U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Process Intensification: Workshop to Identify Technology Opportunities

September 29, 2015

AMO Workshop

Alexandria, VA

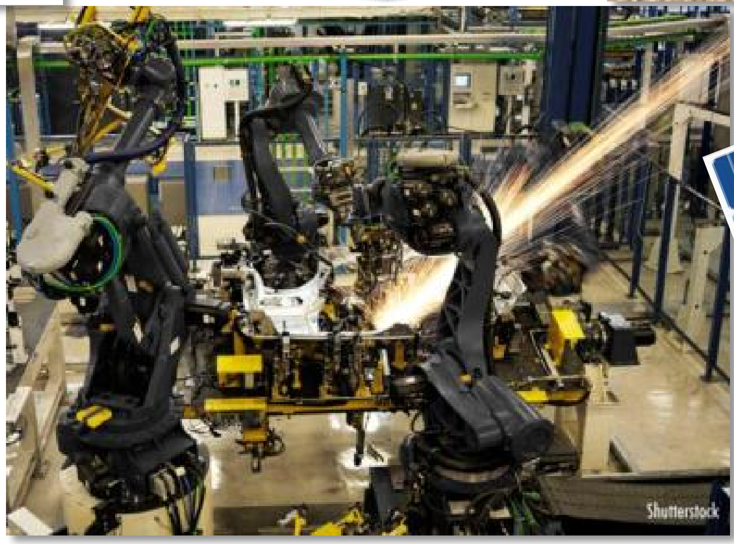
Mark Johnson

Director

Advanced Manufacturing Office

www.manufacturing.energy.gov

Former Status Quo: Clean Energy Products invented here, and made elsewhere



Clean Energy and Manufacturing: Nexus of Opportunities

Security

- Energy self-reliance
- Stable, diverse energy supply

Clean Energy Solutions

Economy

- Competitiveness in clean energy
- Domestic jobs

Environment

- Clean air
- Climate change
- Health

<u>Clean Energy Manufacturing</u>

Making Products which Reduce Impact on Environment

<u>Advanced Manufacturing</u>

Making Products with Technology as Competitive Difference

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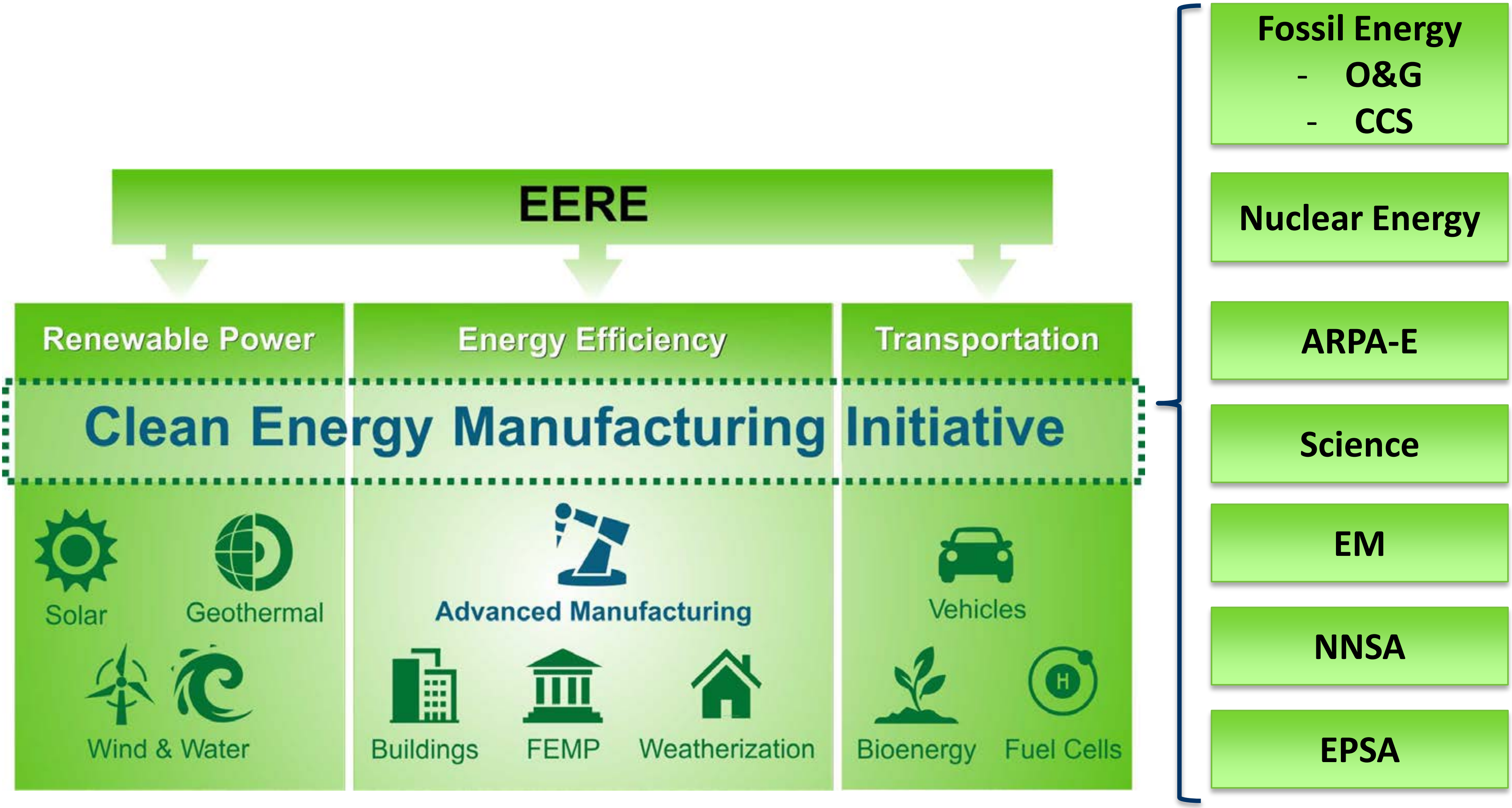
Clean Energy Manufacturing Initiative – Across DOE



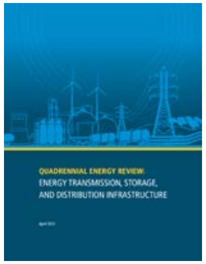
Advanced Manufacturing – Strategic Inputs

Climate Action Plan

(EOP / CEQ / OSTP 2014)

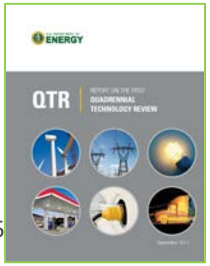
Advanced Manufacturing Partnership (AMP2.0)

(NEC / PCAST / OSTP 2014)



Quadrennial Energy Review

(DOE / EPSA 2015)



Quadrennial Technology Review

(DOE / Science and Technology 2015)

1) Broadly Applicable <u>Efficiency Technologies</u> for Energy Intensive and Energy Dependent Manufacturing

2) Platform <u>Materials & Processes Technologies</u> for Manufacturing Clean Energy Technologies

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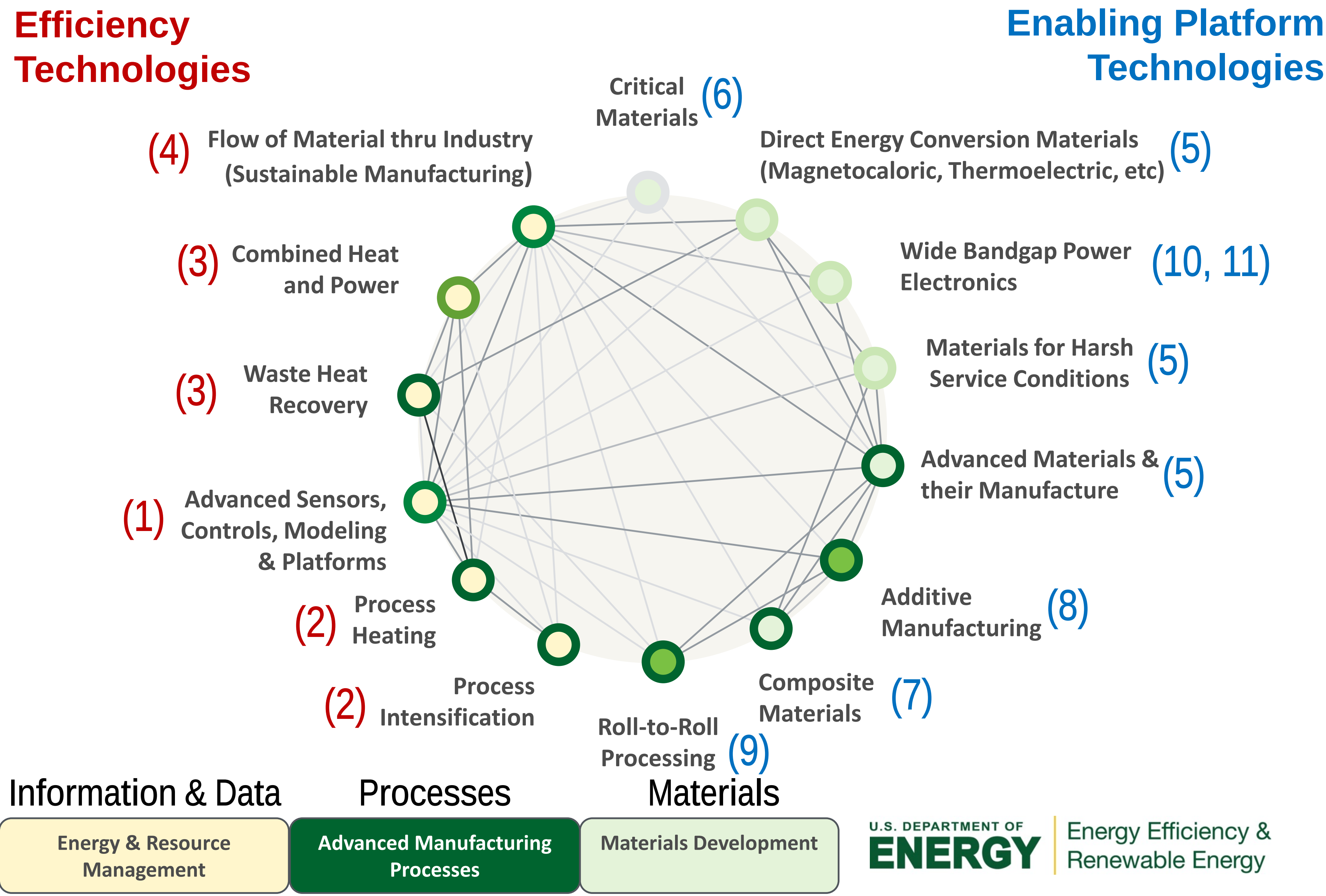
DOE QTR: Manufacturing Technology



