Industrial Activities at DOE: Efficiency, Manufacturing, Process & Materials R&D

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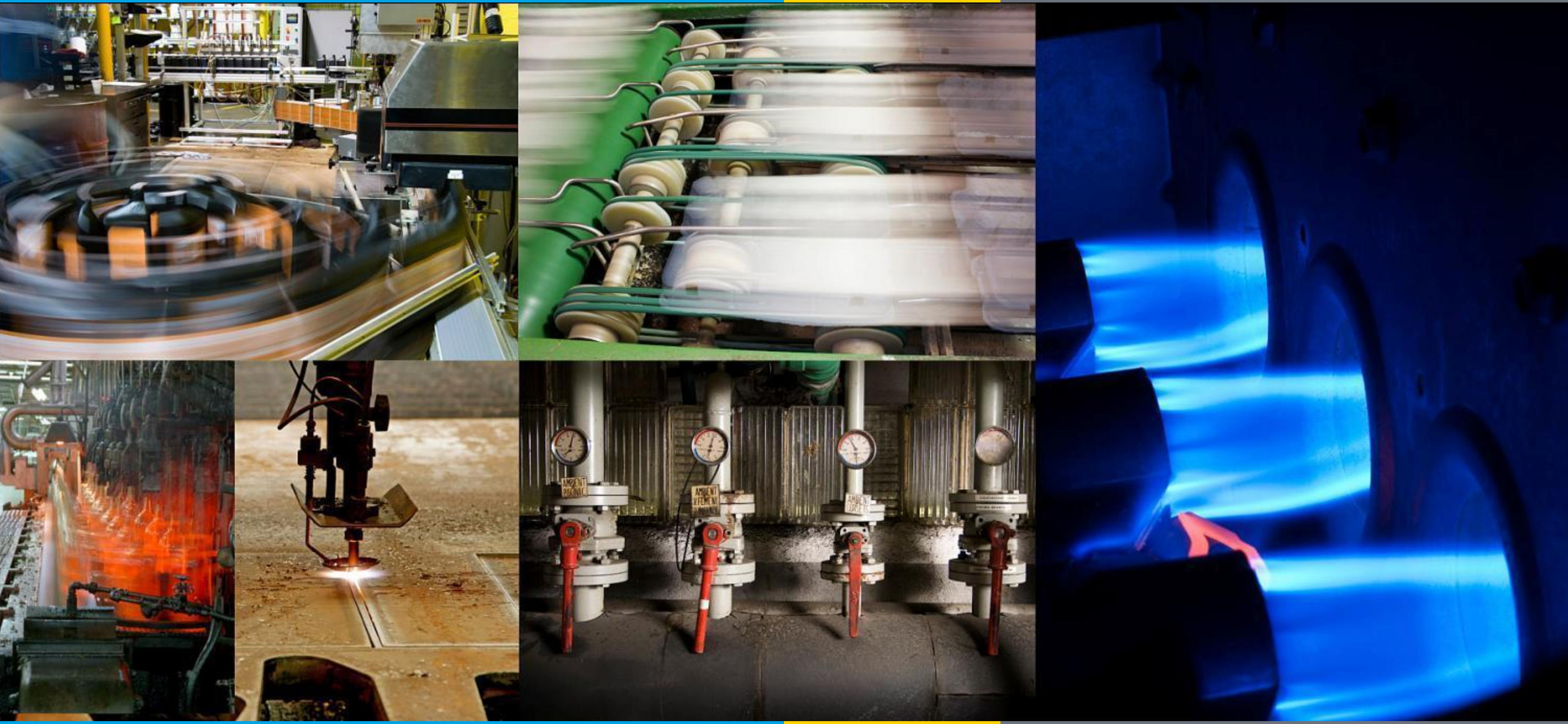

Joe Cresko
David Hardy
Advanced Manufacturing Office

Metrology Workshop
December 9, 2013
NREL

Industrial Energy Use

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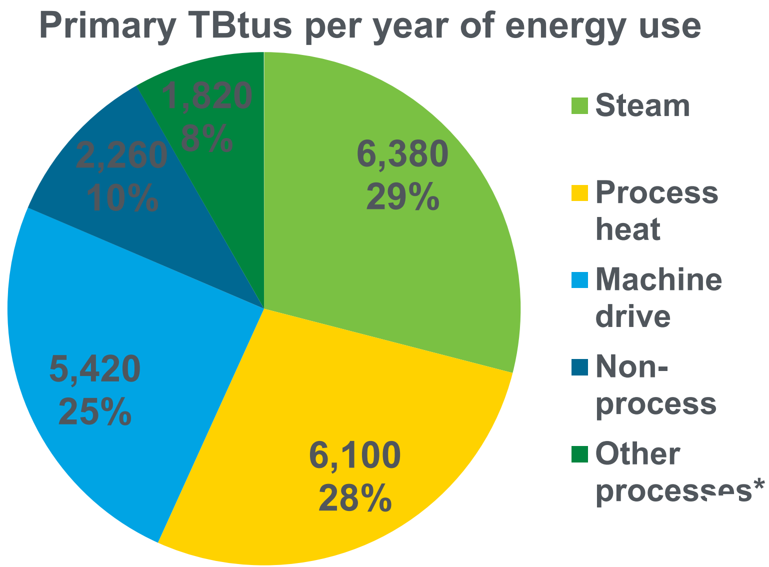
Manufacturing industry

- **Constitutes 11% of GDP**
- **Employs 12 million people**
- **Employs 60% of engineers and scientists**
- **Accounts for 30% of all energy consumption in the United States**



Source: *Manufacturing Energy and Carbon Footprint*, derived from 2006 MECS

AMO programs target:

- Research, Development and Demonstration of new, advanced processes and materials technologies that reduce energy consumption for manufactured products and enable life-cycle energy savings

- Efficiency opportunities through deployment of known technologies to existing manufacturing practices, especially for energy-intensive steam, process heating, and machine drive end-uses

ITP → Advanced Manufacturing Office

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- U.S. Big Picture
- EERE and Advanced Manufacturing Office (AMO) Overview
- AMO RD&D
    - Portfolio management criteria
    - Co-investment focused
    - Foundational Technology focused
- AMO Partnership Approach
    - R&D projects
    - RD&D Infrastructure
    - Technical assistance
    - Interagency coordination

AMO Goals

RD&D

- Reduce the **life-cycle energy consumption** of manufactured goods by 50 percent over 10 years for AMO supported technologies
- Assist EERE to manufacture **clean energy technologies**

  Currently 19 IMIs

Technical Assistance

- Encourage a culture of continuous improvement in **corporate energy management**
- Support achievement of **40 GW of new combined heat and power** by 2020

