# Scale-Up of Magnesium Production by Fully Stabilized Zirconia Electrolysis

DOE Annual Merit Review

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Presenter: Steve Derezinski, MOxST, CEO

Project ID: LM035

# OVERVIEW

## Timeline

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

## Barriers

- Cost-effective and clean production of Magnesium

## Budget

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

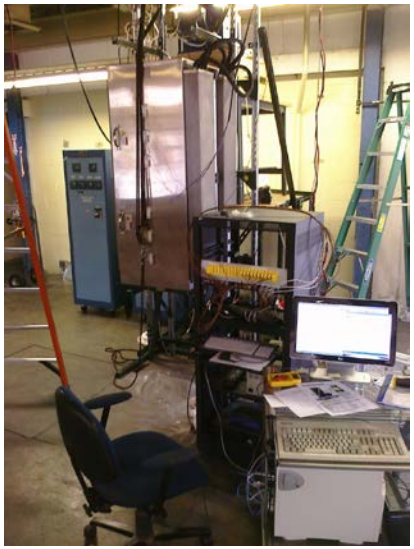
## Partners

- 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



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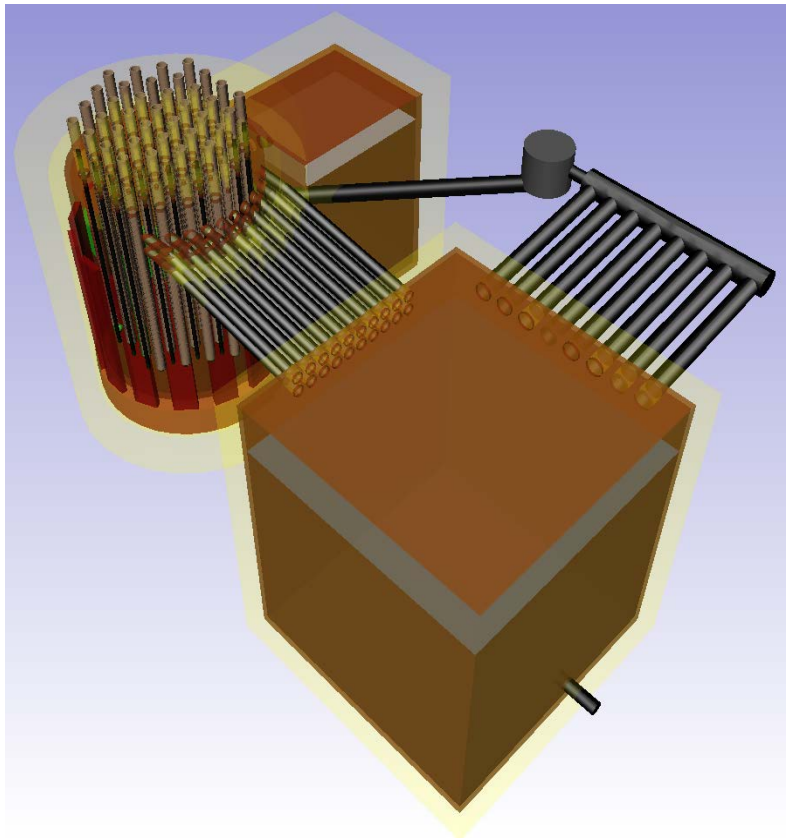
# MOxST Production Furnace Platform



Patented FSZ Technology

(Fully Stabilized Zirconia Electrolysis)

