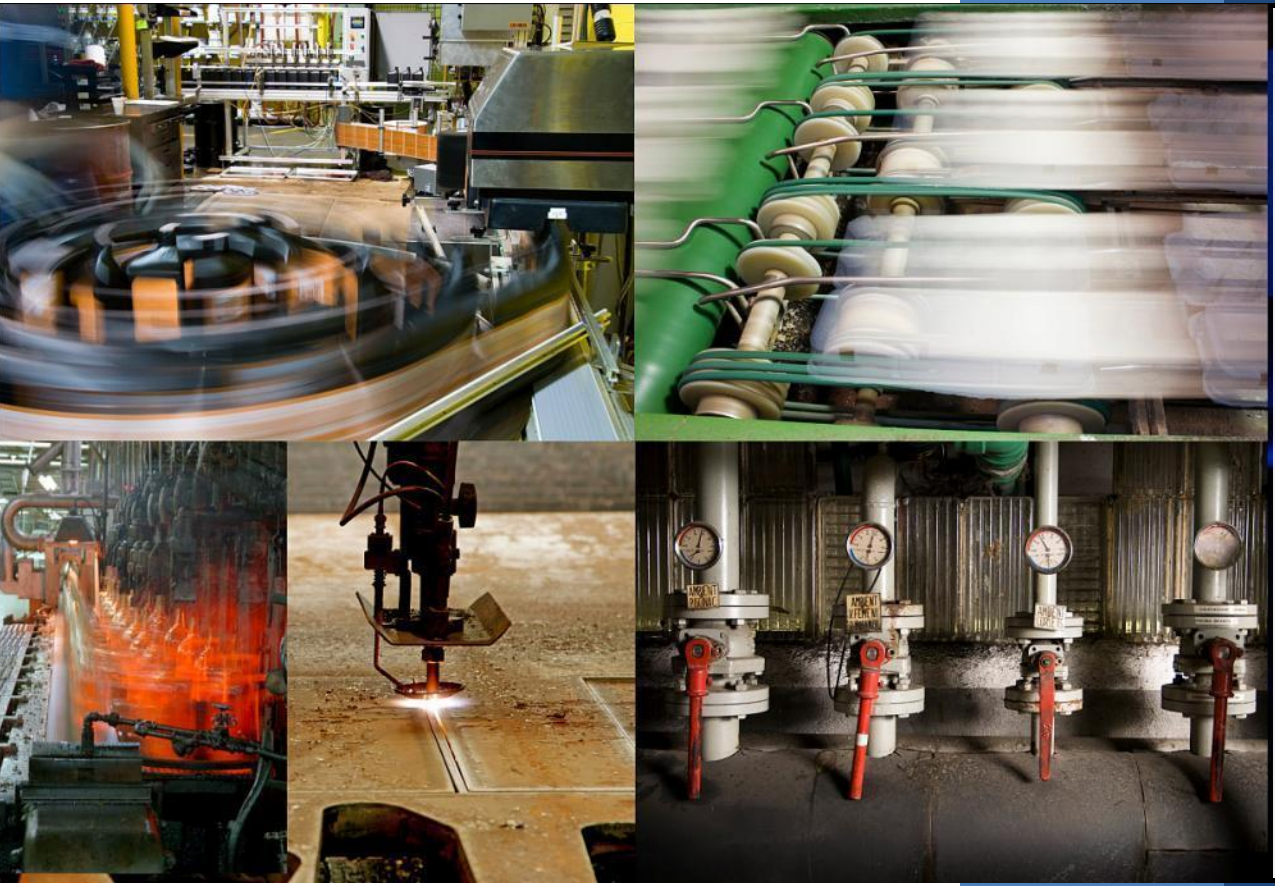


ANL – Diane Graziano, Matt Riddle, Sarang Supekar

LBNL – Arman Shehabi, William Morrow, Sarah Smith, Prakash Rao

NREL – Alberta Carpenter, Maggie Mann, Rebecca Hanes, Samantha Reese, Kelsey Horowitz, Timothy Remo

ORNL – Sujit Das, Sachin Nimbalkar, Pablo Cassorla, Kristina Johnson

Energetics – Sabine Brueske, Heather Liddell, Caroline Dollinger, Hani Hawa

AMO Strategic Analysis Activities

Joe Cresko - Advanced Manufacturing Office, DOE

AMO Peer Review

Arlington, VA
June 13, 2017

This presentation:

- Context for AMO strategic analysis
- Integrating the analyses within AMO's portfolio
- Examples to describe strategic analysis approaches

AMO Strategic Analysis – **POSTERS**

Manufacturing in a Connected Economy

How will the penetration of "smart" products and the Internet-of-Things affect advanced manufacturing R&D opportunities?

Clean Water

What are the opportunities and impact of improved Desalination Technology?

Analysis Methodology, Tools & Integrating Analysis

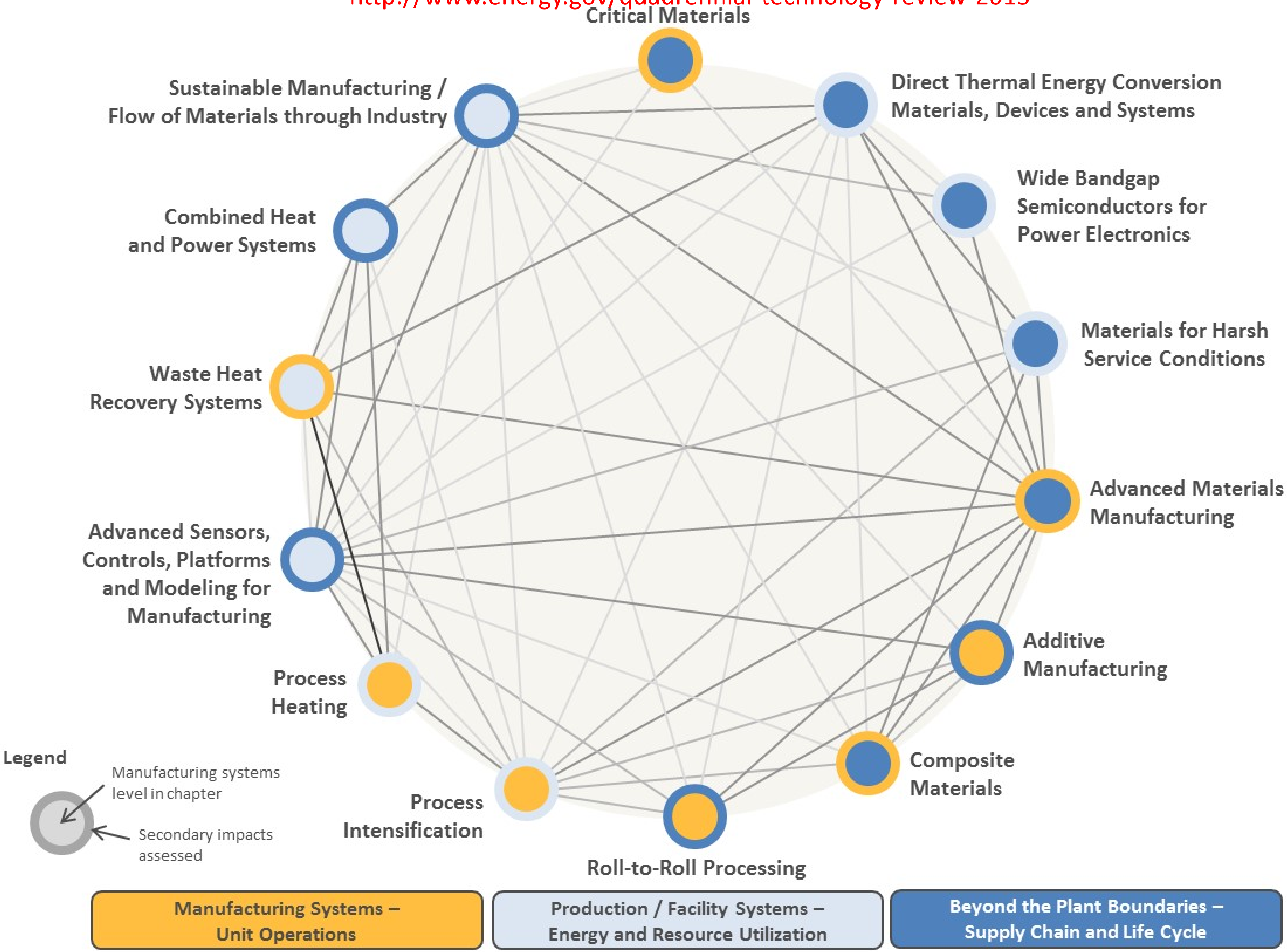
What are the opportunities and impact of advanced manufacturing technologies on productivity and competitiveness?

Sustainable Manufacturing

What are the opportunities and impact of advanced manufacturing technologies on energy productivity and competitiveness?

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

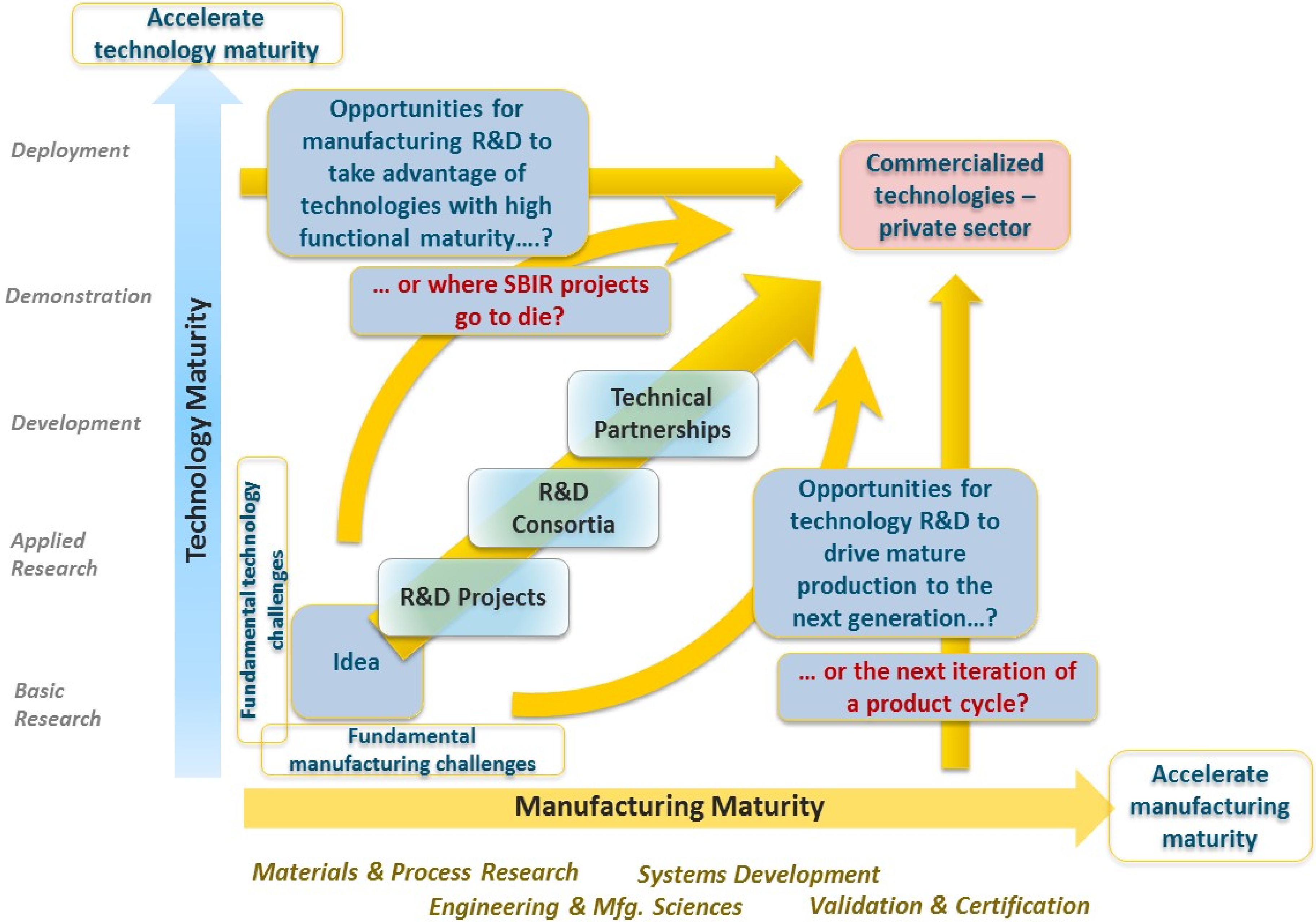
- Describes the Office mission, vision, and goals
- Identifies the technology, outreach, and crosscutting activities the Office plans to focus on over the next five years.

