Boston Electrometallurgical Corporation

Cleaner metals for a greener world.

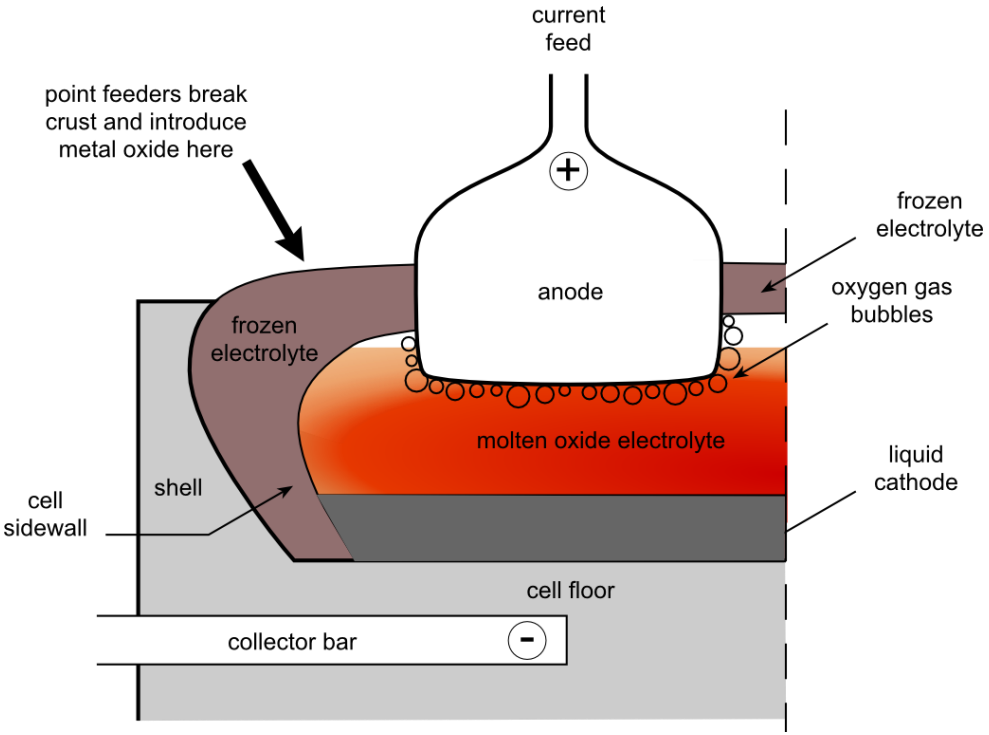
Dr. Robert W. Hyers

August 24 – 25, 2016

Detroit, MI

METALS Annual Meeting

August 24, 2016



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Agenda

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

Team Intro: Boston Electromet

Organization

- BEMC is a startup company formed to scale up the process
  Molten Oxide Electrolysis (MOE).

Project Summary

- Produce liquid titanium
  - High temperature
    + Fast kinetics
    = High productivity
  - Ingots & Billets, not powder
- Variety of Feedstocks
  - Chemistry, minerology, form.
- Capture chemical-grade carbon monoxide byproduct.

Current goal:

- Produce Titanium
- Meet targets for cost, energy, and chemistry.

Objective:

