Kraft, EHK Technologies***

***TMS 2004***

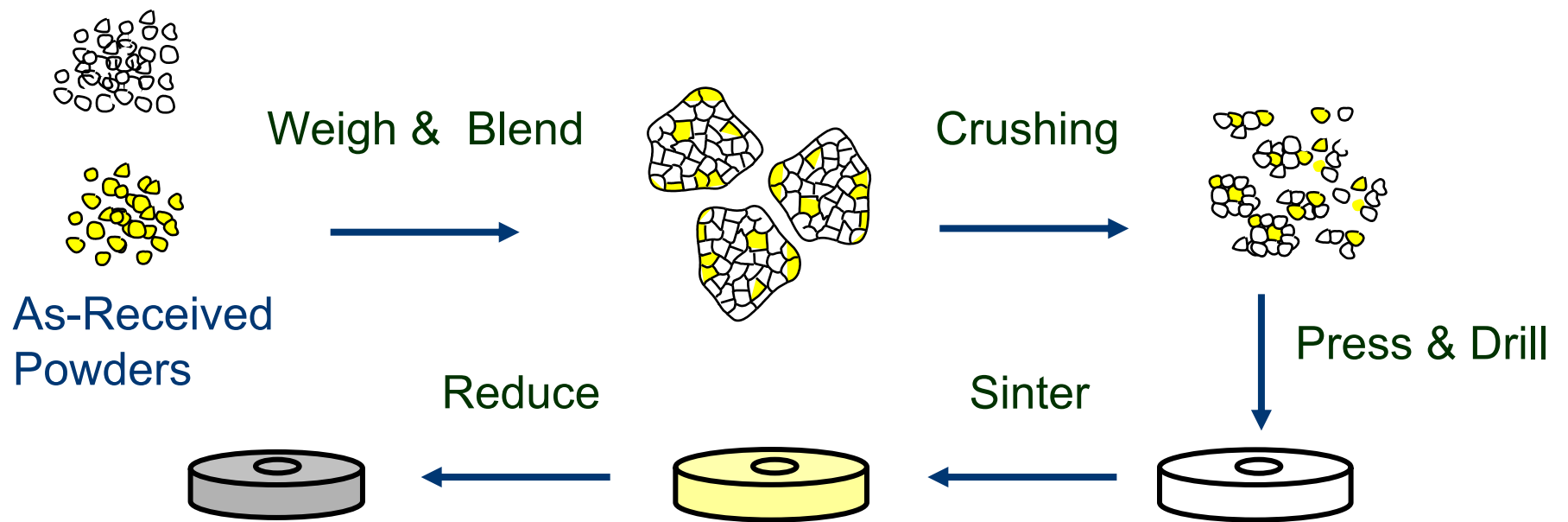
# Emerging Reduction Processes

- Process types:-
  - Chemical Reductant (*ITP Armstrong*)
  - Electrolytic (*MER Corp., GTT*)
  - Electrochemical (*FFC Cambridge, OS*)
- Funding driven by the US (DARPA)
  - Currently into Phase III

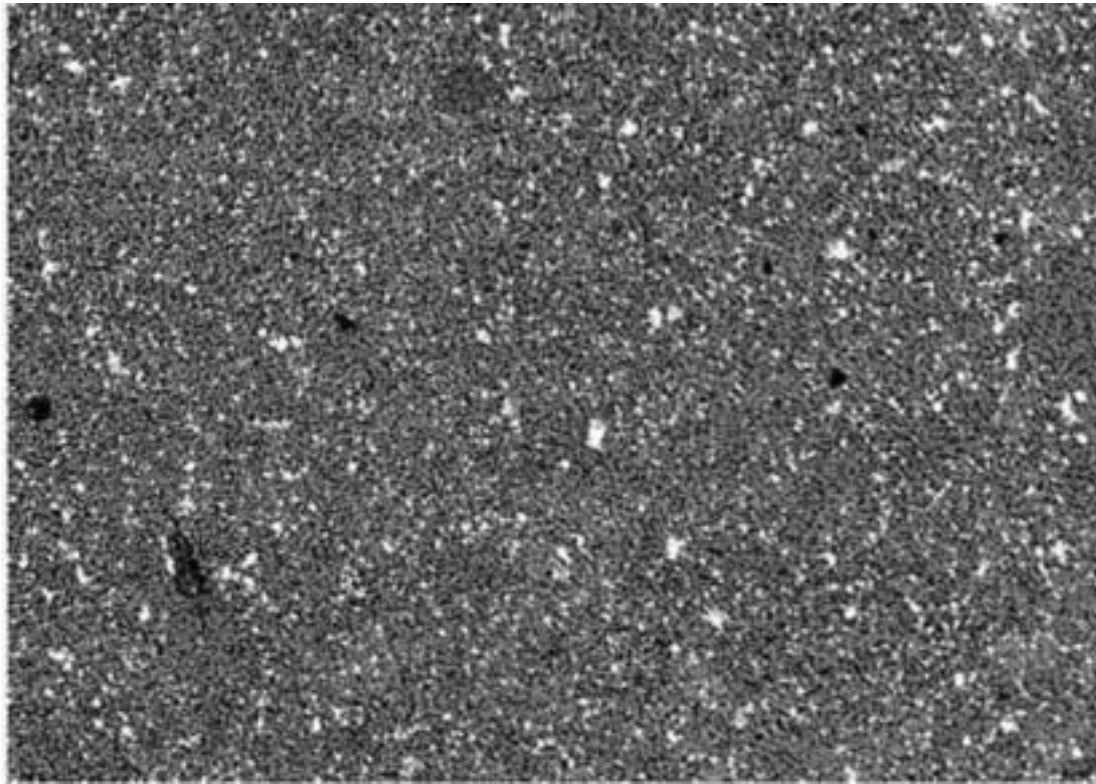
# FFC, OS Processes (Electrochemical Reduction)



