CHANGING WHAT'S POSSIBLE

Advanced Thermo/Electrochemical Metals Extraction (A-TEME)

An ARPA-E Thematic Workshop

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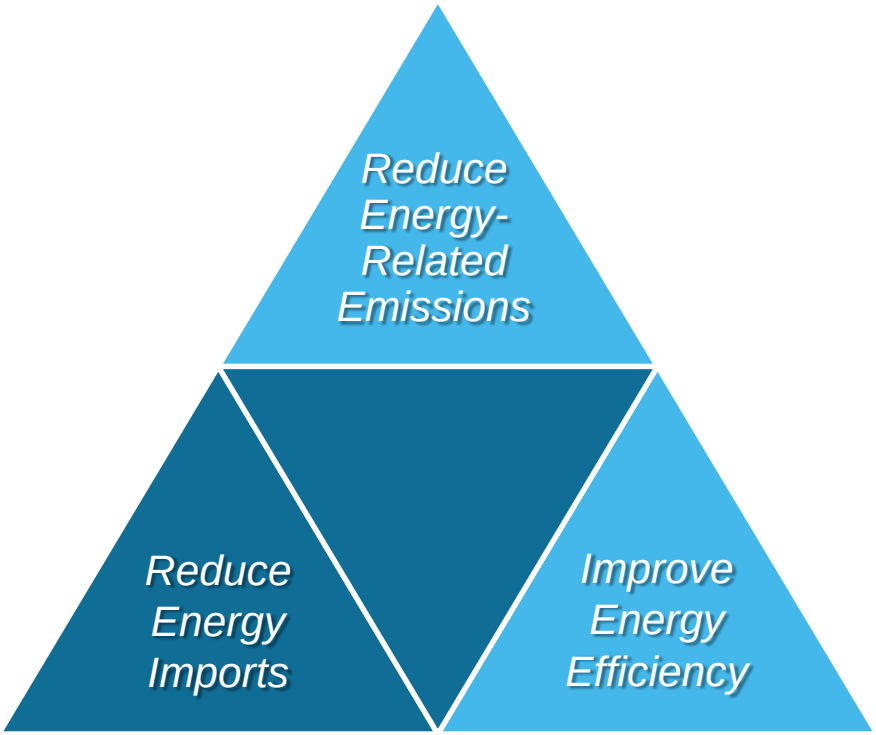
Arlington, VA
January 31st 2013

ARPA-E Mission

Enhance the economic and energy security of the U.S.



Ensure U.S. technological lead in developing and deploying advanced energy technologies

Why Are We Here Today?

A-TEME Mission:

Enable the development of transformative light metal (Al, Mg, Ti) processing technologies that significantly reduce the energy requirement to extract primary metal from ore, reduce emissions associated with primary light metal extraction, and increase the supply of high grade recycled light metal.

Expected Program Outcomes:

1. Energy savings on metals manufacturing of 0.6 Quad/yr
2. Life-cycle energy savings from vehicle light-weighting of a 2 Quad/yr
3. Emissions reduction of 250 Million Tons of CO2/yr
4. Reduced cost light metals to enable advanced energy technologies
5. Renaissance of U.S. light metal manufacturing

ENERGY AND EMISSIONS IMPACT FROM LIGHT METAL EXTRACTION

Global Metal Production and Associated Energy Consumption

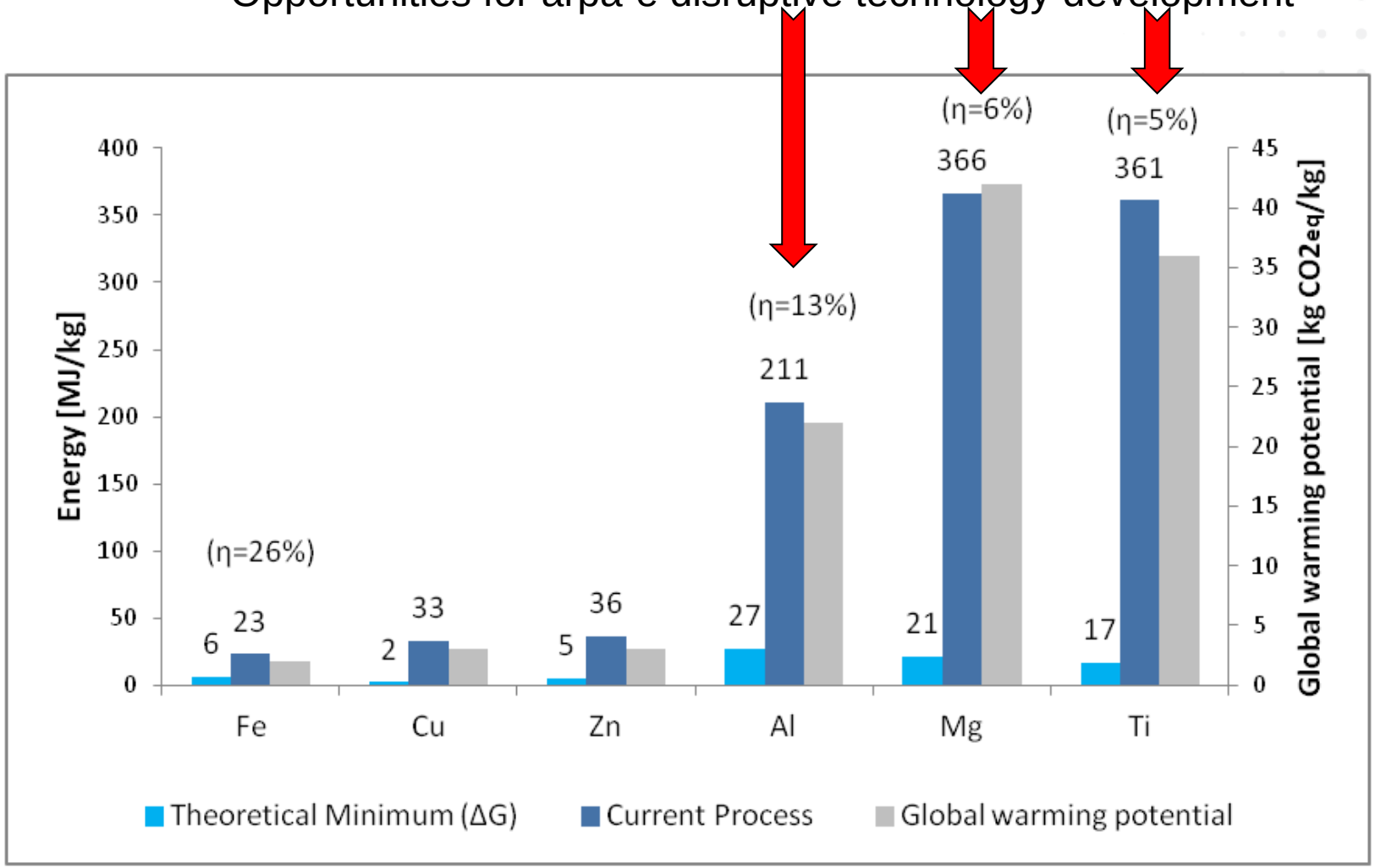
Metal	Annual World Production Millions of tons	Total Energy Consumed Quadrillion BTU
Fe	943[1]	11.6
Al	44.0[3]	8.2
Cu	16[4]	0.7
Mg	0.77[2]	0.2
Ti	0.15[5]	0.09

