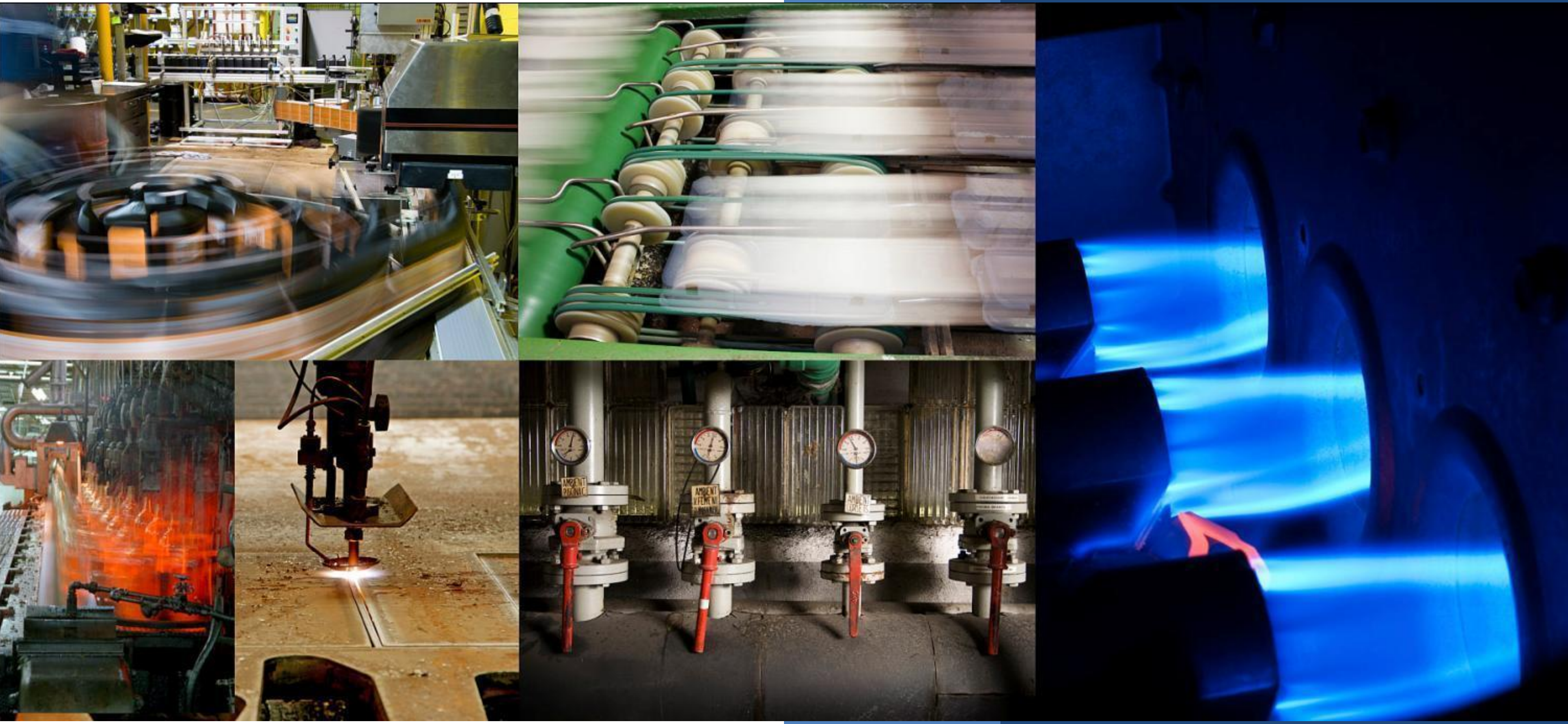
Office of Energy Efficiency & Renewable Energy
Advanced Manufacturing Office

U.S. DEPARTMENT OF ENERGY



A Perspective on Energy Use and Progression of Emerging Advanced Manufacturing Technologies

Joe Cresko - Advanced Manufacturing Office, DOE

Aspen Global Change Institute

November 12, 2018

How can we better inform the scale and speed needed for technology / policy options?

What can we do better?

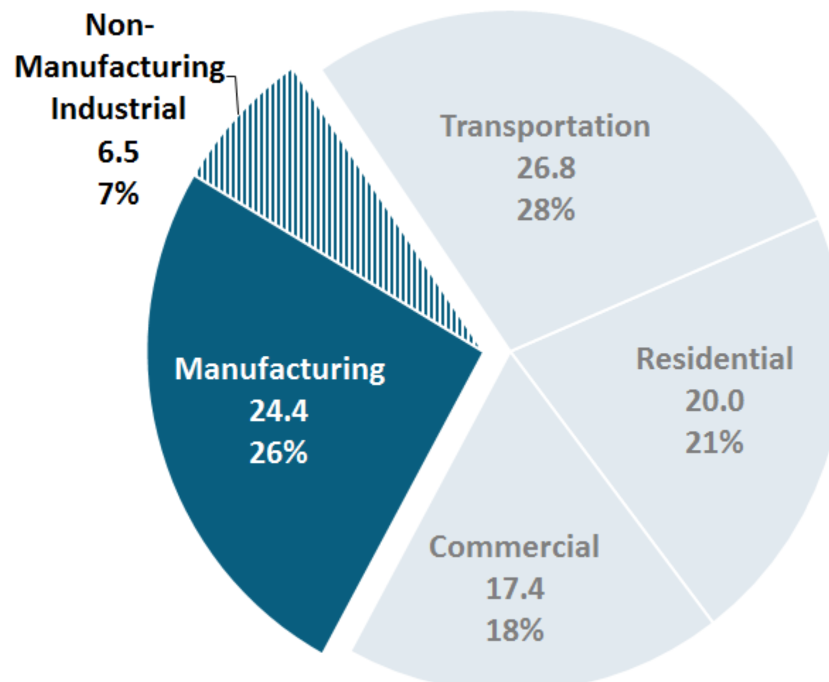
- Prioritize → Can we develop practical approaches to prioritize the next generation of industrial technologies →(based on life cycle energy and carbon productivity)?

- Communicate → Can we provide clear, compelling information that can impact technology/policy decision-making.

What you'll see in this presentation → Context (a little bit about sectors, energy, technologies….)

U.S. Economy-Wide Energy Demand

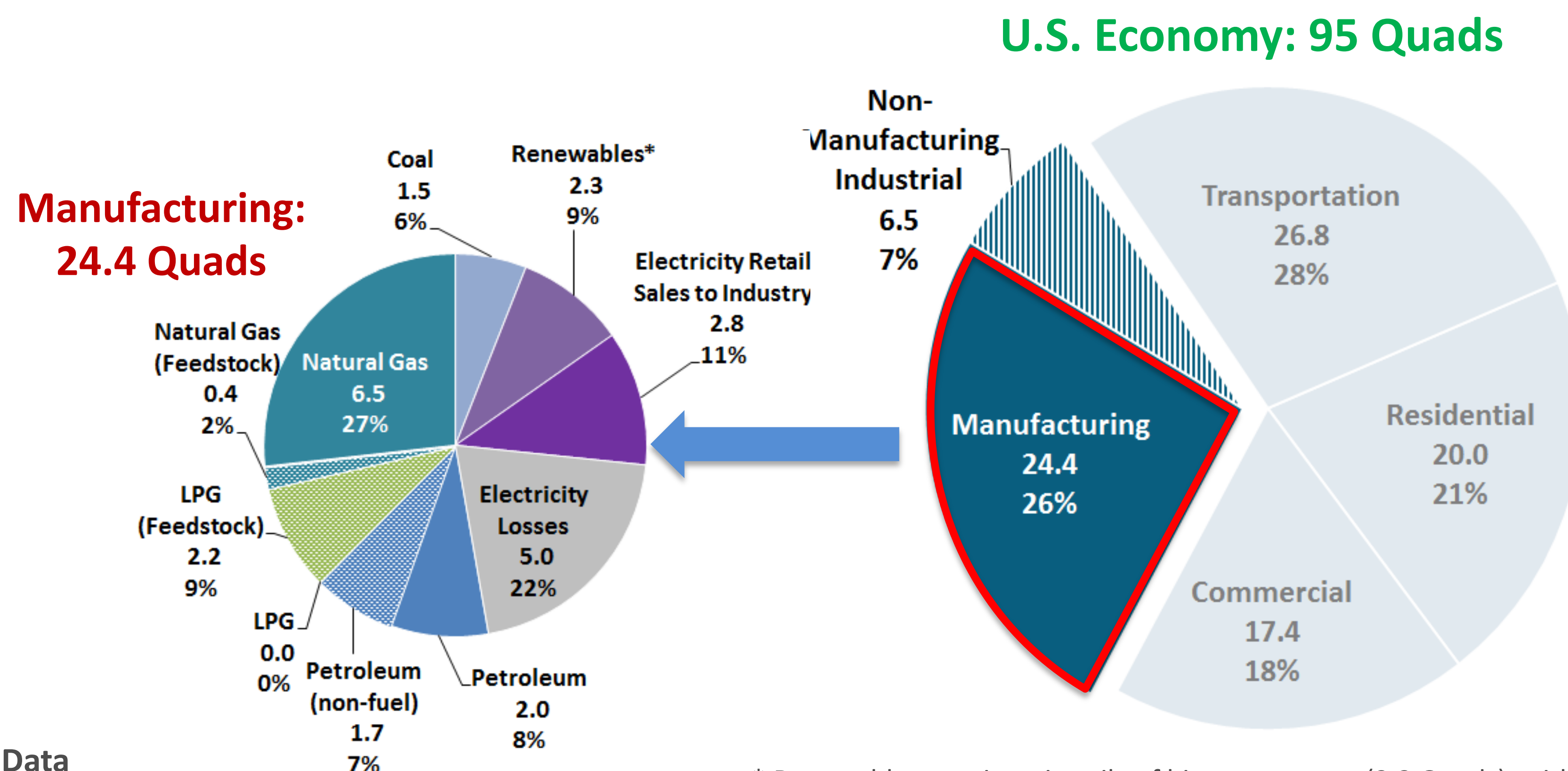
U.S. Economy: 95 Quads



2012 Data

Source: EIA Monthly Energy Review, Aug 2014; AEO 2014

U.S. Manufacturing Energy Use

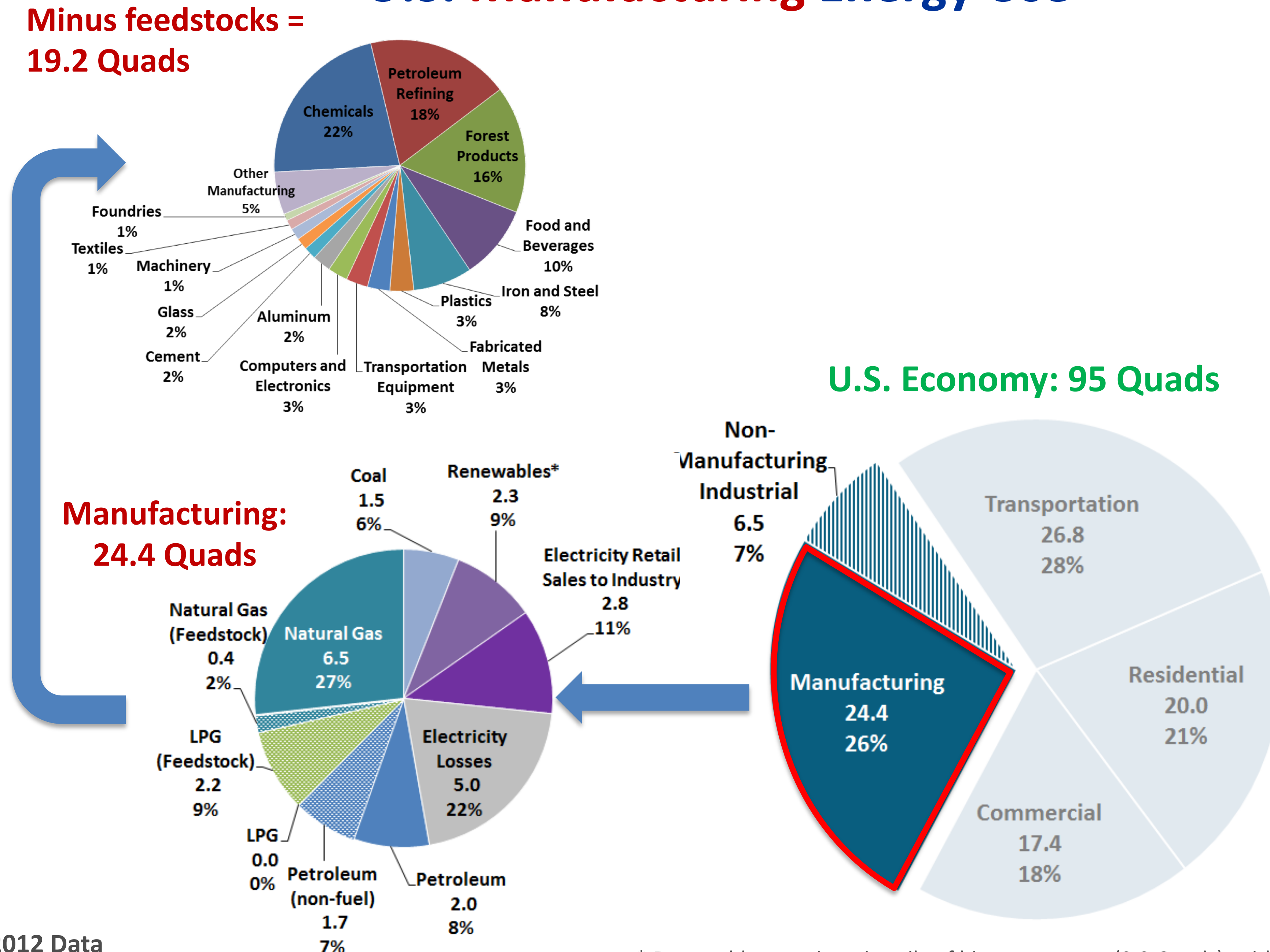


2012 Data

Source: EIA Monthly Energy Review, Aug 2014; AEO 2014

* Renewables consist primarily of biomass energy (2.3 Quads), with the remainder from onsite hydroelectric, geothermal, wind and solar energy.

U.S. Manufacturing Energy Use



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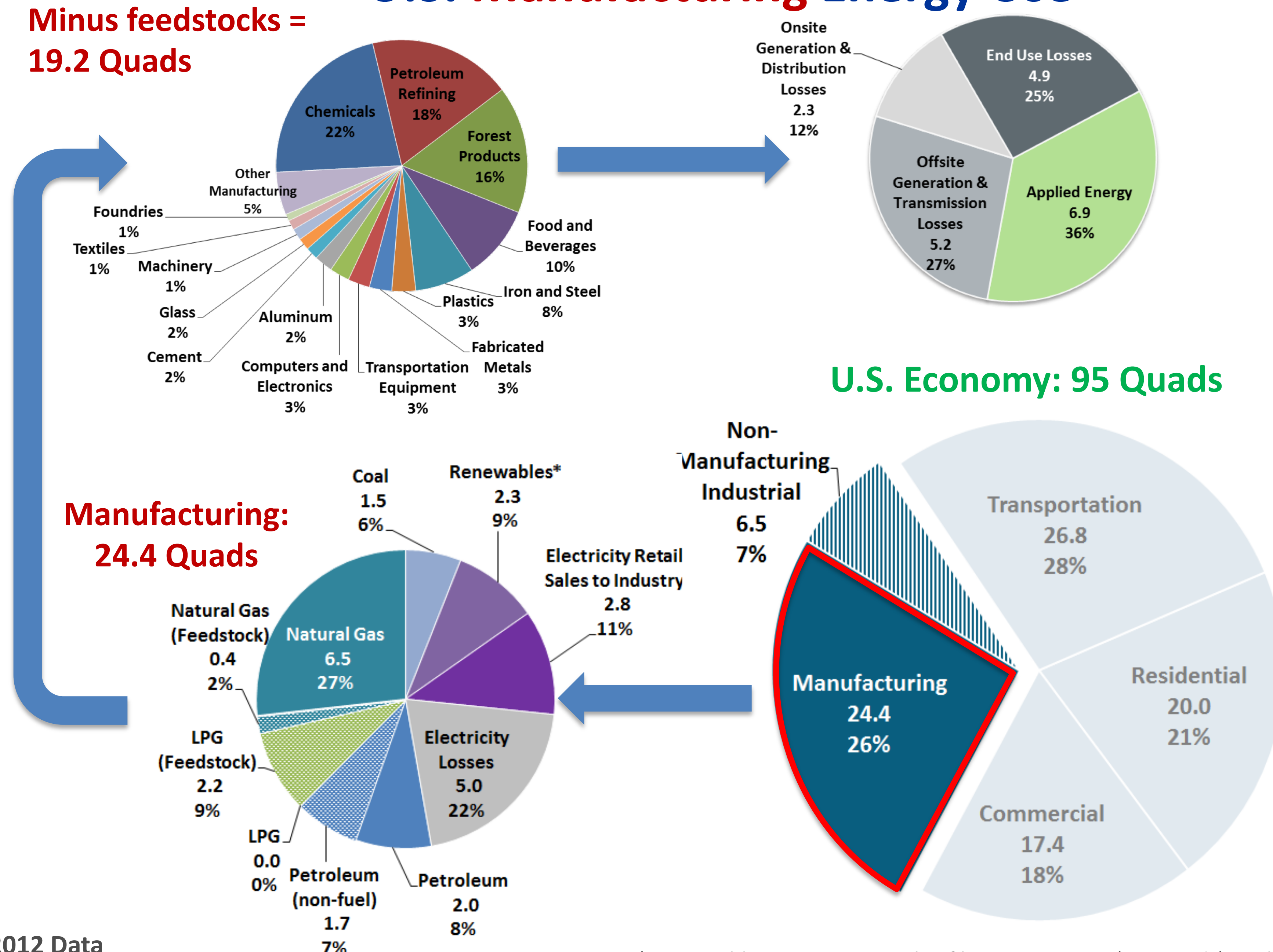
U.S. Manufacturing Energy Use



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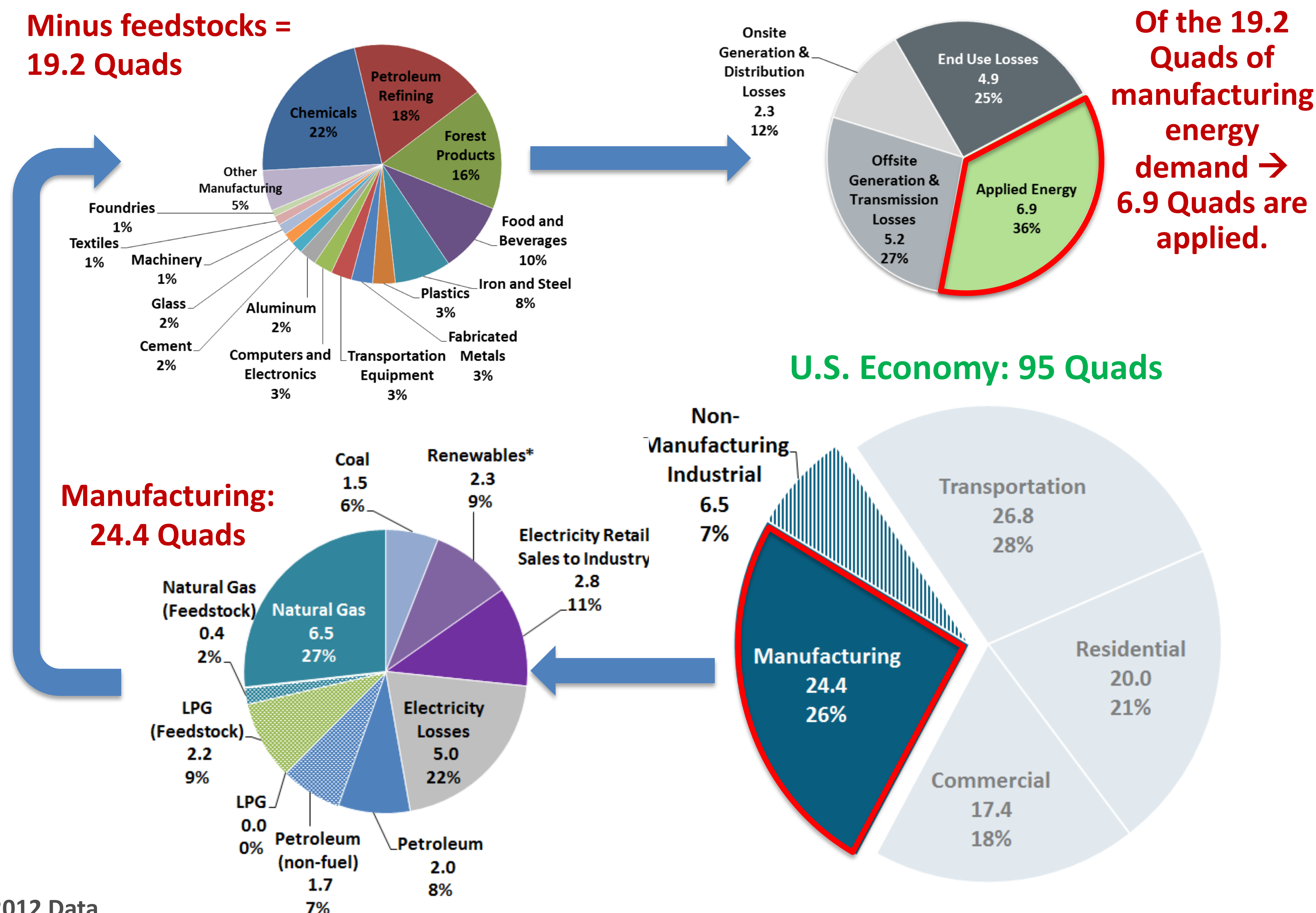

2012 Data

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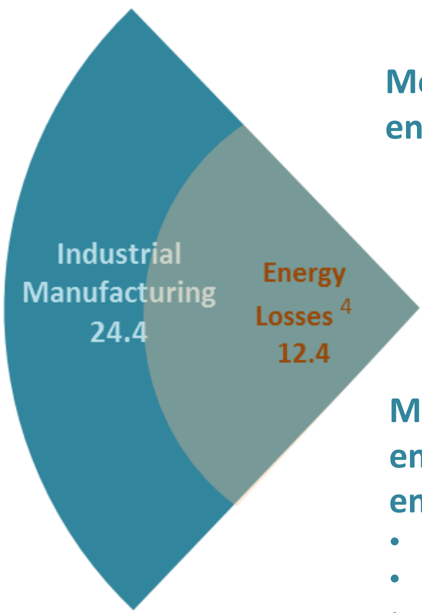
* Renewables consist primarily of biomass energy (2.3 Quads), with the remainder from onsite hydroelectric, geothermal, wind and solar energy.

Opportunity Space for Manufacturing

- **Improve the energy and carbon productivity of U.S. manufacturing.**
- **Reduce life cycle energy and resource impacts of manufactured goods.**

Manufacturing Goods

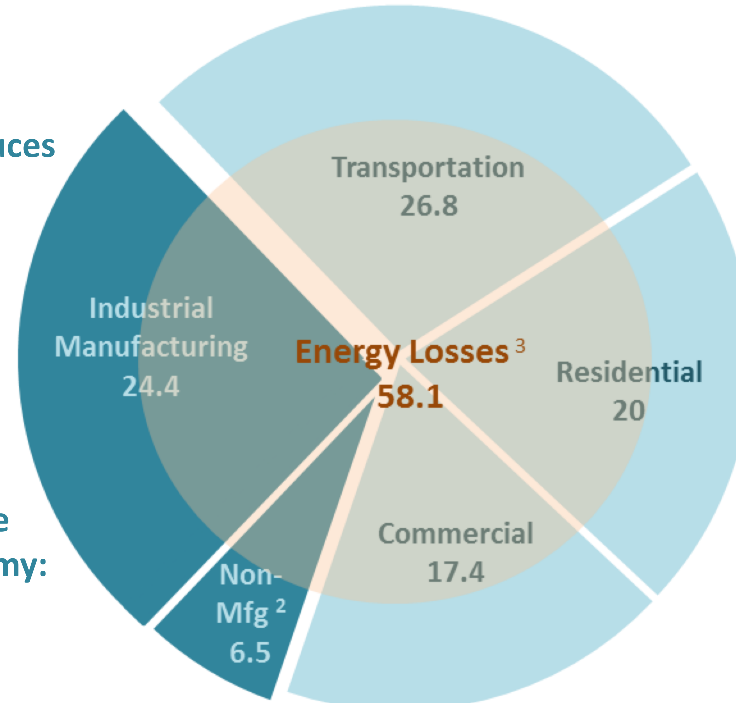


More efficient manufacturing reduces energy losses.