Separates metal oxides into high purity Metal and Oxygen

Produces high purity Oxygen directly

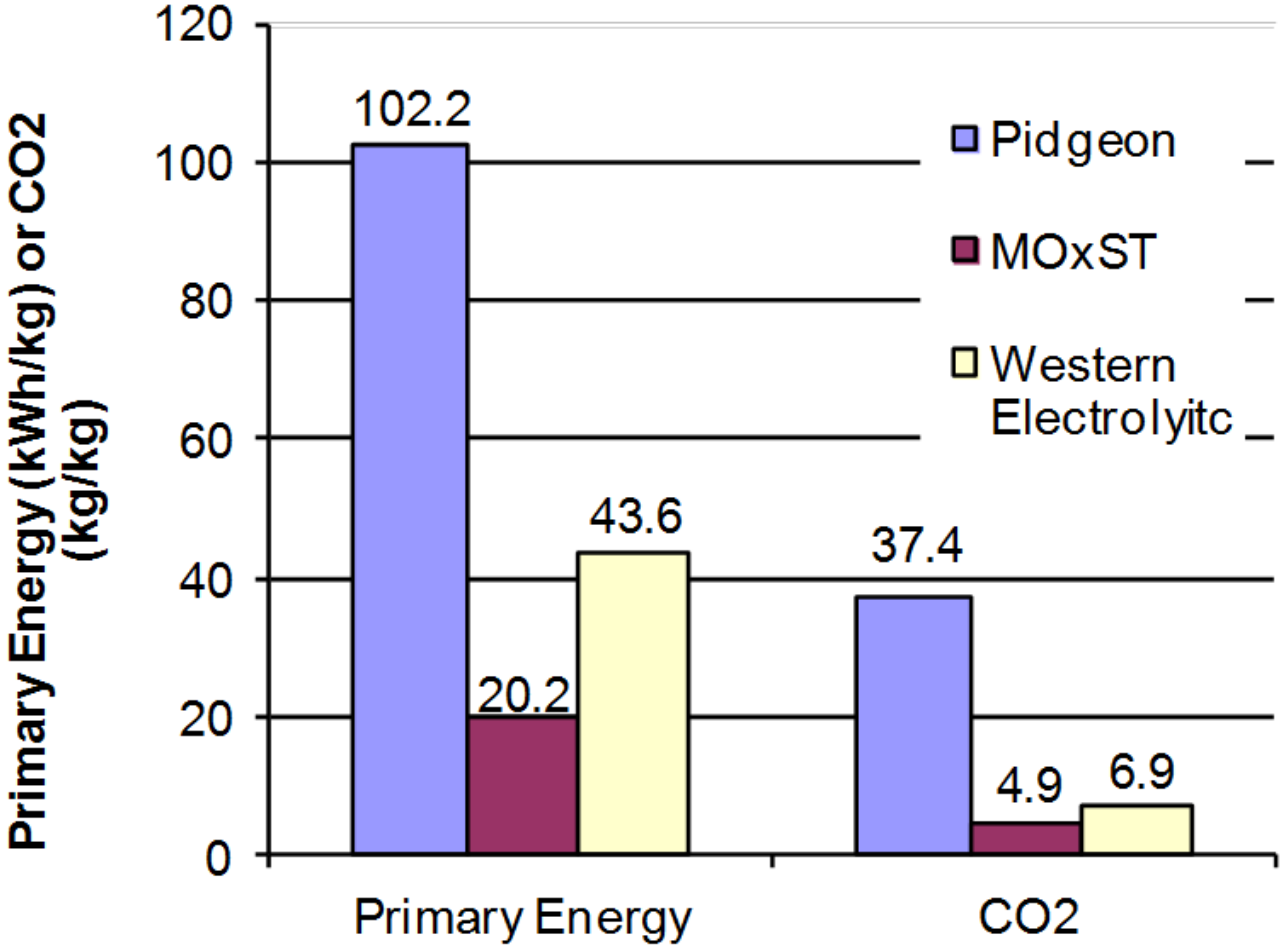
More efficient than conventional methods