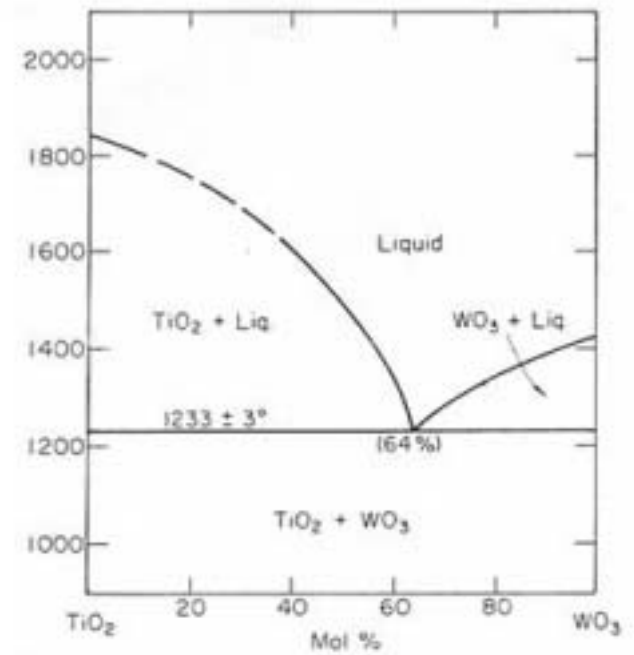
# Preform Production Route



# TiO<sub>2</sub>-WO<sub>3</sub> Mixed Oxide Preform



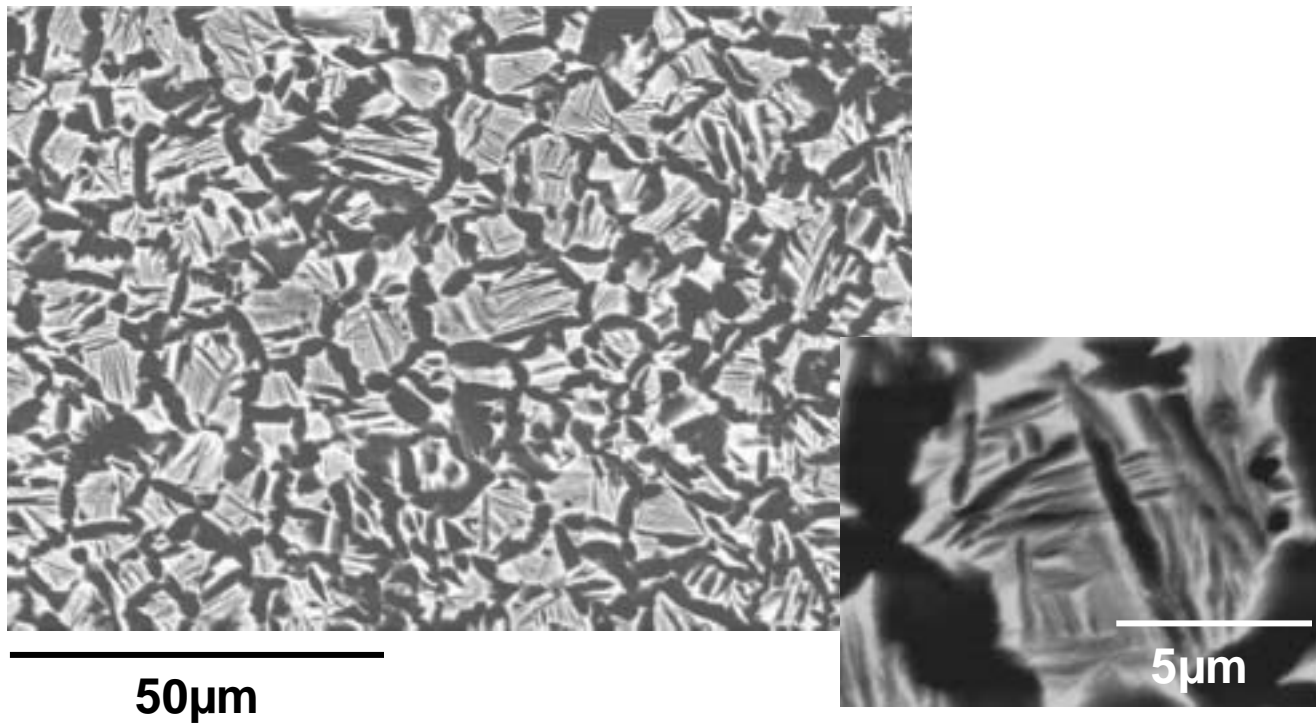
300µm



L. L. Y. Chang, M. G. Scroger, and B. Phillips, *J. Less-Common Metals*, 12 [1] 53 (1967).

# Metallic Ti-10W Alloy

**Note: Chemical homogeneity & Refined grain structure**



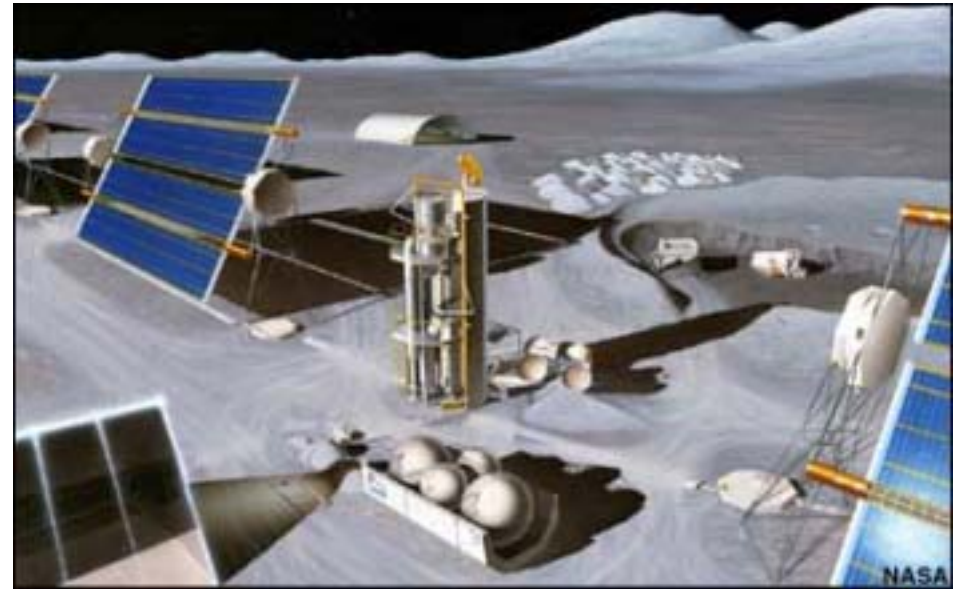
# The final frontier for titanium.....