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Advanced Manufacturing Topical Priorities

Efficiency Technologies for Manufacturing Processes (Energy, CO_2)

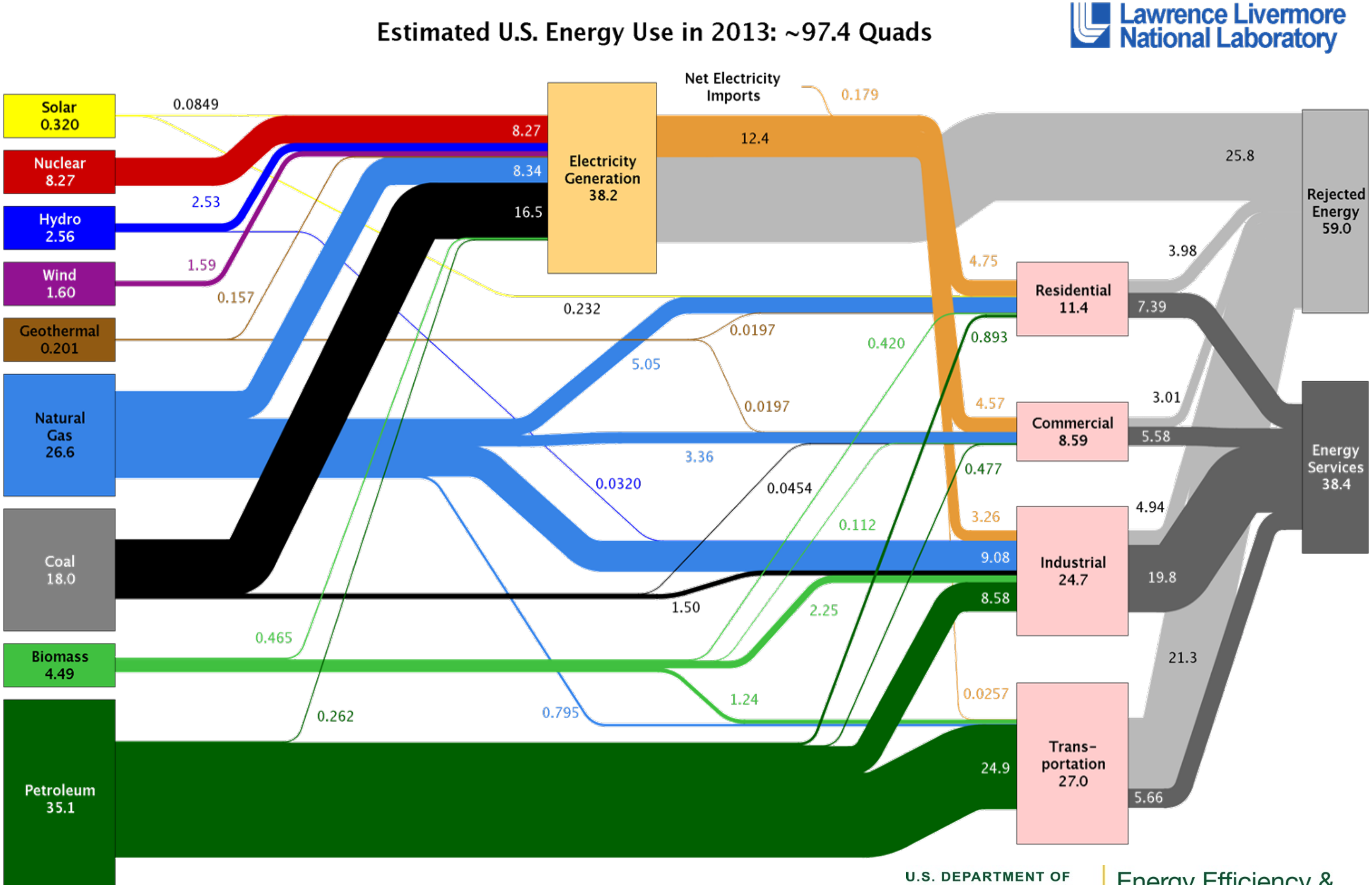
(1) Advanced Sensors, Controls, Modeling and Platforms (HPC, Smart Manf.)
(2) Advanced Process Intensification
(3) Grid Integration of Manufacturing (CHP and DR)
(4) Sustainable Manufacturing (Water-Energy, New Fuels & Feedstocks)

Platform Materials & Technologies for Clean Energy Applications

(5) Advanced Materials Manufacturing
(incl: Extreme Mat'l., Conversion Mat'l, etc.)
(6) Critical Materials
(7) Advanced Composites & Lightweight Materials
(8) 3D Printing / Additive Manufacturing
(9) 2D Manufacturing / Roll-to-Roll Processes
(10) Wide Bandgap Power Electronics
(11) Next Generation Electric Machines (NGEM)

QTR Manufacturing Focus Areas Mapped to Advanced Manufacturing Topical Areas for Technology Development

Energy Consumption by Sector



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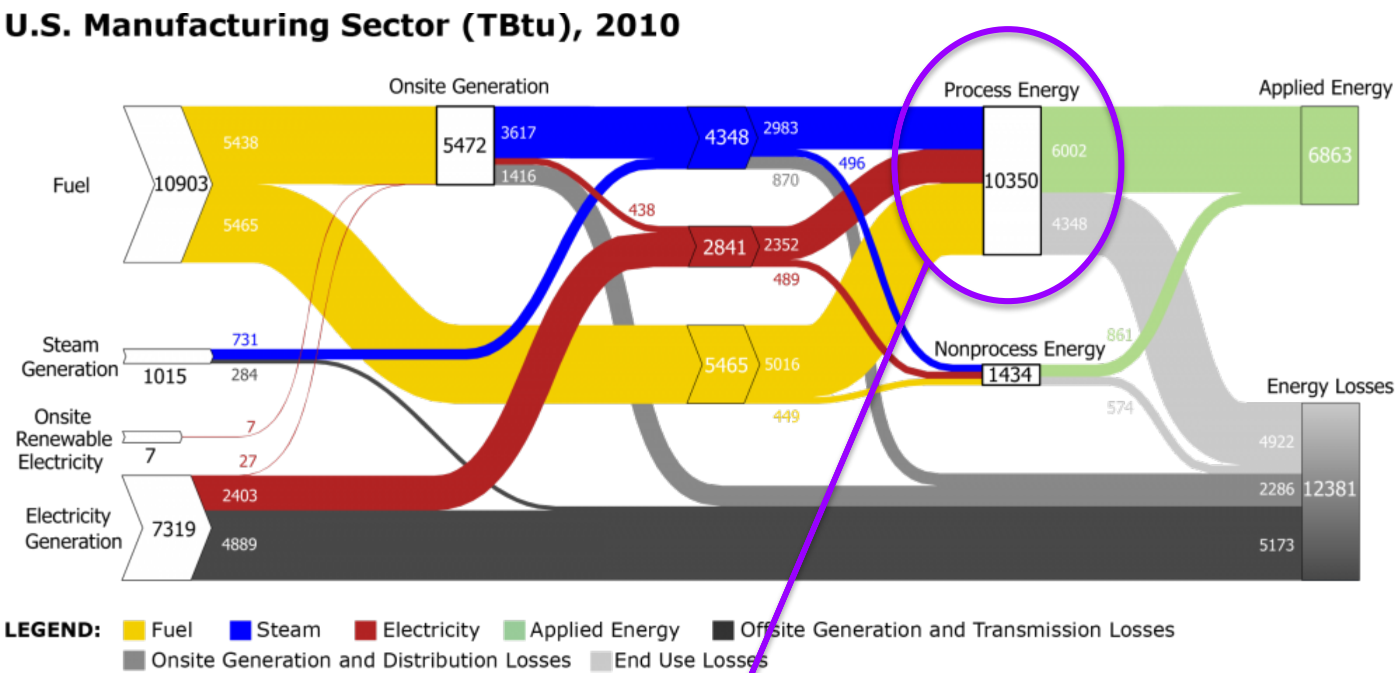
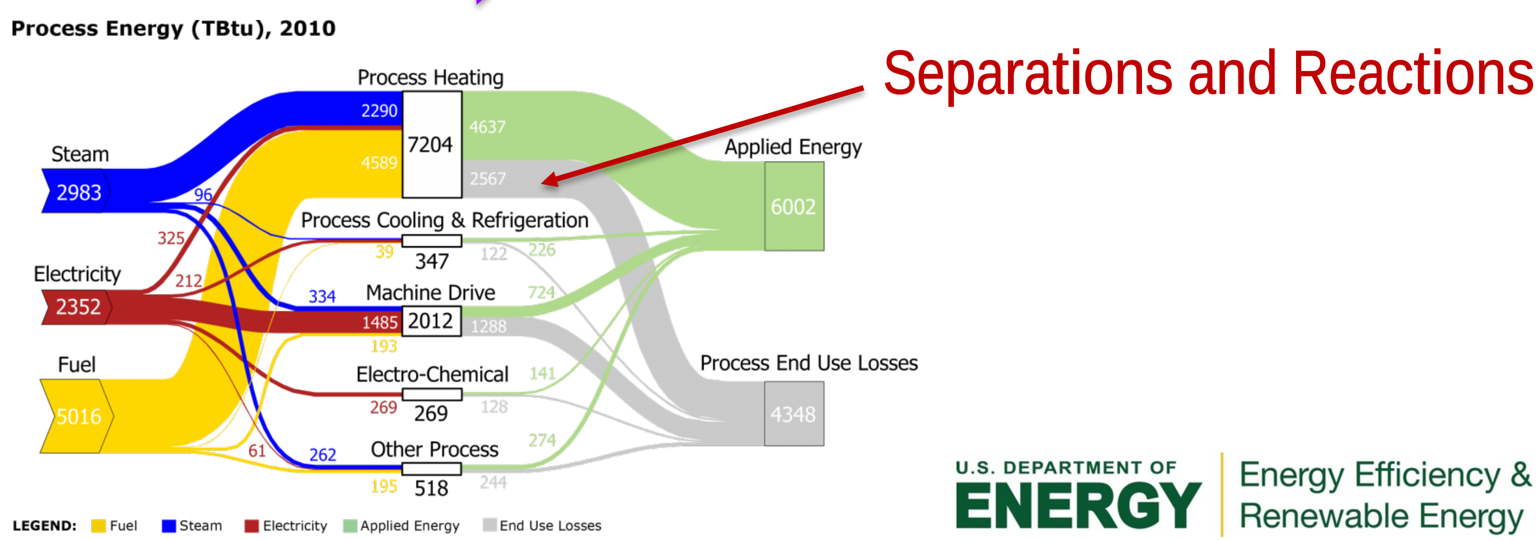
Energy Use in the Manufacturing Sector