TOTAL = 21 quads

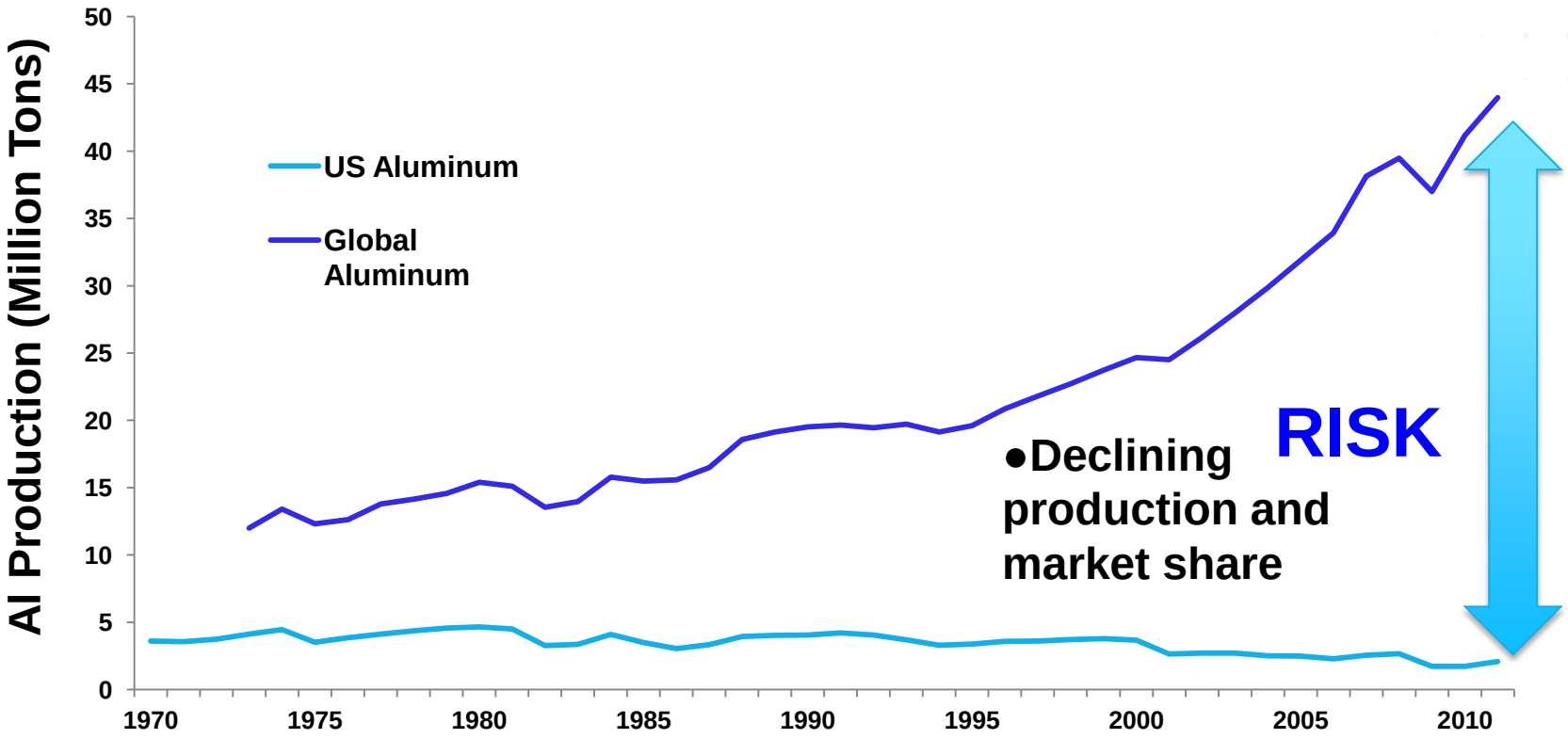
1) Bureau of International Recycling, Ferrous Division – 2011 data (crude – recycled)
2) Index Mundi – Magnesium 2011 data
3) World Aluminum – 2011 data
4) Oracle Mining Group, Copper – 2011 data
5) Global and China Titanium Industry Report 2010 – 2011 – 2010 data

Energy Consumption and Emissions Associated with Metal Extraction

Opportunities for arpa-e disruptive technology development

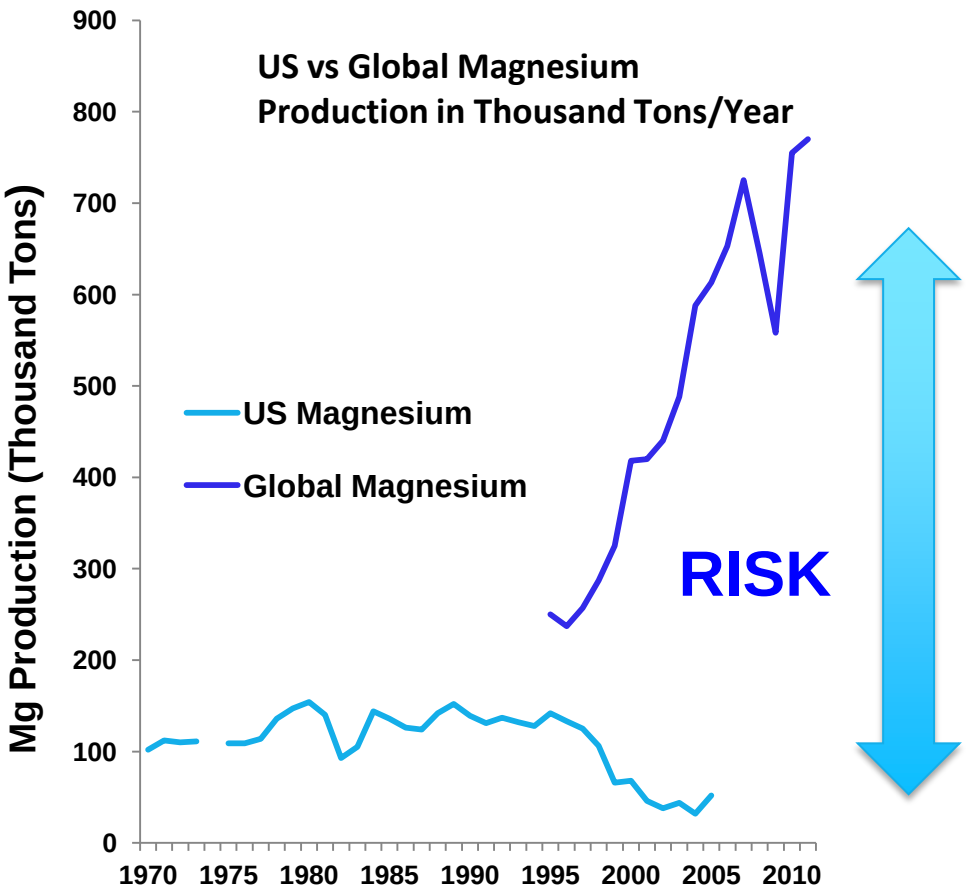


US Primary Aluminum Production in Million Tons/Year

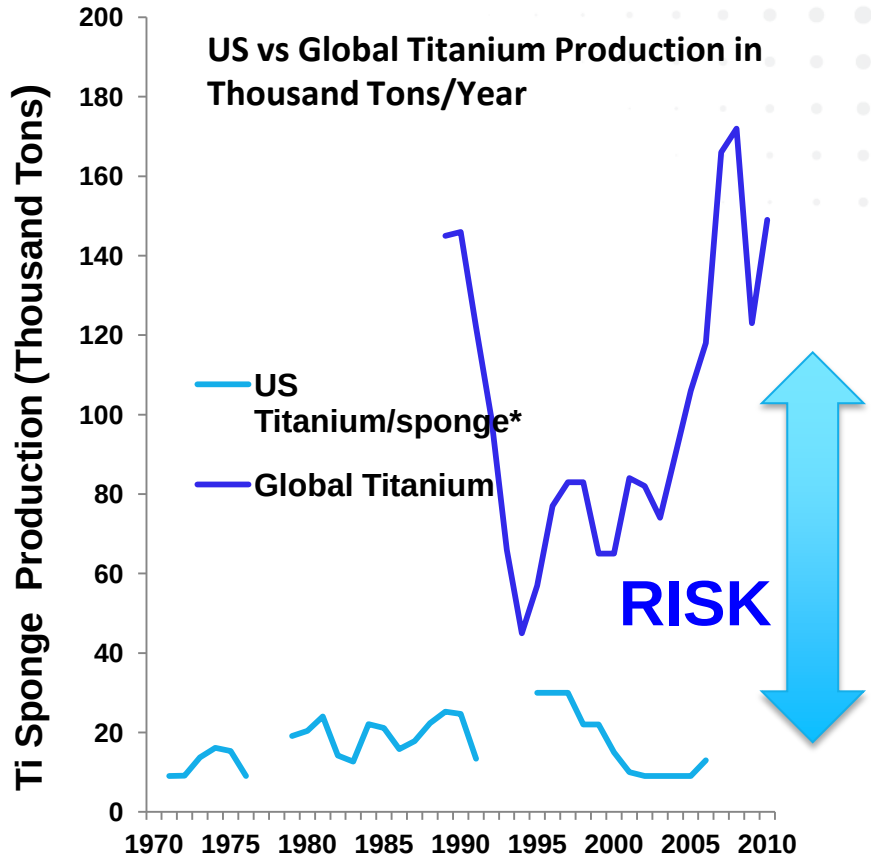


US only 4.7% of market in 2011

US Primary Magnesium and Titanium Sponge Production



US only 5.6% of market in 2011



US only 8.7% of market in 2011

Summary of Energy and Emissions Impact from Light Metal Extraction

- **Global market for metal extraction results in 21 Quad/yr energy consumption**

- **U.S. market share for primary light metal (Al, Mg, Ti) production is alarmingly low**

