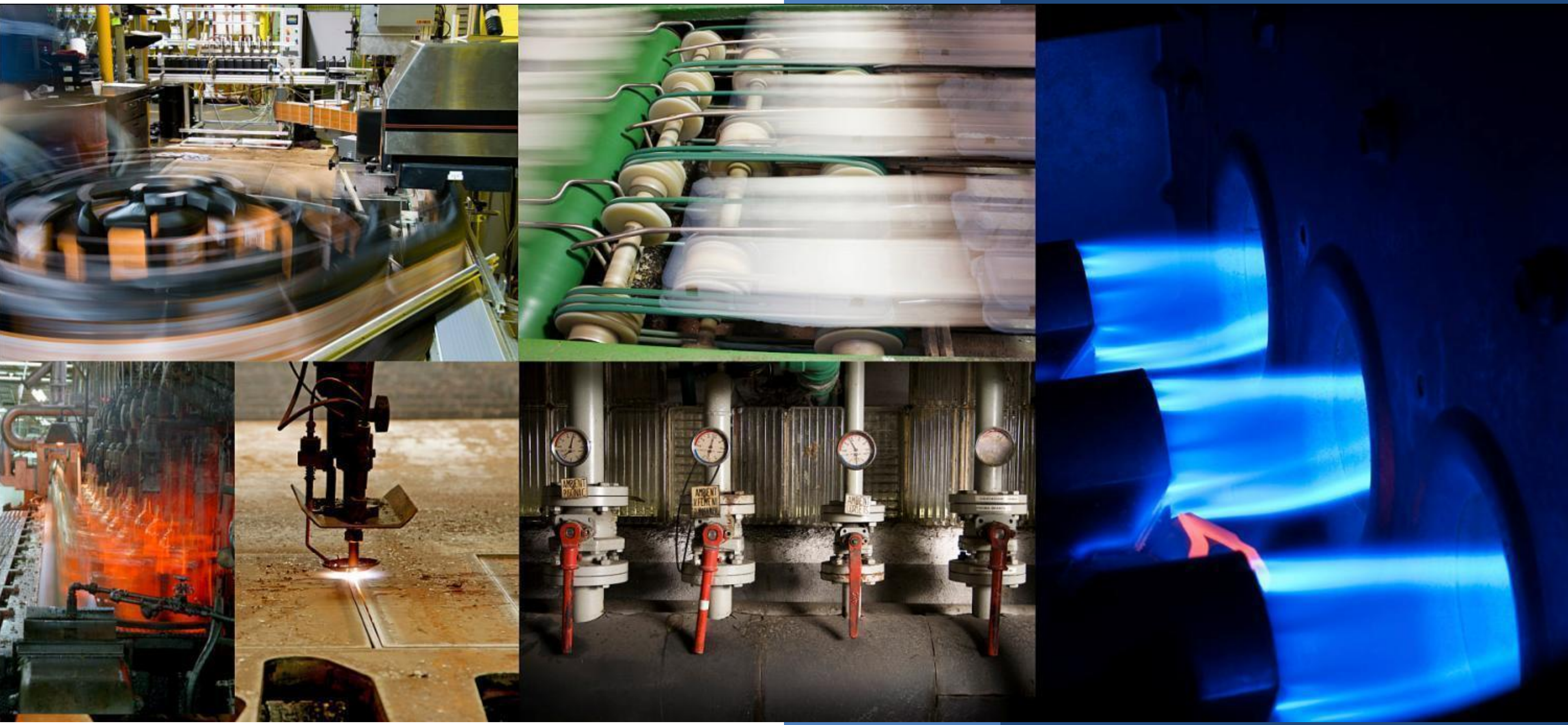
QTR Chapter 8 - Increasing Efficiency and Effectiveness of Industry and Manufacturing

U.S. DEPARTMENT OF ENERGY



2015 Quadrennial Technology Review
Ch. 8 Webinar - Feb. 11, 2015

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Discussion DRAFT

Today's Webinar

- Introduce the 2015 Quadrennial Technology Review (QTR)*
- Provide an contextual overview of QTR Chapter 8 - Industry & Manufacturing (~25 pages)**
- Introduce the fourteen supporting Technology Assessments (~15-30 pages each)
- Build upon outreach initiated at the Dec. 4th-5th "Cornerstone Workshop"
- Initiate a comment period for the draft versions of Chapter 8 and the associated Tech Assessments (Feb. 11th – **24th**)

Goal: Provide an opportunity for subject matter experts from academia, labs, the private sector and other governmental agencies to provide comments and factual information that enable DOE to produce a more informed and improved technical basis for the Chapter and associated Tech Assessments.

**More information can be found at http://energy.gov/qtr including the Framing Document which outlines all the Chapters. Follow the links for "Public Webinars" to get to Chapter 8.*

2015 QTR Chapters

1. Energy Challenges
2. What has changed since QTR 2011
3. Energy Systems and Strategies
4. Advancing Systems and Technologies to Produce Cleaner Fuels
5. Enabling Modernization of Electric Power Systems
6. Advancing Clean Electric Power Technologies
7. Increasing Efficiency of Buildings Systems and Technologies
8. Increasing Efficiency and Effectiveness of Industry and Manufacturing
9. Advancing Clean Transportation and Vehicle Systems & Technologies
10. Enabling Capabilities for Science and Energy
11. U.S. Competitiveness and R&D Needs
12. Integrated Analysis
13. Accelerating Science and Energy RDD&D

Red = core technology chapters

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Red = Focus of today's webinar

Key Issues and Questions for R&D

Some Key Technology and System Assessment/Analysis

Issues & Questions

- What technology and system improvements and innovations will result in the greatest economy-wide impacts?
- What are the most impactful opportunities to leverage abundance of domestic natural gas?
- What timely investments could potentially enable U.S. leadership and open markets?
- What is the appropriate balance between deployment of current SOA vs investment in next-generational technologies?

What's In/Out?

What is <u>in</u> the QTR chapter?

Manufacturing-based technologies for:

- Manufacturing systems
- Production/facility systems
- Supply-chain systems

Economy-wide impacts of these systems

What is <u>not</u> in the QTR chapter?

Regulatory and market policy recommendations

Snapshot of Industry and Manufacturing

Definitions:

- **Industry**: Industry encompasses manufacturing (NAICS 31-33), agriculture (NAICS 11), mining (NAICS 21), and construction (NAICS 23)
- **Manufacturing**: Includes 21 sectors (e.g., chemicals, paper, food, computers and electronics)
- **Advanced Manufacturing**: Making things in a manner such that technology provides a competitive advantage over the practices widely in use.
- **Clean Energy Manufacturing**: Making things such that environmental impact is reduced in the making, use, or disposal of the product made
- **Technology**: Defined by the system of interest

Key Economic Data (2012)	
Manufacturing Share of GDP	13%
Manufacturing Payroll	$594 billion
Manufacturing Exports	$1,163 billion
Manufactured Goods Trade Balance*	-$458 billion
Advanced Technologies Trade Balance	-$91 billion
U.S. Manufacturing Share of World Output	18%

Key Energy and Economic Data (2012)	
Industrial Energy Consumption	30.9 Quads
Industrial Energy Expenditures	$226 billion
Manufacturing Facilities	~300,000
Manufacturing R&D Expenditures (2011)	$201 billion
Manufacturing sector direct employment	12 million

* Does not include crude oil, but does include some petroleum products. Adjusted for re-exports.

Manufacturing in the United States

Is a key driver of our economy, energy productivity[1] and innovation.

"The economic evidence is increasingly clear that a strong manufacturing sector creates spillover benefits to the broader economy, making manufacturing an essential component of a competitive and innovative economy."

Gene Sperling, former Director of the National Economic Council
Remarks at the Conference on the Renaissance of American Manufacturing, March 27, 2012

Approach:

- Efficiency opportunities through deployment of state-of-the-art technologies to existing manufacturing practices.
- Research, Development and Demonstration of new, advanced processes and materials technologies that reduce energy consumption for manufactured products and enable life-cycle energy savings[2]