Half the energy of $MgCl_2$ electrolysis

Zero emissions facilitates siting/permitting

MOxST
Metal Oxygen Separation Technologies Inc

# Magnesium Primary Production -- Energy and CO2 Emission

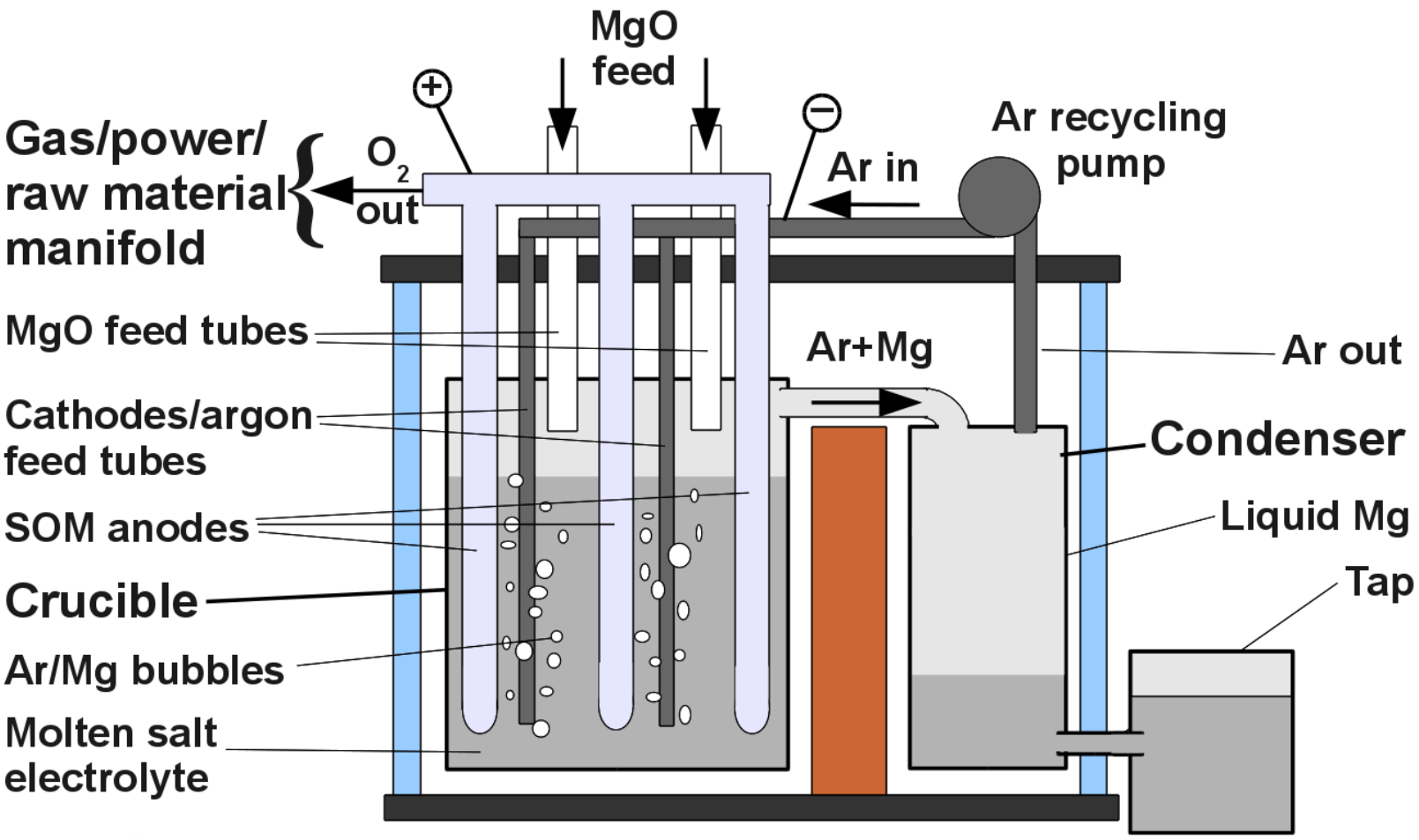


# Engineering and Project update

**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

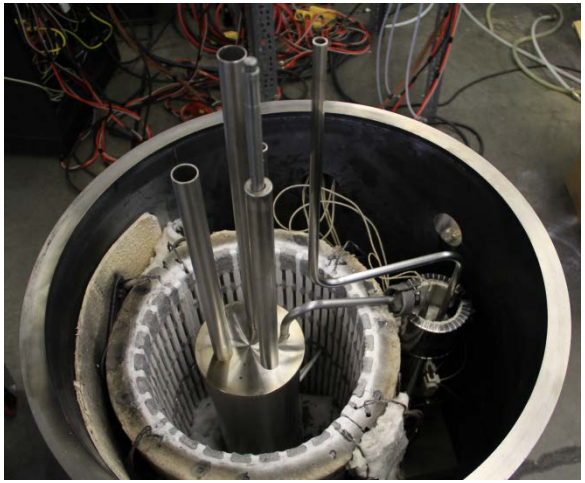


# Overview of System Development
## (VTP Timeline)

- 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)

