A Novel Chemical Pathway for Ti Production

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Lead Institution: University of Utah
Partners: Boeing and Alcoa Ti

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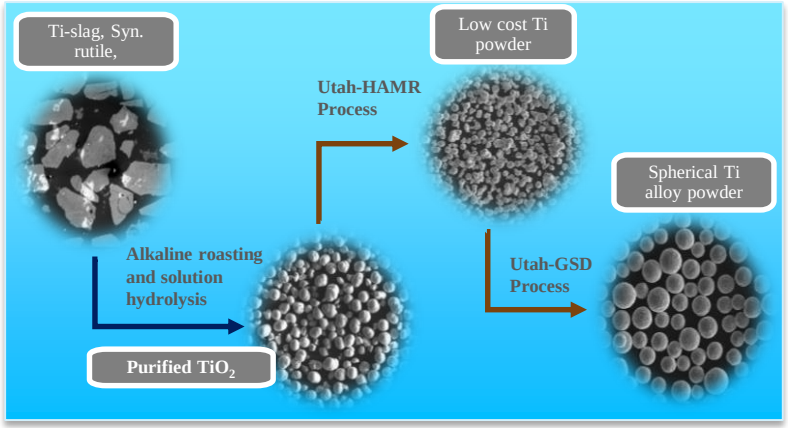


A breakthrough technology for making low cost Ti powders

Agenda

- Team Intro
- Technical Concept
- Technical Progress to date
- TEA Highlights
- Demo Requirements
- Future Goals/Closing Thoughts
- Q&A

Utah Low Cost Ti

University of Utah

The flagship research University in the state of Utah.