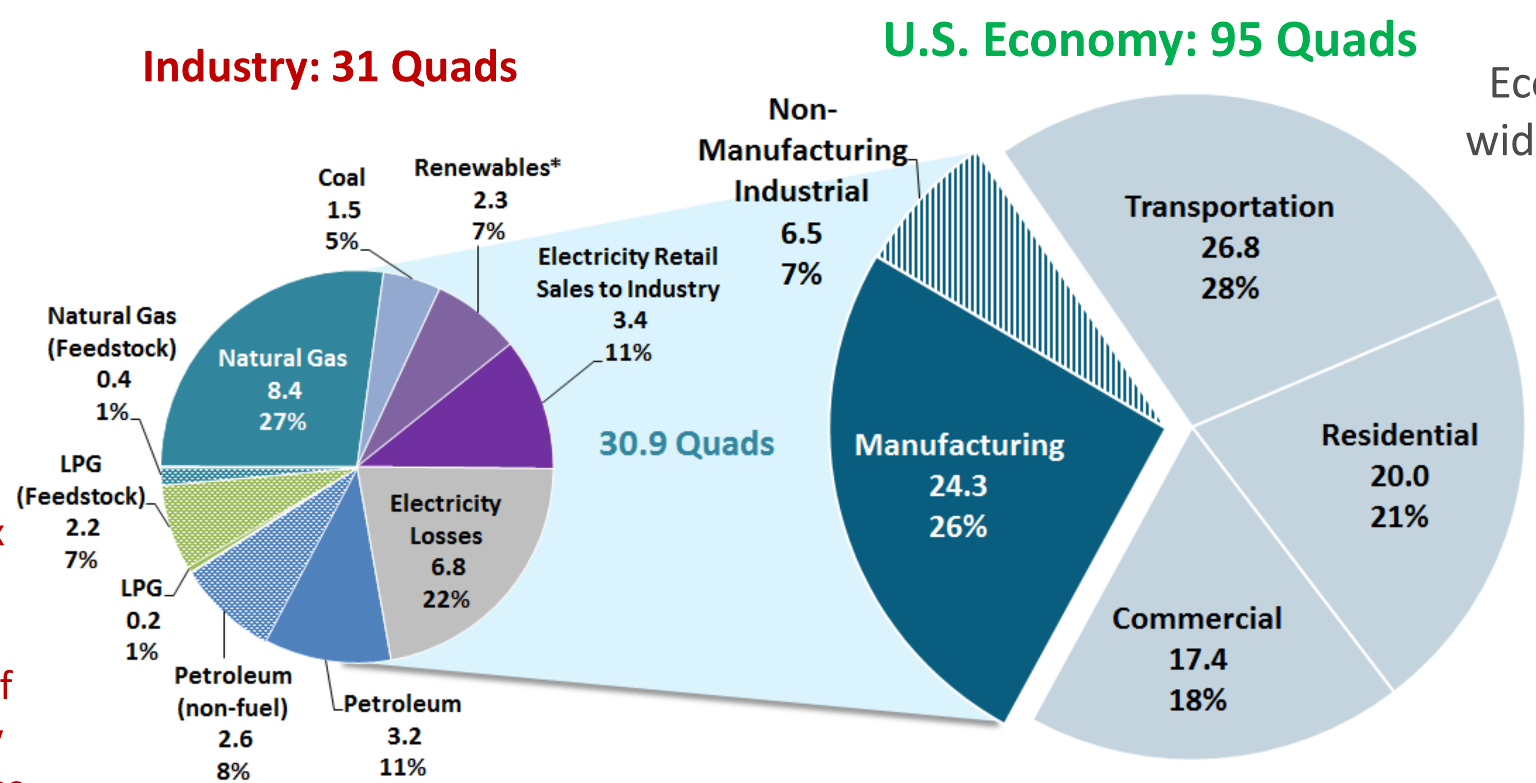
[1] Energy productivity and competitiveness issues will be addressed in more-depth in Chapter 11 of the QTR

[2] Historically DOE has communicated industrial energy use/opportunities in terms of site energy use; little precedent for materials flows, cross-sector impacts, economics & competitiveness.

Industry and Manufacturing Energy Use

- Before discussing U.S. economy-wide impacts, consider industry and manufacturing energy use/loss and manufacturing energy utilization (based on EIA data, years of analysis, etc.)

2012 Data



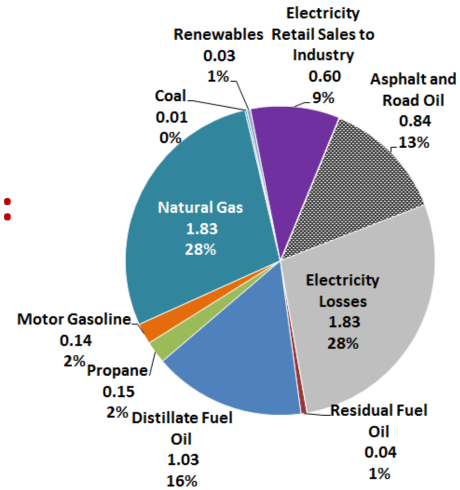
Fuel mix shows diverse nature of industry energy use

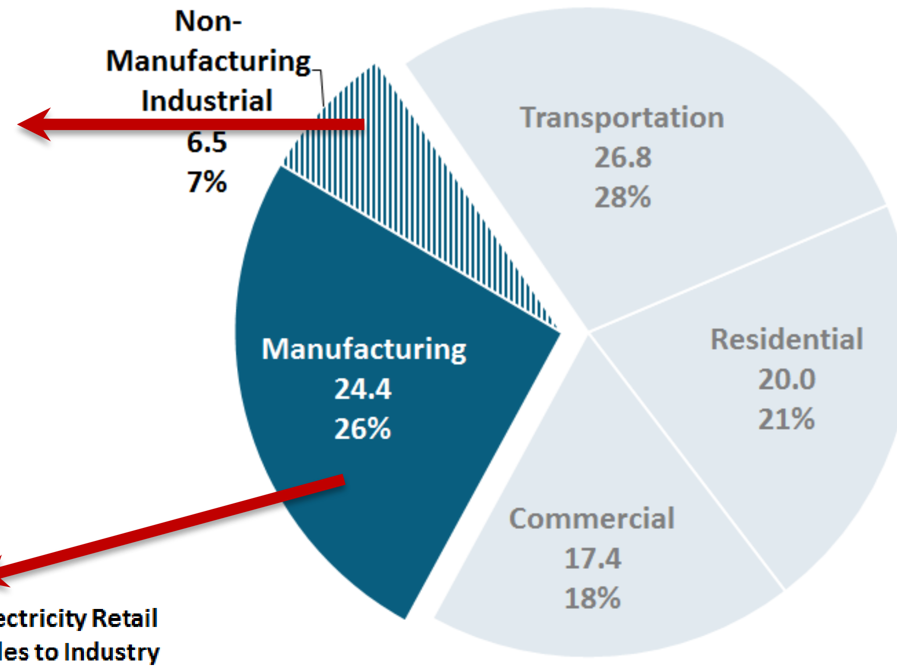
* Renewables consist primarily of biomass energy (2.238 Quads), with the remainder from onsite hydroelectric, geothermal, wind and solar energy.