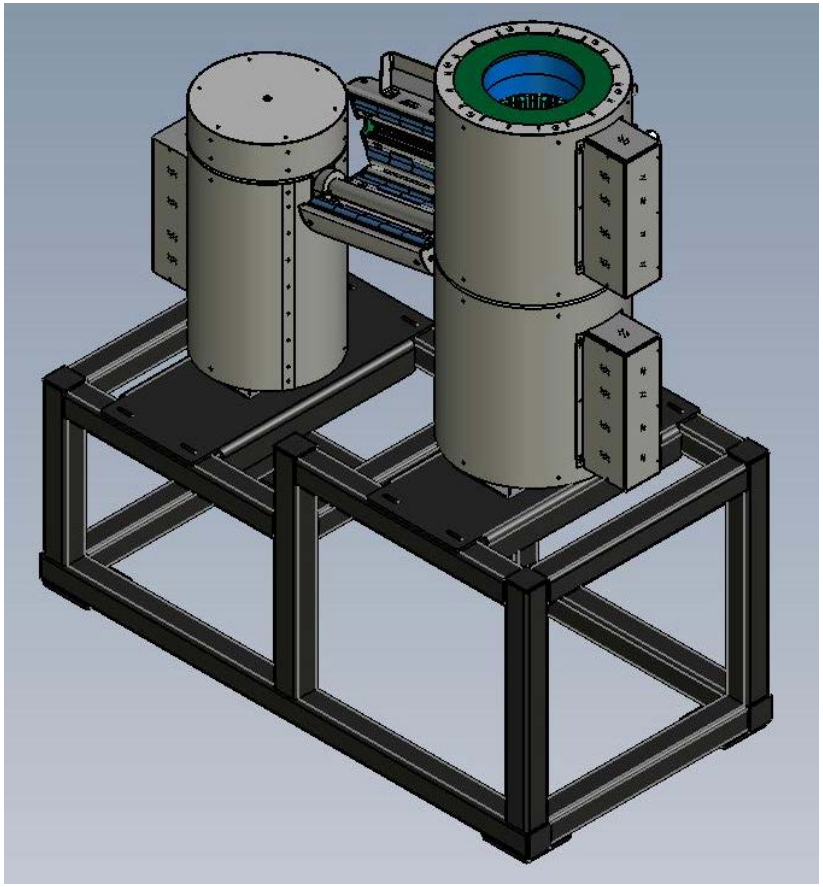
# System Uptime Improvements

- 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



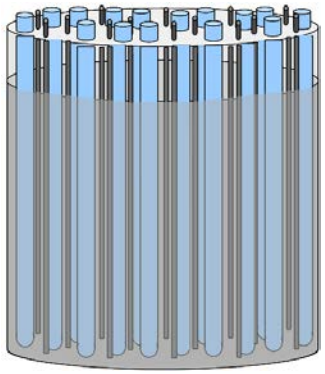
# Continuous Kilo-Scale System

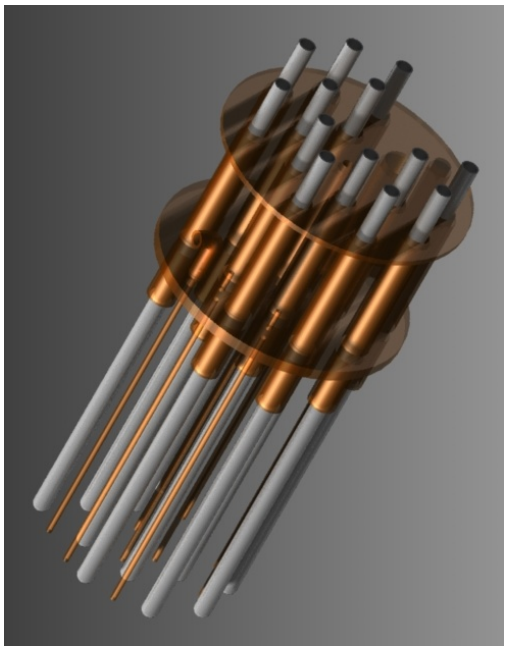
- Demonstrate continuous magnesium production
  - Custom 4-furnace system
  - Single tube with 15 cm immersion
  - In-situ tube replacement
  - Shielded anode and cathode
  - Mechanically stirred
  - Fueled anode
  - Liquid metal anode with solid metal current collector
  - Condense to liquid with fully-baffled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

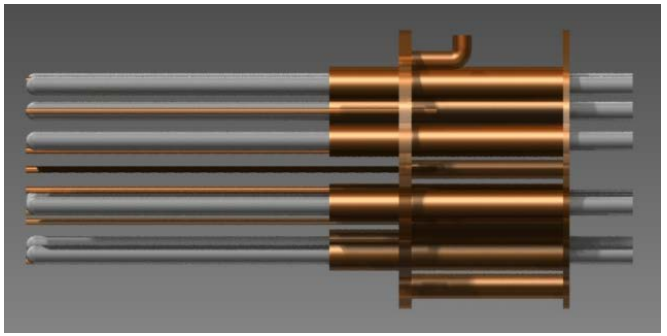


# High-Density Deep Immersion

- 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

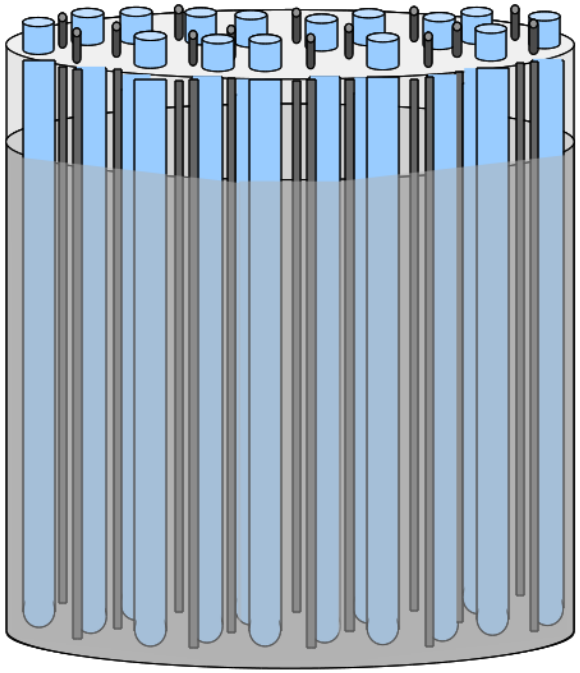






# Alpha Prototype

- 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