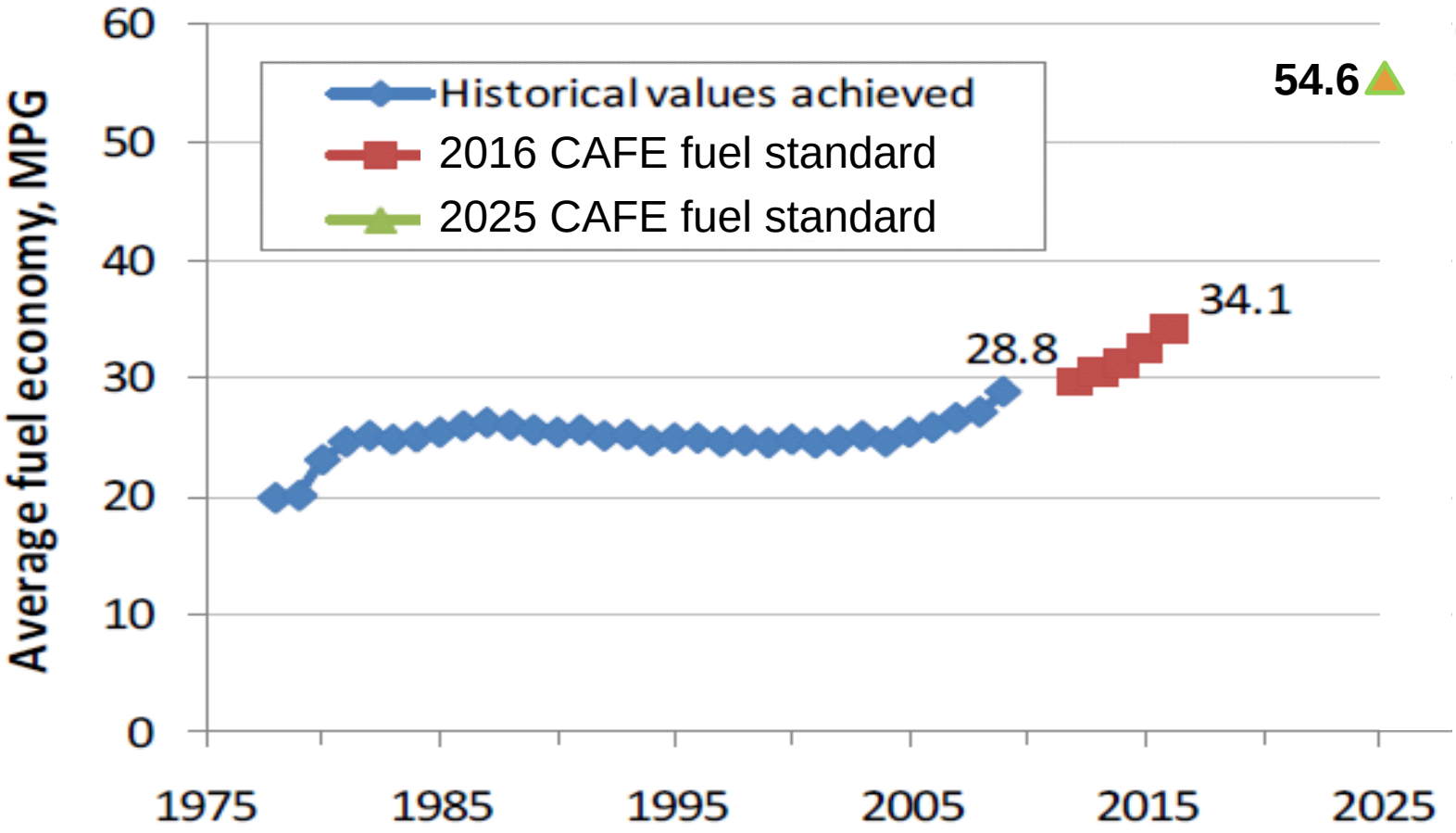
- **Light metal production has high specific energy consumption (MJ/kg)**

- **U.S. light metal manufacturers can gain technological edge through reduced energy requirement for production**

- **If U.S. manufacturers could capture 15% of light metal market at current demand, the result is an energy impact of 1.3 Quad/yr and emissions impact of 151 Million Tons CO2**

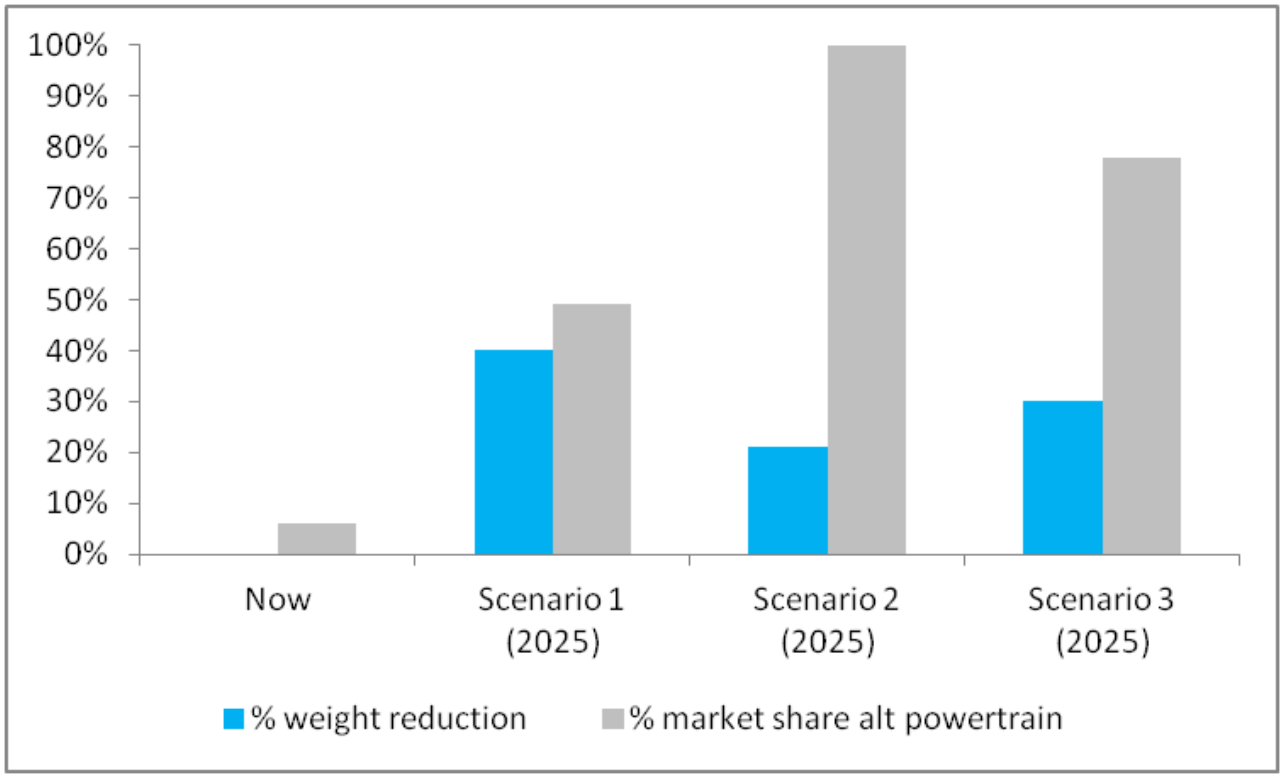
Example Impact: ENERGY IMPACT FROM VEHICLE LIGHTWEIGHTING

The 2016 and 2025 CAFE standards set aggressive targets for vehicle fuel consumption



Scenarios for Meeting the 2025 CAFE Standards – ALL Involve Significant Weight Reduction (MIT Study)

Scenarios for meeting CAFE (55mpg) in 2025



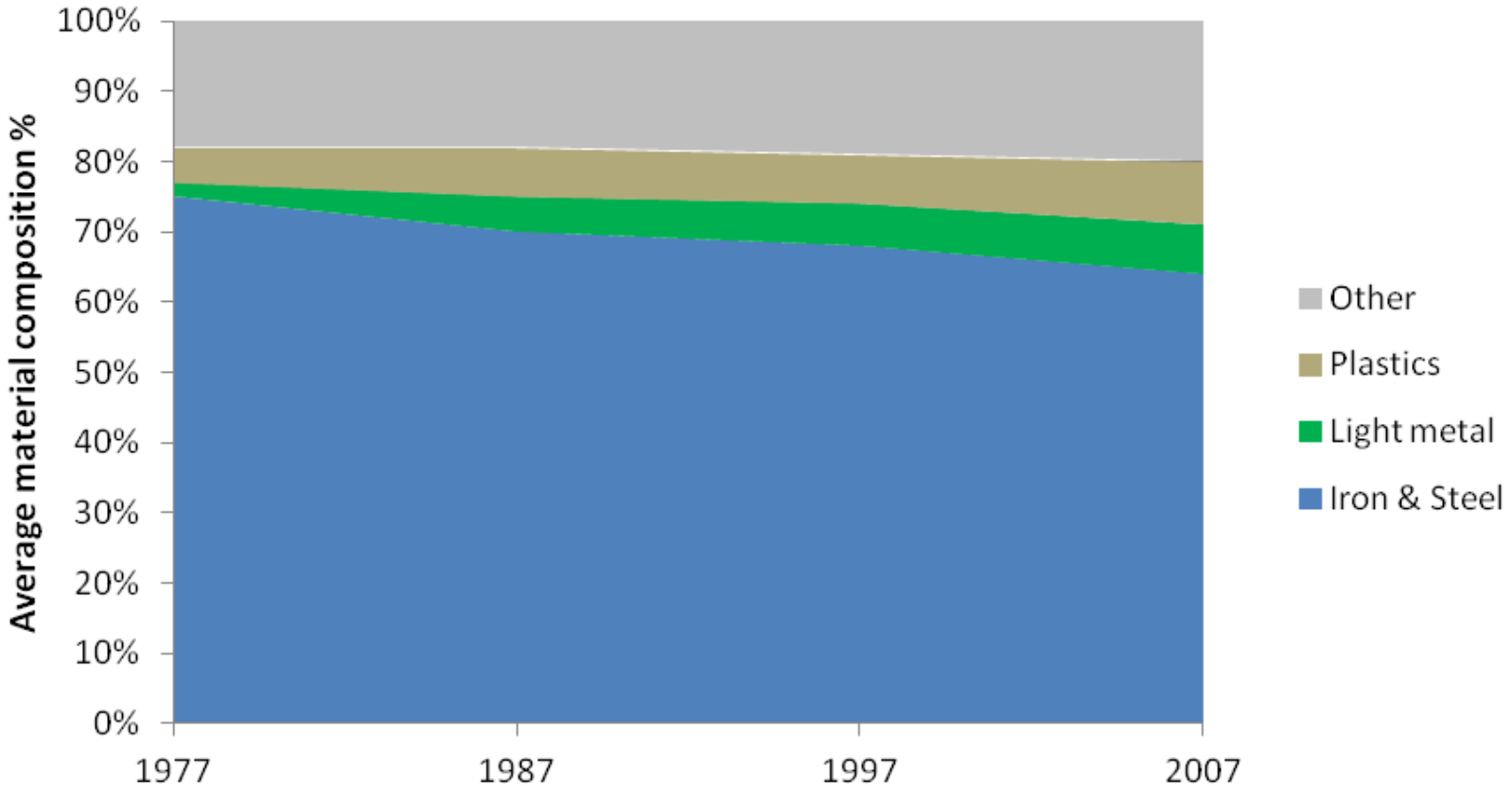
Light metals have higher strength to weight ratio