## What will Nasa do on the moon?

The Guardian

Alok Jha

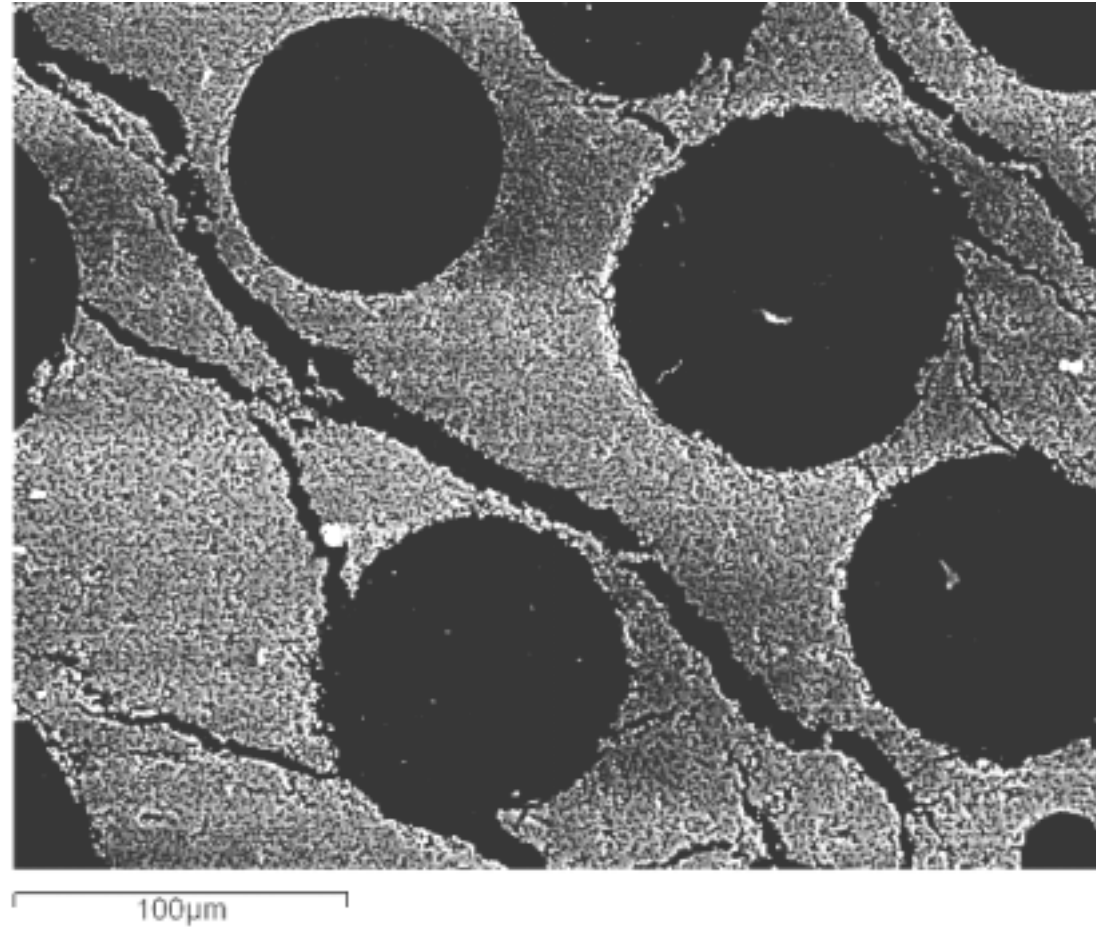
Saturday September 24, 2005



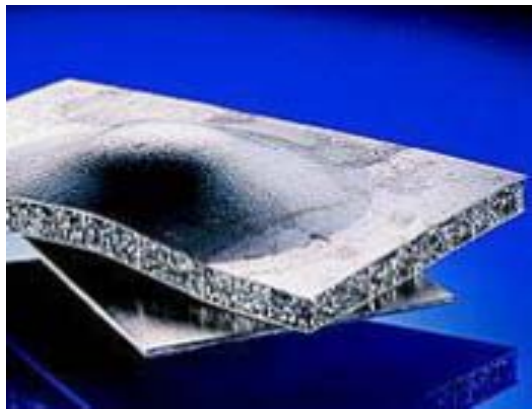
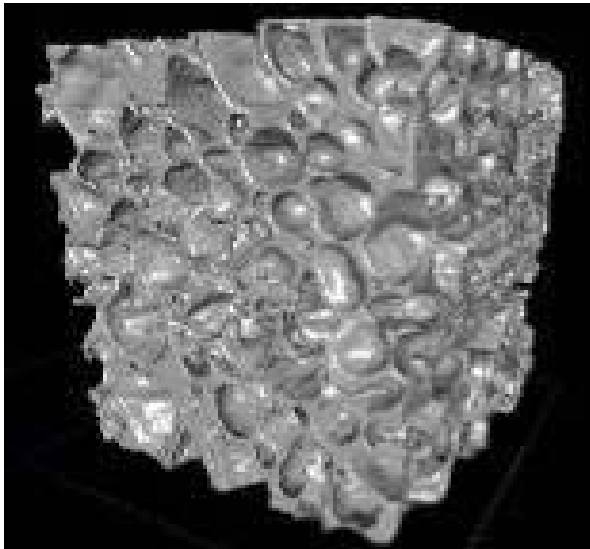
The ultimate plan is to build a base and keep astronauts there permanently: a step on from the permanent presence in space afforded by the International Space Station and a practice run for any future adventures to Mars.

The diggers will mine ilmenite, a mineral from which astronauts can extract oxygen, hydrogen and helium. This could produce air and water, while the flammable gases could be burned to generate electricity.