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

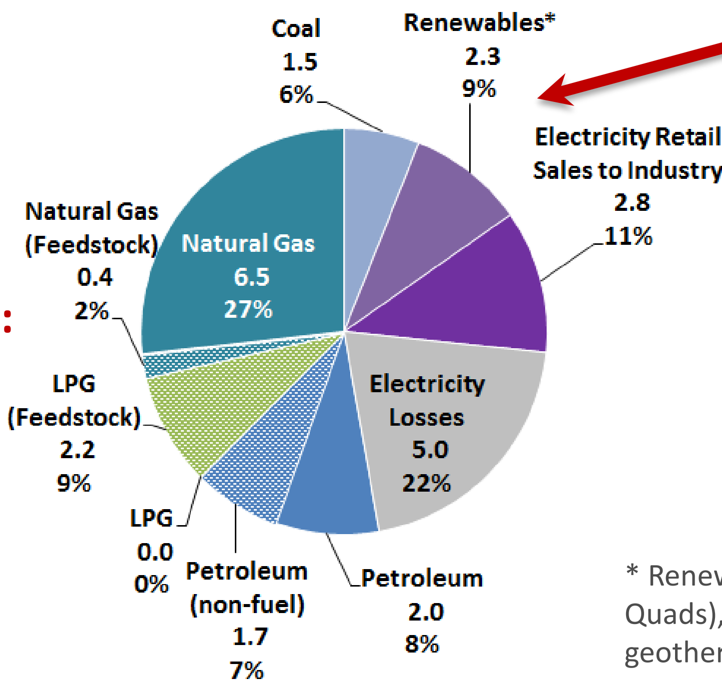
Energy Use by Fuel Type …

Non-manufacturing: 6.5 Quads





Manufacturing: 24.4 Quads



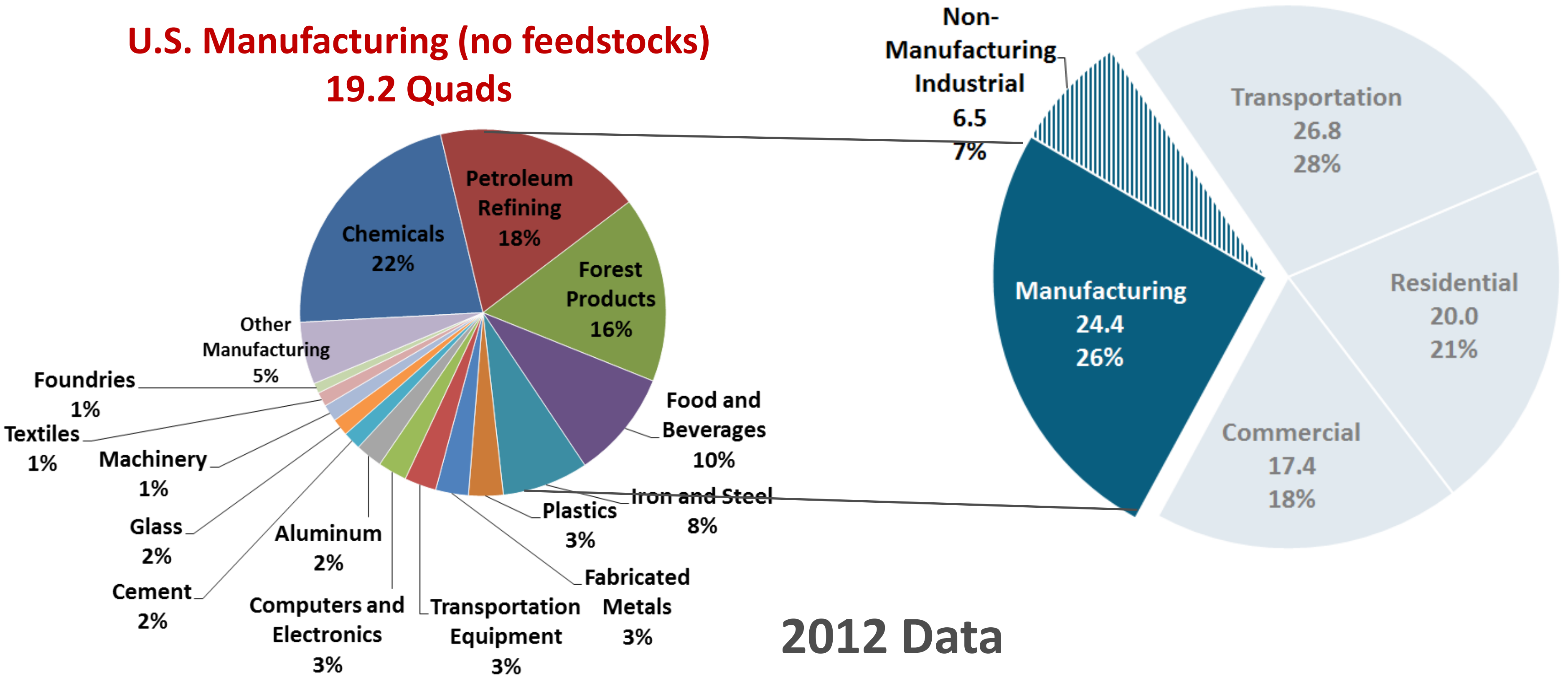
2012 Data

* Renewables consist primarily of biomass energy (2.238 Quads), with the remainder from onsite hydroelectric, geothermal, wind and solar energy.

Note: non-manufacturing natural gas energy use includes plant and lease fuel.

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

…and by Subsector…



2012 Data

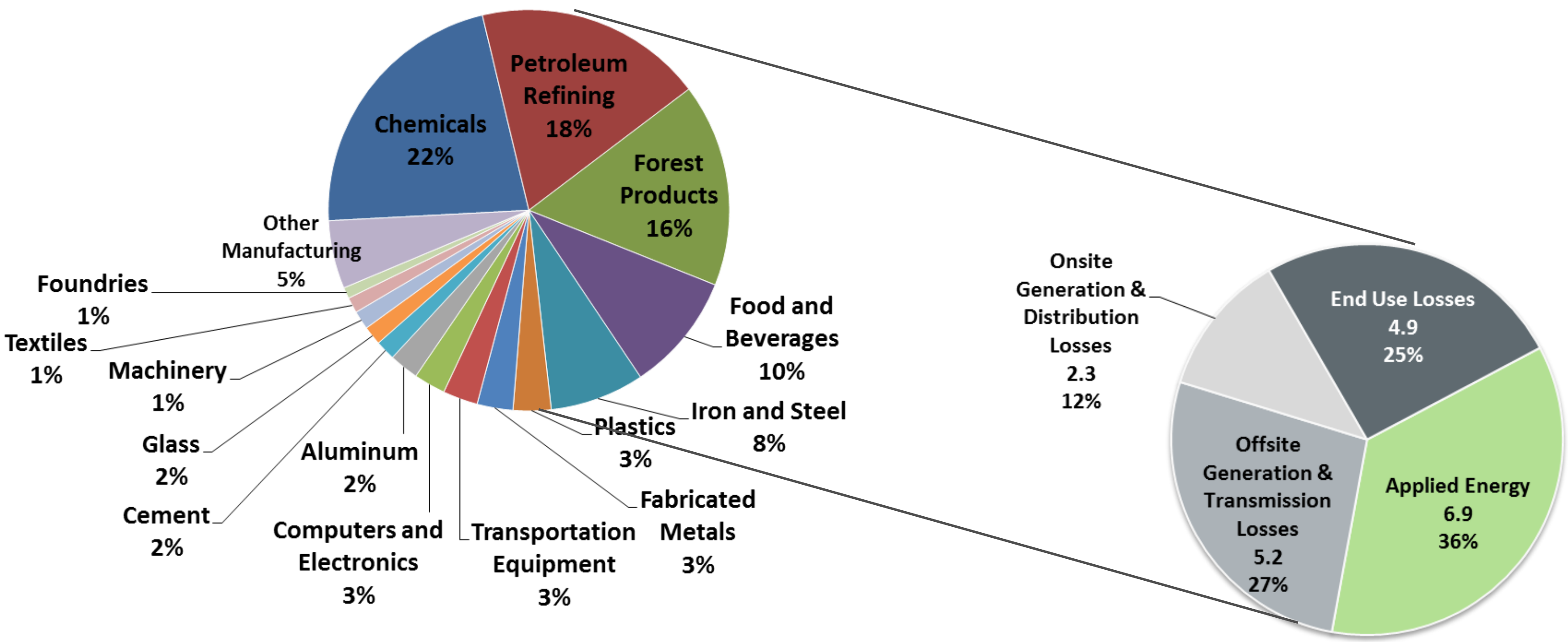
U.S. Economy: 95 Quads

Source: EIA Monthly Energy Review, Aug 2014

Source: AMO Manufacturing and Carbon Footprints. Feedstock energy not included

…to "Applied" Energy, revealing opportunities.

U.S. Manufacturing (no feedstocks) 19.2 Quads



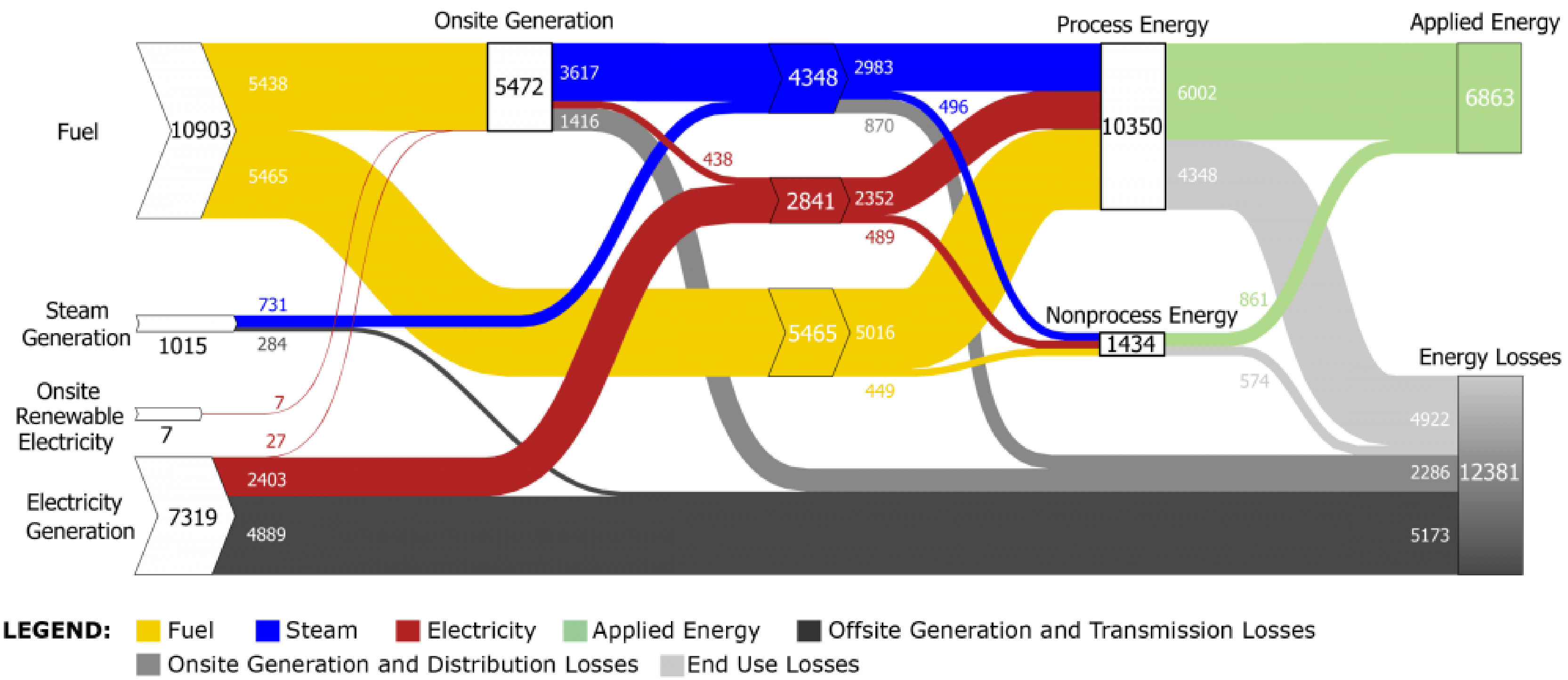
2012 Data

Source: EIA Monthly Energy Review, Aug 2014

Source: AMO Manufacturing and Carbon Footprints. Feedstock energy not included

System Highlights: Bottom-up assessment of technologies

U.S. Manufacturing Sector (TBtu), 2010



Note: 1 quad = 1,000 TBtu

System Highlights: Opportunity Space Impacted by Manufacturing

Energy Production

Energy Delivery

U.S. Energy Economy
95 quads

Transportation Sector 27 quads	Industrial Sector 31 quads
Residential Sector 20 quads	Commercial Sector 17 quads

Energy-efficient technologies reduce the 58 quads lost throughout the U.S. Energy Economy

Manufacturing, facility, and supply-chain improvements reduce the 12 quads lost within the industrial sector

Industrial Systems
31 quads

Supply-Chain Systems

Network of facilities and operations involved in moving materials through industry, from extraction of raw materials to the production of finished goods.