More efficient manufacturing enables technologies that improve energy use throughout the economy:

- Transportation
- Buildings
- Energy Production and Delivery

Use of Manufactured Goods



U.S. Energy Economy by Sector
95.1 quadrillion Btus, 2012 [1]

[1] Energy consumption by sector from EIA Monthly Energy Review, 2012
[2] Industrial non-manufacturing includes agriculture, mining, and construction
[3] US economy energy losses determined from LLNL Energy Flow Chart 2012 (Rejected Energy)
[4] Manufacturing energy losses determined from DOE AMO Sankey/Footprint Diagrams (2010 data)

Drivers to Reduce Energy & Emissions through the Product Life Cycle

Energy Intensity e.g.:
- Process efficiency
- Process integration
- Waste heat recovery

New Processes

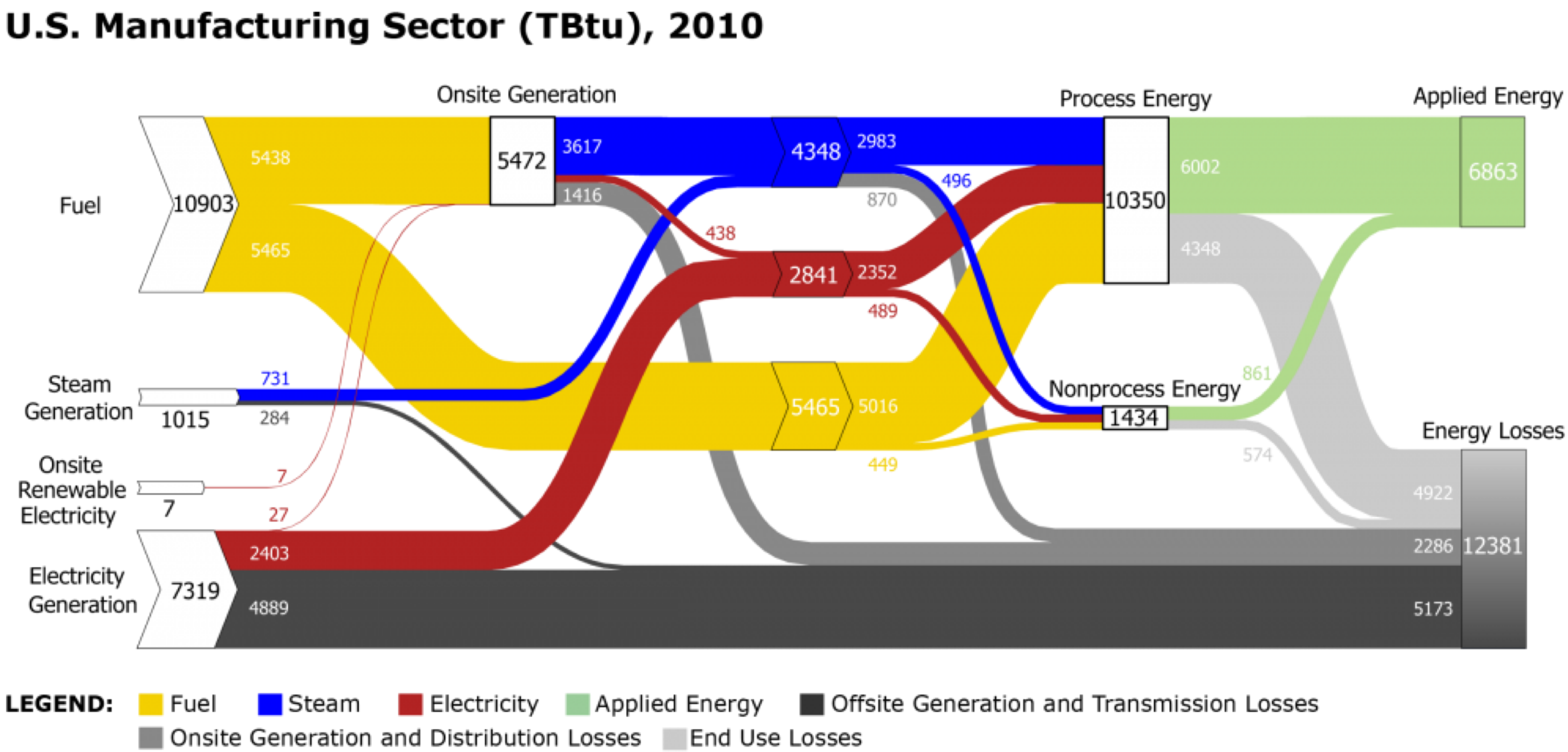
New Materials

Carbon Intensity, e.g.:
- Process efficiency
- Feedstock substitution
- Biomass-based fuels
- Renewables

Use Intensity e.g.:
- Circular Economy
- Design for Re-X (recycling reuse and remanufacturing)
- Material efficiency and substitution

Improved Products by Next Generation Materials and Processses.

How to quantify the opportunity space? Start with current energy use within the manufacturing sector…



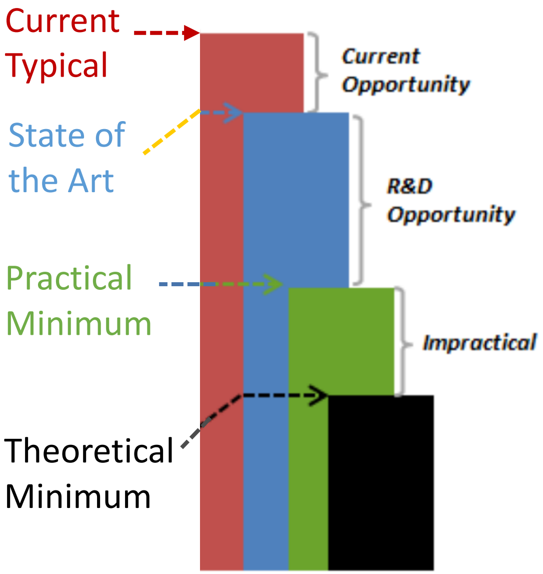
Note: 1 quad = 1,000 TBtu

https://www.energy.gov/eere/amo/static-sankey-diagram-full-sector-manufacturing

… and investigate energy savings potentials – Bandwidth studies.

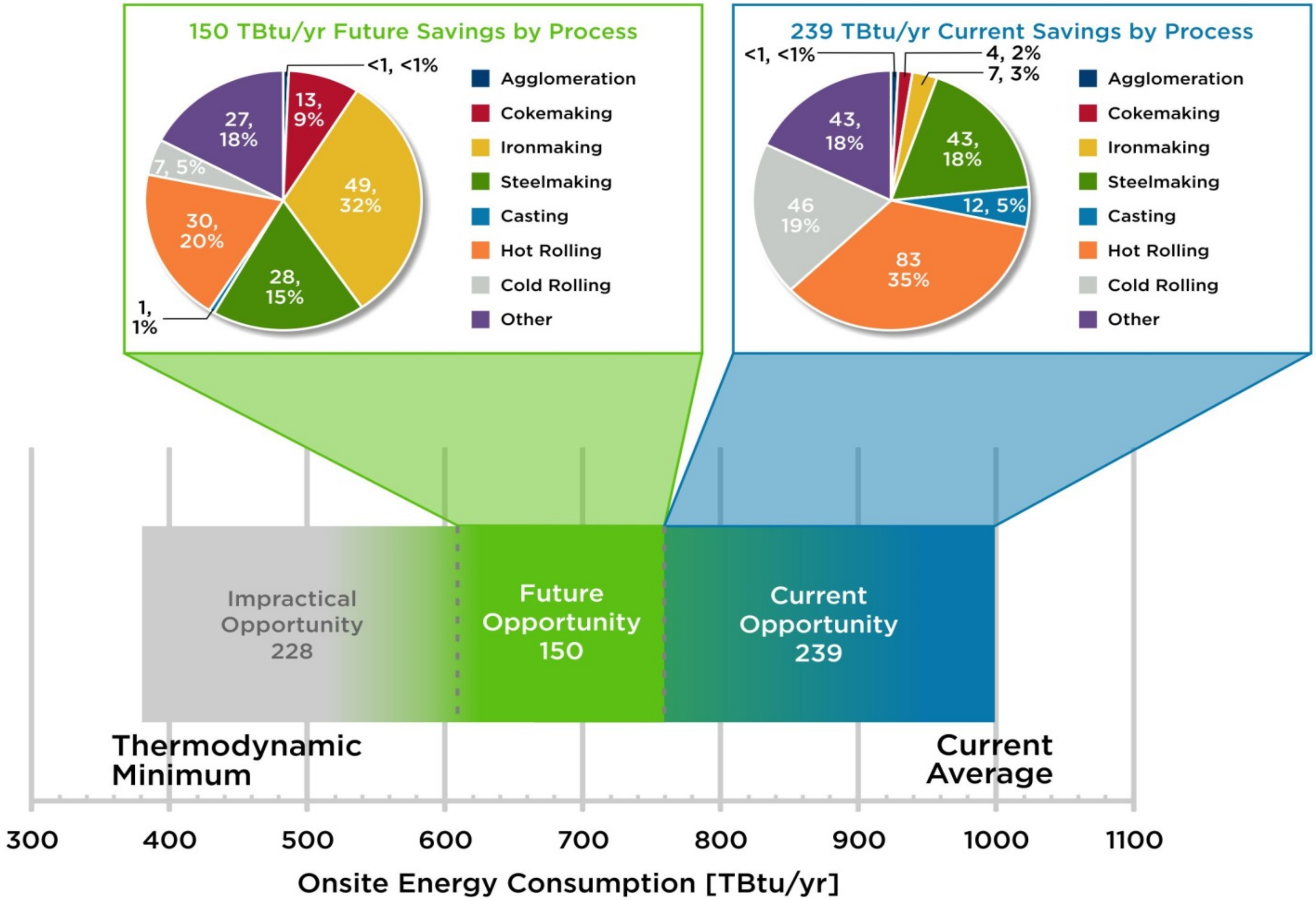
2015 (published)	**Manufacturing sector bandwidth studies:** • Chemicals • Iron & Steel • Pulp & Paper • Petroleum Refining
2017 (published)	**Lightweight materials bandwidth studies:** • Aluminum • Advanced High Strength Steel • Titanium • Magnesium • Carbon Fiber Reinforced Polymer Composites • Glass Fiber Reinforced Polymer Composites **Water/energy studies:** • Desalination Bandwidth Study **Manufacturing sector bandwidth studies:** • Plastics & Rubber Products • Cement • Glass • Food & Beverage

Energy bandwidth studies can frame the range (or *bandwidth*) of potential energy savings in manufacturing, and technology opportunities to realize those savings.



Bandwidth analyses are bottom-up studies starting at the manufacturing process/unit operation level ….

Technical Energy Savings Opportunities: Iron & Steel Industry
2015 Bandwidth Study – potential by major process area



Source: DOE/AMO, Iron & Steel Industry Energy Bandwidth Study (2015)

Note: 1 quad = 1000 TBtu

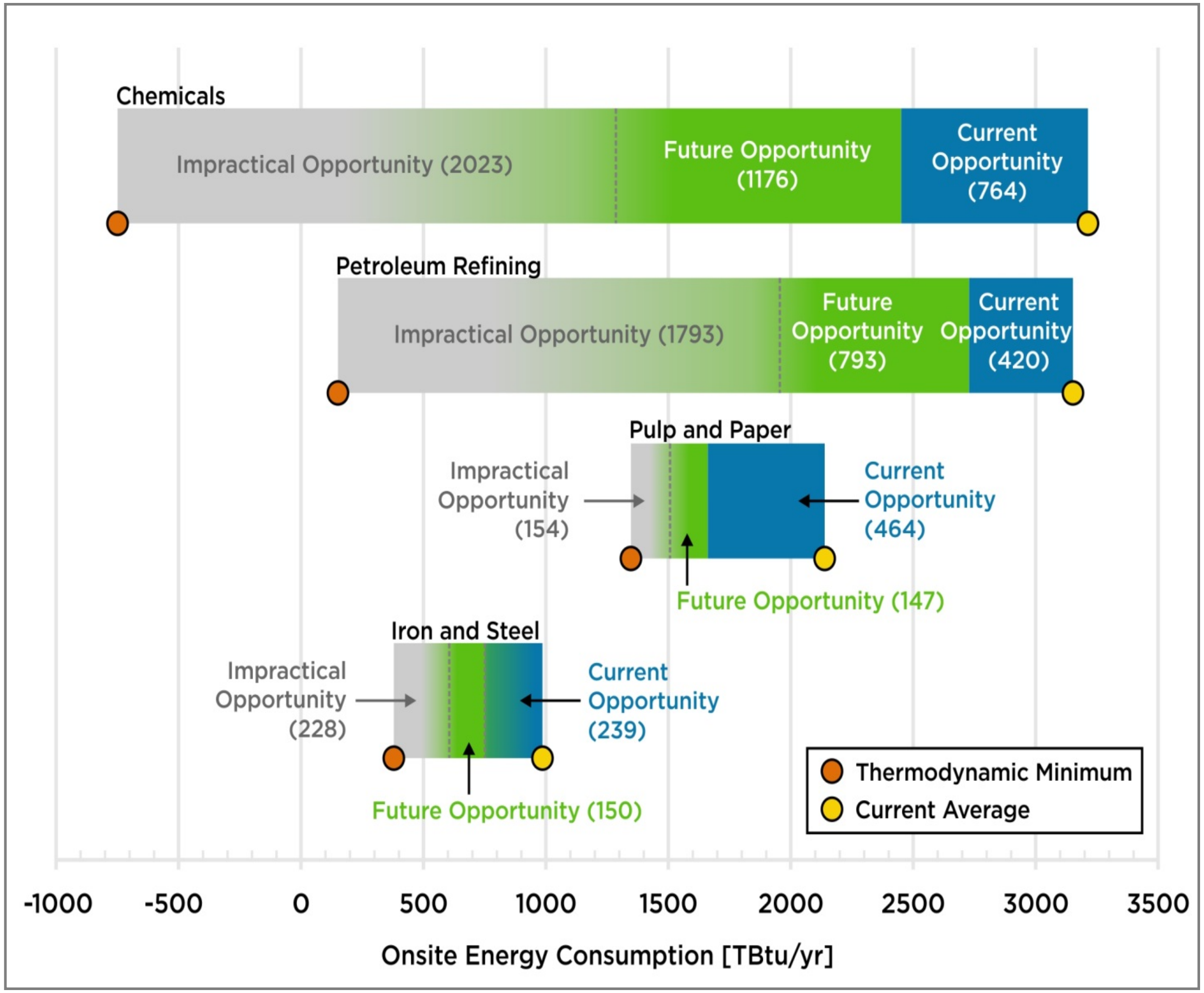
… for potential energy improvements .

Energy Intensity e.g.:
Process efficiency
Process integration
Waste heat recovery

Carbon Intensity, e.g.:
Process efficiency
Feedstock substitution
Biomass-based fuels
Renewables

Use Intensity e.g.:
Circular economy Design for Re-X (recycling, reuse and remanufacturing)
Material efficiency and substitution

Technical Energy Savings Opportunities:



Source: DOE/AMO, Energy Bandwidth Studies (2015)
Note: 1 quad = 1000 TBtu

Carbon Intensity

Energy Intensity e.g.:
Process efficiency
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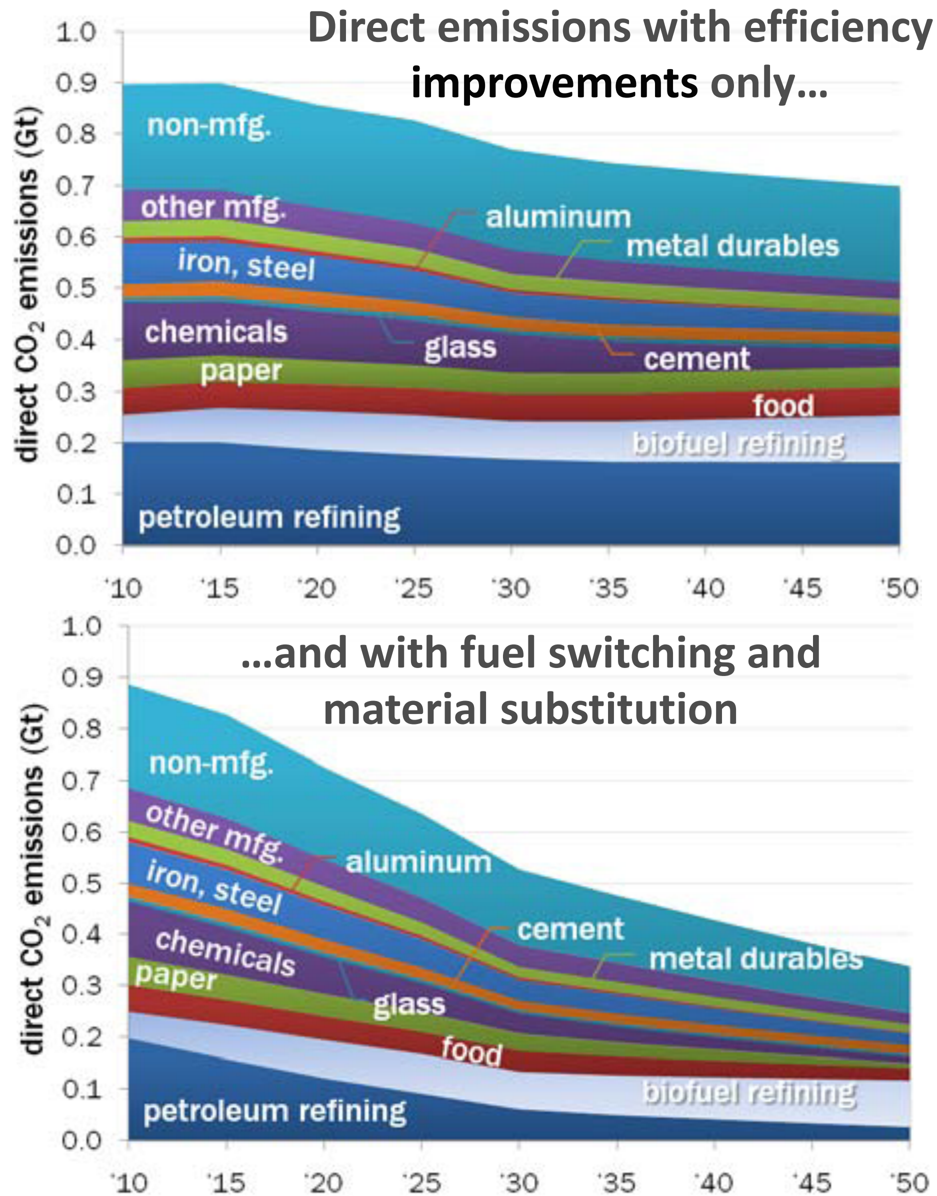

Example analysis based in part on bandwidth SOTA & PM potential, and EIA Annual Energy Outlook (AEO) forecast as baseline.

Use Intensity

Aluminum

btu/lb	primary	secondary
Current average	26,000	2,200
Practically achievable	20,000	925
Current savings potential	6,000 btu/lb Process improvement — Energy Intensity	1,275
Theoretical minimum	10,200	510

23,800 btu/lb Materials shift

Use Intensity

Energy Intensity e.g.:
Process efficiency
Process integration
Waste heat recovery

Carbon Intensity, e.g.:
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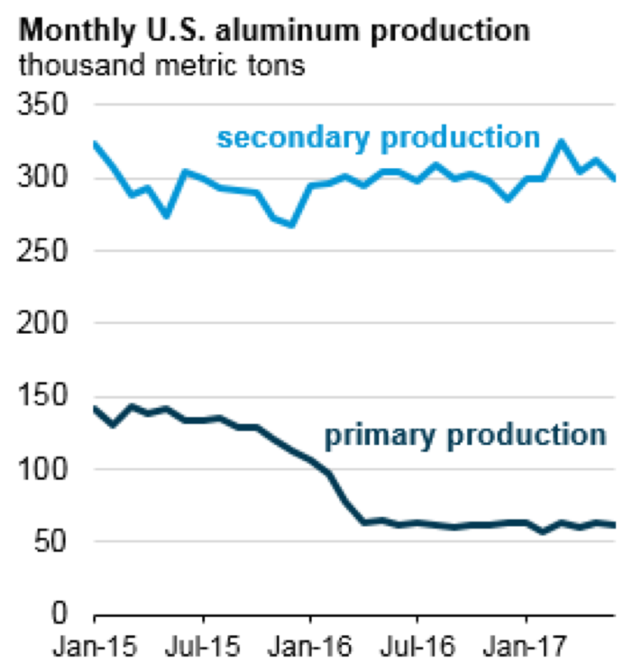
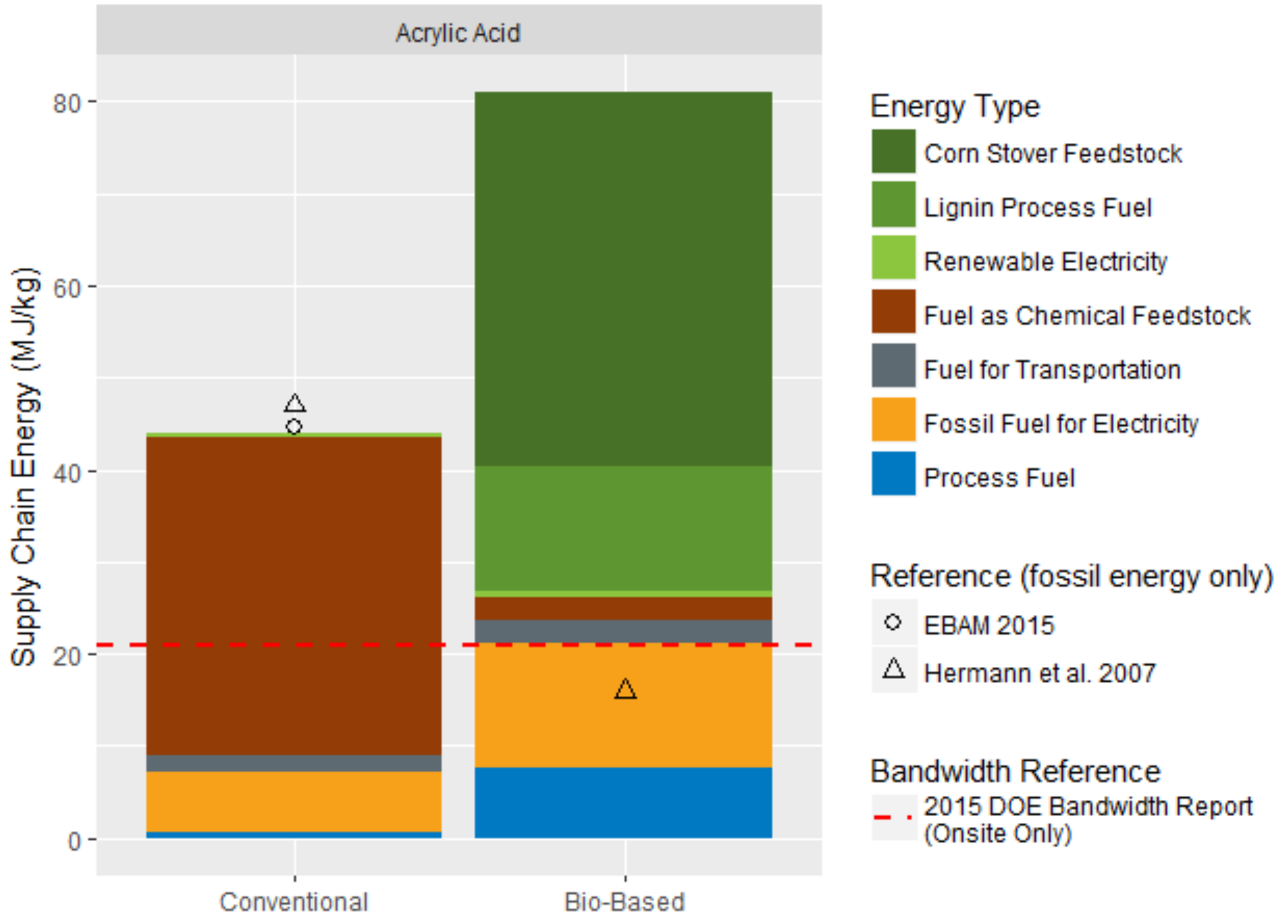


Fuels as Feedstocks: Chemical Bandwidth Extension Analysis to understand full supply chain implications

