Panel on Resource Efficiency and Supply Chain/Value Chain:

Session 1- Water / Energy / Materials Nexus
Session 2 - Advanced Manufacturing through the Supply Chain / Value Chain

AMO Peer Review Meeting
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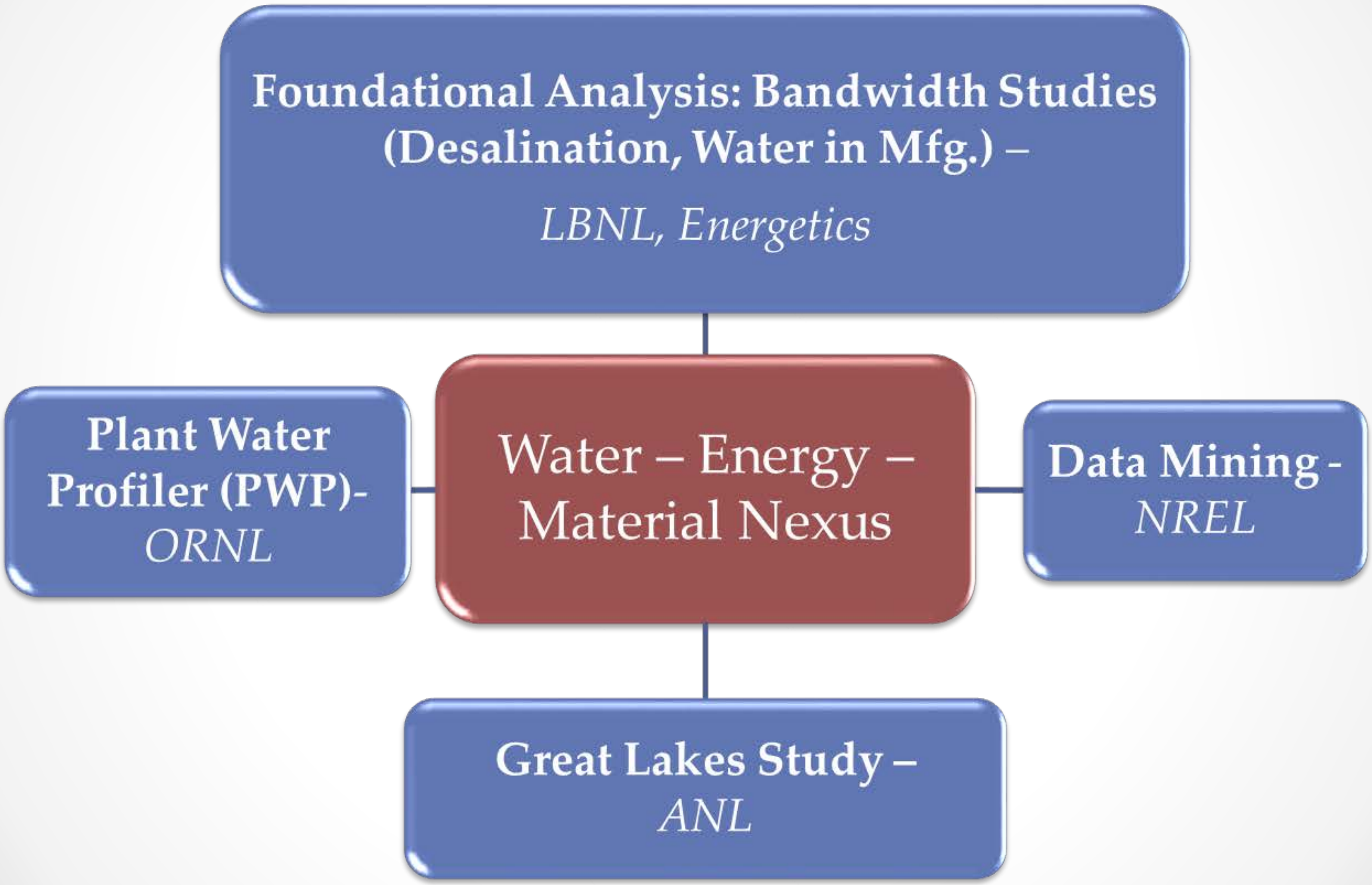
Water – Energy –Materials Nexus

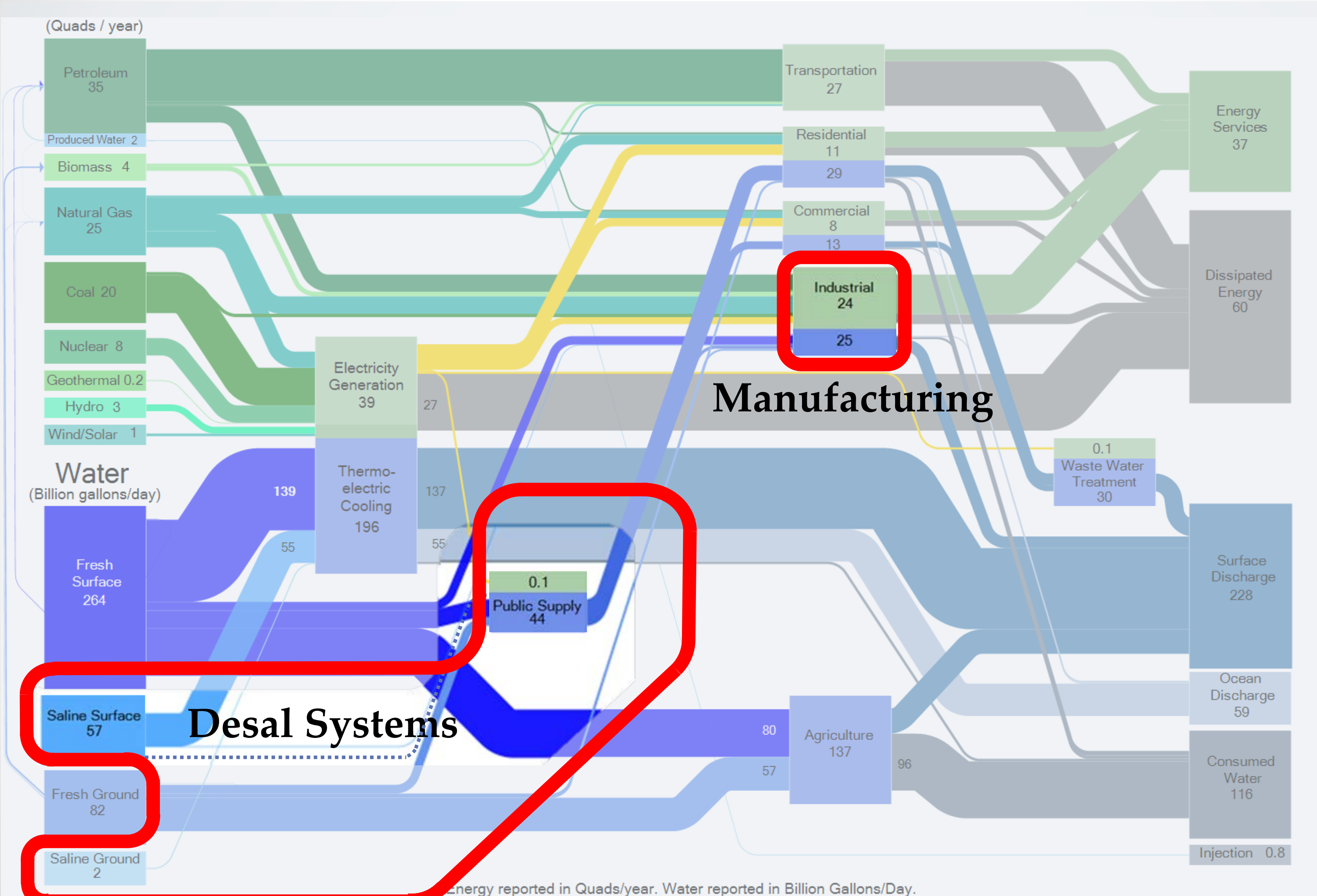


Water - Energy - Materials Nexus: Research Questions

What are the foundational, interdependent effects of energy, water, and materials consumption that enhance the efficiency, sustainability, and competitiveness of U.S. manufacturing. What are the main risks for water use, including water security risks?

- Desalination is currently unable to provide potable water at pipe parity costs. What technology advancements need to be made to do that?
- How is water used in industry?
- What are regional issues of industrial/manufacturing water use?
- What are the main drivers for industrial water use?
- What technology solutions will improve resource utilization?

2014 U.S. Water and Energy Consumption



Water – Energy –Materials Nexus Analysis Strategy

Foundational: What we know and don't know

- Analysis methods + data requirements
- Data Mining
- Regional

Analysis Products

- Strategies and Guidelines
- Compiled data set
- Plant Water Profiler

Bandwidth Studies (Desal & Industrial)

Timeline

FY16

FY17

Foundational – Analysis Methods and Data Requirements (some highlights)

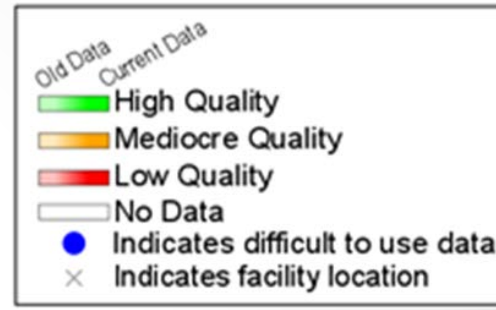
What we know:

- Estimated 75% of Industrial water is self-supplied – but its end-uses are poorly documented/metered.
- Water losses in the municipal water supply network are reported to be as high as 40% for some municipalities.

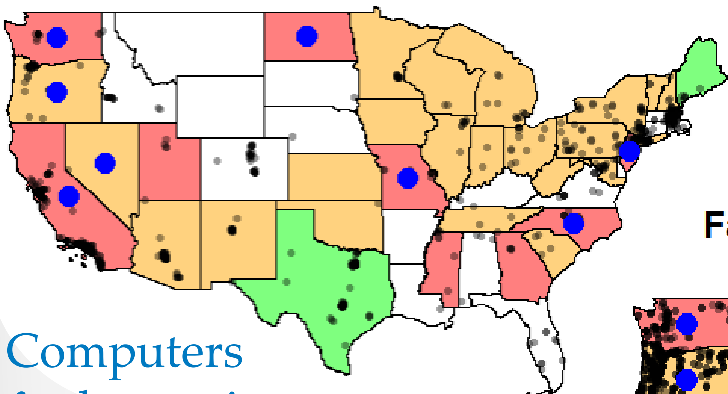
What we don't know:

- Quantification of water/energy use by key subsectors (e.g., food) & at the facility level
- Where water is used in manufacturing processes
- Energy and water reduction potential & costs (inside/outside facilities)
- Water risk/criticality matrix -- water risk vs. criticality for key products including fuels, materials, and technologies
- Impact of select/key manufacturing operations on the water shed
- Level & condition of metering at industrial facilities

Quality of water data at the state level – identify gaps in facility level data availability