Production/Facility Systems

Equipment, process flow, and energy strategies that comprise a goods-producing facility

Manufacturing Systems

Equipment used for manufacturing process and nonprocess unit operations

Example: Petroleum Refining

Refining Industry ~4 quads

Petroleum Refinery ~26 TBtu

Facility Steam ~5 TBtu

Atmospheric Distillation Unit ~4 TBtu

Hydro-cracker ~2 TBtu

Catalytic Reformer ~3 TBtu

Note: 1 quad = 1,000 TBtu

- *Technologies for clean & efficient manufacturing*
- *Technologies to improve energy use in transportation*
- *Technologies to improve energy use in buildings*
- *Technologies to improve energy production and delivery*

System Highlights: Bottom-up assessment of technologies

	Example: Petroleum Refining	Example: Chlorine Production	Example: Additive Manufacturing
Supply-Chain Systems	Refining Industry ~4 quads	Chemicals Industry ~6 quads	Fabricated Metal Prod. Industry ~0.5 quads
Production/ Facility Systems	Petroleum Refinery ~26 TBtu Facility Steam ~5 TBtu	Chlorine Plant ~4 TBtu Water Cooling System <<1 TBtu	Powder Metallurgy Plant ~<1 TBtu Compressed Air System ~<1 TBtu
Manufacturing Systems	Atmospheric Distillation Unit ~4 TBtu Hydro-cracker ~2 TBtu Catalytic Reformer ~3 TBtu	Electrolytic Cell ~3 TBtu Drying Tower <1 TBtu Gas Compressor <1 TBtu	CAD Modeler <<1 TBtu 3D Printer <<1 TBtu Depowdering Station <<1 TBtu

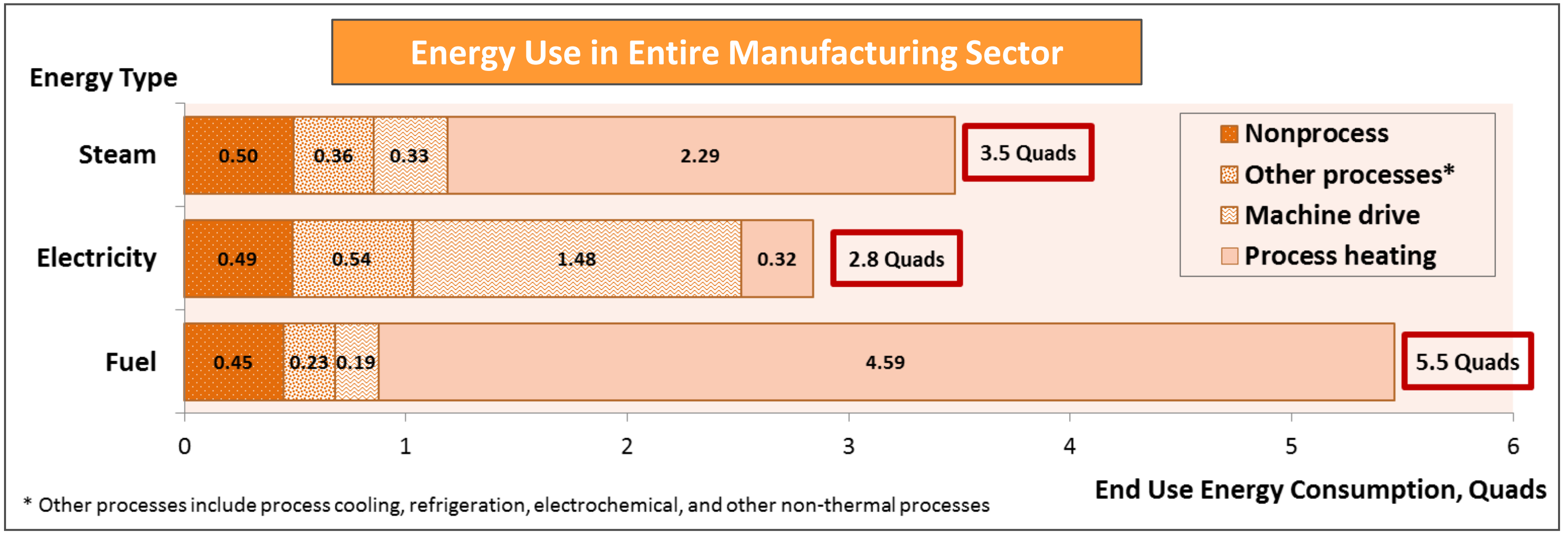
Note: 1 quad = 1,000 TBtu

R&D Strategy: Systems-of-Systems Approach to Manufacturing Energy Use Reveals Economy-Wide Opportunities

System Level	Examples	R&D Opportunity Examples
Manufacturing Systems *Technology and equipment used for manufacturing process and nonprocess unit operations*	• Composites/curing system • Chemicals separation system	• Transition from autoclave to out-of-the autoclave technology • Transition from distillation to membranes • Smart manufacturing equipment
Production/Facility Systems *Equipment, process flow, and energy strategies that comprise a goods-producing facility*	• Petroleum refinery • Vehicle assembly plant • Facility steam systems • Enterprise computer/control systems	• Process intensification • Smart enterprise systems • Advanced CHP systems • Grid-friendly equipment
Supply-Chain Systems *Facilities and operations involved in moving materials through an industry, from the extraction of raw materials to the production of finished goods.*	• Steel industry • Transportation equipment industry	• Recyclability/design for re-use • Alternative materials development • Use of low-carbon fuels and feedstocks • Market transformation opportunities

Transformative industrial technologies—achieved or advanced through R&D—feed into each of the system levels. Since manufactured products penetrate all sectors, **impacts are economy-wide.**

Interdependency of Manufacturing Systems and Production/Facility Systems



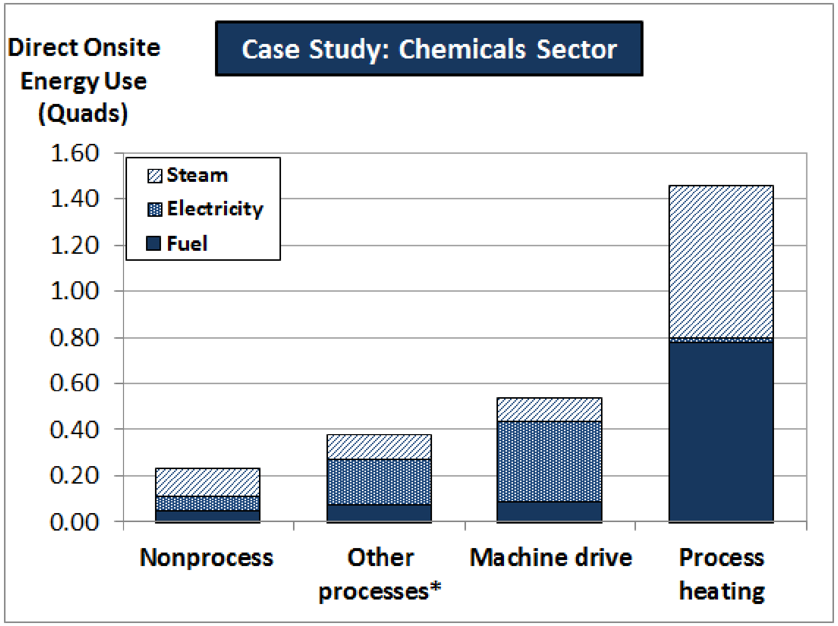
Machine-driven systems:
- Pumps, fans, compressors, etc.

Process heating systems:
- Furnaces, ovens, kilns, evaporators, dryers, etc.

Other process systems:
- Electrochemical systems , process cooling, etc.

Nonprocess systems:
- Facility HVAC, lighting, onsite transportation, etc.