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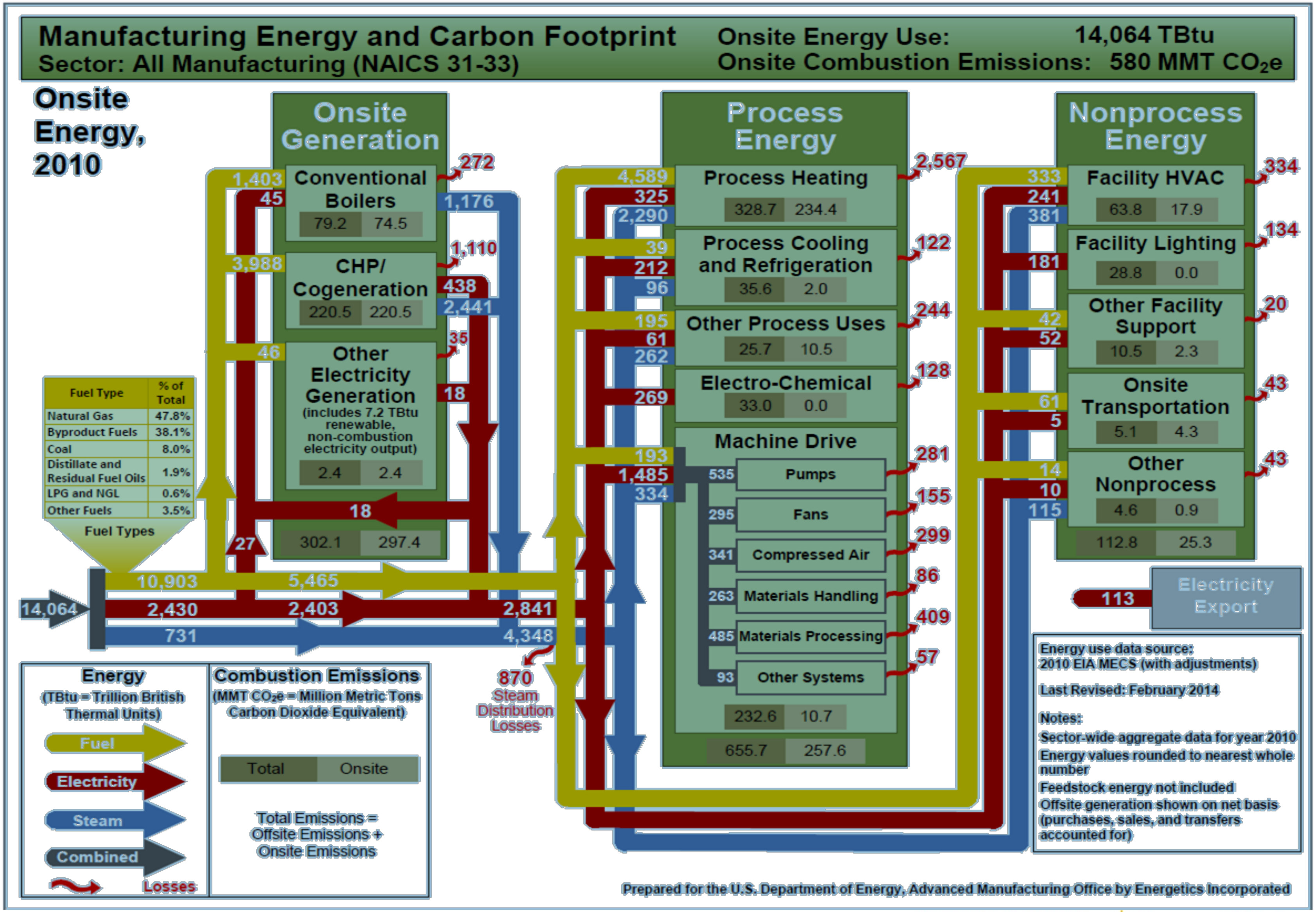
Deeper Look at Energy in Manufacturing



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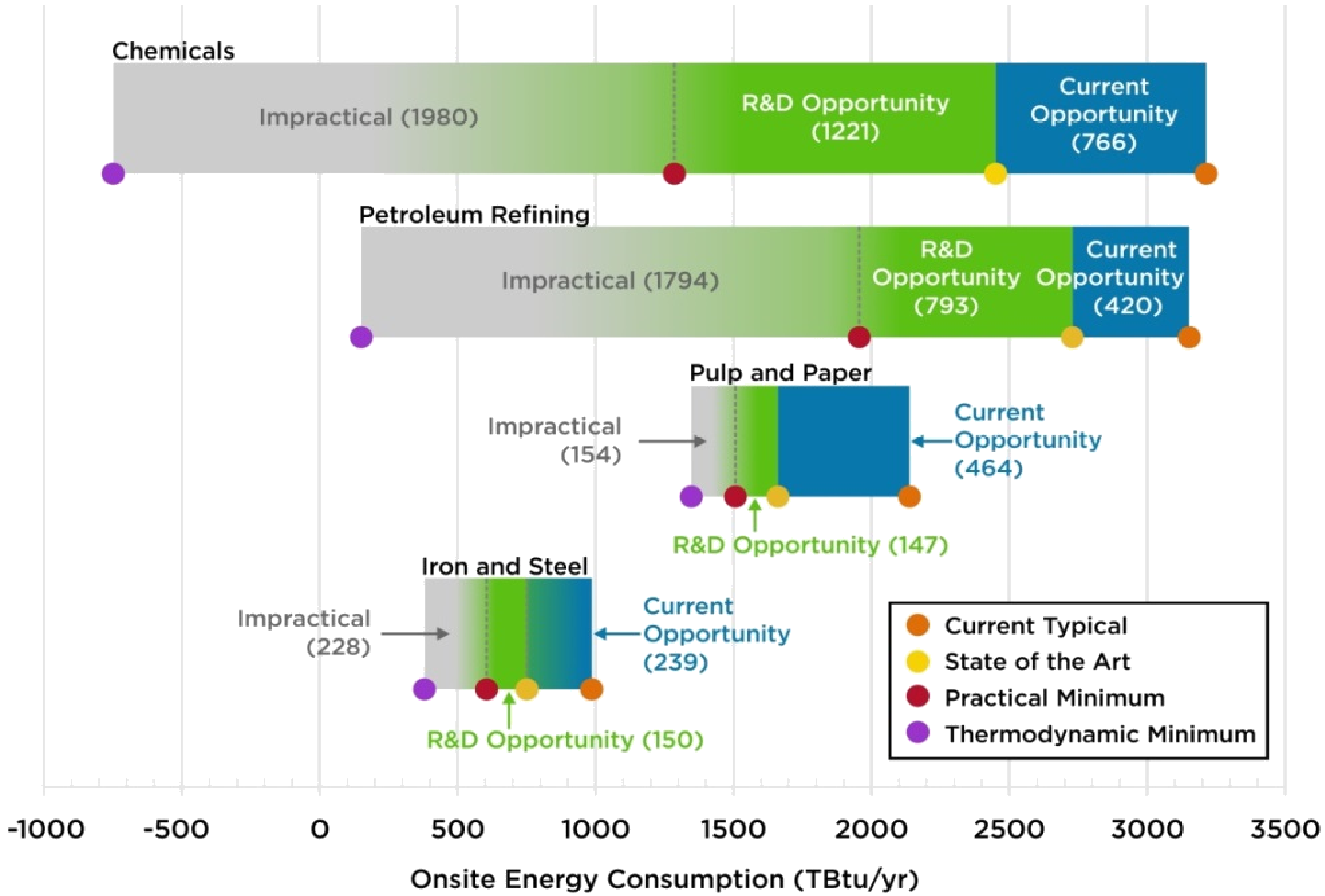
Bandwidth Studies: Energy Savings Potentials



Current opportunities represent energy savings that could be achieved by deploying the most energy-efficient commercial technologies available worldwide. R&D opportunities represent potential savings that could be attained through successful deployment of applied R&D technologies under development worldwide

Energy Intensive Industries

Primary Metals
1608 TBTU

Petroleum Refining
6137 TBTU

Chemicals
4995 TBTU

Wood Pulp & Paper
2109 TBTU

Glass & Cement
716 TBTU

Food Processing
1162 TBTU



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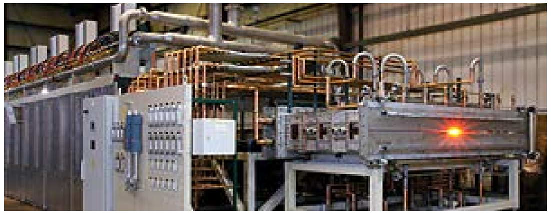
Processes for Clean Energy Materials & Technologies

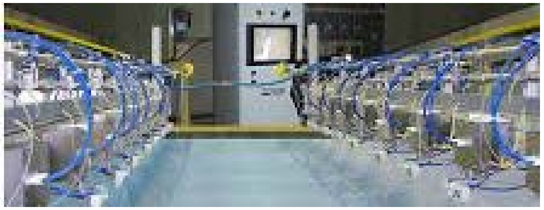
Energy Dependence: Energy Cost Considered in Competitive Manufacturing