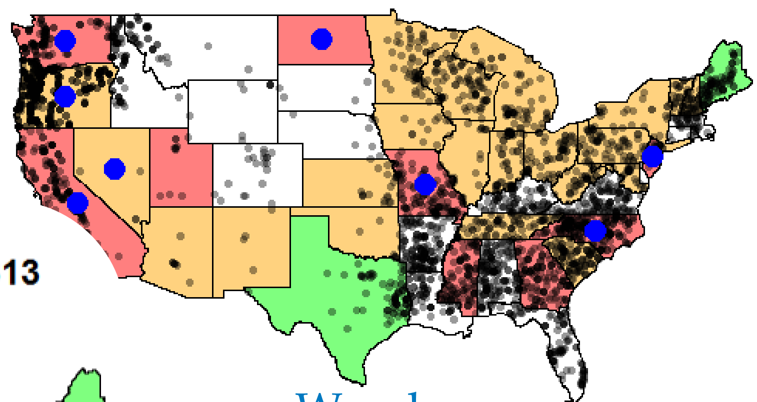


State Water Data Quality
Facilities shown: NAICS Code 334



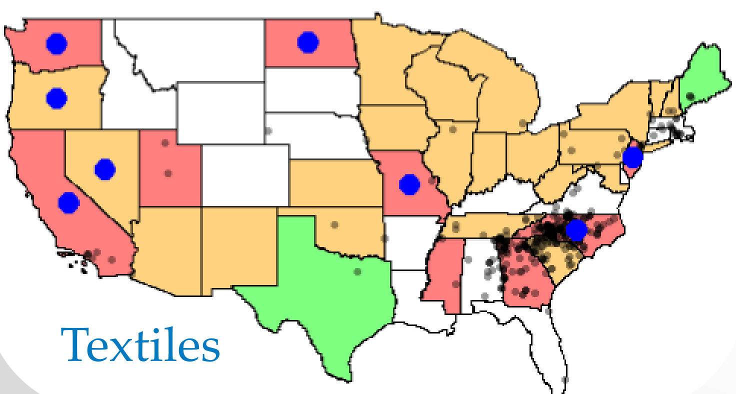
Computers & electronics

State Water Data Quality
Facilities shown: NAICS Code 321



Wood products

State Water Data Quality
Facilities shown: NAICS Code 313



Textiles

Data Attribute Checklist
Any data, public data
Facility level data
Purchased / Self-supplied
Location
NAICS/SIC Code
Metered
Mixed
Estimated
Data age: >2010 or ≤ 2010
Fresh/Brackish/Saline
Water Source
Discharge Data
Amount Treated Prior to Intake
Monthly/Annual Intake

Energy-Water-Materials Nexus – Great Lakes Study

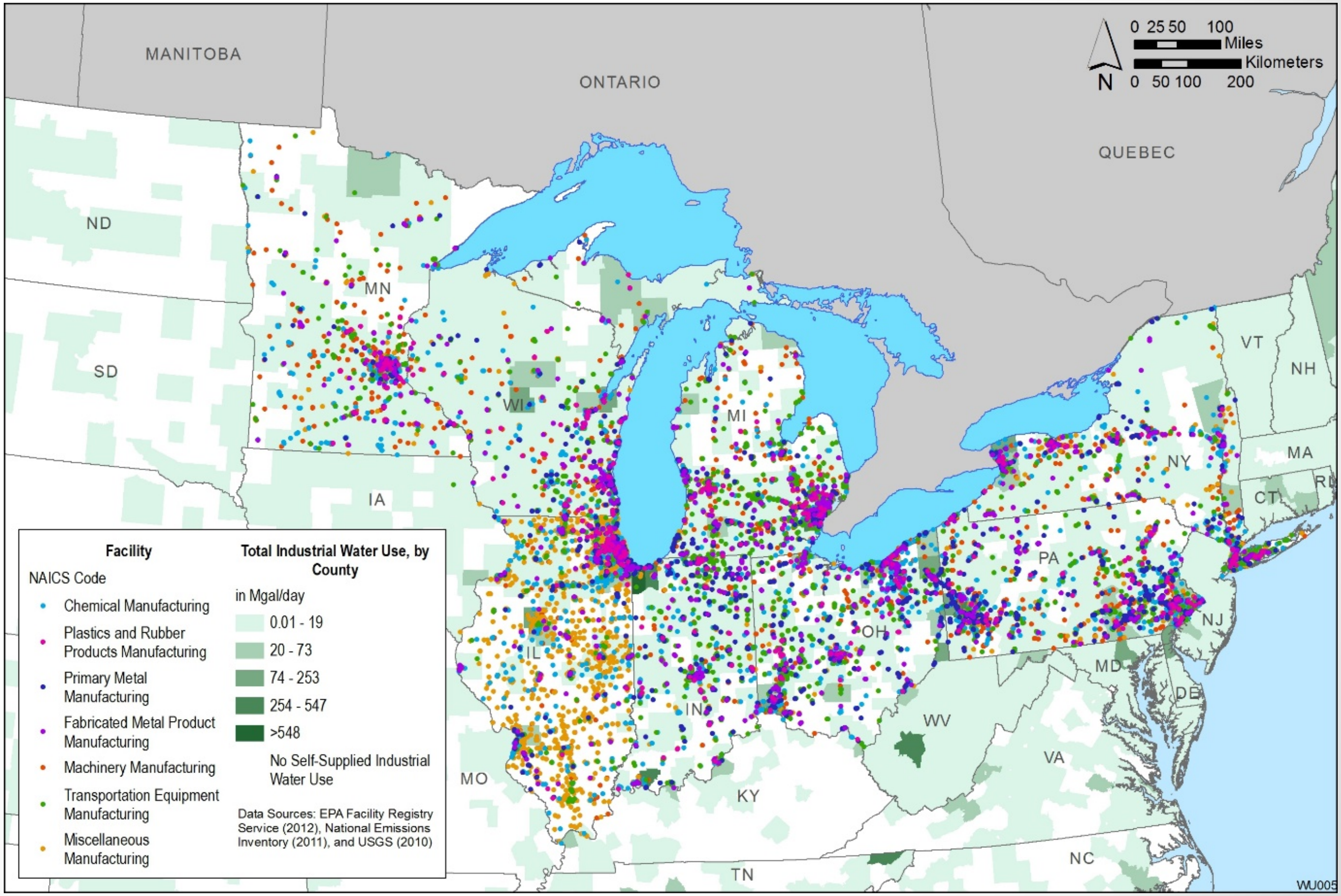
What are the water-energy-materials nexus issues facing industry and how might the availability of water resources affect their technology solutions?

Why study the Great Lakes states?

- Water issues are regional
- The Great Lake states are water and manufacturing rich
- Water quality is important

Project scope

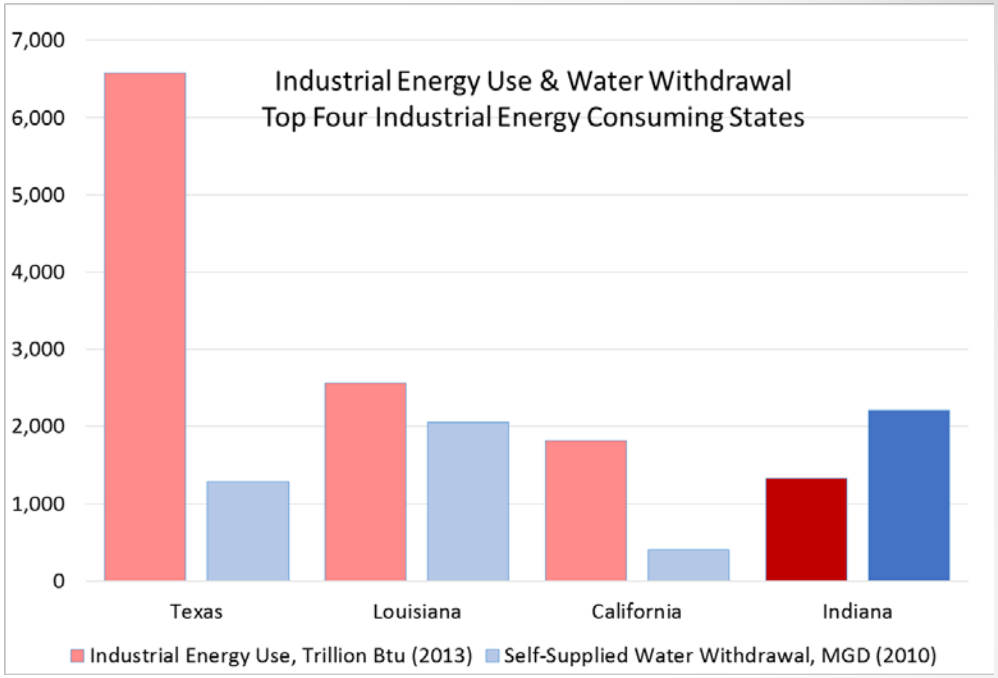
- Assess available industrial water data
- Catalog gaps in publically available data in the context of energy-water-materials evaluation methods



State water analysis - Indiana

Indiana profile

- 2010 USGS data –highest industrial self-supplied water withdrawal
- EIA data 2013 – 4th highest industrial energy consumer
- Watersheds:
  - Wabash River – 90% of IN area
  - Lake Michigan, Ohio River – industrial concentration areas
- Manufacturing subsectors w/ high water discharge
  - Primary metal
  - Chemical
- Data found to be inconsistent from year to year and between data sources
- Ongoing regional research:
  - Industrial water data analysis and methods
  - Water regulations



Manufacturing Subsector	Value Added ($million)
Transportation equipment	7,430
Fabricated metal product	6,931
Miscellaneous	3,285
Primary metal	2,891
Plastics and rubber products	2,745
Machinery	2,551
Chemical	2,449
Food	1,746
Computer and electronic product	1,106

* High water discharge

Description of Energy Water Bandwidth Studies

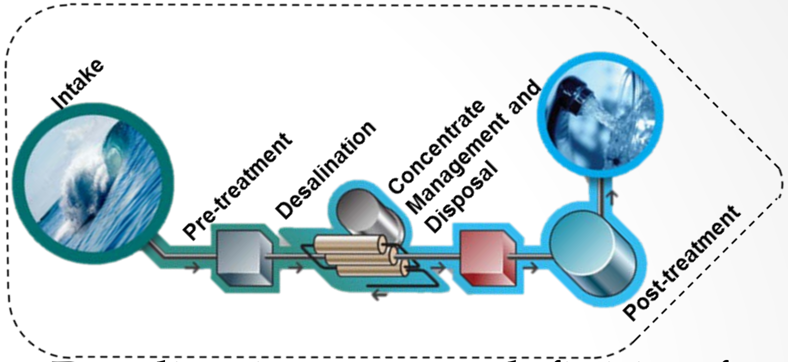
FY16 – In Progress

- *Study 1: Desalination Systems*

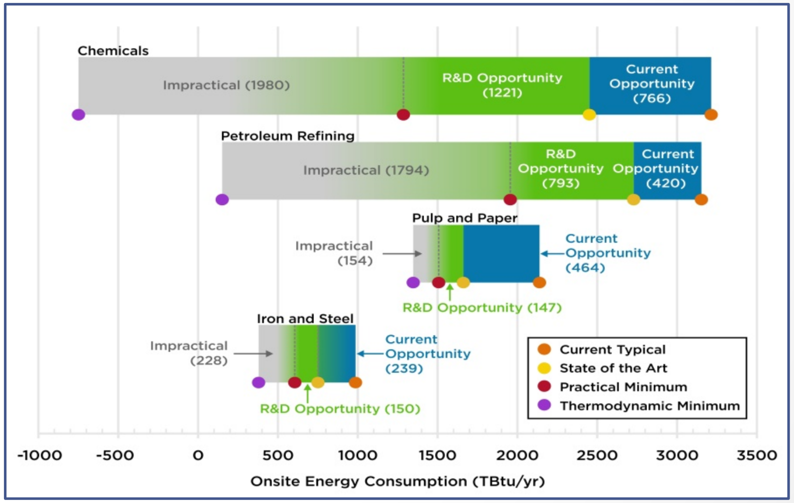
  Evaluate energy and CO_2 emissions impacts of providing municipal water from seawater using various desalination systems.