  2009-2012, over 440 CHP projects, with 270 receiving technical site evaluations

Industrial Energy Use

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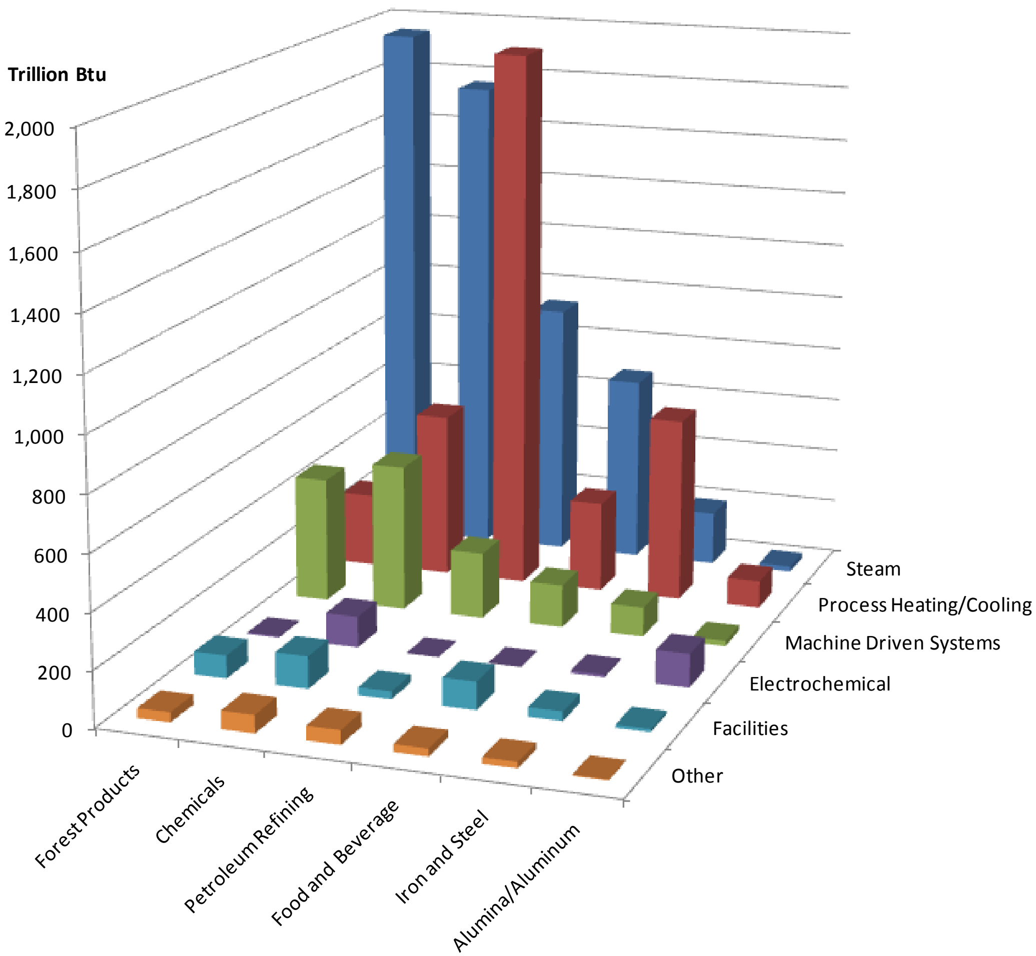

Source: Based on Energy Information Administration , 2006 Manufacturing Energy Consumption Survey, (Published 2009/2010)

Major Energy Uses

- **Steam Systems:** Boilers and steam distribution networks for industrial processes and machine-driven systems, chemical reaction and separation vessels (>4,750 TBtu in steam use)
- **Process Heating:** Furnaces, ovens, digesters, evaporators, kilns, and melters that are used in many types of manufacturing processes (~5,000 TBtu in fuel use)
- **Motor Systems:** Motor-driven equipment (e.g. pumps, compressed air, material handling) accounts for >1,700 TBtu of electric energy use

Impact through the Supply Chain

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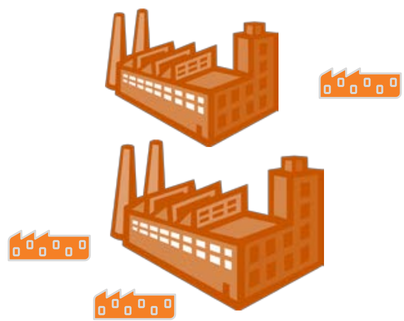
Materials and process industries produce 50% of the total dollar value of manufacturing shipments while consuming 86% of total manufacturing site energy use (fuel use only, non-feedstock).

Manufacturing Supply Chain

Energy and cost-saving benefits accrue at each plant and accumulate downstream.

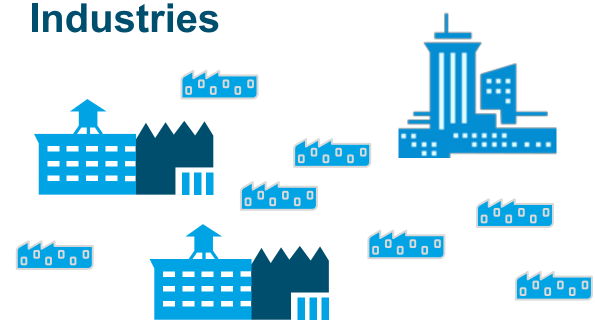
Materials and Process Industries



Key Sectors: Petroleum Refining, Chemicals, Cement, Glass, Steel, Aluminum, Food & Beverage, Wood & Paper Products

13.5 Quads (site)* 56,000 facilities

Fabrication and Assembly Industries



Key Sectors: Transportation Equipment, Fabricated Metals, Plastics, Machinery, Electrical Equipment

2.1 Quads (site)* 138,300 facilities

* Excludes feedstock energy

Source: EIA, MECS 2006.

Economy-wide lifecycle Energy impacts

Primary Energy Consumption by sectors, 2012 (Total 95 Quads)

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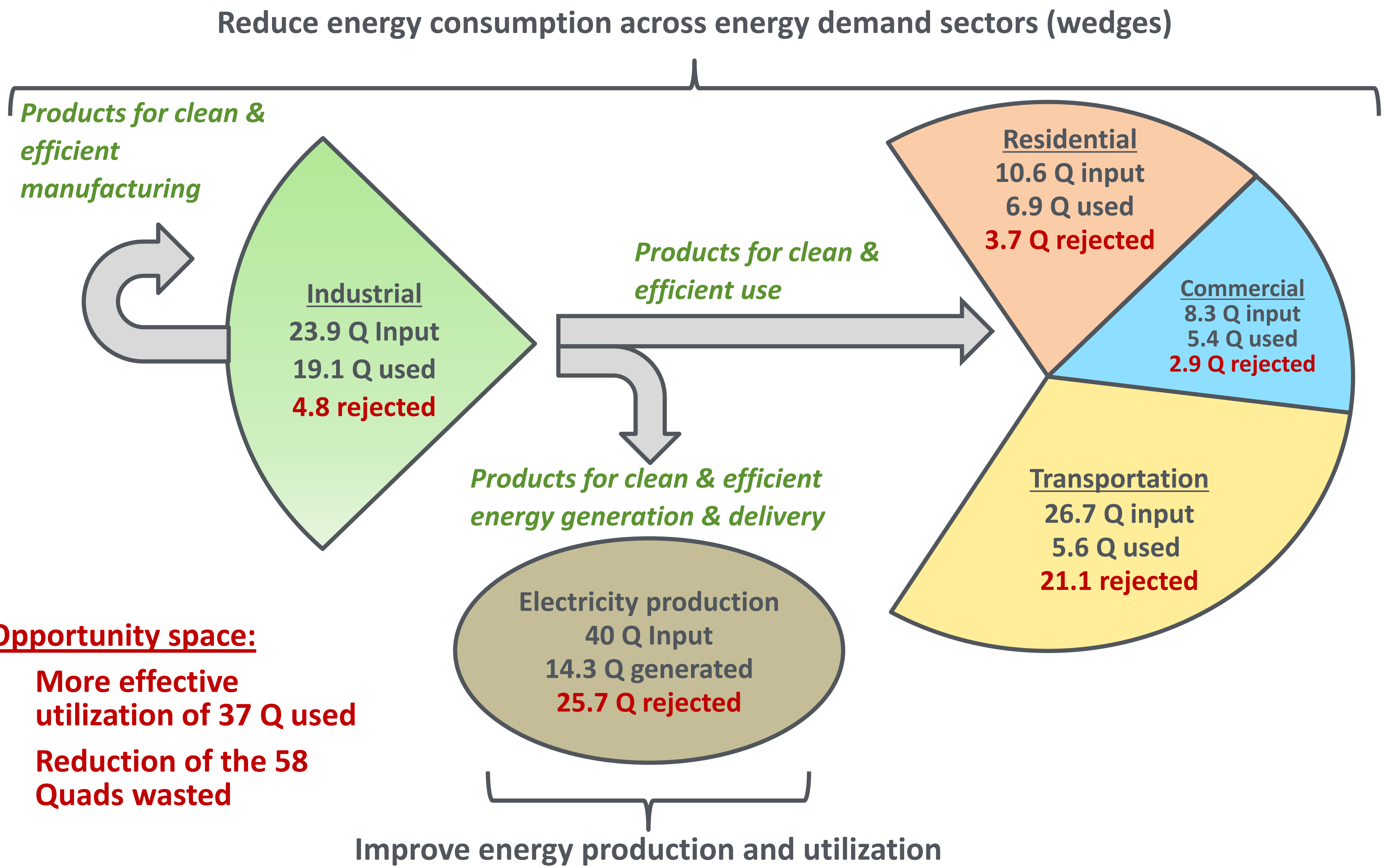