# Engineering Macro Porosity



# Titanium Foams

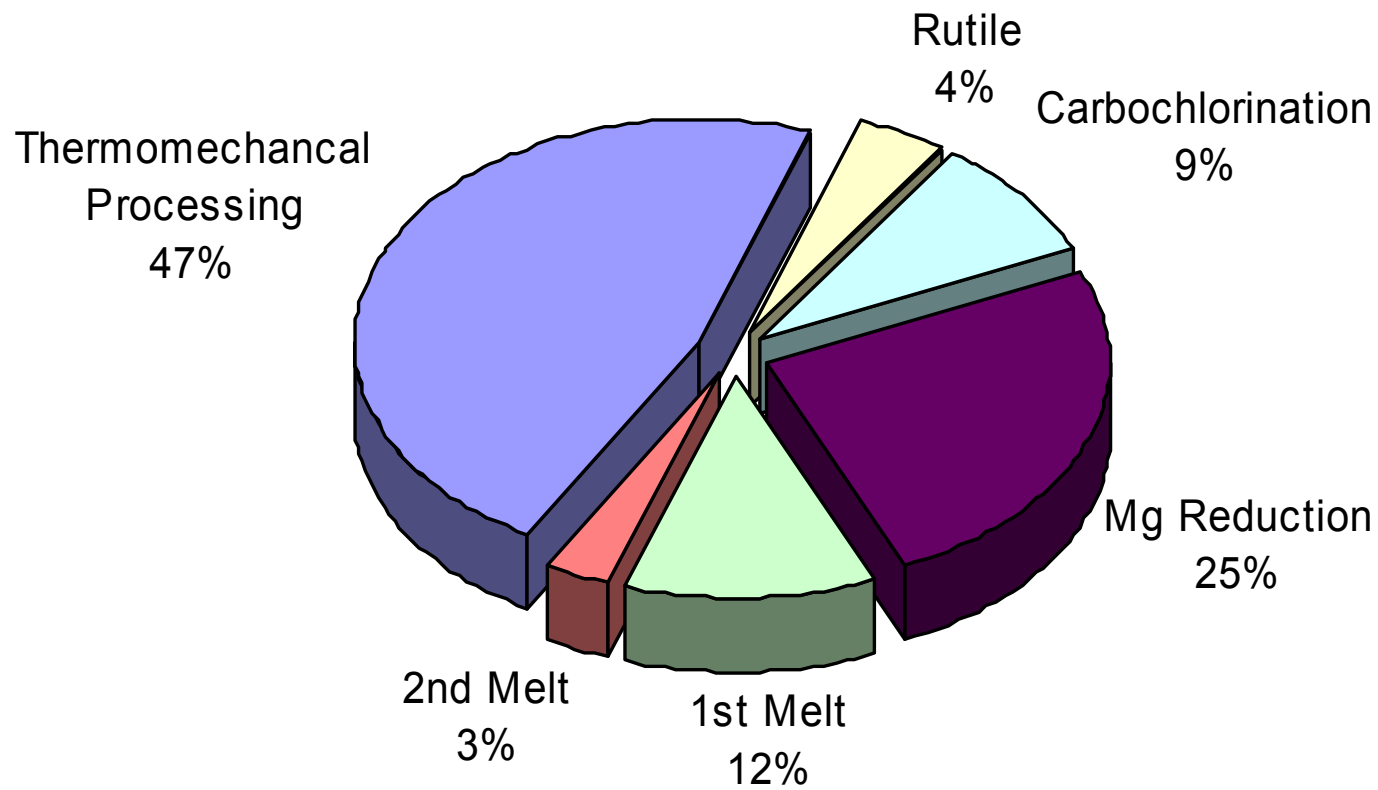
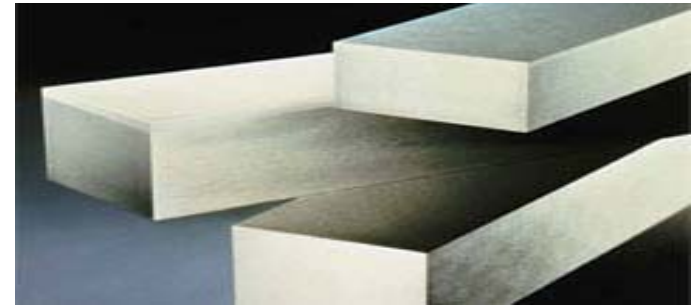


	E (GPa)	$\sigma_y$ (MPa)	%
Ti foams	0.6-2.2	10-50	2-5
Solid Ti	110	175	-
Trabecular bone	0.4-2	50-150	2-5

## The Potential. The Facts.

- Could replace the Kroll process for the primary production of titanium allowing the low cost production of titanium.
- Can be used to produce pre-alloyed master alloys or particulate/powder
- Can be used to produce notoriously difficult alloys
- Can be used to produce metallic foams

# The Economics



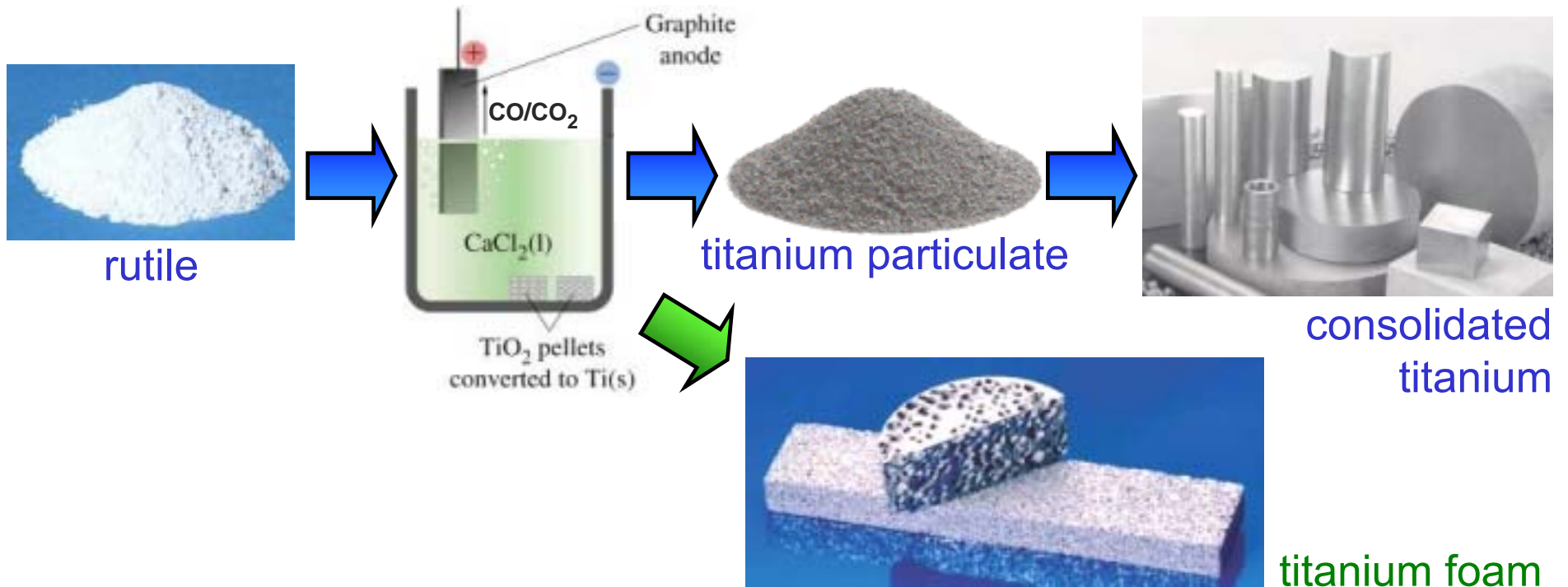
*[Source Ed Kraft, EHK Technologies TMS 2004]*