  Study 2: Manufacturing Sector

  Evaluate water use characteristics in the U.S. manufacturing sector with a focus on energy, CO_2 emissions, local watershed impacts, and reduction potential



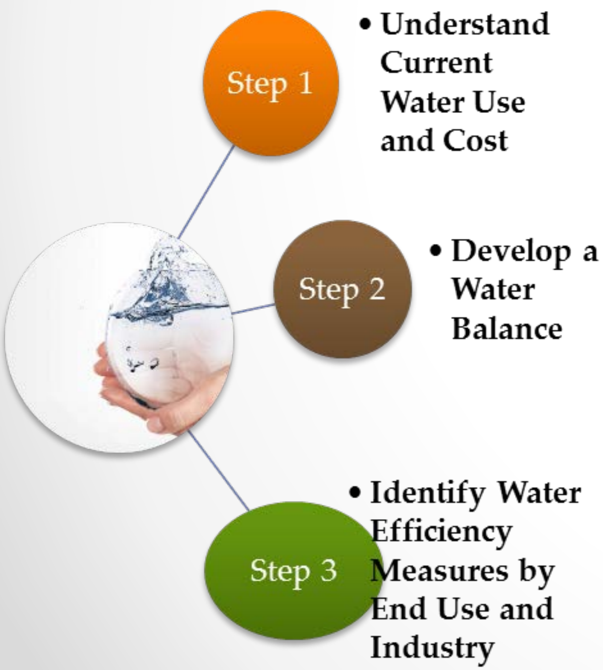
Desalination system definition for Bandwidth Studies

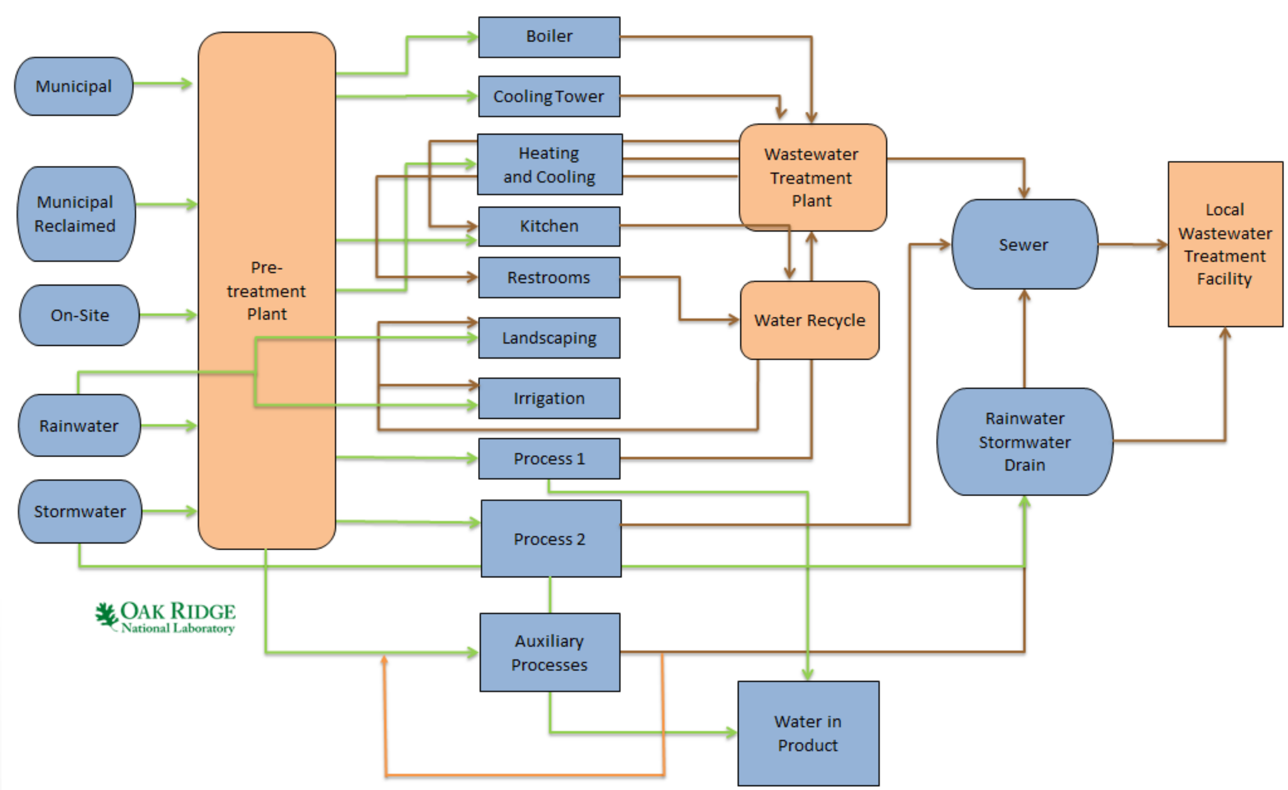


Energy Bandwidth study results. Energy-Water results to follow in form, but with adaptation

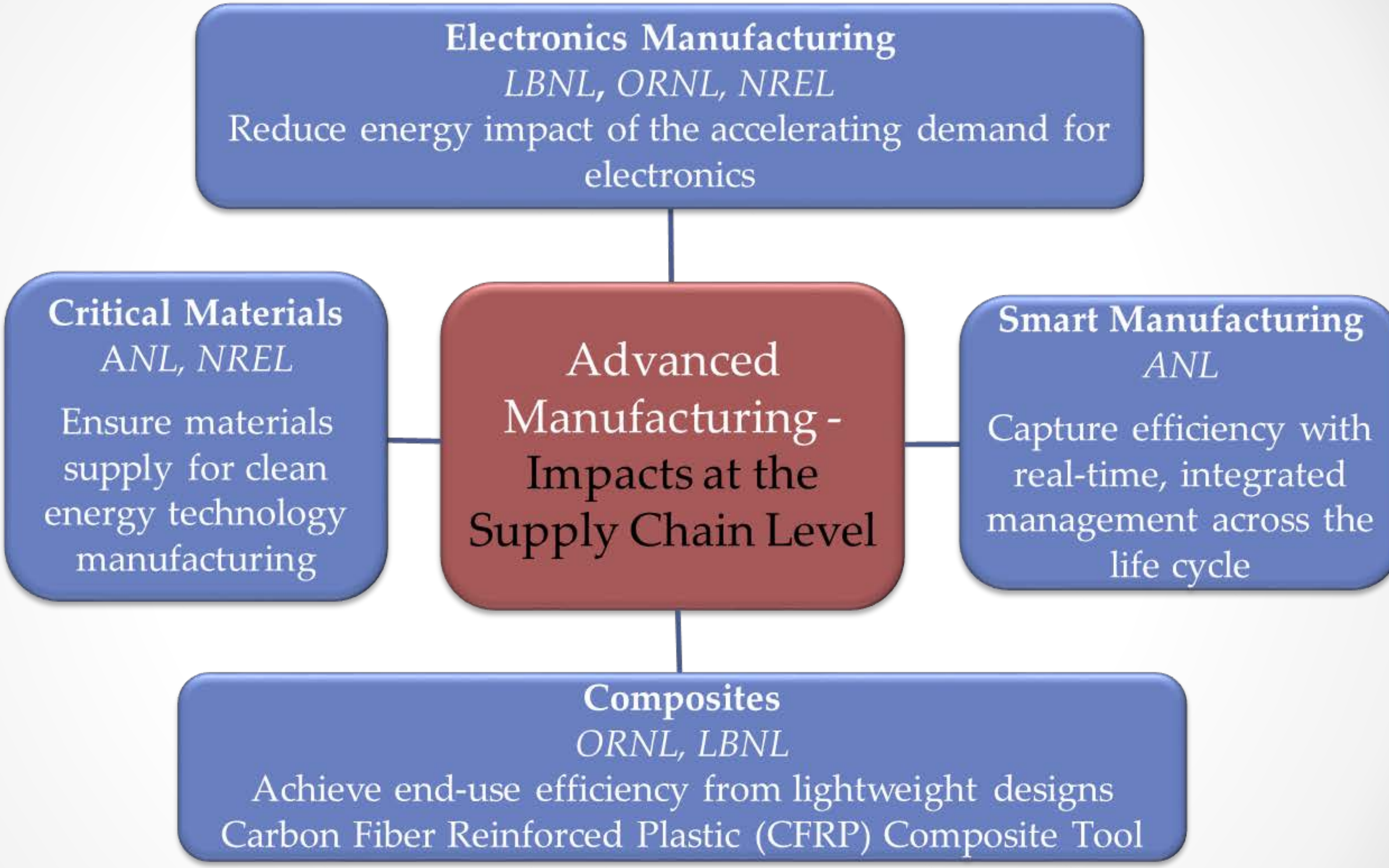
Plant Water Profiler (PWP) Tool for Industry

- The PWP tool will provide users details of water purchases, how water is consumed, potential cost and water savings, and list of next steps that could be followed to save water.
- Purpose - Help manufacturers to:
  - Understand and track their water use
  - Identify and document savings opportunities





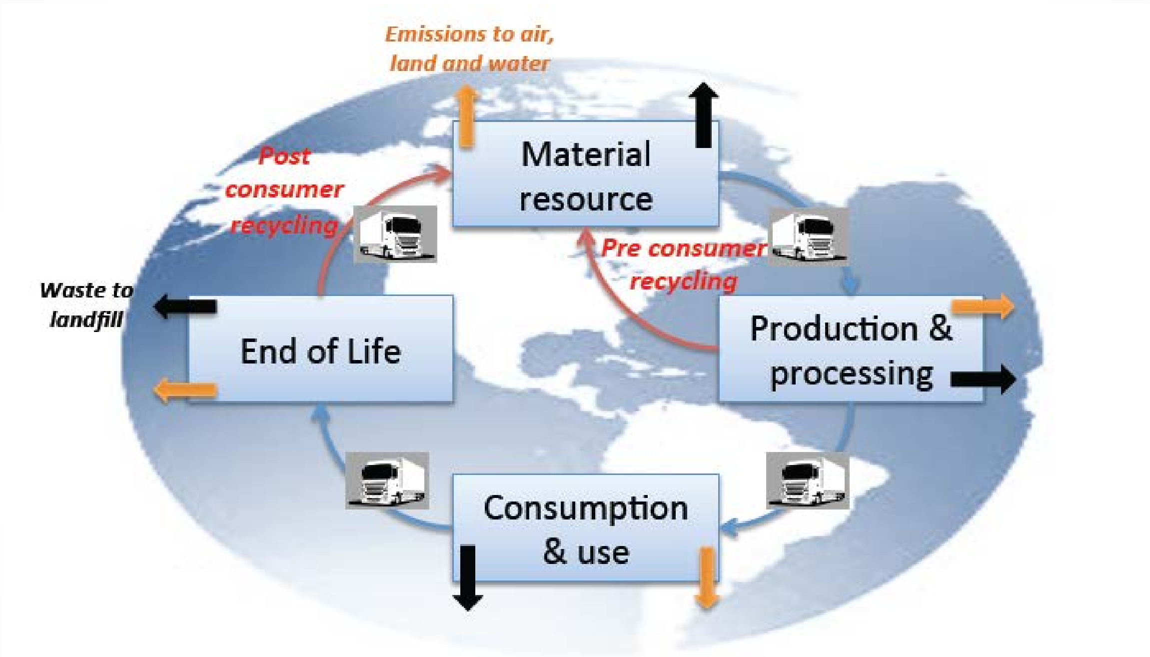
Advanced Manufacturing – Supply Chain / Value Chain