Dr. Ali Yousefiani,
Technical Fellow, Boeing Research & Technology

Dr. Don Li,
Senior Manager, R&D, Alcoa Ti

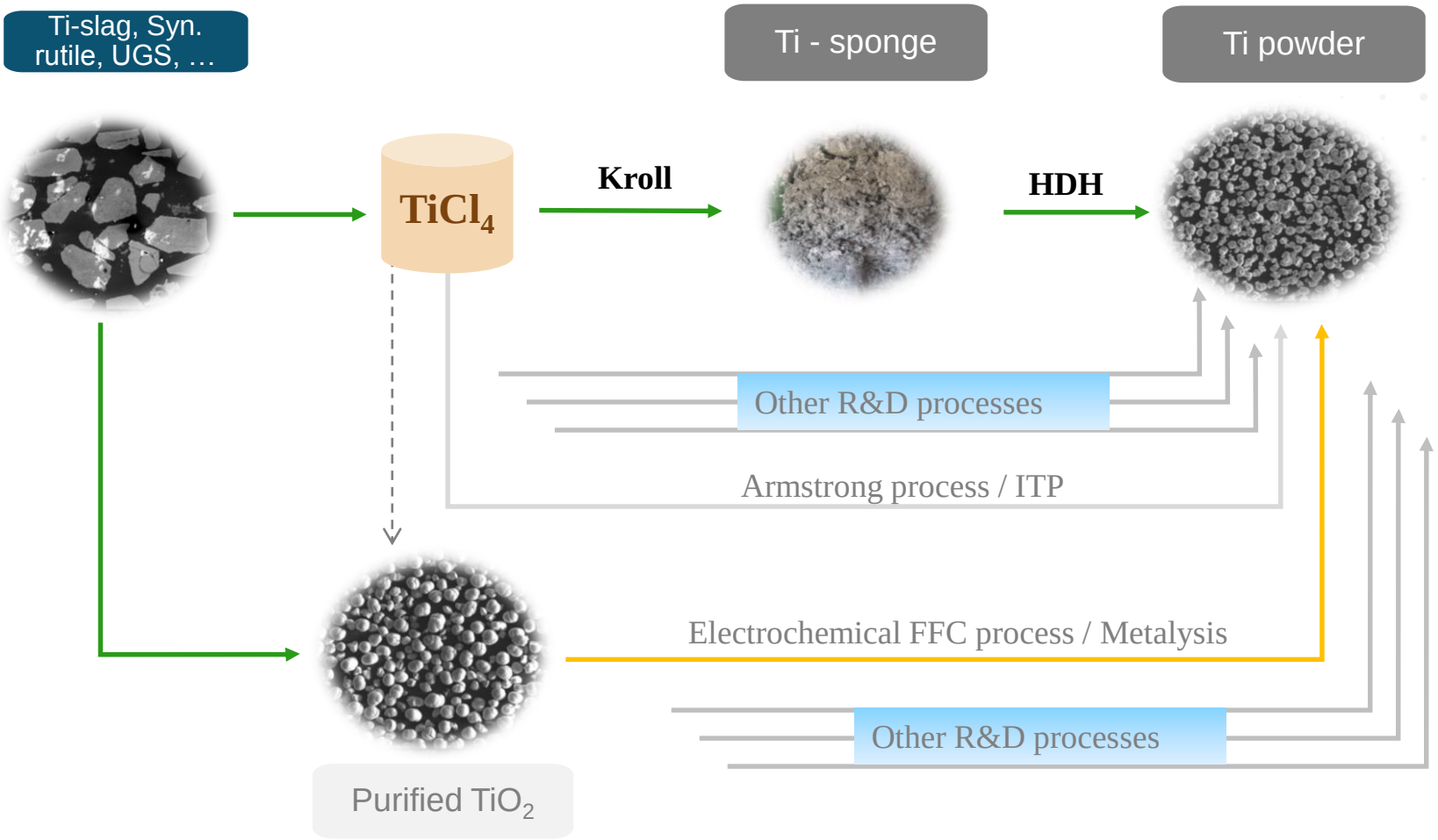
Current goals

- Produce 10Kg of powder for industrial partners to assess the product quality and market potentials
- Develop a continuation plan to secure funding for pilot production research

Project Summary

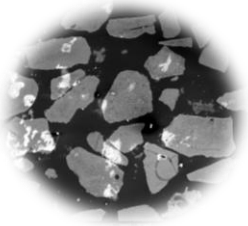
- Ti sponge (primary metal) is expensive (~$10/Kg Ti sponge).
  Ti powder is more expensive ($30-80/Kg CP-Ti powder).
  Spherical Ti alloy powder for 3D printing is extremely expensive ($200-500/Kg).
- A new chemical pathway was found and demonstrated in a lab scale that can produce normal non-spherical Ti powder at 1/3 or less of its current cost. The process is termed hydrogen assisted magnesiothermic reduction of TiO_2 (HAMR)
- A novel process (GSD) is also developed to make spherical Ti alloy powder for additive manufacturing at a fraction of the cost of the current technologies.
- Both HAMR and GSD processes are now at TRL 4. They are ready for scale up.

Current Processes for Production of Titanium



Utah Processes from UGS to TiO2 and from TiO2 to Ti

Ti-slag, Syn. rutile, UGS, …



Alkaline roasting

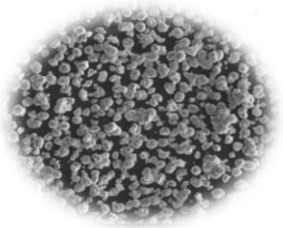
Solution hydrolysis

Purified TiO_2

Hydrogen assisted Mg reduction of TiO_2 (HAMR)

Mg reduction & deoxygen

Ti powder

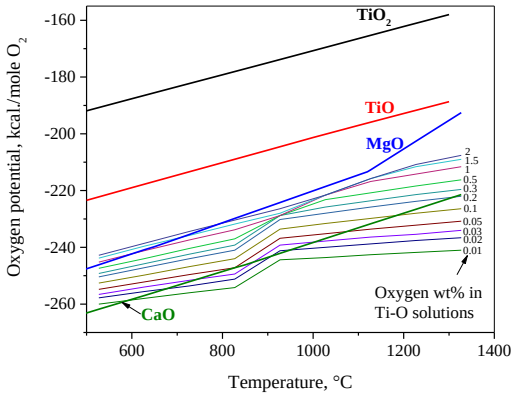


Challenges – Solutions

THE UNIVERSITY OF UTAH

Challenges

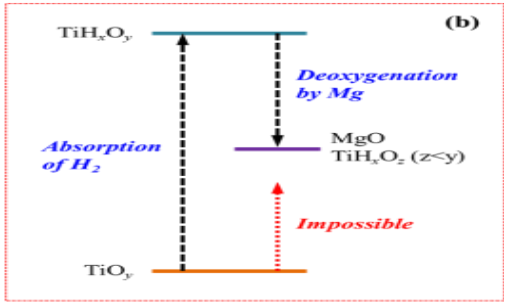
- TiO_2 is extremely stable
- H_2 cannot reduce TiO_2
- Mg cannot reduce TiO_2 to lower than 2_{wt}%O



Science

- Scientific discovery:

