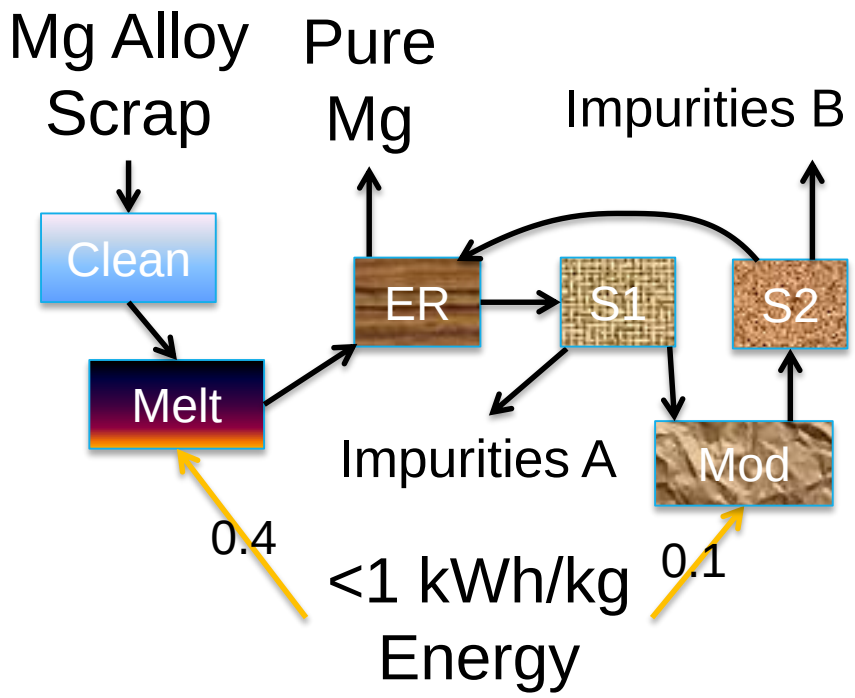
INFINIUM Magnesium

August 24 – 25, 2016

Detroit, MI

METALS Annual Meeting



Agenda

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

The INFINIUM Team

Clean Metal Production for Clean Energy

Team Members
- Adam Powell, PI
- Aaron Tajima, project manager, lead designer
- Matthew Earlam, TT&O lead

Current Goals
- Proof-of-concept technology demonstration at ≥1 kg/hr scale
- Scale-up magnesium refiner design with energy use <1 kWh/kg

Project Summary
- New process for magnesium alloy refining/recycling
- Very low energy: <1 kWh/kg product
- Continuous → low capital and labor costs
- High purity product suitable for low-corrosion alloys
- Liquid metal product
- Small machine, very high throughput
- Very low total cost

