U.S. DEPARTMENT OF ENERGY | Office of Science

Basic Research Needs for Transformative Manufacturing

Basic Energy Sciences Advisory Committee
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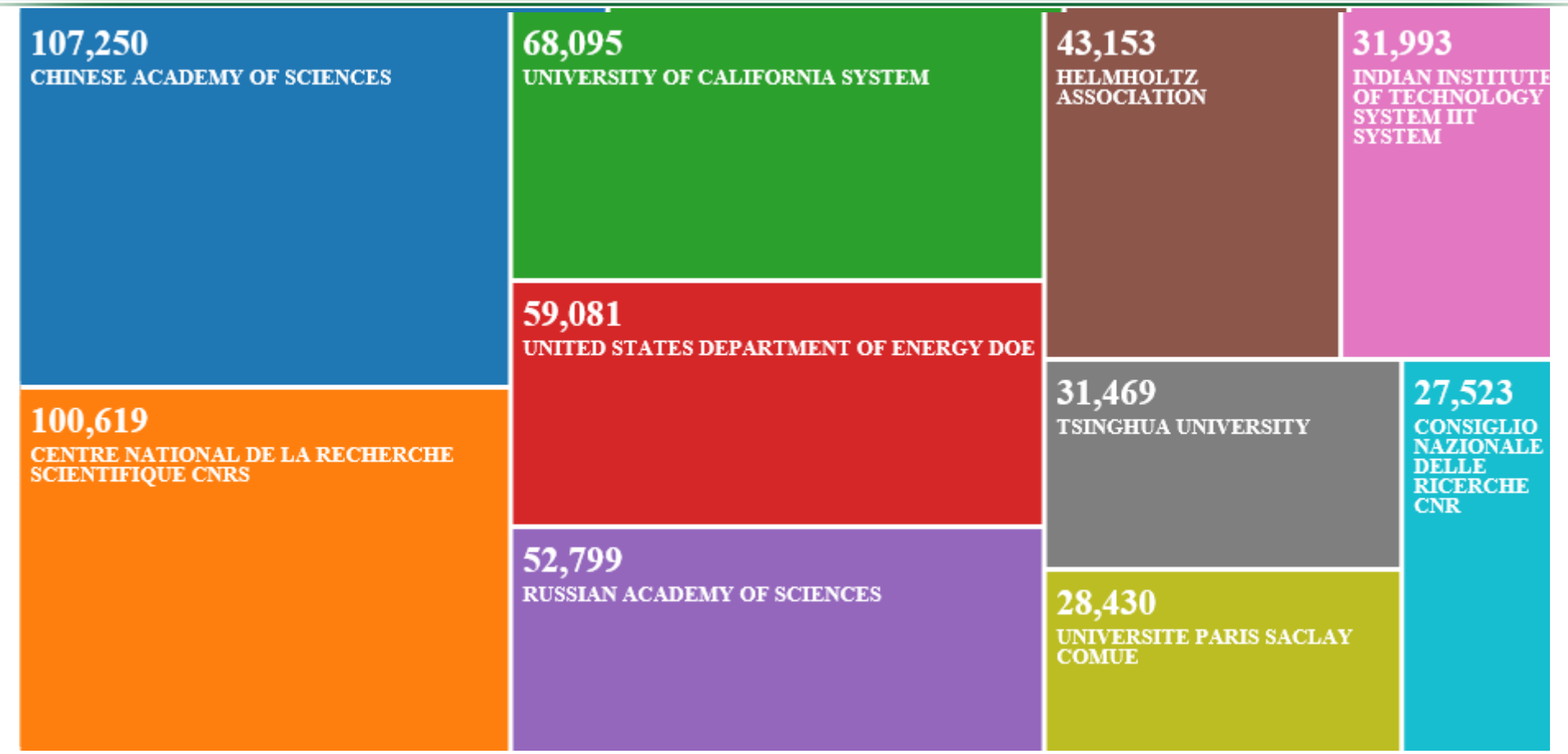
Manufacturing Facts and Stats