Opportunity space:

- **More effective utilization of 37 Q used**
- **Reduction of the 58 Quads wasted**

Next-Generation Industry Vision

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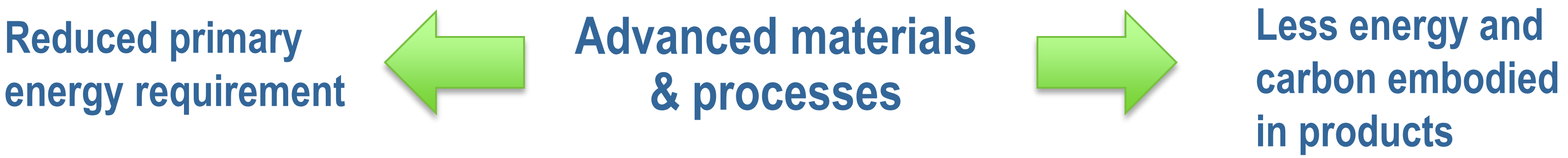
- Innovate new, cost-competitive materials, products, and processes for the low-carbon economy
- Develop novel manufacturing methods for producing materials and components that substantially reduce energy and carbon footprints
- Revitalize the manufacturing sector by developing rapid manufacturing processes that allow for continuous innovation and shorter product development lifetimes

Focus on energy-efficient, affordable, high-performance materials and processes to generate energy and carbon savings throughout the manufacturing value chain.



Example Next-Generation Materials Opportunities

Next-generation materials will achieve reductions in cost, energy, and pollution with improved product quality and performance. Potential areas of R&D investment include:

Low-cost titanium

Improved performance and life in energy-intensive systems (process heaters, power generation) and other applications (aircraft, geothermal, automotive)

Lightweight metallic materials

Magnesium and metal matrix composites for structural applications in vehicles

Smart coatings, thin films and electrochemicals

Materials that provide functional surface interactions, enabling a new generation of smart products

Inexpensive, high-performance carbon fibers

Wide range of clean energy applications (e.g., wind turbine blades)

Next-Generation Manufacturing Opportunities

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Provides highly efficient processing via process integration, low-energy pathways, smart systems, and entirely new technologies. Specific approaches include:

New production systems, such as innovative bioprocessing techniques

Reduce use of fossil-based feedstocks for chemicals and materials

Advanced forming & fabrication technologies

Allow for parts/product manufacture in near-final form with minimal materials and energy use

Non-thermal-based chemical conversion processes

Will lower energy use compared to thermal chemical conversion processes

High-performance separations

Yields energy and cost savings in a wide range of industries such as chemicals, paper, food, and fuels production

Next-Generation Manufacturing Opportunities (cont.)

Nanoscale manufacturing & processing

Enable the next generation of materials production via low energy pathways. Achieve higher performance materials with increased functionality produced via low energy-intensity manufacturing

Single/minimal stage manufacturing pathways

Consolidated pathways dramatically lower energy use by reducing number of processing steps. Reduce embodied energy of finished part compared with today's state-of-the-art

Smart manufacturing systems

Intensified use of manufacturing intelligence speeds time to market, enables dynamic demand response, and improves energy and materials performance through seamless process optimization across the value chain

Keystone Investments (Innovative Manufacturing Initiative)

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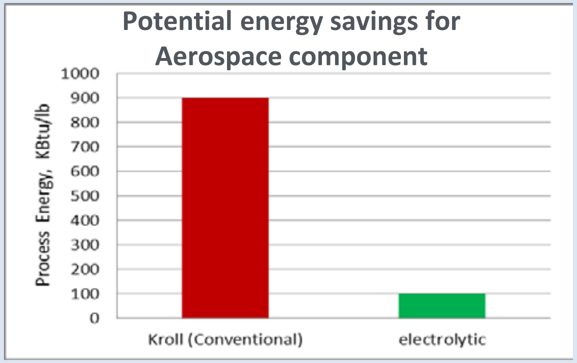
Example technologies representative of a potential project:

Electrolytic processing of Titanium

Conventional Kroll Process:
7 or more process steps involving 2-3 energy intensive melts

Net-Shape Electrolytic Process:
Fewer process steps resulting in near net-shaped components



Source: *ORNL titanium study*

Out-of-the-Autoclave Production of Composites

Conventional Autoclave: Requires sustained heating of all tooling in enclosed autoclave

Next-generation Composites:
Alternative processes can replace autoclaves for energy and cost savings

Source: *DARPA*

AMO RD&D Focus: Bridging the Gap

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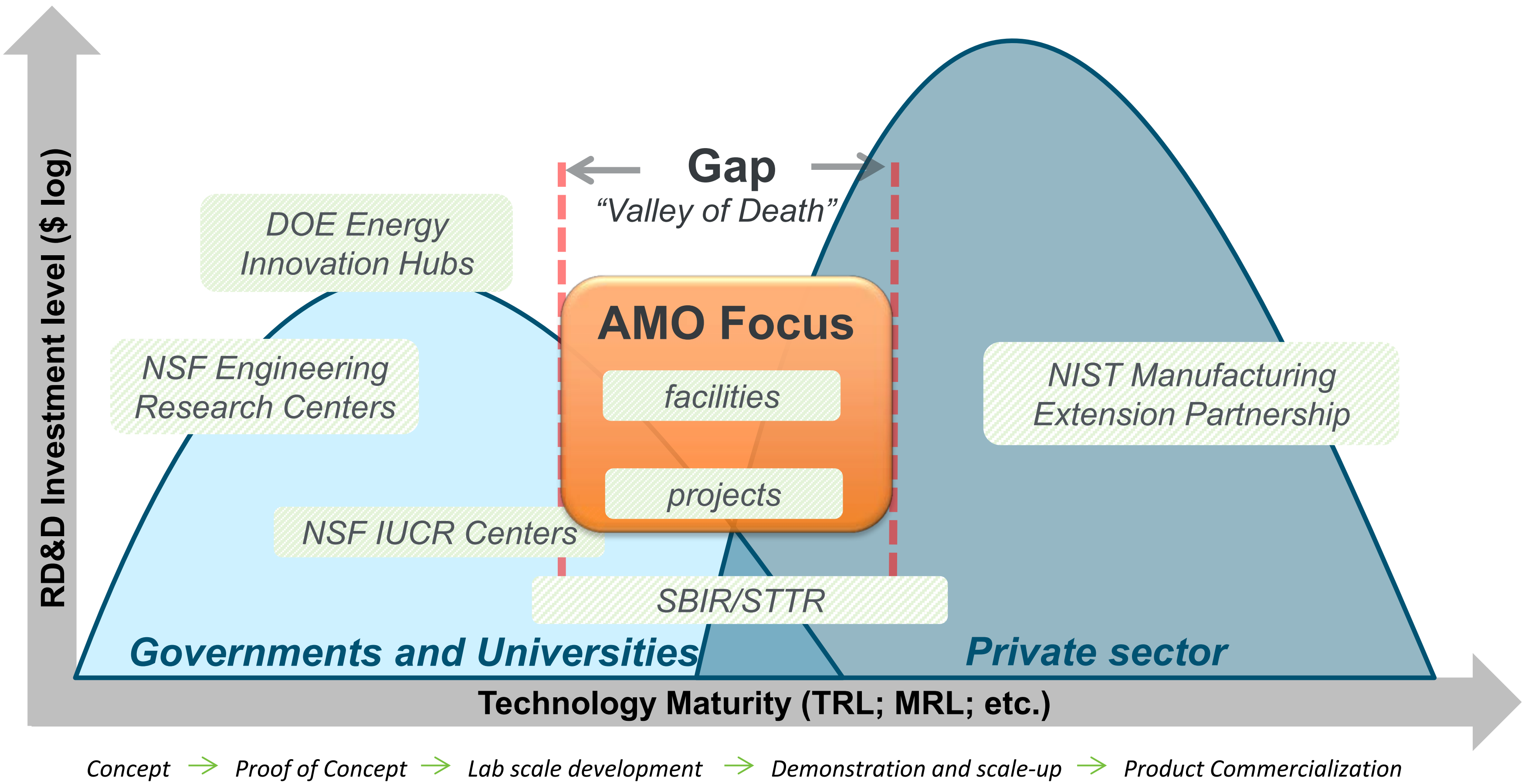
AMO Investments leverage strong Federal support of basic research by partnering with the private sector to accelerate commercialization