Steam systems and other onsite generation:
- Boilers, cogeneration (CHP) equipment, other onsite electricity generation (solar or geothermal)



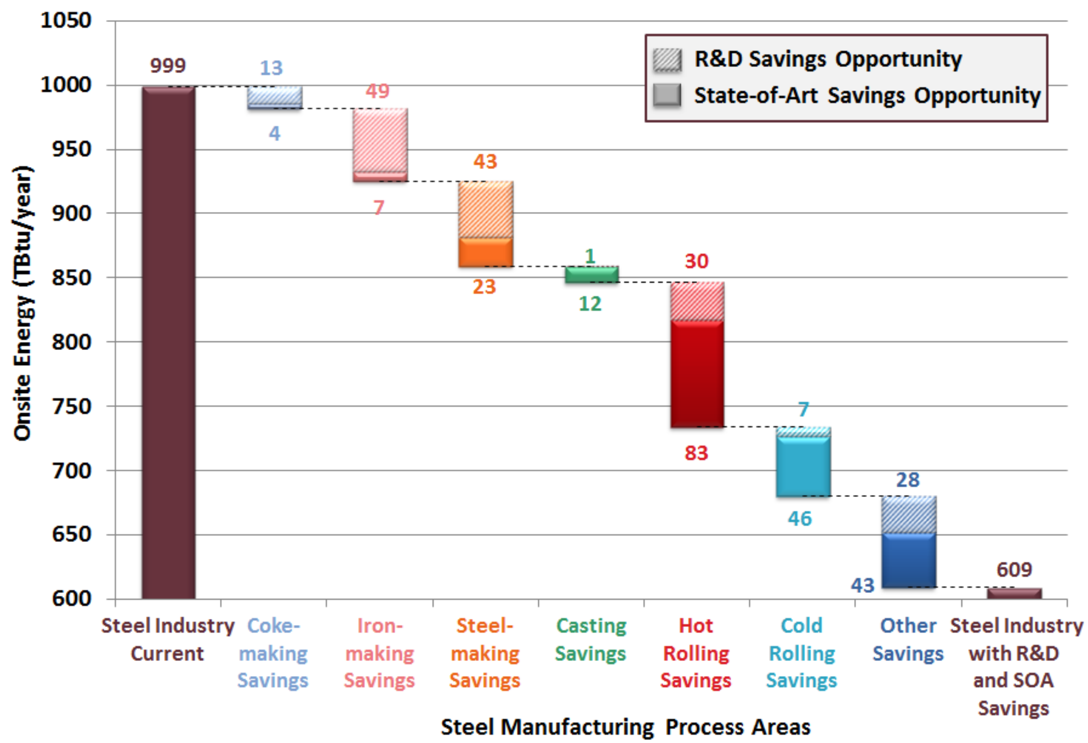
Technology Highlights – Energy Intensity Improvements

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

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

Use Intensity e.g.:
Recycling
Reuse and remanufacturing
Material efficiency and substitution
By-products
Product-Service-Systems

Technical Energy Savings Opportunities: Iron & Steel Industry



- **The 2014 Iron and Steel Industry Energy Bandwidth Study explores the energy intensity of steel manufacturing by major process area**
- **Energy bandwidths illustrate energy savings opportunity**
- **Greatest savings opportunity: ironmaking and steelmaking (R&D savings); rolling operations (overall savings)**

Source: DOE/AMO, Iron & Steel Industry Energy Bandwidth Study (2014)
Note: 1 quad = 1000 TBtu

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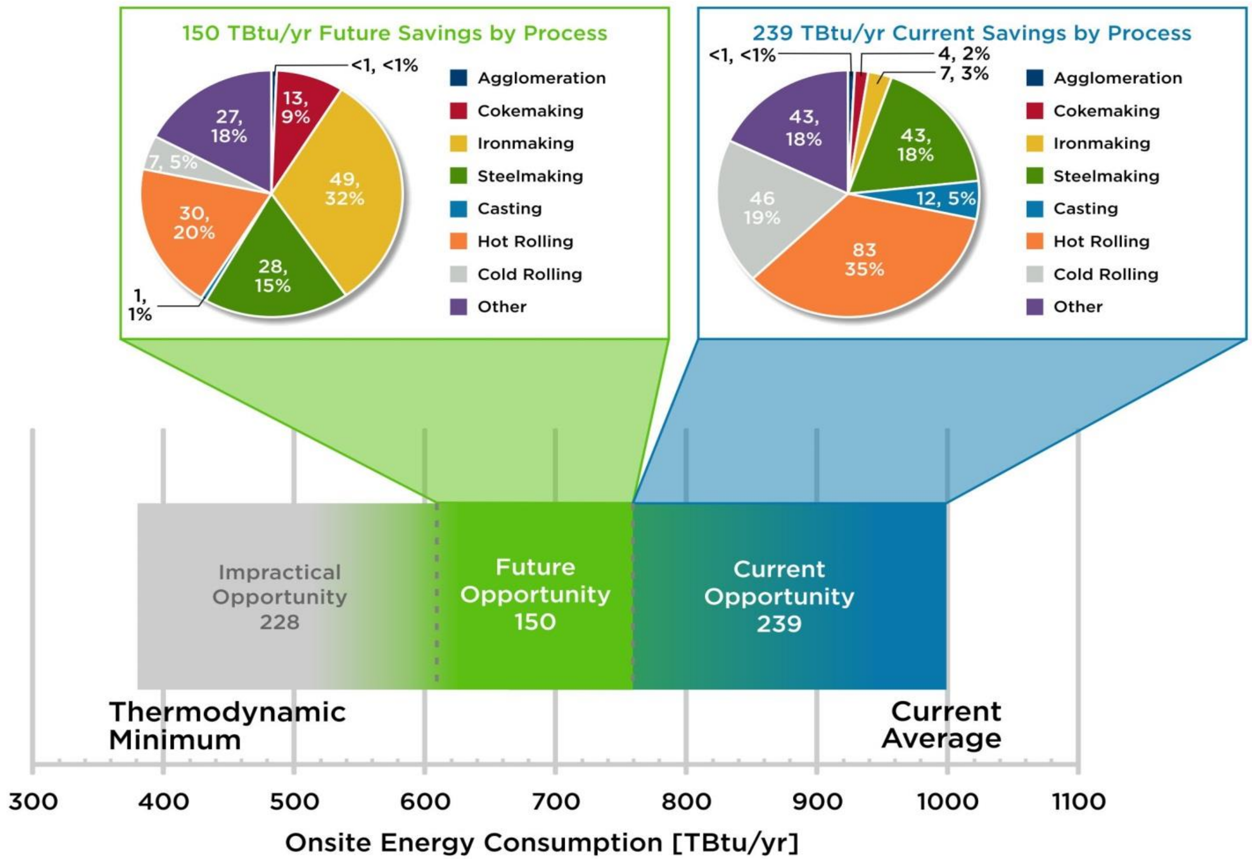

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Bandwidth Studies underway

Chemicals, e.g.:

- Advanced Distillation Technologies
- New Membranes (liquid, gas)
- New Catalysts

Pulp and Paper, e.g.:

- Black Liquor Gasification
- Directed Green Liquor Utilization
- New Fibrous Fillers

Petroleum Refining, e.g.:

- Thermal Cracking
- Progressive Distillation
- Dividing-wall Columns
- Improved Heat Integration

Iron and Steel, e.g.:

- Heat Recovery
- Slag Recycling
- Endless Rolling
- High Temperature Insulation Materials

Technology Highlights – Carbon Intensity Improvements

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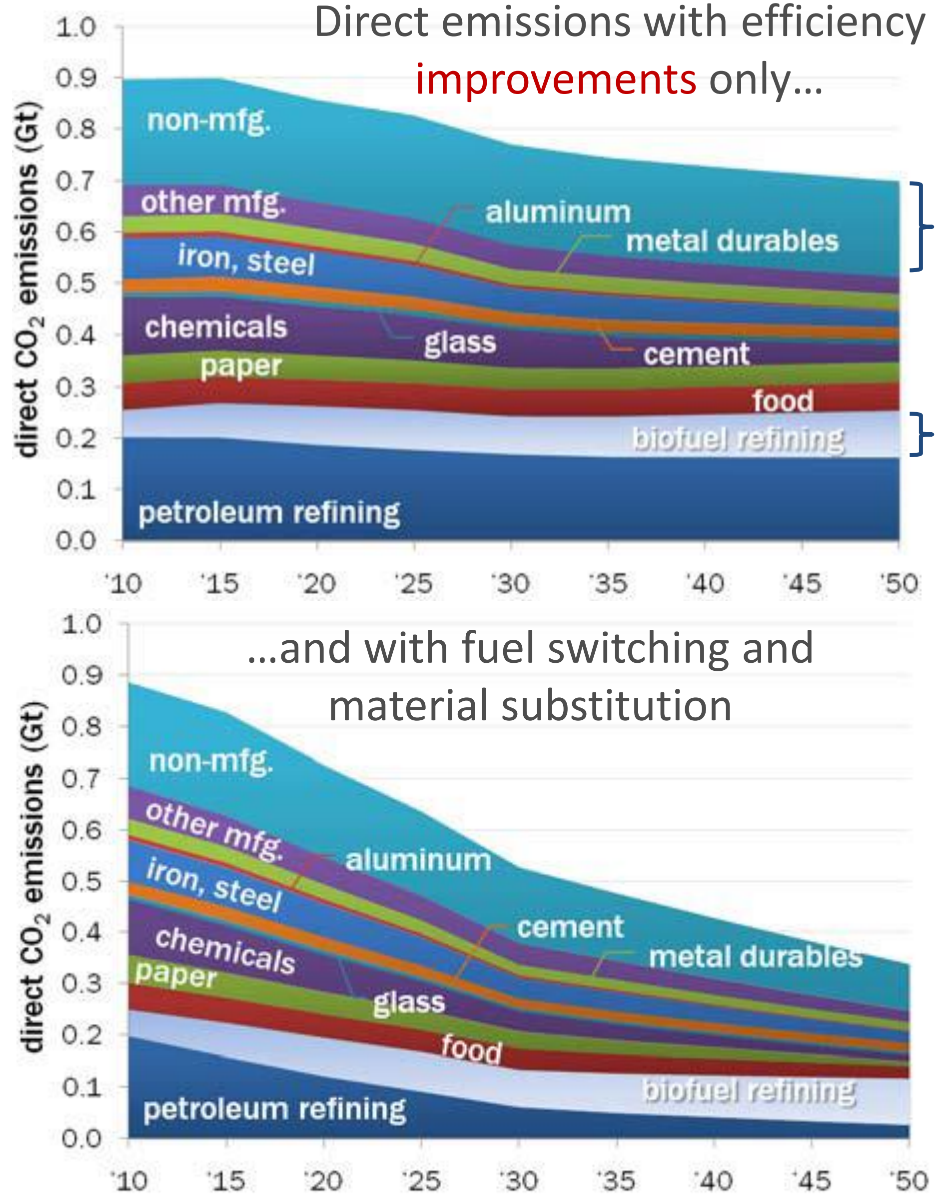
Product-Service-Systems