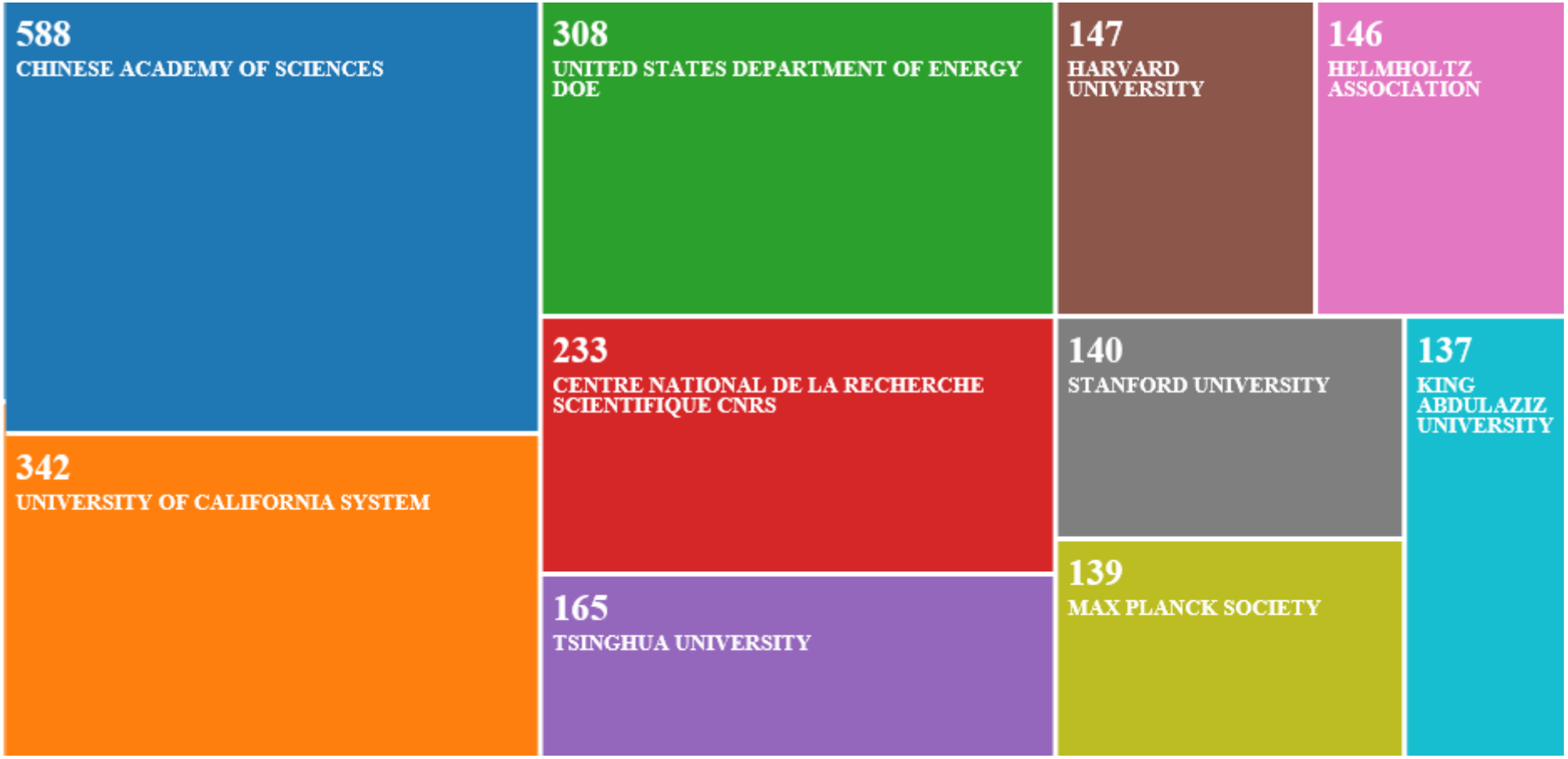
- Manufacturing is a broad and complex field, including traditional and advanced materials fabrication, chemical industries, component assembly, etc.
- The U.S. manufacturing sector uses approximately 25% of the nation's energy, thus energy is a significant cost in manufacturing.
- Manufacturing represents nearly 12% of the GDP of the United States (https://tradingeconomics.com/united-states/gdp-from-manufacturing)
- Internationally, the United States ranks second to China in manufacturing. China became the leading country in 2010. (https://fas.org/sgp/crs/misc/R42135.pdf)
- The United States has 12.75 million manufacturing jobs, ~ 8.5 percent of the workforce. (https://www.thebalance.com/u-s-manufacturing-what-it-is-statistics-and-outlook-3305575) Manufacturing employment fell by 25% from 1990 to 2016. (https://fas.org/sgp/crs/misc/R42135.pdf)
- For applied research and technology, there are several national initiatives and programs – including Manufacturing, USA (https://www.manufacturingusa.com/), a public-private network of 14 manufacturing institutes
  - 4 managed by DOE-EERE Advanced Manufacturing Office
  - Research and development collaborations to solve technology challenges and train people on advanced manufacturing skills