Strategic question: *What innovative manufacturing technologies and system improvements might result in the* ***greatest economy-wide impacts****?*

Advanced Manufacturing – Impacts at the Supply Chain Level

Manufacturing affects the way products are designed, fabricated, used, and disposed. ***Prospective life cycle sustainability analysis*** *is essential to assess the impacts of advanced manufacturing technologies.*



Opportunities for Manufacturing Innovation throughout the Supply Chain: integrated product & process design, advanced materials and technologies, use and reuse of materials & products

Materials extraction & refining → Intermediate product manufacture → Final product manufacture → Product use → End-of-life, Reuse

Strategic Analysis Projects - Overview

Analysis Topics	Analytic Focus
Electronics manufacturing	Enhanced understanding of electronics' supply chains and life cycle impacts.
• Consumer electronics	Materials and energy use associated with electronics using Appliance Standard's data and forecasts
• Automotive electronics	Life cycle energy and emissions impact analysis of increasing trend in automotive electronic content
• Wide band gap (WBG) semiconductors	Manufacturing supply chain analysis through medium voltage industrial motor drives and SWOT analysis of potential WBG market
Smart manufacturing	Technology gaps; efficiency opportunities illustrated in battery manufacturing case study.
Composites	Use-phase lightweighting for energy efficiency;
Critical materials	Economic viability of recycling rare earth materials in the United States.

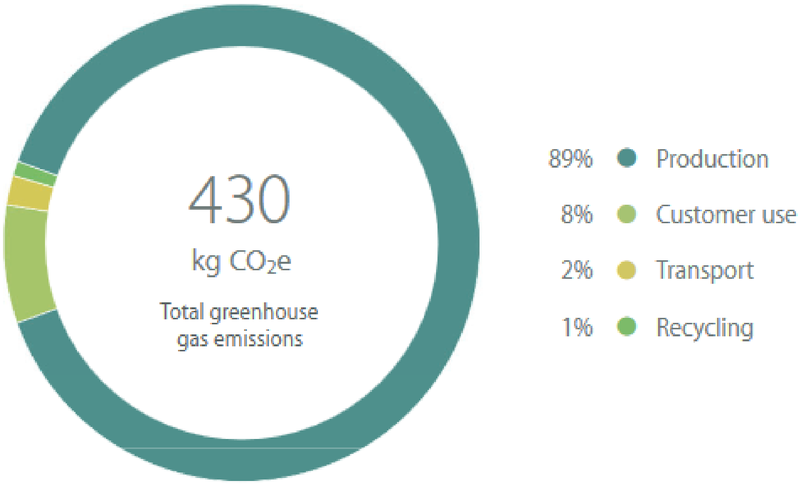
Electronics Manufacturing

Research Questions

- How is the addition of electronics into all appliances changing the demand for components traditionally found in computers?
- What are the energy and environmental impacts from the increase in consumer, automotive, and industrial demand for electronics?
- How can the energy and environmental impacts of electronics manufacturing be lessened?
- Where are the opportunities for U.S. manufacturing of electronic products?

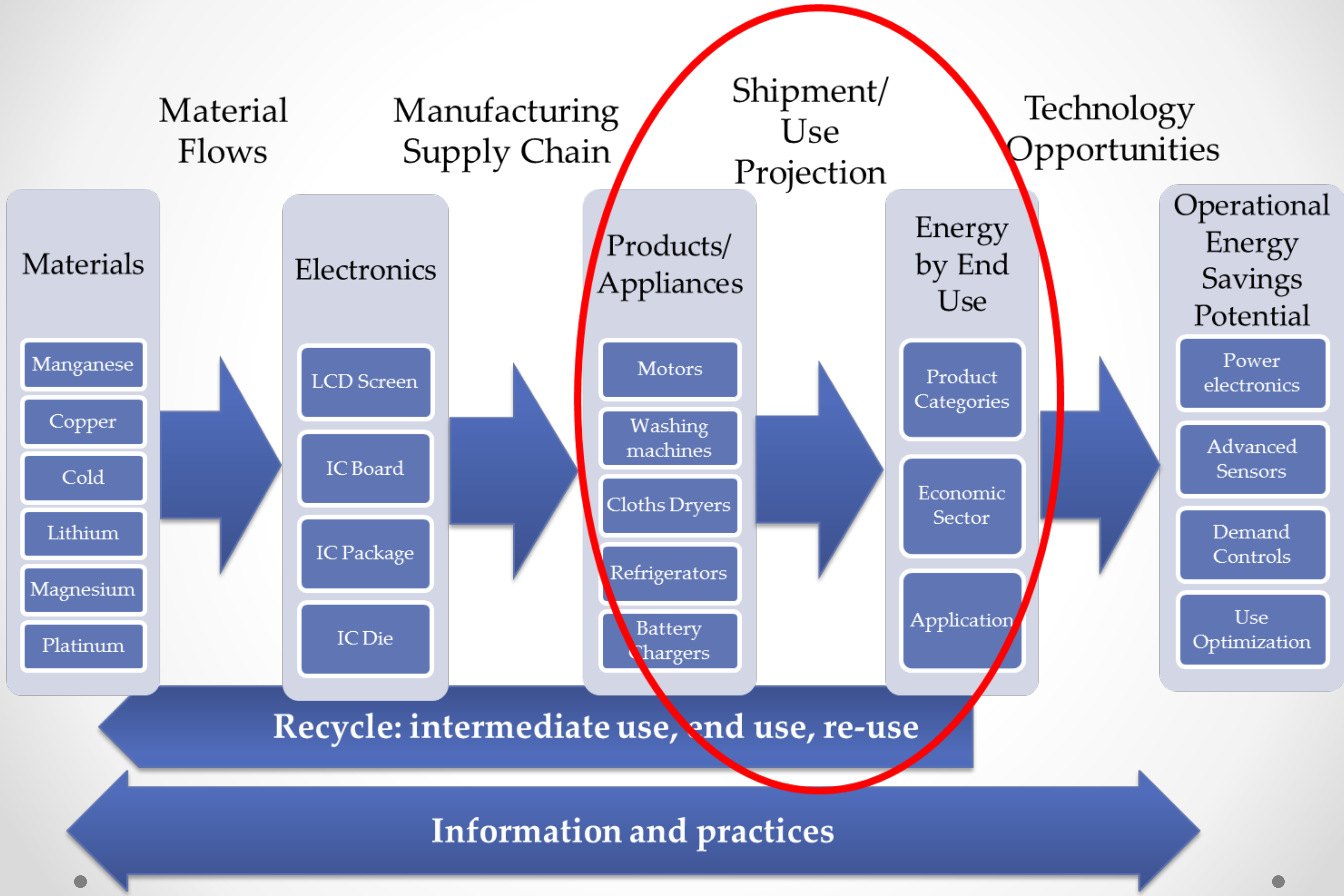
Models
MLH72, MLHA2, MLHE2, MMGL2,
MLH82, MLHC2, MLHF2, MMGM2
Date introduced April 19, 2016

Greenhouse Gas Emissions for 12-inch MacBook



Apple Inc. (2016). 12-inch MacBook: Environmental Report. https://www.apple.com/environment/reports/.

LCA of Electronics in Consumer Appliance

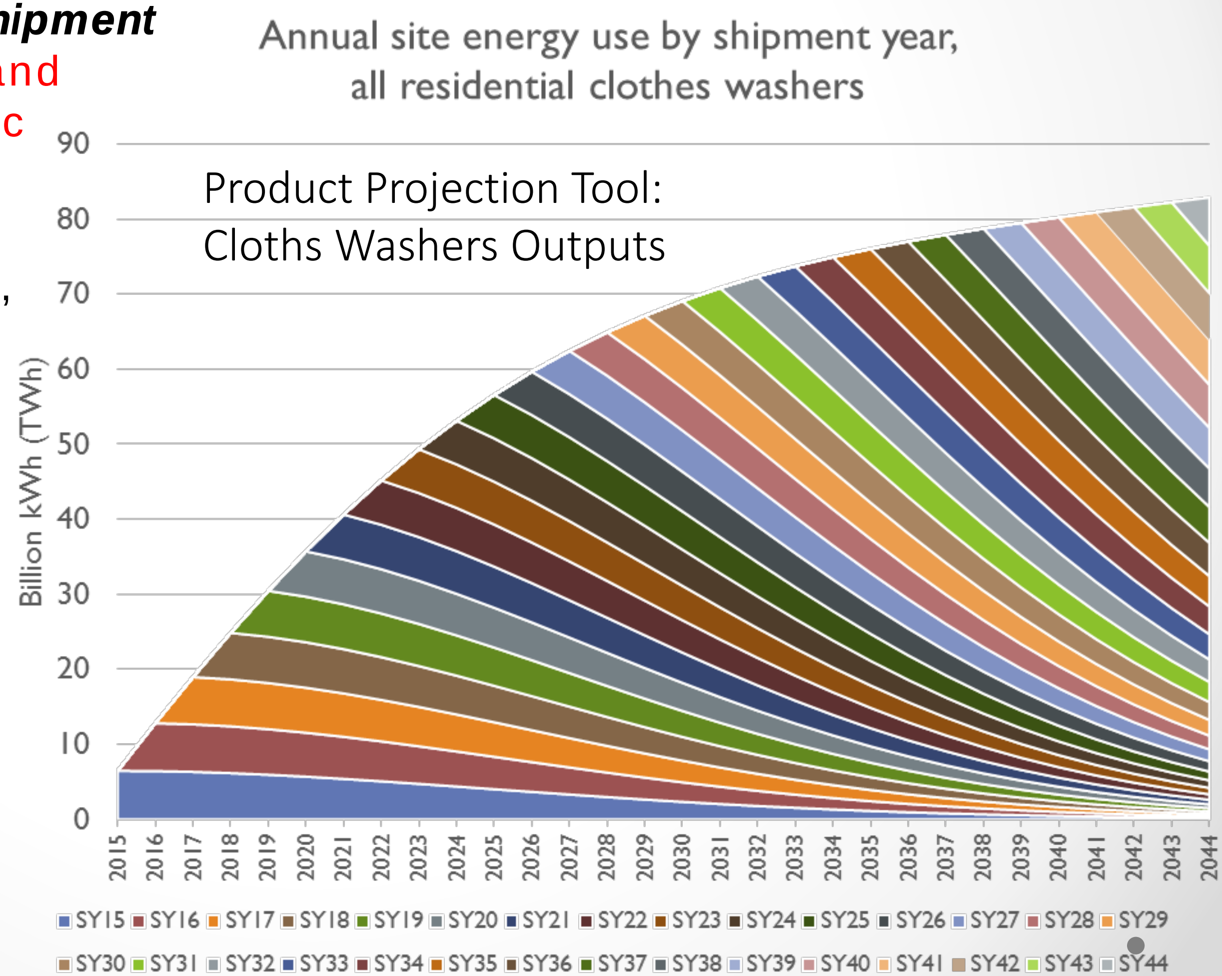


Appliance Electronics LCA Approach

- Identify appliance standards data to project electronics demand and energy efficiency potential both in the ***electronics manufacturing*** and the ***end-product operational energy***