Agriculture, mining, construction: Opportunities for advanced engines, biofuels, etc.

Carbon capture and sequestration (CCS) technologies offer additional opportunities

Example analysis using the Buildings, Industry, Transport, Electricity Scenario (BITES) tool

Technology Highlights – Use Intensity Improvements

Energy Intensity e.g.:
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Use Intensity e.g.:
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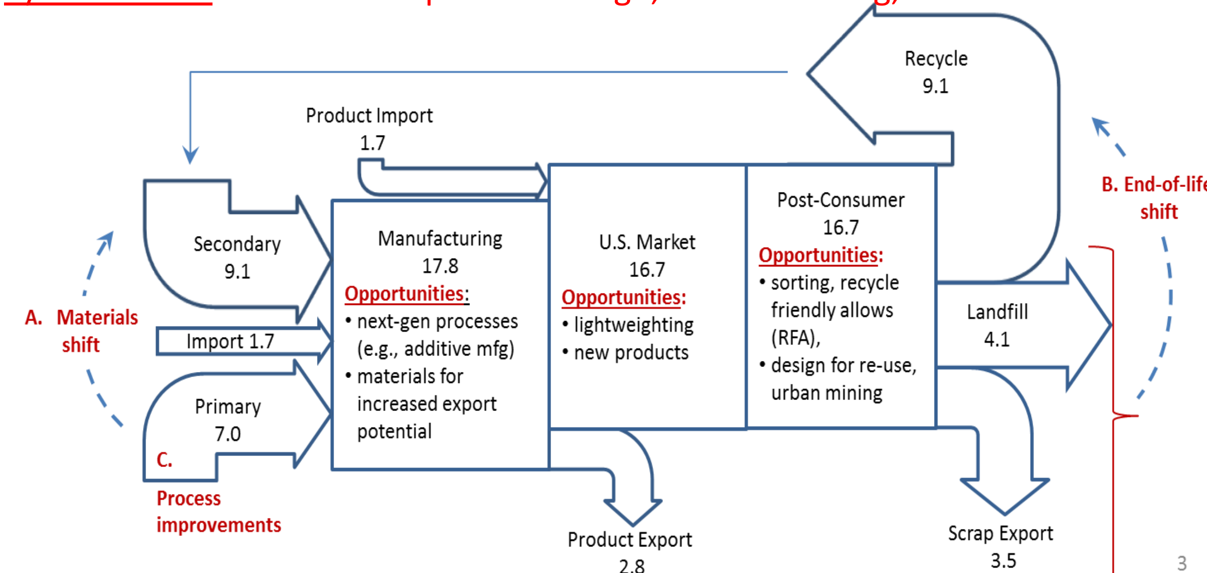
Material efficiency and substitution
By-products
Product-Service-Systems

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

23,800 btu/lb Materials shift

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

Case Study – Optimized Aircraft Bracket*

Primary Processing (15.9 MJ/kg)

Atomization (14.8 MJ/kg)

Conventional Machining - Buy-to-Fly Ratio 8:1

Mill Product (slab, billet, etc.) → Secondary Processing (8.72 kg) → Machined Product → Final Processing → Finished Part

Additive Manufacturing - Buy-to-Fly Ratio 1.5:1

Powder → (0.57 kg) → Electron Beam Melting (EBM) → Final Processing (0.38 kg) → Finished Part

*"Average" conventional bracket 1.09 kg, "average" AM bracket 0.38 kg

Process	Final part kg	Ingot consumed kg		Raw mat'l MJ	Manuf MJ	Transport MJ	Use phase MJ	End of life	Total energy per bracket MJ	Total energy per (120 brackets) MJ
Machining	1.09	8.72		8,003	952	41	217,949	Not considered	226,945	27.3 MM
EBM (Optimized)	0.38	0.57		525	115	14	76,282	Not considered	76,937	9.2 MM

Source: MFI and LIGHTEnUP Analysis

Key assumptions:

- Ingot embodied (source) energy 918 MJ/kg (255 kWh/kg)[5]
- Forging 1.446 kWh/kg[5] , Atomization 1.343 kWh/kg[6,7,8], Machining 9.9 kWh/kg removed[9], SLM 29 kWh/kg[10, 11], EBM 17 kWh/kg[10]
- 11 MJ primary energy per kWh electricity
- Machining pathway buy-to-fly 33:1[15], supply chain buy point = forged product (billet, slab, etc.)
- AM pathway buy-to-fly 1.5:1, supply chain buy point = atomized powder
- Argon used in atomization and SLM included in recipes but not factored into energy savings in this presentation

Technology Highlights – Use Intensity Improvements

Additive Manufacturing

Applications in Multiple Sectors

- **Lightweight components** for the transportation sector
- **Advanced tooling** for manufacturing
- **Custom products** and small-batch production
- Accelerated design cycles for **rapid product development**

R&D Challenges

- Fabrication of **large products**
- **Distributed manufacturing**
- **Time-quality** optimization
- Materials **efficiency**

Energy, cost, and environmental impacts (throughout life cycle) are application dependent.

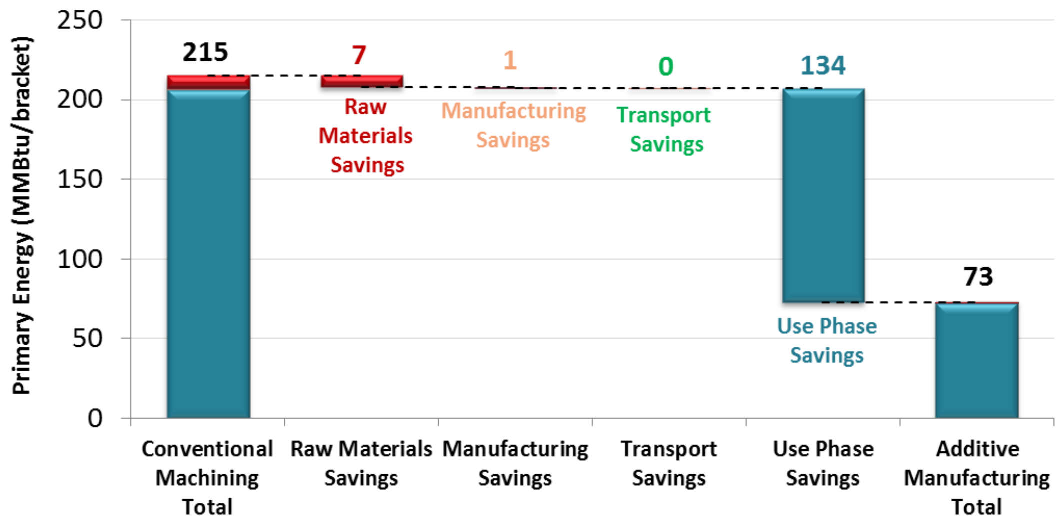
Case Study: Optimized Aircraft Bracket

1.09 kg

- 65% weight reduction
- 81% reduction in buy-to-fly ratio
- 66% energy savings
- Most savings occur in use phase