Material	Strength to weight ratio
Steel	0.04 – 0.06
Al	**0.11**
Mg	**0.13**
Ti	**0.12**

Adapted from "Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035"
MIT Publication No. LFEE 2007-04 RP

Iron and steel usage on the decline

Material composition of the average automobile in the US



Potential Fuel Energy Savings from Automobile Lightweighting

- **Embedded energy in metal due to extraction not included in analysis below**

Material	Mass savings (% of vehicle)	Annual fuel savings (L/vehicle/yr)	Total energy savings (Q/yr)
Al	33%	328	2.58
Mg	41%	407	3.21
Ti	19%	188	1.48

Assumptions:

- 0.0036L/km fuel reduction per 100 kg reduced vehicle mass
- 20,000km traveled/car/yr (~12,500 mi)
- 239 million cars on the road (US 2012)
- 35MJ/L energy content of gasoline
- All steel replaced by light metal (equal bending stiffness/strength basis)

Potential Fuel Energy Savings from Automobile Liqhtweighting

- **In order to gain an efficiency benefit by lightweighting, embedded energy content in light metals must be reduced**

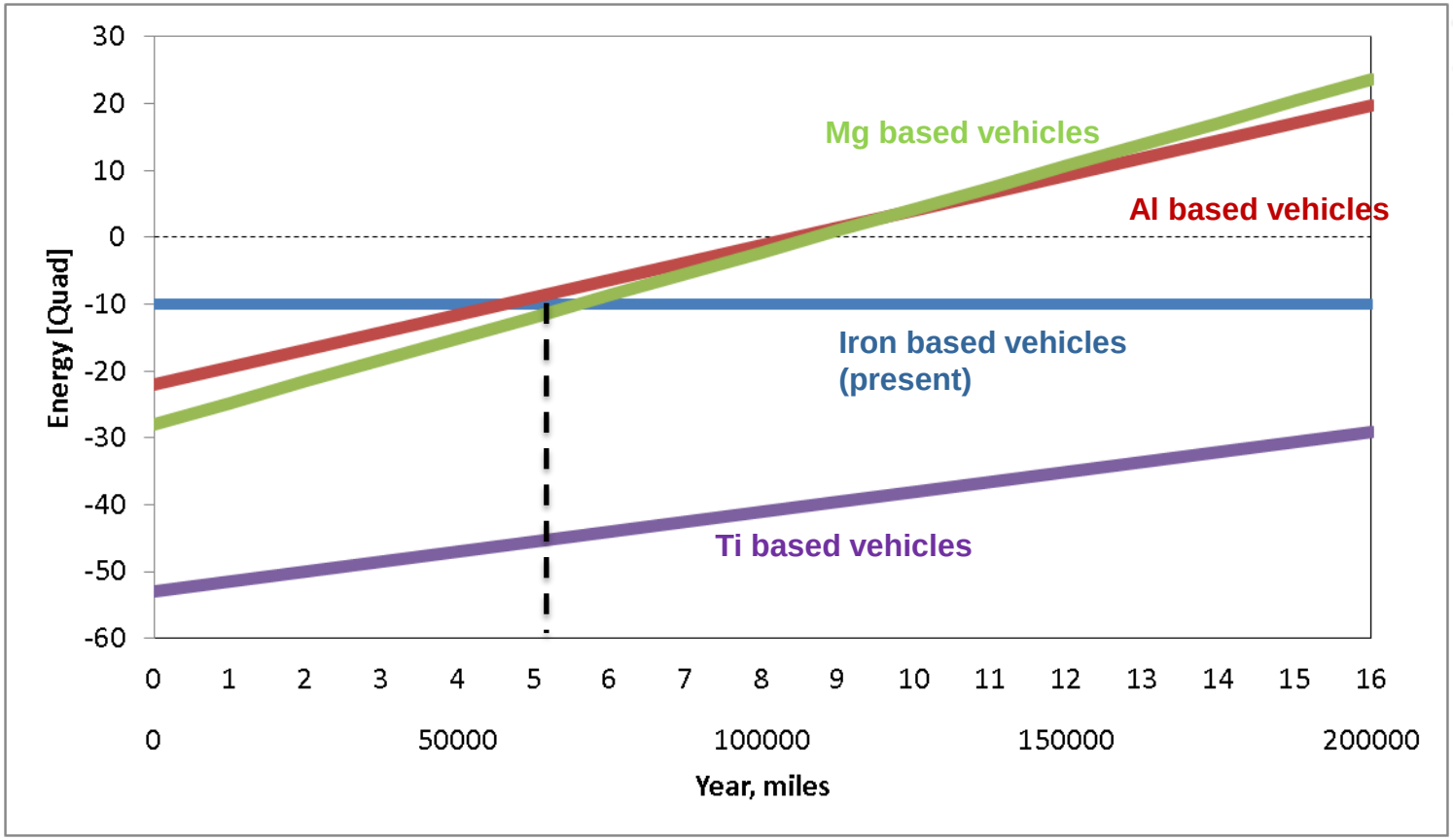
Material	Total Lightweighting energy savings (Q/yr)	Embedded energy (Q/yr)	Net energy saved (Q/yr)
Steel	-	-	
Al	2.58	2.1	0.48
Mg	3.21	2.7	0.51
Ti	1.48	5.1	-3.62

Assumptions:

- **10 yr lifetime of vehicle**
- **Entire fleet of vehicles replaced with light metal**

Potential Fuel Energy Savings from Automobile Liqhtweighting

Would take ~5 years and >50,000 miles to break even with steel based vehicles



Assumption: 12,500 mi/yr

Summary of Energy and Emissions Impact from Light Metal Extraction

- **Potential energy savings from vehicle lightweighting is approximately 3 Quad/yr**

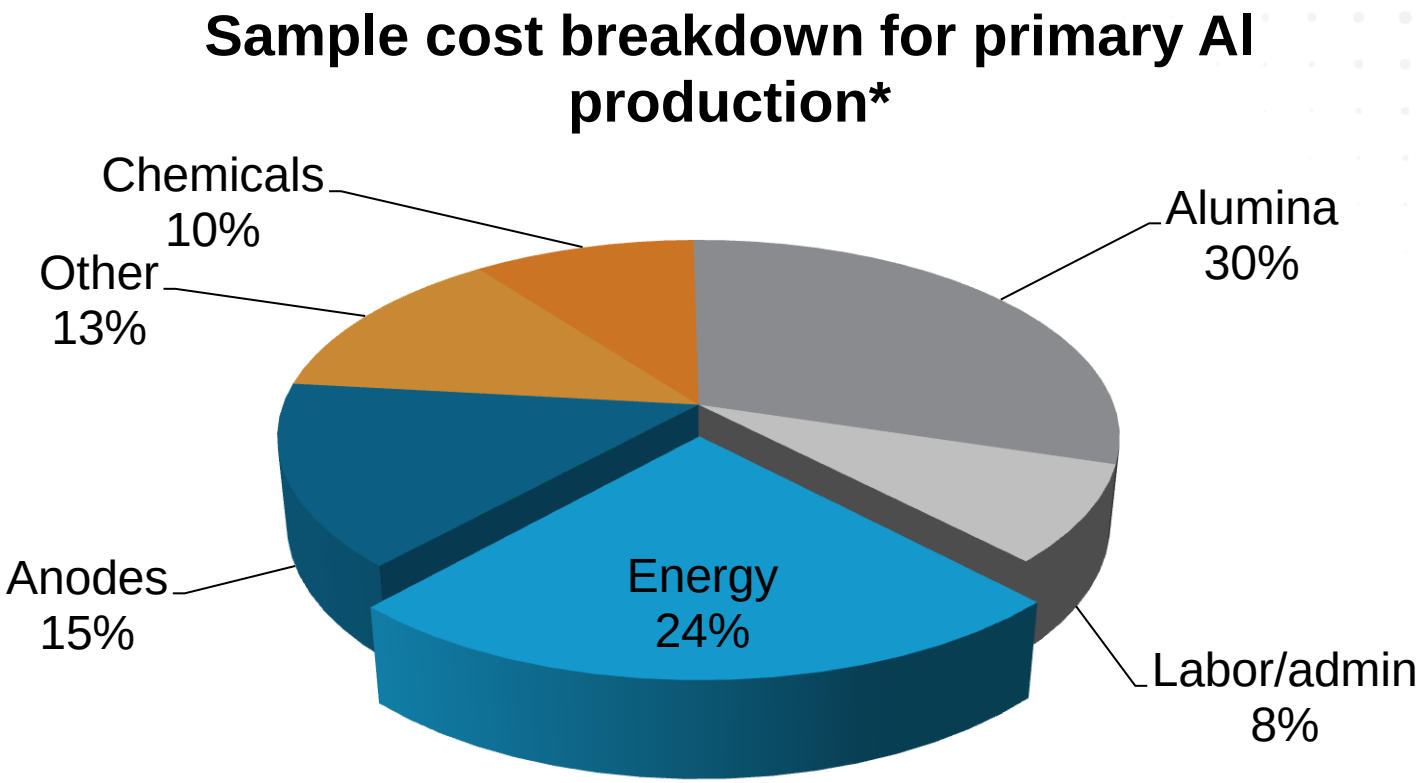
- **Corresponding emissions reduction is 200 million tons/yr**