Solar PV Cell



Carbon Fibers

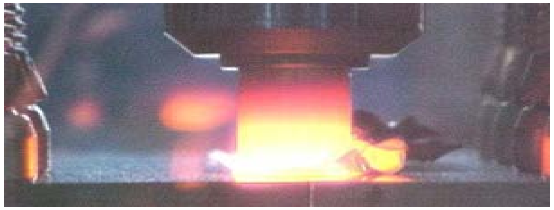
Light Emitting Diodes



Electro-Chromic Coatings

Membranes

EV Batteries

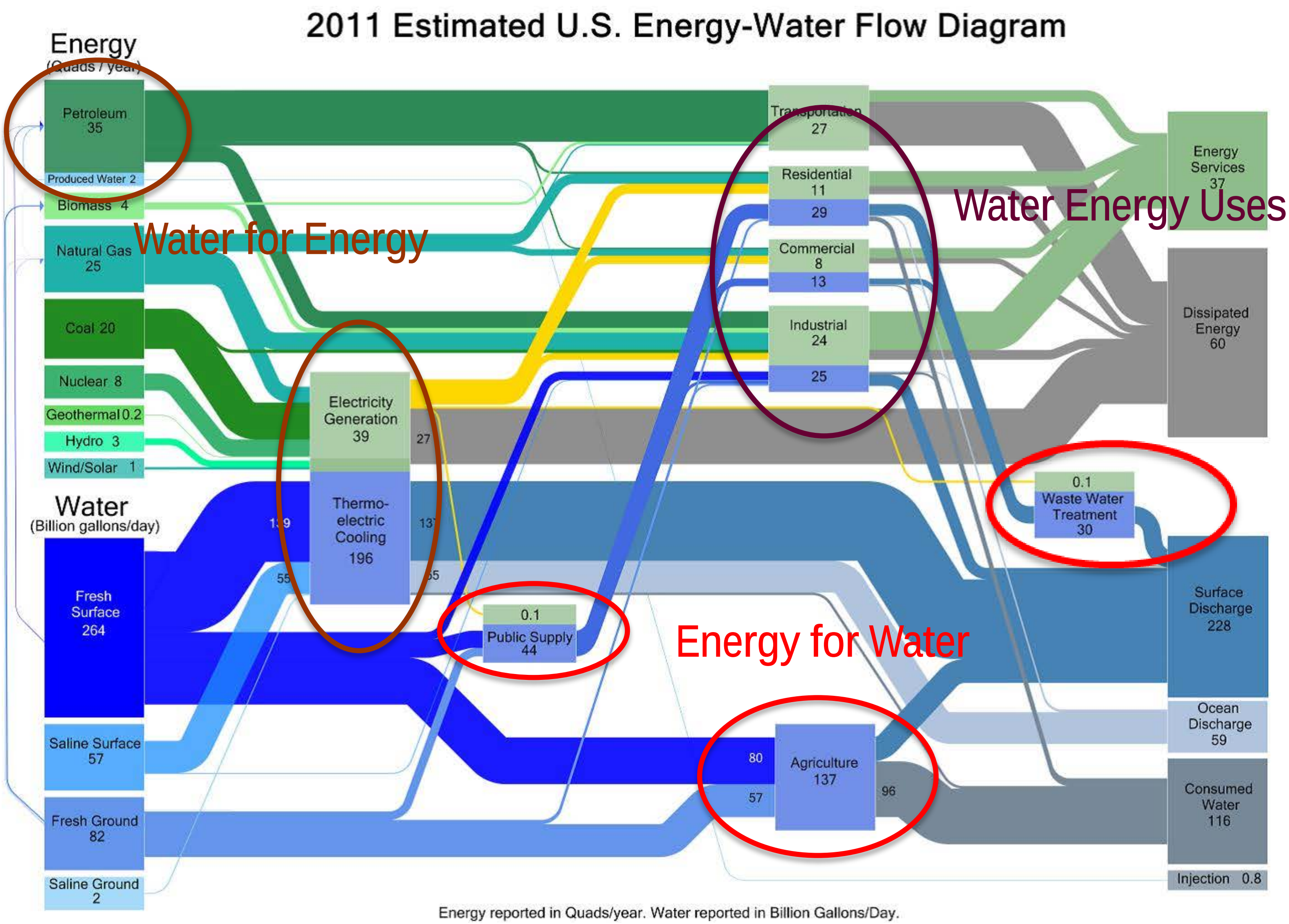


Multi-Material Joining

Possible Impact Areas of Cross-Cutting Technology for Energy Intensive Industry Sectors

	Chemicals & Bio-chemicals	Petroleum Refining	Primary Metals	Forest & Food Products	Clean Water
SMART Manufacturing	●	●	●	●	●
Process Intensification	●	●	●	●	●
CHP & Grid Integration	●	●	●	●	●
Sustainable Manufacturing	●		●	●	●

Water and Energy in Sustainable Manufacturing



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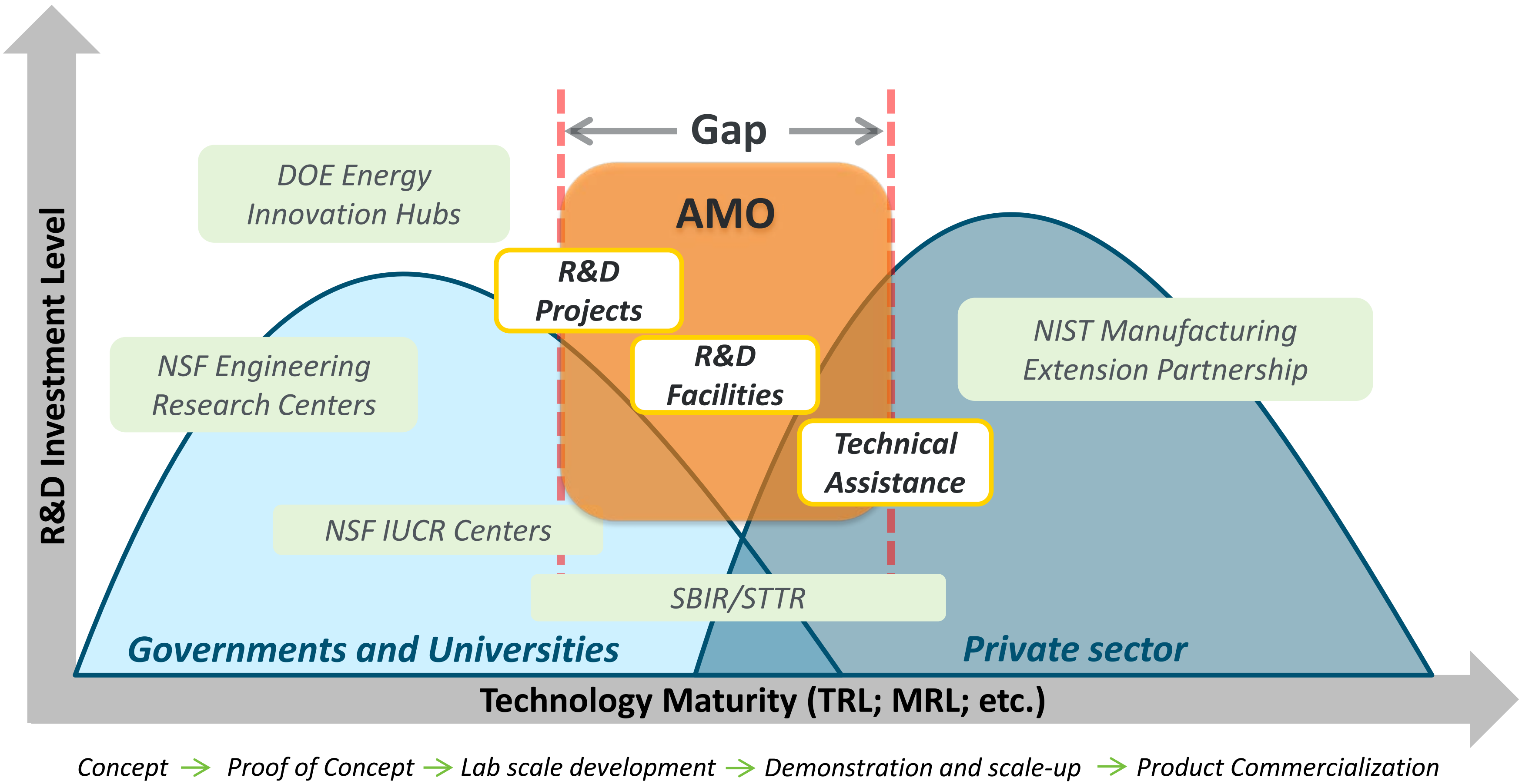
Bridging the Gap to Manufacturing

AMO: Advanced Manufacturing Office



Modalities of Support

Technology Assistance: (Dissemination of Knowledge)

Better Plants, ISO-50001 / SEP, Industrial Assessment Centers, Combined Heat and Power Tech Assistance Centers, Energy Management Tools & Training

Technology Development Facilities: (Innovation Consortia)

Critical Materials Hub, Manufacturing Demonstration Facility (Additive), Power America NNMI, IACMI NNMI, CyclotronRoad, HPC4Manufacturing

Technology Development Projects: (Individual R&D Projects)

Individual Projects Spanning AMO R&D Space - University, Small Business, Large Business and National Labs. Each a Project Partnership (Cooperative Agreement).

AMO Elements

Three partnership-based approaches to engage industry, academia, national labs, and state & local government:

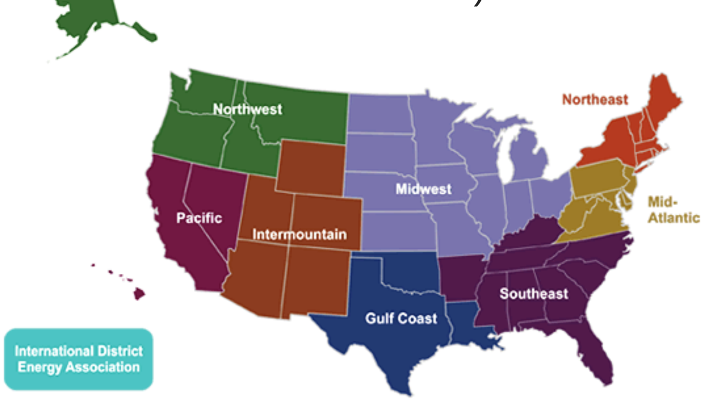
1. **Technical Assistance** – driving a corporate culture of continuous improvement and wide scale adoption of proven technologies, such as CHP, to reduce energy use in the industrial sector
2. **Research and Development Projects**
3. **Shared R&D Facilities**

Industrial Technical Assistance

Efficient On-Site Energy

Clean Energy Application Centers

(to be called Technical Assistance Partnerships since in FY14)



Simplot Bringing Earth's Resources to Life · SAINT-GOBAIN · NISSAN · legrand · ALCOA · GE · 3M

Energy-Saving Partnership

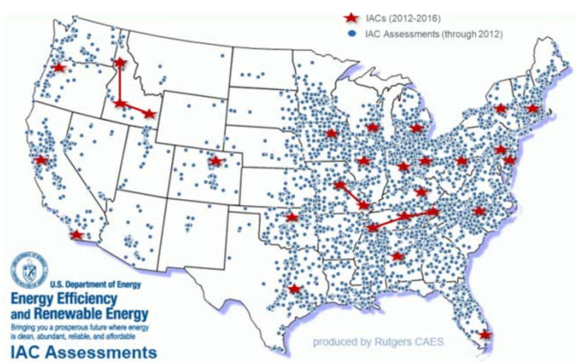
Better Buildings, Better Plants,

Industrial Strategic Energy Management

Schneider Electric · BRIGGS & STRATTON · Cummins · Johnson Controls

Student Training & Energy Assessments

University-based Industrial Assessment Centers



Better Plants U.S. DEPARTMENT OF ENERGY

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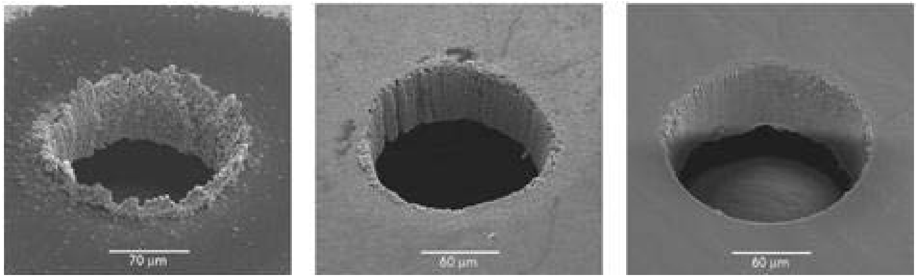
AMO Elements