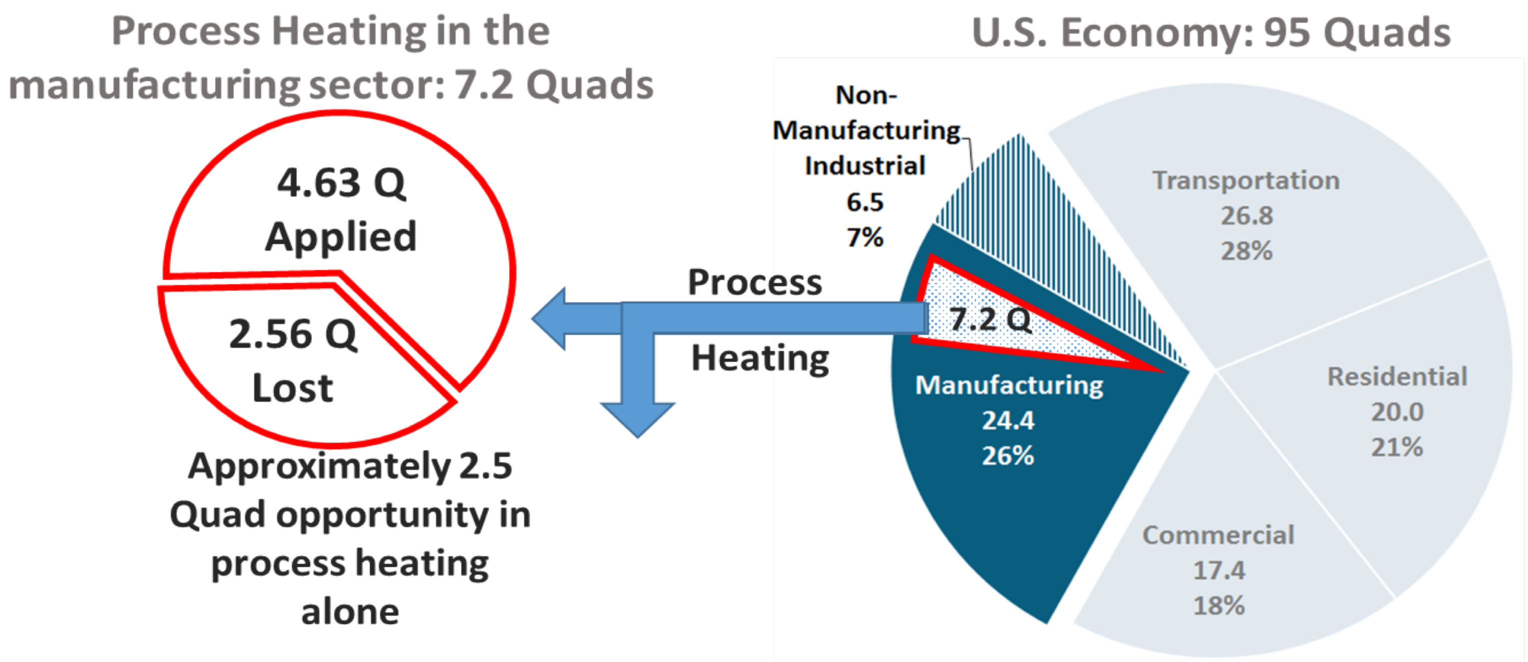
- **Goal 1:** Supply chain analysis based on 2015 DOE chemical sector energy bandwidth study
- **Goal 2:** Determine supply chain impacts associated with bio-based chemical production

- 73 fossil-based and 3 bio-based chemical supply chains analyzed using NREL's **MFI tool***
- Fossil **feedstock** energy is reduced by 80-90% in bio-based scenarios
- GHG emissions may be **higher** for some bio-based pathways, due to higher process fuel or electricity requirements



* https://www.nrel.gov/manufacturing/mfi-modeling-tool.html

Opportunities in process heating

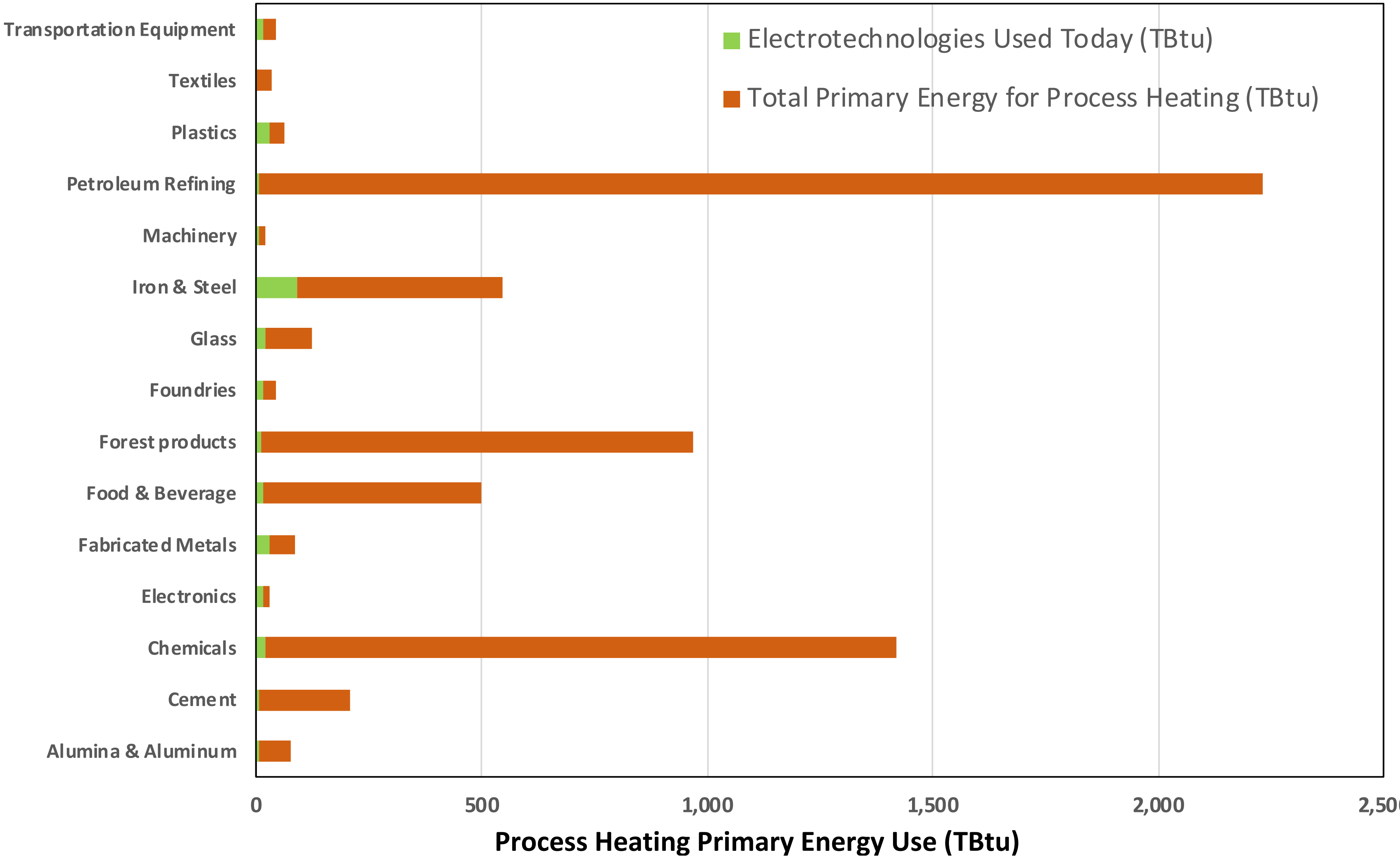


Source: EIA Monthly Energy Review, Aug 2014; AEO 2014

- **7 Quads**. Process heating accounts for a sizable fraction of total U.S. energy use, and more direct energy use than any other energy consuming processes in manufacturing.
- **95% fossil fuel based**.
- **Potential?** What is potential to avoid the 2.5 Q of energy losses and reduce the 4.6 Q of energy demand in process heating?
- **Opportunity for electrification?** Traditional industrial (thermal) processes can be inefficient, difficult to control and result in materials and products with compromised quality and performance.
- **Timeframe?** Can adoptions of electric arc furnaces; Hall-Herault for aluminum; induction melting & heat-treating; etc. inform future technology adoption/progression?

Use of Electricity for Process Heating in Different Industries

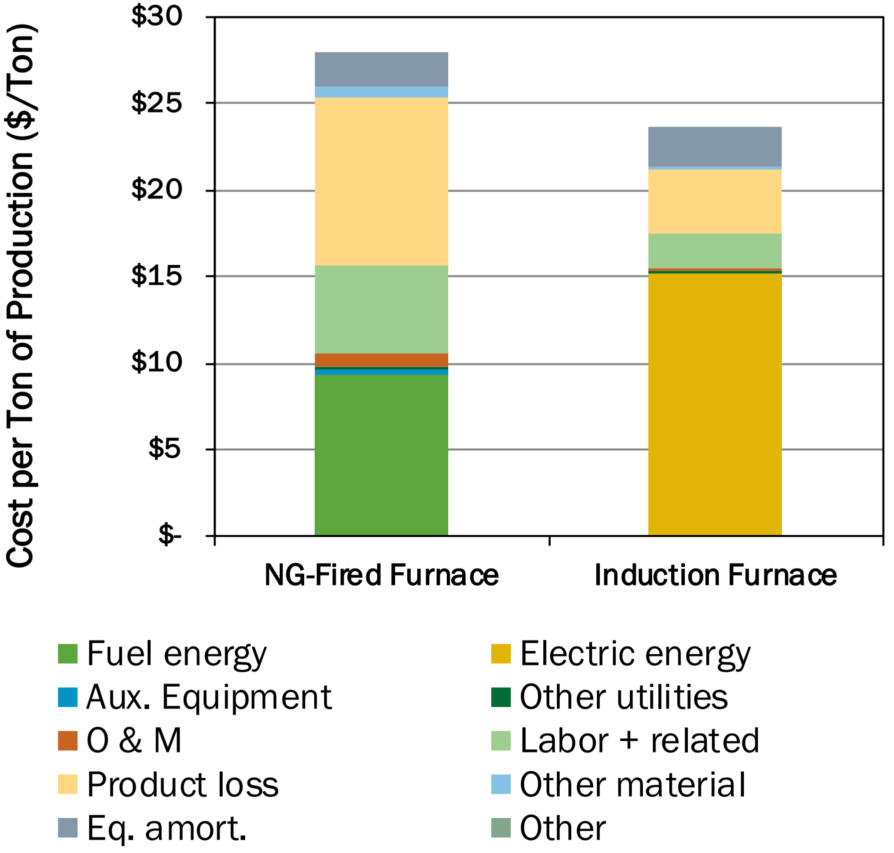
(Source: Manufacturing Energy Consumption Survey, Energy Information Administration, 2010)



Electrotechnologies Analysis Model and Case Studies

Study and Analysis Objectives

- Identify use of **current and emerging ETs** in process heating applications.
- Identify the **barriers to the large scale implementation** of ETs in the manufacturing sector
- **Quantify the economic and other benefits** from the use of ETs or hybrid systems at manufacturing process level for major industries.
- **Estimate of the national level impact** (i.e., increase in electricity use and production requirement) with application of ETs in all major industries.



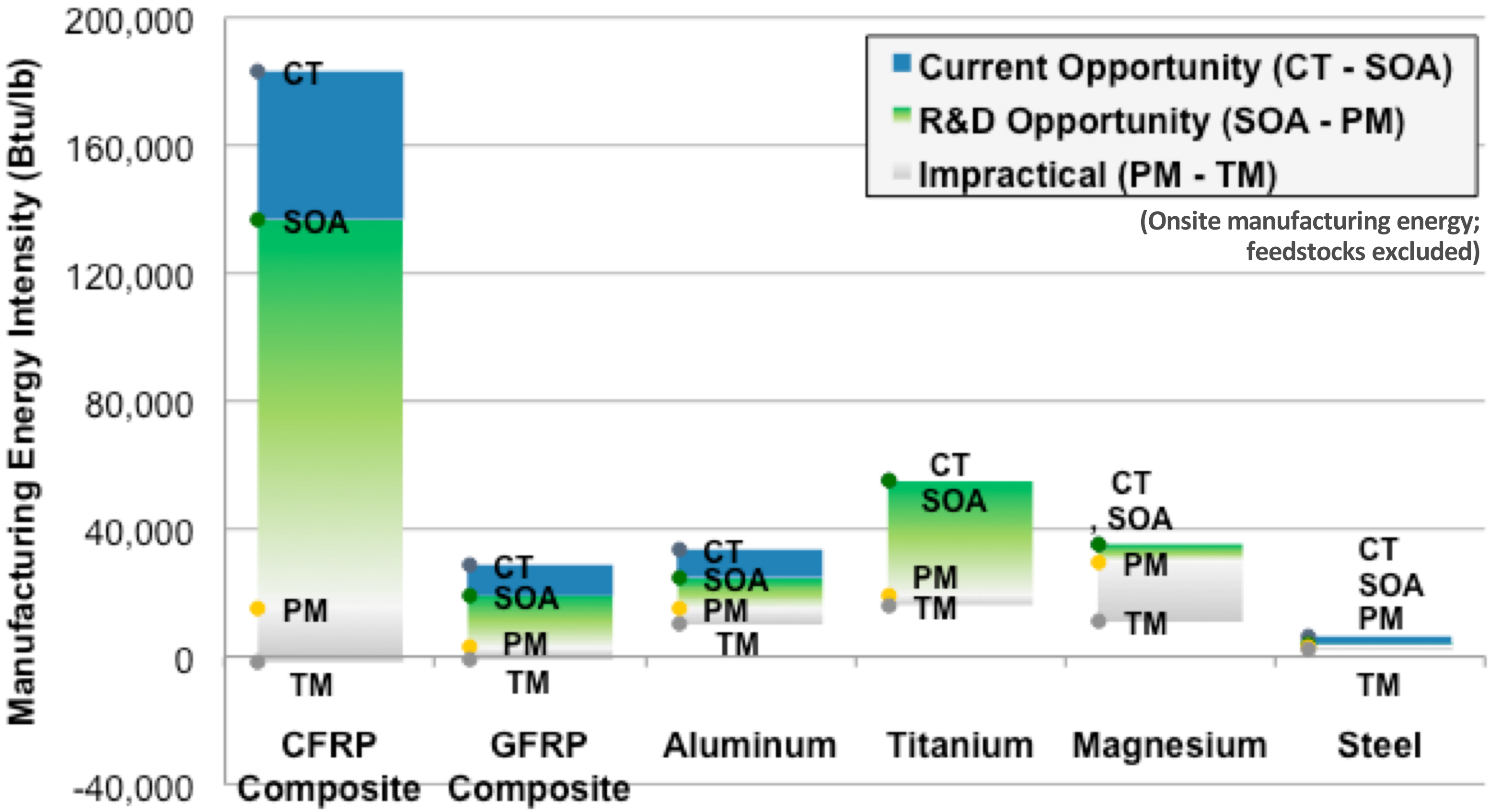
Preliminary - case study on NG-Fired Furnace vs Induction Furnace in a Forging Plant

Global Manufacturing Sector Energy Consumption by fuel type, 2015.

	Coal and coal products	Electricity	Natural gas	Oil products	Biofuels and waste	Other
World	31%	27%	20%	10%	7%	5%
United States	8%	25%	48%	4%	12%	2%
Canada	6%	36%	35%	6%	15%	2%
France	9%	36%	42%	6%	6%	0.4%
Germany	12%	35%	34%	5%	7%	8%
Italy	5%	38%	32%	11%	3%	11%
Japan	29%	32%	14%	20%	4%	0%
United Kingdom	9%	36%	32%	16%	4%	3%
China	57%	28%	4%	5%	0%	6%
Rest of World	19%	24%	25%	14%	13%	5%

Source: IEA World Energy Balances. Accessed September 2017.

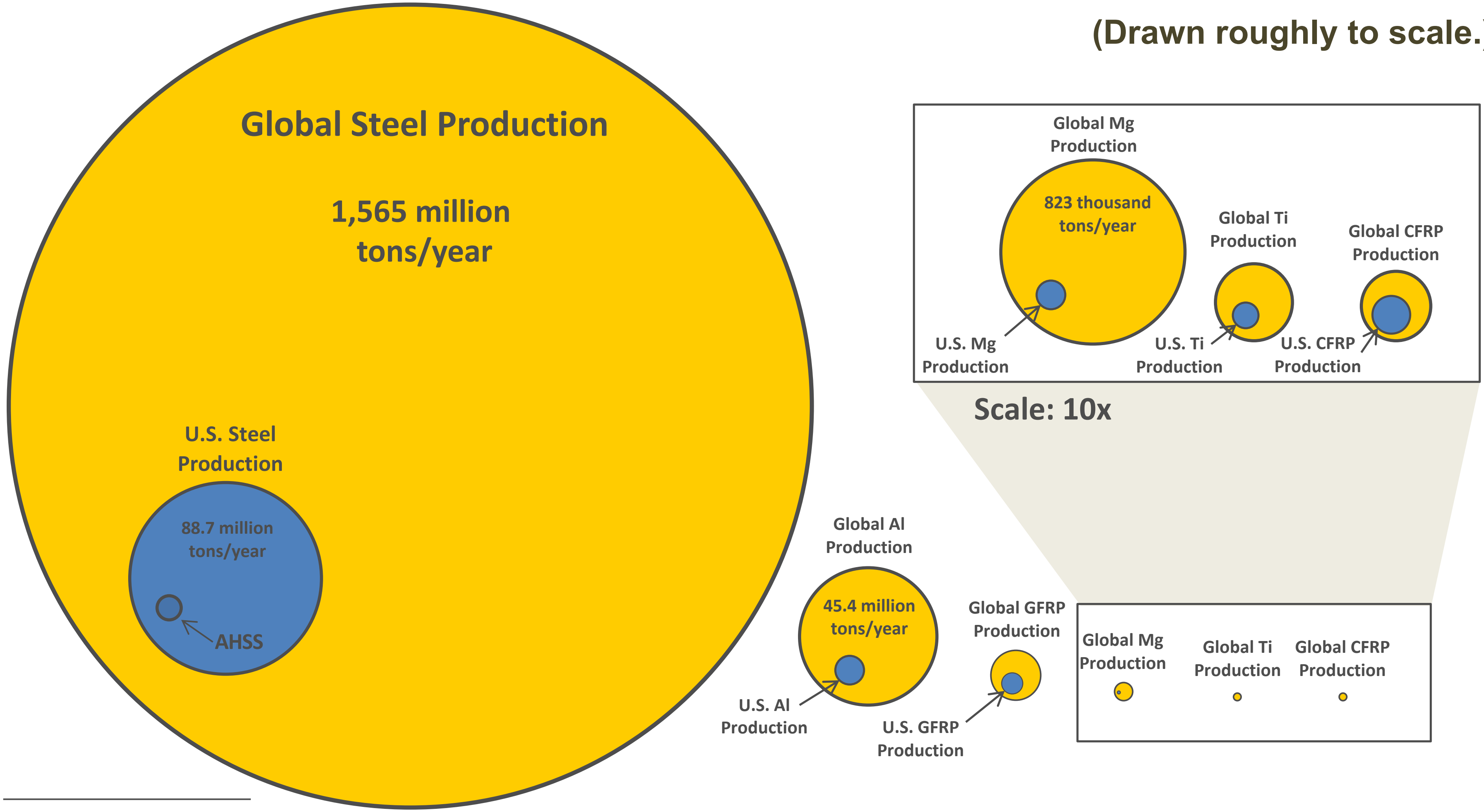
Looking forward - anticipate and address tomorrow's energy intensive materials with R&D today



CFRP composites have the highest manufacturing energy intensity, but with R&D advances could compete with incumbent materials on an energy/performance basis.

https://energy.gov/eere/amo/energy-analysis-sector

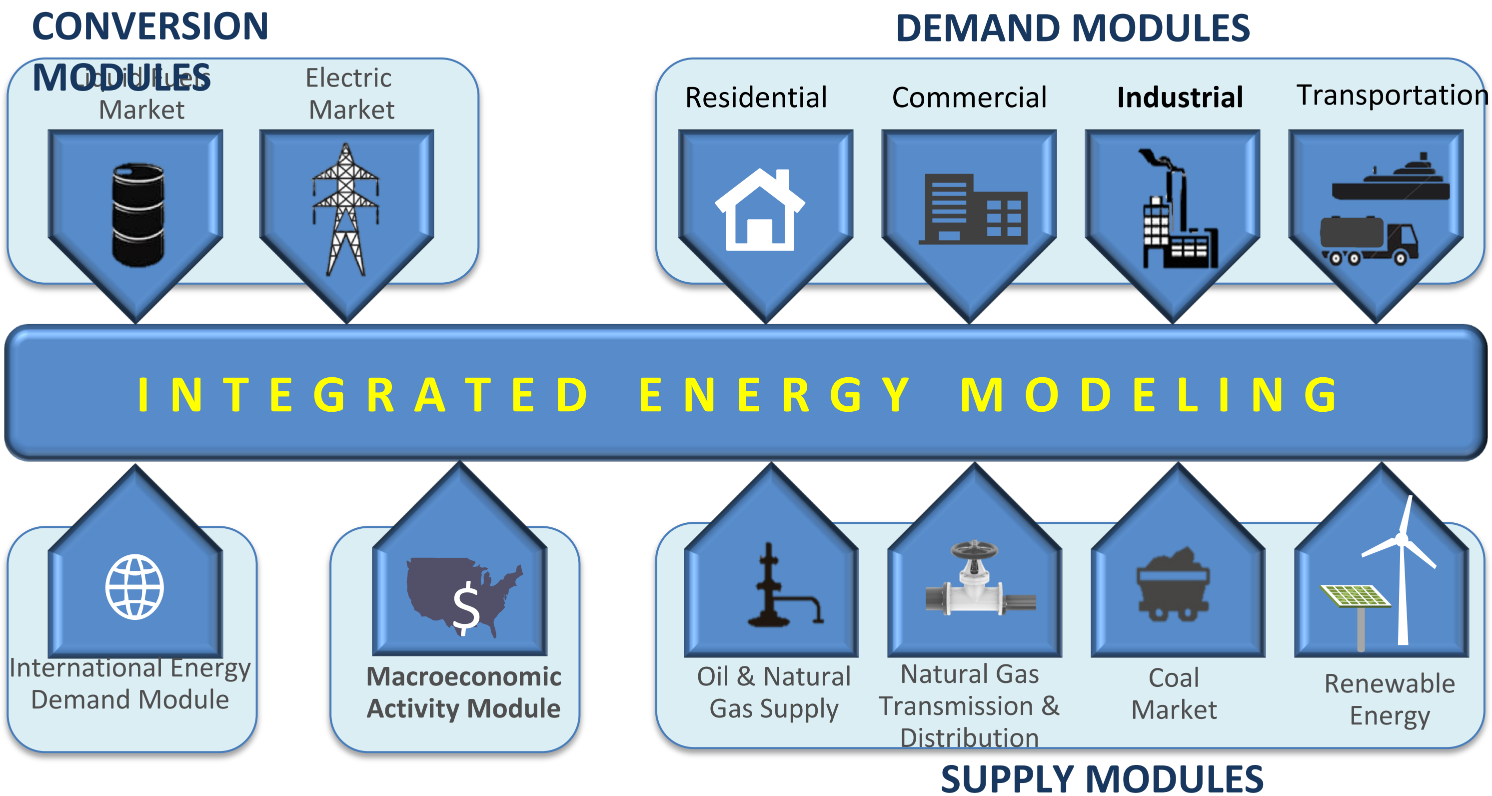
Context - Global and U.S. production of steel and lightweight materials (2010)



Steel: Global 1,565 million tons/year; U.S. 88.7 million tonnes/year
Aluminum: Global 45.4 million tons/year; U.S. 1.9 million tons/year
GFRP: Global 6.0 million tons/year; U.S. 1.1 million tons/year
Magnesium: Global 823 thousand tons/year; U.S. 21 thousand tons/year
Titanium: Global 146 thousand tons/year; U.S. 17 thousand tons/year
CFRP: Global 117 thousand tonnes/year; U.S. 33 thousand tonnes/year

National Energy Modeling System (NEMS)

NEMS is a simulation model of the U.S. energy system organized by energy producing, consuming, and conversion sectors.



- The Industrial Demand Module (IDM) estimates energy consumption by energy source (fuels and feedstocks) for 15 manufacturing and 6 non-manufacturing industries.
- Process energy is modeled in two different ways, either with technologies by process flow or by end uses using efficiency (TPC) curves

The Annual Energy Outlook (AEO) is based on NEMS

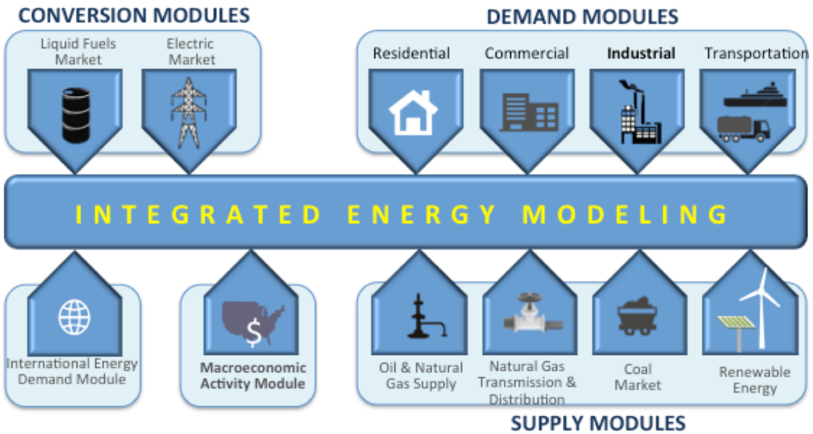
Examples of constraints/concerns with the industrial model:

- The Industrial Demand Module (IDM) provides very limited opportunities to shift to certain energy sources, e.g. electricity based technologies. There are no electric boiler options in the model.