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

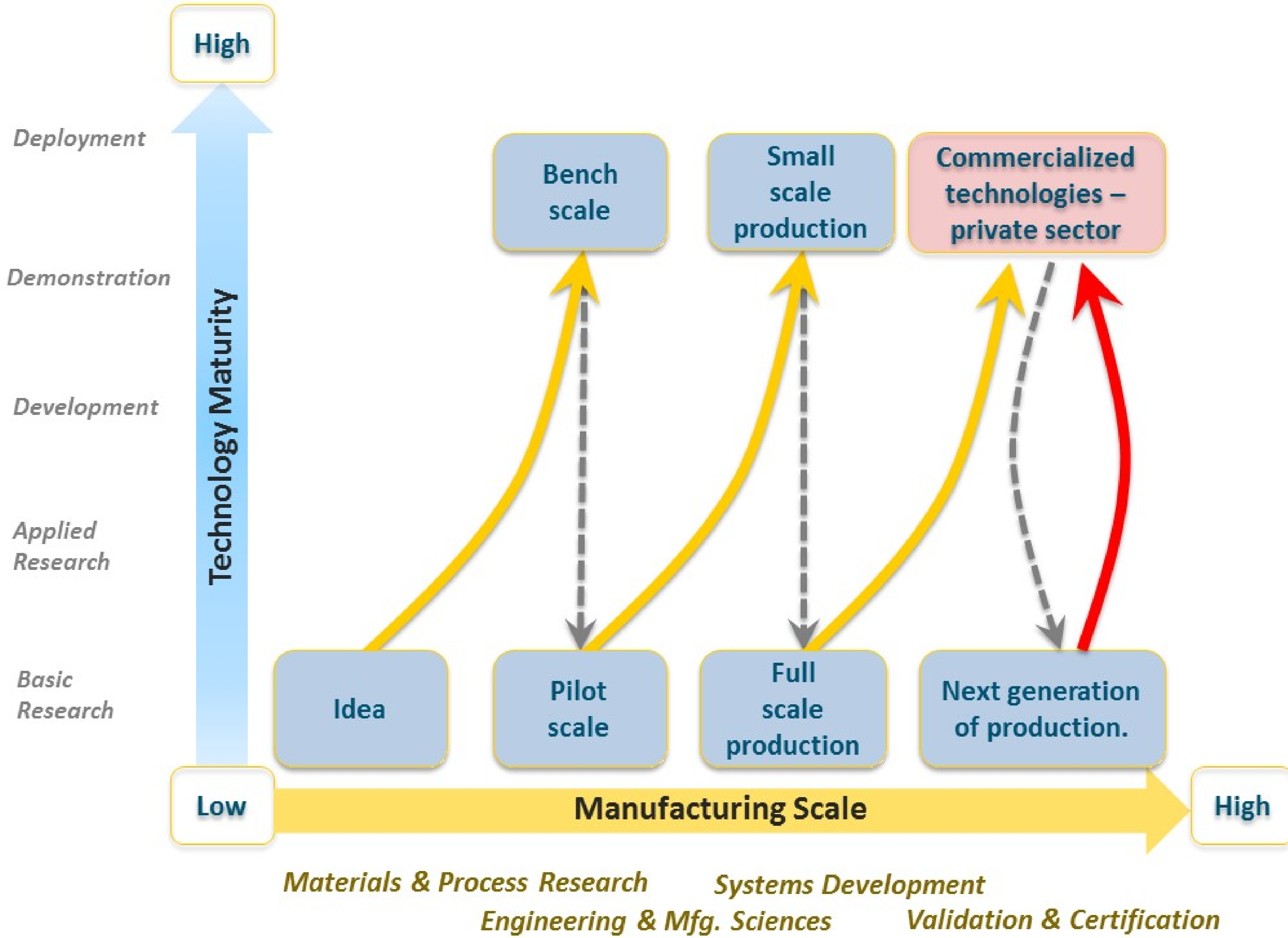
Public feedback and comments can be sent to AMO_MYPPInfo@ee.doe.gov

AMO Multi-Year Program Plan (MYPP) Framework

AMO opportunities to reduce uncertainty in technology and manufacturing



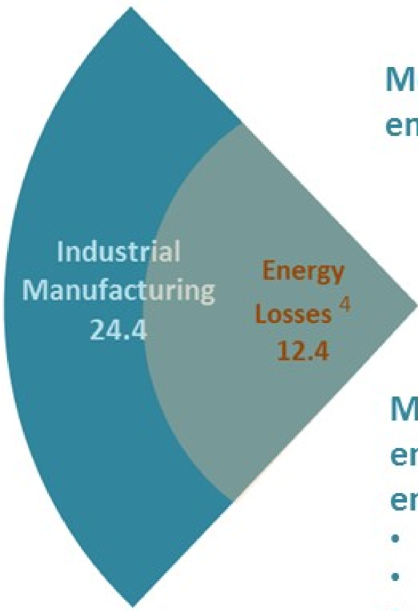
AMO pathways to advance technology maturity and manufacturing scale



What is the broader energy opportunity space for advanced manufacturing?

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

Manufacturing Goods

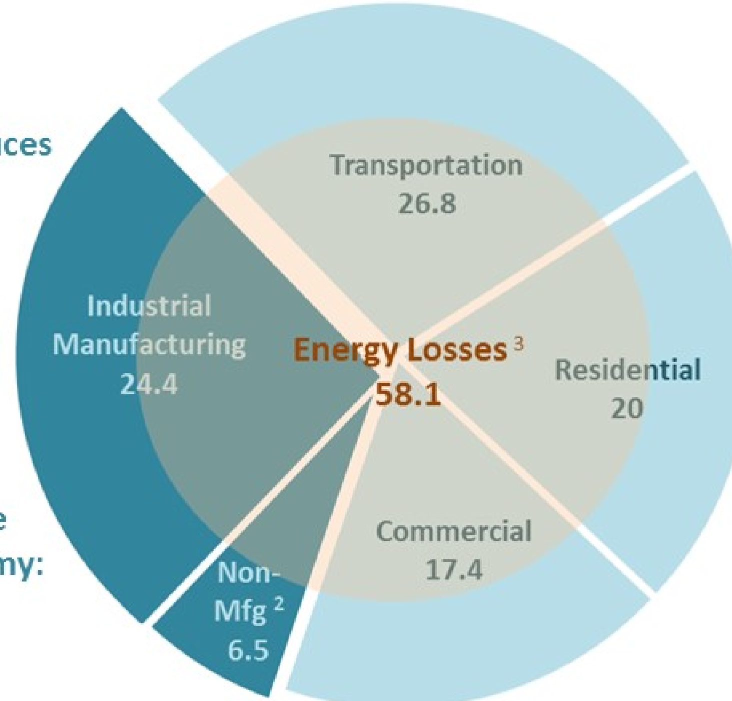


More efficient manufacturing reduces energy losses.

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)

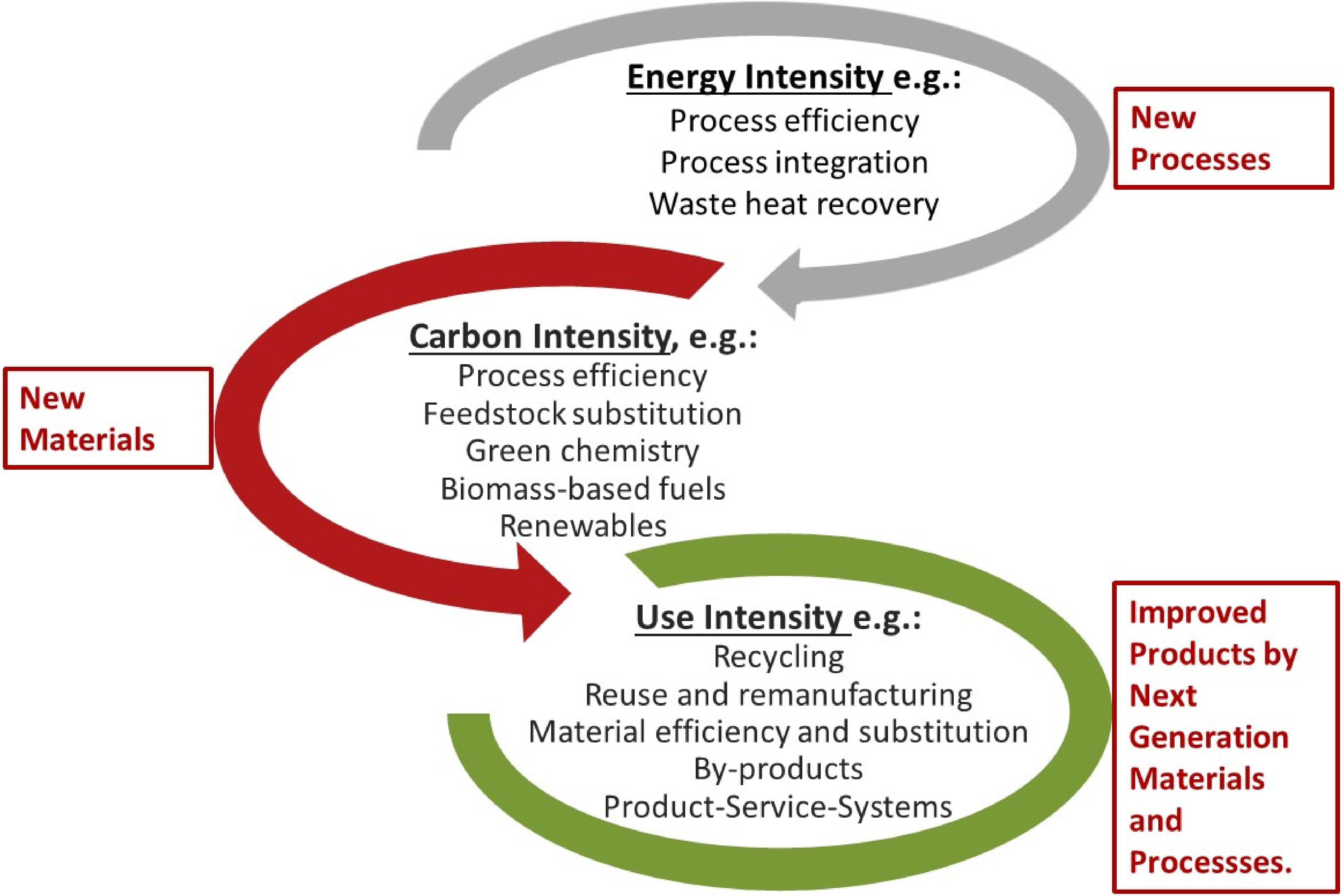
Setting and Quantifying Goals

Success Indicators

- Demonstrate selected advanced manufacturing technologies and deploy practices that increase the rate of **energy intensity** improvement from business as usual (~1 % per year) to 2.5% per year.
- Develop advanced materials, manufacturing technologies, and targeted end use products with the potential to reduce **lifecycle energy impact** by 50% by 2025 compared to the 2015 state-of-the-art.