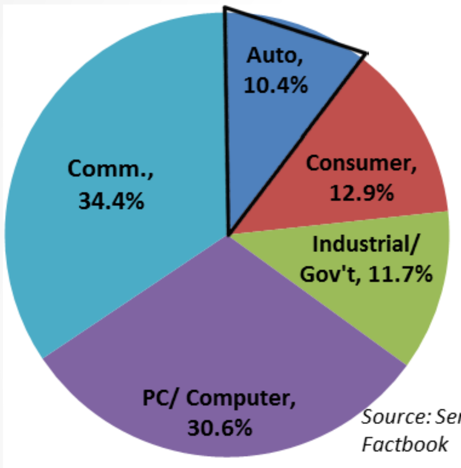
- Use ***highly disaggregated shipment projections*** to predict demand and opportunities for specific electronics

- Apply to various appliances, such as:
  - Battery Chargers
  - Clothes Dryers
  - Clothes Washers
  - Computers
  - Electric Motors
  - Lamps/Ballasts
  - Portable Air Conditioners
  - Refrigerators
  - Room Air Conditioners
  - Servers
  - Water Heaters



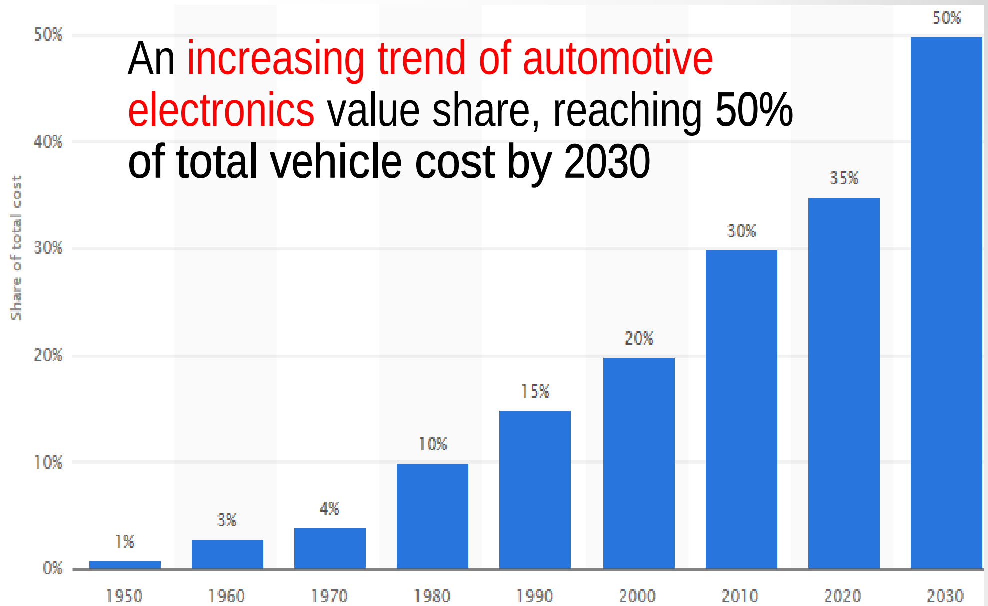
Automotive Electronics LCA

- Automotive, consumer, and industrial electronics application area have similar share of total semiconductor use



Source: Semiconductor Factbook

An increasing trend of automotive electronics value share, reaching 50% of total vehicle cost by 2030



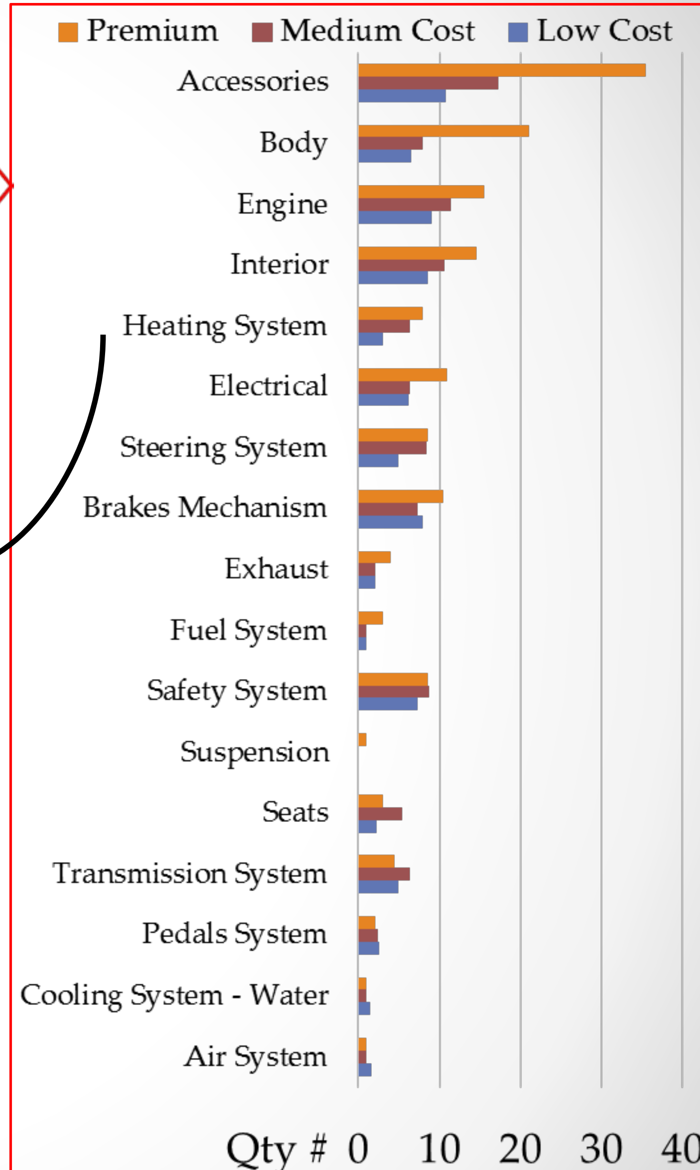
- Manufacturing energy, emissions, and cost besides strategic material use impacts could be significant even with a small amount of electronics use (<u>similar emission impacts of heavier steel vs lighter electronics use</u>)

Honda Civic Hybrid 1.5 2015	Mass (kg)	kgCO $_2$e
Steel (51% of car's total mass)	664.8	1,075
Electronics (LCD+PCB+IC)	2.9	1,190

Automotive Electronics LCA Approach

ECU Teardown

Quantity of:
<u>Electric Control Units (ECUs)</u>
<u>+ Sensors</u>



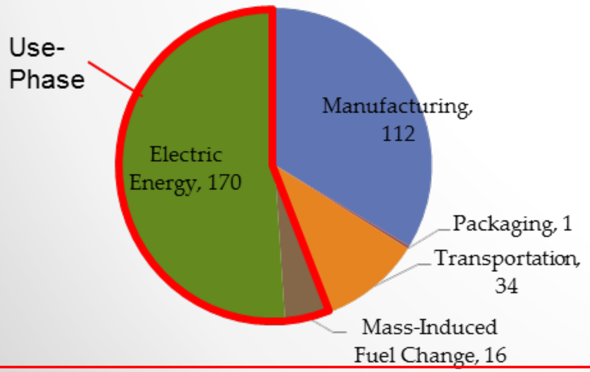
*<u>**Electronics = ECUs + Sensors**</u>. Source: A2mac1 Macro Teardown DB

Heating ECU (Representative ECU for LCA)

LCA for *detailed* ECU components

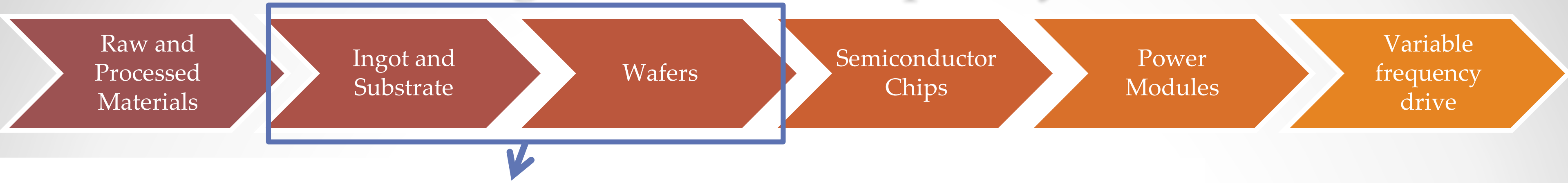
Components = IC, Capacitors, Transistors

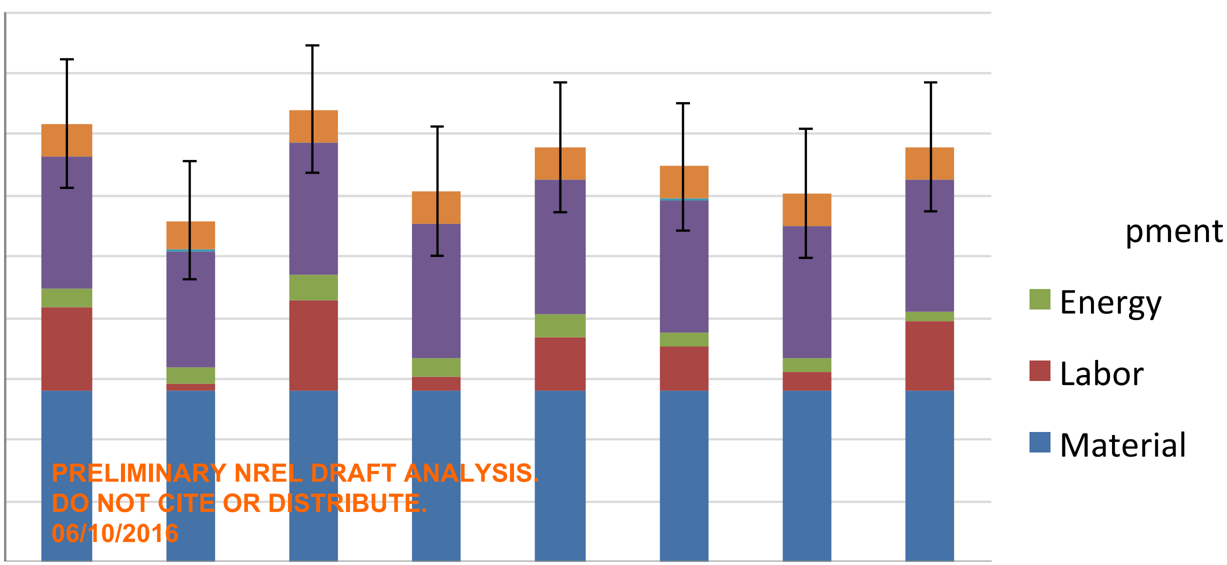
Heating ECU (98 grams) LCA Results



- 334 MJ or 93 kWh
- 39 L of Water
- 22 KgCO2eq

Manufacturing Cost and Competitiveness Analysis for SiC in Medium Voltage Variable Frequency Motor Drives