Manufacturing, Processing, Fabrication – Web of Science Analysis



- 3.9 M publications for key words “manufacturing OR processing OR fabrication”; “health” related topics removed; images limited to the largest categories – there are many more!
- ~22% US, >22% Europe, 20% China
- 1.5% DOE – the opportunity

Web of Science Analysis: Highly Cited for FY 2016, 2017, 2018



Web of Science citation analysis requires less than 10,000 records – this analysis shown above is for the high cited papers for 2016-18 -- ~6,600 publications

Organization analysis shows DOE for 308 of these papers, nearly 5%

BRN Workshop on Transformative Manufacturing

Workshop Chair: Cynthia Jenks (ANL)

Co-chairs: Jennifer Lewis (Harvard)
Ho Nyung Lee (ORNL)

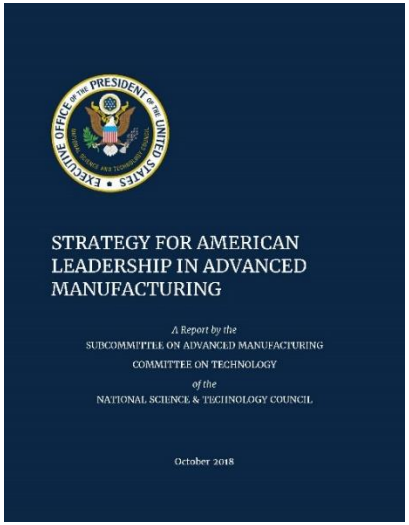
Workshop Date: December 10-12, 2019
Location: Rockville Hilton

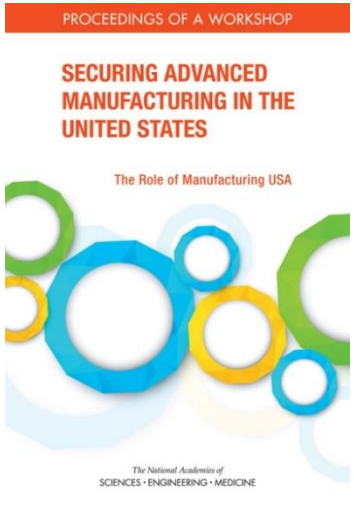
Background and Charge:

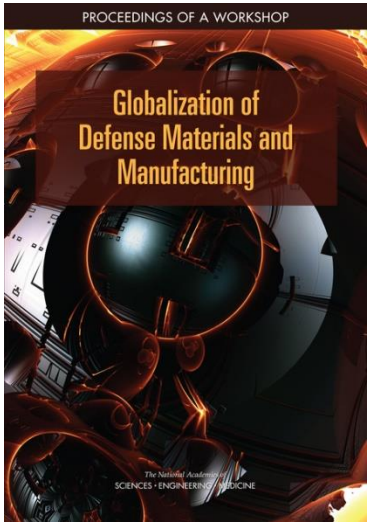
- Manufacturing is an emphasis area for DOE: Energy use in primary industries and national priorities related to other sectors
- To date, BES Basic Research Needs workshops have not directly assessed barriers and opportunities related to future manufacturing
  - Microelectronics BRN included one dimension, with a follow-on round table on lithography in planning stages
  - Foundational discussion in other BES reports including the Synthesis Science BRN, Extreme Environments BRN, Catalysis BRN, Polymer Upcycling roundtable
- Identify fundamental research to overcome scientific and technical barriers for innovations that would transform manufacturing in the future
  - Working with the DOE EERE Advanced Manufacturing Office to establish a status document for the participants

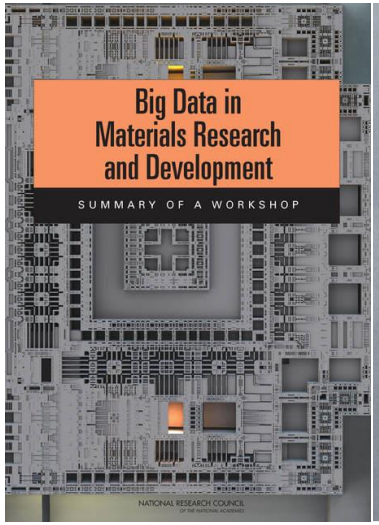
National Academy, OSTP and DOE Reports Highlight Aspects of Manufacturing