How do advances in composites manufacturing contribute?

Drivers to Reduce Energy & Emissions through the Product Life Cycle



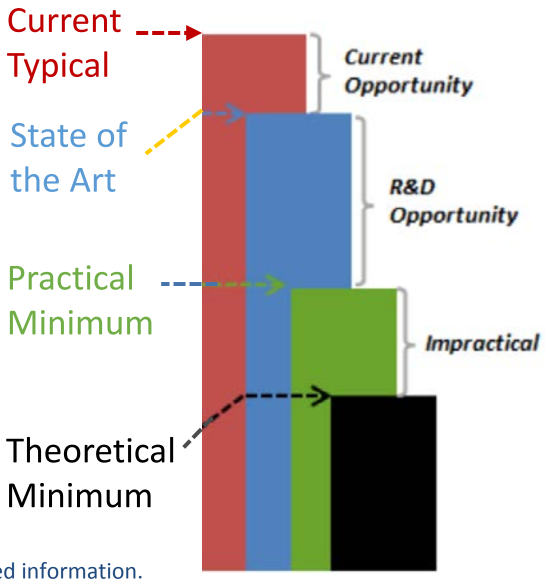
Develop studies to provide foundational data in multiple sectors

Bandwidth Studies: Recently Completed and In-Progress

Collaborators: NREL; LBNL; Energetics

2015 (published)	**Manufacturing sector bandwidth studies:** • Chemicals • Iron & Steel • Pulp & Paper • Petroleum Refining
2016 (Under Peer Review)	**Lightweight materials bandwidth studies:** • Aluminum • Advanced High Strength Steel • Titanium • Magnesium • Carbon Fiber Reinforced Polymer Composites • Glass Fiber Reinforced Polymer Composites
Analysis near completion	**Water/energy studies:** • Desalination Review Study • Desalination Bandwidth Study **Manufacturing sector bandwidth studies:** • Plastics & Rubber Products • Cement • Glass • Food & Beverage **Follow-on analysis:** • Lightweight Materials Integrating Analysis

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



Example - from QTR to Multi-Year Program Planning

Additive Manufacturing – Targets

Supply-Chain Systems

Demonstrate AM components whose physical properties and cost/value outperform selected conventionally produced parts by 20%.

Production/Facility Systems

Develop next-generation AM systems that deliver consistently reliable parts with predictable properties to six standard deviations ("six-sigma") for specific applications.

Manufacturing Systems/Unit Operations

Develop rapid qualification methodologies that reduce certification cost to 25% of the total component cost

Composite Materials – Targets

Supply-Chain Systems

Develop technologies that reduce embodied energy and manufacturing GHG emissions of carbon fiber reinforced polymer (CFRP) by 75% compared to 2015 current typical technology.

Production/Facility Systems

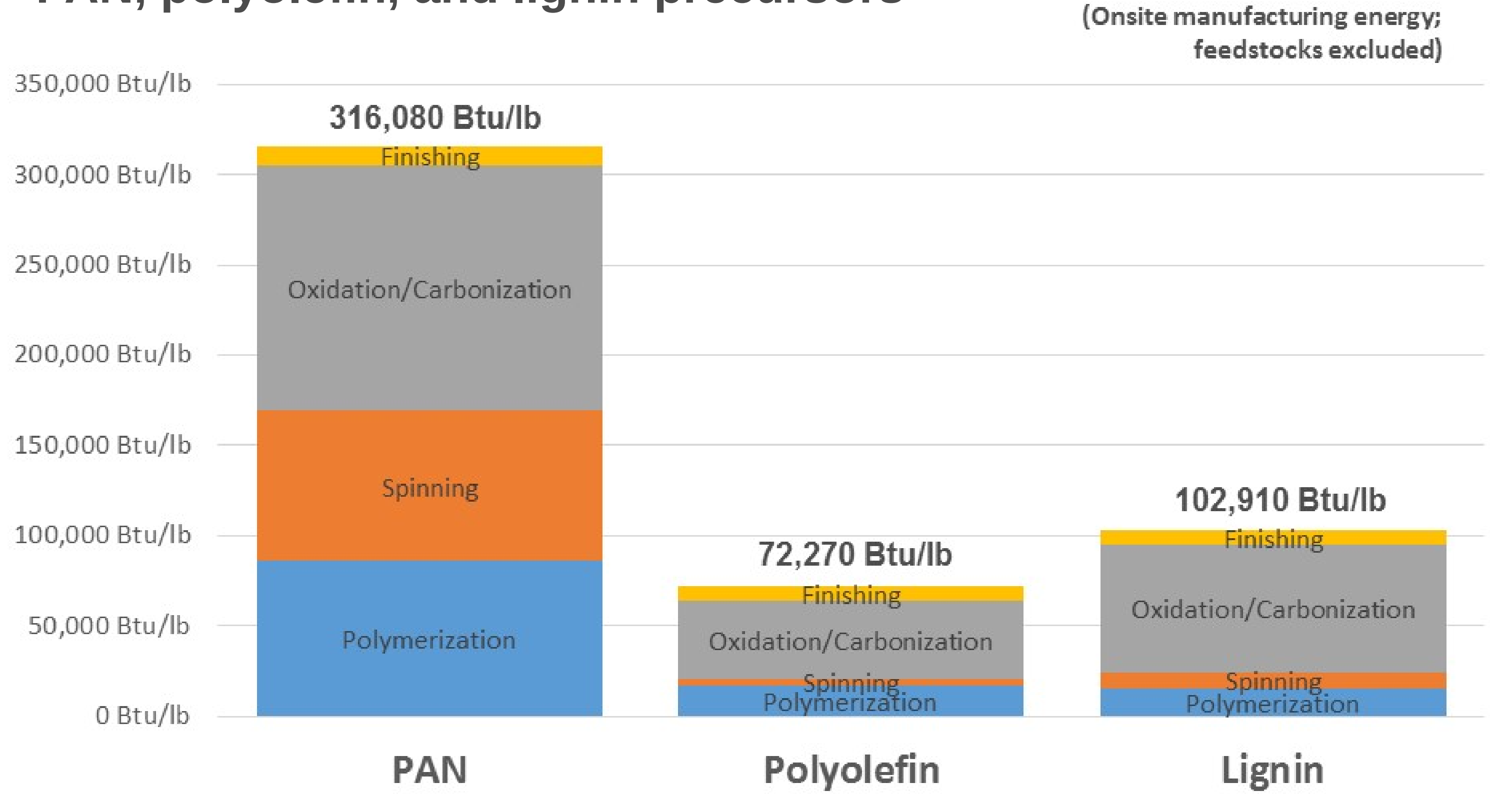
Reduce production cost of finished CFRP components for targeted clean energy applications by 50% compared to 2015 state-of-the-art technology.

Manufacturing Systems/Unit Operations

Develop composite molding process with <90 second part-to-part cycle time for a structural component with surface area >0.5m^2

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

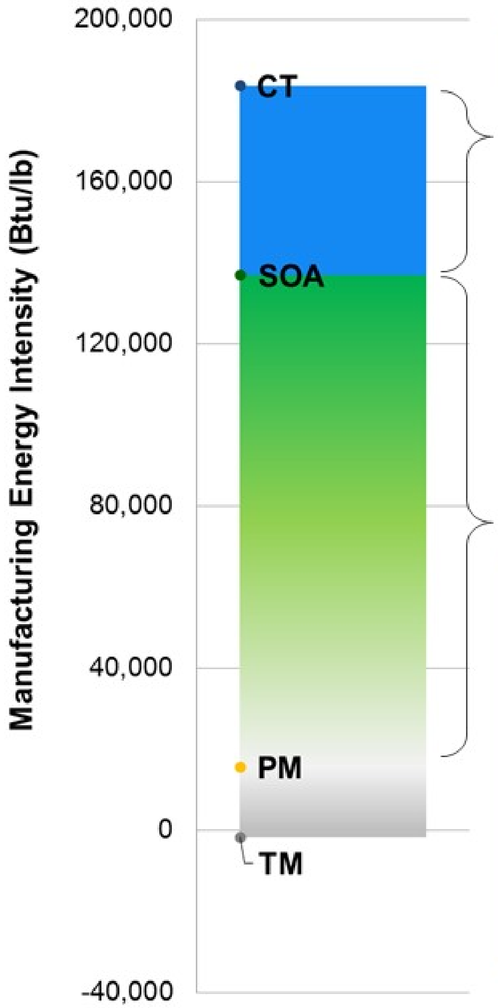


Carbon fiber production from novel precursors (including materials that may not be in use as precursors today) represents a key technology development opportunity for R&D.

* 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

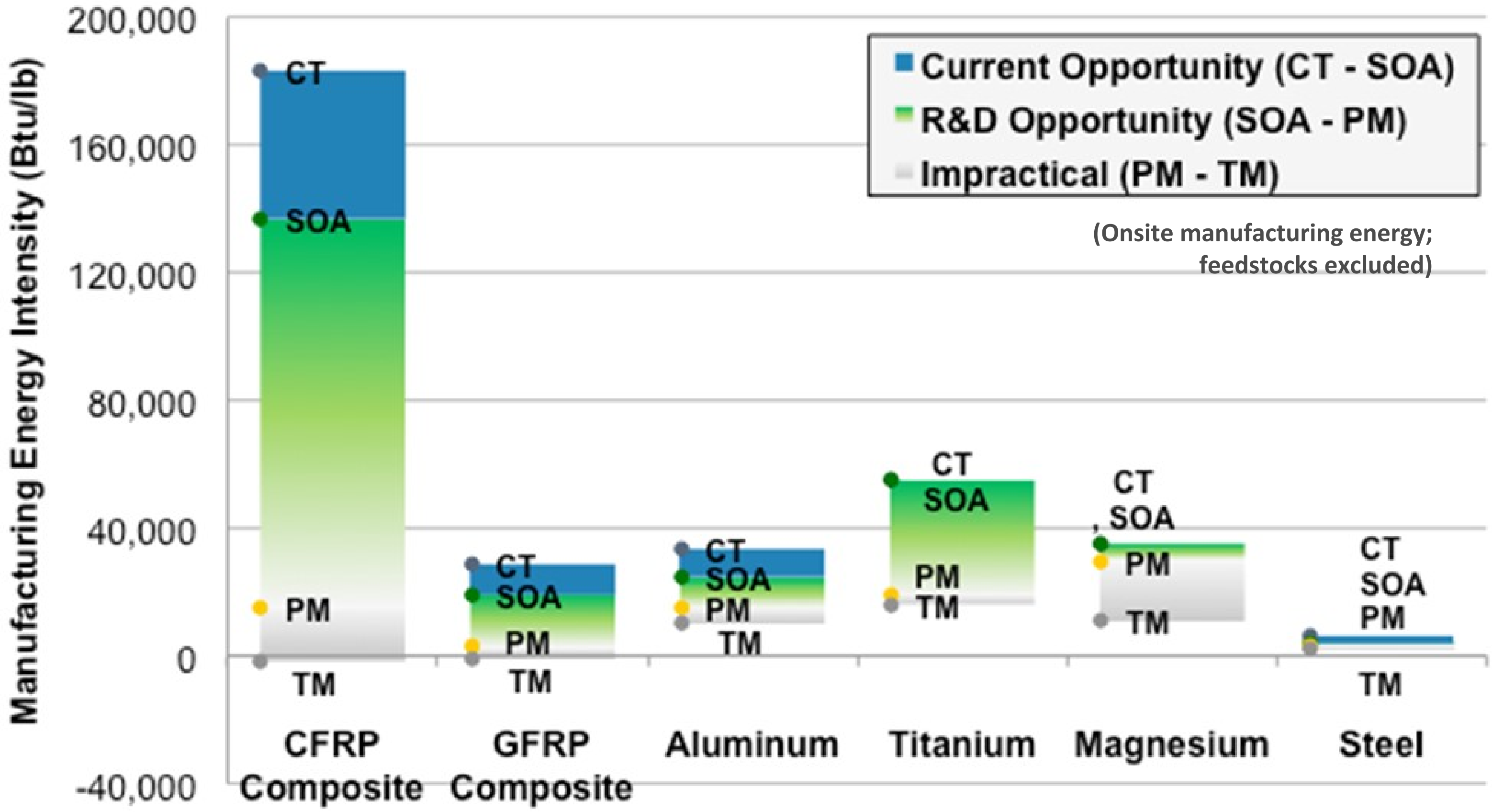
Additional energy savings if applied R&D technologies under development worldwide were successfully deployed

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.