- **Lightweighting energy savings can only be achieved by reducing the embedded energy in light metal extraction**

- **A trend toward vehicle lightweighting has already begun; an opportunity exists to address the metal embedded energy.**

SOME ECONOMIC CONSIDERATIONS FOR LIGHT METALS MANUFACTURING

Impact of Reduced Energy on Aluminum Cost



**Values vary depending on region, current energy prices, etc. (especially for energy and anodes)*

Source: Metal Miner, Carbon Trust, ORNL

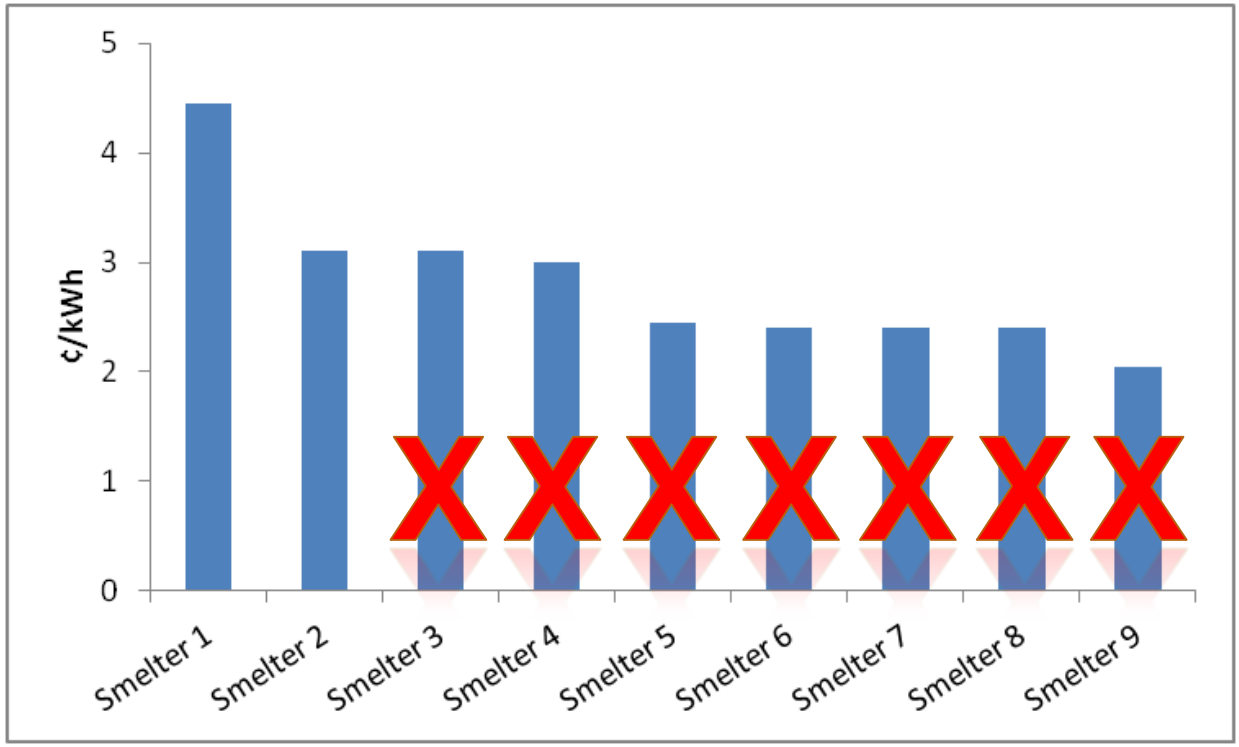
Points of Interest on Aluminum Smelting

- Aluminum smelting is only done where inexpensive electricity is available; <3 cents/kW-hr
- Aluminum smelters enjoy hydroelectric power
- Domestic smelters are not economically viable with rising electrical costs

Hydropower Drives Smelter

Pacific Northwest Smelters Face Economic Crisis

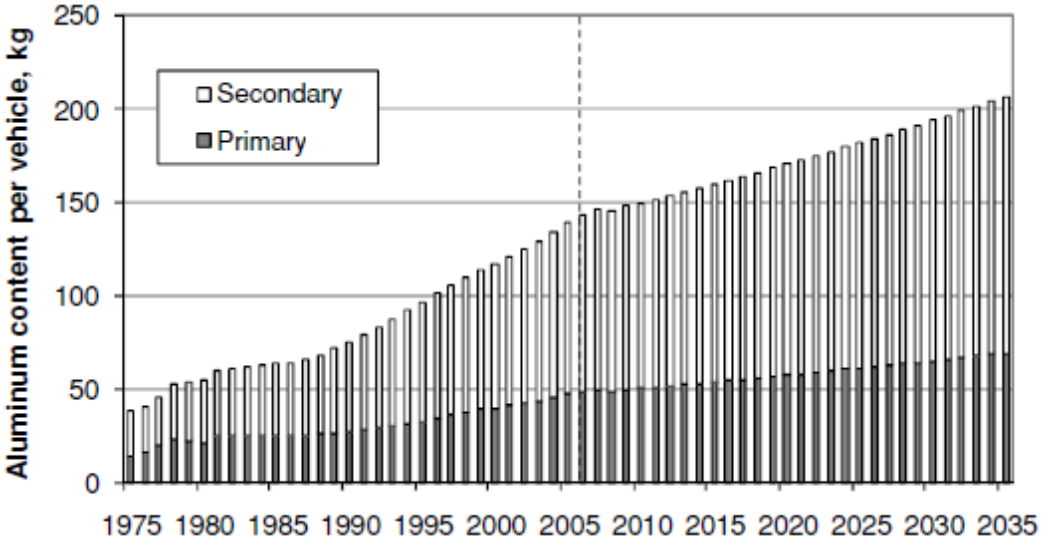
Affordable Electricity Price Limits of Al Smelters at $1500/ton Al price



- If we load electric vehicles onto the grid, electricity cost rises and domestic aluminum smelting is not economically viable
- Electric vehicles are coming!

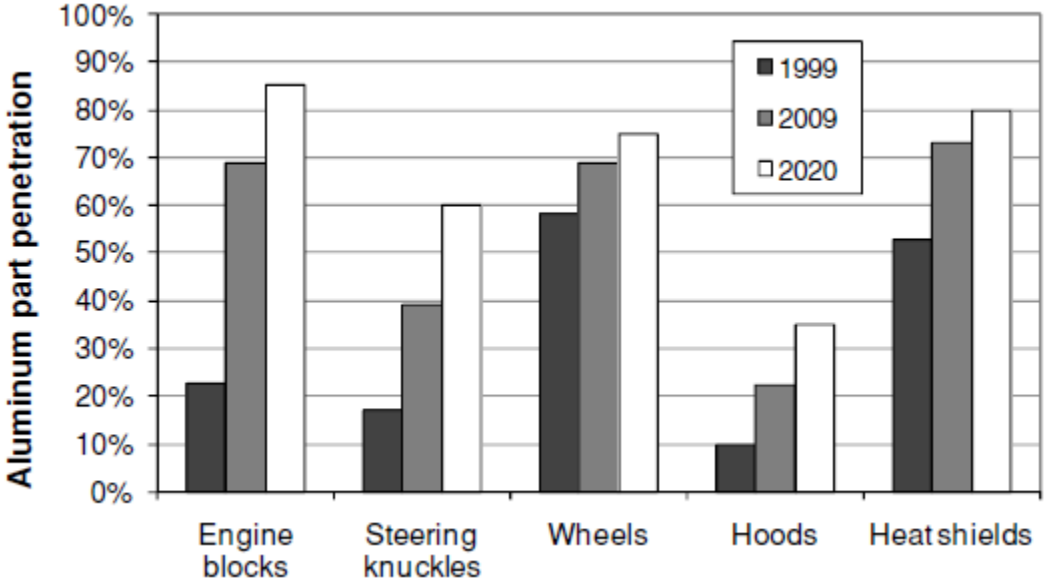
Forecasting Electricity Demand of the Region's Aluminum Plants, DSI, 2005