- Technology choice (in processes) is only available for 5 major industries. *Cement & Lime (AEO2012), Aluminum (AEO2013), Glass (AEO2014) , Steel (AEO2016), Pulp & Paper (AEO2016)*

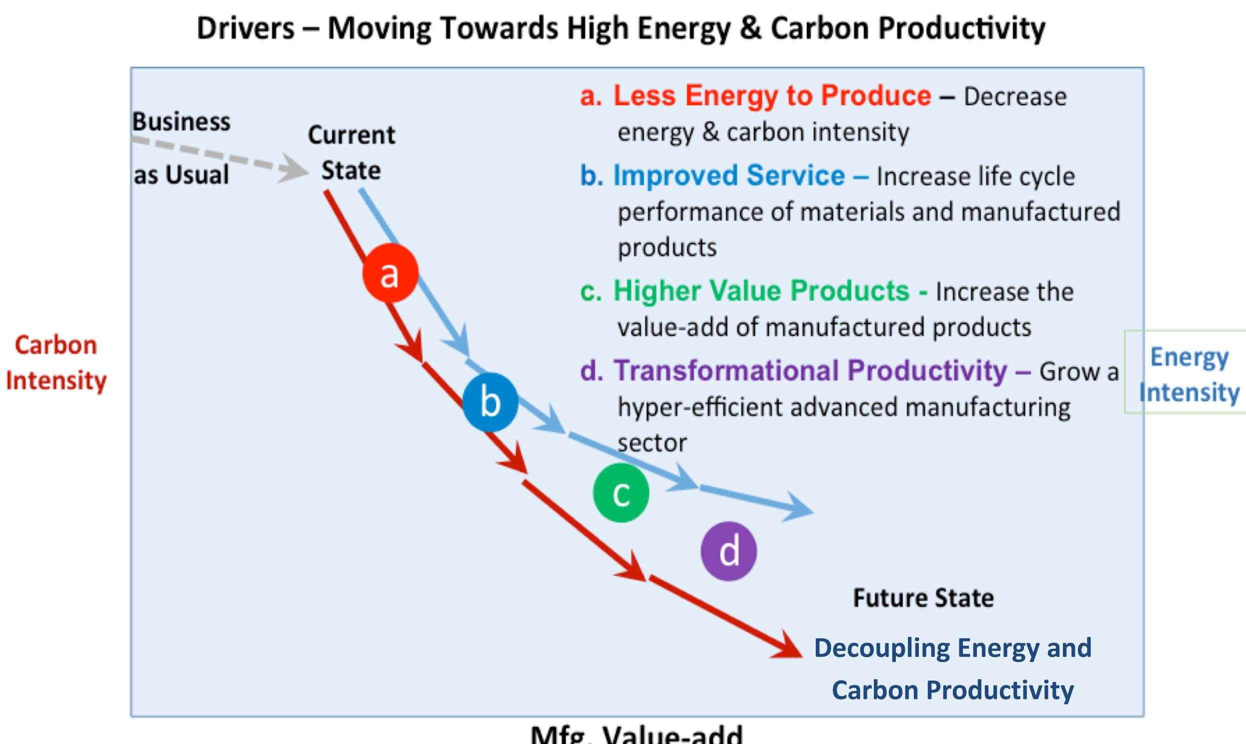
- Diagnostic cases have illustrated that for the fuel competition (among selected technologies), electricity prices have the greatest influence on technology shares, with a limited impact from the alternative-specific constants (‘forcing electricity’) and no significant impact from the cost of the technologies.

Do our current frameworks demonstrate a lack of vision?



Technology static over decades. Future structure largely based on current structure.

Pessimistic or pragmatic?



Future looks very different.

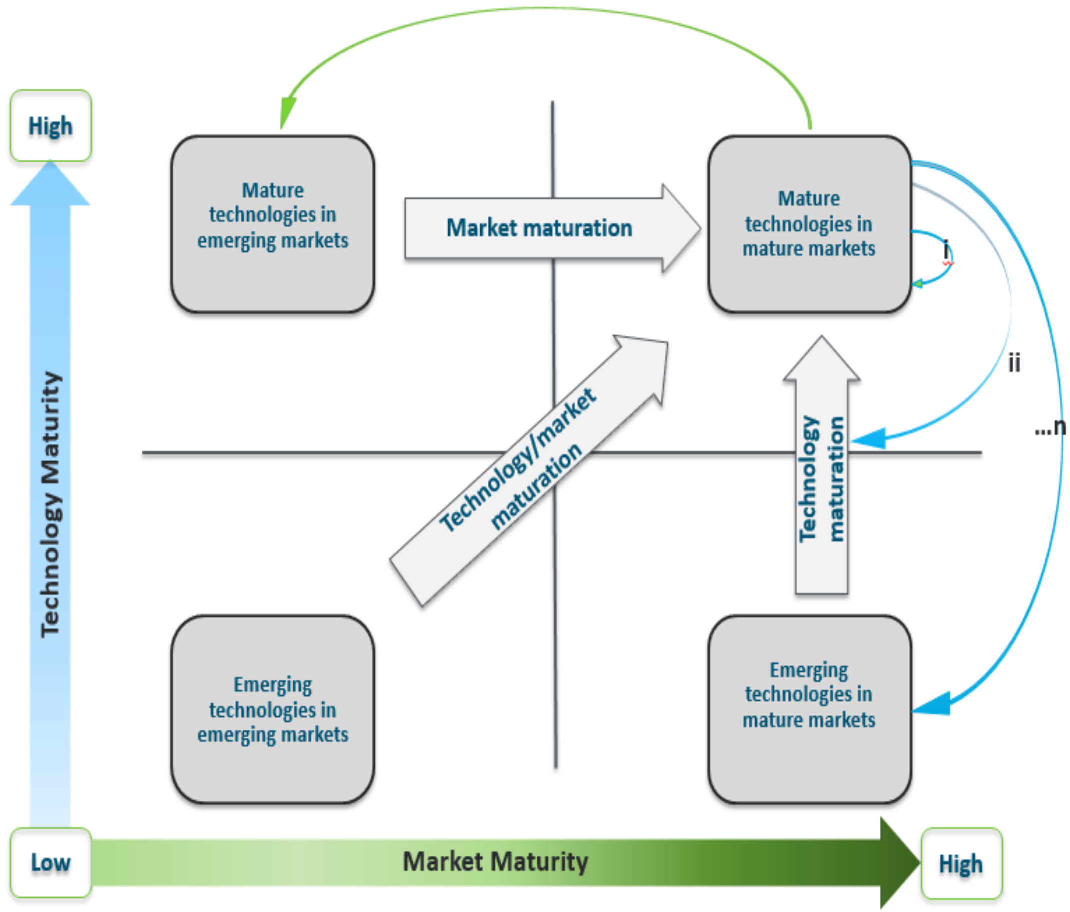
Optimistic or delusional?

Technology progression cycles

Physical science innovation timeline

Technology Stage	Timing
Theory	Decades
Fundamental research	Decades
Technology development	5–10 years
Proof of concept	1–2 years
Prototype	6 months
Alpha product	6–12 months
Qualification & manufacturing	12 months
Product extensions	2 years +

Survey of 116 firms New product cycle times (months)	
New-to-the-world	53.2
New product lines	36.0
Next generation improvements	22.0
Incremental improvements	8.6



Griffin, A. (2002). Product development cycle time for business-to-business products. *Industrial Marketing Management*, *31*(4), 291-304.
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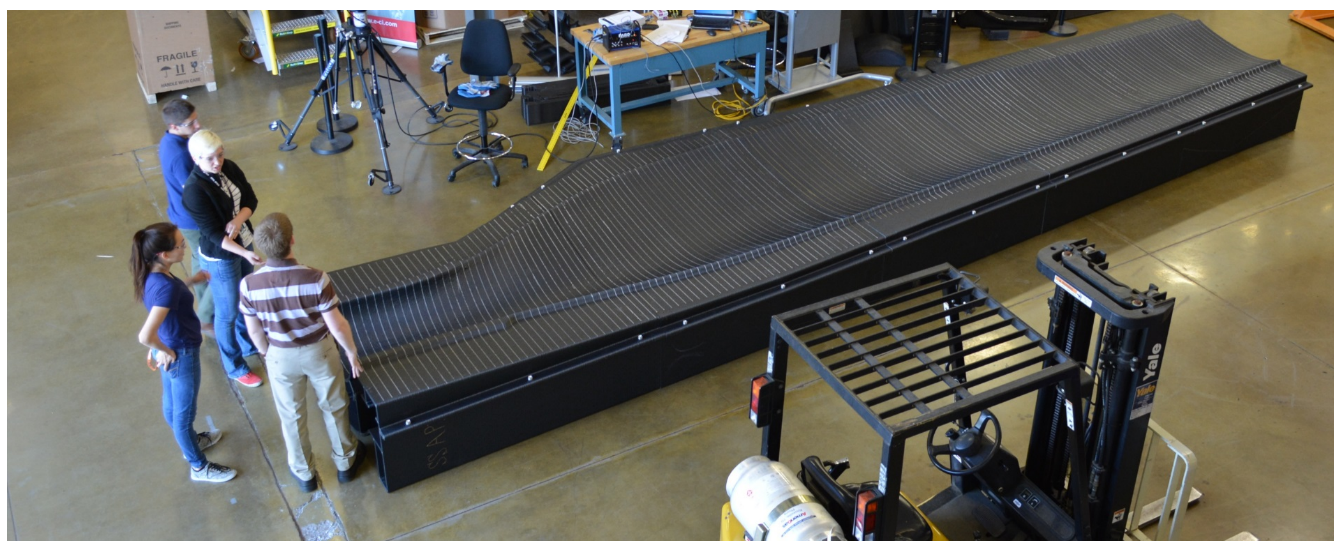
Technology Progression – Confluence of Additive/Composites Manufacturing Technologies

Big Area Additive Manufacturing (BAAM)

- **Obstacle:** Most additive processes are slow (1-4 in^3/hr), use higher cost feedstocks, and have small build chambers.
- **Solution:** ORNL has worked with equipment manufacturers and the supply chain to develop large scale additive processes that are bigger, faster, cheaper, and increase the materials used.

- **Large Scale Printers**
  - Cincinnati System 8'x20'x6' build volume
- **Fast Deposition Rates**
  - Up to 100 lbs/hr (or 1,000 ci/hr)
- **Cheaper Feedstocks: Pellet-to-Part**
  - Pelletized feed replaces filament with up to 50x reduction in material cost
- **Better Materials**
  - Higher temperature materials
  - Bio-derived materials
  - Composites Hybrids

Additive Manufacturing or Composites Manufacturing?

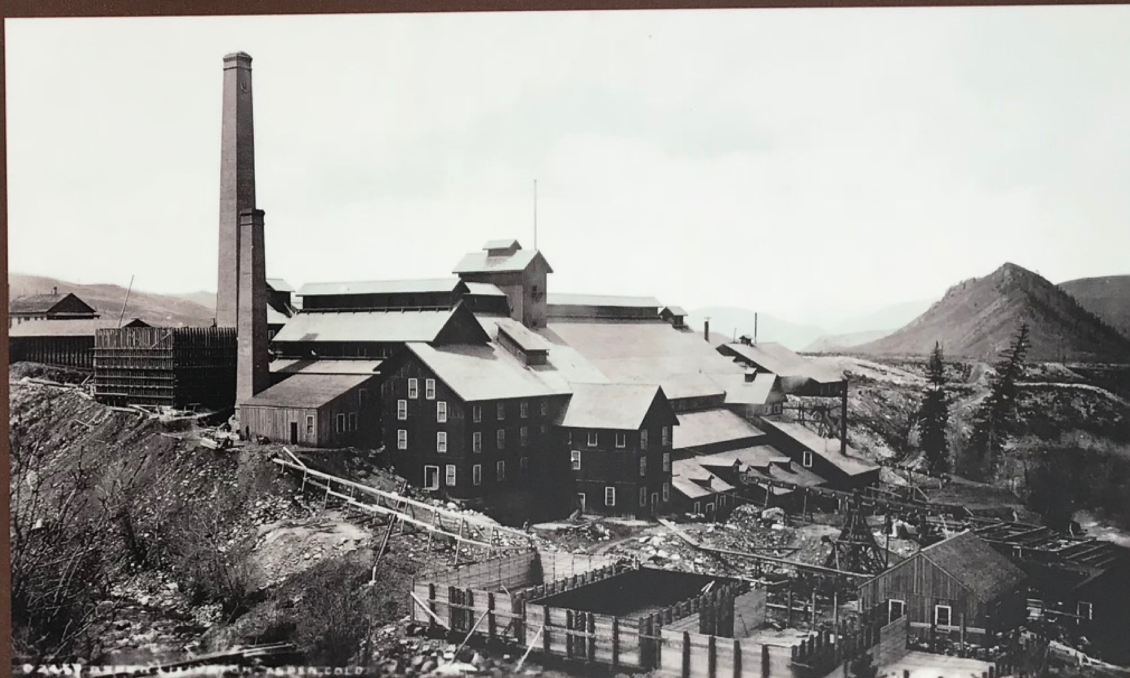


Shelby Cobra replica and tooling for wind turbine blade, printed via additive manufacturing at the DOE Manufacturing Demonstration Facility at ORNL

Opportunities for improved methods that can inform technology / policy options:

- Refined methods to account for technology choice and technology progression in large scale models (e.g. NEMS).
- Approaches to prioritize the next generation of industrial technologies based on life cycle energy and carbon productivity.
- Integrated analysis techniques that can assess a range of technology choices.

Aspen's big news in 1892 was the building of the Holden Lixiviation works on the west side of town. The newspaper declared that "the sweet day dreams of those who have longed to see Aspen a great city are about to be realized." Completed just 14 months before congress repealed the Sherman Silver Act, the plant never cleared a profit and went bankrupt almost immediately. It was one of only eighteen plants build world-wide to utilize the experimental Russell Lixiviation process to refine low grade ore.



Courtesy History Colorado

The Russell Lixiviation process used crushing, heat, and chemical salts to refine silver from ore as low grade as ten ounces per ton (Aspen ores averaged 400 to 600 ounces of silver per ton, but much low grade ore had to be discarded). The fumes from the plant's Stetefeldt furnaces were

2018

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Bandwidth Studies on Energy Use and Potential Energy Savings in U.S. Industrial Sectors

Visit: https://www.energy.gov/eere/amo/energy-analysis-data-and-reports

Sector (Year Published)	Link
Advanced High Strength Steels Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/AHSS_bandwidth_study_2017.pdf
Aluminum Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Aluminum_bandwidth_study_2017.pdf
Carbon Fiber Reinforced Polymer Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Carbon_fiber_bandwidth_study_2017.pdf
Cement Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Cement_bandwidth_study_2017.pdf
Chemical Manufacturing (2015)	https://www.energy.gov/sites/prod/files/2015/08/f26/chemical_bandwidth_report.pdf
Food and Beverage Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Food_and_beverage_bandwidth_study_2017.pdf
Glass Fiber Reinforced Polymer Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Glass_fiber_bandwidth_study_2017.pdf
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Iron and Steel Manufacturing (2015)	https://www.energy.gov/sites/prod/files/2015/08/f26/iron_and_steel_bandwidth_report_0.pdf
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Plastics and Rubber Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Plastics_and_rubber_bandwidth_study_2017.pdf
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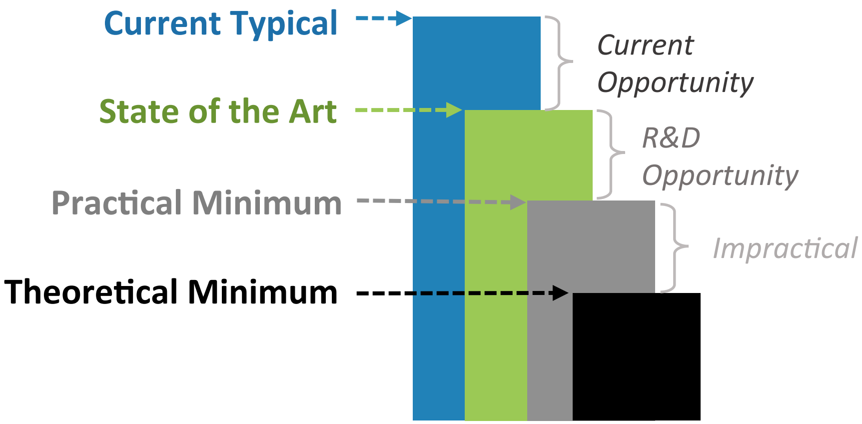
Seawater Desalination Systems (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Seawater_desalination_bandwidth_study_2017.pdf
Titanium Manufacturing (2017)	https://www.energy.gov/sites/prod/files/2017/12/f46/Titanium_bandwidth_study_2017.pdf

Assess energy savings opportunities within manufacturing….

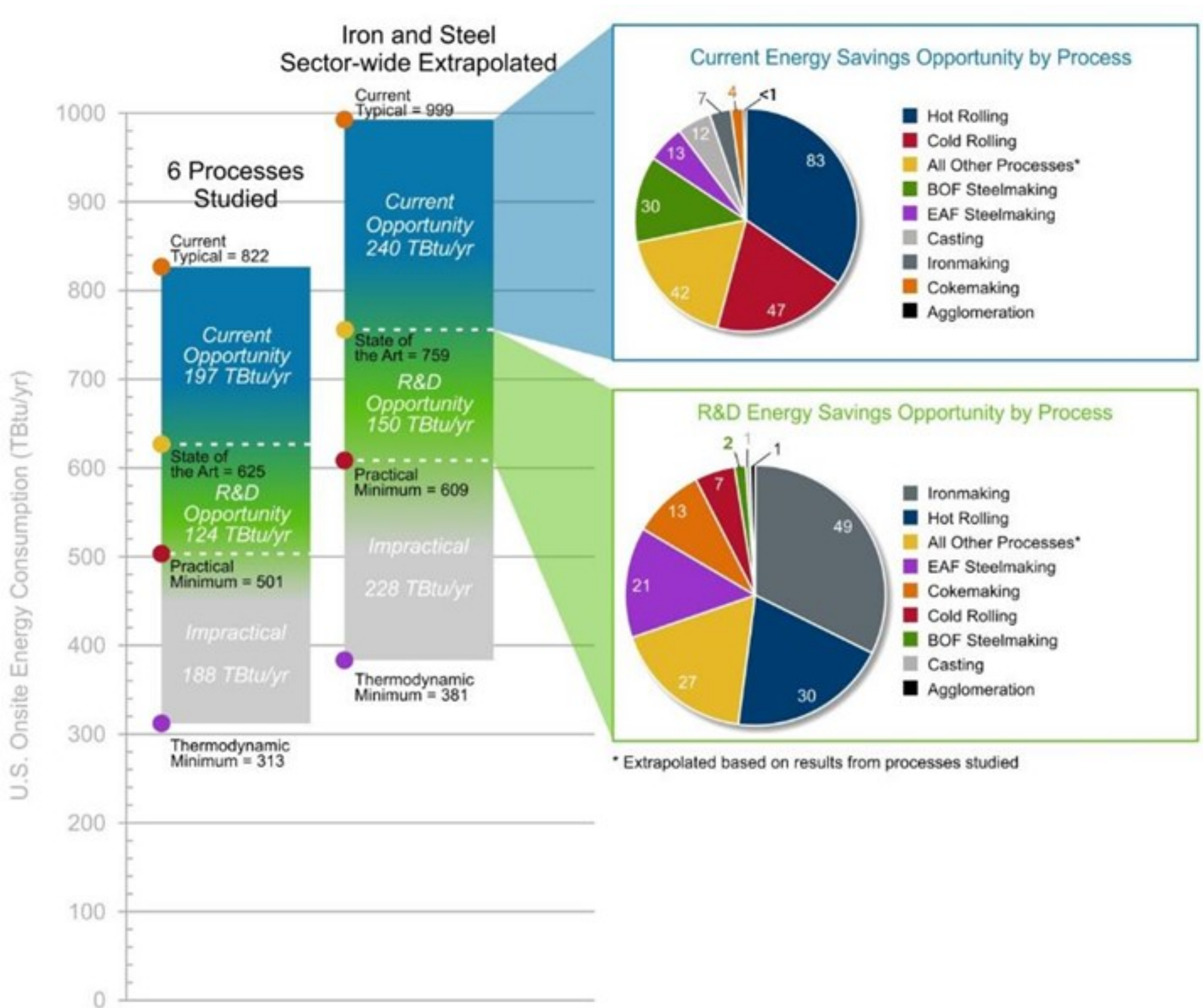
Energy bandwidth studies frame the range (or *bandwidth*) of potential energy savings in manufacturing, and technology opportunities to realize those savings.



Measures of energy intensity studied:

Current Typical (CT)	State of the Art (SOA)	Practical Minimum (PM)	Thermodynamic Minimum (TM)
Basis: Literature review and stakeholder outreach, based on current typical manufacturing processes in the U.S.	Basis: Literature review and stakeholder outreach, based on the most energy-efficient technologies and practices available worldwide	Basis: Modeled based on plausible energy savings from identified R&D technologies under development worldwide	Basis: Calculated analytically using a Gibbs free energy approach assuming ideal conditions

Technical Energy Savings Opportunities: Iron & Steel Industry 2015 Bandwidth Study – potential by major process area



Source: DOE/AMO, Iron & Steel Industry Energy Bandwidth Study (2015)

Note: 1 quad = 1000 TBtu

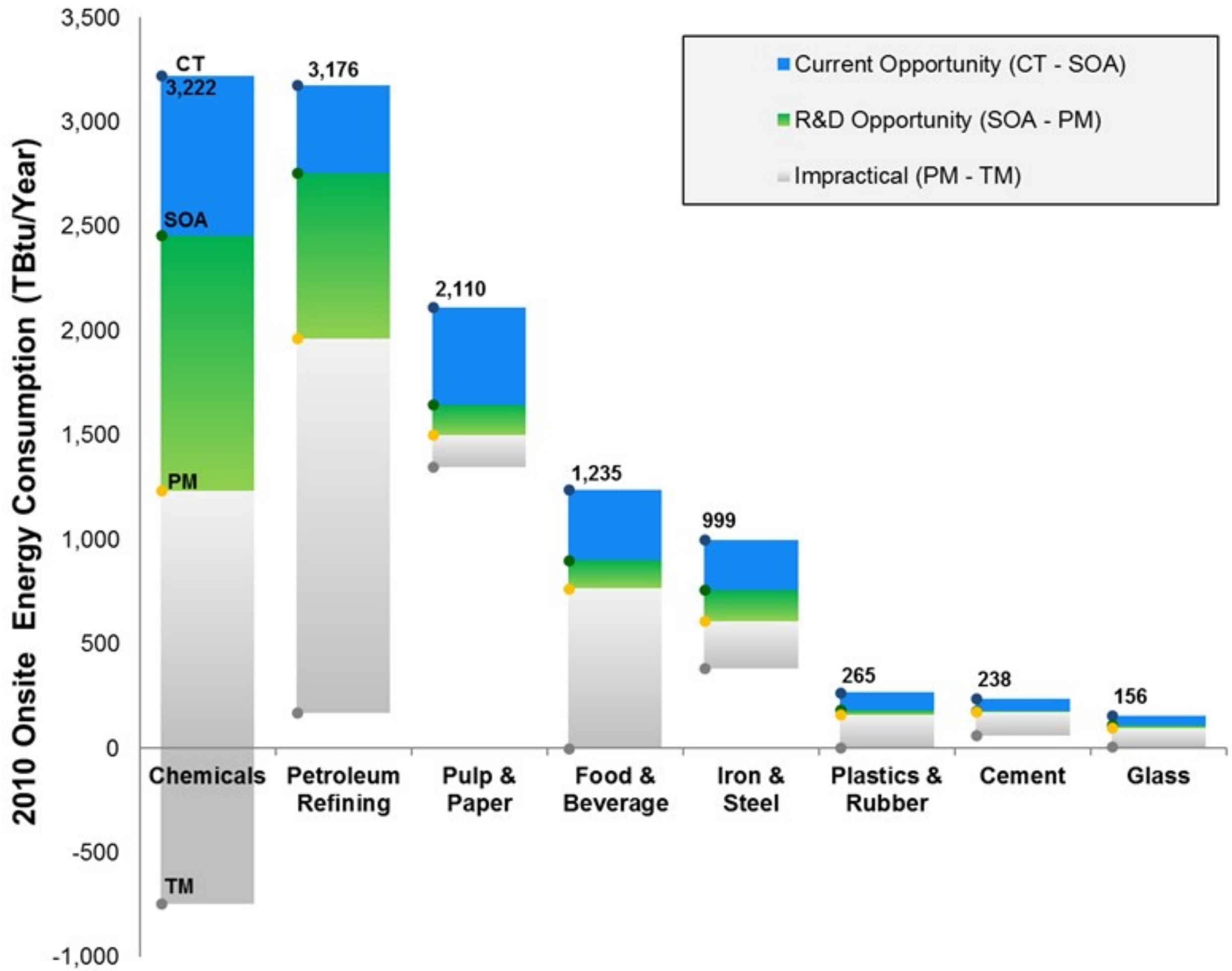
… for potential energy improvements.