With R&D advances, carbon fiber composites could compete with incumbent materials on an energy intensity basis



High manufacturing energy use drives costs up and reduces competitiveness with incumbent materials

CFRP composites have the highest manufacturing energy intensity, they also have the largest energy savings opportunity.

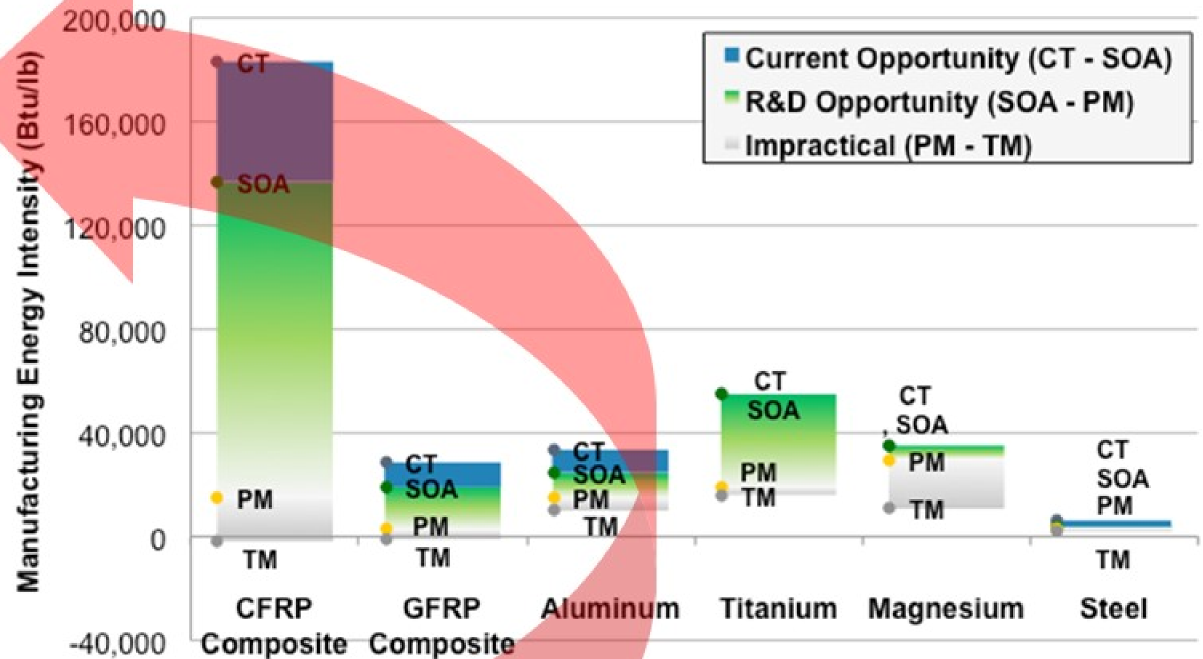
https://energy.gov/eere/amo/energy-analysis-sector

Use 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

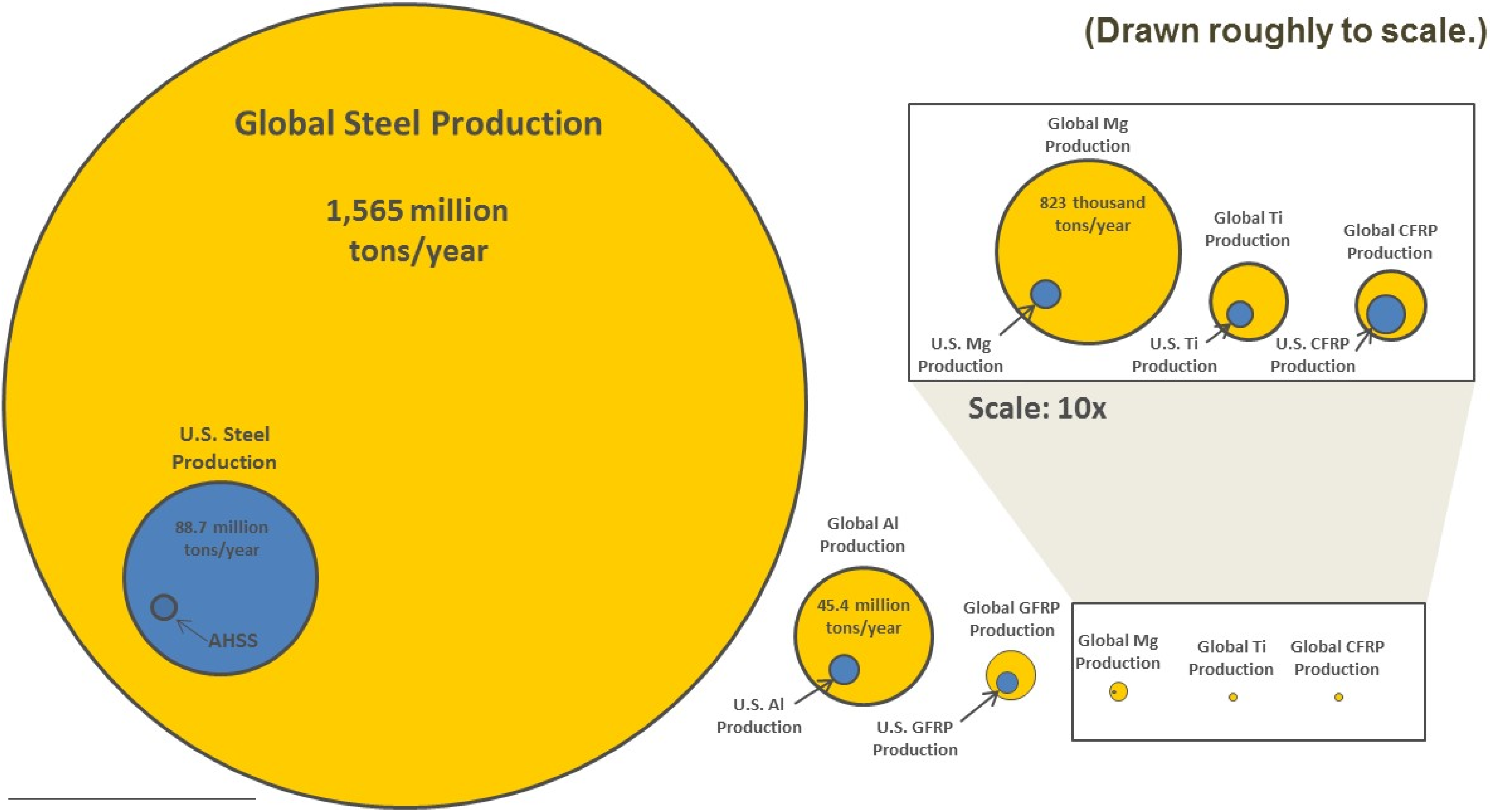
Use Intensity e.g.:
Recycling
Reuse and remanufacturing
Material efficiency and substitution
By-products
Product-Service-Systems



High manufacturing energy use drives costs up and reduces competitiveness with incumbent materials

CFRP composites have the highest manufacturing energy intensity, they also have the largest energy savings opportunity.

Drivers Global and U.S. production of 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

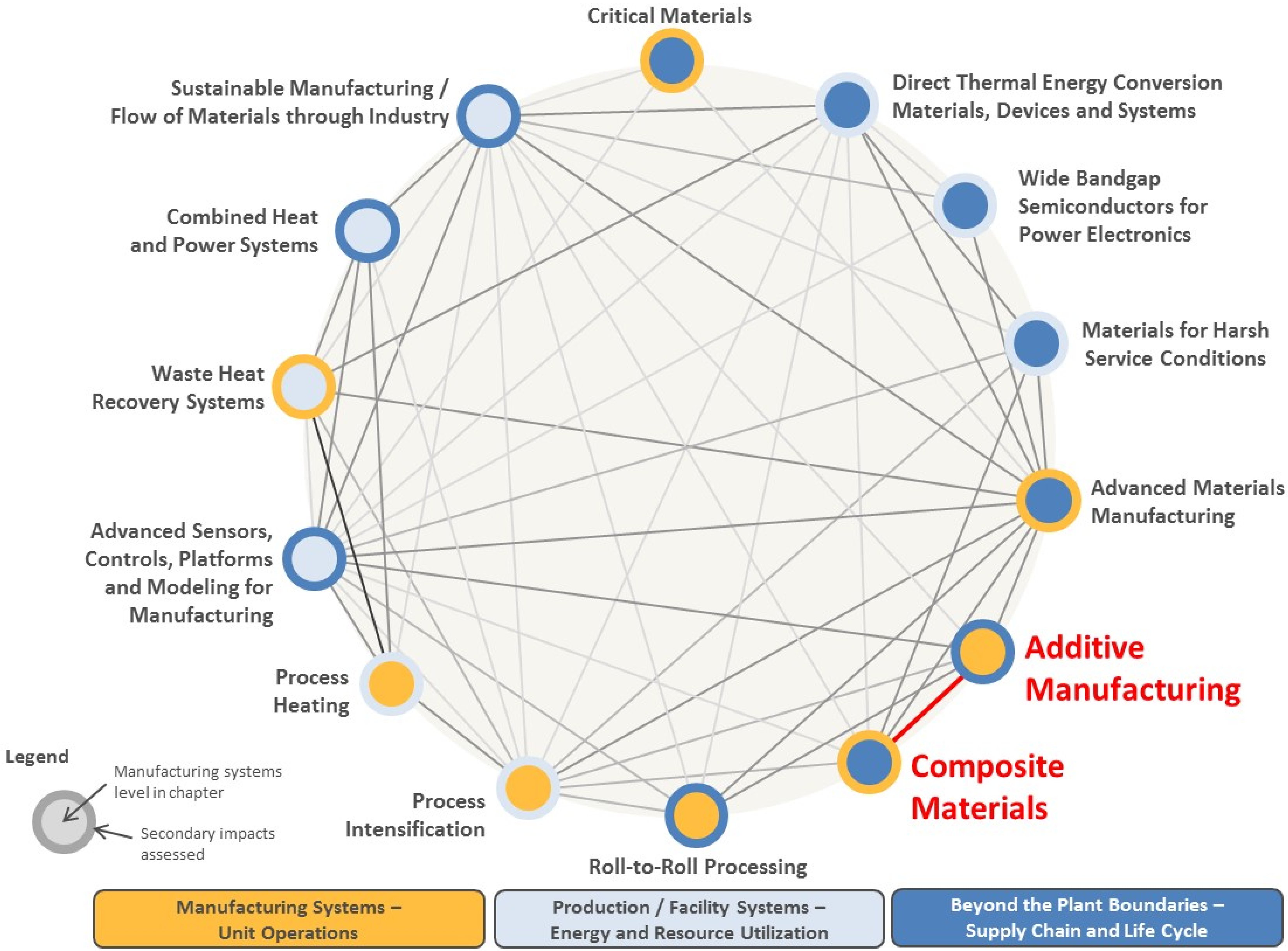
Technology Progression – Confluence of Additive/Composites Manufacturing Technologies