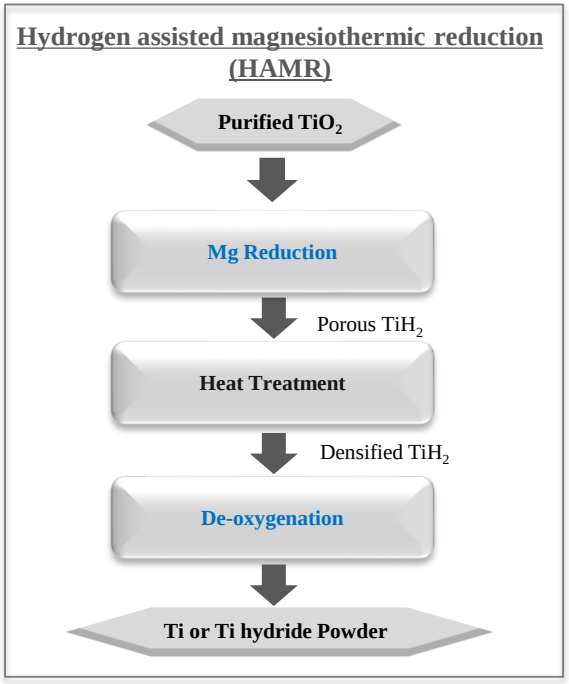
Hydrogen destabilizes Ti-O, making the reaction of Mg with Ti-O from being thermodynamically unfavorable to being favorable.



Ref.: Ying Zhang, Z. Zak Fang, et al. Thermodynamic Destabilization of Ti-O Solid Solution by H_2 and Deoxygenation of Ti Using Mg, ***JACS****, 2016, 138: 6916-6919.*

Technology

- Mg reduction in H_2 atmosphere
- Reduction in molten salt – kinetics
- Two step process: reduction and deoxygenation



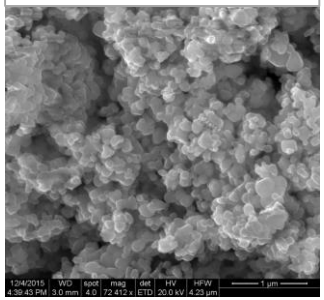
The HAMR Process and Product

Impurity contents in final Ti powder

Weight percent (%)	Mg	Al	Fe	Si	Cl	O	N	C	H
Final Ti powder	<0.1	<0.03	<0.10	<0.04	<0.1	<0.12	<0.02	<0.03	<0.03
ASTM-B299-13 (GP Ti sponge)	0.5	0.05	0.15	0.04	0.2	0.15	0.02	0.03	0.03

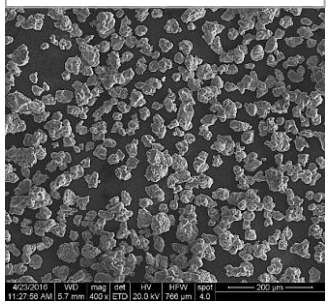
The ASTM standard for general purpose Ti sponge is met!