Energy Intensity e.g.:
Process efficiency
Process integration
Waste heat recovery

Carbon Intensity, e.g.:
Process efficiency
Feedstock substitution
Biomass-based fuels
Renewables

Use Intensity e.g.:
Circular economy Design for Re-X (recycling, reuse and remanufacturing)
Material efficiency and substitution

Technical Energy Savings Opportunities:



Source: DOE/AMO, Energy Bandwidth Studies (2015, 2017)
Note: 1 quad = 1000 TBtu

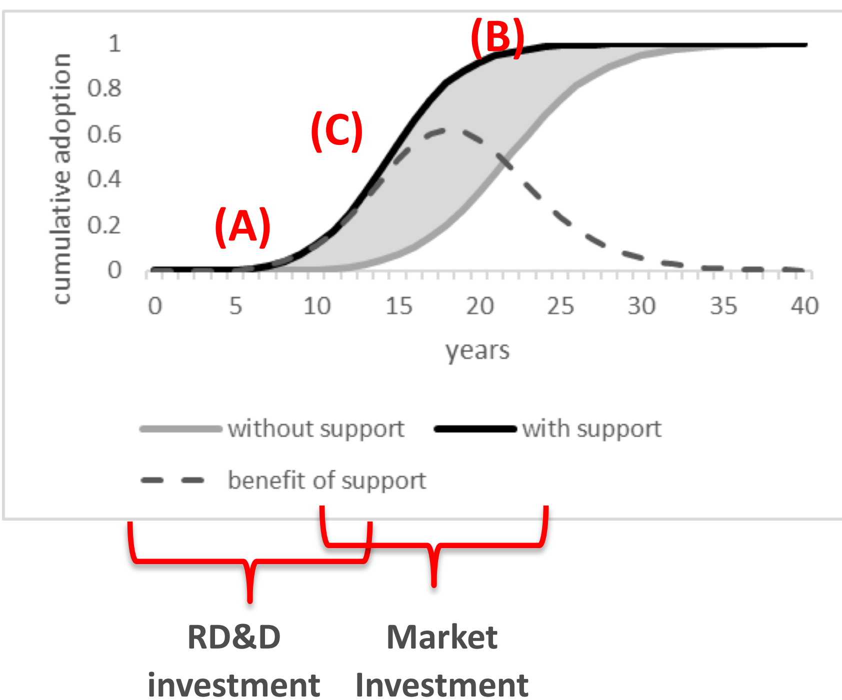
Technology Adoption Back-up Slides

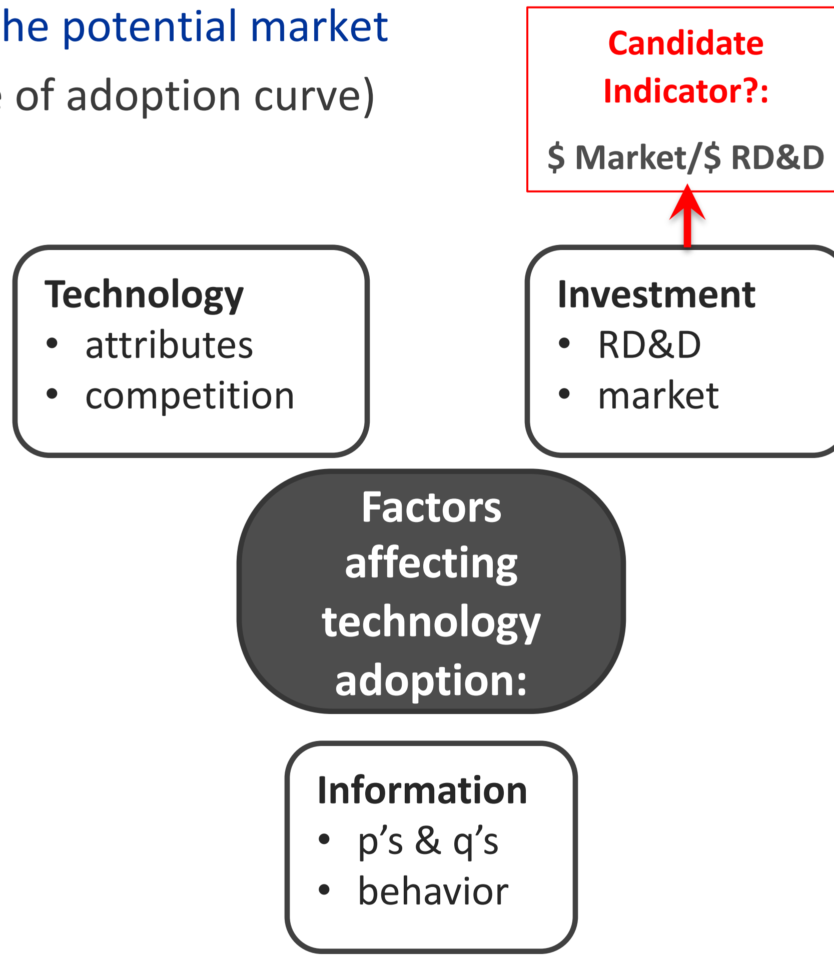
What we have done up to now: technology adoption w./energy focus

(A) Adoption start time (when technology will be introduced into market)
- RD&D process
- Technology and manufacturing readiness

(B) Full adoption level
- Total size of potential market determined on a technology-by-technology basis
- Technology may only capture a portion of the potential market

(C) Adoption trajectory (adoption speed and shape of adoption curve)
- Linear
- Bass diffusion & variants

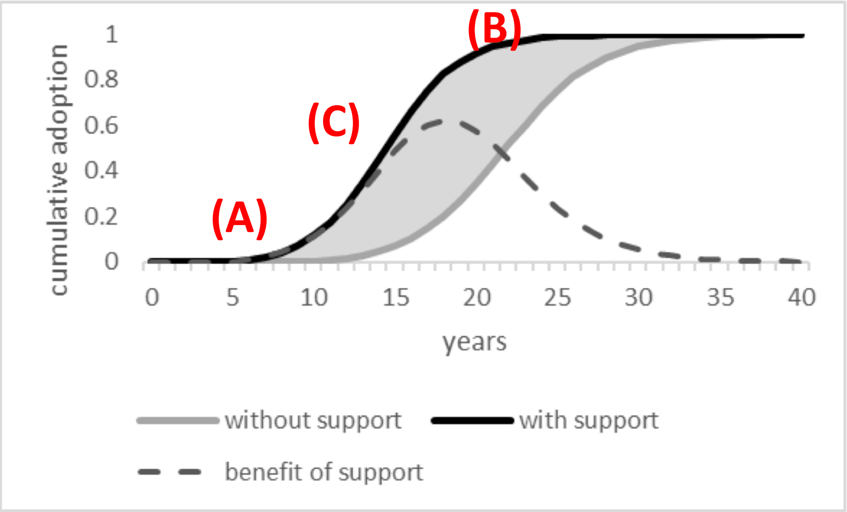




(A) Adoption Start time

Factors influencing concept-to-commercial time

- Technology complexity
- Technical difficulty
- Project “newness”
- Development process
- Co-development w/customers, suppliers
- Financial and regulatory support



Survey of 116 firms New product cycle times (months)	
New-to-the-world	53.2
New product lines	36.0
Next generation improvements	22.0
Incremental improvements	8.6

Source: [2]

Physical science innovation timeline

Technology Stage	Timing
Theory	Decades
Fundamental research	Decades
Technology development	5–10 years
Proof of concept	1–2 years
Prototype	6 months
Alpha product	6–12 months
Qualification & manufacturing	12 months
Product extensions	2 years +

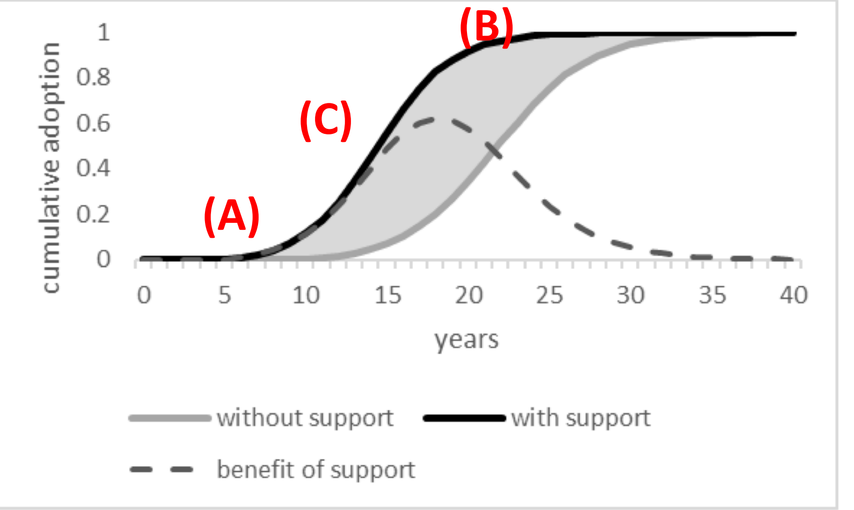
Source: [3]

TRENDS FROM PRIOR DATA: studies of adoption speeds

fast adoption	adoption time	medium adoption	adoption time	slow adoption	adoption time
Hybrid corn	6.0	Video game	17.6	Blender	32.6
Conversion to 70% H2O2 delivery systems	6.0	Digital watch	18.3	Radio	33.5
Continuous bleach ranges	6.2	Chain hotels	18.4	Tecorder (software): tape	33.5
CT Head Scanner	7.3	Water softeners	18.5	Airplane piston	34.4
CT Body Scanner	7.6	Cellular phone	18.6	Recorder (software): LP	35.2
Personal computer: specific technologies	8.4	Power lawn mowers	19.0	Heating pad	36.5
Rapid bleach process	8.8	Advanced compressors	19.6	Tire cord materials	37.1
DRAM technologies	9.1	Calculator	20.3	Shaver	38.2
Recover players	9.2	Can opener	20.9	Metal beer can	38.4
Hard drive technologies	9.8	Electric knife	21.1	Airplane turbine	40.8
Mainframe technologies	10.8	T-8 lamps	22.2	Waste disposal	45.0
McDonalds	11.5	VCR	22.4	Recorder: turntable	45.2
TV: color	12.2	Variable valve vehicle drive	22.8	Detergent: natural	48.9
Flame retention burner	12.3	Aluminum soft drink can	24.4	Freezer	49.9
Mammography	13.1	Recorder (software): CD	25.2	Broiler	50.3
Electric heat pump	14.1	CD Player	25.3	Oil cracking: thermal	52.9
Low-E windows	14.2	Automatic coffee makers	25.5	Microwave	55.4
Food processor	15.2	Condensing gas furnace	26.0	Mixer	55.4
Steam irons	15.3	Electric bed coverings	26.8	Dishwashers	56.1
DOE-2 Building model	15.4	Home freezers	28.0	Detergent: synthetic	56.3
Trash compactor	15.6	Vacuum cleaner	28.0	Compact fluorescent	67.5
Electronic ballasts	16.2	Metal soft drink can	28.4	Oil cracking: catalytic	73.3
Ultrasound	16.4	PC	28.8	Oil cracking: hydro	90.7
Electric range	16.5	Cassette deck	29.2	Clothes Washer	91.2
Floppy drive technologies	16.8	Aluminum beer can	29.6	Steel: Bessemer	91.7
Room air conditioners	17.0	TV: black-and-white	30.2	Steel: Electric	106.1
Boat trailers	17.5	Multivalve vehicle drive	30.5	Steel: Open hearth	125.4
Clothes dryers	17.5	Refrigerators (electric)	31.2	Fluorescent lamp	129.2

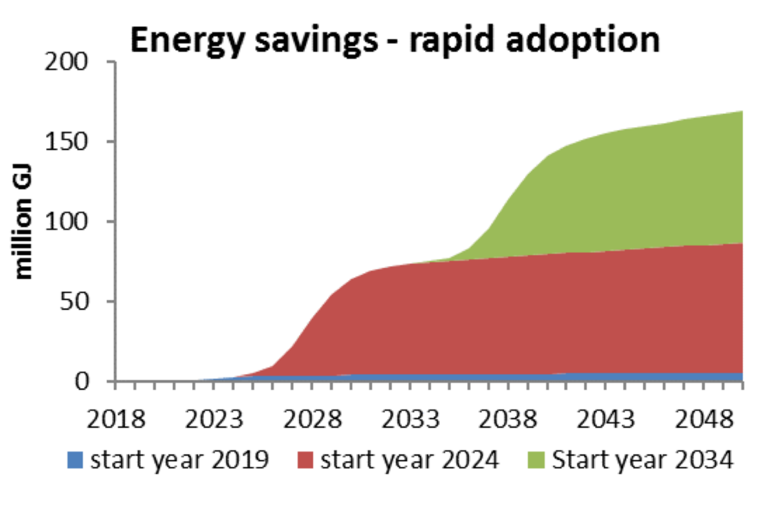
Adoption times are years to reach 95% adoption, calculated based on p and q estimates from sources [7, 9-15]

(B) Full adoption level



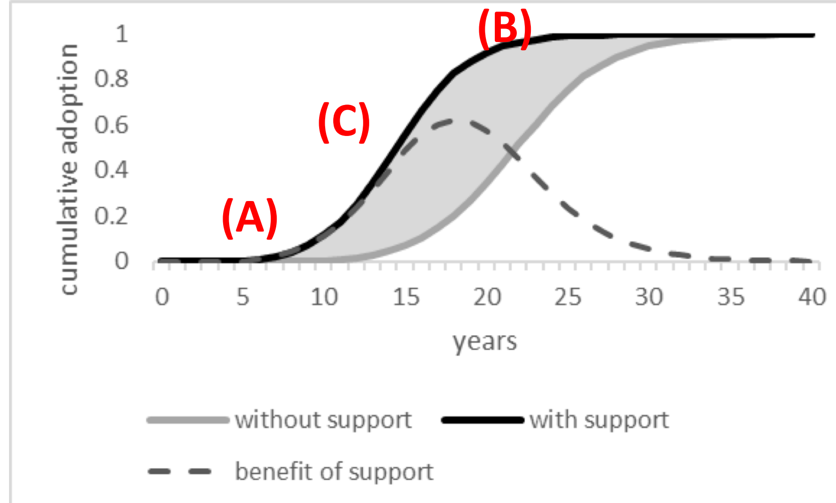
Additive manufacturing (AM) of airplane parts [4]

- Determine number and weight of airplanes in market
- Evaluate airplane parts to determine applicability of AM technology based on
  - Materials used
  - Load rating
  - Shape complexity
  - Volume
- Compare with competing technologies
  - Carbon fiber
  - Lightweight metals



Component systems	*Component category*	Mass fraction
Wing	*Structural*	0.23
Wing	*Auxiliary*	0.01
Body	*Structural*	0.18
Body	***Auxiliary***	0.01
Galley & Lavatory	***Structural***	0.03
Floor panels, other	***Structural***	0.02
Seats	***Functional***	0.07
Engine	*Structural*	0.02
Engine	***Functional***	0.09
Engine	***Auxiliary***	0.01
Alighting gear	*Structural*	0.09
Alighting gear	*Auxiliary*	<0.01
Tail systems	*Structural*	0.04
Tail systems	*Auxiliary*	<0.01
Propulsion systems	***Functional***	0.04
Nacelle systems	*Structure*	0.04
Nacelle systems	***Auxiliary***	<0.01

(C) Adoption Trajectory: Adoption Speed



Diffusion of Innovations [5]

- Relative advantage
- Compatibility
- Complexity
- Trialability
- Observability

Technology attributes [6] characterizing:

- Relative advantage
- Technical context
- Information context

	Characteristics	Attributes			
Relative advantage	Internal rate of return	Low (<10%)	Medium (10–30%)	High (>30%)	
	Payback period	Very long (>8 years)	Long (5–8 years)	Medium (2–4 years)	Short (<2 years)
	Initial expenditure	High (>10% of invest. budget)	Medium (0.5–10% of invest. budget)	Low (<0.5% of invest. budget)	
	Non-energy benefits	Negative	None	Small	Large
Technical context	Distance to core process	Close (Core process)	Distant (Ancillary process)		
	Type of modification	Technology substitution	Technology replacement	Technology add-on	Organizational measure
	Scope of impact	System (system-wide effects)	Component (local effects)		
	Lifetime	Long (>20 years)	Medium (5–20 years)	Short (<5 years)	Not relevant
Information context	Transaction costs	High (>50% of initial expenditure)	Medium (10–50% of initial expenditure)	Low (<10% of initial expenditure)	
	Knowledge for planning and implementation	Technology expert	Engineering personnel	Maintenance personnel	
	Diffusion progress	Incubation (0%)	Take-off (<15%)	Saturation (>85%)	Linear (15–85%)
	Sectoral applicability	Process related	Cross cutting		

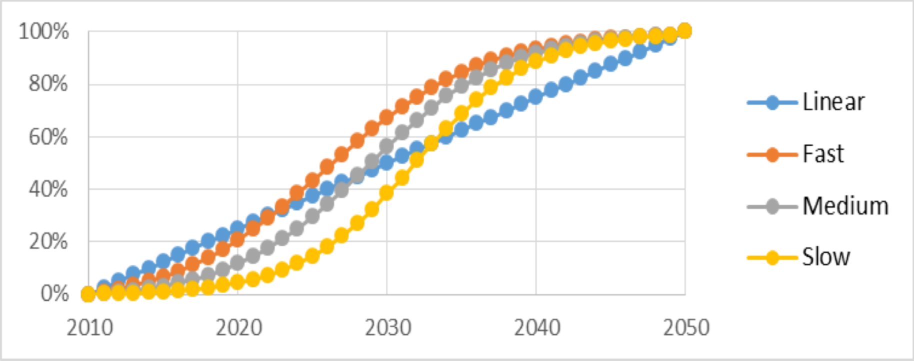
Lower adoption rate — Higher adoption rate

Table adapted from: Fleiter, T., Hirzel, S., & Worrell, E. (2012). The characteristics of energy-efficiency measures–a neglected dimension. *Energy policy*, *51*, 502-513.

Adoption trajectory: Bass curve

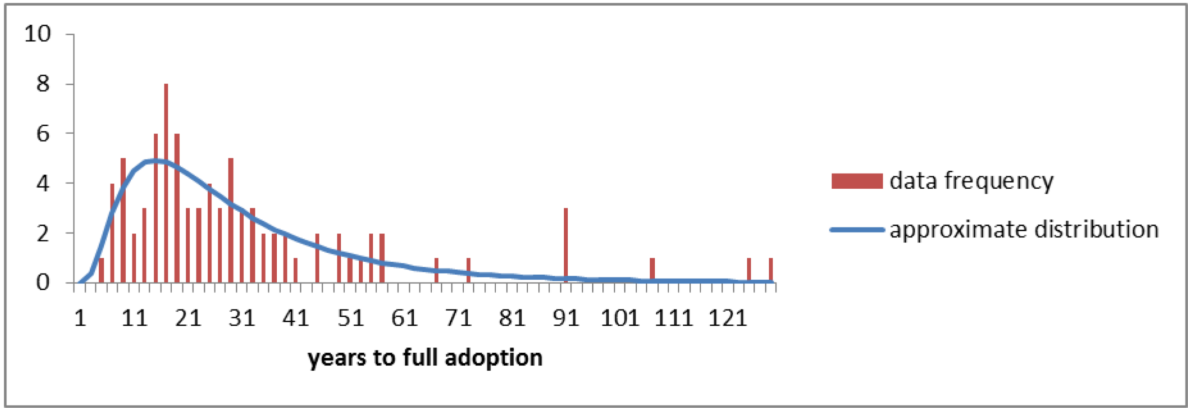
- Shape of Bass curve determined by two parameters
  - p: coefficient of innovation determines early adoption speed
  - q: coefficient of imitation determines speed after initial adoption

- Alternative way of specifying Bass curve: time to 'full adoption' vs. shape parameter q/p
  - In LIGHTEn UP, Bass adoption is implemented by allowing the user to specify the time to full adoption, and providing three options for the shape parameter q/p: slow, medium, and fast
  - Slow, medium, and fast values for q/p selected based on ranges of q's and p's collected from the technology diffusion literature



Predicting technology adoption from limited data: using prior data from other technologies

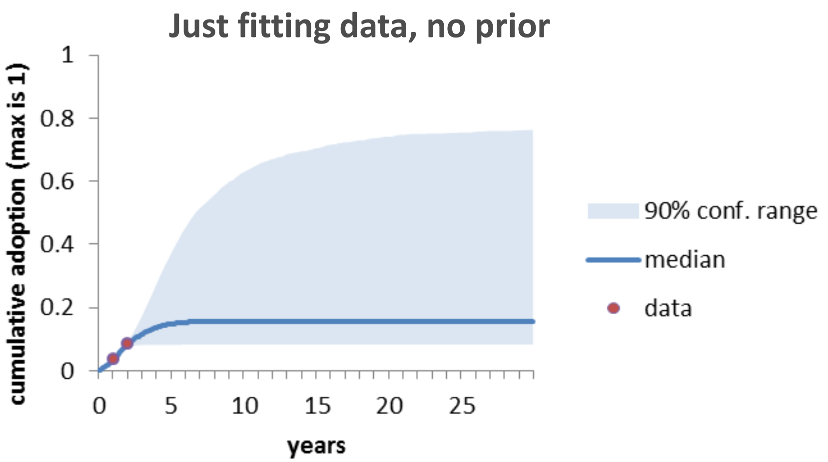
- Prior data analysis:
  - Obtained estimates of q and p from variety of data sources [7, 9-15]
  - Calculated years to 95% adoption using q and p estimates

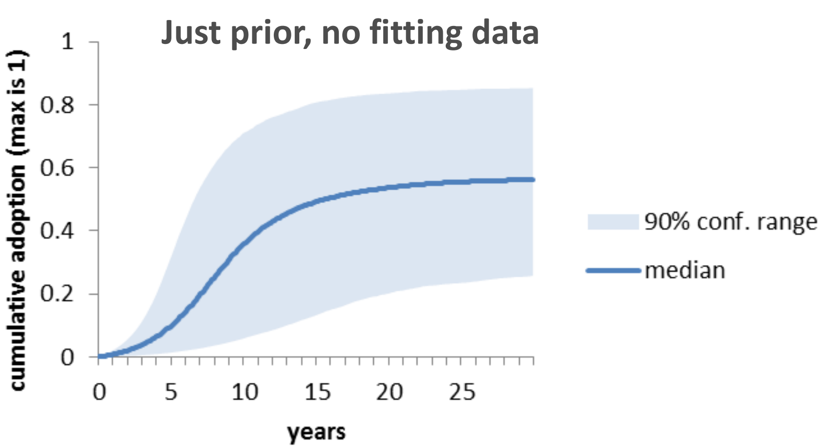


- Prior data informing q and p - match technology with similar existing technologies for which recent data are available
  - Similar technology
    - Example: variable speed drive for pumps, fans, compressors
  - Similar technology characteristics
    - Example: Distance to core process - close (reactive distillation : microwave enhanced cracking)
    - Example: Type of modification - technology substitution (composite turbine blades : permanent magnet turbine generators)
- Option: metamodel of existing studies to choose adoption speed for a new technology based on values of selected characteristics (e.g. relative advantage, distance to core process)

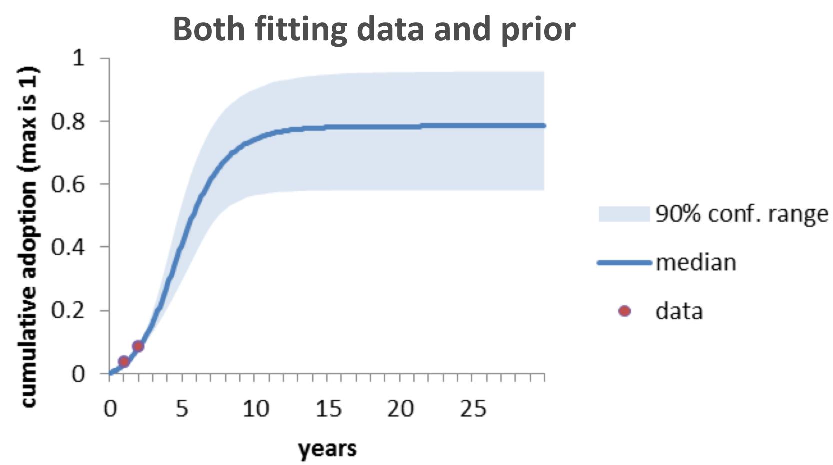
predicting technology adoption from limited data: using early adoption data

- Bayesian approaches combine data fitting with knowledge about likely parameter ranges