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

Deeper Dive → Intersection materials and processes for Additive and Composites Manufacturing

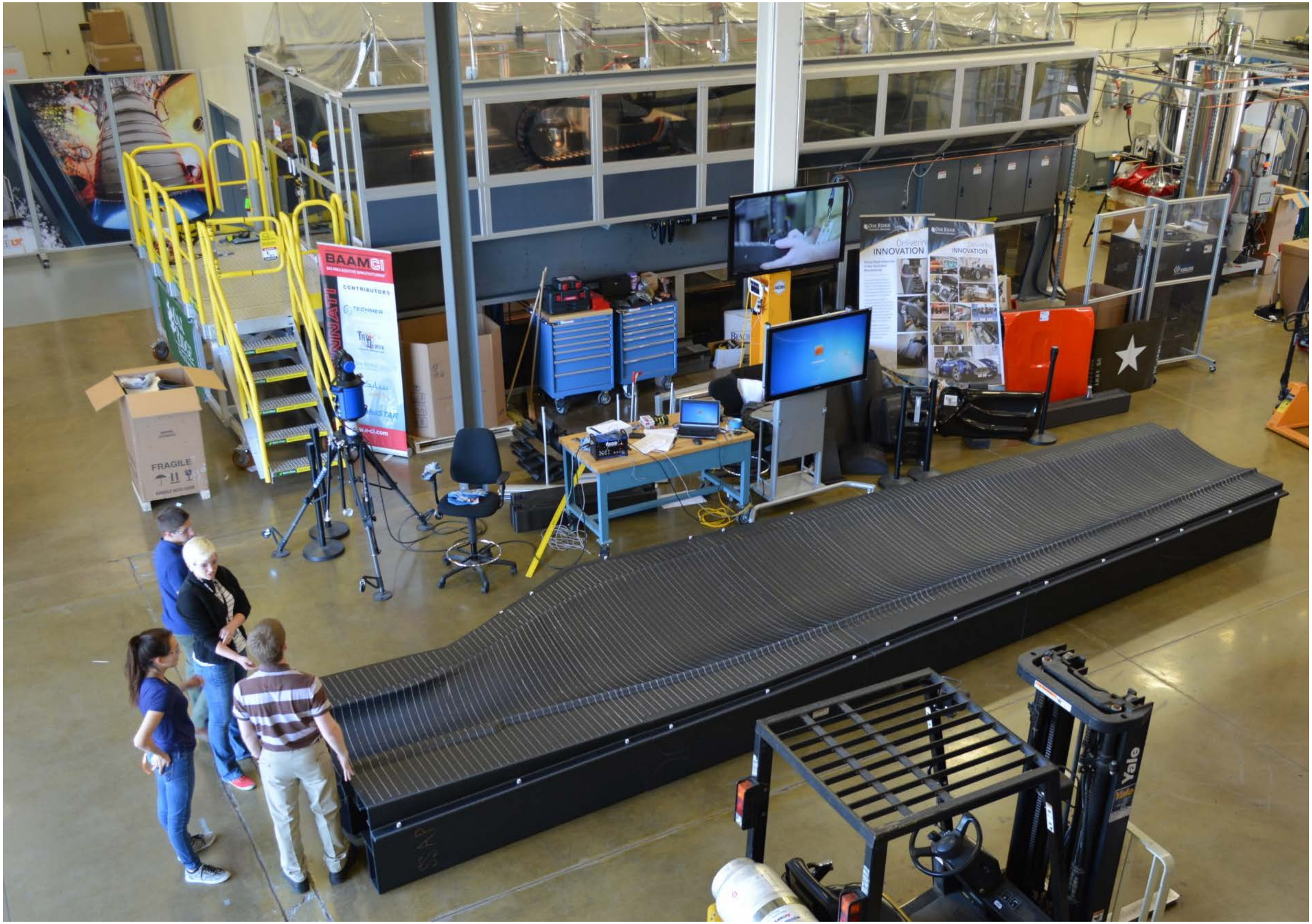


Additive Manufacturing or Composites Manufacturing?

Shelby Cobra sports car printed via additive manufacturing at the DOE Manufacturing Demonstration Facility*

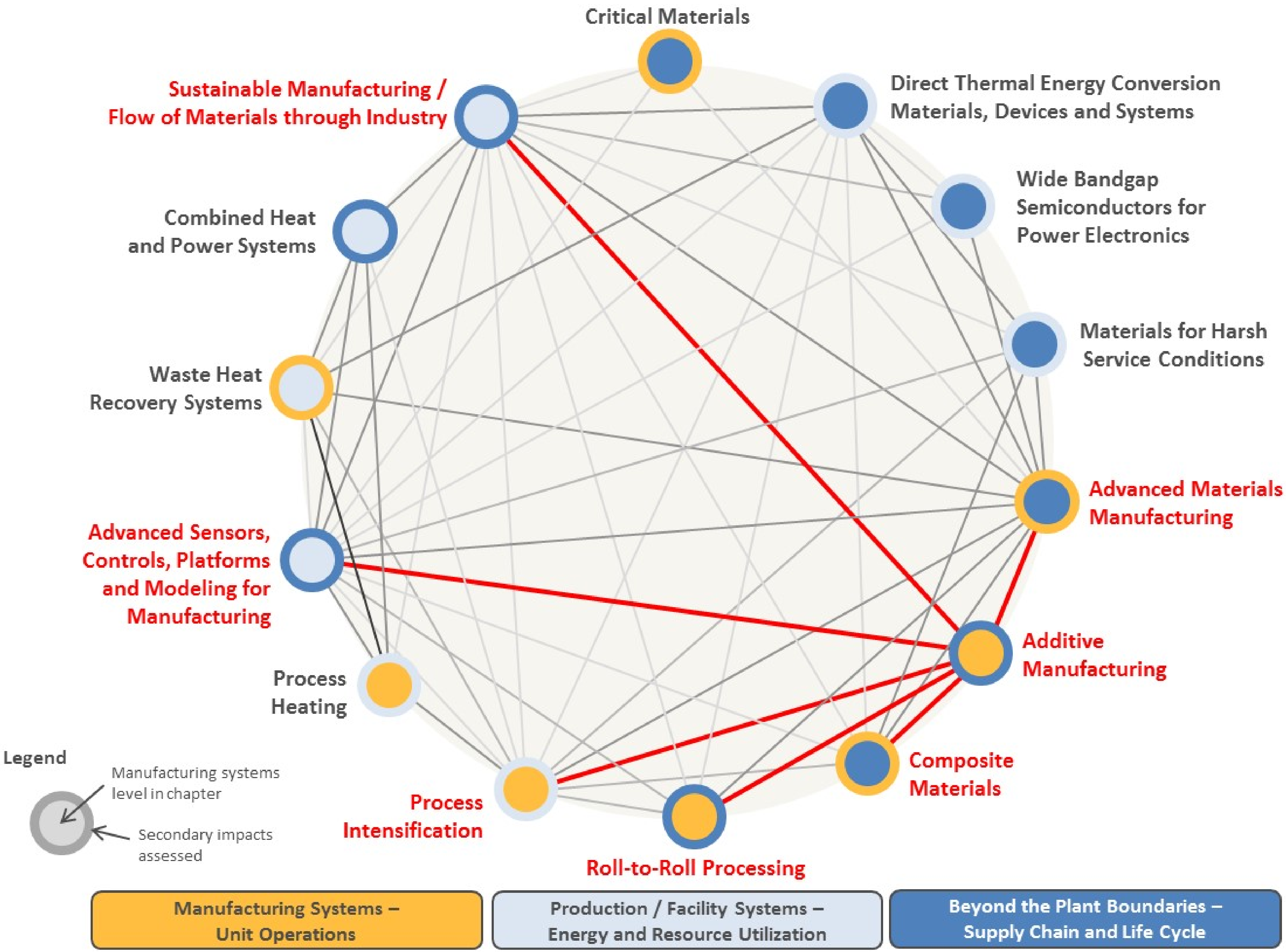
Oak Ridge National Laboratory – Manufacturing Demonstration Facility
https://vimeo.com/139009290

