Scale-Up of Magnesium Production by Fully Stabilized Zirconia Electrolysis

DOE Annual Merit Review
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Project ID: LM035
### Timeline

- **Project start date:** 10/1/2011
- **Project end date:** 12/31/2014
- **Percent complete:** 0-7.5%

### Budget

- **Total project funding:** $12M
  - $6M DOE
  - $6M MOxST
- **FY11:** $0M DOE
  - $0M MOxST
- **FY12:** $2M DOE
  - $2M MOxST

### Barriers

- Cost-effective and clean production of Magnesium

### Partners

- Praxair, Inc.
- Spartan Light Metal
- Cosma International, Automotive Partnerships Canada
- Kingston Process Metallurgy
- Boston University
MOxST Business Overview

Founded in 2008 to commercialize the platform technology

Today, 11 employees, 10,000 sq ft office in Natick, MA, Lab, Machine shop, fabrication, test cells for development
MOxST Production Furnace Platform

Patented FSZ Technology
(Fully Stabilized Zirconia Electrolysis)

Separates metal oxides into high purity Metal and Oxygen

 Produces high purity Oxygen directly

More efficient than conventional methods

Half the energy of MgCl2 electrolysis

Zero emissions facilitates siting/permitting
Magnesium Primary Production -- Energy and CO2 Emission

- Pidgeon: 102.2 kWh/kg or 20.2 kg/kg CO2
- MOxST: 43.6 kWh/kg or 4.9 kg/kg CO2
- Western Electrolytic: 37.4 kWh/kg or 6.9 kg/kg CO2

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Engineering and Project update

Lou Spiridigliozzi, VP Engineering

- Senior engineering executive in high-growth innovative companies
- MIT S.B., 2 S.M., MBA/LGO from MIT Sloan
- Experience in bringing innovative processes to market
Electrolysis Components

- Gas/power/raw material manifold
- MgO feed tubes
- Cathodes/argon feed tubes
- SOM anodes
- Crucible
- Ar/Mg bubbles
- Molten salt electrolyte

Ar in → MgO feed → Ar recycling pump

O₂ (out) → Ar out

Condenser

Liquid Mg

Tap

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Overview of System Development (VTP Timeline)

• Demonstration of system uptime improvements (2012)
  • Anode and cathode shielding
  • Fueled anode
• Continuous kilo-scale production cell currently under construction (2012)
  • Demonstrate reliable long-term operation
  • Work issues effecting long-term uptime
    • Zirconia protection
    • Anode current-transport material design and robustness
• High-Density 13-tube experimental system currently in design (2012)
  • Demonstrate effectiveness of concepts for system scaling
• Design and build 12-19 tube alpha system (2012)
• Operate and refine alpha system (2013)
• Design full-scale industrial beta system (2013)
• Build and operate beta system (2014)
• Plans for commercial system production rollout (2014)
System Uptime Improvements

- Demonstrate Improved Uptime
  - Single tube with 15 cm immersion
  - Shielded anode and cathode
  - Mechanically stirred
  - Fueled Anode
  - Liquid metal anode with solid metal current collector
  - Condense to liquid with lightly-baffled condenser with mold release and ejector pin
  - Band heaters used for condensing path
  - Ram-fed MgO port
Continuous Kilo-Scale System

- Demonstrate continuous magnesium production
  - Custom 4-furnace system
  - Single tube with 15 cm immersion
  - In-situ tube replacement
  - Shielded anode and cathode
  - Mechanically stirred
  - Fueled anode
  - Liquid metal anode with solid metal current collector
  - Condense to liquid with fully-baffled condenser
  - Vacuum pour from condenser
  - Screw-fed MgO port
High-Density Deep Immersion

• Demonstrate features necessary for Alpha prototype
  • Thirteen tubes with 30 cm immersion
  • Manifolded shielding for anode
  • Solid cathode
  • Oxygen-generating anode
  • Mechanically stirred
  • Enhanced shielding and transport
  • Liquid metal anode with solid metal current collector
  • Condense to liquid with fully-baffled condenser
  • Vacuum pour from condenser
  • Screw-fed MgO port
Alpha Prototype

- Continuously-operating 12-19 tube magnesium production system
  - 3 lb/hr tube geometry and density
  - Manifolded shielding for anode
  - Mechanically stirred
  - Enhanced shielding and transport
  - Oxygen-producing, manifolded anode
  - Advanced anode and current collector system
- Condense to liquid with fully-baffled condenser
- Magnesium pumped from condenser
- Screw-fed MgO port
Overview of Anode Development

• Yttria-Stabilized Zirconia Tube
  • Geometry
  • Fabrication
  • Composition
  • Manufacture

• Anode
  • Design for oxygen-generating anode
  • Design for fueled anode
Baseline Anode System

- Baseline tube
  - 6YSZ
  - Slipcast
  - Purchased
  - High-impurity level
  - ¾” OD, ½” ID
  - 24” Length w/ 6” immersion

- Anode
  - Liquid metal anode
  - Solid metal current collector
  - Oxygen-generating
Optimized Baseline Anode System

• Baseline tube
  • 8YSZ
  • Slipcast
  • Fabricated in-house
  • Low-impurity level
  • ¾” OD, ½” ID
  • 24” Length
• Anode
  • Liquid metal anode
  • Solid metal current collector
Further Tube Evaluations

• Geometry
  • Radius
    • (e.g., 1.25” OD, 1.0” ID)
  • Wall Thickness
• Composition
  • Alternative zirconia-stabilizing additives
  • Alternative forming additives
• Processing
  • Sintering profiles
  • Alternative green-state forming techniques
  • Advanced densification techniques
Further Anode Evaluations

• Oxygen-Generating
  • Anode
    • Alternative materials
  • Current Collector
    • Protected collector rods
    • Alternative rod materials
    • Multi-phase collector

• Fueled
  • Anode
    • Alternative liquid metals
  • Current Collector
    • Coated solid collector rods
  • Fuel
    • Natural Gas, Syngas, etc.
Summary

• Project getting underway
• Engineering scaleup
• Partnerships growing