Purified TiO_2

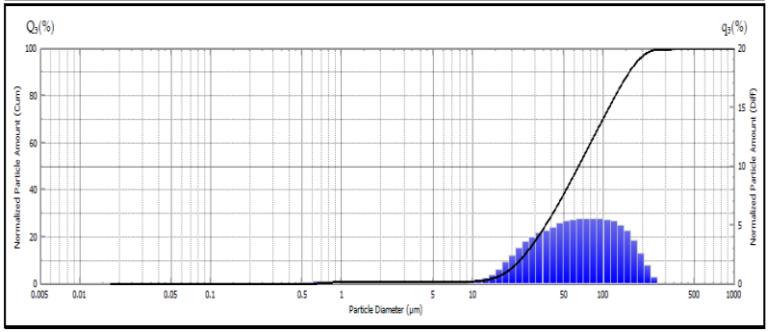


As-reduced TiH2

Deoxygenated Ti

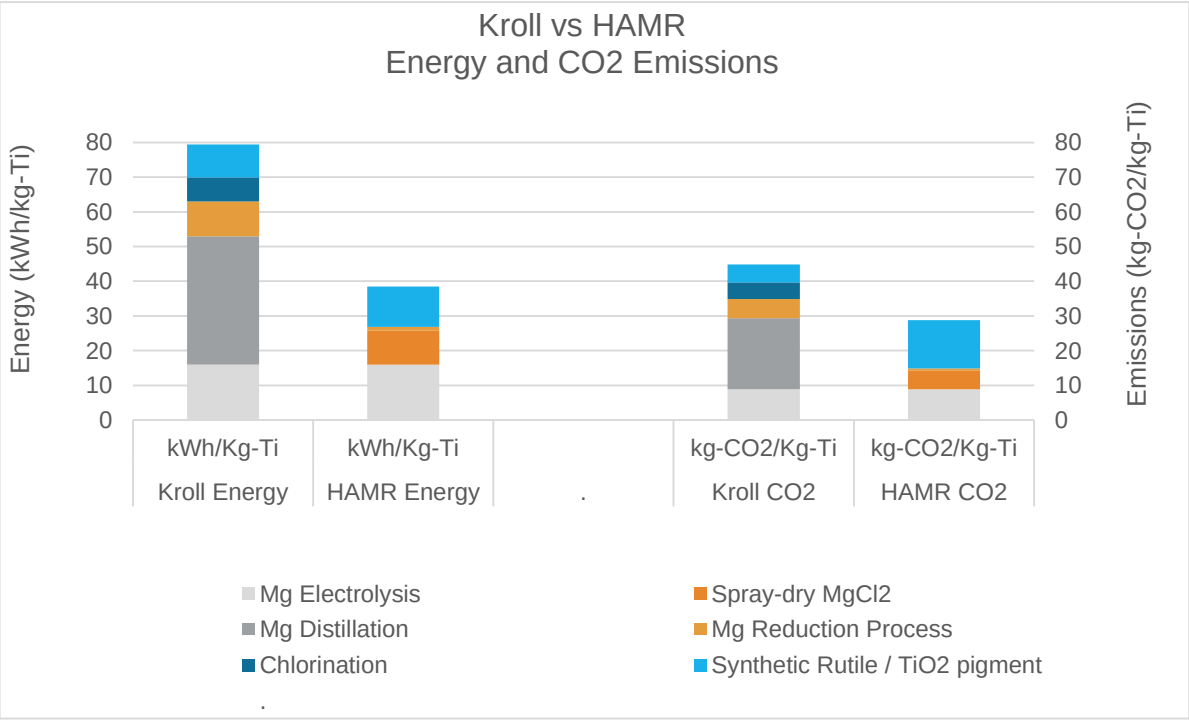


10%D(μm)	50%D(μm)	90%D(μm)	0%D(μm)	0%D(μm)	0%D(μm)	0%D(μm)	0%D(μm)	0%D(μm)
22.547	63.858	157.049	0.000	0.000	0.000	0.000	0.000	0.000



TEA Highlights

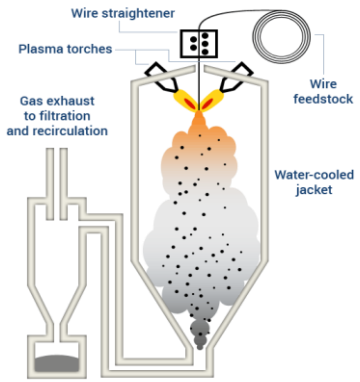
Estimated energy consumption and CO_2 emission of HAMR process compared with Kroll process



Spherical Ti64 powder for 3D Printing

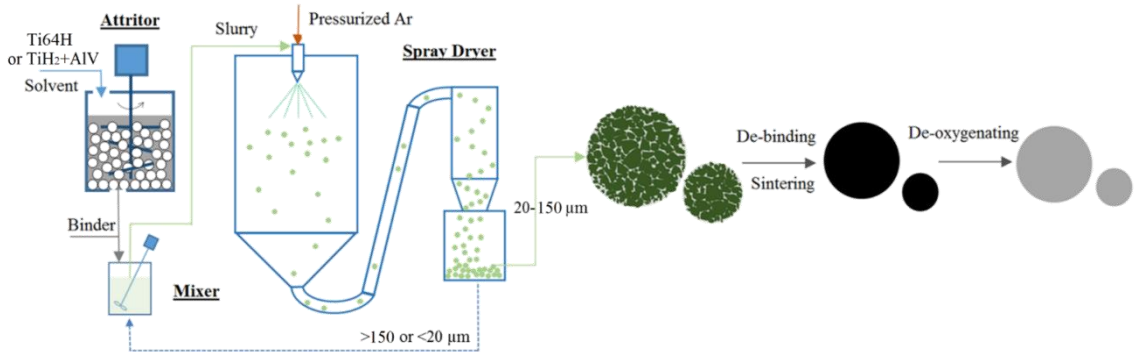
Current processes and challenges

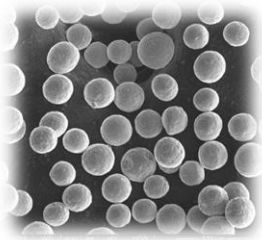
- Ti is a popular metal for 3D printing.
- Spherical Ti powder needed for 3D printing is prohibitively expensive **($250-500/Kg)**
- Current plasma atomization processes suffer from low yield and expensive feed stock material for atomization



The new Utah GSD (granulation-sintering-deoxygenation process)

- GSD process is inherently high yield. Particle size distribution can be customized.
- GSD process uses low cost feed stock (e.g. scrap metal).
- Low oxygen – owing to a breakthrough deoxygenation technology developed as a part of this program.