Tooling – Wind turbine blades



QTR Technology Assessments - Manufacturing

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



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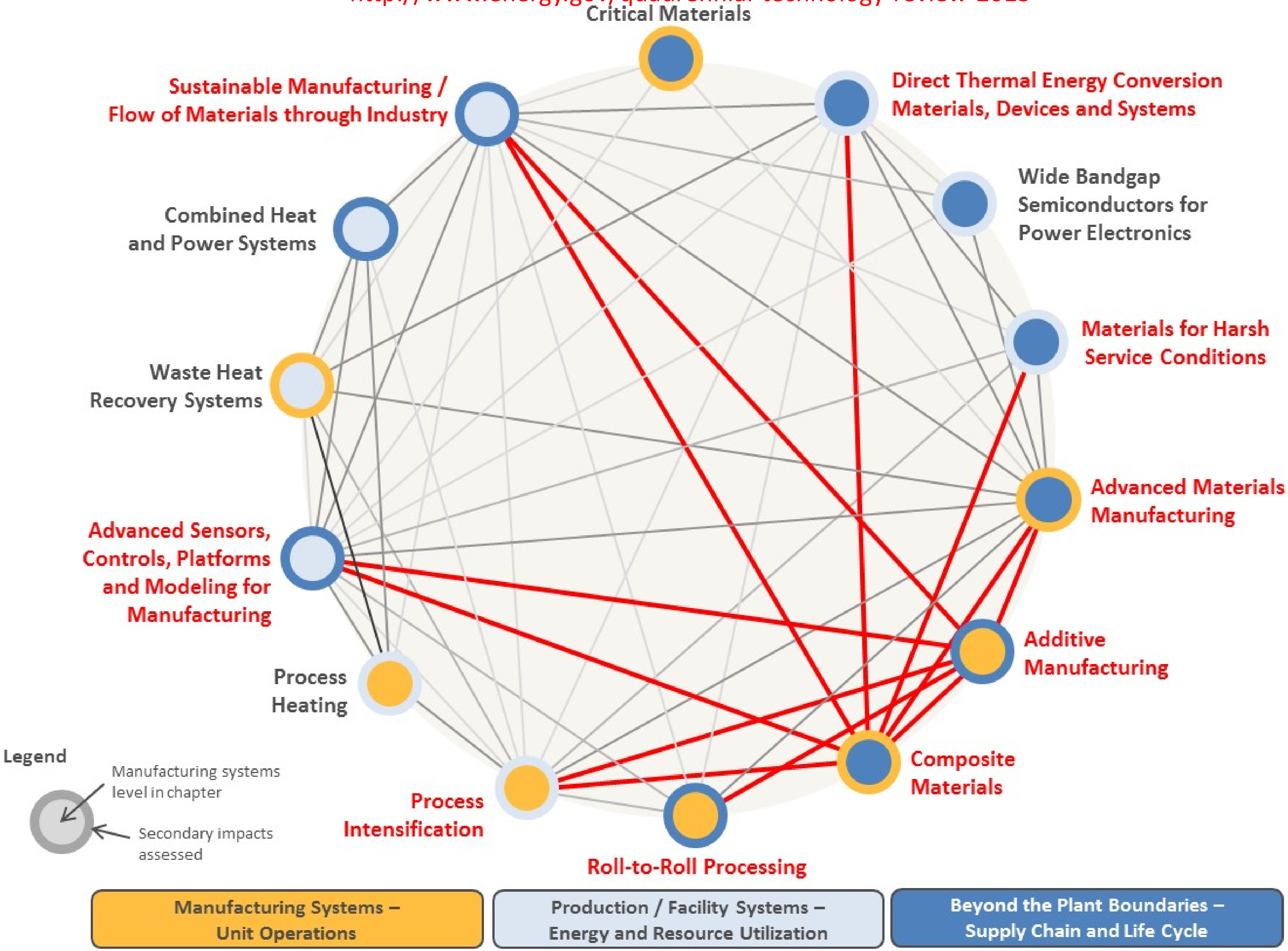
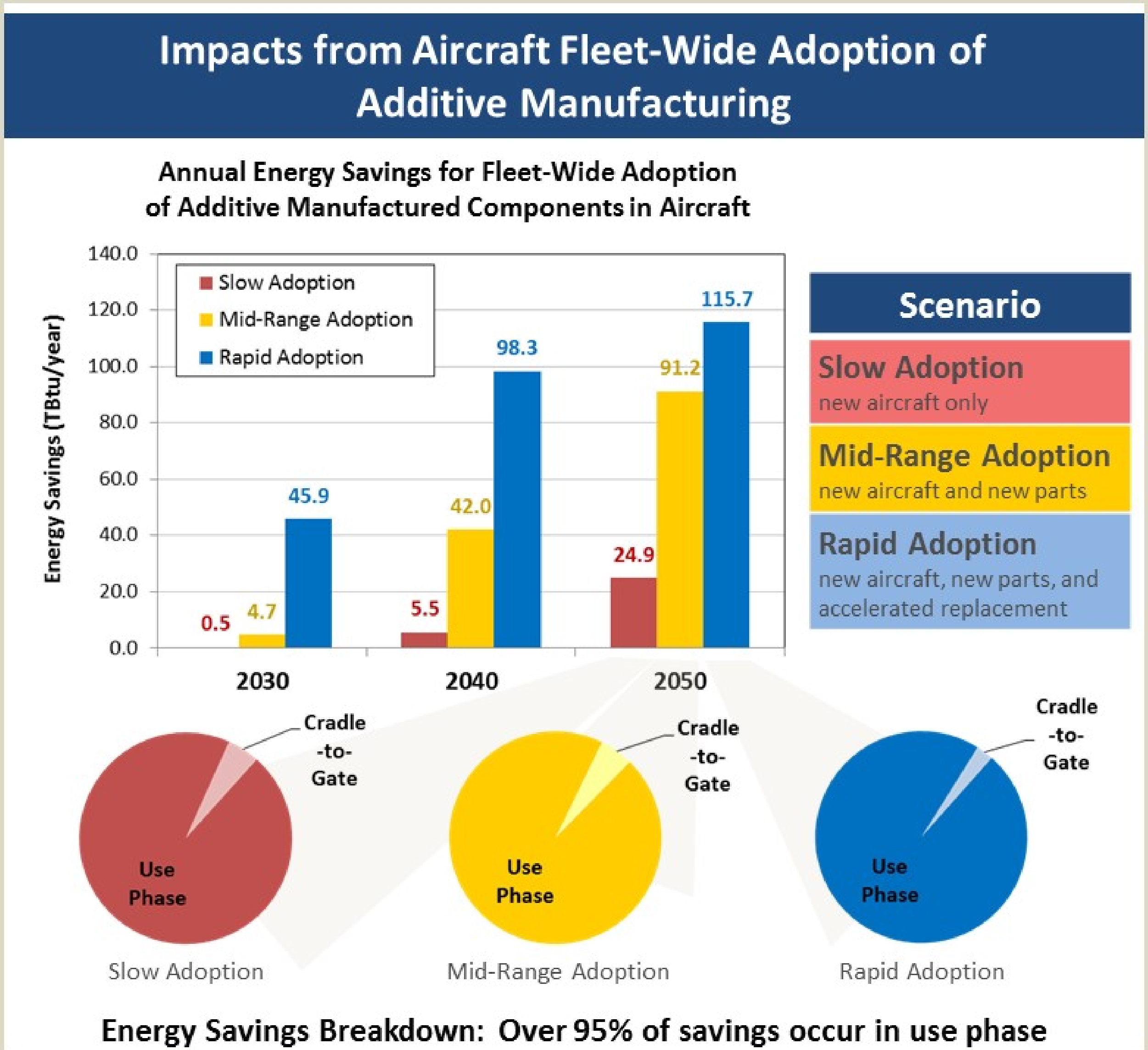


Potential use intensity improvements from additive – in aerospace



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

Supply Chain / Value Chain Analysis

Manufacturing location decisions

Supply chain analysis

Economic competitiveness

Cost of mfg in different locations, by cost category (e.g., labor, capital)

Raw materials, Production & capacity by mfr and location

Examples: labor availability, reliability of grid, currency, quality

What is the global & regional supply chain?

How does competitiveness align with roadmaps?

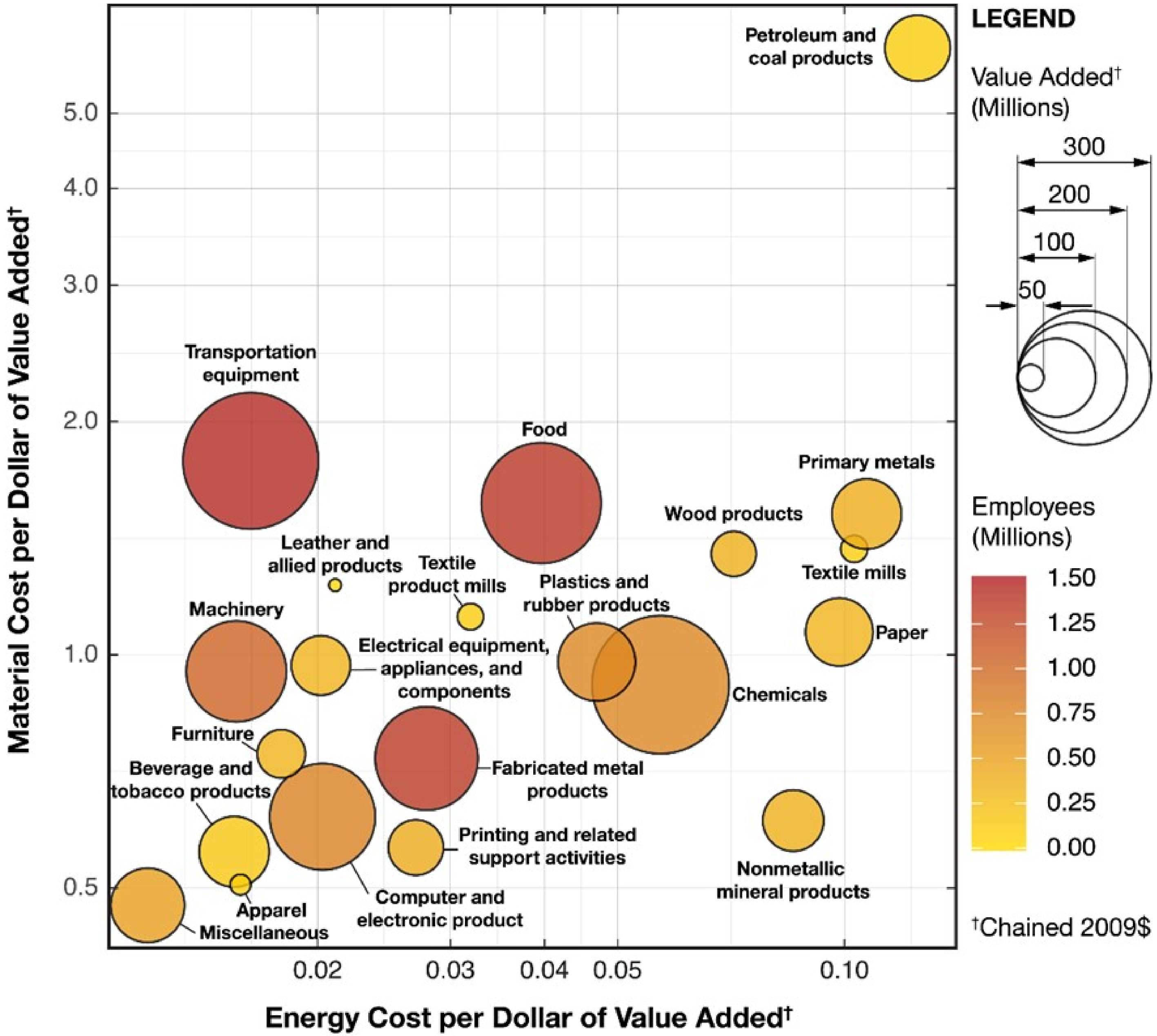
How is competitiveness changing?

What are competitiveness drivers?

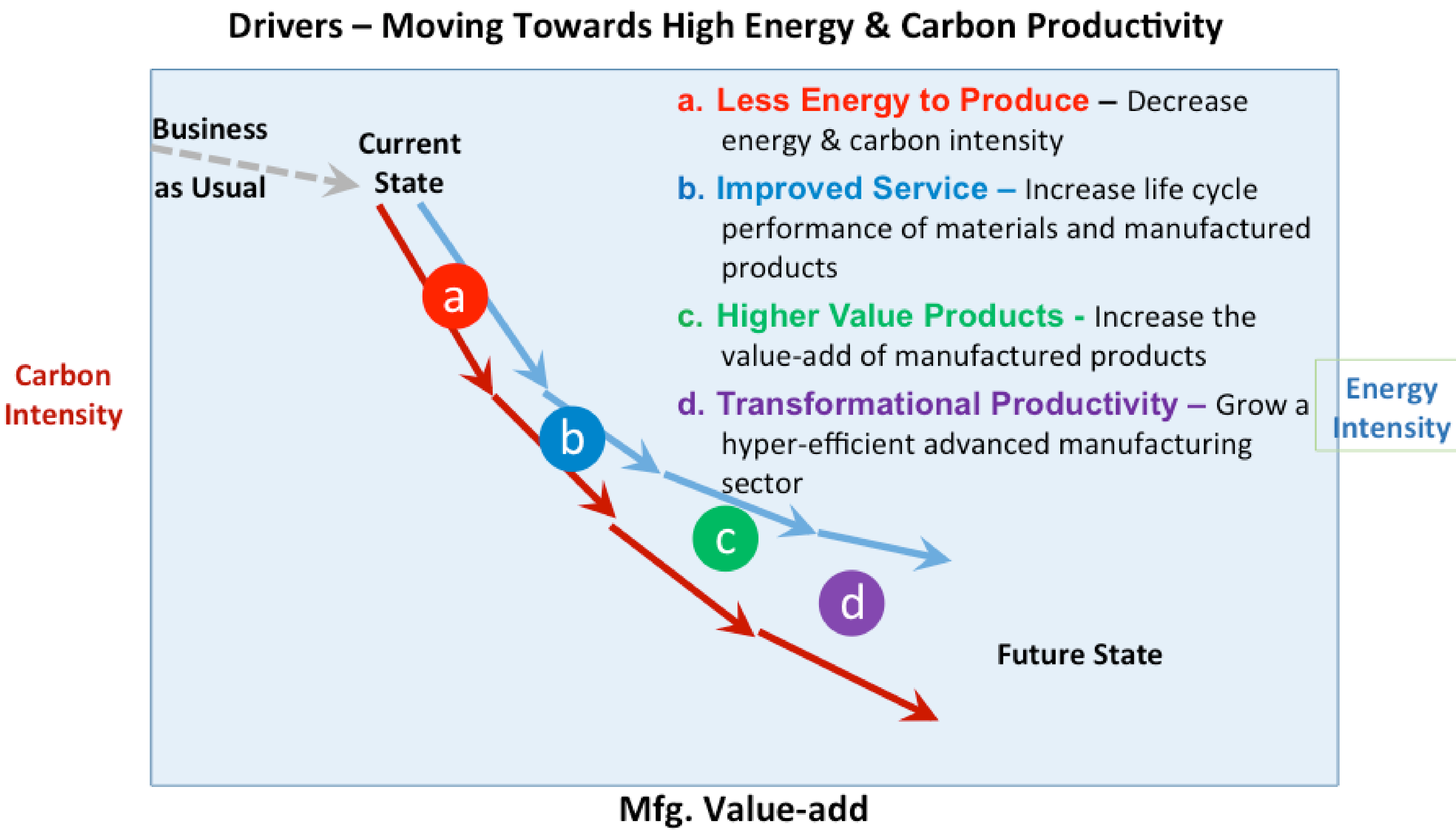
The Clean Energy Manufacturing Analysis Center (CEMAC), sponsored by the U.S. Department of Energy (DOE), provides objective analysis and up-to-date data on global supply chains and manufacturing competitiveness of advanced energy technologies.