Manufacturing Demonstration Facilities

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Two pathways through the MDF

INPUT: New Processes, techniques, tools, capabilities and other ***production enabling innovations and technologies***

INPUT: Innovations and ideas for the ***creating new materials or products***

Manufacturing Demonstration Facility

Advanced Manufacturing Technologies: ***e.g. Additive Manufacturing***

Legacy Manufacturing Technologies: ***e.g. melding, joining, welding***

Virtual, model-driven library: ***e.g. foundries, chemicals***

Process control / metrology

Design Capabilities:

Characterization ***e.g. testing and validation, prognosis, shared quality control technologies***

OUTPUT: **Business case for manufacturing** new materials or products:

- Production rate
- Processes established
- Partners Identified
- Risks identified
- Cost estimates based on production data
- The case for commercialization

Innovative material or product to market

OUTPUT: Equipment sales, control systems, robotics, services and other ***production enabling products***

Existing Supply Chains

MDF Example: Oak Ridge National Lab

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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.

Carbon Fiber

Exit end of Microwave Assisted Plasma (MAP) process, jointly developed by ORNL and Dow

Program goal is to reduce the cost of carbon fiber composites by improved manufacturing techniques such as MAP, which if scaled successfully could reduce carbonization cost by about half compared to conventional methodology.

Institutes – Potential Technical Focus Areas

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Technical Focus Areas:

1. Additive manufacturing* and carbon fiber*
2. Additive manufacturing**
3. Wide band gap materials***

Additional Candidate Areas:

- Titanium
- Low cost (out of the autoclave) composites
- Biomanufacturing
- Advanced magnetics
- Electrotechnologies
- Advanced membranes
- In-situ metrology, process control
- Joining
- Others……?

* ORNL
** NAMII → America Makes
*** Award anticipated early 2013

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Back-up Slides

Strategic Planning - Next Generation Materials Data Collection

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Data collection method

- ORNL queried ~300 people working in different aspects of next generation materials
- Peer-reviewed literature

Type of data collected for next generation materials

- At the level of major type within a broad category of next generation materials
- Major characteristic material properties
- Potential substitution/property enhancement/new application enabler
- Manufacturing technology
- Potential application area(s)
- Potential benefits from a life cycle perspective (supply, i.e., manufacturing as well as demand, i.e., use phase)
- Cost in the next 5-15 years
- Development stage and constraints faced by this material
- Most promising next generation materials in the next 5-15 years

Next Generation Materials Categories

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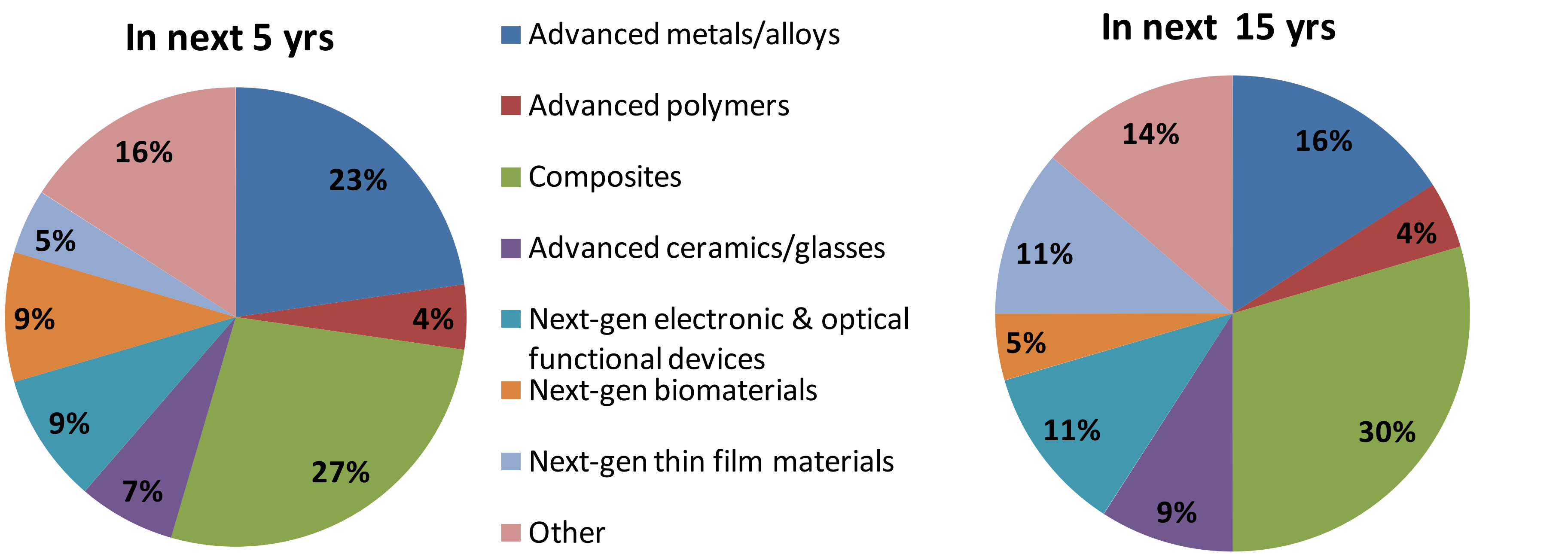
Next-generation materials are those materials that are either commercially available but manufactured in small quantities or those not currently available but close to commercialization.



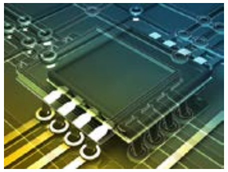
Respondents’ selection of material with greatest energy saving potential

Advanced Metals and Alloys (53)

- **Vehicle Lightweighting**
  - Reduced energy consumption in the
  - "use" stage
  - 6-8% fuel economy improvement per 10% vehicle mass reduction
  - Materials include advanced aluminum, magnesium, titanium alloys, and high strength steel
- **Improved Heat Transfer in the Process Heating Industry**
  - Examples are nickel silicide and ferritic steels → improved efficiency

Advanced Chemicals (11)

- **Paint and Paper Industry**
  - Ultrafine kaolin replaces TiO_2; less energy to manufacture and lower cost
- **Refrigeration**
  - Hydrofluoroether (e.g., HFO-1234yf) replaces HFC-134a; has a GWP of only 4, as compared to 1430 of HFC-134a
- **Semiconductor Industry**
  - PFC alternatives such as C_3F_8, C_4F_8O, NF_3 replace C_2F_6



Nos. within parenthesis indicate types of materials obtained from online survey and literature

Next Generation Materials Database – 170+ Materials

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Next Generation Composites (22)

- **Lightweighting Materials**
  - Carbon fiber reinforced polymer composites (CFRP), glass fiber reinforced polymer composites (GFRP), and metal matrix composites replace iron or mild steel
- **Alternative Construction Materials**
  - Aramid reinforced polymer composites, CFRP, and GFRP replace steel reinforcement in concrete structures
- **Clean Energy Production**
  - Carbon fiber and glass fiber reinforced epoxy composites used in wind energy generation (for wind blades and spar caps); stronger and lightweight
- **Aircraft Manufacturing**
  - Glass fiber or carbon fiber reinforced PPS thermoplastics used for wing fixed leading edges, engine pylon covers, and engine nacelle acoustic liners; replace aluminum
- **Air Pollution Control Systems**
  - Silica-titania composites used in air pollution control systems save natural gas consumption in Regenerative Thermal Oxidizers

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Next Generation Materials Database – 170+ Materials

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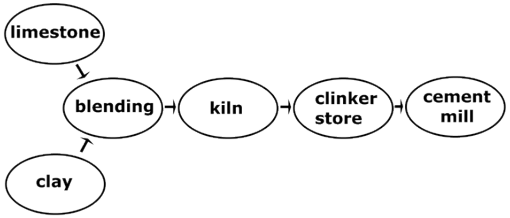
Advanced Ceramics and Glasses (21)