Aluminum Demand



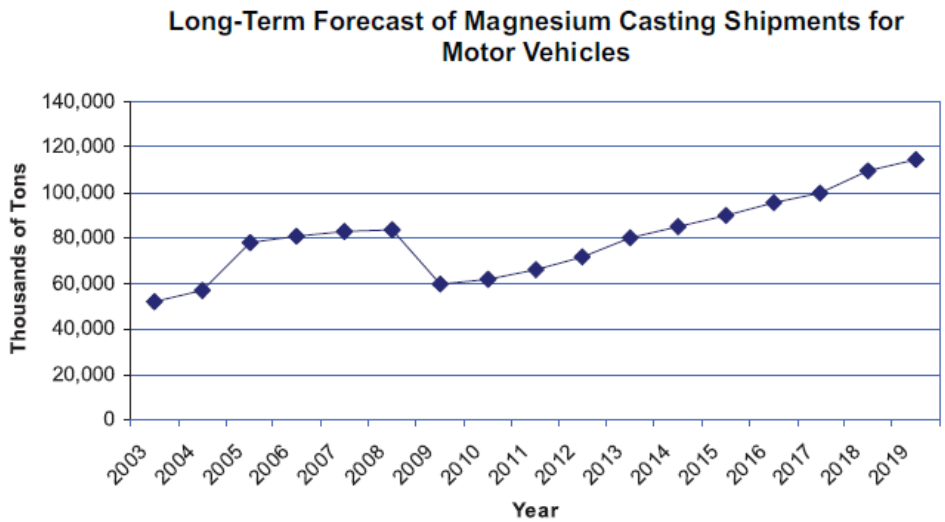
Demand growth for both primary and scrap re-used Al for vehicle light weighting

Vehicle parts where Aluminum will continue to penetrate

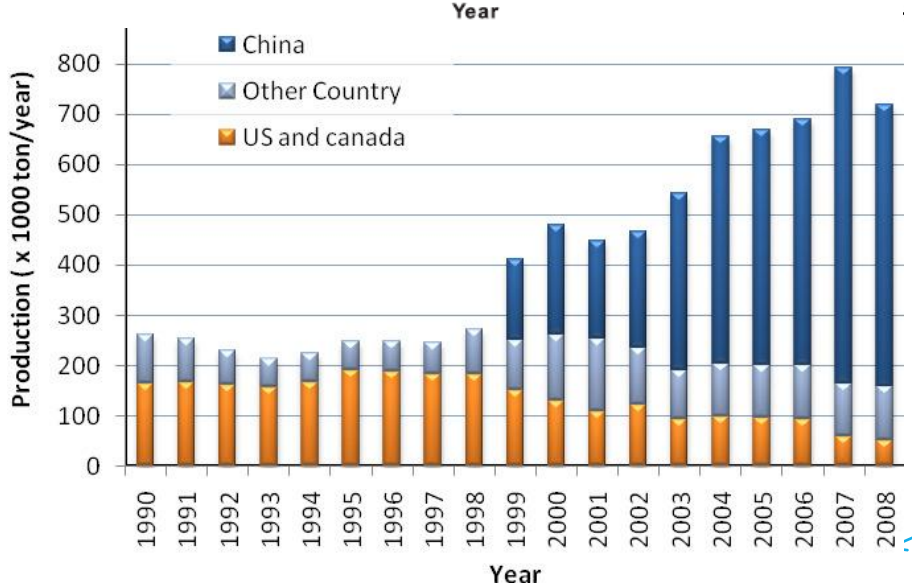


Magnesium Demand

- Magnesium demand is on the rise; U.S. is losing market share



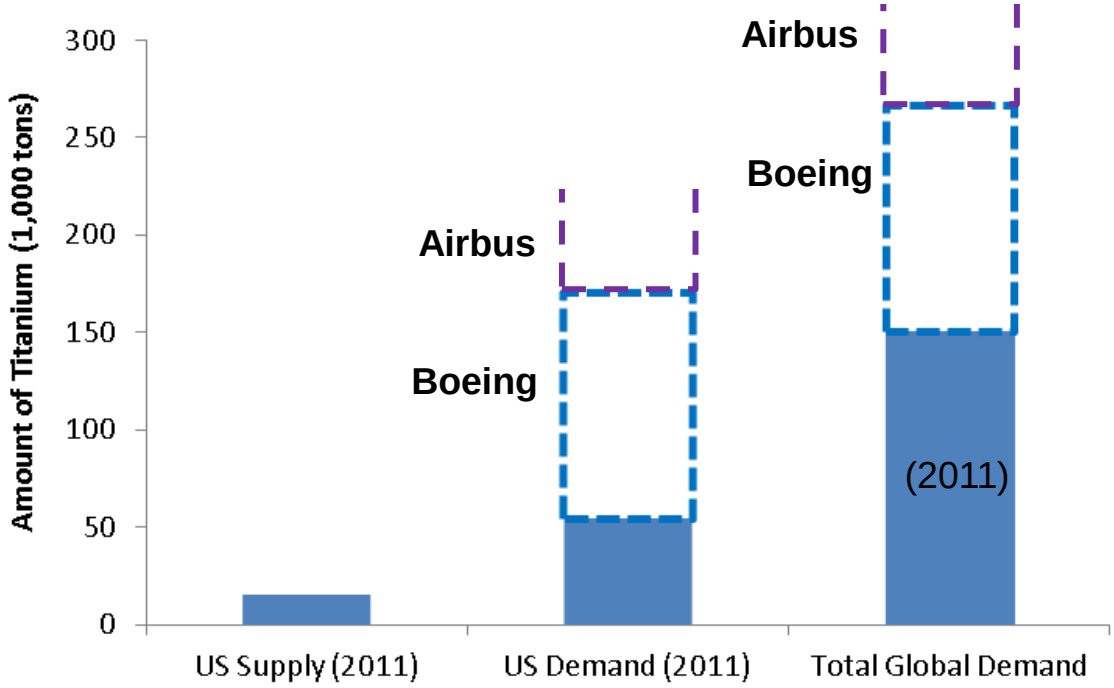
The U.S. Automotive Materials Partnership sees the potential of magnesium content per vehicle increasing by an order of magnitude from 5 kg today to 160 kg by 2020.



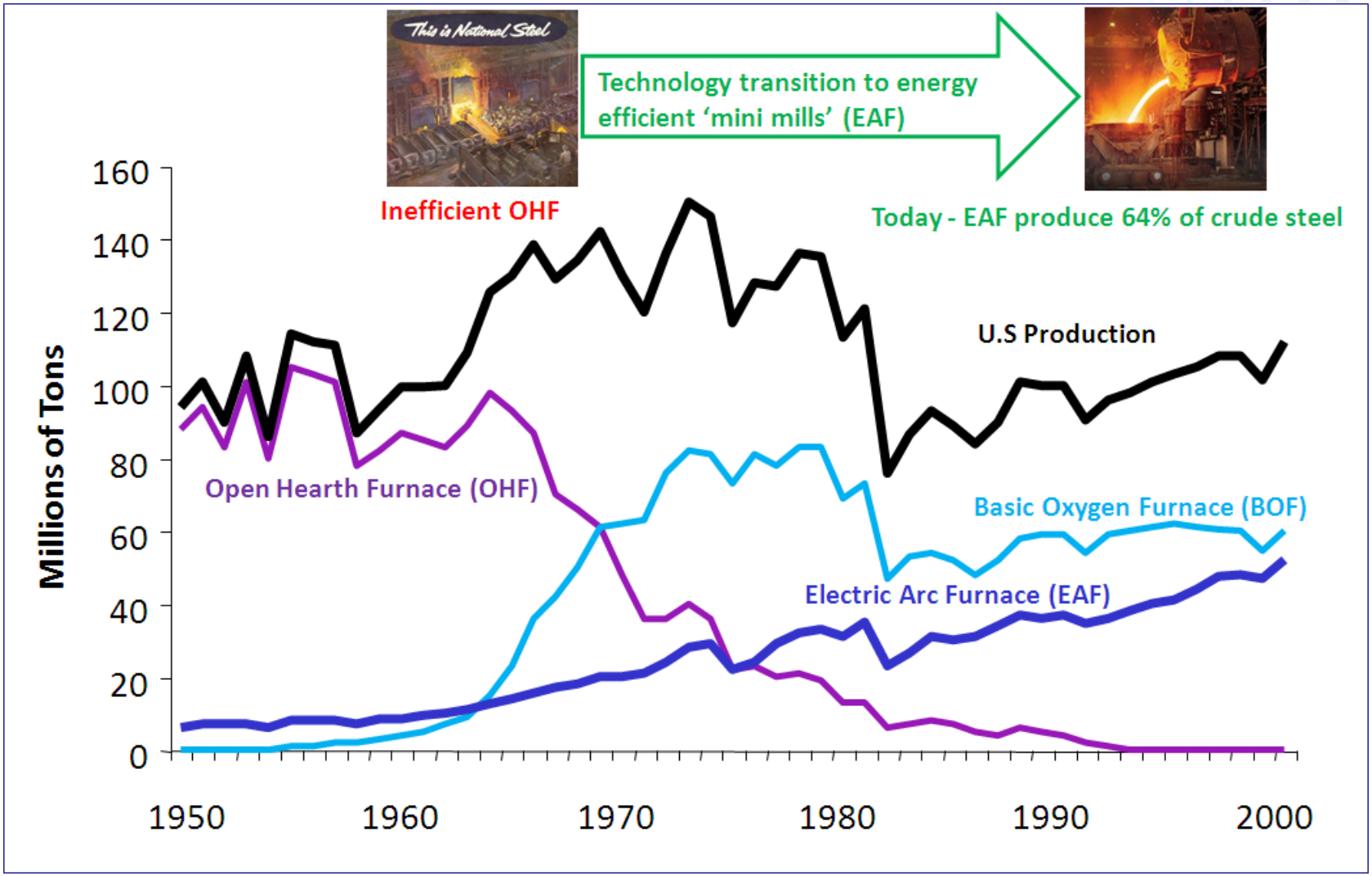
Only 1 Mg production plant left in US (Utah)