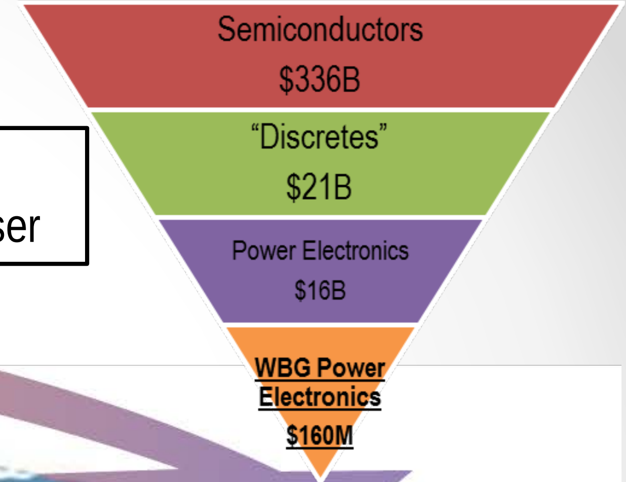
Approach:

- Bottom-up, regional cost models
- Look across the full value chain
- SWOT analysis – potential impact of policies and research
- Future work: impact of taxes, incentives, cost of capital, and fixed costs on regional minimum sustainable pricing and competitiveness

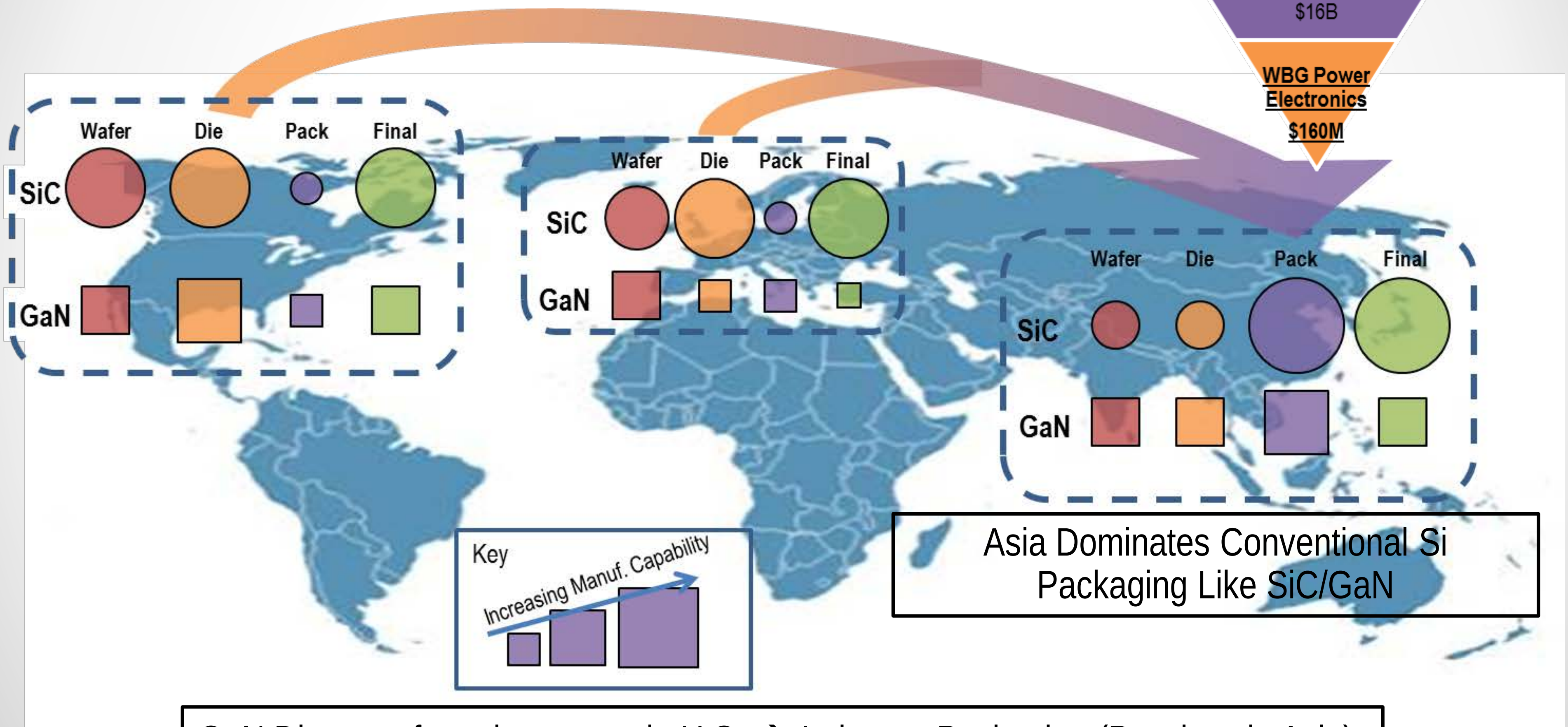
Chart above currently includes only manufacturing costs - does not include R&D, SG&A, cost of capital, or taxes. No subsidies currently included

For more information on minimum sustainable price methodology: http://www.manufacturingcleanenergy.org/blog-20160510.html

Wide Band Gap Supply Chain

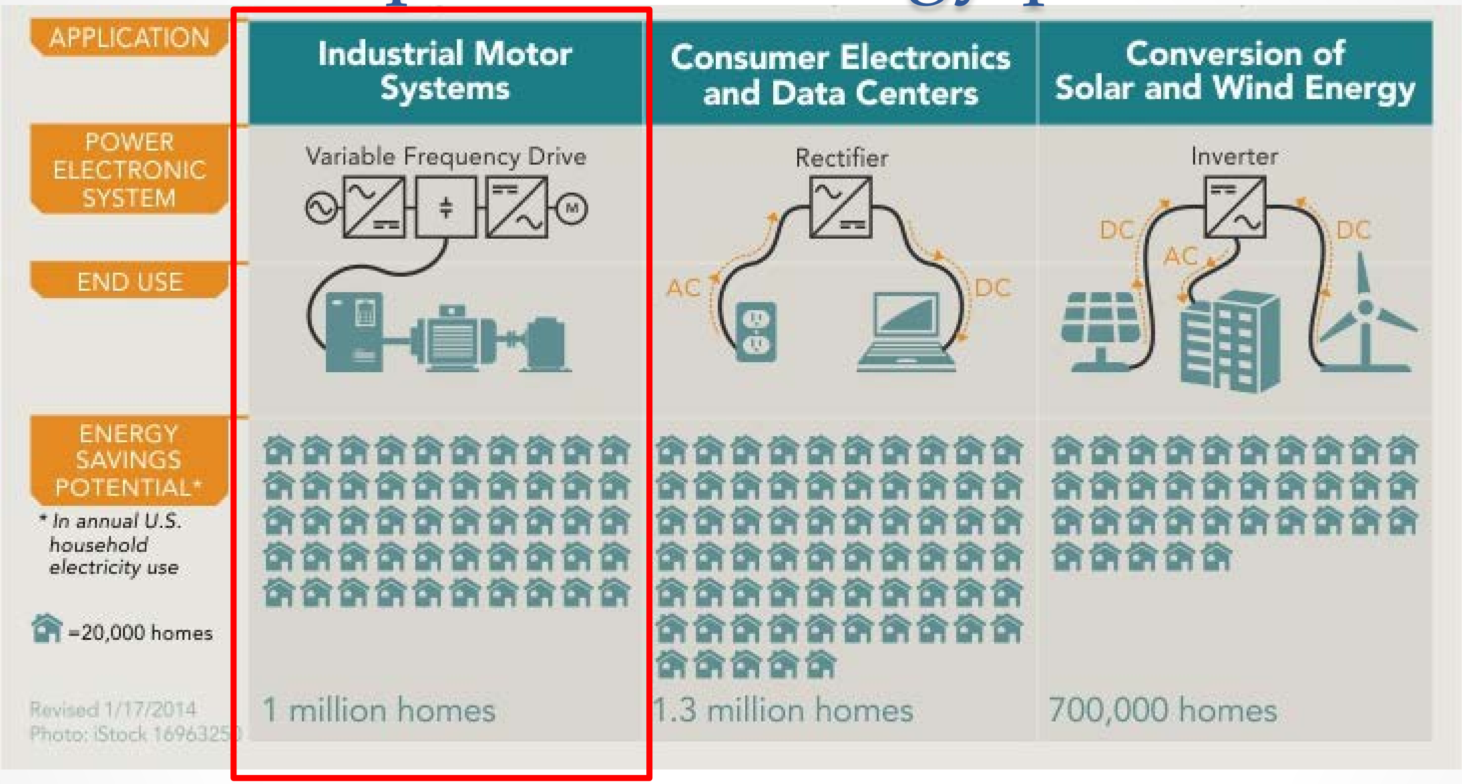


SiC Wafer and Die strong in U.S. & Europe → Shipped to Asia for Packaging (Passives in Asia) → Final product Manufacturing at End-User



GaN Die manufacturing strong in U.S. → In-house Packaging (Passives in Asia) → Limited final product Manufacturing than SiC

Energy savings attributable to WBG across multiple clean energy products



Potential energy savings:

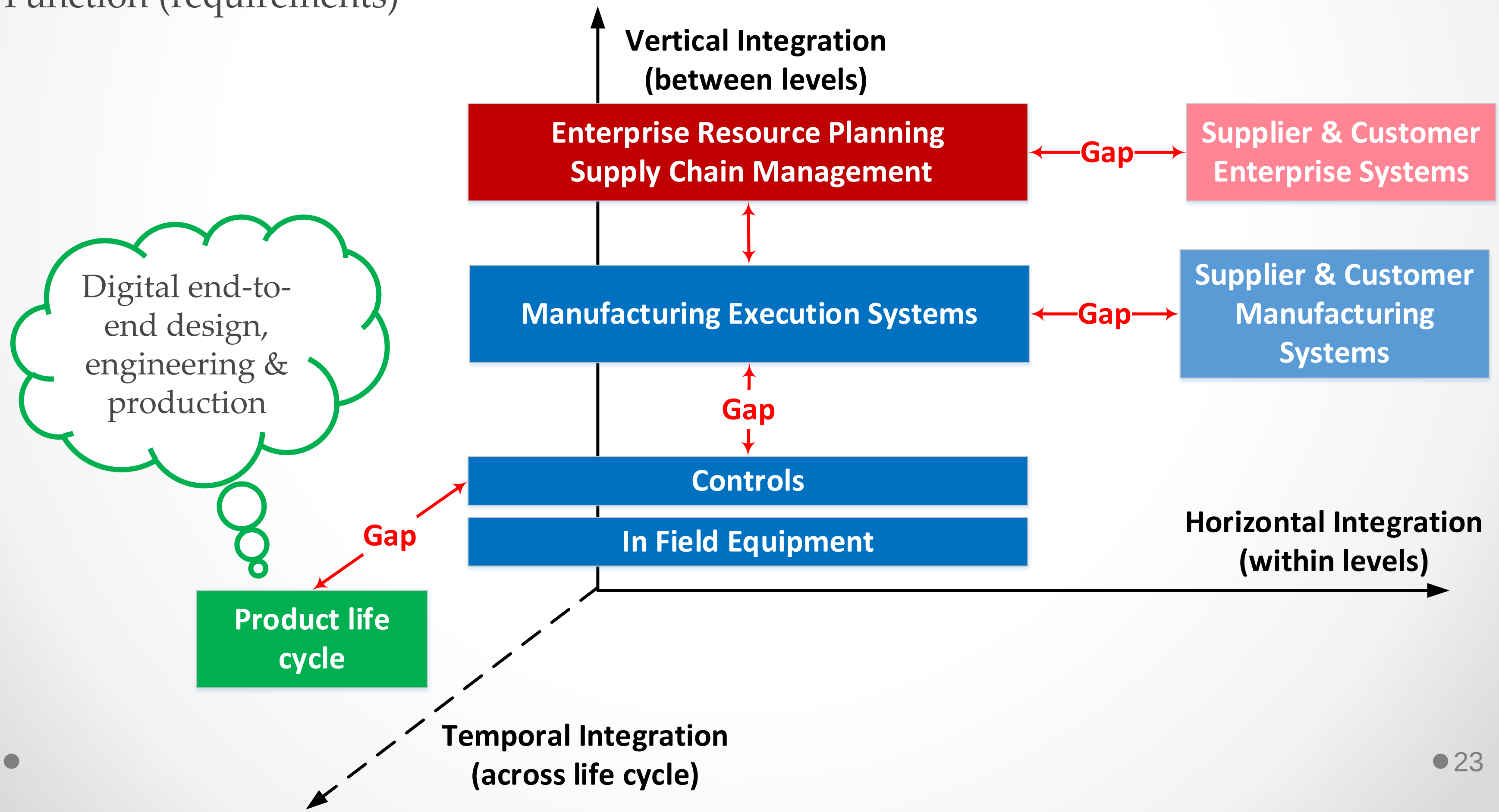
- 10 TWh (equivalent to energy use in 1 million homes) for replacing existing industrial motor systems
- 723 TWh theoretical maximum assuming 100% adoption of SiC variable frequency drives