- **Cement Manufacturing**
  - Granulated Blast Furnace Slag replaces clinker in cement manufacturing, resulting in a decrease of 0.4 to 1.8 MMBtu of thermal energy per ton of cement



- **Advanced Refractory Materials**
  - Magnesium aluminate spinel as a replacement refractory material, provides better performance and has a longer life

- **Skylights**
  - Fiber-reinforced silica aerogel composite replaces glass or in skylights; highly flexible and good thermal insulation

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Next Generation Materials Database – 170+ Materials

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Advanced Polymers (17)

- **Carpets, Textile Fiber and Nonwovens**
  - Polytrimethylene terephthalate (PTT) - an innovative new thermoplastic t be spun into both textile fibers and yarns; overcomes some of the drawbacks of polypropylene; combines the best qualities of nylon and polyester
- **Aerospace and Electronics**
  - Cyanate ester - a new class of thermosetting resins, replaces epoxy resins; inherently tougher, has significantly better electrical properties and lower moisture uptake; ease of handing and processing similar to epoxy resin systems

Next Generation Thin Film Systems (8)

- **Superhydrophobic Materials**
  - For example, NanoTiO2 on windings of motors in harsh environments, such as food processing; greatly increases performance and motor life
- **Thin-film solar cells**
  - Cadmium telluride replaces crystalline silicon in solar cells; less material used, lower life cycle impacts, lower cost

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Next Generation Materials Database – 170+ Materials

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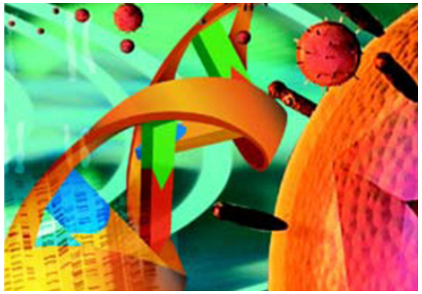
Next Generation Electronic & Optical Functional Devices (29)

- **Next Generation Semiconductors**
  - Gallium Arsenide for silicon (10 x faster)
  - Gallium Nitride for power electronics in electric and hybrid cars; improved efficiency and lower "use" stage energy
  - Graphene nanoribbons transistors to replace silicon (10 x faster)

- **Power Transmission**
  - High Temperature Superconducting (HTS) wires use YBCO to transmit power with virtually no transmission losses
- **Solar Photovoltaic Applications**
  - InGaP used in high efficiency solar PV cells for space applications
  - Cadmium Telluride (CdTe) in thin-film solar cells
- **Grid Level Energy Storage**
  - Nanoscale NaFePO4 and MgMOS6 used as intercalation compounds, for optimum grid performance
- **Superconducting Materials**
  - NbTi (Niobium-Titanium) magnets for MRI and other; less material and lower weight

Nos. within parenthesis indicate types of materials obtained from online survey and literature

Next Generation Biomaterials (19)



- **General Benefits of Biomaterials**
  - Reduced dependence on fossil fuels
  - Biodegradable
- **Biomaterials include:**
  - Bio-based naphtha replaces petroluem feedstocks
  - Soy-biohybrid foam to replace polyurethane (PU) foam
  - Hydrnol fuel (organic liquid hydrogen carrier); holds up to 12% H2 by wt.
  - Trifluoroiodomethane (CF3I) potential replacement for SF6 in high-voltage applications
  - Bio-based 1,3-Propanediol; PDO is the building block for many polymers
  - Ingeo Polylactide, Polyhydroxyalkanoates (PHA), and polyhydroxybutyrates (PHB) replace common plastics
  - Bio-based n-methylpyrrolidone (NMP), n-vinylpyrrolidone (NVP), and succinonitrile (all from glutamic acid)

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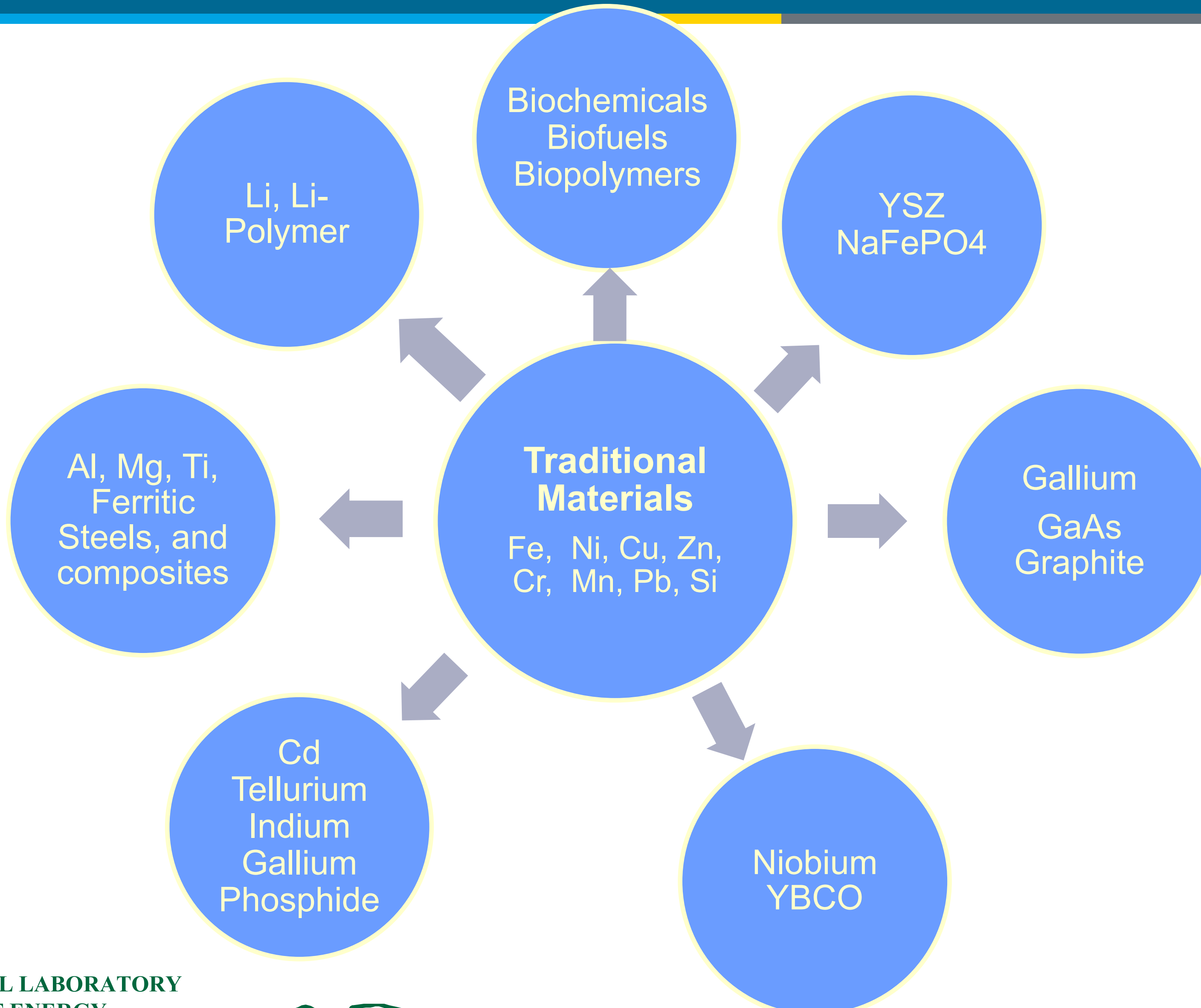
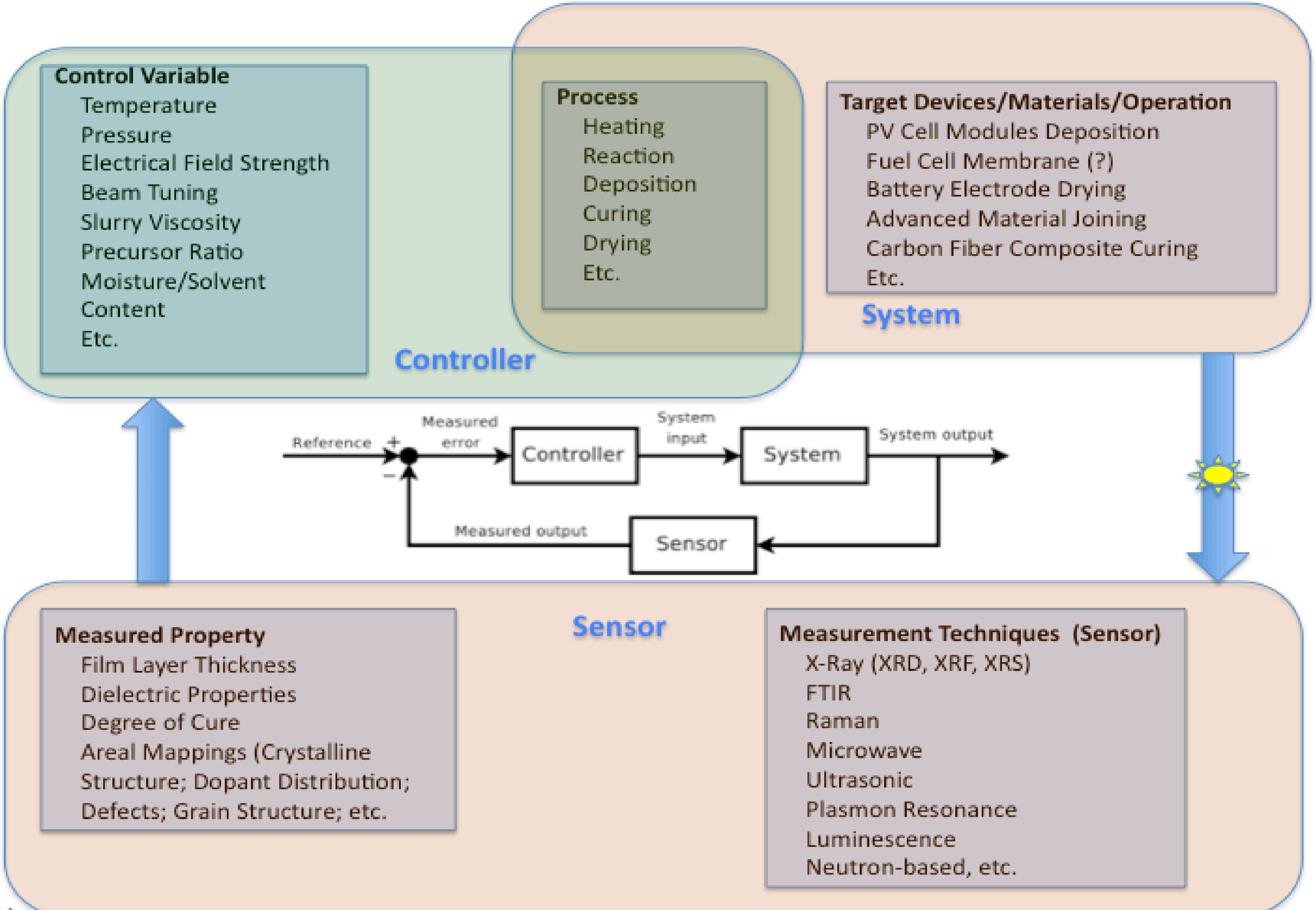
Next Generation Materials – Future Trends