0.38 kg

Life-Cycle Energy Savings for Additive Manufactured Aircraft Bracket



Source: *MFI and LIGHTEnUP Analysis*

Note: 1 quad = 1 × 10^9 MMBtu

Technology Highlights – Use Intensity Improvements

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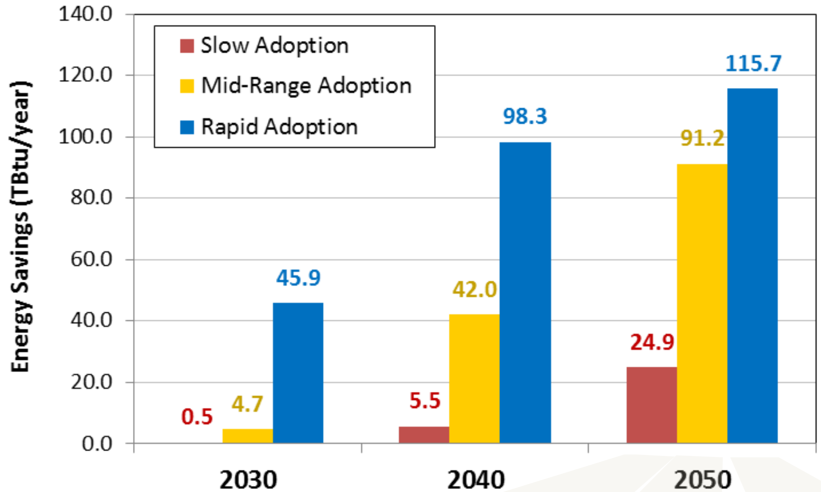
Impacts from Aircraft Fleet-Wide Adoption of Additive Manufacturing

Annual Energy Savings for Fleet-Wide Adoption of Additive Manufactured Components in Aircraft

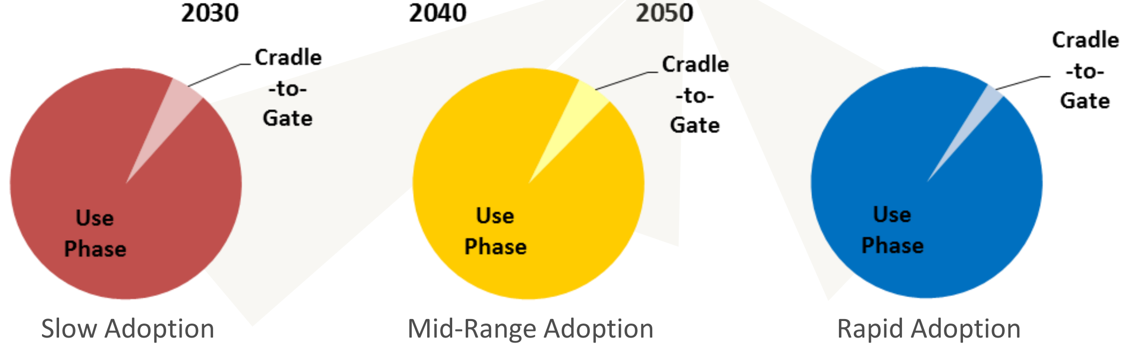


Scenario

Slow Adoption
new aircraft only

Mid-Range Adoption
new aircraft and new parts

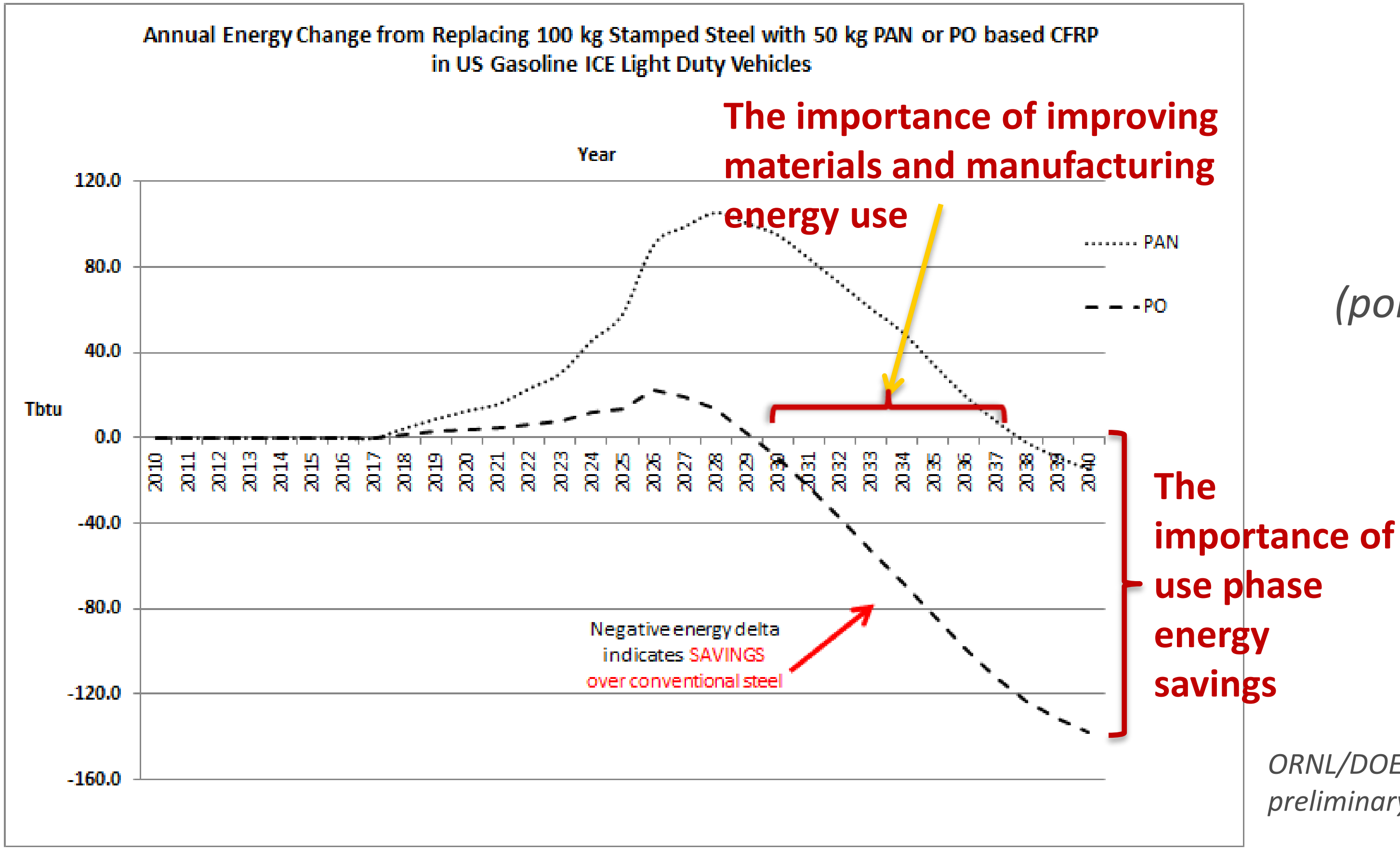
Rapid Adoption
new aircraft, new parts, and accelerated replacement



Energy Savings Breakdown: Over 95% of savings occur in use phase

Source: *R. Huang, et al.*, "The Energy and Emissions Saving Potential of Additive Manufacturing: The Case of Lightweight Aircraft Components." (Analysis In Progress). ***Note:*** 1 quad = 1,000 TBtu

Life Cycle Energy Consumption Savings from Lightweighting Carbon Fiber Reinforced Plastics (CFRP) vs. Steel



Improved CF
(polyolefin - PO)
versus
Current CF
(polyacrylonitrile - PAN)

ORNL/DOE analysis – preliminary results

- Carbon Fiber (CF) is currently ~ 5x more energy intensive than steel: savings accrue in the use phase
- Improved CF is ~ ½ energy intensity than PAN: 11,300 MJ/vehicle (PO) vs. 20,200 MJ/vehicle (PAN)
- Per vehicle savings over 13 yr, 250,000 km: 11,500 MJ per PO vehicle, 2600 MJ per PAN vehicle
- Penetration into US LDV fleet - Net energy impact of PO (dashed line) vs. PAN (dotted line): **Significantly improved materials and manufacturing energy investment improves net energy footprint**

Examples of Topics Addressed in Ch. 8

Introduction & Context
- Drivers for Industry & Manufacturing
- Industrial Energy Use & Greenhouse Gas Emissions
- Opportunity Space: Industrial Energy Efficiency
- Opportunity Space: Economy-Wide Impacts of Manufactured Products
- DOE's Role in Strengthening U.S. Manufacturing

Systems: Manufacturing Systems
- Process heating systems
- Motor driven systems
- Steam systems and onsite generation
- Other process and nonprocess systems

Systems: Production Systems
- Industry bandwidth studies
- Process intensification and system integration
- Industrial demand-side management
- Industrial carbon capture and storage
- Efficient use of delivered energy