Smart Manufacturing

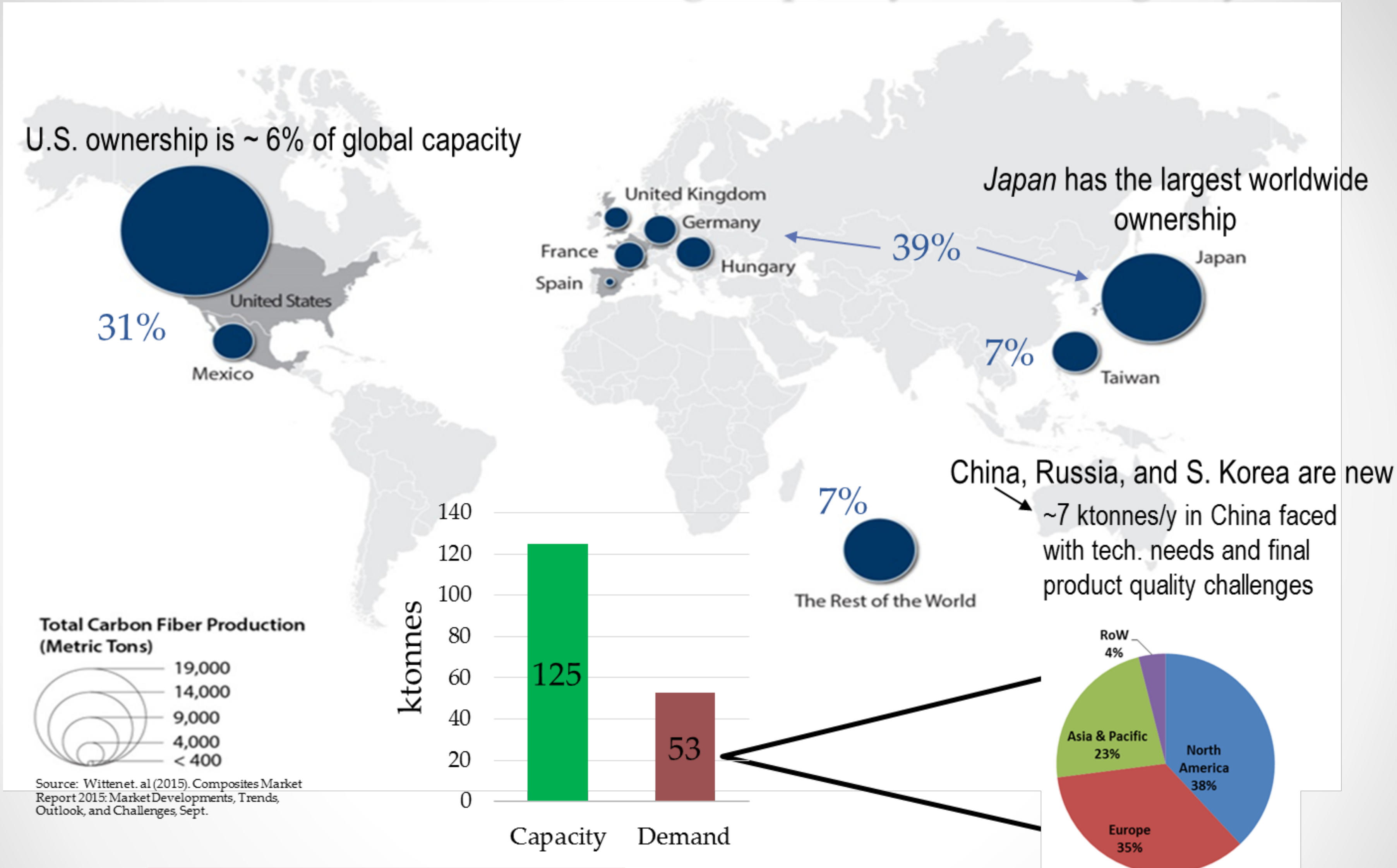
What industries have opportunities for efficiency improvements through the use of smart manufacturing technologies and how big is that opportunity?

Data driven change:

- Objectives (**performance metrics**)
- Scale (stakeholders, **integration**)
- Function (requirements)



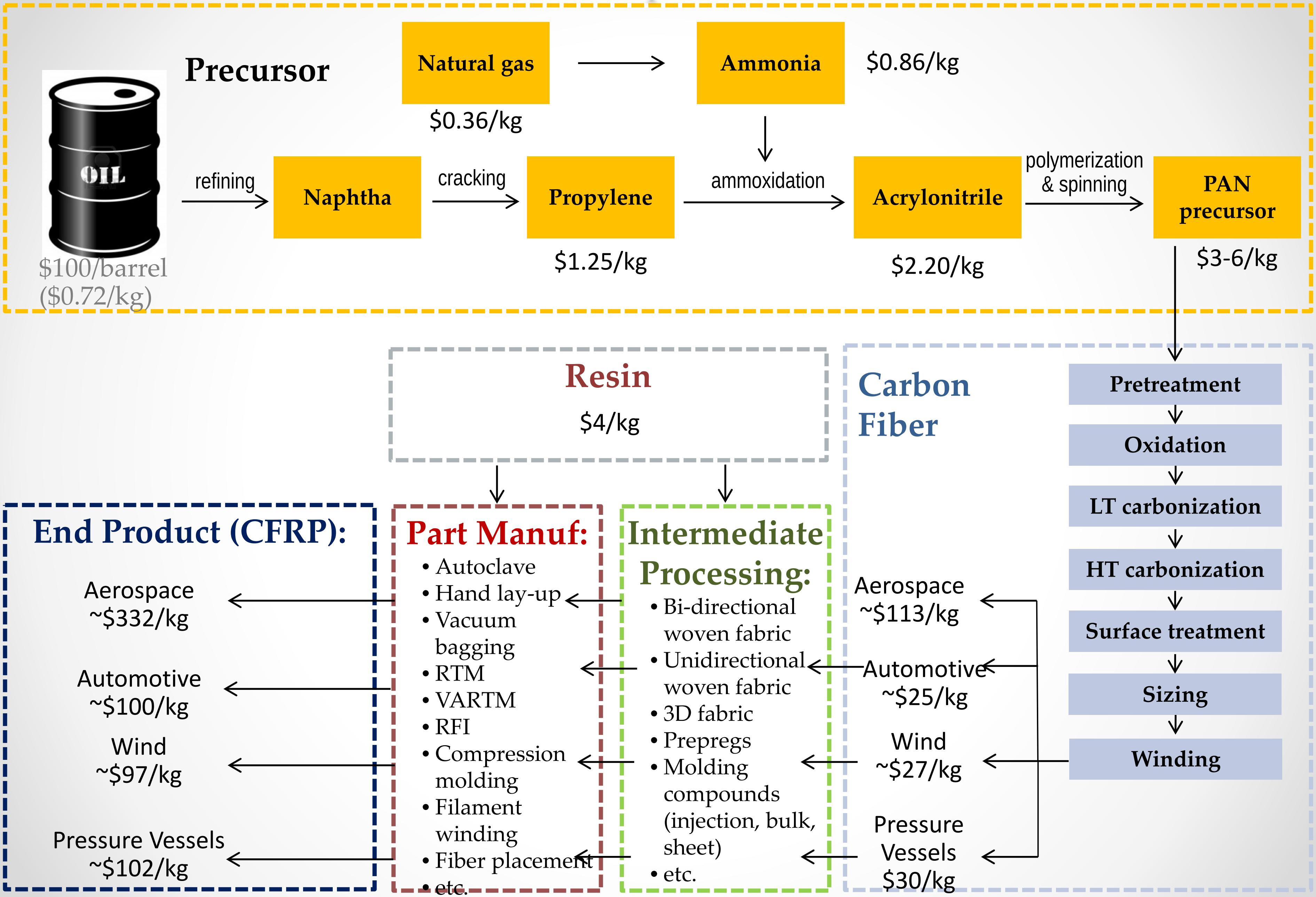
2014 Carbon Fiber Manufacturing Capacity Increasing Beyond US



~88% of global fiber capacity held by ten leading manufacturers

2014 Carbon Fiber Composites Demand =105 ktonnes

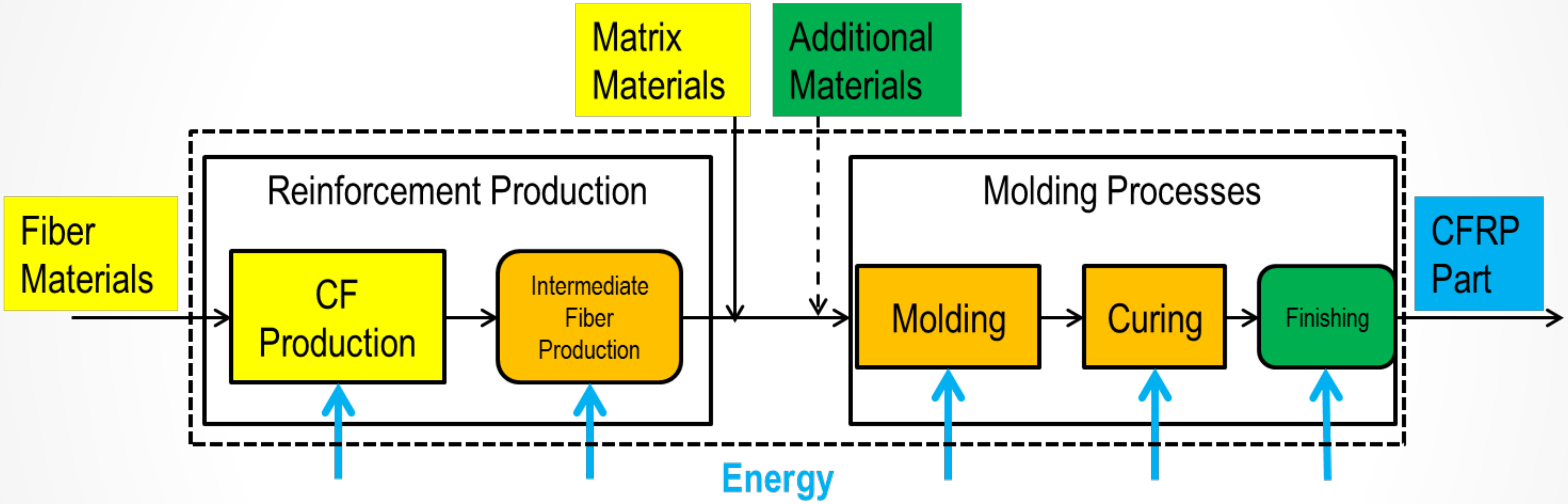
Carbon Fiber Composites Value Chain



Source for CF and CFRP prices: (2)