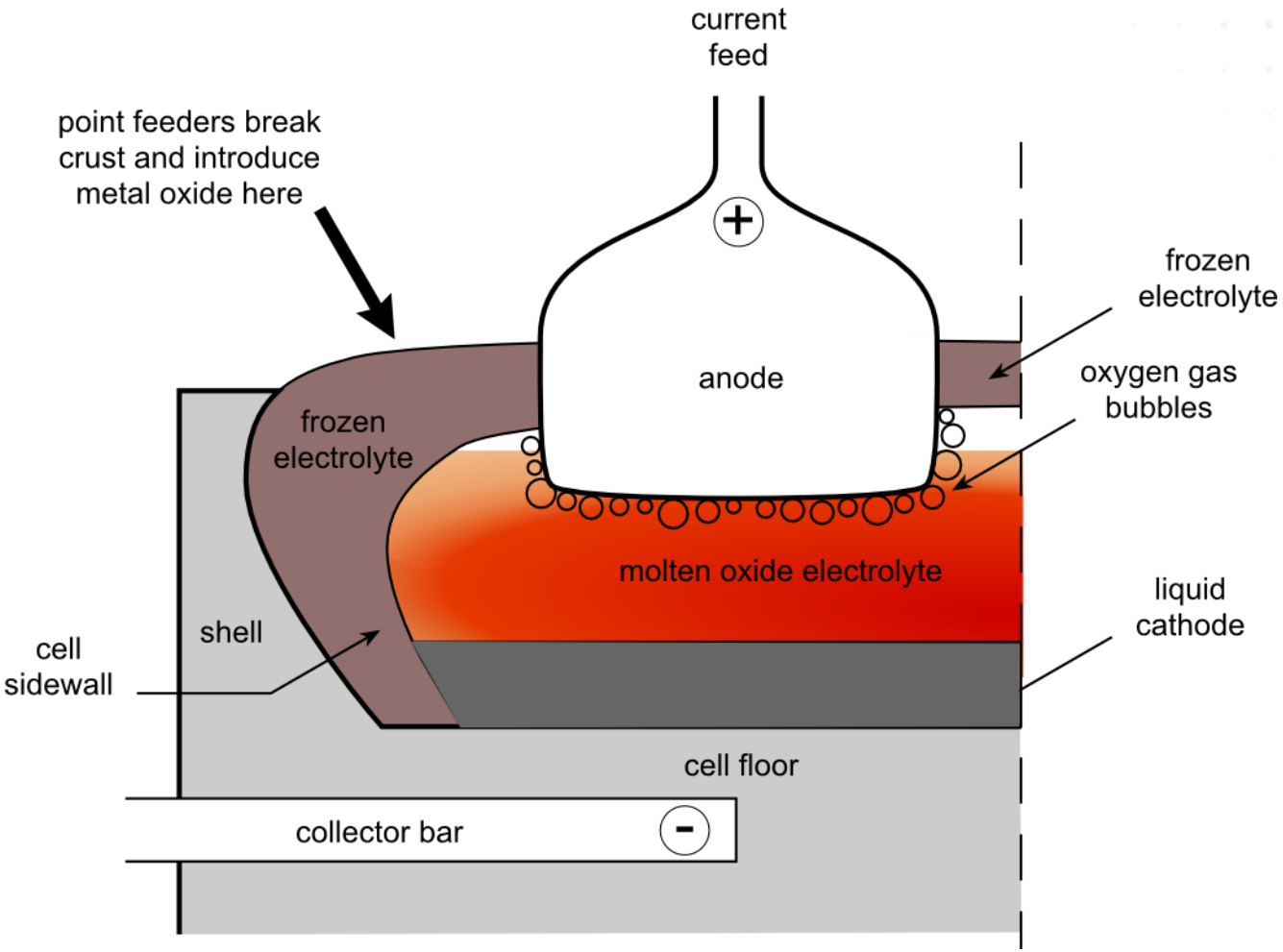
- Titanium at the cost of stainless steel!

Technical Concept

"*It might, however, be fair to say that titanium will be made competitively by fusion electrolysis within the next five to ten years*"
- W.J. Kroll, AIME, ***1959***

- Basis: molten oxide electrolysis.
- Novelty: operate above melting point of titanium, producing product as a liquid.
- Benefits:
  - Higher productivity.
  - Directly cast ingot, billets from cell.
  - Working pilot-scale system to adapt for Ti.
  - Lower energy, lower cost.
- Why was this project considered a good fit for ARPA-E funding?
  - High technical risk: solution is over 50 years late!
  - High payoff:
    - 0.7 quads commercial aviation
    - Part of 5-13 quads in unrecovered waste heat in US alone.

Technical Concept



Technical Progress to Date

- What are the overall project phases?
  - Contract started May 5, 2016.
  - Phase I: Produce measurable Ti in solution: lab or pilot cell.
  - Phase II: Produce a lot of Ti in solution: pilot cell.
  - Phase III: Produce commercial alloys.

- Where do you still have additional work to complete?
  - 2.75 years of 3-year project.

TEA Highlights

- What price range are you targeting for this product? How does this compare to current market?
  - Adopted from METALS program.
  - Ti for the cost of Stainless Steel. 5-10 X reduction in ingot/billet costs.

- How efficient is your process from an energy perspective?
  - Theoretical Energy for our process (no losses, inc CO): 4.98 kWh/kg
  - Theoretical Minimum energy (ARPA-E): 4.7 kWh/kg
  - ARPA-E METALS target <35 kWh/kg.
  - Kroll: (ARPA-E) 100 kWh/kg.

- What CO_2 emissions are you anticipating from your process?
  - All electric; CO_2 depends only on generation.
  - Theoretical energy gives 3.5 kg CO_2/kg Ti for current US power mix.
  - Current industrial practice (ARPA-E): 36 kg CO_2/kg Ti.
  - ARPA-E METALS target <11 kg CO_2/kg Ti.

TEA Highlights

- What are other benefits of your process over a comparable process?
  - Reduced production of chlorocarbons such as dioxins.

- What scale are you targeting for optimal efficiencies?
  - Modular production, like aluminum smelter.
  - One module: 100's – 1000's of tpa.
  - Plant: 10's – 100's of modules.
  - Largest Al smelter: 1440 cells.

Demo Requirements

- What does the demo phase of this project look like?
  - Scale: one commercial-size cell.
  - Cost Range: TBD.
  - Projected Outcomes: Validation of cost, energy, quality.

- What partnership needs, if any, does your research require?
  - Too early to discuss.

Future Goals/Closing Thoughts

- What is the ultimate end goal for this project?
  - Liquid titanium.

- Where do you see yourselves in 5 years?
  - Demo plant operating.
- 10 years?
  - Producing commercial Ti.

- What is the prospective impact of this project from an industry perspective? Energy perspective? CO2?
  - Enabling substitution of Ti for stainless. Large savings energy, CO_2.

- What would you like the audience to take away from this presentation?
  - Look us up in 2018!

QUESTIONS?