Process Control Context



In some cases, e.g. microwave processing, the system can act as the "sensor" (by monitoring and controlling forward and reflected power).

AMO RD&D Focus: TRL 4 to 8

TRL 4-Basic technological components are integrated - Basic technological components are integrated to establish that the pieces will work together.
TRL5-Fidelity of breadboard technology improves significantly - The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
TRL6-Model/prototype is tested in relevant environment - Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
TRL7-Prototype near or at planned operational system - Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.
TRL8-Technology is proven to work - Actual technology completed and qualified through test and demonstration.

Concept *Proof of Concept* *Lab scale development* *Demonstration and scale-up* *Product Commercialization*

AMO Technology focus

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AMO invests in "**foundational technologies**"

A **foundational technology** has a **high economic and energetic impact** relative to the technology development cost. Foundational technologies are broadly applicable and pervasive across many industries and markets.

Example foundational technology areas include ***but are not limited to***:

- Additive Manufacturing
- Low Cost Carbon Fiber Composites
- Low Cost, Lightweight Metal Structures
- Manufacturing of Biobased Products
- In-Situ Metrology and Process Controls
- Multimaterial Joining*
- Microwave (MW) and Radio Frequency (RF) for Advanced Manufacturing*
- Sustainable Nanomaterials*
- Membrane Technology*
- Wide Bandgap Semiconductors*

* Workshops held in June-July 2012

Partnership driven

Three primary partnership-based vehicles to engage with industry, academia, national laboratories, and local and federal governments:

1. **Research, Development, and Demonstration Projects -** to support innovative manufacturing processes and next-generation materials

2. **RD&D Infrastructure** - to reduce barriers to exploration of new ideas

3. **Technical Assistance -** to industry to create a culture of continuous improvement in corporate energy management

RD&D Projects

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Innovative Manufacturing Initiative

- **Goal:** Enable a **doubling of energy productivity** in U.S. industry
- **Plan:** Public-private project partnerships to accelerate commercialization of new product or process technologies at industrially relevant scales
- **Focus:** Cross-cutting, foundational technologies
  - **Example:** Working with PolyPlus Battery Company to increase lithium batteries' energy density by 2-10X at 50% cost with a goal of increasing from small applications to vehicles within 10 years
- **Funding:** 13 initial selections in FY12 (~$54 M DOE); 26 projects held for potential funding based on pending FY13 budget

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RD&D Infrastructure: Manufacturing Demonstration Facilities

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Barriers addressed:

- Access to expensive technologies and capabilities
- Sharing overhead costs - more efficient use of capital
- Increases visibility of unknown process options
- Accelerates partnership development and supplier relationships

Effect on U.S. competitiveness:

- Increased pool of domestic competitors, especially SMEs
- Increased rate of new product development
- Positive feedback between production and research/design accelerates both

Additive Manufacturing

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Additive manufacturing, commonly known as "3D Printing," is a suite of emerging technologies to fabricate parts using a layer-by-layer technique, where material is placed precisely as directed from a 3D digital file.

Additive manufacturing can[1]:

- reduce energy intensity and waste
- enable remanufacturing
- support innovative designs
- create agile supply chains
- reduce time to market

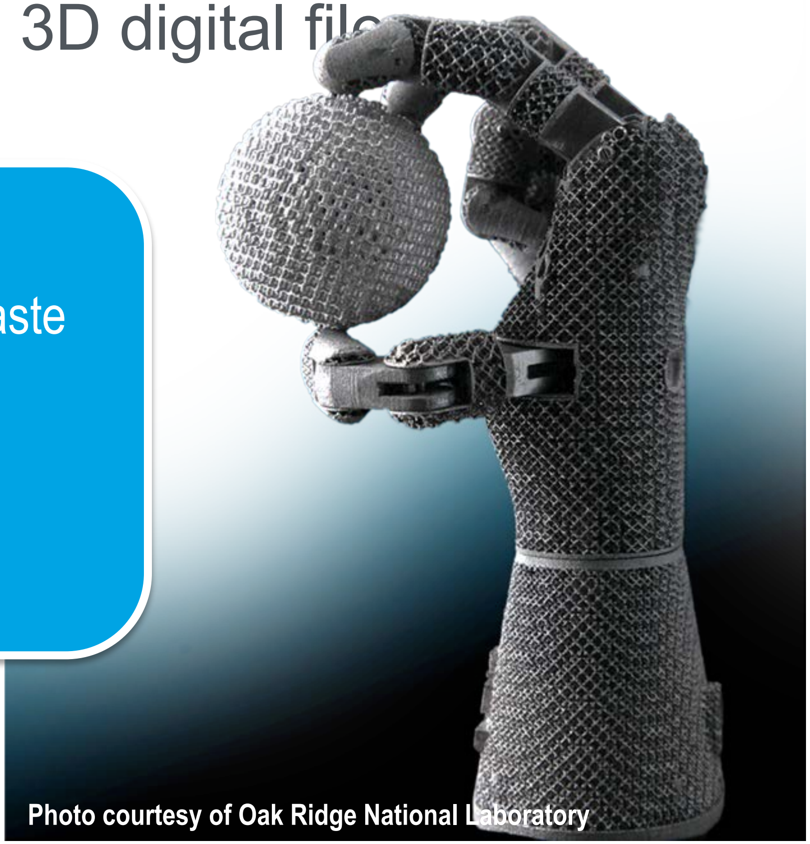

Photo courtesy of Oak Ridge National Laboratory

[1]http://www1.eere.energy.gov/manufacturing/pdfs/additive_manufacturing.pdf

Promise of Additive Manufacturing

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Unprecedented capability to design and create products