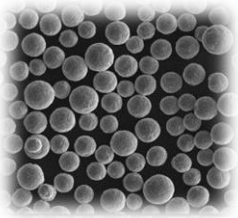




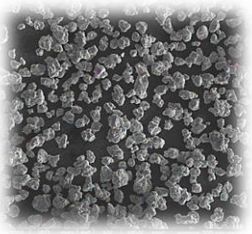
Using GSD process, cost of powder is estimated at $20-50/Kg depending on feed stock material, as opposed to $250-500/Kg.

TEA Highlights

Market Needs



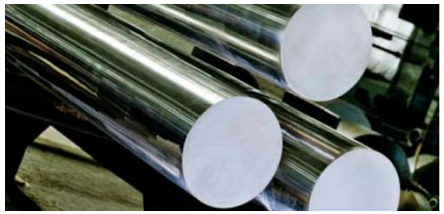
3D printing



Powder

CP-Ti powder market

Ti billets



TEA Highlights

Projected prices based on new technology vs. current market prices based on Kroll process

Product	Current market price (approx.)	Projected price based on the new technology	
		HAMR CP-Ti	GSD Spherical Ti
Ti sponge (Kroll process)	$8-12 /Kg	N/A	N/A
Ti powder	$30-60/Kg (HDH CP-Ti powder)	$7-15/Kg (depend on scale)	N/A
Ti billet (preform for mill products)	$30-40/Kg (sponge-ingot-billet)	$15-25/Kg (powder-compaction-sintering)	N/A
Spherical Ti powder	$250-500/Kg	N/A	$50-150/Kg (depending on scale)

Demo Requirements

Commercialization strategy -

- Start-up company to focus on pilot scale and commercialization
- Short term to start with GSD spherical Ti alloy powder for additive manufacturing
- Long term goal to commercialize HAMR CP-Ti powder for current powder markets and eventually Ti billet market

Pilot scale development

- Current at *TRL 4*. Aiming to reach *TRL 7* through a development pilot scale project.
- Pilot scale plant aims to produce powder at 10Kg/day.
- Develop sufficient quantity of materials to be qualified by customers and the industry
- Demonstrate the engineering feasibility of the process and be ready for large scale production

Future Goals / Closing Thoughts

- Two novel processes are developed for making
  - ✓ ***Conventional Ti powder*** *for a wide range of applications*
  - ✓ ***Spherical Ti alloy powder for additive manufacturing***
- The new processes reduce costs of production by greater than 50%
- Current at *TRL 4*. Aiming to reach *TRL 7* through a pilot scale development project.
- Seeking funding for scale up development project
- A start-up will be the vehicle of commercialization, in collaboration with the U of Utah.
- Focus on commercializing spherical Ti powder for AM/3D printing in the plus-up project phase
- In long term, commercialize HAMR pure Ti powder for Ti billet markets

QUESTIONS?

TEA Highlights

Comparison of the Utah-HAMR process to Kroll and FFC Processes

	Principle	Feed material	Reducing agent	Product quality	Morphology	Challenge	Status
Kroll	Thermal chemical 2Mg+TiCl4=2MgCl2+Ti	$TiCl_4$	Mg	Low to extremely low impurity	Sponge and sponge fine	Distillation is energy-intensive	Commercial
FFC	Electrochemical TiO2+4e-=Ti+2O^{2-}	TiO_2	e-	O: 0.29%* C: 0.07% Ca: 0.13%	Partially sintered porous powder	Scaling-up**	Pilot plant
HAMR	Thermal chemical Mg+TiO2+H2=Ti-H-O +MgO Ti-H-O+Mg+H2=Ti-H +MgO	TiO_2	Mg	O:<0.12% C: <0.02% Mg: <0.10%	Discrete HDH-like powder	Consistency needs to be demonstrated.	Kg scale lab-tested

* According to limited information in public literature. Company internal reality could be different.

Demo Requirements

- What does the demo phase of this project look like?
  - Scale
  - Cost Range
  - Projected Outcomes
- What partnership needs, if any, does your research require?
  - Note: this can be omitted if you don't feel comfortable telling the group exactly where you are at the moment.

Future Goals / Closing Thoughts

- What is the ultimate end goal for this project?
- Where do you see yourselves in 5 years? 10?
- What is the prospective impact of this project from an industry perspective? Energy perspective? CO2?
- What would you like the audience to take away from this presentation?

TEA Highlights