Website: www.manufacturingcleanenergy.org

Productivity – how will technologies impact value-add?



Decoupling Energy and Carbon Productivity



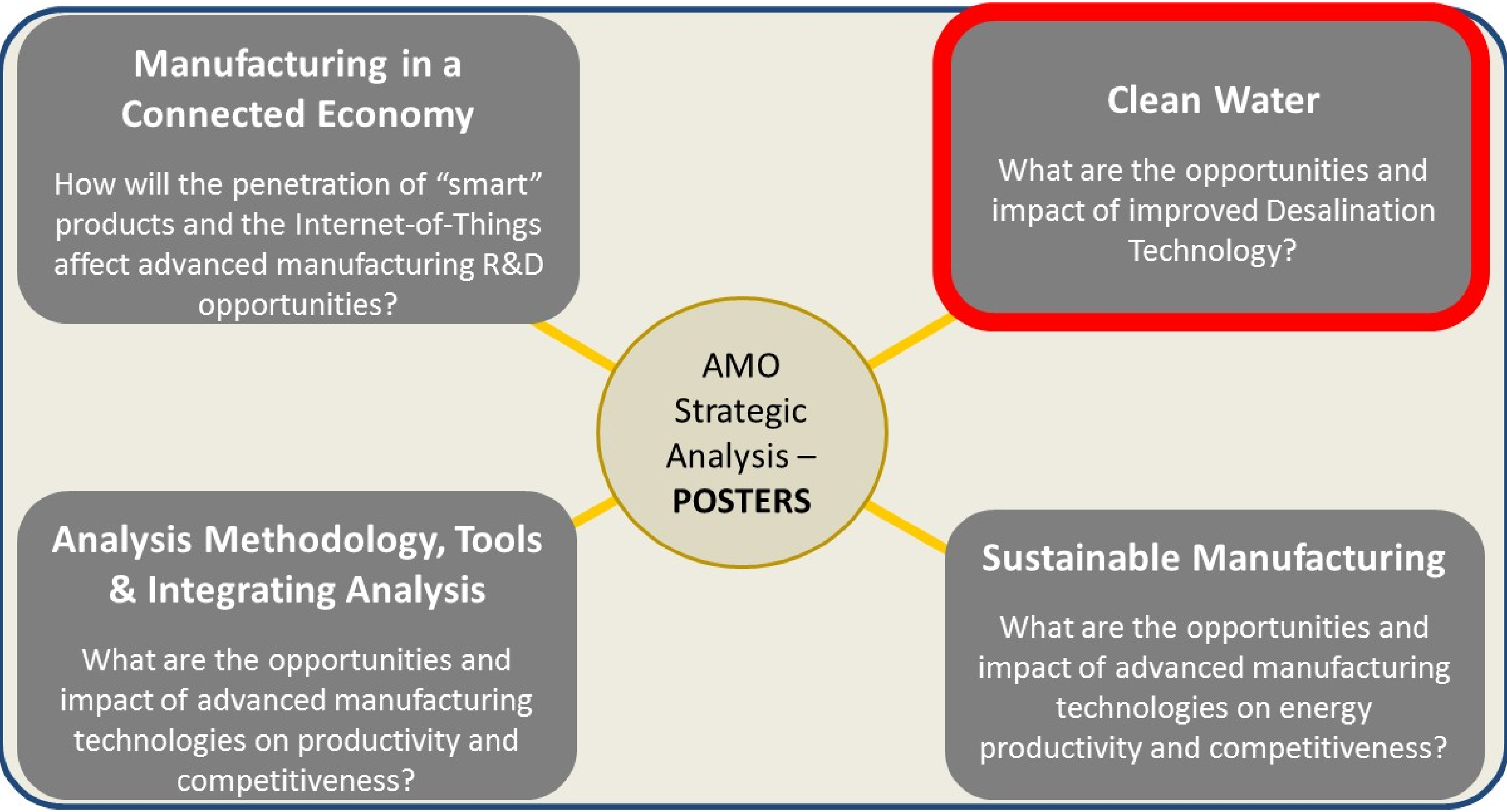
Materials & Adv. Mfg. Integrating Analysis Collaborations with the National Laboratories

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

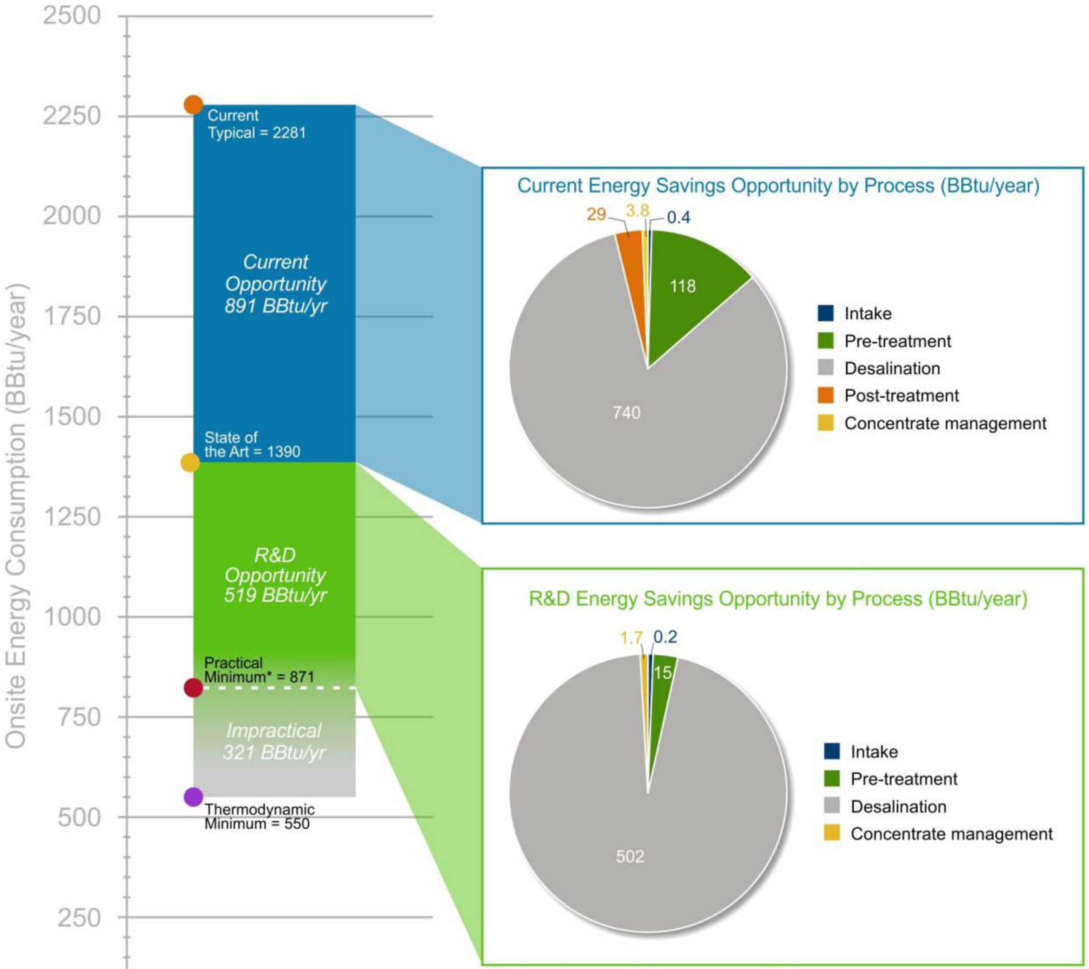
National Renewable Energy Laboratory	Lawrence Berkeley National Laboratory	Oak Ridge National Laboratory
Materials Flow through Industry (MFI) Tool: a tool for analytically tracking the energy and GHG impacts of shifts in material flows, and to quantify supply chain impacts of current and next-generation technologies	**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	**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

Please check out our posters!



Desalination - Energy Savings Opportunity for RO system w/ Open Ocean Intake



CT, SOA, TM operating conditions: RO-based system at 50% recovery of 500 ppm (0 ppm for TM) product water from 35,000 ppm feedwater. PM operating conditions: semi-batch RO-based system at 42% recovery of 379 ppm product water from 36,357 ppm feedwater.

($/m³)	Unit Cost Savings	Energy Cost	Overall
CT	-	0.54	1.98
SOA	0.06	0.48	1.92
PM	0.07	0.41	1.85
TM	0.05	0.36	1.80

Energy costs: $0.07/kWh electricity and $6.29/MMBtu steam

Preliminary results (subject to change)