# Powder/Particle Processes

- Laser Forming / Laser Powder Deposition.
- Near Net Shape HIPing
- MIM, CIP, Press Sinter
- *Revitalise* Bulk Consolidation Processes.

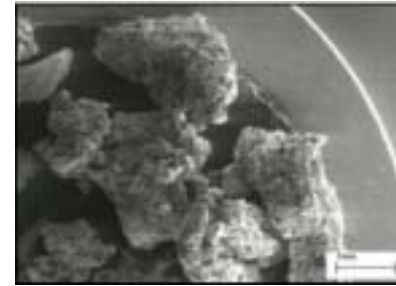
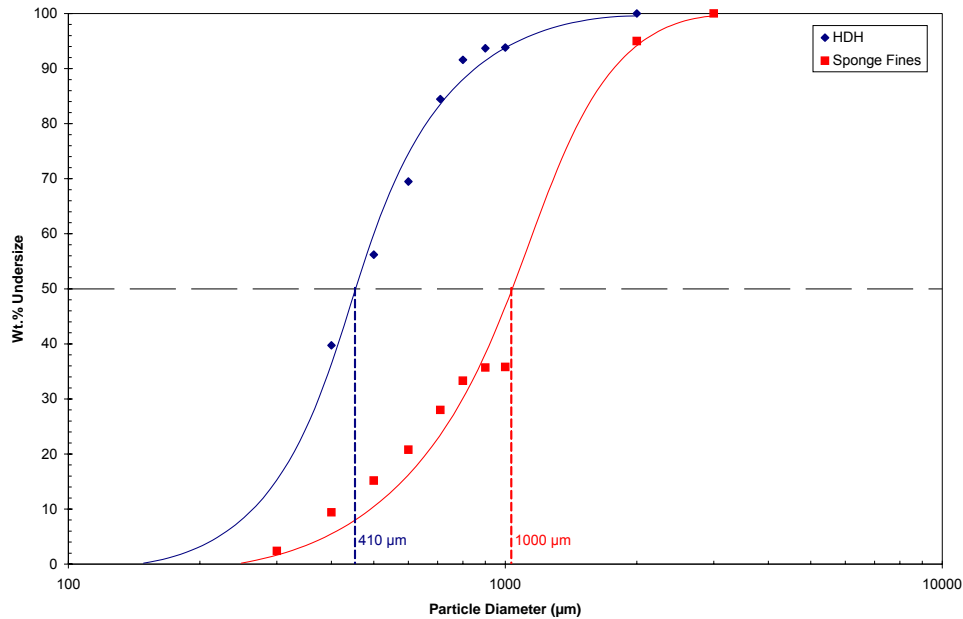
# Current Strategy

GENERATE A STEP CHANGE IN THE COST OF TITANIUM



Assess the viability of a number of particulate consolidation routes and establish optimum particulate characteristics for each route

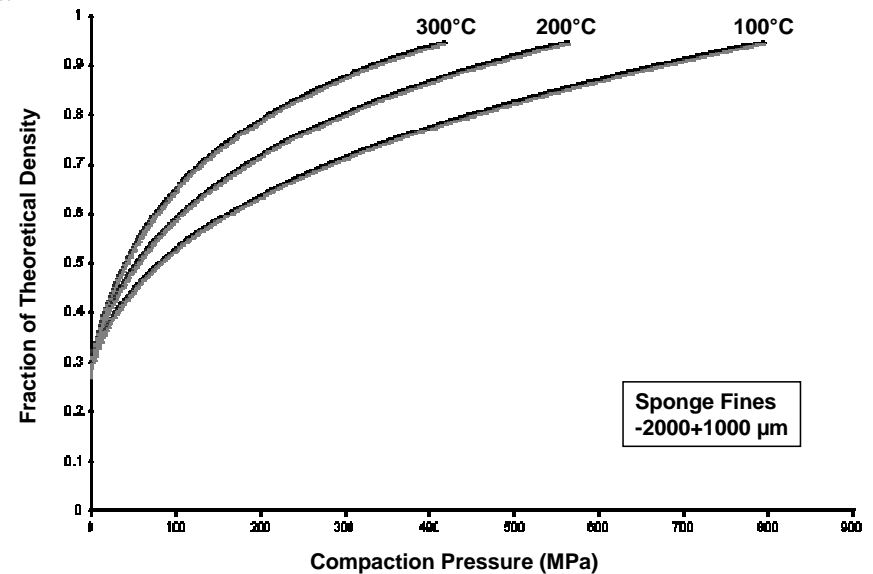
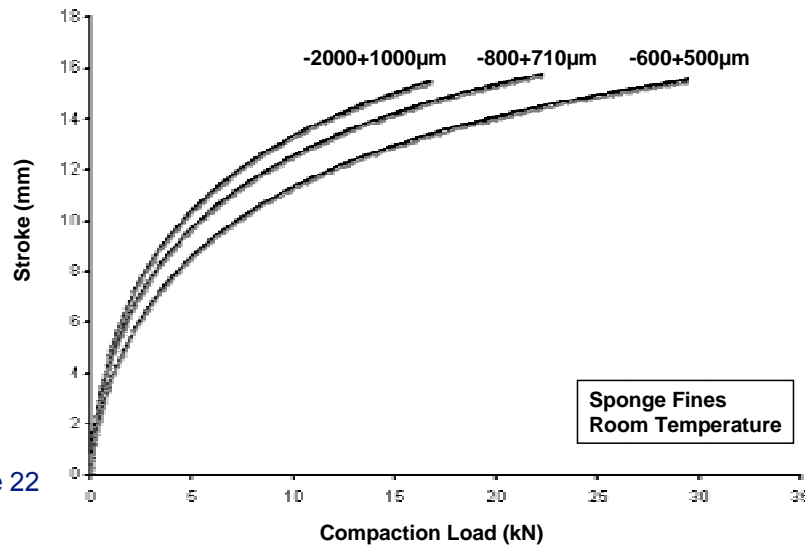
# Particulate Consolidation Studies