Titanium Demand

- **Boeing 787 and 777 lightweight aircraft require 80 and 50 metric tons of titanium per airplane, respectively (enabler of carbon fiber)**
- **Boeing projects 34,000 new airplanes to be built between 2012-2031**
- **2.2 million tons required to meet demand or 116 thousand tons/yr**



Precedent for revival in U.S. Metals Manufacturing: STEEL



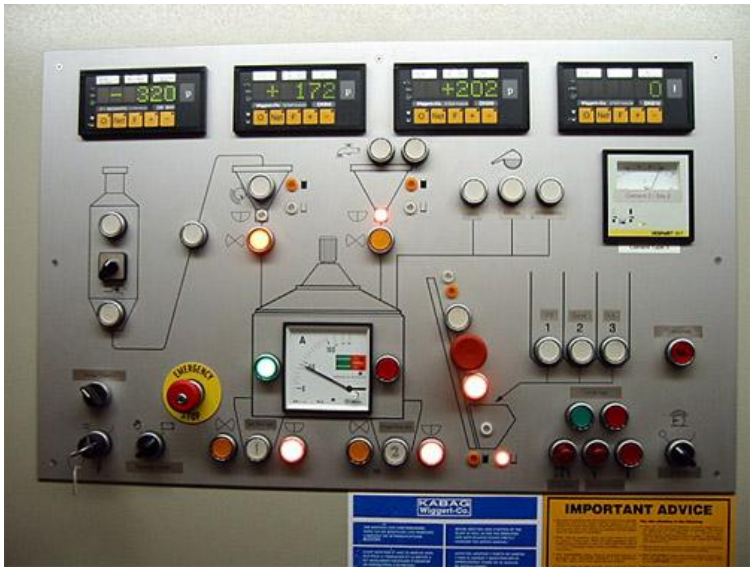
Small Modular Infrastructure: *the business case for scaling down.*

Eric Dahlgren, Klaus S. Lackner
School of Engineering and Applied Science, Columbia University
Caner Gocmen, Garrett van Ryzin
Graduate School of Business, Columbia University

- **Small scale allows more rapid adoption of new technology to give a competitive edge**

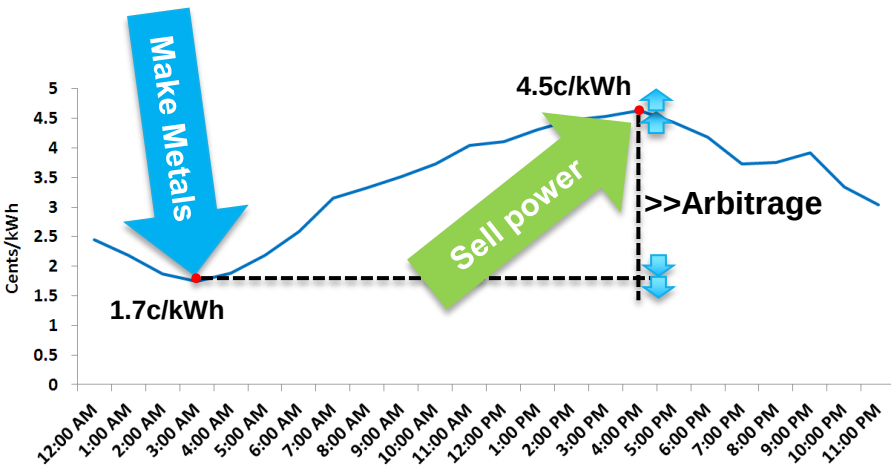
- **Adoption of automated systems can neutralize economies of scale**

- **Small scale allows manufacturer to more easily tailor product to customer needs**



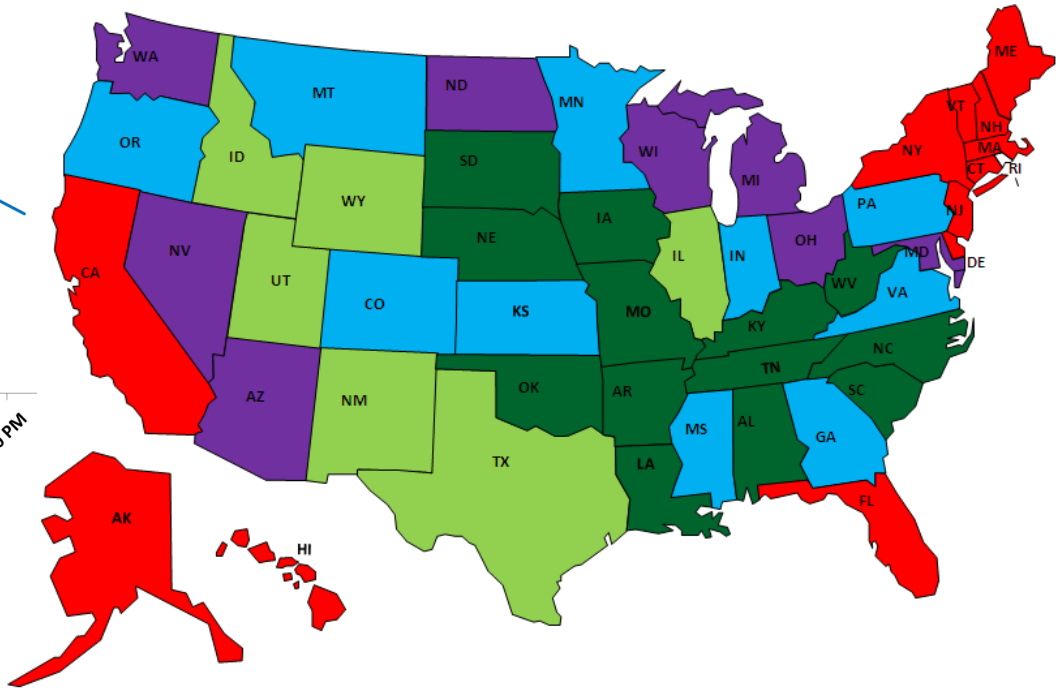
Small Modular Infrastructure: *the business case for scaling down.*

Arbitrage ~ manufacture @ off peak hours & sell power at peak hours



Utility (ComEd) hourly prices, Northeastern Illinois during summer

Geographic Advantage ~ cheap electricity resources



Industrial rates by states in cents/kWh during summer

4.1 - 5.0 | 5.1 - 6.0 | 6.1 - 7.0 | 7.1 - 8.0 | >8.1

U.S. Light Metal Manufacturers Need a Technological Edge

Ideal transformative new technology will:

1) Significantly reduce energy requirements and emissions for primary light metals extraction

2) Enable continuous processing that is amenable to significant automation

3) Tolerate interruptions in power or energy source for sustained periods

4) Amenable to thermal recovery and power production

ARPA-E Programs and Projects

1. Impact

- Aimed at ARPA-E mission areas
- Shows a credible path to market
- Has a large practical application

2. Transform

- Challenges what is possible
- Disrupts existing learning curves
- Can leap beyond today's technologies

3. Bridge

- Translates science into breakthrough technology
- The path lacks technical or financial resources
- Catalyzes new interest and investment

4. Team

- Comprised of best-in-class people
- Brings skills from different disciplines
- Focuses on translation of technologies to the market

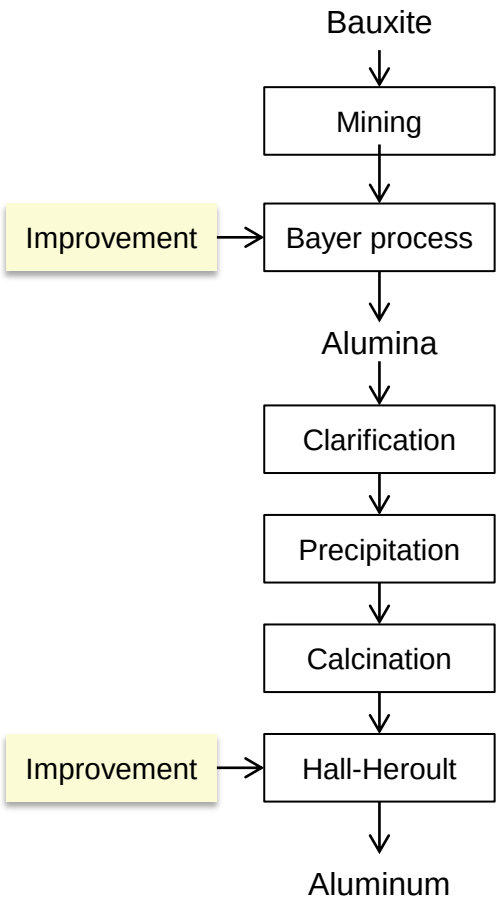
Program Director ☑

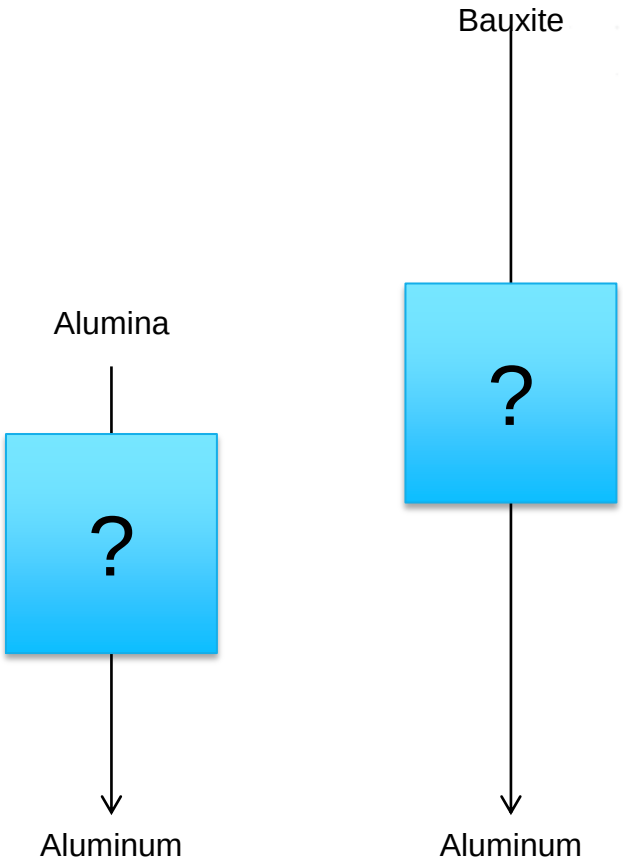
Workshop Participants ☐

ARPA-E not seeking incremental improvement; radically different innovations sought