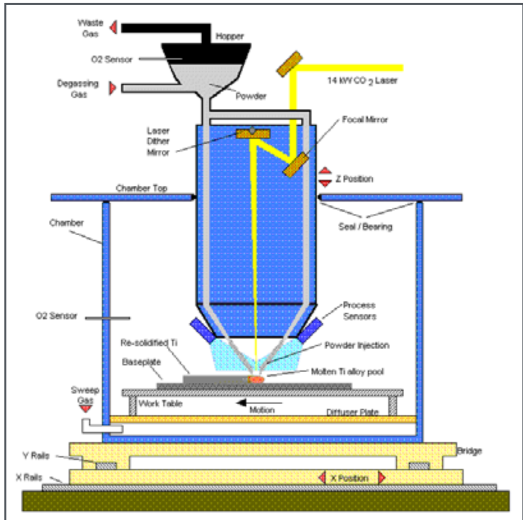
Courtesy of EADS Innovation Works

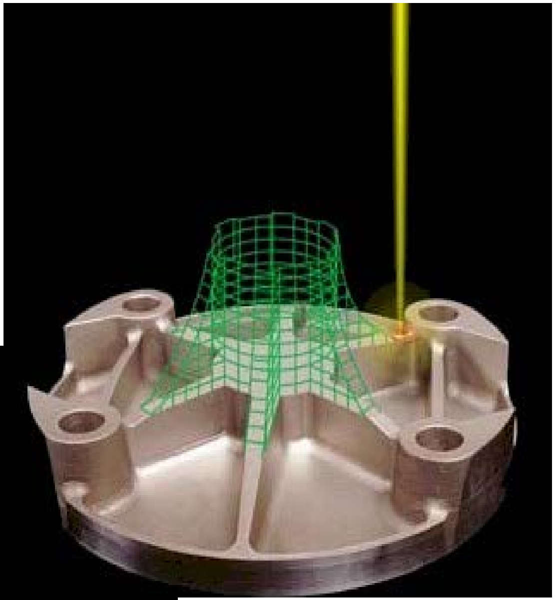
Topology optimization. Same strength, half the weight

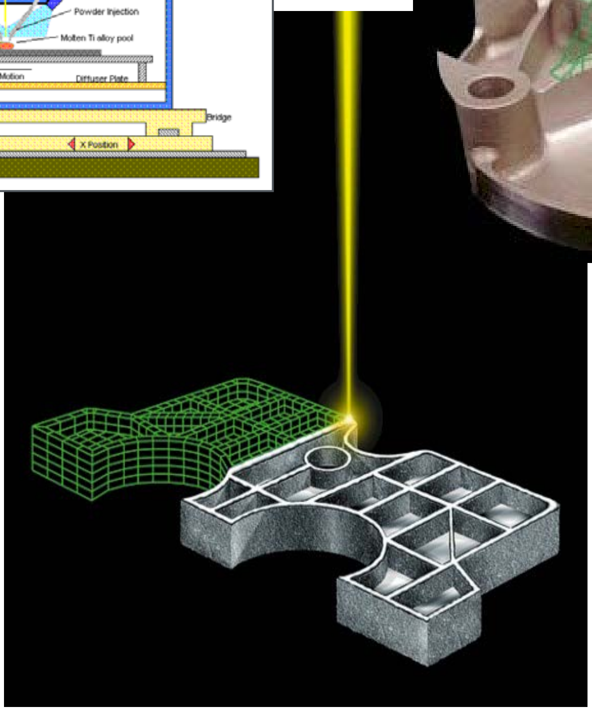

Image courtesy of GE Aviation

"…in our lifetime at least 50% of the engine will be made by additive manufacturing"
– Robert McEwan GE

Example: Additive Manufacturing







AeroMet process □Boeing, Northrup Grumman, NavAir

W. Coblenz, DARPA/DSO 2000

- 3-D graphical models, parts built in layers
- No tools, dies, or forms
- Near final shape
- Reduced delivery times 75%
- Mechanical properties equivalent to wrought
- Reduced material use
- Reduced inventory
- Significant cost and energy savings

RD&D Infrastructure:
The Critical Materials Energy Innovation Hub

Critical materials* – elements that are key resources in manufacturing clean energy technologies

- Enable wind turbines, solar panels, electric vehicles, and energy-efficient lighting

Goal – reduce the impact of supply chain disruptions and price fluctuations

- integrate scientific research, engineering innovation, and manufacturing and process improvements
- develop solutions including mineral processing, manufacture, substitution, efficient use, and end-of-life recycling

Funding – investing up to $120 million over five years (2013-2017)

- Consortium of 4 national laboratories, 7 universities and 8 companies
- Led by Ames National Laboratory

* As defined by U.S. Department of Energy. 2011. *Critical Materials Strategy*. Washington, DC: DOE.

Partnership driven

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Industrial Technical Assistance: **Better Buildings, Better Plants Overview**

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- **Industrial component of the Better Buildings Challenge**
  - National leadership initiative that calls on CEOs, university presidents, and state and local leaders to create American jobs through energy efficiency
  - Supports President's goals to improve energy efficiency in commercial and industrial buildings by 20% or more by 2020 and help manufacturers save $100 billion on their energy bills over the next decade
  - Launched December 2011
- **Manufacturers can engage in:**
  - **Better Buildings, Better Plants *Challenge***
    - Small group of market leaders that pursue leading-edge energy efficiency strategies and agree to share their approaches and results with the public
  - **The Better Buildings, Better Plants *Program***
    - Broader-based initiative composed of over 100 manufacturers that make energy efficiency commitments and report progress once a year to DOE
  - DOE provides recognition for efforts and targeted TA to speed adoption of sound energy management practices

Better Plants CHALLENGE U.S. DEPARTMENT OF ENERGY

Industrial Technical Assistance: Better Plants Program

- **Voluntary pledge to reduce energy intensity by 25% over ten years**
- **118 Program Partners, over 1,600 plants, ~6% of the total U.S. manufacturing energy footprint**
- **Partners implement cost-effective energy efficiency improvements that:**
  - Save money
  - Create jobs
  - Promote energy security
  - Strengthen U.S. manufacturing competitiveness

Newest Partners

- Lennox International
- Harley-Davidson Motor Co.
- International Paper
- Texas Instruments Inc.
- PaperWorks Industries, Inc.

- **Through the Better Plants Program, companies receive national recognition and technical support from DOE**

Industrial Technical Assistance:
Superior Energy Performance (SEP)

U.S. DEPARTMENT OF ENERGY

- SEP is a market-based, ANSI/ANAB-accredited certification program that provides industrial facilities with a roadmap for achieving continual improvement in energy efficiency through improvements in energy management practices with the application of ISO 50001 energy management standard.
- 10 SEP certified plants have improved their energy performance between 6 and 25% over a three year period.