Three partnership-based approaches to engage industry, academia, national labs, and state & local government:

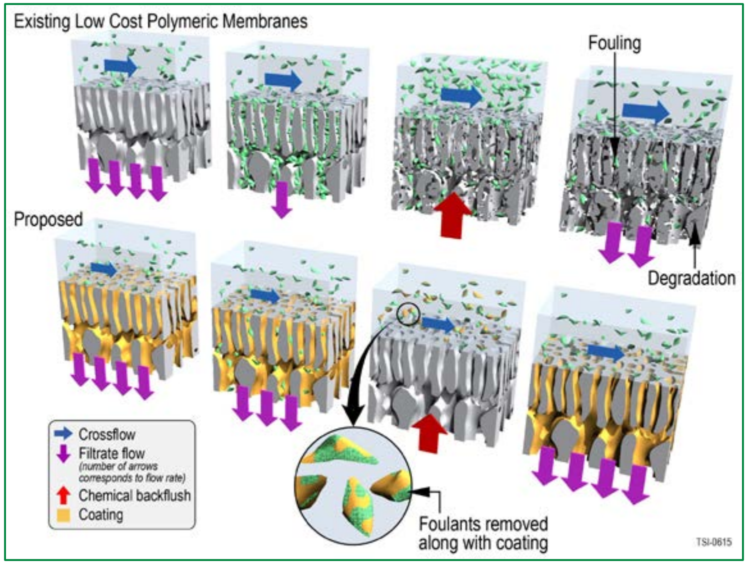
1. **Technical Assistance**
2. **Research and Development Projects -** to support innovative manufacturing processes and next-generation materials
3. **Shared R&D Facilities**

R&D Projects: Manufacturing Processes



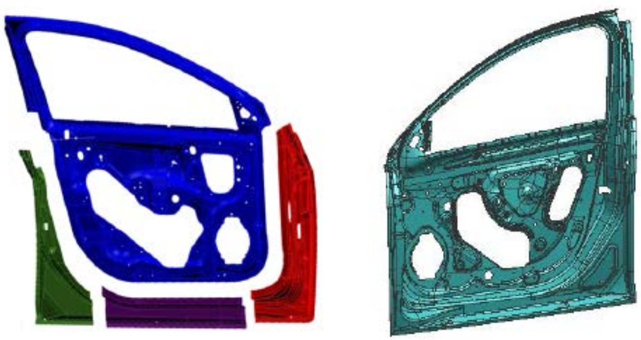
Ultrafast, femtosecond pulse lasers (right) will eliminate machining defects in fuel injectors.

Image courtesy of Raydiance.



Protective coating materials for high-performance membranes, for pulp and paper industry.

Image courtesy of Teledyne

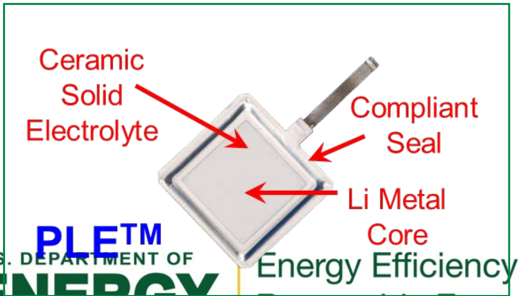


Energy-efficient large thin-walled magnesium die casting, for 60% lighter car doors.

Graphic image provided by General Motors.

A water-stable protected lithium electrode.

Courtesy of PolyPlus

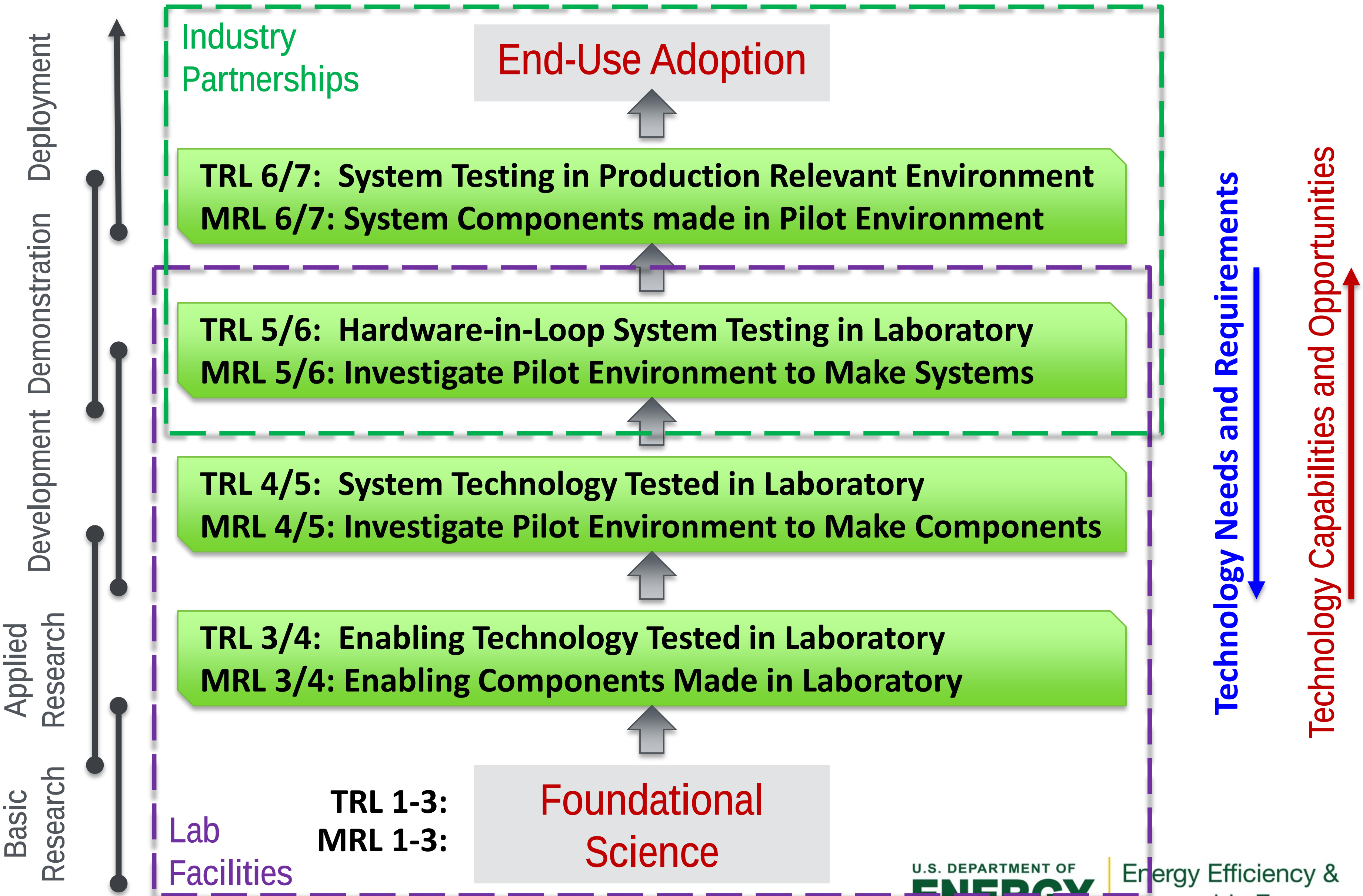


AMO Elements

Three partnership-based approaches to engage industry, academia, national labs, and state & local government:

1. **Technical Assistance**
2. **Research and Development Projects**
3. **Shared R&D Facilities** - affordable access to physical and virtual tools, and expertise, to foster innovation and adoption of promising technologies

Manufacturing Technology Maturation



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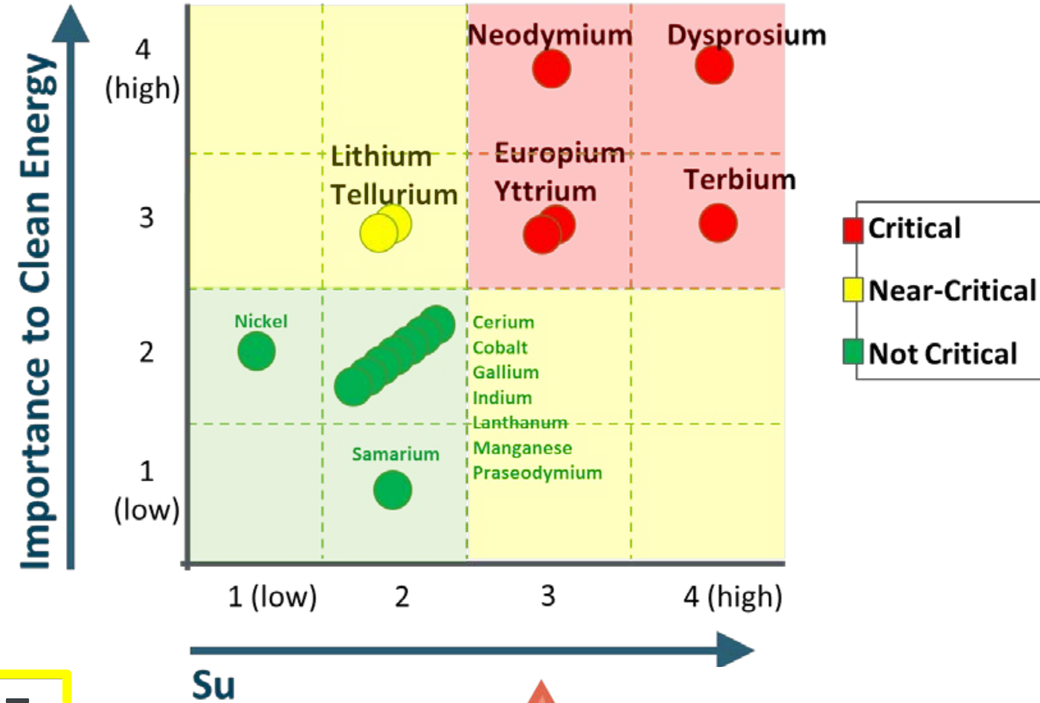
Accelerating Energy Innovations

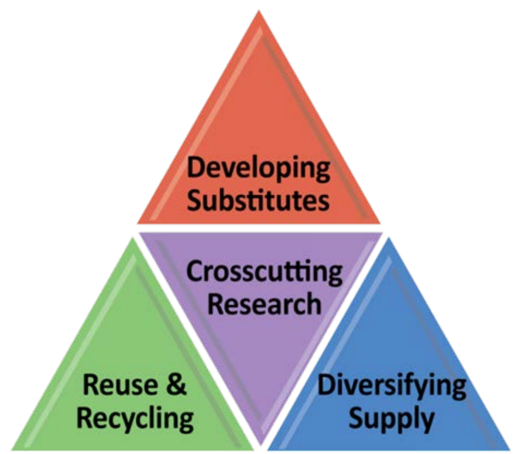
Critical Materials Institute

A DOE Energy Innovation Hub

- Consortium of 7 companies, 6 universities, and 4 national laboratories
- Led by Ames National Laboratory



	Dy	Eu	Nd	Tb	Y	Li	Te
Lighting		✓		✓	✓		
Vehicles	✓		✓			✓	
Solar PV							✓
Wind	✓		✓				



Critical Materials - as defined by U.S. Department of Energy, *Critical Materials Strategy*, 2011.