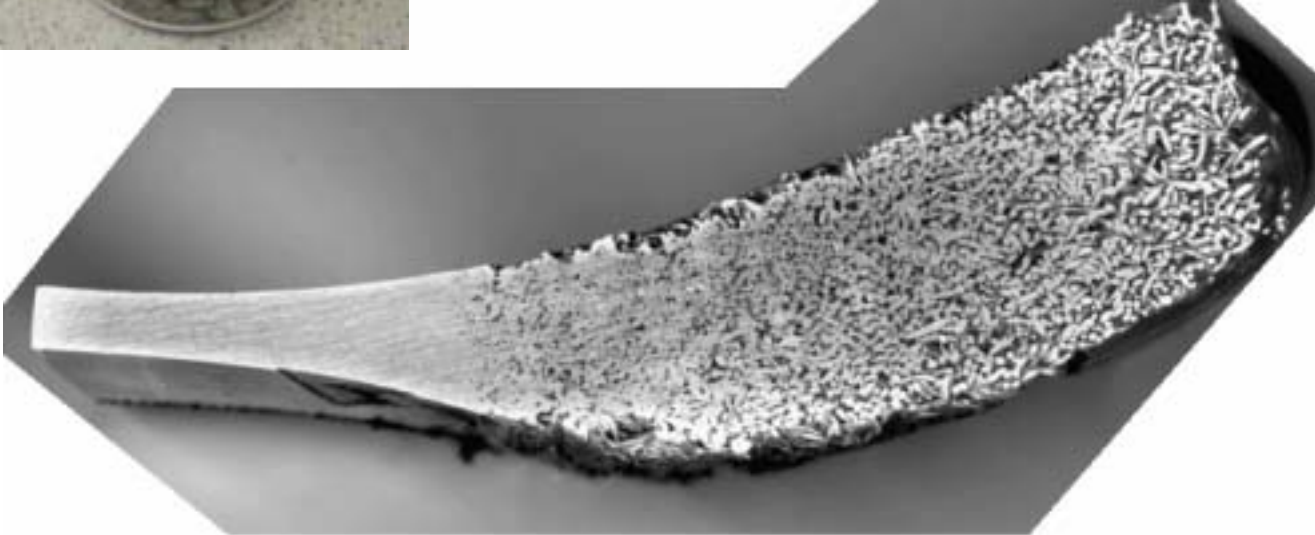
Sponge Fines ( -2000+1000 µm)

HDH (-2000+1000 µm)

Source	Size (µm)	Quantity (kg)	Fe (wt.%)	O (ppm)	N (ppm)	H (ppm)
Sponge Fines CP Ti	1000 – 2000	30	0.53	450	30	29
HDH CP Ti	100 – 1000	50	0.35	1300	240	65