Presentation of awards to Volvo Trucks and Nissan North America in recognition of achieving SEP certification
at Alliance to Save Energy's Industrial Energy Efficiency Forum in May 2012

Superior Energy Performance Accomplishments

- ISO 50001 energy management standard published June 2011: US leadership in developing standard with DOE support was pivotal
- 4 ASME system assessment standards and guidance published
- 40 SEP demonstration plants
  - 30 underway
  - 10 plants complete – saved 2.4 Trillion Btu cumulatively as of FY2012
- Workforce: Certified Practitioner in Energy Management System program developed (50 people certified to date)
- Supporting tools developed
  - eGuide tool to assist plants in implementing ISO 50001
  - EnPI tool to assist to perform statistical regression analysis to assess energy performance improvement measurement

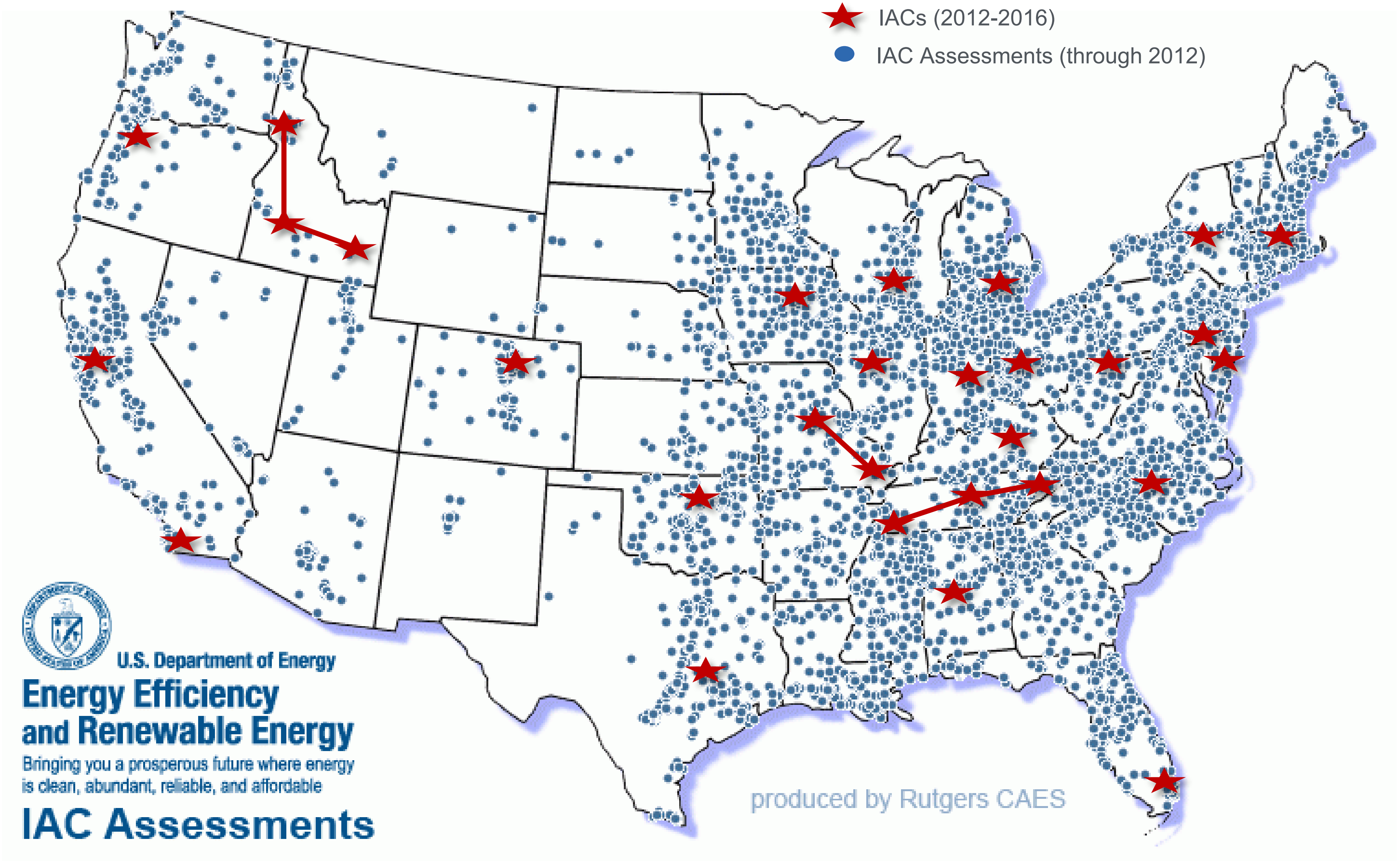
Industrial Technical Assistance: **Workforce Development**

U.S. DEPARTMENT OF ENERGY

- **Industrial Assessment Centers:** Creating the next generation of energy engineers:
  - Conduct hands-on assessments of small and medium-sized manufacturing firms
  - Foster a specialized energy engineering curriculum
  - Over 3,100 students trained - nearly 60 percent of IAC graduates go on to careers in the energy industry
  - Over 15,600 assessments and provided nearly 117,600 recommendations for small and medium-sized manufacturing plants
  - Assessments have identified nearly $515M in energy savings and nearly 3.4 million metric tons in CO2 emissions reductions since 2006
- Certified Practitioner in Energy Management System program developed
  - 50 certified practitioners to date

Industrial Assessment Centers (IACs)

U.S. DEPARTMENT OF ENERGY



DOE CHP Deployment: Overview & Accomplishments

U.S. DEPARTMENT OF ENERGY

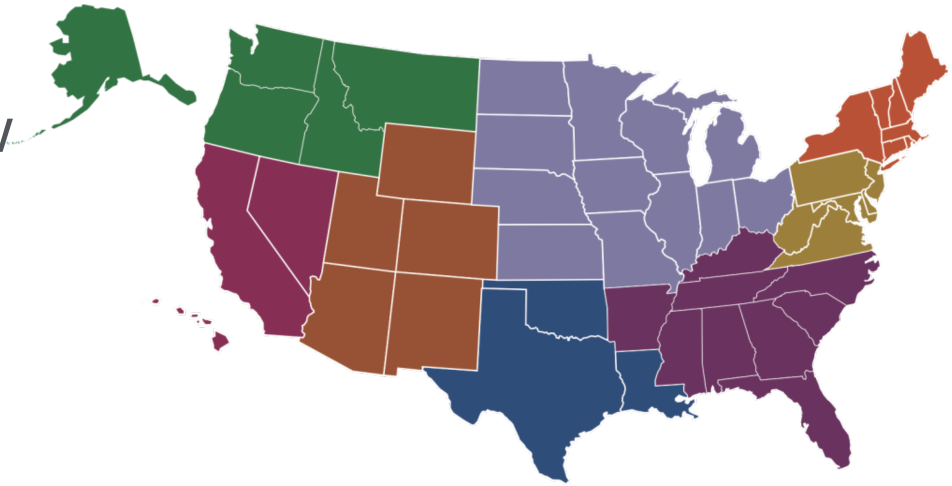
- Supported Aug 30, 2012 *"Accelerating Investments in Industrial Energy Efficiency "* Executive Order
  - Includes 40 GW new CHP by 2020 goal
- Regional Clean Energy Application Centers/ Technical Assistance Partnerships
  - Since 2003, provide regional expertise on CHP: education & outreach, technical assistance, market development
  - In FY12, over 150 CHP projects, representing 500 MW, are moving forward in the project development process with assistance from the CEACs
  - Provided technical analysis and assistance on CHP potential and benefits, and standby rates, to a variety of state PUCs, including NJ, CO, UT, AR and IA.
  - CEAC coordination & implementation plans around six targeted market sectors – leverage resources and expertise:
- Developed the DOE Boiler MACT technical assistance program, in coordination with EPA.
  - Implementing pilot in Ohio with the Ohio PUC, including assisting with a series of Ohio PUC workshops and trainings - Midwest CEAC lead.
- Regional Industrial EE & CHP Dialogue Meetings with SEE Action

Regional Clean Energy Application Centers (CEACs) / Technical Assistance Partnerships (TAPs)

- **Market Assessments:** Analyses of CHP market potential in diverse sectors, such as health care, industrial sites, hotels, & new commercial and institutional buildings.

- **Education and Outreach:** Providing information on the benefits and applications of CHP to state and local policy makers, regulators, energy end-users, trade associations and others.

Eight Regional CEACs & International District Energy Association



http://www1.eere.energy.gov/manufacturing/distributedenergy/ceacs.html

Thanks!

Thank you.

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