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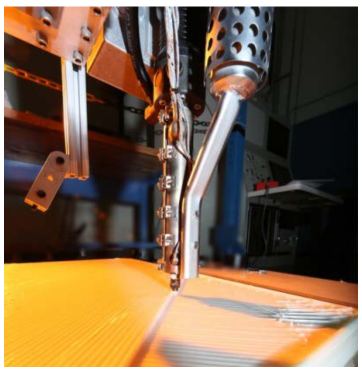
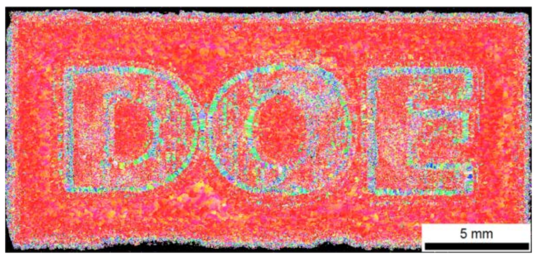
Manufacturing Demonstration Facility

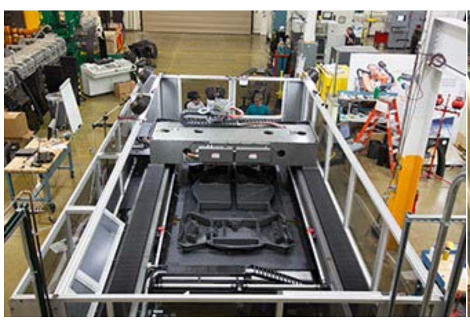
Supercomputing Capabilities

Spallation Neutron Source

America Makes







Additive Manufacturing

Arcam electron beam processing AM equipment

POM laser processing AM equipment

Program goal is to accelerate the manufacturing capability of a multitude of AM technologies utilizing various materials from metals to polymers to composites.

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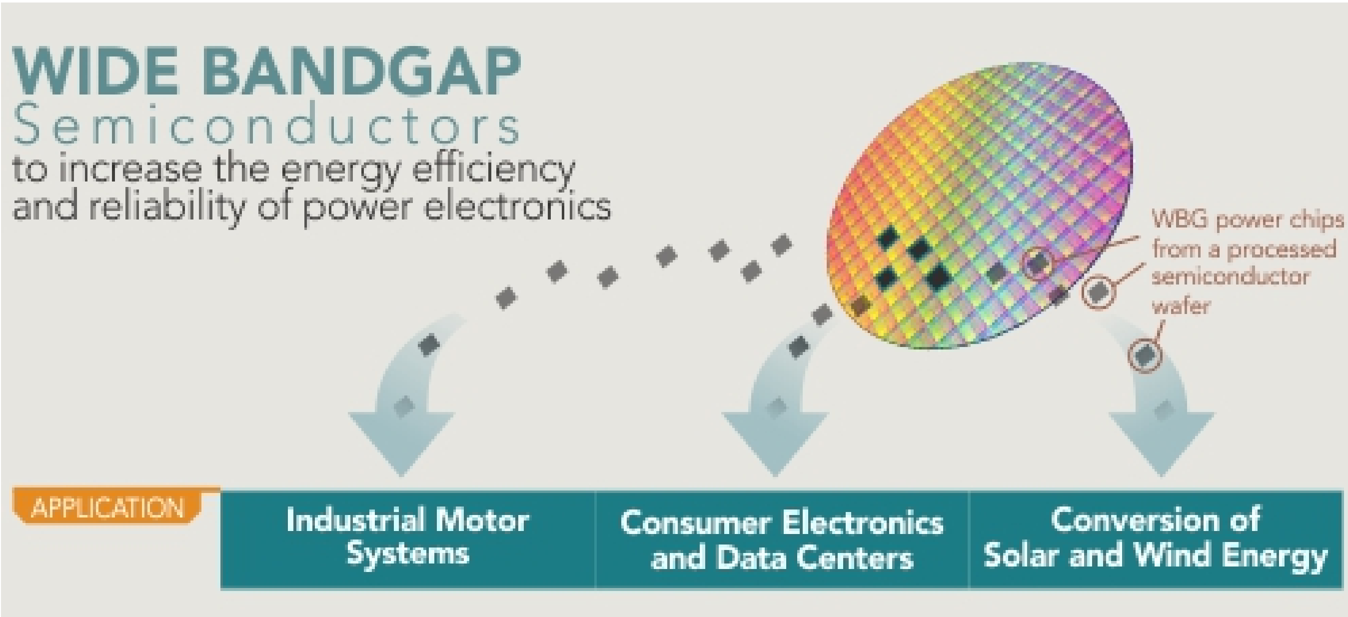
PowerAmerica:
Next Generation Power Electronics Manufacturing Institute



Institute Mission:
Develop advanced manufacturing processes that will enable large-scale production of wide bandgap semiconductors

- Higher temps, voltages, frequency, and power loads (compared to Silicon)
- Smaller, lighter, faster, and more reliable power electronic components
- $3.3 B market opportunity by 2020.[1]
- Opportunity to maintain U.S. technological lead in WBG

Poised to revolutionize the energy efficiency of electric power control and conversion

[1] Lux Research, 2012.

Institute for Advanced CompositeMaterials Innovation (IACMI)



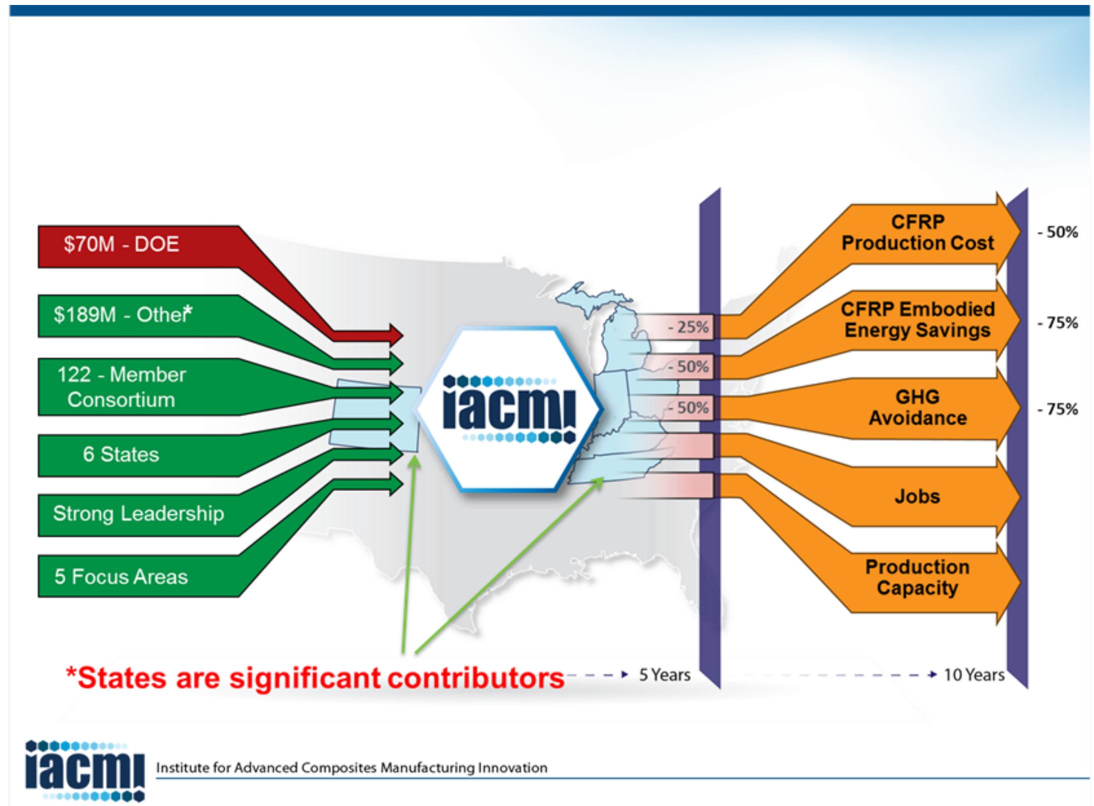
Objective

Develop and demonstrate innovative technologies that will, within 10 years, make advanced fiber-reinforced polymer composites at…

50% Lower Cost

Using 75% Less Energy

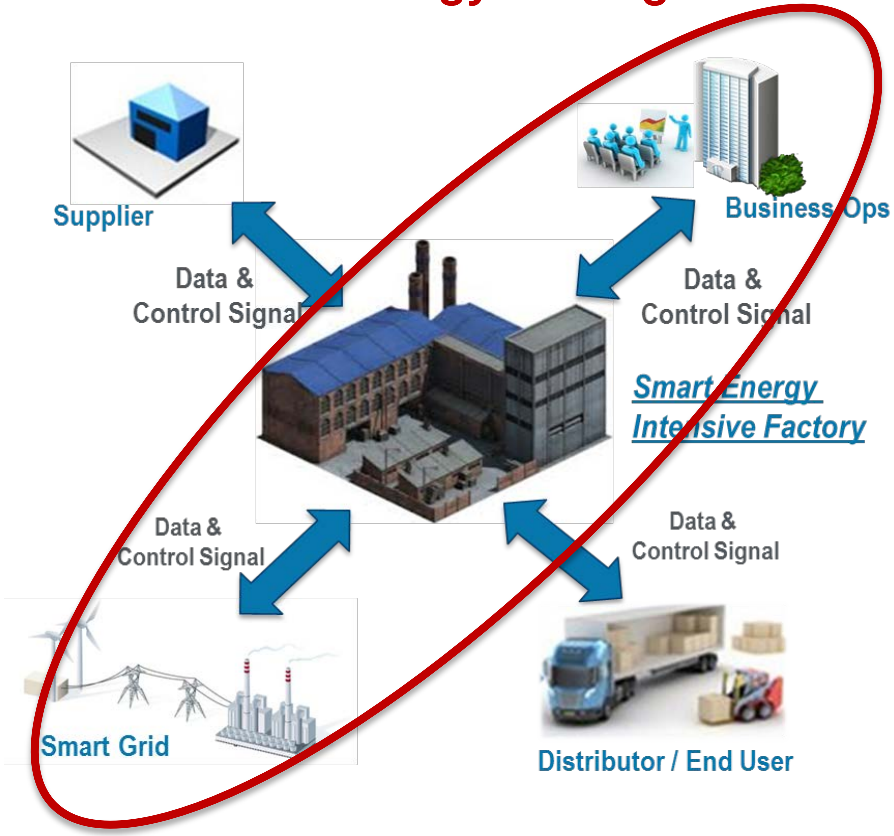
And reuse or recycle >95% of the material



SMART Manufacturing: Advanced Controls, Sensors, Models & Platforms for Energy Applications

Focus on Real-Time

For Energy Management



- Encompass machine-to-plant-to-enterprise real time sensing, instrumentation, monitoring, control, and optimization <u>of energy</u> **(>50% improvement in energy productivity)**
- Enable hardware, protocols and models for advanced industrial automation: requires a holistic view of data, information and models in manufacturing at Cost Parity (>**50% reduction in installation cost**)
- Significantly reduce energy consumption and GHG emissions & improve operating efficiency – (**15% Improvement in Energy Efficiency)**
- Increase productivity and competitiveness across all manufacturing sectors:

  Special Focus on <u>Energy Intensive</u> & <u>Energy Dependent</u> Manufacturing Processes

Leverage AMP 2.0 and QTR

Topical Engagementwith Industry

Advanced Materials	→	Materials in Extreme Conditions
	→	Sustainable Materials in Manufacturing
Process Intensification	→	Process Intensification (Chemical)
	→	Process Intensification (Thermal)
Roll-to-Roll Processing	→	Functional Membrane Structures
Advanced Sensors, Controls, Models, Platforms	→	Smart Manufacturing

What is Process intensification?