# Direct Particle Rolling



2 mm

# Direct Particle Rolling



**Variable Feed Rate**  
**Angle**  
**Rotation Speed**

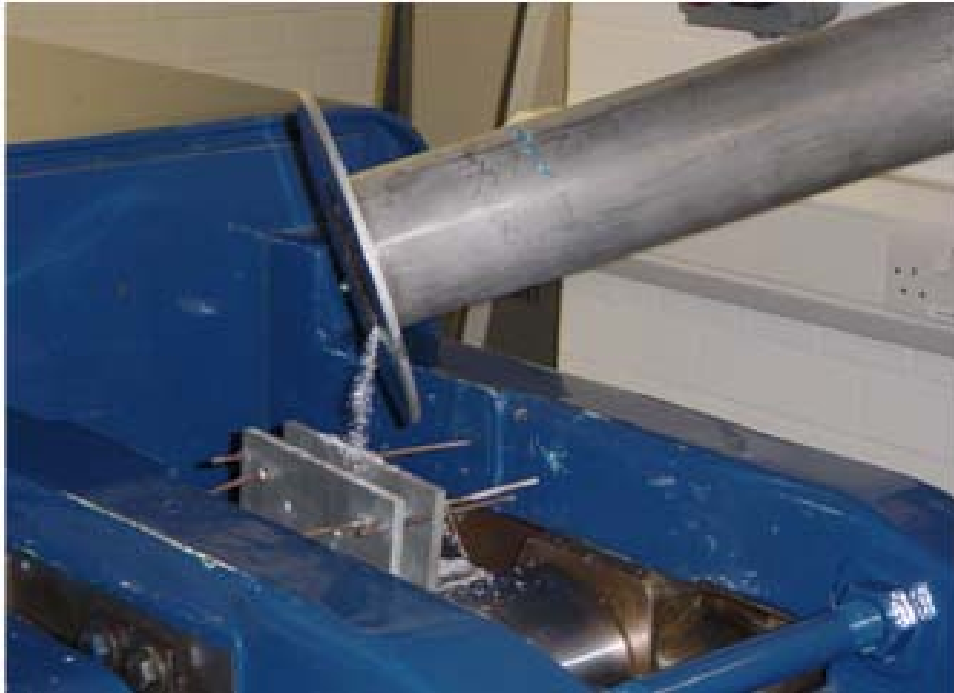
**Variable Roll Diameter**

**Variable Roll Speed**

**Inert Atmosphere**

**Max Temperature 1200°C**

# Bulk Consolidation of Particulate

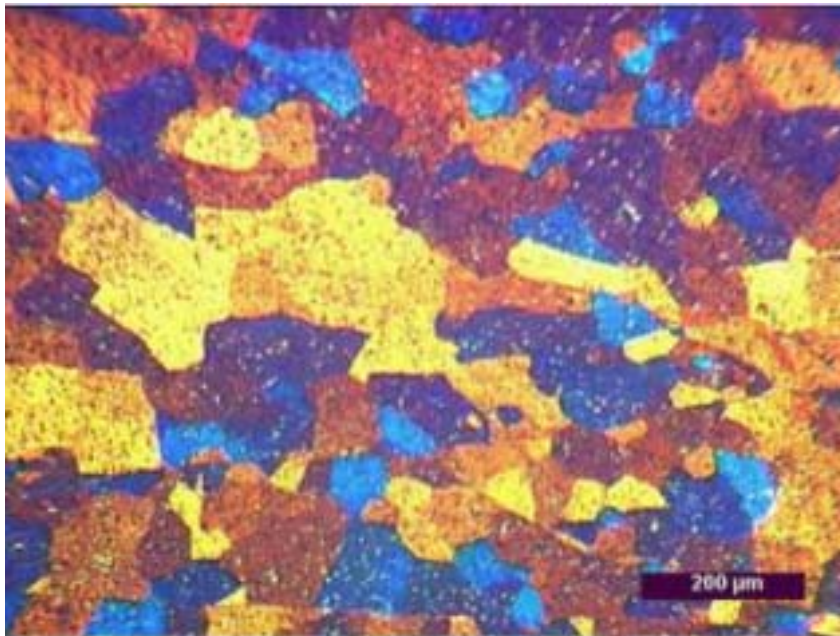


# Bulk Consolidation of Particulate

**Initial Trials  
in CP Al &  
Al-4Mg**

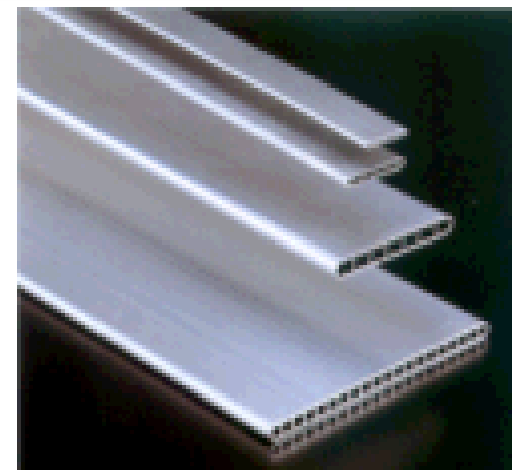
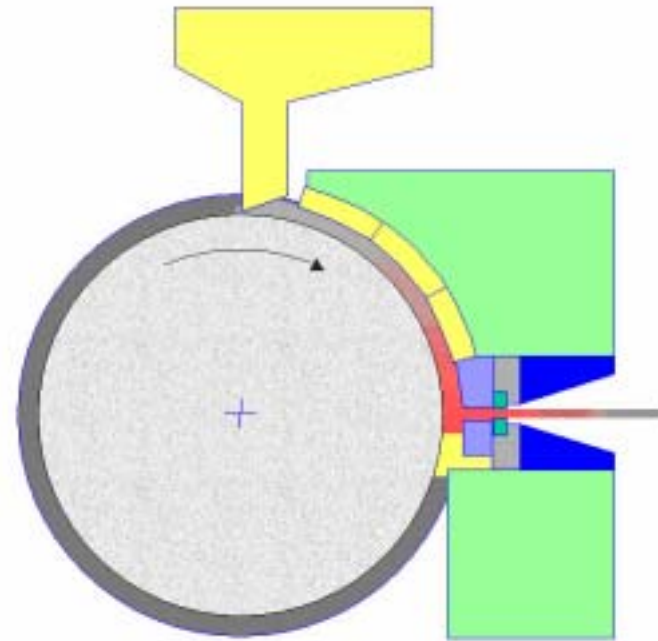