Carbon Fiber Reinforced Polymer Composites Manufacturing Energy Estimator (CFRP Tool)

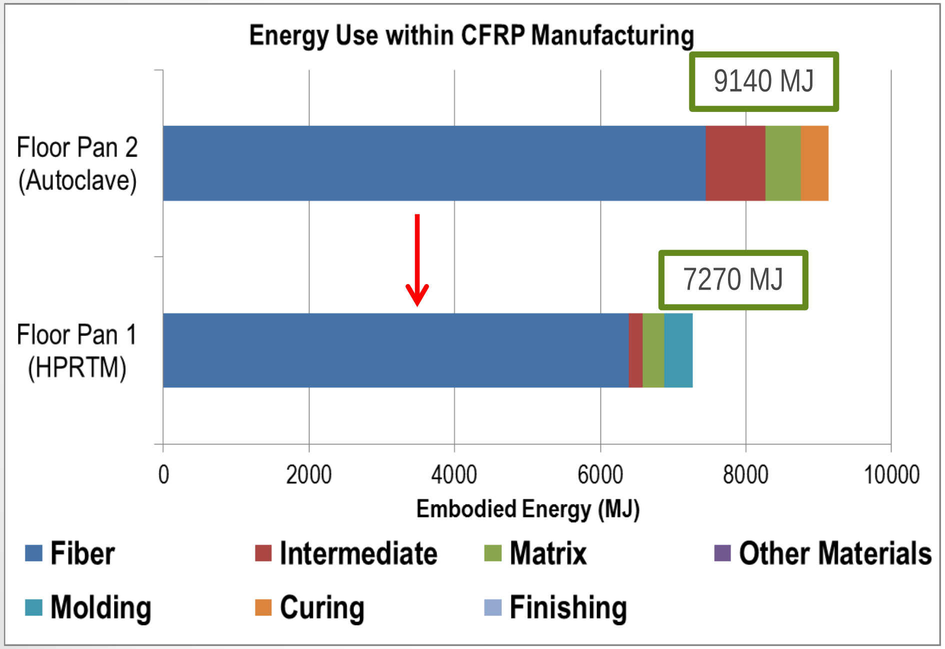
- Evaluates *embodied energy* intensity of CFRP *product manufacturing* for several technology pathways via major manufacturing steps using a consistent user-friendly framework

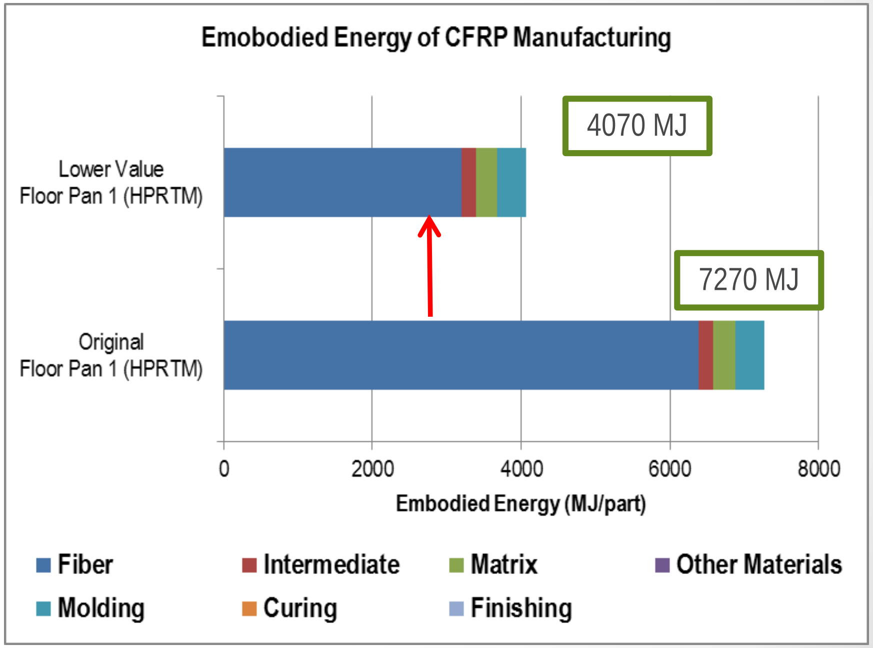


- Contains manufacturing energy data by major manufacturing processes
- User can tailor the manufacturing processes into pathways for specific products
- Capability to add-on new manufacturing processes

CFRP Tool Capabilities

- Energy use at Individual Component, Major Production Step, and Overall Production
- Carbon fiber contributes to more than 80% of total CFRP embodied manufacturing energy
- Sensitivity analysis helps examine the manufacturing energy reduction opportunities

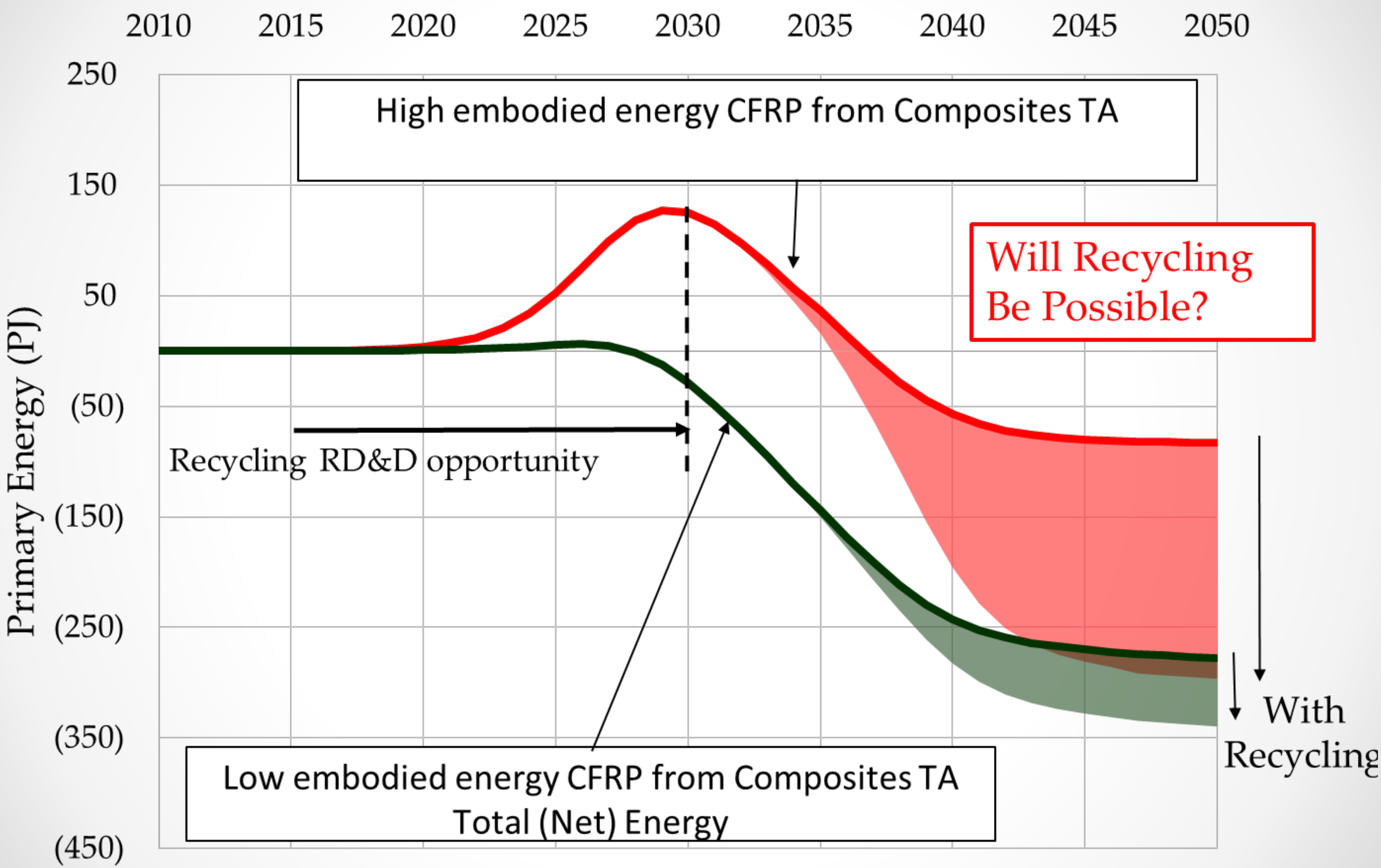




Higher prepreg autoclave molding manufacturing energy due to higher scrap rate than molding energy

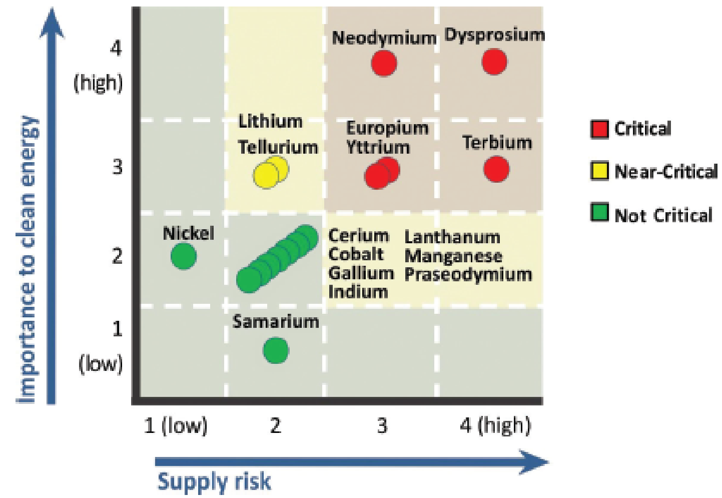
50% reduction in Fiber Energy
↓
44% reduction in Total Energy

Net Energy Impact with utilization of recycled CFRP in vehicles



Critical Materials

- Economic feasibility of recycling technologies, initial focus on rare earth materials
  - o Challenge to U.S. critical materials recycling – sparse domestic supply chains
- Text analytics study – identify trends in literature, IP and research funding to understand trends in criticality of materials



Inputs

Distributions (e.g., minimums and maximums) for:

- Operating costs in relation to plant size
- Capital equipment costs in relation to plant size
- Rare earth recovery rates
- Domestic secondary supply & demand for rare earth materials

Calculation module

Stochastic Cash Flow Analysis

Outputs

- Minimum sales price for a given plant size
- Minimum demand and material availability to sustain production at a given price point (primary material price)
- Distributions and ranges