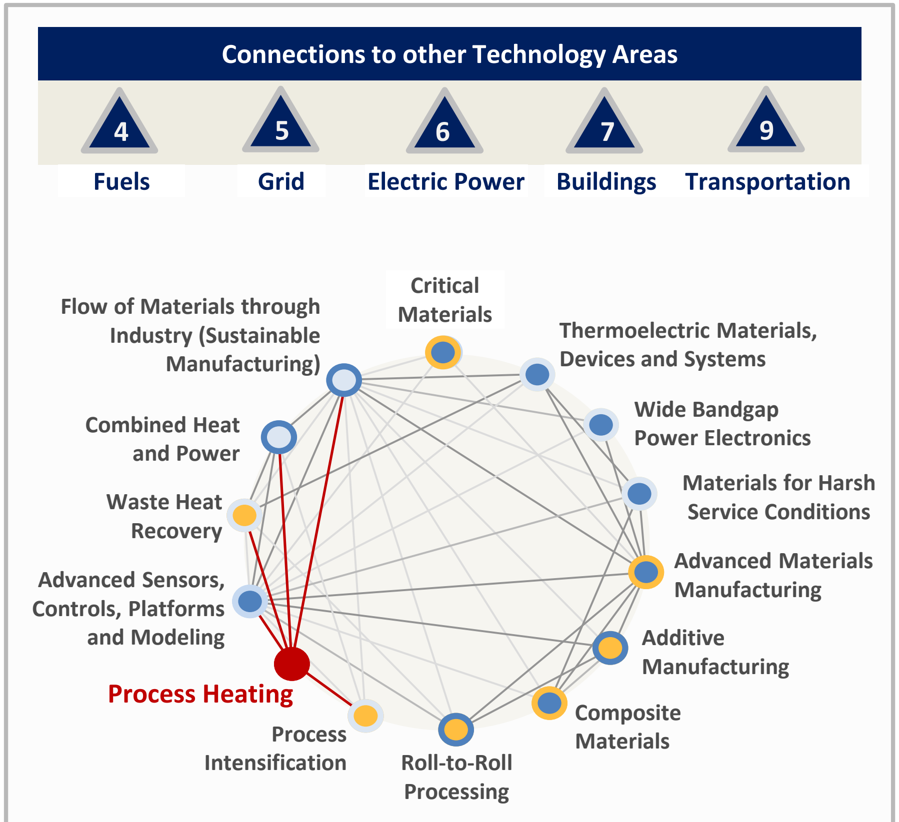
- Termed in 1970s by Kleemann et al. and Ramshaw[15,16]
- What does "process intensification" mean?

> ***Process intensification*** *is a chemical process with the precise environment it needs to flourish, results in better products, and processes which are* ***safer, cleaner, smaller, and cheaper****.*
>
> \- The BHR Group[19]

Workshop in 2014 ⇒ Clear need to split into two paths

THERMAL ⇐ ⇒ CHEMICAL

Process Heating



New Scientific Opportunities

- Computational modelling of thermal processes
- low cost / high power RF, microwave sources
- High and low thermal conductivity materials
- Materials discoveries: corrosive / hot environment

Range of Applications

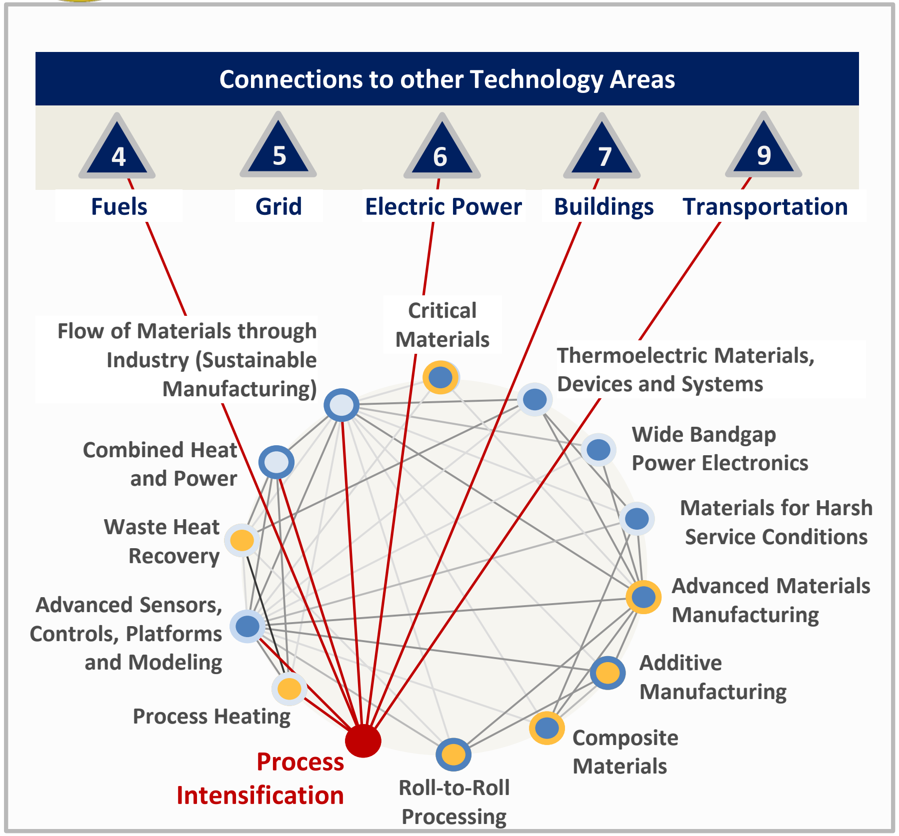
- Mini-mill approach to materials:
  Glass, non-ferrous metals, cement
- Scale-able efficiency enhancements
  to existing processes: pulp-paper, food
- Smaller/ flexible CHP / WH utilization

Process heating R&D opportunities and estimated energy savings*

R&D Opportunity	Applications	Estimated Annual Energy Savings Opportunity
Non-thermal water removal	Drying and Concentration	500 TBtu
Hybrid distillation	Distillation	240 TBtu
New catalysts	Catalysis and Conversion	290 TBtu
Low-energy material processing	Cross-Cutting	150 TBtu
High-temperature materials	Cross-Cutting	150 TBtu
Ultrahigh efficiency boilers	Steam Production	350 TBtu
Waste heat recovery systems	Cross-Cutting	260 TBtu
Net and near-net-shape design and manufacturing	Casting, Rolling, Forging, and Powder Metallurgy	140 TBtu
Integrated control systems	Cross-Cutting	130 TBtu
Total savings opportunity		2,210 TBtu
		(of 7,204 TBtu consumed overall)

*Source: R. B. Chapas and J. A. Colwell, "Industrial Technologies Program Research Plan for Energy-Intensive Process Industries," prepared by Pacific Northwest National Laboratory for the U.S. DOE (2007)

Process Intensification and Feedstock Conversion



Range of Applications

- On-site upgrading of Natural Gas
- Small-Modular Chemical Processes (Energy Intensive and Dependent)
- Efficiency Water Separation / Processing
- Environmental Management / Clean-up

2010 production, energy consumption, and estimated energy savings potential from successful implementation of process intensification for 11 energy-intensive chemicals*

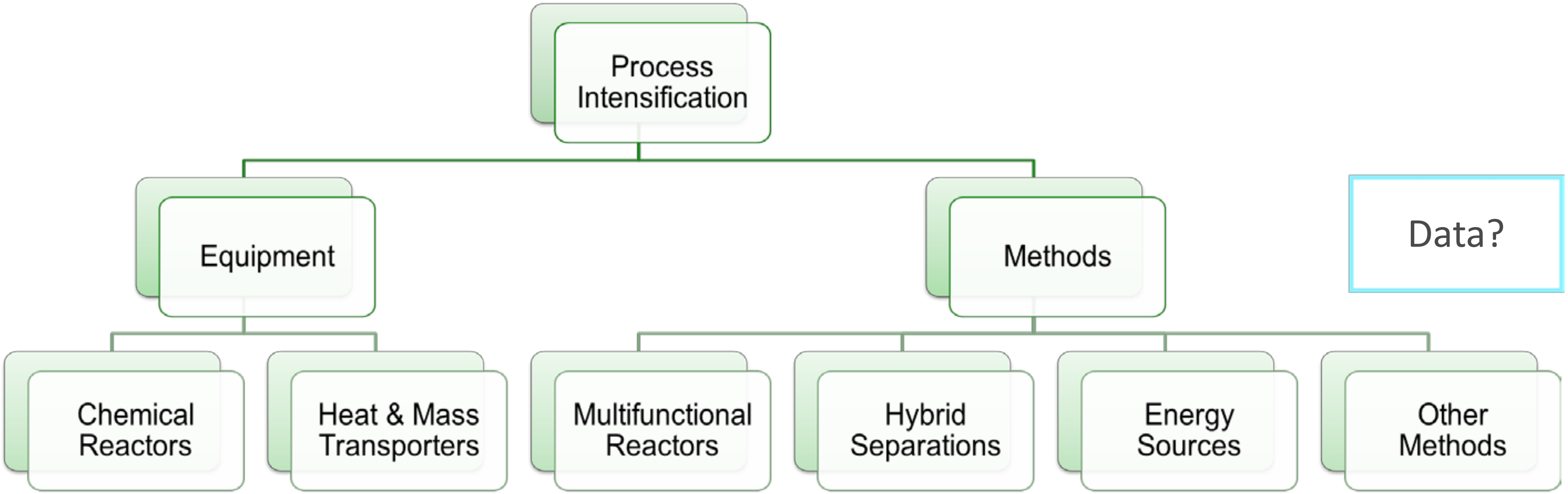
Chemical	Production ($1x10^6$ lbs)	Calculated Site Energy (TBtu/yr)	Energy Reduction Opportunity (TBtu/yr)
Ethanol	66,080	307 TBtu	264 TBtu
Ethylene	52,864	374 TBtu	107 TBtu
Ammonia	22,691	133 TBtu	78 TBtu
Chlorine / Sodium Hydroxide	21,465 / 16,581	141 TBtu	36 TBtu
Nitrogen/Oxygen	69,609 / 58,287	99 TBtu	18 TBtu
Terephthalic Acid	2,217	16 TBtu	17 TBtu
Hydrogen	6,591	6 TBtu	17 TBtu
Propylene	31,057	42 TBtu	11 TBtu
Carbon Black	3,415	13 TBtu	7 TBtu
Ethylene Oxide	5,876	11 TBtu	4 TBtu
Methanol	2,024	10 TBtu	4 TBtu
TOTAL	**358,757**	**1,152 TBtu**	**563 TBtu**

*Source: *Chemical Industry Energy Bandwidth Study*. Prepared by Energetics, Inc. for U.S. Department of Energy, AMO. *To be published in 2015*.