100 mm



**Readily consolidated to  
100% dense 3 mm sheet**

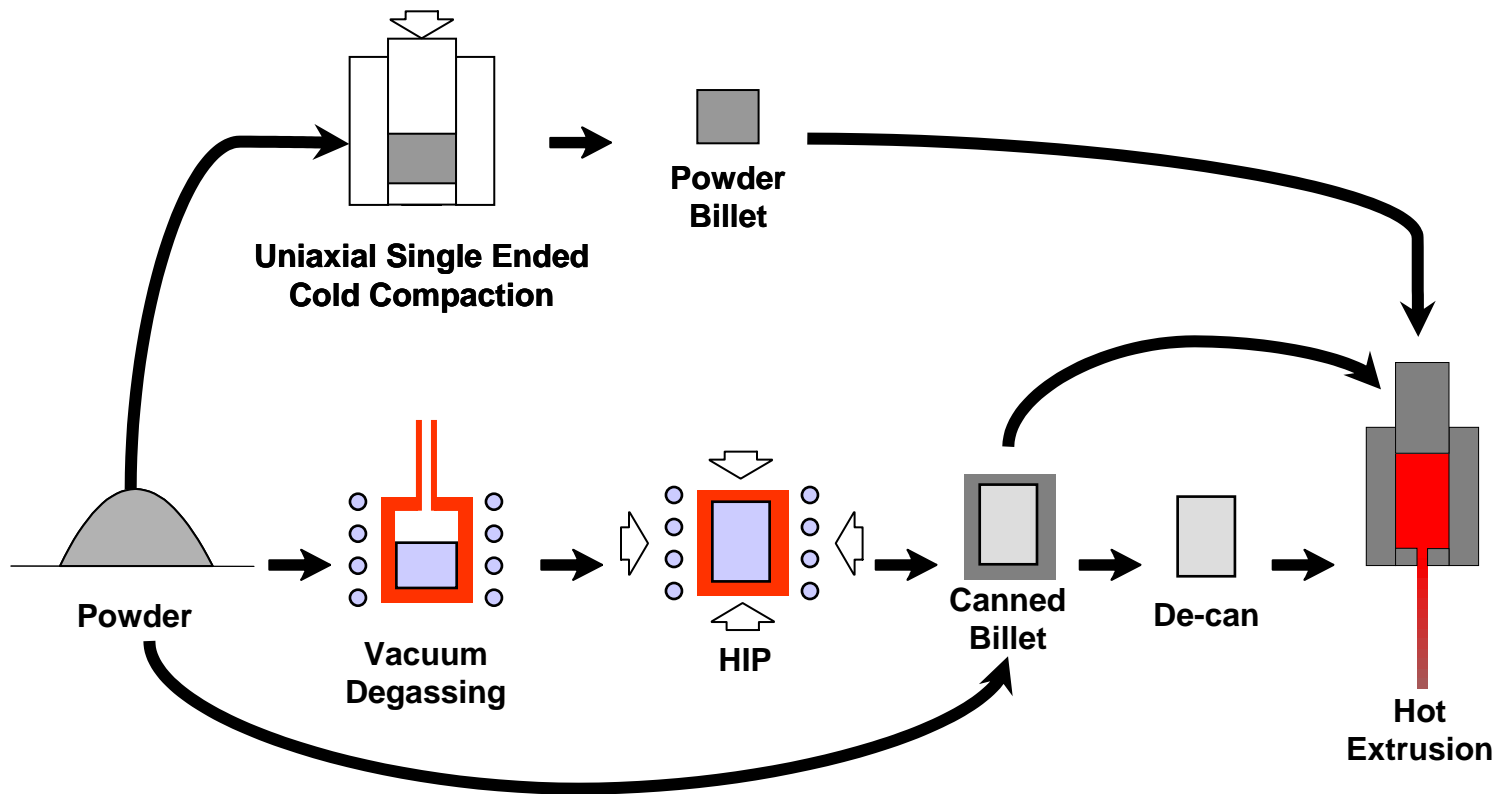
# Continuous Extrusion - Conform™



# Bulk Consolidation - Conventional Techniques

Can – Degas – HIP – Extrude

DPE (direct powder extrusion canned or cold compacted)



# Solid State Processing at Imperial College London

**Extrusion**

**Forging**

**Powder Consolidation**

**Rolling**

**Cold Isostatic Pressing**

**Hot Isostatic Pressing**

**Swaging**

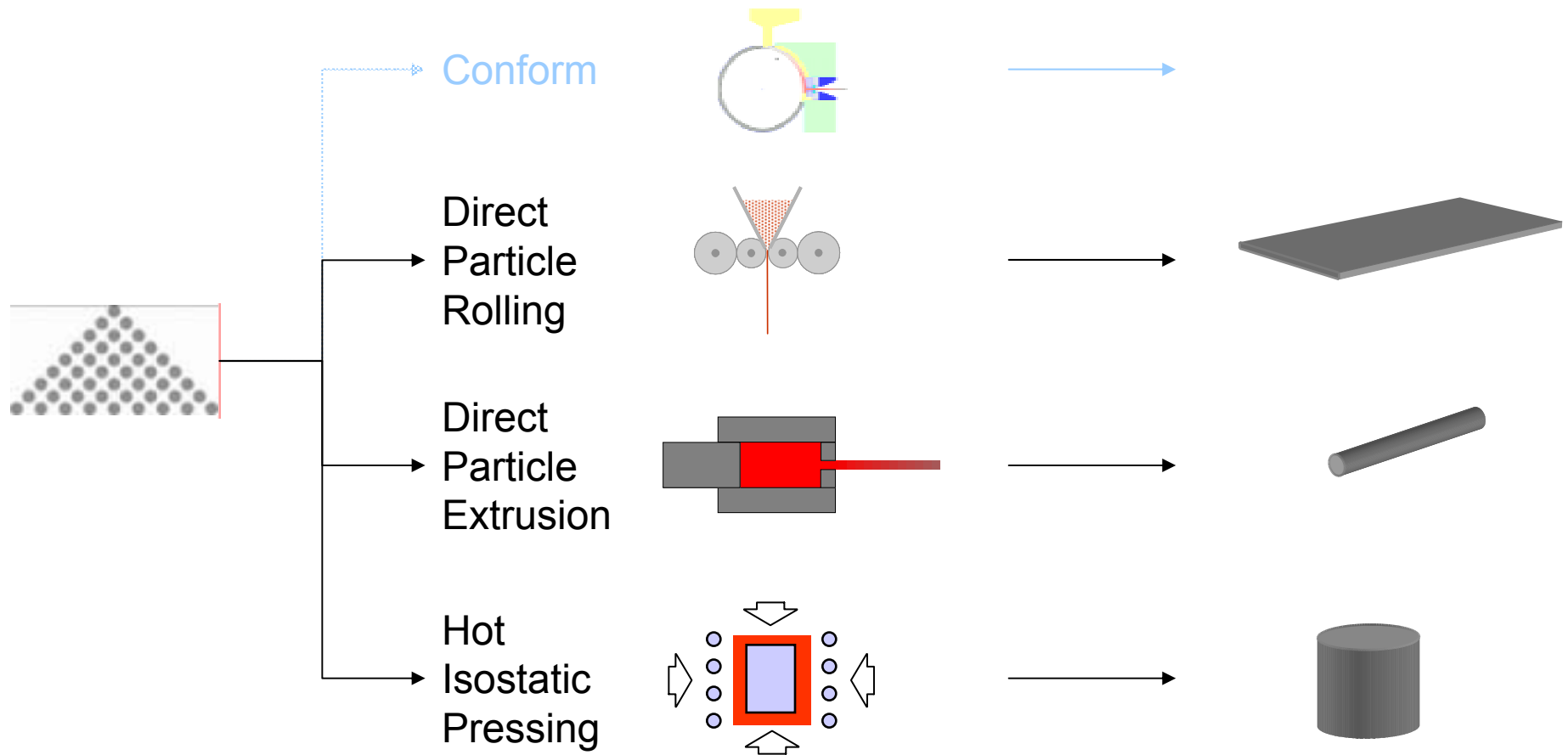
**Drawing**

} **5 MN Vertical Press**

**3 Mills**




# Approach



# Acknowledgements

- Dr Richard Dashwood
- Dr Kevin Dring, Rohit Bhagat, Kartik Rao, Dave Tricker



Powdermatrix 

**THANK YOU**

Dr Martin Jackson  
Department of Materials  
Imperial College London  
South Kensington campus  
LONDON SW7 2AZ  
[martin.jackson@imperial.ac.uk](mailto:martin.jackson@imperial.ac.uk)