Traditional R&D path: improvements in cost/energy intensive processes

****ARPA-E Example Path**: Entirely *new processes* to enable a large leap forward in performance





Workshop Breakout Sessions

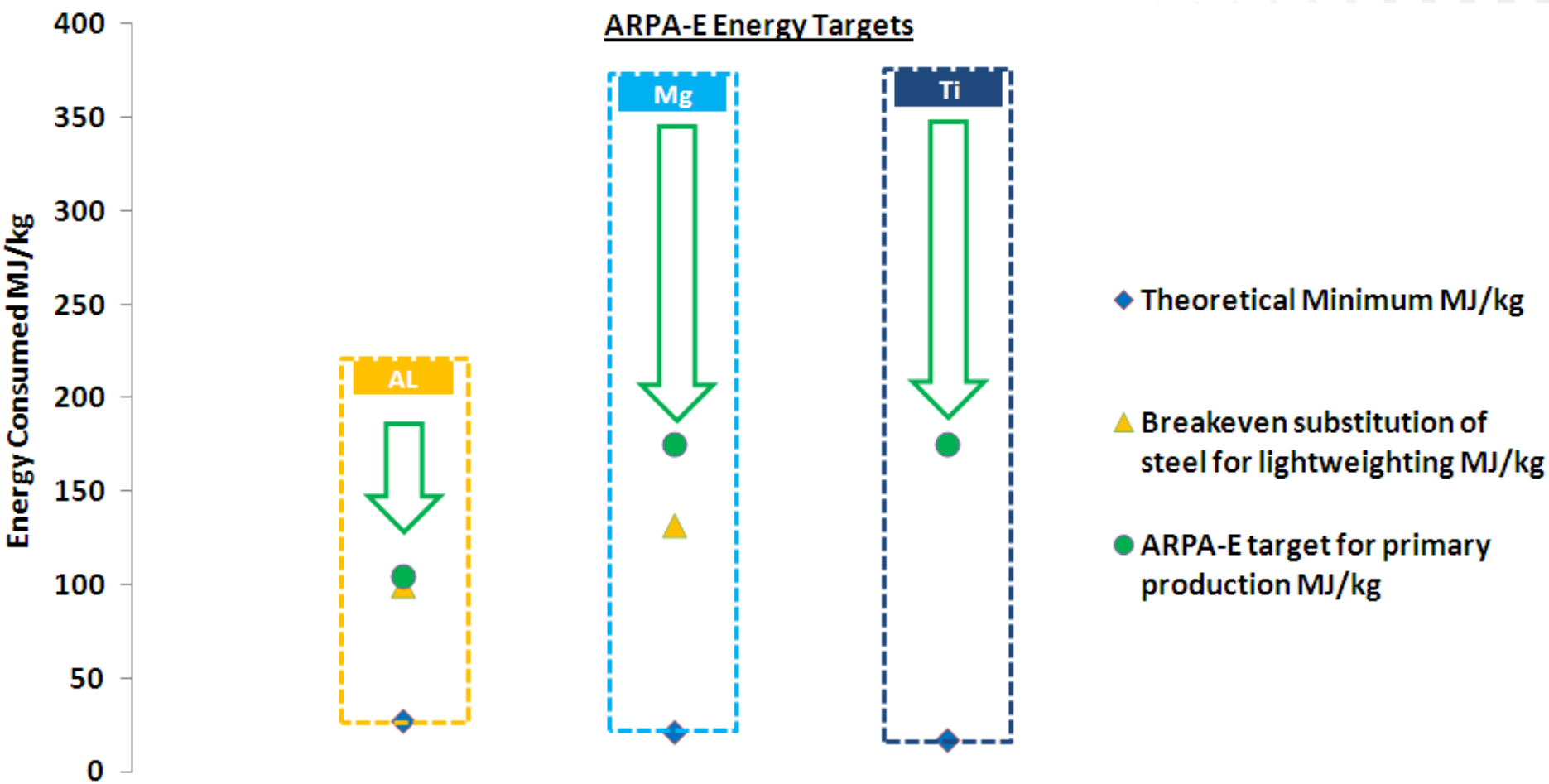
Breakout Session I: Technology paths that enable program goals

1) Electrochemistry
2) Thermochemistry
3) Renewable Energy
4) Heat Recuperation and Power Generation
5) Recycling and Innovative Technologies

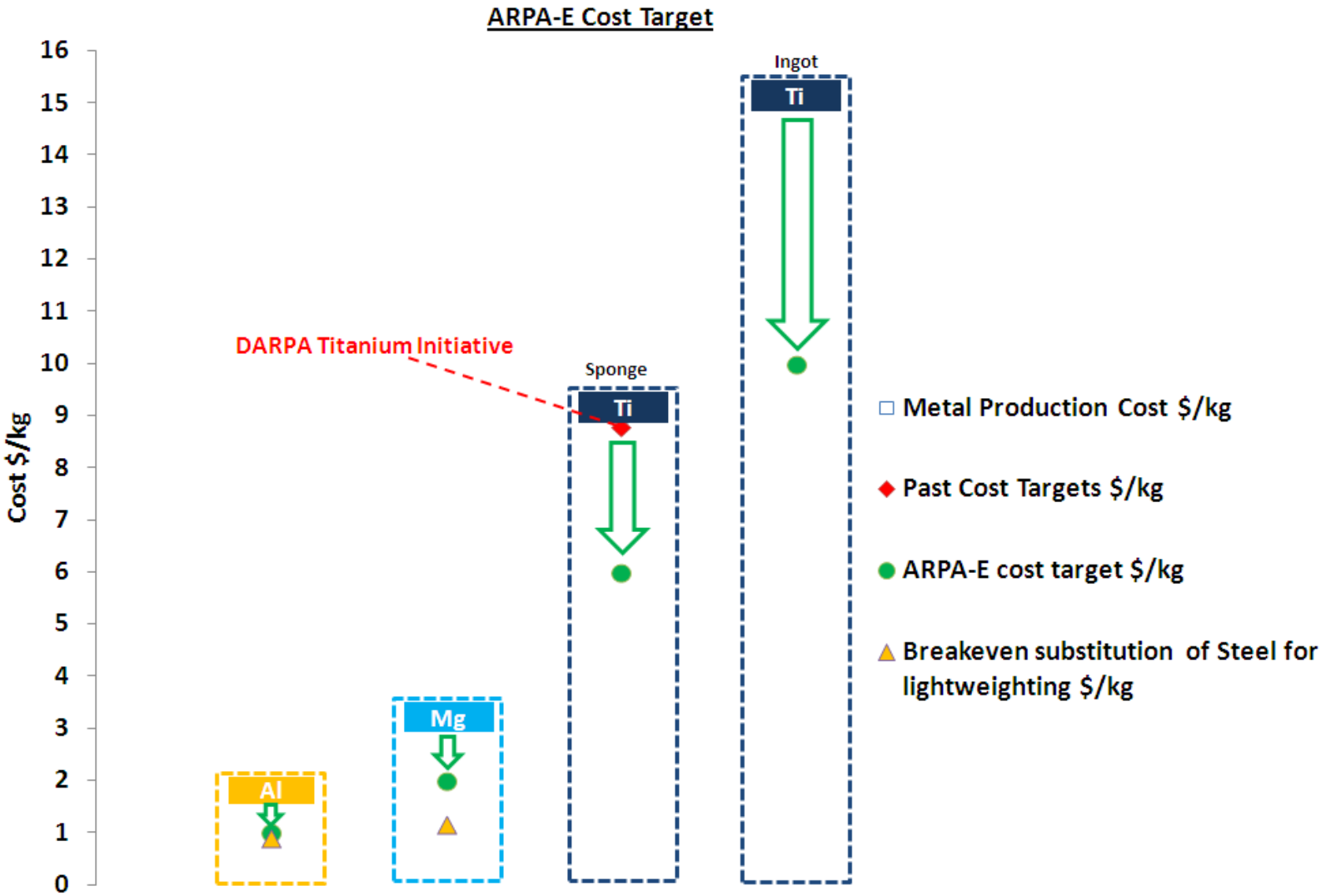
Breakout Session II: Setting program performance targets

1) Aluminum
3) Magnesium
2) Titanium

Benchmarking Performance Targets



Benchmarking Performance Targets



Thank You for Your Participation in Today's Workshop!