New Scientific Opportunities

- Leverage High Fidelity Computational Design of Materials Chemical Processes
- Breakthroughs in Catalysis (EFRCs, etc)
- Micro-reactor / Micro-mixing Structures
- Integrated Thermal Exchange Systems

Examples of Process Intensification



- Spinning disk reactor
- Static mixer reactor
- Static mixing catalysts
- Monolithic reactors
- Microreactors
- Heat exchange reactors
- Supersonic gas/liquid reactors
- Jet-impingement reactor
- Rotating packed-bed reactor

- Static mixers
- Compact heat exchanger
- Microchannel heat exchangers
- Rotor/stator mixers
- Rotating packed beds
- Centrifugal adsorber

- Reverse-flow reactors
- Reactive distillation
- Reactive extraction
- Reactive crystallization
- Periodic separating reactors
- Membrane reactors
- Reactive extrusion
- Reactive comminution
- Fuel cells

- Membrane adsorption
- Membrane distillation
- Adsorptive distillation

- Centrifugal fields
- Ultrasound
- Solar energy
- Microwaves
- Electric fields
- Plasma technology

- Supercritical fluids
- Dynamic (periodic) reactor operation

- Mix, React, Separate & Manage Heat
- Materials, Processes and Information

Questions We Asked: RFIs and Workshops

Core Questions	Application to NNMI Topic Selection
High Impact:	• What is manufacturing challenge to be solved? • If solved, how does this impact clean energy goals? • If solved, who will care and why specifically?
Additionality:	• Who is supporting the fundamental low-TRL research & why wouldn't they support mid-TRL development? • Who else might fund this mid-TRL development & how might EERE/AMO support catalyze this co-investment?
Openness:	• Has this mid-TRL Manufacturing Challenge been Stated Broadly? • Is there Fertile low-TRL Scientific Base to Address the Challenge? • Has a Broad Set of Stakeholders been Engaged in Dialog?
Enduring Economic Benefit:	• Would this Manufacturing Challenge Impact More than One Clean Energy Technology Application? • Is Industry Currently Trying to Identify Solutions?
Proper Role of Government:	• What is the National Interest? What is the Market Failure? (Why Would Industry Not Solve this By Itself?) • Is there a Pathway for Federal Funding to End & What are the Metrics for This Transition? • Is there Large Potential for Follow-On Funding, & What are the Stage Gates to Follow-On Support?
+ Appropriate Mechanism	• Why is this specific mid-TRL Problem Best Addressed through a 5-Year, Multi-participant, Industry-oriented Institute (NNMI) now?

High Impact

Knowns

- Chemicals are Energy Intensive
- Specific Chemicals have High Energy Intensity
- New Resources / Feedstocks for Chemicals (Nat Gas)
- Other Sectors would Benefit
- Need for Students
- Research is Expensive

Unknowns

- What are the specific unmet technical challenges?
- What new insights might be applied to these challenges?
- How would multiple sectors work on shared issues?
- How might direct competitors interact?

LIKE QUANTIFICATION OF POSSIBLE IMPACTS

Sample list of knowns and unknowns

Additionality

Knowns

- Chemical (or other specific industry) would benefit
- Collection Radius is a critical factor in distributed resources
- Traditional scaling laws are can lead to risk aversion
- Other countries are working in on Process Intensification

Unknowns

- Existing R&D trajectory for PI development?
- How might PI community grow if we are successful?
- What is the technical and economic white-space?
- What are Necessary Secondary Technologies

  (ex: Stable, Cost effective Materials; new Processes)?

Sample list of knowns and unknowns

Openness

Knowns

- Engaging with Industry will Provide New Thinking
- Open, Merit-Based Competition provides Opportunity for New Ideas

Unknowns

- Can Different Industries find Common Areas of Interest?
- What are those Common Interests?
- Is there a Supply Chain that Needs to Be Developed?
- Who is Missing?
- What can be Learned From Prior Efforts?

Sample list of knowns and unknowns

Enduring Impact

Knowns

- Specific Industries would Greatly Benefit from Technology, if Developed
- Specific Companies & Organizations would Greatly Benefit from Technology, if Developed
- There is an Enduring Need for Products which could be Developed
- US could Benefit from Technology & Ecosystem

Unknowns

- If it is so beneficial, why couldn't Industry or Companies just do this?
- If the Technology is Developed, why would Industry, States, etc. continue to Support this?
- Are there State / Regional or NGO groups which would Benefit if Successful?

Sample list of knowns and unknowns

Role of Government

Knowns

- Most Companies Unlikely to Support full Eco-System on its Own
- Your Specific Company / Organization is Not Going to Support this on its Own
- New Resources / Feedstocks Are Happening (Nat Gas)
- Need for Trained Workforce
- Research is Expensive

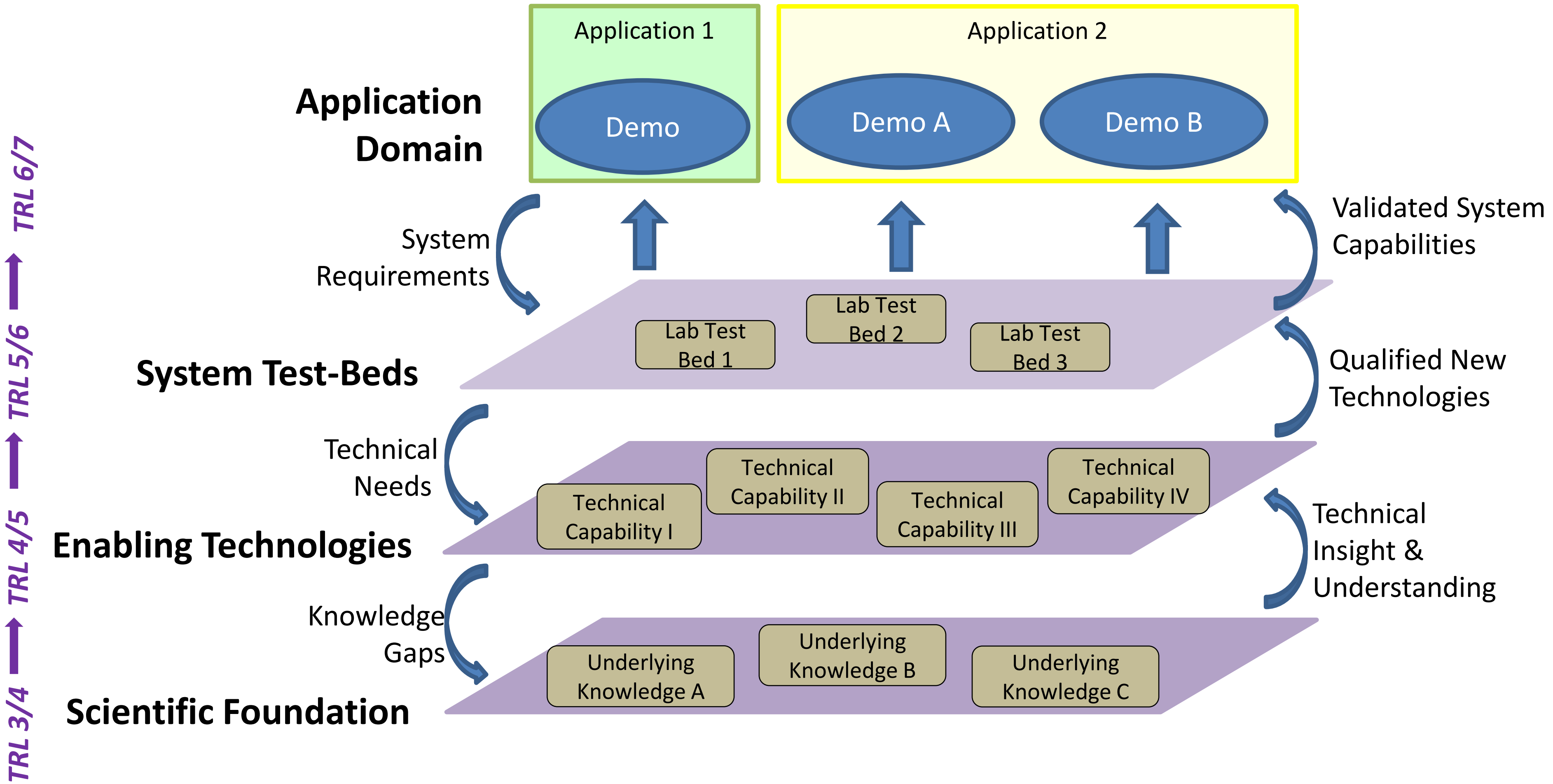
Unknowns

- What are the Technical and Economic Barriers / Market Failures (these are BIG industries)?
- How Should Information be Shared / Propagated?
- If there is an Economic Driving Force, What is the Activation Barrier?

Sample list of knowns and unknowns

Technical Challenge Hierarchy

Multi-Disciplinary Technology Translation



LIKE QUANTIFICATION OF POSSIBLE REQUIREMENTS, NEEDS & GAPS

Summary

- Want Input from Community
- Getting Quantitative (unrealistic) “Goal” is Challenging in any emerging field
- A Quantitative (unrealistic) “Goal” is Necessary
- Don’t Over Constrain Solution with Goal:

  Define Problem, not Solution
- All of Us can find Solutions that None of Us could Alone.
- No Consensus, Please…

What does Success Look Like?

Energy Products
Invented Here…

…And Competitively
Made Here!

Thank You

Questions?

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