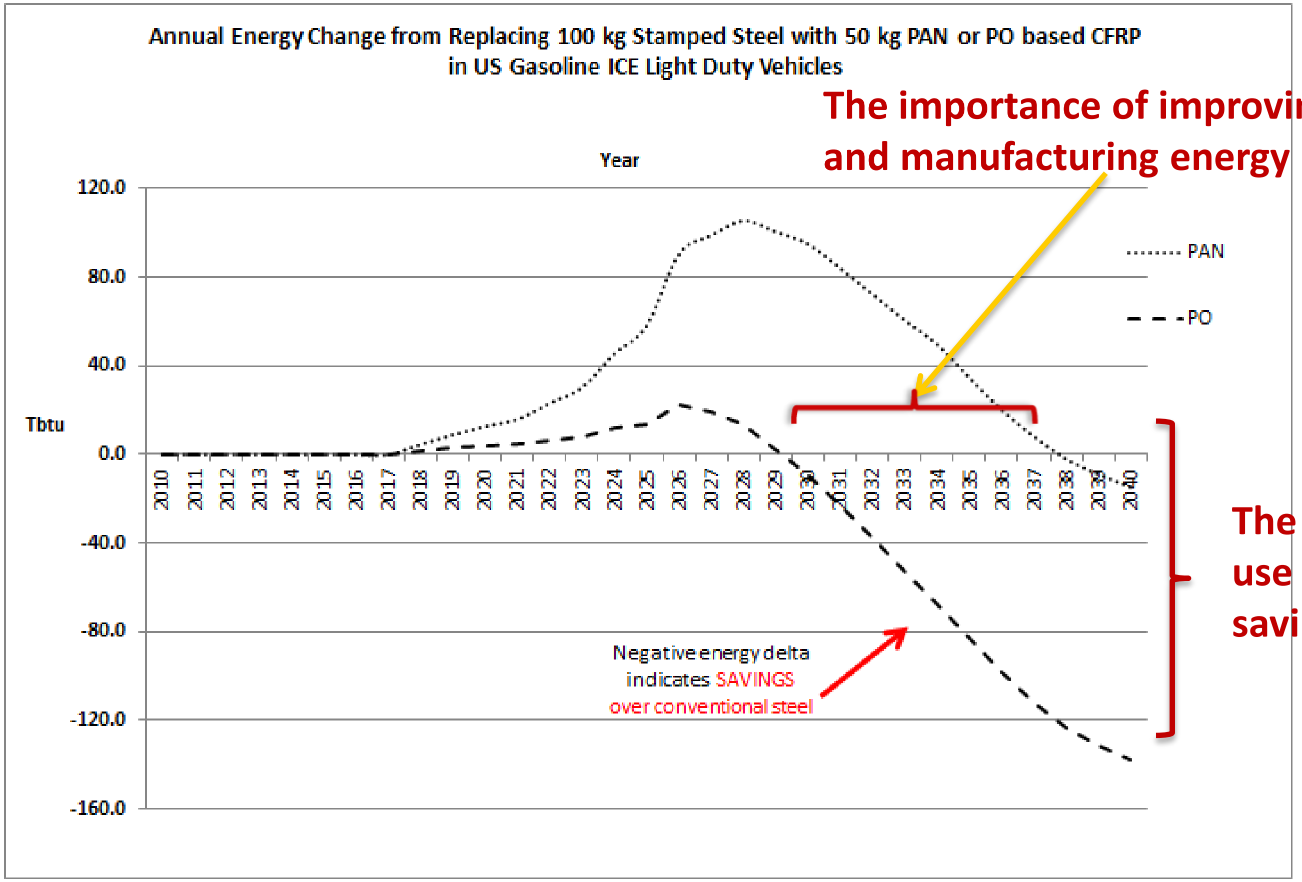
Systems: Supply-Chain Systems
- Minimizing materials use
- Alternative and functional materials
- Materials genome, computational manufacturing
- Recyclability & design for re-use
- Low-Carbon, domestic fuels & feedstocks
- Water/energy systems

Technologies
- Additive Manufacturing
- High-Efficiency Separations
- Roll-to-Roll Processing
- Wide Bandgap Power Electronics and Motor Drive
- Waste Heat Recovery
- Advanced Metrology for Real-Time Process Improvement
- Smart Manufacturing
- Composite Materials
- Energy Conversion Technologies

Life cycle, cross-sector example - Energy Consumption Savings from Lightweighting

50 kg Carbon Fiber Reinforced Plastics (CFRP) replacing 100 kg Steel;

Improved CF (polyolefin) vs. current CF (polyacrylonotrile)



Why manufacturing energy use matters – accounting for vehicle turnover.

- Savings of 2600 MJ per polyacrolynonitrile (PAN) vehicle and 11,500 MJ per polyolefin (PO) vehicle
- Net energy impact of PO (dashed line) in US LDV fleet also compared with PAN (dotted line)
- Significantly greater materials and manufacturing energy investment with PAN – net energy savings temporally delayed and lesser magnitude

Characteristics of Key Technologies

Opportunity for DOE to Invest in Technologies that are:

- **Transformative:** Result in significant change in the life-cycle impact (energetic or economic) of manufactured products
- **Pervasive**: Create value in multiple supply chains, diversifies the end use/markets, applies to many industrial/use domains in both existing and new products and markets
- **Globally Competitive**: Represent a competitive/strategic capability for the United States
- **Significant in Clean Energy Industry**: Have a quantifiable *energetic* or *economic* value (increase in value-added, increase in export value, increase in jobs created)

Industry & Manufacturing Technology Assessments

1. Thermoelectric Materials, Devices, and Systems

- Thermoelectric materials (bismuth telluride, lead telluride, etc.), including high-ZT materials
- Waste heat recovery equipment
- Thermoelectric generation of electricity

2. Wide Bandgap Power Electronics

- Opportunities for silicon carbide (SiC) and gallium nitride (GaN) to replace silicon (Si) in power electronics
- Applications including AC adapters, data centers, and inverters for renewable energy generation

3. Composite Materials

- Advanced composite materials, e.g. carbon fiber reinforced polymers
- Structural composite materials for lightweighting, including automotive, wind, and gas storage applications
- Forming and curing technologies for thermosetting and thermoplastic polymer composites

4. Critical Materials

- Permanent magnets for wind turbines and electric vehicles
- Phosphors for energy efficient lighting
- Supply diversity and global material criticality

5. Roll-to-Roll Processing

- Roll-to-roll (R2R) applications such as flexible solar panels, printed electronics, thin film batteries, and membranes
- Deposition processes such as evaporation, sputtering, electroplating, chemical vapor deposition, and atomic layer deposition
- Metrology for inspection and quality control of R2R products

Industry & Manufacturing Technology Assessments

6. Process Heating

- Fuel, electricity, steam, and hybrid process heating systems
- Sensors and process controls for process heating equipment
- Process heating energy saving opportunities, e.g. waste heat recovery, non-thermal drying, and low-energy processing

7. Combined Heat and Power

- CHP use in the manufacturing sector
- Bottoming and topping cycles
- R&D opportunities for CHP, such as advanced reciprocating engine systems, packaged CHP systems, and fuel-flexible systems

8. Additive Manufacturing

- 3-D printing technologies including powder bed fusion, directed energy deposition, material extrusion, vat photopolymerization, material jetting, and sheet lamination
- Material compatibility for additive manufacturing technologies, including homogenous (e.g., metals) and heterogeneous materials (e.g., reinforced polymer composites)

9. Advanced Sensors, Controls, Modeling and Platforms

- Smart systems and advanced controls
- Advanced sensors and metrology, including power/cost sensors and component tracking across the supply chain
- Distributed manufacturing
- Predictive maintenance
- Product customization
- Cloud computing and optimization algorithms

Industry & Manufacturing Technology Assessments

10. Flow of Materials through Industry (Sustainable Manufacturing)

- Supply chain issues, from resource extraction to end of life (life cycle analysis)
- Mechanisms for reducing material demand, such as lightweighting, scrap reduction, recycling, and increased material longevity
- Design for re-use / recycling

11. Process Intensification

- Process intensification equipment and methods
- Application areas where process intensification could provide solutions to energy, environmental, and economic challenges
- Feedstock use and feedstock conversion technologies
- Focus on the energy-intensive chemical sector

12. Waste Heat Recovery

- Waste heat recovery technologies, including recuperators, recuperative burners, stationary and rotary regenerators, and shell-and-tube heat exchangers
- Major waste heat sources such as blast furnaces, electric arc furnaces, melting furnaces, and kilns
- Opportunities for low, medium, and high-temperature waste heat recovery

Industry & Manufacturing Technology Assessments

13. Materials for Harsh Service Conditions

- Materials for extreme environments including high temperatures, high pressures, corrosive chemicals, heavy mechanical wear, nuclear radiation, and hydrogen exposure, e.g.:
- Phase stable alloys for ultrasupercritical turbines and high-temperature waste heat recovery
  - Corrosion-resistant materials for pipeline infrastructure
  - Irradiation-resistant materials for nuclear applications
  - Functional coatings for aggressive environments

14. Next Generation Materials and their Manufacture

- Emerging processes for production of advanced materials, such as magnetic field processing, plasma surface treatments, atomically precise manufacturing, powder metallurgy, and advanced joining technologies for dissimilar materials
- Materials Genome as related to materials design for Clean Energy Manufacturing
- Computational Manufacturing
- Technologies to accelerate the development of key materials with important use-phase attributes (e.g., lightweighting, corrosion resistance), including manufacturing, secondary processing, and recycling

Technology Assessment Comment Form

Tech Assessments **Comment Form** (with instructions) will be posted on the website.

http://energy.gov/downloads/webinar-qtr-chapter-8-industry-and-manufacturing

- Comment Period for Chapter 8 Technology Assessments: Feb. 11th – **Feb 24th**.
- Comments to be entered on the **Comment Form** (attached).
- **Comment Forms** to be sent to this email address: QTR_Chapter8@ee.doe.gov
- Comments will not be accepted after **Feb. 24th**.

NOTE: THE DEADLINE GIVEN IN THE WEBINAR RECORDING IS INCORRECT!

Thanks for your participation!