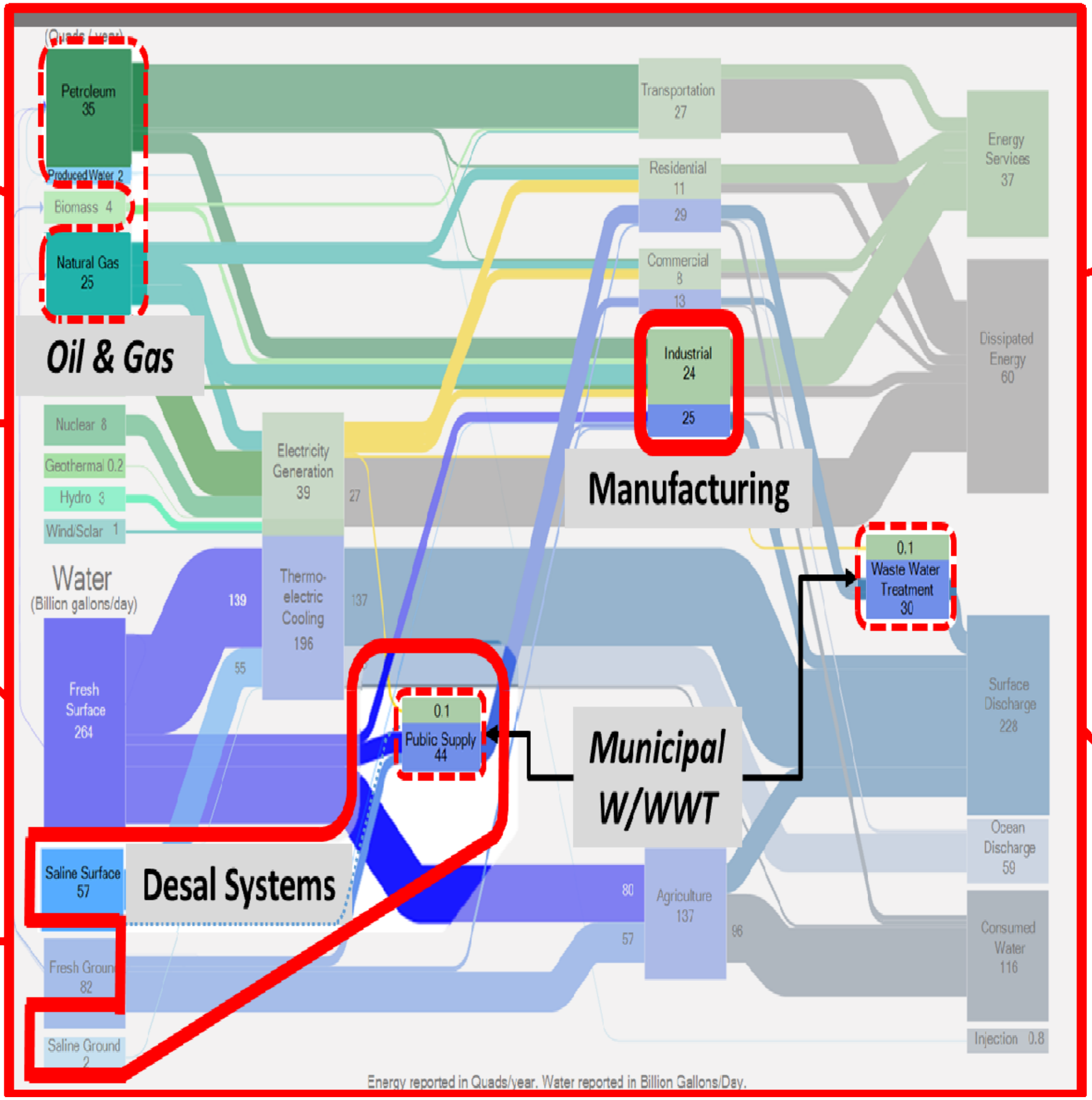
Crosscutting technologies will have impact across the WEN

Separations /treatment
- Membranes
- Thermal
- etc.

Fluids Pumping:
- Motor driven systems
- Materials

Heat transfer:
- Corrosive resistant materials
- Waste heat integration

Infrastructure:
- Piping
- Structural materials



System integration:
- Smart technologies
- Modular designs
- Processes
- Joint energy grid/water system

Sustainability:
- RE integration
- Consumptive water use
- Chemicals (alternatives)
- Life cycle water use
- Fit-for-use, reuse
- ZLD

Thank you.

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Energetics – Sabine Brueske, Heather Liddell, Caroline Dollinger, Hani Hawa

AMO Strategic Analysis Team - presentations, journal articles and technical reports (2013-Present)

2017

- Supekar, S., Graziano, D.J., Skerlos, S.,J. and Cresko, J. (2017). Comparing Life Cycle Impacts of Conventional Metalworking Fluids with Gas-Based Alternatives across Different Materials and Processes. ACLCA XVII, Portsmouth, New Hampshire.
- Yao, Y., Morrow III, W. R., Marano, J., Masanet, E., "Quantifying Carbon Capture Potential and Cost of Carbon Capture Technology Application in the U.S. Refining Industry", (in review at Energy Journal).
- Lisa Schwartz, Max Wei, William Morrow, Jeff Deason, Steven R. Schiller, Greg Leventis, Sarah Smith, Woei Ling Leow, Todd Levin, Steven Plotkin, Yan Zhou, Joseph Teng, "Electricity end uses, energy efficiency, and distributed energy resources baseline", LBNL-1006983, Lawrence Berkeley National Laboratory, 2017.
- Reese, S., Horowitz, K., Remo, T., and Mann, M. (2017) *A Manufacturing Cost and Supply Chain Analysis of SiC Power Electronics Applicable to Medium-Voltage Motor Drives*. *PowerAmerica Webinar.*
- William R. Morrow (LBNL), , Alberta Carpenter (NREL), Joe Cresko (US DOE), Eric Masanet (NU), Sachin Nimbalkar (ORNL) and Arman Sandor, Debra, Donald Chung, David Keyser, Margaret Mann, and Jill Engel-Cox. *Benchmarks of Global Clean Energy Manufacturing*. No. NREL/TP--6A50-65619. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2017.
- Horowitz, K., Remo, T., and Reese, S., *A Manufacturing Cost and Supply Chain Analysis of SiC Power Electronics Applicable to Medium-Voltage Motor Drives*. No. NREL/TP--6A20-67694. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2017.
- Remo, T., Horowitz, K., Reese, S., and Mann, M. 2017 Regional Manufacturing Cost Structures and Supply Chain Considerations for SiC Power Electronics in Medium Voltage Motor Drives. Proceedings of the Motor & Drive Systems 2017.
- Armstrong, K. & Das, S. (2017). Wide Bandgap Semiconductor Opportunities in Power Electronics, Technical Highlights Report, Clean Energy Manufacturing Analysis Center.
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- Das, S. (2017). "innovation in Engineered Plastics, Carbon Fiber & Composites," invited presentation at the Advanced Design & Manufacturing Automotive Conference, held on Mar. 29, Cleveland, OH.

2016

- Huang, R., Riddle, M., Graziano, D., Cresko, J., and E. Masanet. (2016) ”Multi-scale System Dynamics Modeling for Evaluating the Current State, Future Trends and Associated Implications of Additive Manufacturing”, *ASME 2016 International Mechanical Engineering Congress & Exposition*, *accepted,* Phoenix, Arizona.
- Huang, R., Graziano, D., Riddle, M., Cresko, J., and E. Masanet. (2016) “Knowns and Unknowns of the Current State, Future Trends, and Associated Implications of Additive Manufacturing”, *Materials Science & Technology 16 Technical Meeting and Exhibition*, *invited*, Salt Lake City, Utah.
- Shehabi, A., Smith, S.J., Horner, N., Azevedo, I., Brown, R., Koomey, J., Masanet, E., Sartor, D., Lintner, W. 2016. United States Data Center Energy Usage Report. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-1005775.
- Rao, P., Aghajanzadeh, A., Sheaffer, P., Morrow, W, Brueske, S., Dollinger, C., Price, K., Sarker, P., Ward, N., Cresko, J., “Volume 1: Survey of Available Information in Support of the Energy-Water Bandwidth Study of Desalination Systems”, LBNL-1006424, Lawrence Berkeley National Laboratory, 2016.
- William R. Morrow, III, “How Smart Factories Optimize Energy Use and Improve Productivity – California’s Perspective”, Silicon Valley Energy Summit, Precourt Energy Efficiency Center, Stanford University, Palo Alto, CA, June 3rd, 2016.
- Morrow, W., Shehabi, A., Smith, S., “Lifecycle Industry GreenHouse gas, Technology and Energy through the Use Phase (LIGHTEnUP) – Analysis Tool User’s Guide” LBNL-1005777 Lawrence Berkeley National Laboratory, 2016.
- Morrow III, W.R., Yao, Y., Marano, J., “Refineries in a Carbon Constrained Future - the Potential for Facility-Wide CO2 Capture at Plant Utilities”, 12AIChE - 2016 AIChE Annual Meeting, November 13-18th, 2016, San Francisco, CA.
- William R. Morrow III, Joe Cresko, Sujit Das, Heather Liddell, “Net Energy Consequences of Carbon Fiber Reinforced Polymer Composites in U.S. Light-Duty Vehicle Fleet Light-weighting”, The Composites and Advanced Materials Expo (CAMX 2016), September 26-29th, 2016, Anaheim CA.
- Shehabi, A., Smith, S., Fuchs, H., Morrow, W. “LCA and the Internet of Things: Life cycle modeling of electronics manufacturing”, American Center for Life-Cycle Analysis, XVI (ACLCA XVI) September 28-30, 2016, Charleston, SC.
- Joe Marriott, Tom Skone, Garvin Heath, Michael Wang, William R. Morrow III, “Contributions to LCA from the Department of Energy”, Life-Cycle Analysis, XV (LCA XVI), September 27-29th, 2016, Charleston, SC.

2016 cont.

- William R. Morrow III, Alberta Carpenter, Joe Cresko, Sujit Das, Diane Graziano, Sachin Nimbalkar, Arman Shehabi, "Developing Robust Methods for Prospective LCA for Early Stage Technologies (Part 1 and 2)", Life-Cycle Analysis, XV (LCA XVI), September 27-29th, 2016, Charleston, SC. Woodhouse, M. Mone, C. Chung, D. Elgqvist, E. and Das, S. *(2016). Clean Energy Manufacturing Analysis Center: 2015 Research Highlights. ORNL/SR-2016/98, NREL/BR-6A50-65312, Denver, CO. Mar.*
- Hanes, R. and A. Carpenter. 2016. Evaluating opportunities to improve material and energy impacts in commodity supply chains. Proceedings of the International Symposium on Sustainable Systems and Technologies, v4. May 2016. (in process).
- Hanes, R. and A. Carpenter. 2016. Evaluating opportunities to improve material and energy impacts in commodity supply chains. International Symposium on Sustainable Systems and Technology (ISSST), May 16-18, 2016, Phoenix, AZ.
- Carpenter, A., M. Mann, R. Gelman, J. Lewis, D. Benson, J. Cresko and S. Ma. Materials Flows through Industry tool to track supply chain energy demand. LCA XIV Paper proceedings. October 2016.
- Das, S. (2016). "Carbon Fiber Composites Industry Supply Chain Competitiveness," Education Session presentation at CAMX conference, held on Sept.26-29, '16, Anaheim, CA.
- Cassorla, P. & Das, S. (2016). "Life Cycle Analysis of Automotive Electronics," paper presented at the ACLCA XIV conference, held on Sept. 27-29,'16 in Charleston, SC.
- Armstrong, K. & Das, S, (2016)."Wide Bandgap Semiconductor Opportunities in Power Electronics," paper presented and published at the 4th IEEE Workshop on Wide Bandgap Power Devices and Applications (WiPDA), held on Nov. 7-9,'16, Fayetteville, AR.
- Das, S. (2016). "OEM Strategies on LightWeight Metals" an invited presentation at the Advanced Lightweight Vehicles and Materials 2016 Forum, held on 13-14 Oct.'16, Berlin, Germany.
- Das, S. Warren, J. West, D. & Schexnayder, S. M. (2016). Global Carbon Fiber Composites Supply Chain Competitiveness Analysis. Clean Energy Manufacturing Analysis Center.
- Woodhouse, M. Mone, C. Chung, D. Elgqvist, E. and Das, S. (2016). Clean Energy Manufacturing Analysis Center: 2015 Research Highlights. ORNL/SR-2016/98, NREL/BR-6A50-65312, Denver, CO. Mar.

2015

- Huang, R., Riddle, M., Graziano, D., and E. Masanet. (2015) “Multiscale Life-cycle Techno-economic Assessment Model for Advanced Manufacturing Technologies”, *International Society for Industrial Ecology,* England.
- Yao, Y., Graziano, D., Riddle, M., and E. Masanet (2015) “Looking into the Future of the Ethylene Industry: A Generic Assessment Model for Emerging Technologies”, AIChE Annual Meeting, Salt Lake City, Utah.
- Yao, Y., Graziano, D., Riddle, M., and E. Masanet (2015) “A Case Study of MAMTech Assessment Model: Prospective Life-cycle Technology Assessment of Future U.S. Ethylene Production”, *ACLCA XV*, Vancouver, Canada.
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