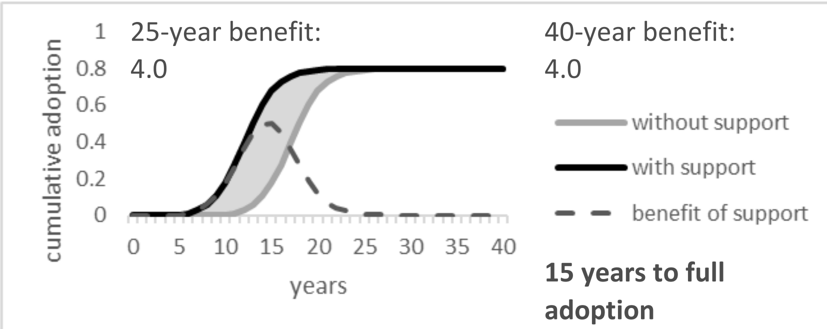


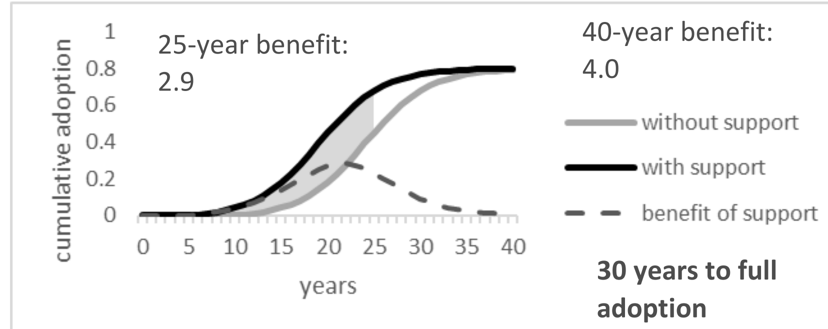
Assumptions: priors drawn from
p ~ N(0.011, 0.013)
q ~ N(0.45, 0.30)
m ~ N(0.57, 0.24)
std. dev. of error in fitting data = 0.01



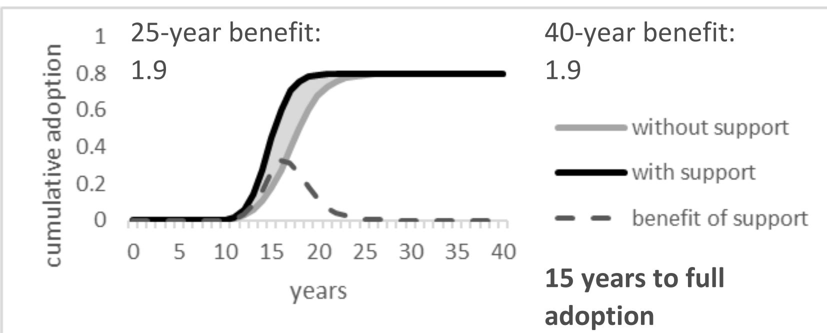
Notional Policy Impacts on Technology Adoption

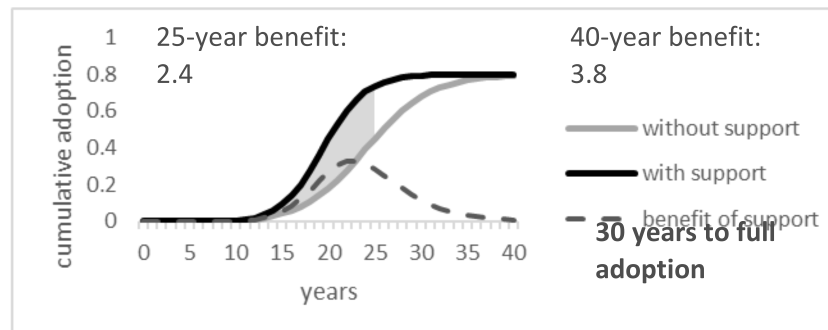
• Accelerate start time by 5 years



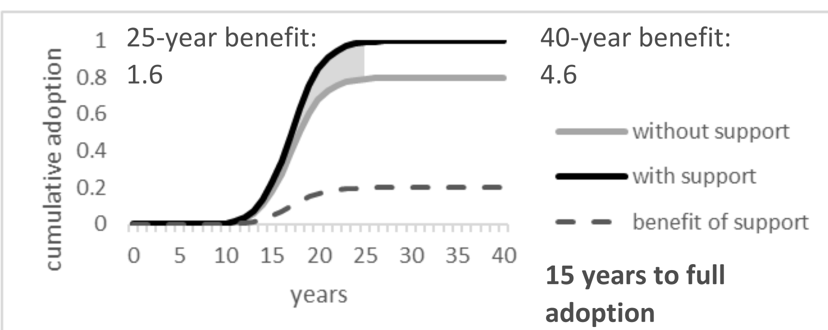


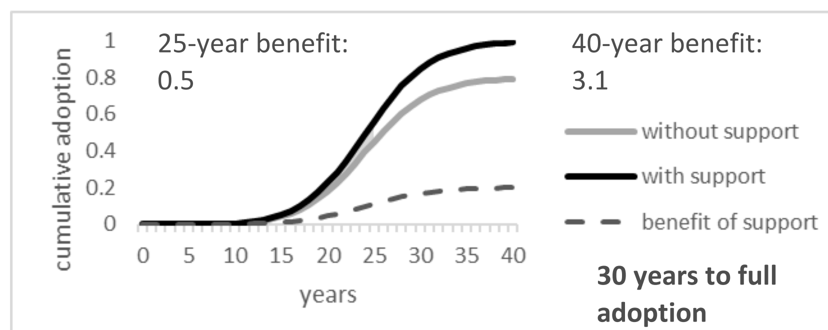
• Reduce time to full adoption by 33%





• Increase market share by 25%





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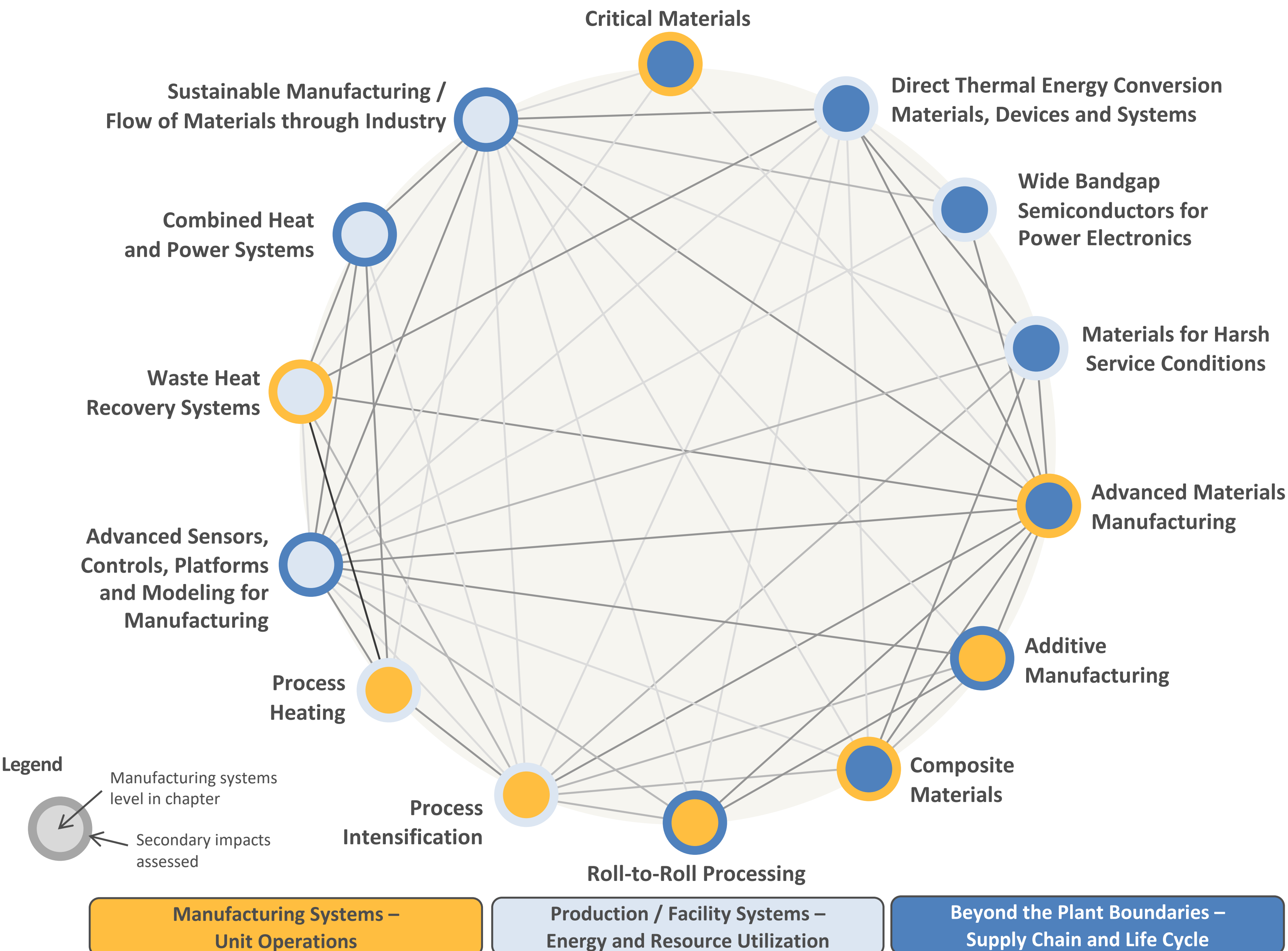
Back-up Slides

QTR Technology Assessments - Manufacturing

http://www.energy.gov/quadrennial-technology-review-2015



AMO Strategic Goals

- Improve the productivity and energy efficiency of U.S. manufacturing.
- Reduce lifecycle energy and resource impacts of manufactured goods.
- Leverage diverse domestic energy resources in U.S. manufacturing, while strengthening environmental stewardship.
- Transition DOE supported innovative technologies and practices into U.S. manufacturing capabilities.
- Strengthen and advance the U.S. manufacturing workforce.

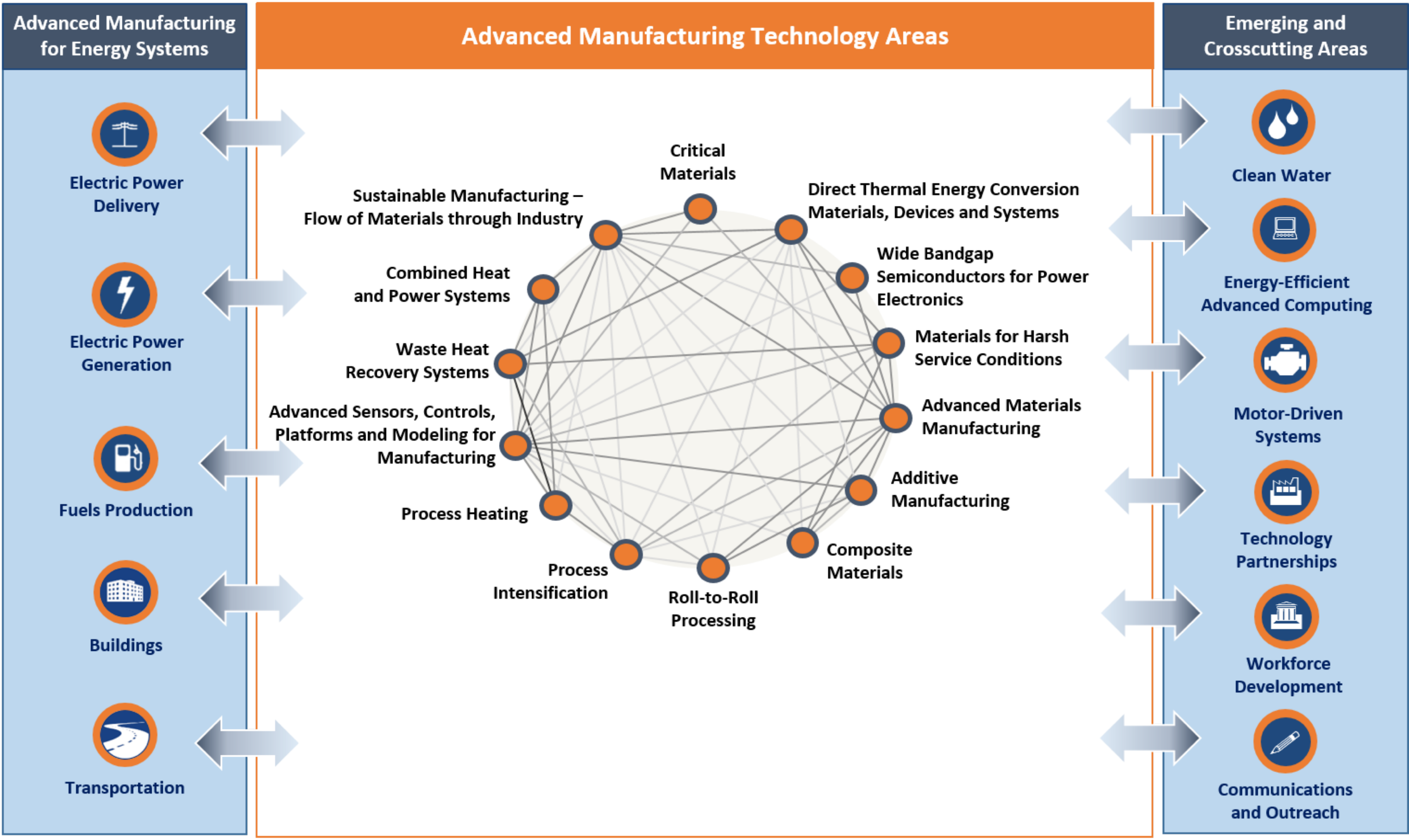
Multi-Year Program Plan

- Describes the Office mission, vision, and goals
- Identifies the technology, outreach, and crosscutting activities the Office plans to focus on over the next five years.

https://energy.gov/eere/amo/advanced-manufacturing-office

Public feedback and comments can be sent to AMO_MYPPInfo@ee.doe.gov

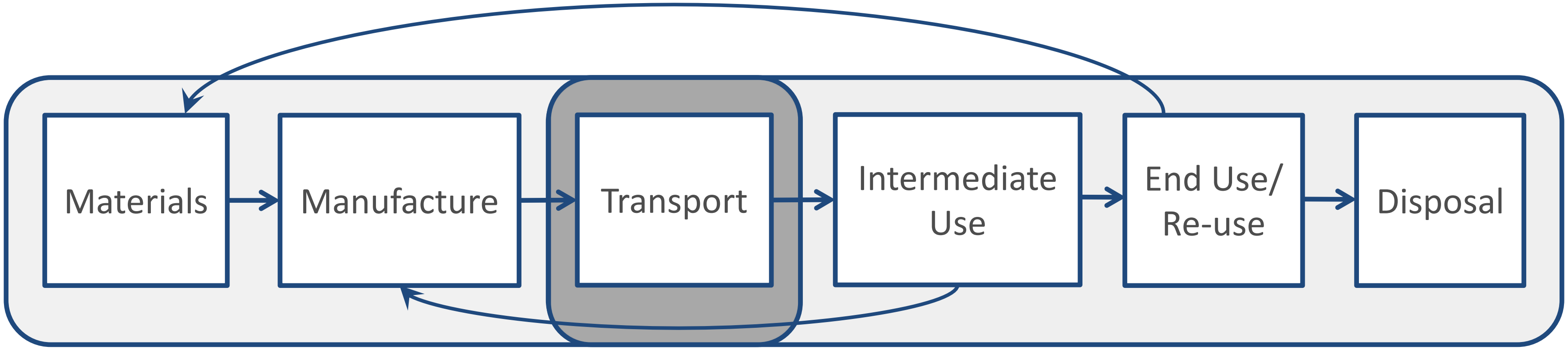
AMO Multi-Year Program Plan (MYPP) Framework



Sustainable Manufacturing TA → describes systems framework, methodologies, tools used elsewhere….

Approach– Outline a framework to better capture economy-wide affect energy and GHG emissions, and to help characterize improvement opportunities, including:

- *Changes in materials and industrial/manufacturing processes*
- *Material flows and manufactured products*
- *Cross-sectoral and life cycle impacts*
- *Embodied Energy & GHGs*

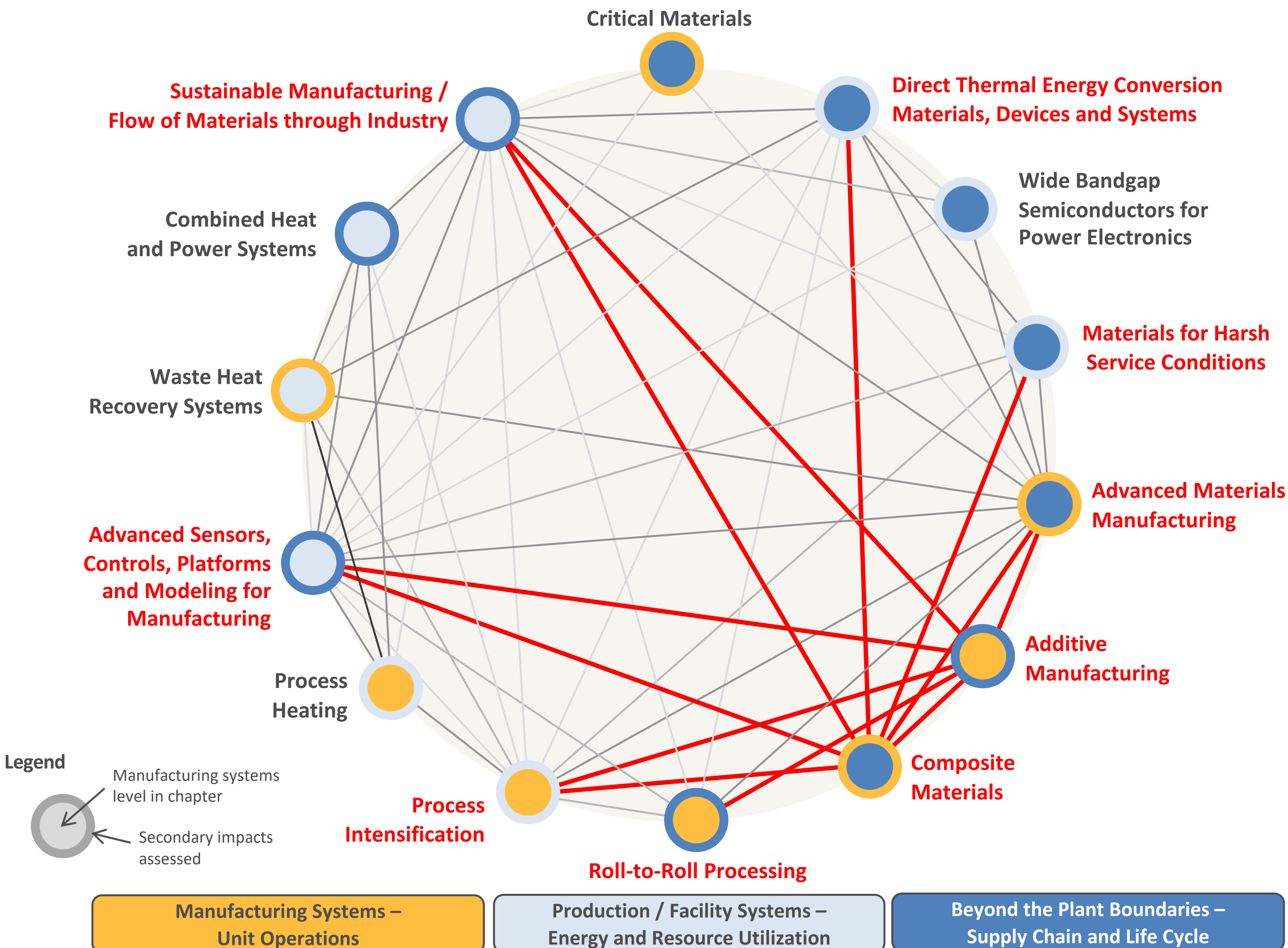


- Energy reductions
- Emissions reductions

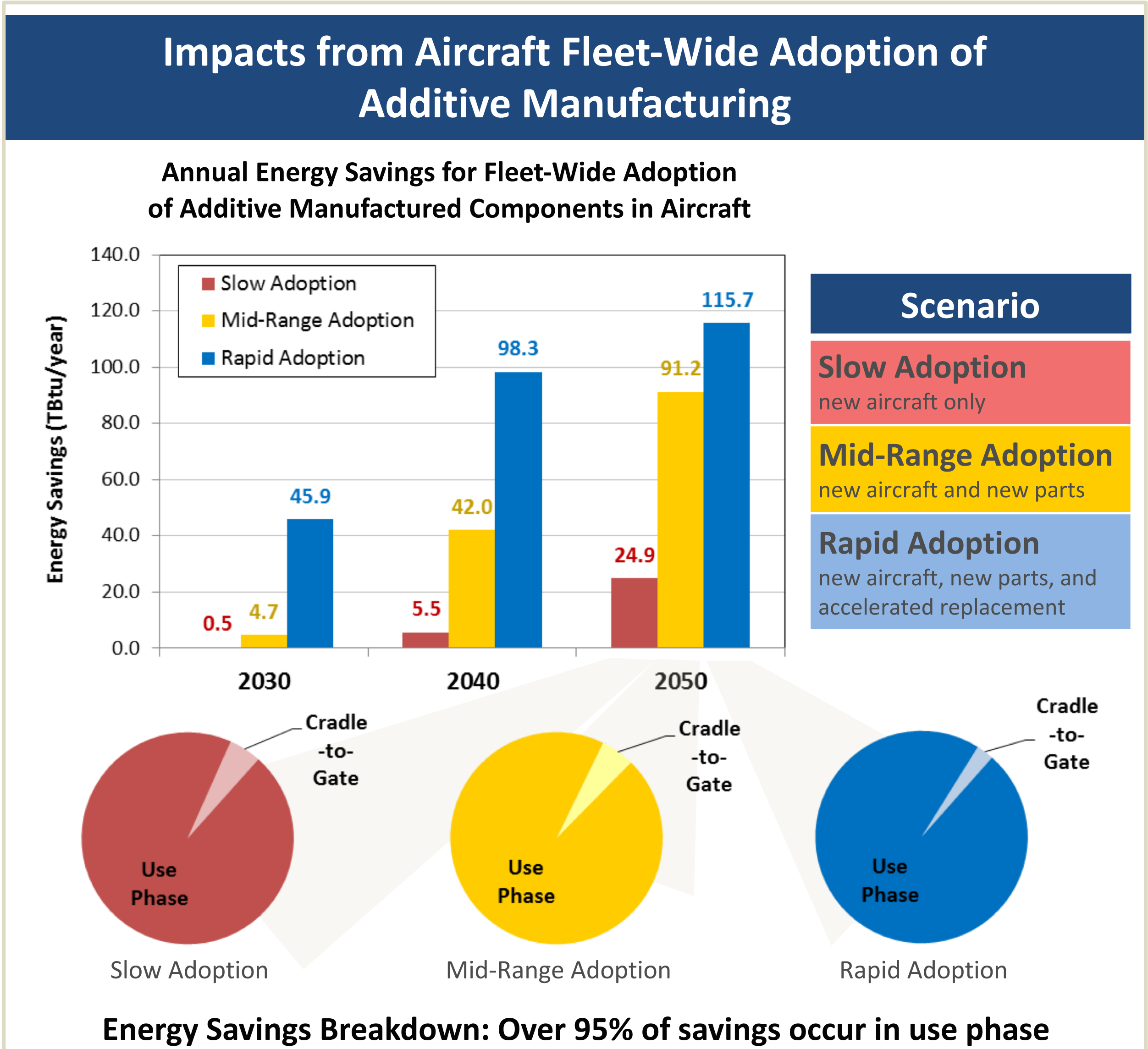
- Use and re-use energy/emissions reductions
- Increased value-added
- Improved quality / Improved service

QTR Technology Assessments - Manufacturing

http://www.energy.gov/quadrennial-technology-review-2015



Potential use intensity improvements from additive – in aerospace

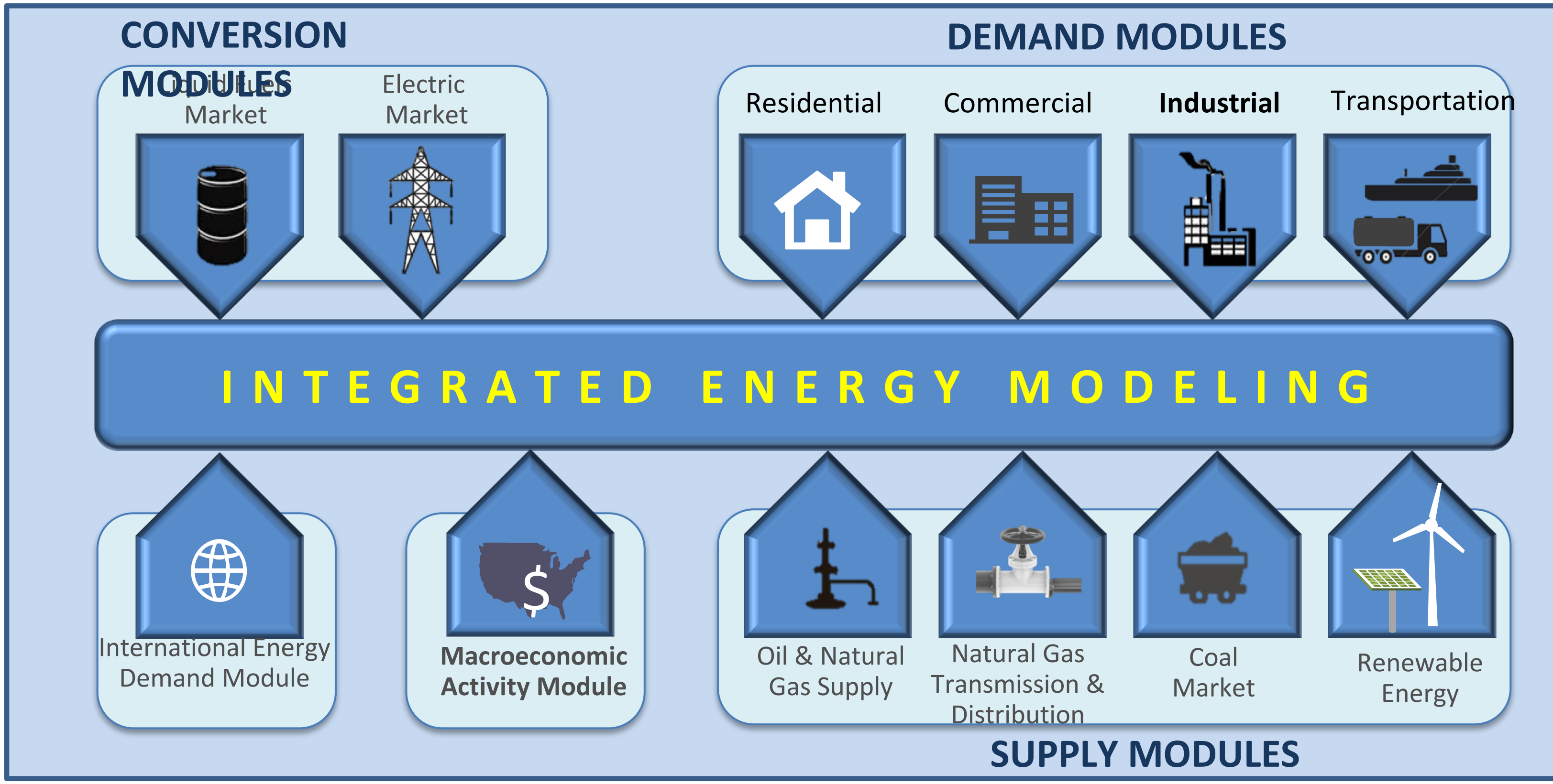


Source: *R. Huang, Riddle, Graziano, Warren, Das, Nimbalkar, Cresko, Masanet* "The Energy and Emissions Saving Potential of Additive Manufacturing: The Case of Lightweight Aircraft Components." Journal of Cleaner Production, 2015

Note: 1 quad = 1,000 TBtu

National Energy Modeling System (NEMS)

NEMS is a simulation model of the U.S. energy system organized by energy producing, consuming, and conversion sectors.