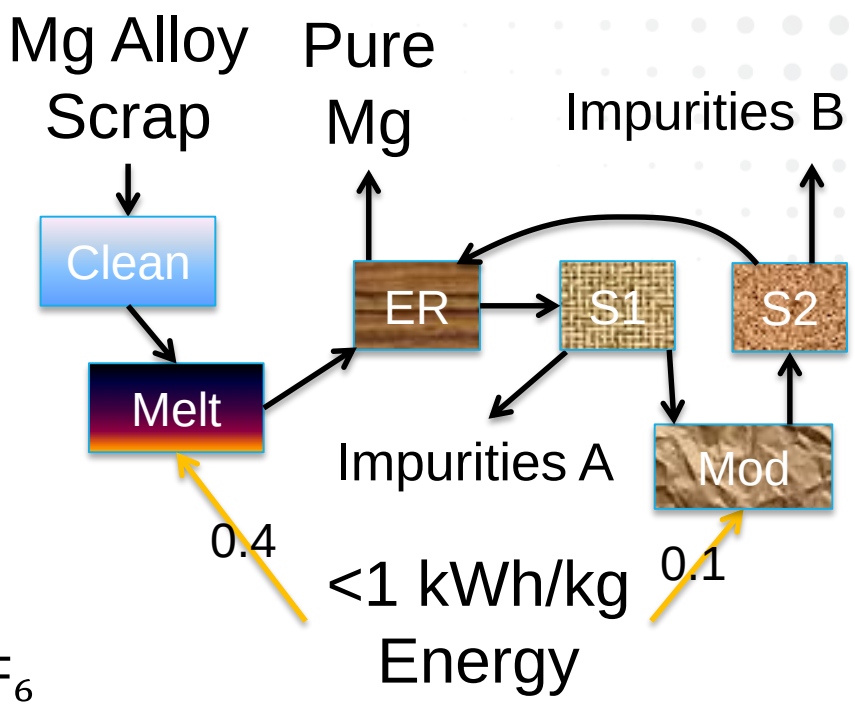
Motivation

- Mg could reduce vehicle weight, energy use and emissions more than Al provided several barriers can be overcome:
  - Recycling scrap → vehicle parts
  - Low-cost secure primary supply
  - Warm/cold-formable sheet
  - Improved corrosion behavior
  - Multi-material joining
  - Large thin-wall castings

  This high risk project addresses two key barriers to increased Mg use
- Mg recycling difficulties today:
  - Impurities: due to attachments etc. sorting can not achieve purity for low-corrosion alloy specs AZ91D/E, AM60B/C – too much Fe, Cu, Ni
  - Liquid Mg handling: requires cover gases to prevent fire
  - Poor safety track record: many Mg recycling companies have had explosions/fires
  - Result: post-consumer Mg alloy scrap recycling rate is 20-30%
    - Compare to 60-80% for steel and aluminum

Technical Concept

- INFINIUM Mg refining technology:
  - Continuous → low labor, capital
  - Low energy <1 kWh/kg product
  - Purity suitable for new vehicle parts
- Barriers/risks:
  - Very novel separation methods
  - Materials: liquid Mg is ok, Al and others are difficult
  - Reactivity: can't hold Mg in open containers without cover gas e.g. SF_6



- Today's technologies for Mg refining:
  - Distillation: 5-7 kWh/kg, slow batch process, high surface area pyrophoric solid "crown" product requires remelting
  - Electrorefining: 4-5 kWh/kg, slow continuous process

Technical Progress to Date

- Project phases:
  - Foundation: materials selection, component/subsystem testing, lab-scale system design
  - Proof-of-Concept: first implementation
  - Technology development: lower energy use, higher product purity
  - Post-project demonstration: much larger throughput
- Current status:
  - Six months in, Foundation phase is nearly complete
  - Moving forward with component/subsystem test stand fabrication and design of first complete recycler
  - Project end date: February 2018
- Biggest successes to date:
  - Successfully tested some of the novel subsystems, all of which must work to make the overall system succeed
  - Identified and tested candidate materials for system components

TEA Highlights

- Price range: this will be competitive at world (ex-US) magnesium prices
  - *Low enough cost to increase scrap value and incentivize higher recycling rates*
- Energy/emissions:
  - <1 kWh/kg
  - Direct emissions only from scrap cleaning and melting
- Benefits:
  - Much lower cost than other refining processes
  - Much better purity than any sorting technology can achieve alone
  - Small fraction of the cost of primary production
- Typical plant scale: 5000-20,000+ TPY

Demo Requirements

- If this project succeeds, the Demonstration phase will build and test a small industrial refiner
  - Scale: ~1000 TPY
  - Cost Range: very low
  - Projected Outcomes: economical for refining, will need to quickly grow scrap supply to keep up with production
- Partnership requirements
  - Working on market analysis and potential partners – including finance – to enable successful Demonstration phase

Future Goals/Closing Thoughts

- Two-year project end goals:
  - All technical problems solved, working system at large lab scale
  - Complete design for Demonstration phase ready to start fabrication
- 5-10 year vision:
  - 20-30 kT/yr magnesium recycling output in US, Europe, Japan
  - Increased magnesium alloy scrap availability by providing a market for nonferrous sorters
  - Begin scale-up of primary production enabled by this technology
- Prospective impact:
  - Meet goals of Mg 2020 report (USCAR 2006) → replace 630 lbs steel/aluminum components per vehicle with 340 lbs magnesium *which have already been done before*
  - Enable new magnesium-intensive vehicles like Ford/Magna MMLV Mach II with >40% weight reduction
  - Lower oil imports and transportation sector energy/emissions

QUESTIONS?