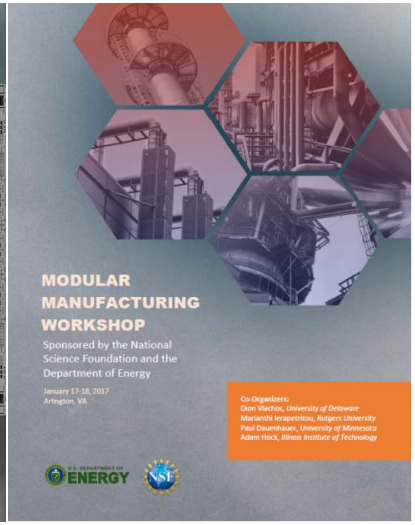
- Many assessments and reports are available – largely technology focused
- Relevant discussions and recommendations:
  - Develop and transition new manufacturing technologies
  - Allow for flexibility in operation, improve energy efficiency
  - Data issues in manufacturing
  - Develop physics-based models across scales
  - International awareness
  - Workforce issues











Science Could Provide Solutions to Manufacturing Roadblocks

Examples

MANUFACTURING ROADBLOCKS	SCIENCE SOLUTIONS
▪ Poor device performance	▪ Control atomic-level interactions and reactivity
▪ Material defects introduced upon scaling	▪ Develop precision material synthesis and crystal growth methods
▪ Non-linear scaling relationships	▪ Understand fluid dynamics and non-equilibrium chemistry
▪ Unexpected effects during processing	▪ Develop synthesis simulation methods across scales
▪ Poor quality products	▪ Design catalysts that are robust to commodity chemical impurities

Adapted from Jenks, ANL

Example: Overcoming Scaling Nonlinearity

Batch reaction scaling

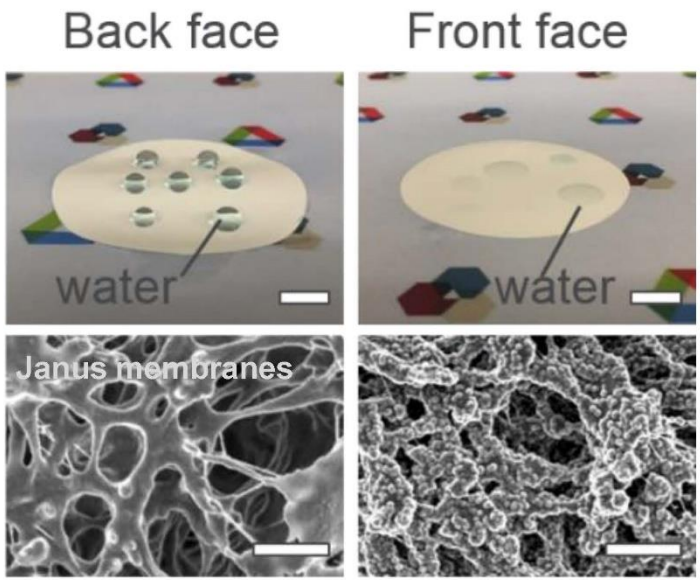
- Scaling up of reactions discovered in the laboratory is, for the most part, an art
- Basic research needed to improve our understanding of non-equilibrium chemical synthesis

Understanding non-equilibrium processes that become important when scaling up would decrease time to market

