Aluminum Production Metrics/Targets Breakout

Energy Barriers

•Possible to even get nearer to 40 MJ/kg when you account for the Bayer process but 80% of Al in US is produced through recycling routes.

•It is not clear that a 30% energy reduction is the tipping point to bring back primary US Aluminum production

Cost breakdown

•25% of the cost is energy, even if this was eliminated completely, the ultimate cost would still be over $1/kg

Current cost

•$6k/ton/yr is the current capital intensity for a Greenfield plant, a 30% reduction in capital intensity is desirable

•Cash cost target is $1700/ton (net)

Considerations

•Consider setting an energy cost target although even if efforts are successful, there is no guarantee of re-capturing the market

Grade range

•98% is the lowest grade alloy and 99.7% is high value standards

• Should probably just reference ASTM standards

Challenge with constraining

•If the purity target is too high, big lower value markets could be over looked.

Emissions

• Emissions being generated from the Aluminum industry is about 1% of US emissions

•Consider bringing this down towards 0 by finding uses for CO2 and if any CO is produced use it as a fuel

Recycling

•Flexible primary/secondary production technologies as under 50% of recycled Aluminum goes into cars

Magnesium Production Metrics/Targets Breakout

ARPA-E is considering setting an energy extraction target of 175 MJ/kg for primary Mg production. What are the challenges to meeting the target?

- Is 175 MJ/kg really a reach? This is close to SOA Mg-Cl electrolysis.

- Challenges dependent on pathway
  - CSP using MgO. Goal is to substitute as much process heat as possible.
    - Fundamental engineering around electrochemistry
    - Carbon or hydrocarbon at anode to reduce electrochemical potential
  - Electrochemistry
    - Maximize Current efficiency
    - Minimize Over-potential
    - Cell engineering – how do you provide heat?
  - Thermochemical – high T for Mg (at least 1700 C)
    - quenching to prevent back reaction
    - thermal management
    - efficiency limited by chemistry (electrochemistry and solid-state)

ARPA-E is considering setting a cost target of $2/kg for primary Mg production. Can this target be met solely through energy reduction?

- Energy consumption only accounts for capital cost
- Raw material cost not considered, which is linked to energy costs because of purification.
  - Low grade precursor can be benefit if you can avoid added costs for purification.
- CapEx comparison – electrolytic process is 4-5X more. Opportunity is removing process steps.
- Can we have new process that allows straight pathway to finished product?
  - Molten metal directly to die casting

ARPA-E is considering setting a purity constraint on primary magnesium of >99.5%. Considering different alloys require different purity constraints, is a purity target appropriate?

- What is impurity? Ni or Fe would kill it at 0.5%.
- Should be able to meet requirements of die casting alloys? ASTM standards should referenced.
- What about markets for lower grade product? Smaller markets.
- Some impurities are desirable in alloys – Al, Zn, Mn, rare earths.

Are there any other targets or constraints that ARPA-E should consider setting besides energy, cost, and purity?

- Distinction between fossil and renewable energy source with cost target
  - Emissions including, but not limited to CO_2
  - Should this be framed in exergy rather than energy?

- Sourcing. Most Mg is coming from China. How do we get a commercially viable process in North America?
  - Automated that is more amenable to high labor cost. Continuous helps.
  - Strategic issue: how do we avoid rare earth problem?
    - What happens to automotive sector if we lose Chinese?

What specifications should be placed on recycled magnesium?

- Can you produce Mg from recycled material?
  - Automotive sector.
- Post-consumer problem recycled to make die-cast Mg.
  - Really hard, but big impact.
- Is recycling competitive given how much Mg feedstock we have?
  - Automotive sector.

- Recycling cost specs should be lower than first production.
  - No market reason to do it otherwise
- Energy to start with separated recycled Mg << theoretical limit to starting with MgO.
  - Assuming a starting alloy to baseline
- How do you do the sorting?
  - How effective should it be?
  - What about parts stuck together?

Titanium Production Metrics/Targets Breakout

ARPA-E is considering setting an energy extraction target of 175 MJ/kg for primary Ti production.
What are the challenges to meeting the target?

- Rather then chlorinating and focusing on innovation from this point, can we start all the way from ore
- If you can use not so pure TiO_2 you can save steps which in fact saves energy
- Huge buy to fly ratios in a full Life cycle perspective are energy contributors
- Magnesium chloride (Kroll) having to breakdown again is high cost and energy
- Sodium reclamation (Armstrong) is a challenge and can ruin powder quality
- MER has reached an experimental energy target of 100 MJ/kg
- DARPA is focused on the bad processes not the whole primary production
- Primary production methods integrated with additive manufacturing compressing LCA energy has not been looked at before
- TiO_2 slag reduction through Electrochemical routes never got enough support in the past as Ti prices were so low that it effected the research which was expensive

ARPA-E is considering setting a cost target of $6/kg for primary Ti sponge and $10/kg for primary Ti ingot. Can these targets be met solely through energy reduction?

- •MER has reached a target of $3/kg
- •Titanium reaching the cost of Duplex Stainless Steel (corrosion resistance, high quality steel) which it can out perform, could be transformation especially for industrial use
- •Need to look at more upstream approaches (ore – metal) as downstream is being chocked, especially from $TiCl_4$ feedstock
- •Energy reductions play a part in components like distillation (65% of the total energy used), but there are other factors too like materials and buy to fly ratio

ARPA-E is considering setting a purity constraint on Titanium of >99%. Considering different alloys require different purity constraints, is a purity target appropriate?

Quality

- 250 microns, 35 seconds hall flow, 1400 ppm impurities quality

Challenge

- Getting below 1 micron cost increases exponentially

Are there any other targets or constraints that ARPA-E should consider setting besides energy, cost, and purity?

- Confidence in supply
- Not enough powder producers (under supply)
- Measuring oxygen %wt on powder is challenging
- Insitu feedback tools that can control powder
- Homogeneity of feed for sintering process

Given that titanium has excellent strength/weight and corrosion resistance characteristics, what markets and applications relevant to energy provide a growth opportunity for the usage of Ti (eg. Nuclear? Shipping? Others?)? Where can the use of Ti have the greatest impact on energy technologies?

Nuclear and process industry (looked at)

- Not possible for cladding as Titanium becomes highly unstable in neutron bombarding conditions
- Heat exchangers, boilers, condensers Ti is ideal, but industrialists are very cautious due to price volatility and quicker returns on investment therefore cheaper stainless steel is preferred.
- Good with steam cycles as Ti does not corrode they must run at faster flow rates when using sea water to prevent biofouling, however this makes cooling more efficient.

Cars (potential)

- A weight saving calculation was done with Titanium replacing steel in the chassis making this component of the car 50% lighter

Ship hulls (looked at)

- Galvanic corrosion resistance and light weighting over steel

Chemical tankers/Oil and gas tankers (potential)

- Good for light weight corrosion resistance applications