- The Industrial Demand Module (IDM) estimates energy consumption by energy source (fuels and feedstocks) for 15 manufacturing and 6 non-manufacturing industries.
- Process energy is modeled in two different ways, either with technologies by process flow or by end uses using efficiency (TPC) curves

Use Intensity Improvements

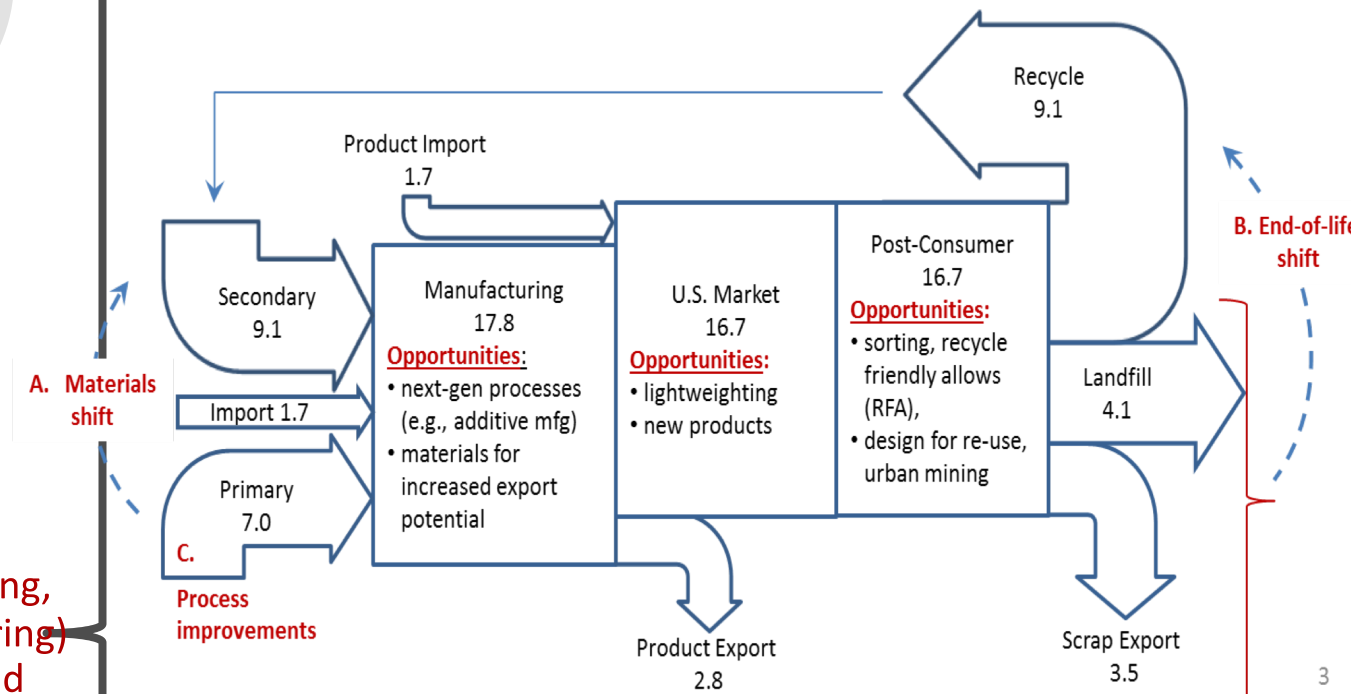
Energy Intensity e.g.:
Process efficiency
Process integration
Waste heat recovery

Carbon Intensity, e.g.:
Process efficiency
Feedstock substitution
Biomass-based fuels
Renewables

Use Intensity e.g.:
Circular economy
Design for Re-X (recycling, reuse and remanufacturing)
Material efficiency and substitution

Expanded Technology Opportunity Space:

- Materials Shift – To enable increase of secondary aluminum by manufacturing
- End-of-life shift – To enable greater capture and use of landfill + scrap export
- Systems-wide– Materials & product design, manufacturing, use and re-use.

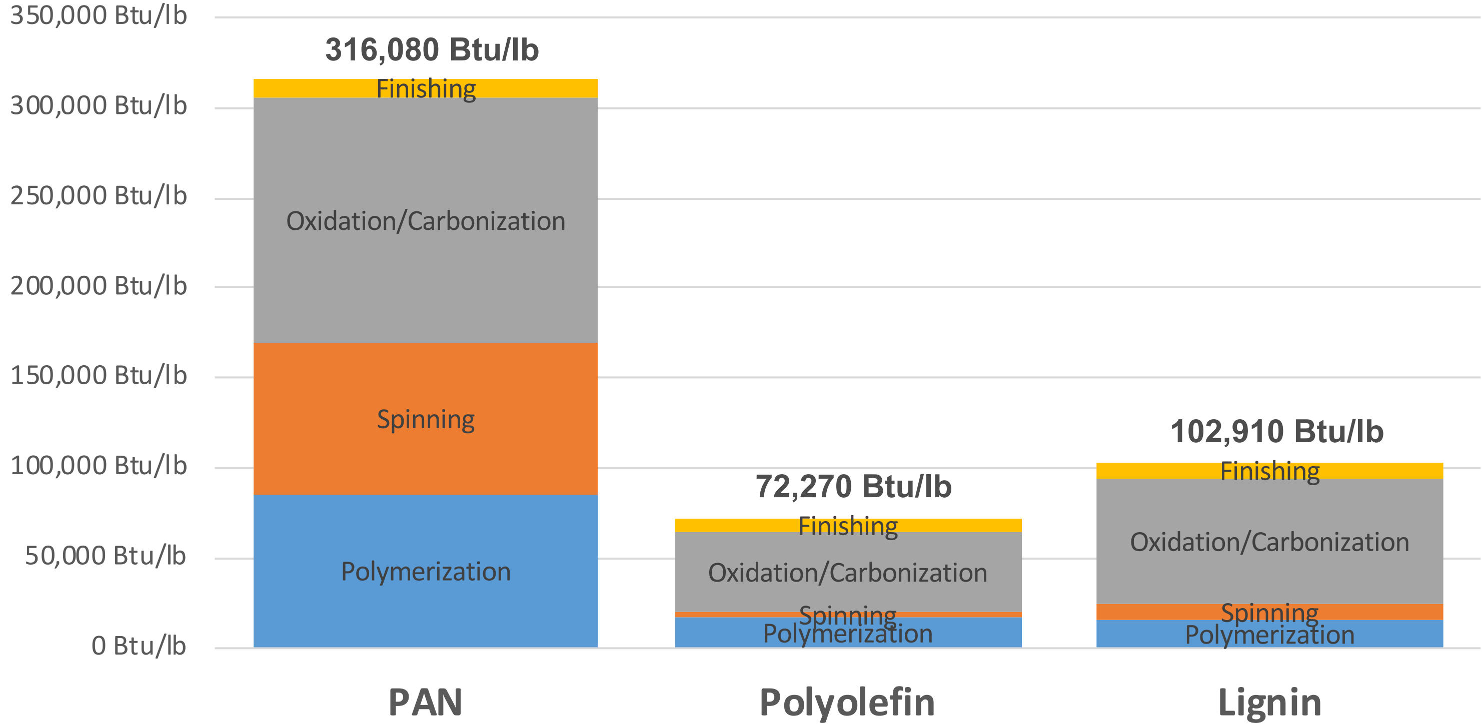


Aluminum Materials Flows – U.S. and Canada, 2009 Billions of Pounds

Energy savings for carbon fibers could be realized through, for example, lower-energy-intensity precursor materials

Energy intensity comparison* for carbon fibers produced from PAN, polyolefin, and lignin precursors

(Onsite manufacturing energy; feedstocks excluded)

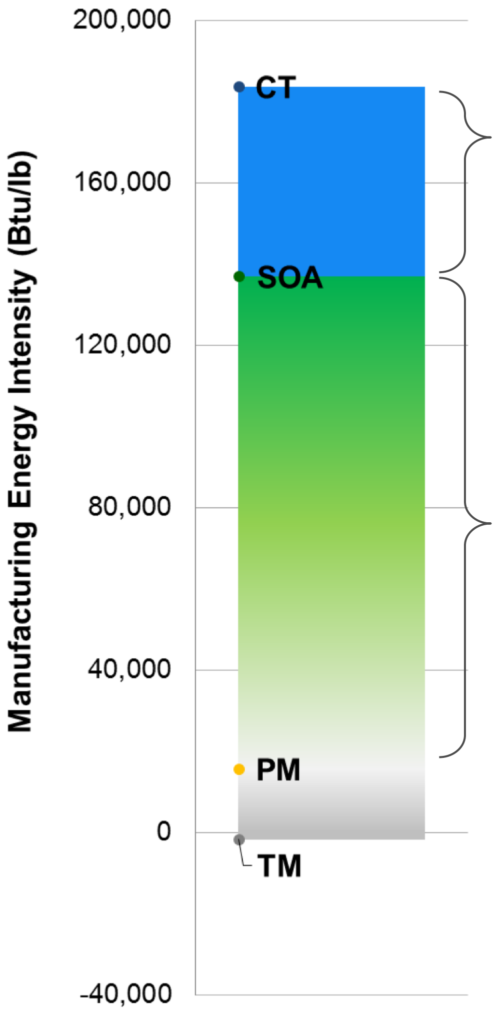


Carbon fiber production from novel precursors (including materials that may not be in use as precursors today) represents a key technology development opportunity for R&D.

* Energy data provided by Sujit Das, Oak Ridge National Laboratory

Results presented are draft data; studies are currently being peer reviewed.

The *Current Opportunity* and *R&D Opportunity* for energy savings were both sizable for carbon fiber composites



CFRP Composites: Energy Bandwidth Summary

Current Opportunity

Energy savings if the best technologies and practices available were used to upgrade production

SOA Technology Examples:

- motor re-sizing and/or variable speed drives
- waste heat recovery
- moderate carbon fiber recycling or down-cycling

R&D Opportunity

Additional energy savings if applied R&D technologies under development worldwide were successfully deployed

R&D Technology Examples:

- alternative precursor processes
- selective heating for carbon fiber conversion
- recovery/recycling of the polymer matrix
- advanced carbon fiber recycling enabling increased recovery

Results presented are draft data; studies are currently being peer reviewed.

Materials & Adv. Mfg. Integrating Analysis Collaborations with the National Laboratories

Integrating analyses leverage tools and analytical capabilities at the National Laboratories, through the DOE AMO Strategic Analysis Team

National Renewable Energy Laboratory

Materials Flow through Industry (MFI) Tool: a tool for analytically tracking the energy and GHG impacts of shifts in material flows, and to quantify supply chain impacts of current and next-generation technologies

Lawrence Berkeley National Laboratory

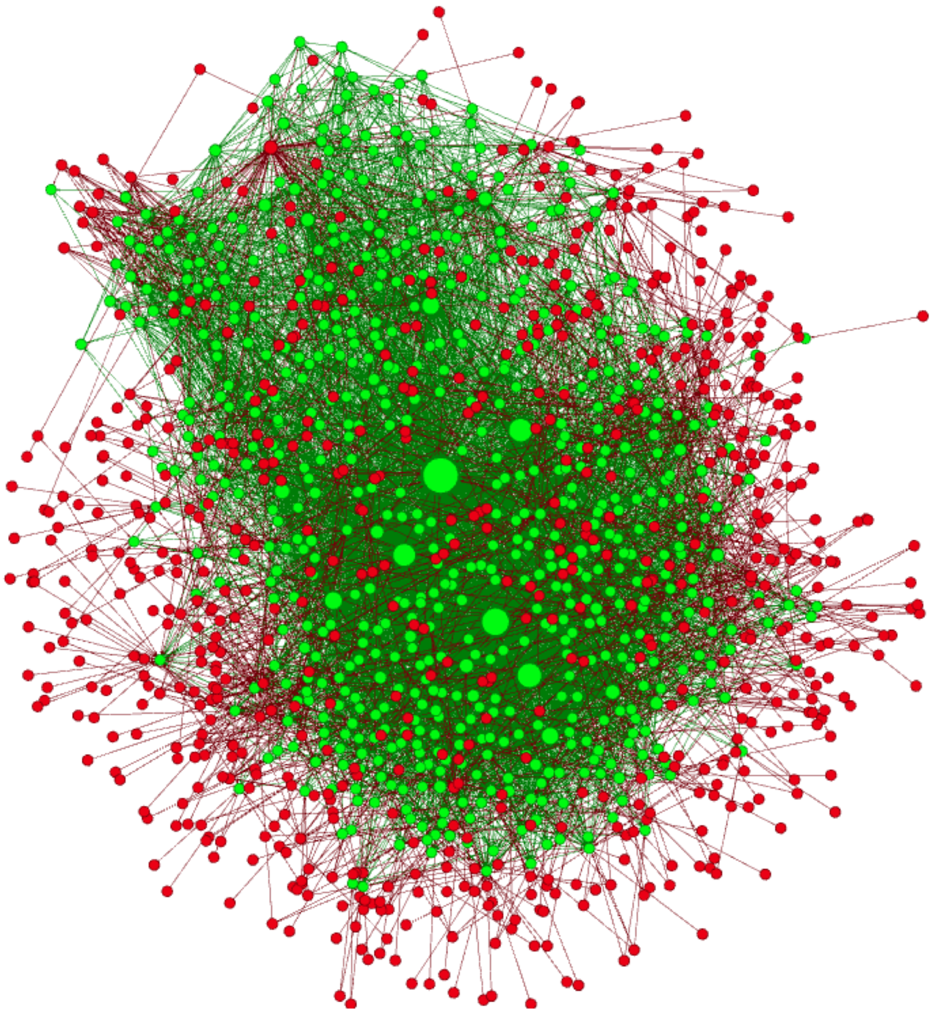
LIGHTEn-UP* Tool: a scenario framework for assessing prospective net energy and GHG impacts of a technology/product, accounting for both manufacturing and end-use life cycle phases

Oak Ridge National Laboratory

Additive Manufacturing Life Cycle Energy Tool: a user-friendly tool that manufacturers can use to evaluate additive vs. conventional manufacturing processes on a life cycle energy basis.

* LIGHTEn-UP: Lifecycle GH gas, Technology, and Energy through the Use Phase

Material Flows Through Industry (MFI)



Network diagram of the MFI database. A connection between nodes indicates that a product is used to produce another product.

Linear network model of U.S. industrial and manufacturing sectors

Based on a database of 1,365 recipes

- Mass/energy balance for each material → Input-output model of a manufacturing process

Database contains:

- 639 products with recipes
- 670 products without recipes

Additional products and recipes are added as data gaps are identified

Defining Manufacturing Scenarios

Manufacturing Scenario Parameters

Product and Steps

- Choose end product(s)
- Choose number of supply chain steps
- Default is 10 steps, which captures about 95% of the total supply chain

Technology Mix

- Specify the combinations of technologies used to produce a product
- Change for end products and for products upstream in the supply chain

Material Substitution

- Replace existing materials or chemicals with next-generation alternatives
- Make the substitution in product demand or upstream in the supply chain

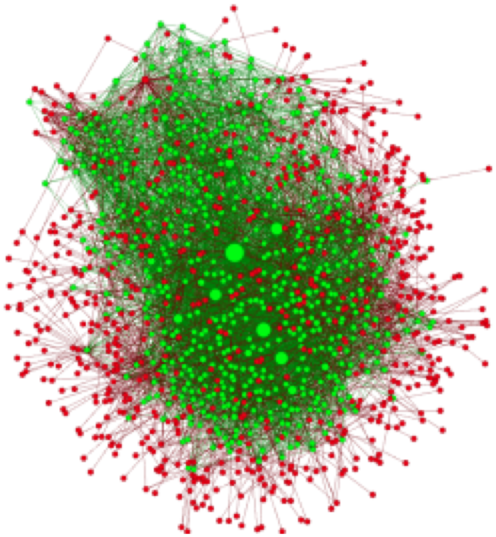
Sector Efficiency Potential

- Improve energy efficiency by replacing existing process equipment with best available
- Implement at the recipe, sector or economy scale

Material Flows Through Industry (MFI)

Define Manufacturing Scenario → Run MFI Model → Interpret Outputs

- Product and Steps
- Technology Mix
- Material Substitution
- Sector Efficiency Potential



- Fossil fuel consumption
- GHG emissions
- Material inventories
- Water use

- Track consumption throughout the supply chain
- Quantify “What”, “Where” and “How Much”
- Identify hot spot processes and important inputs

Caveats and MFI Limitations

MFI system boundary is cradle-to-gate

- Results represent commodity production only
- Use phase, end-of-life is not captured

Some potentially significant effects are not captured

- Vehicle lightweighting leads to reduced fuel use, emissions
- Advanced smelting technologies are more difficult, less safe to operate
- Increased recycling decreases landfilling, bauxite imports

……So, how do we look at broader life cycle impacts…..?

Cross-sectoral Impacts Assessment Tool – *LIfecycle GHgas, Technology and Energy through the Use Phase* (LIGHTEn-Up)

Examples of Sectors and Complexity

Increasing Complexity ↓

Example	Sector Impact			
	Industrial	Residential	Commercial	Transportation
Combustion Air Preheating In Steel Hot Rolling	Yes	No	No	No
Light-Weighting Airplanes with "Additive Manufacturing" Parts	Yes	No	No	Yes
LED lighting in Buildings	Yes	Yes	Yes	No
Wide-Band Gap Materials	Yes	Yes	Yes	Yes

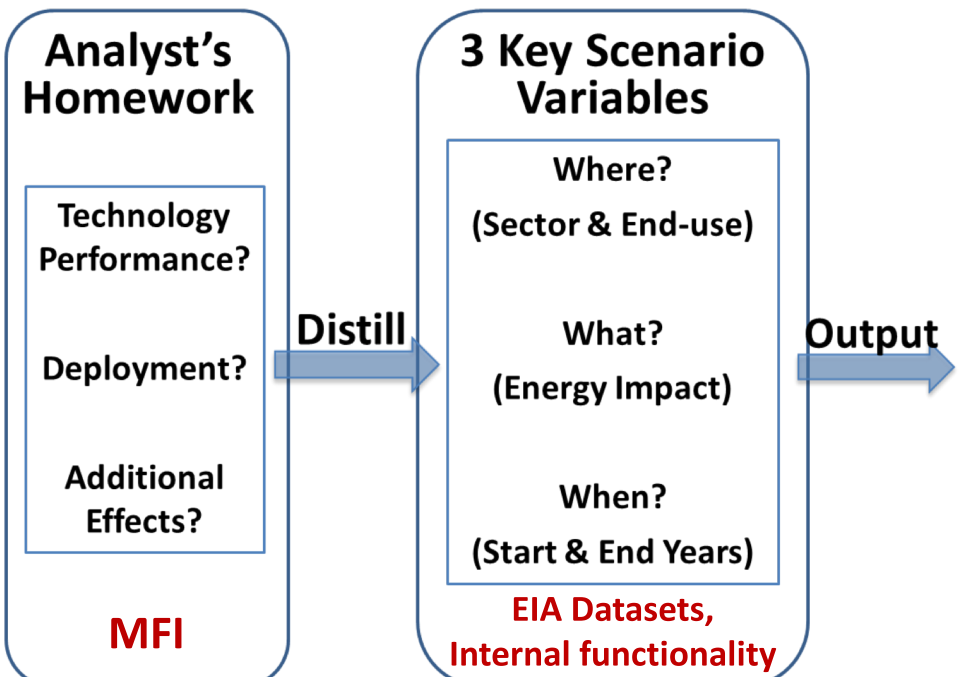
LIfecycle GHgas, Technology and Energy through the Use Phase (LIGHTEn-Up) Tool & Analysis Framework

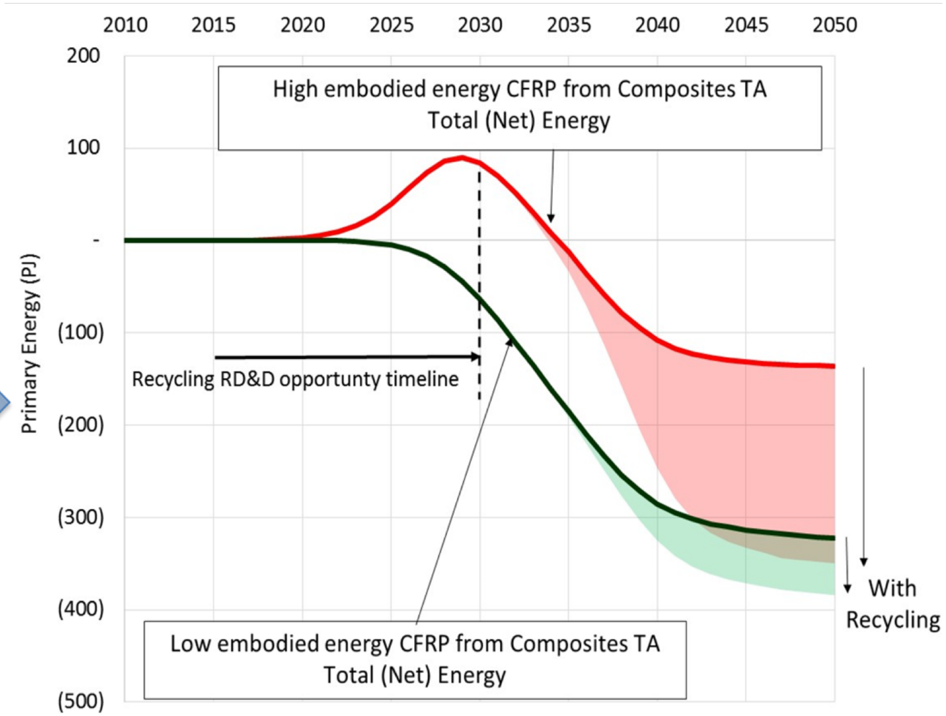
Objectives:

- A substantive, transparent, and intuitive scenario framework
- Prospective net energy and GHG impacts of technologies utilized in both manufacturing and end-use-phases across the U.S. economy

About the Data

- Benchmarked to publically available DOE datasets
- Annual Energy Outlook – U.S. economy-wide energy consumption forecast out to 2040
- Includes EIA's Manufacturing Energy Consumption Survey (MECS) 2010 detailed energy consumption by end-uses