Example: Improving Manufacturing Quality

Membranes and sorbents with engineered interfaces

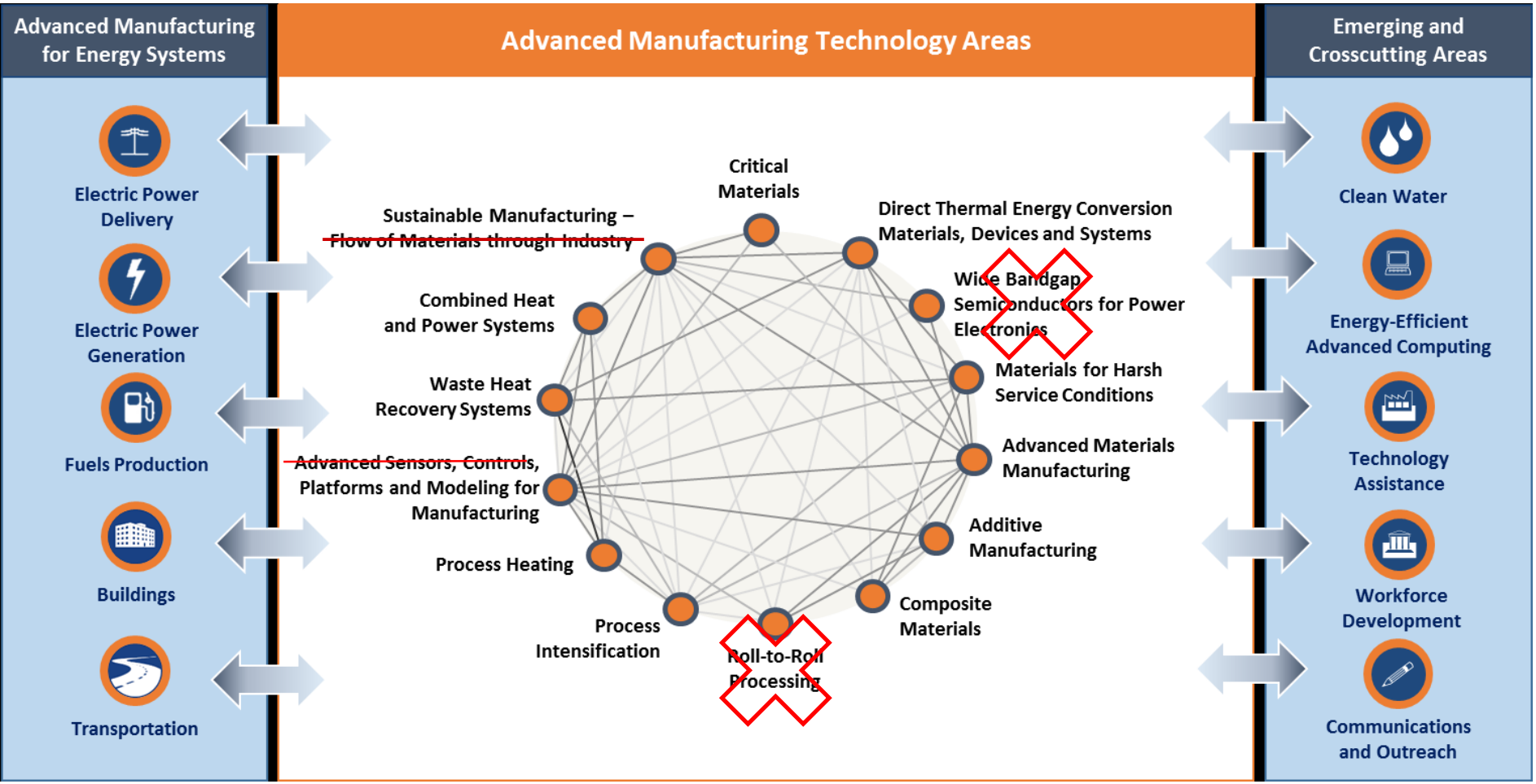
- Precise control of interfacial properties in porous substrates can enable efficient filtration and sorption
- Scaling-up requires basic understanding of substrate-precursor interactions



Basic understanding of precursor interactions with porous substrates would inform efforts to scale these technologies

Adapted from Jenks, ANL

EERE Advanced Manufacturing Office View – Manufacturing Technical Areas



BRN workshop will consider enabling science that could support many of EERE AMO's focus areas

Preliminary Panel Topics for the Workshop

- Precision Synthesis Science
  - Chemistry, materials, biomimetic; Composites, heterogeneous building blocks
- Processing and Scale-Up Science
  - From lab-scale towards larger quantities and complexity
  - Beyond synthesis to include secondary treatments
- System Integration Science
  - Hybrid or integrated manufacturing processes; Components, modular assemblies
  - Decentralized chemical processes
- Sustainable Manufacturing
  - Full life cycle manufacturing; Substitutes
  - Energy efficient processes; Alternatives to traditional heating
- Digital Manufacturing
  - Rapid in situ characterization / closed feedback control; Qualification (codes)
  - Multiscale computational algorithms & predictive design tools
- Crosscutting topics
  - Defects, interfaces, heterogeneity
  - Theory, modeling, AI, data, machine learning, etc.

Questions