For examples of LIGHTEn-UP analysis output, see the Composites and Sustainable Manufacturing Technology Assessments, available at: http://energy.gov/quadrennial-technology-review-2015-omnibus#chap6ta

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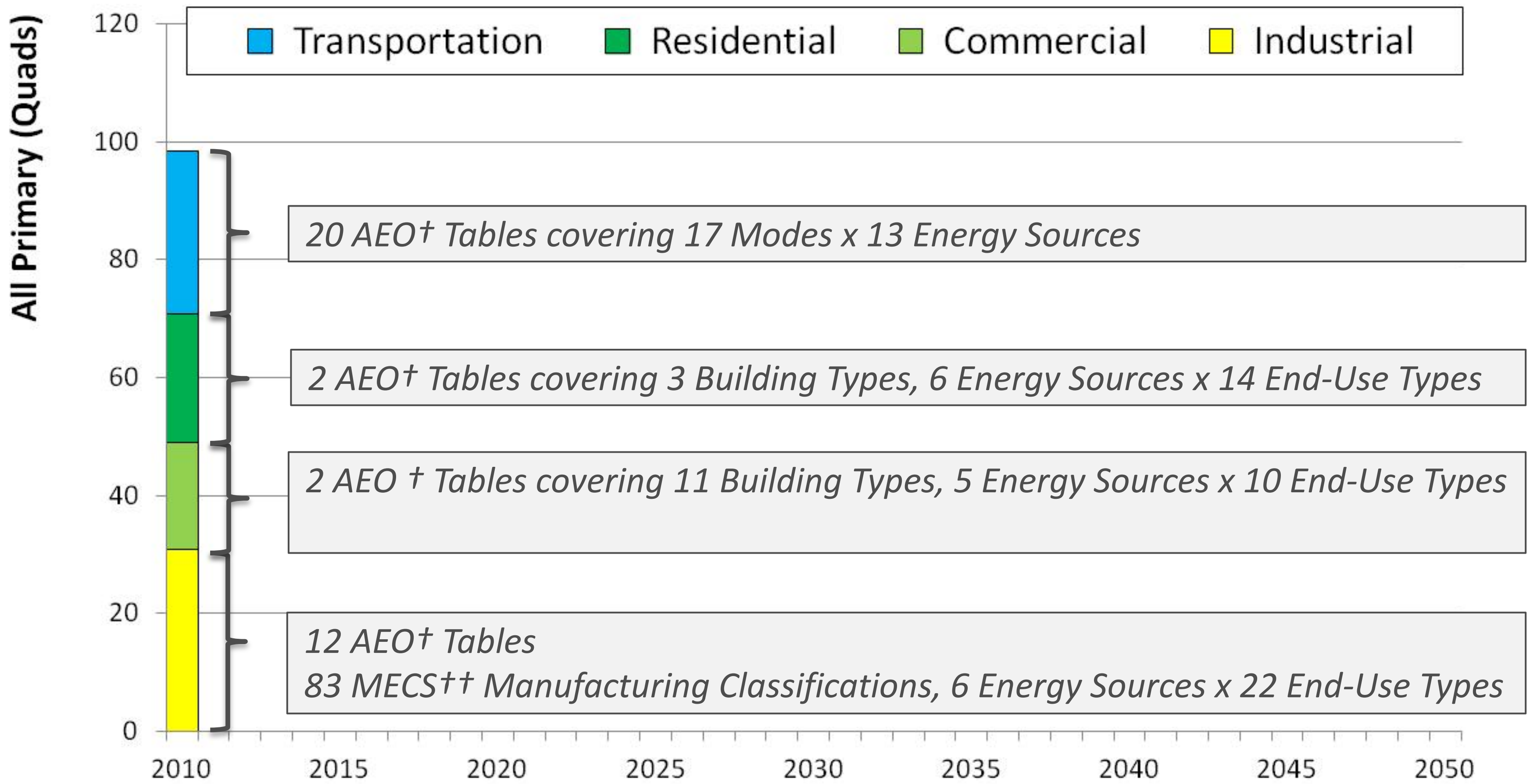
Publically Available U.S. Energy Consumption Data



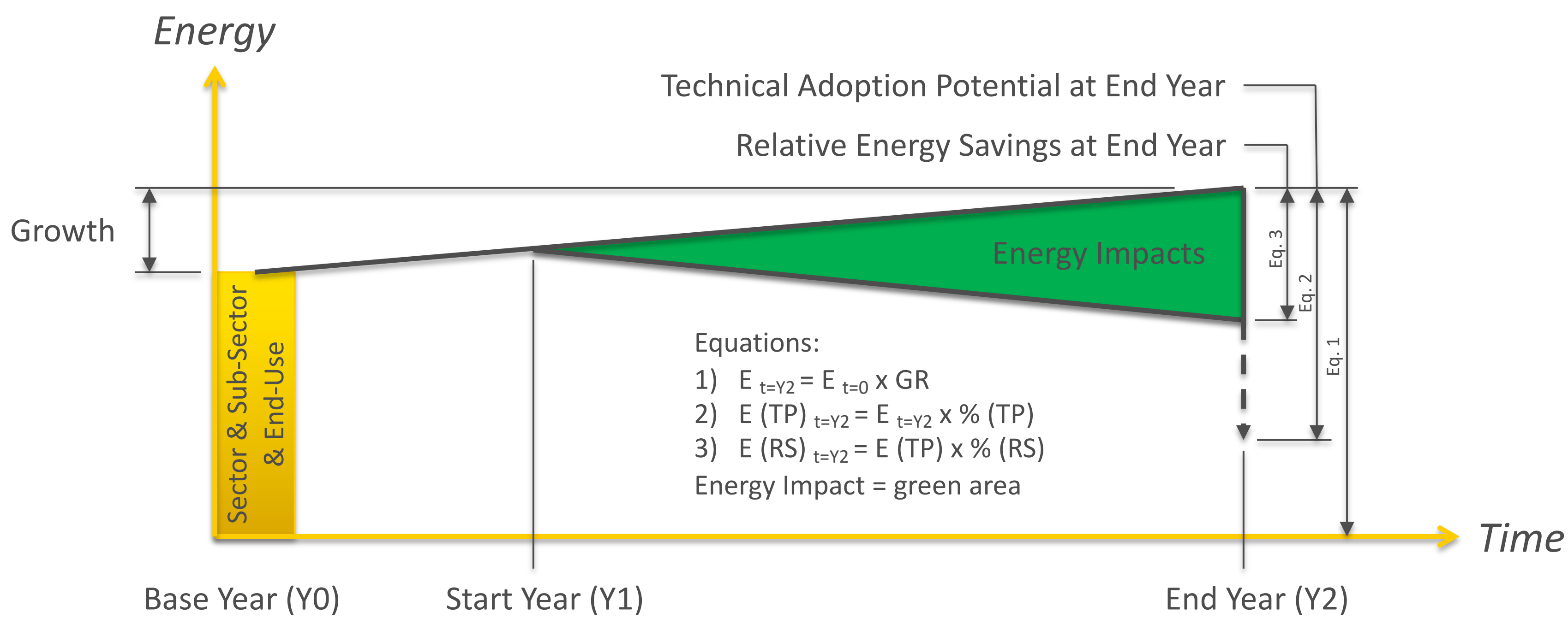
About the Data

† *Annual Energy Outlook (AEO) Tables* – U.S. economy-wide energy consumption forecast to 2040

†† *Manufacturing Energy Consumption Survey* (MECS) 2010 – Detailed energy consumption by end-uses

LIGHTEn-UP Tool User Interface
Where? What? When?

What Sector & End-Use?			What Impact at End Year			When?	
Industrial Commercial Residential Transportation	Sub-Sector	End-Use	Technical Adoption Potential %	Relative Energy Savings %	Growth Rate Assumption	Start Year	End Year



LIGHTEn-UP output: net energy accounting

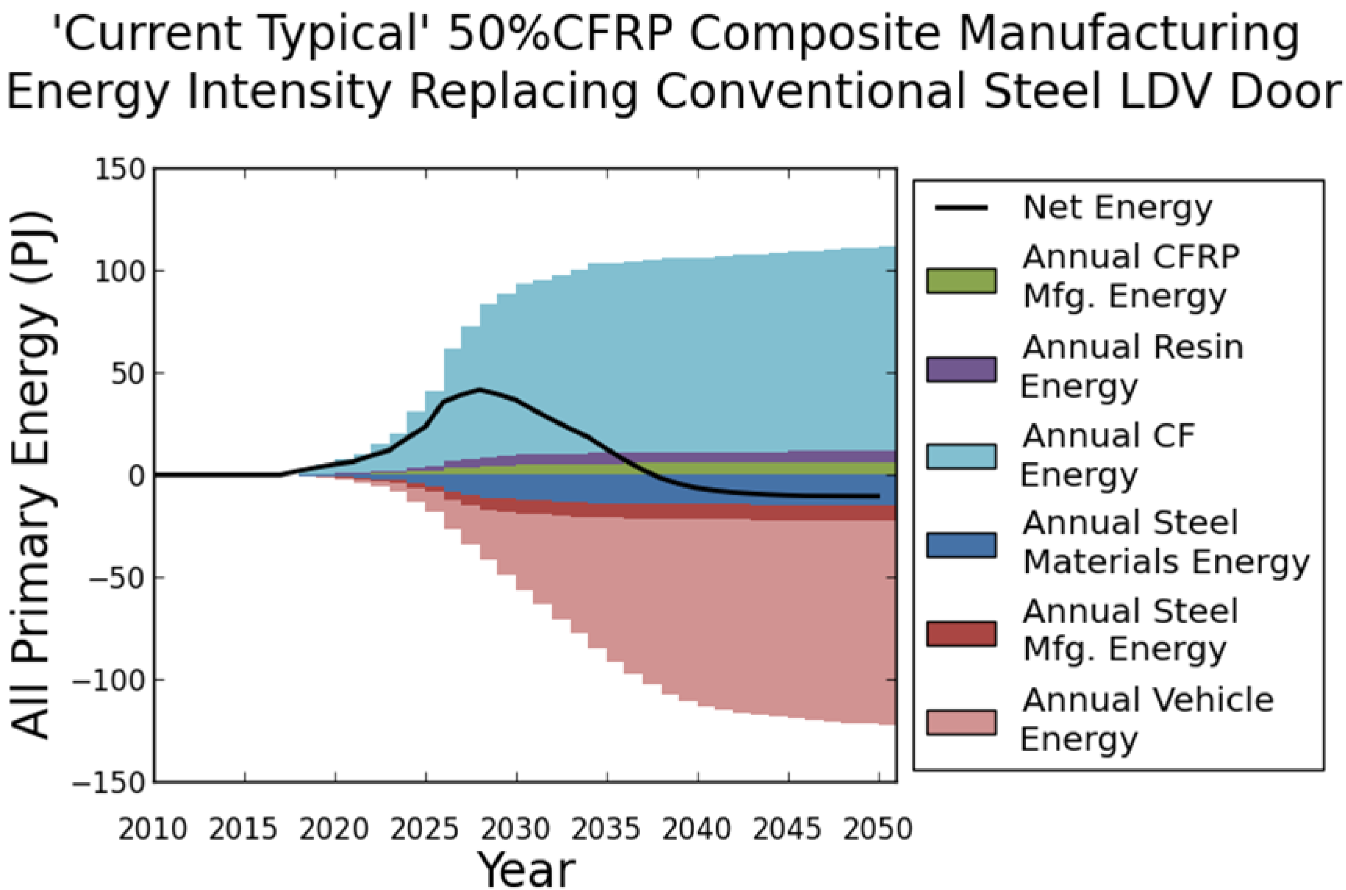
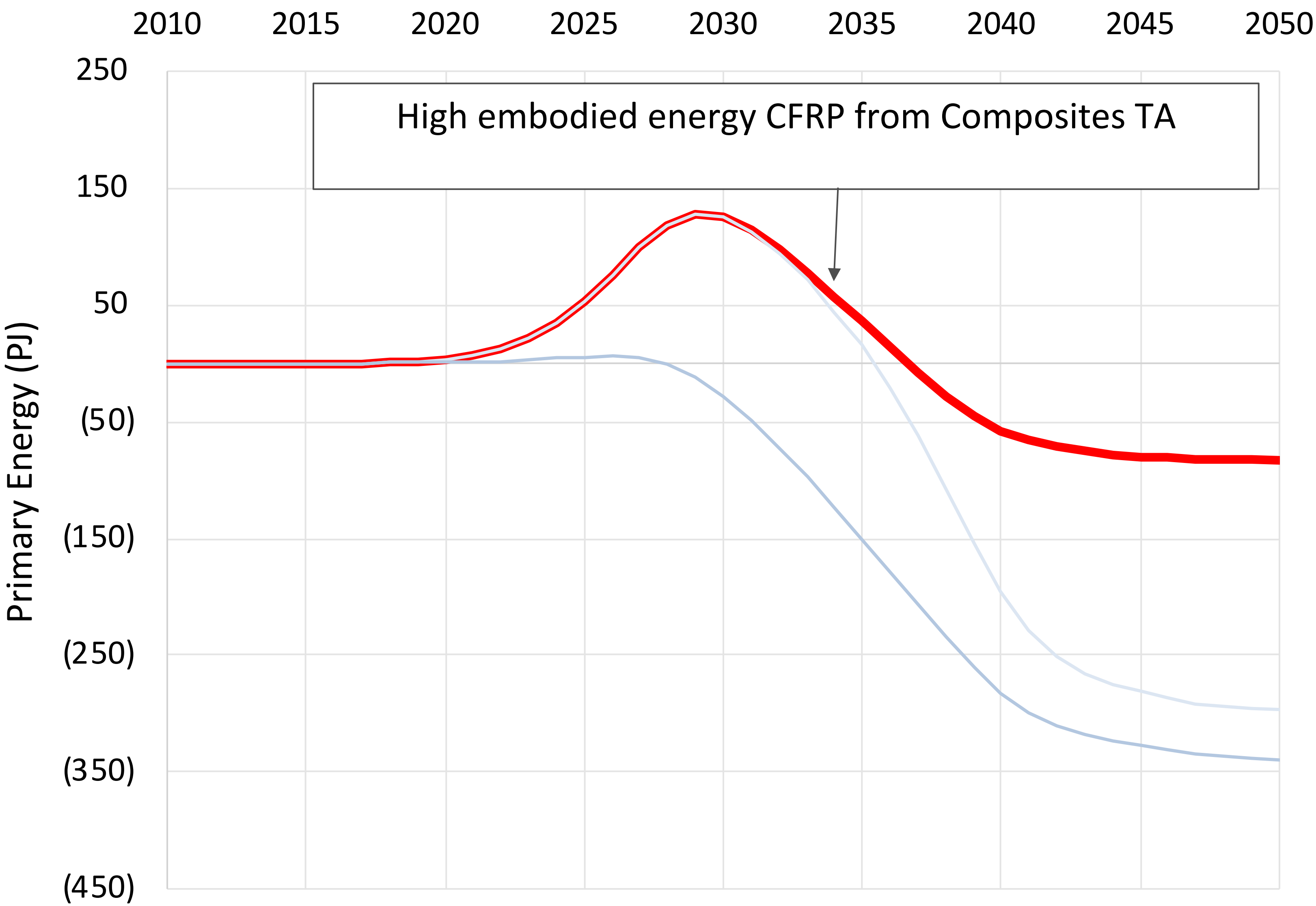


Figure Reference: Sunter, D. A., Morrow III, W. R., Cresko, J. W., and Liddell, H. P. H., "The manufacturing energy intensity of carbon fiber reinforced polymer composites and its effect on life cycle energy use for vehicle door lightweighting," presented at the 20th International Conference on Composite Materials (ICCM), Copenhagen, Denmark, July 19–24, 2015.

LIGHTEn-UP Analysis - Net Energy Impact with utilization of recycled Carbon Fiber Reinforced Plastic Composites (CFRP) in vehicles



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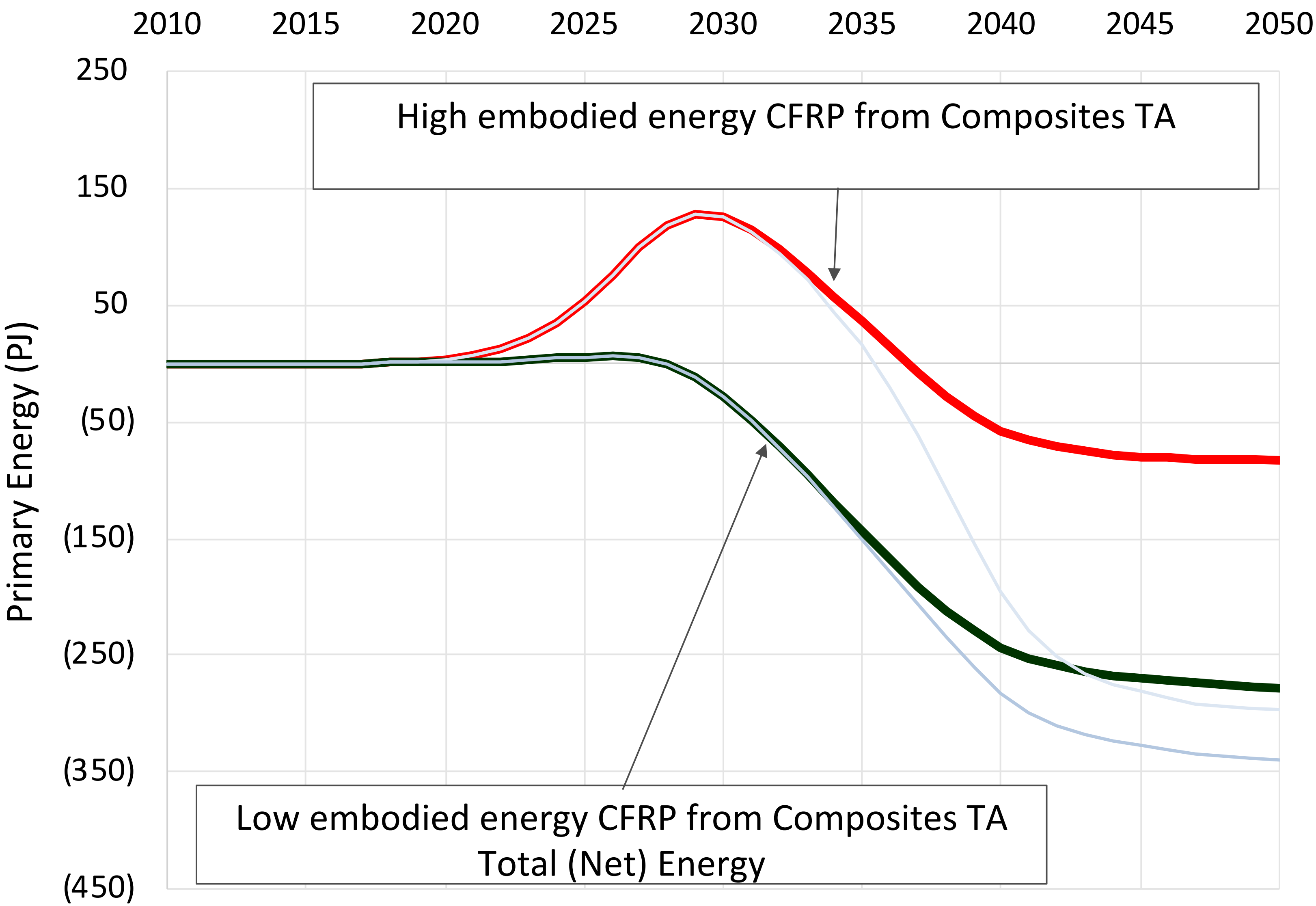

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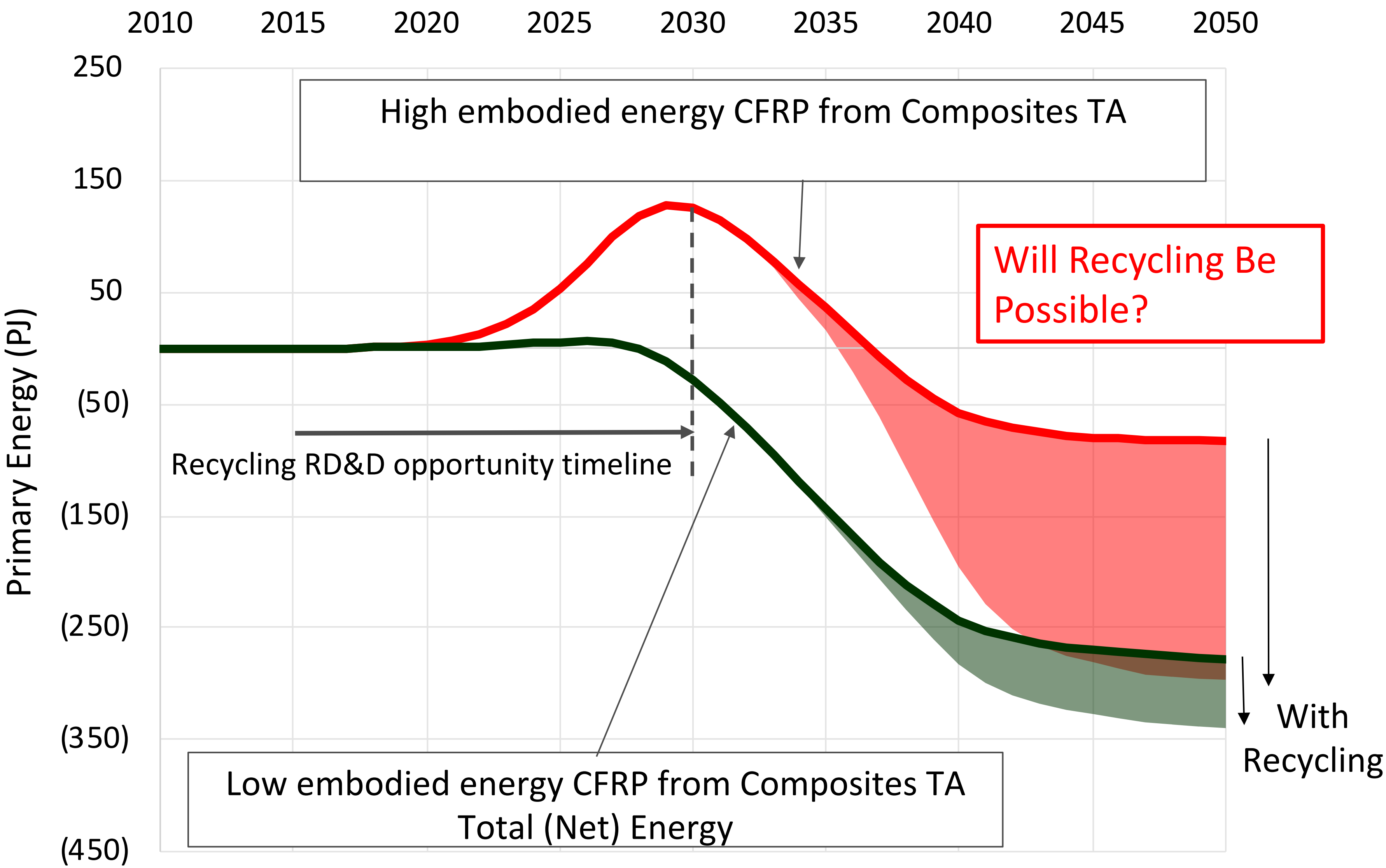

For net energy benefits from CFRP lightweighting, fuel savings must fully offset the increased manufacturing energy

- Policymakers and automotive manufacturers are looking to lightweight materials such as CFRP* composites, and viable manufacturing processes, to reduce vehicle mass and meet fuel economy standards.

- However, it may take many years of vehicle use for accumulated fuel savings to fully offset the manufacturing energy for these materials.

- Example at right shows a payback period of 20 years from initial adoption of a CFRP component in the vehicle fleet.

- In some cases, energy payback may never be reached at all! Important opportunity to reduce the life cycle energy impacts by improving the manufacturing operations, and developing a circular economy for CRFPs.

- CFRP = Carbon Fiber Reinforced Polymer

Energy Productivity Drivers

a. **Less Energy to Produce –** Decrease energy intensity (i.e. **energy/mass**) of existing commodities/materials by developing new pathways towards practically achievable minimum energy requirements.

b. **Improved Service –** Increase life cycle performance of materials and manufactured products (i.e. **service/mass**) via approaches such as hyper-utilizing existing commodities and materials that result in significantly greater service for the amount of material used.

c. **Higher Value Products -** Increase the value-add of manufactured products (**i.e. value-add/service**) by developing new, high-value commodities and materials substitutes that can be manufactured at scale with energy and emissions that are lower than the practical limits of existing commodities and materials

d. **Transformational Productivity –** Grow a hyper-efficient advanced manufacturing sector

- with a particular focus on new greenfield development of low energy, low-carbon high value-add materials and products;
- target those technologies and processes that can exceed current practical limits of energy and carbon productivity; and
- anticipate and develop technologies that optimize life cycle resource efficiency to prevent the possible future rebound of energy & carbon intensive production.