Quadrennial Technology Review-2015

Public Webinar

Review Lead:
Sam Baldwin

2015-02-18
Webinar Logistics

• Due to the large number of expected participants, the audio and video portions of this webinar will be a “one way” broadcast. Only the organizers and QTR authors will be allowed to speak.

• Submit clarifying questions using the GoToWebinar control panel. Moderators will respond to as many questions as time allows. Substantial input regarding chapter content should be submitted by email to: DOE-QTR2015@hq.doe.gov
# Webinar Schedule (all times EST)

<table>
<thead>
<tr>
<th>Begin</th>
<th>End</th>
<th>Chapter</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00 AM</td>
<td>10:30 AM</td>
<td>N/A</td>
<td>QTR and Webinar Overview</td>
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<tr>
<td>10:30 AM</td>
<td>12:00 PM</td>
<td>4</td>
<td>Fuels</td>
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<td>12:00 PM</td>
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<td>Electric Grid</td>
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<td>1:00 PM</td>
<td>2:30 PM</td>
<td>6</td>
<td>Power Generation</td>
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<td>2:30 PM</td>
<td>3:30 PM</td>
<td>7</td>
<td>Buildings</td>
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<td>3:30 PM</td>
<td>4:30 PM</td>
<td>8</td>
<td>Manufacturing</td>
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<td>4:30 PM</td>
<td>5:30 PM</td>
<td>9</td>
<td>Transportation</td>
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</table>
• President Obama set forth the Administration’s Climate Action Plan in June 2013 with three key thrusts:
  – Cutting carbon emissions in the United States
  – Preparing the United States for the impacts of climate change
  – Leading international efforts to address global climate change

• Research, development, demonstration and deployment of innovative energy technologies will be critical to achieving these objectives.

• The QTR 2015 will facilitate DOE’s contribution to the President’s Climate Action Plan by examining an “all of the above” range of energy technologies to inform future planning.
Quadrennial Reviews Underway

- **Quadrennial Energy Review**: Called for by the President to analyze government-wide energy policy, particularly focused on energy infrastructure.

- **Quadrennial Technology Review**: Secretary Moniz requested the second volume be published in parallel with the QER to provide analysis of the most promising RDD&D opportunities across energy technologies in working towards a clean energy economy.

The resulting analysis and recommendations of the QTR 2015 will inform the national energy enterprise and will guide the Department of Energy’s programs and capabilities, budgetary priorities, industry interactions, and national laboratory activities.
Expanded Scope of QTR 2015

- The QTR will evaluate major changes since the first volume of the QTR was published in 2011 and provide forward leaning analysis to inform DOE’s strategic planning and decision making.

- In doing so, the QTR 2015 will provide three levels of analyses:
  - **Systems Analyses** – Uses systems frameworks to evaluate the power, buildings, industry, and transportation sectors, enabling a set of options going forward.
  - **Technology Assessments** – Examines in detail, the technical potential and enabling science of key technologies out to 2030.
  - **Road Maps** – Uses these analyses and assessments to extend R&D Roadmaps and frame the R&D path forward.

- The QTR is a comprehensive assessment of science and energy technology research, development, demonstration, and deployment (RD3) opportunities to address our nation's energy-linked economic, environmental, and security challenges.
QTR 2015 Chapter Outline

1. Energy Challenges
2. What has changed since QTR 2011
3. Energy Systems and Strategies

4. Advancing Systems and Technologies to Produce Cleaner Fuels
5. Enabling Modernization of Electric Power Systems
6. Advancing Clean Electric Power Technologies
7. Increasing Efficiency of Buildings Systems and Technologies
8. Increasing Efficiency and Effectiveness of Industry and Manufacturing
9. Advancing Clean Transportation and Vehicle Systems and Technologies
10. Enabling Capabilities for Science and Energy

11. U.S. Competitiveness
12. Integrated Analysis
13. Accelerating Science and Energy RDD&D
14. Action Agenda and Conclusions; Web-Appendices Web Appendices
Quadrennial Technology Review-2015
Chapter 8: Industry & Manufacturing
Public Webinar

Chapter Leads:
Joe Cresko
Dev Shenoy

2015-02-18
Today’s Webinar

• Introduce the 2015 Quadrennial Technology Review (QTR)*

• Build upon outreach initiated at the Dec. 4th-5th “Cornerstone Workshop”*

• This session will provide an contextual overview of QTR Chapter 8 - Industry & Manufacturing (~25 pages)

• This session will introduce the fourteen supporting Technology Assessments (~15-30 pages each)**

**Goal**: Provide an overview of the QTR, and the opportunity for public input into the QTR. Substantial input regarding chapter content should be submitted by email to: DOE-QTR2015@hq.doe.gov

*More information can be found at [http://energy.gov/qtr](http://energy.gov/qtr) including the Framing Document which outlines all the Chapters.

**Follow the links for “Public Webinars” to get to draft Chapter 8 Tech Assessments.**
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Type your questions here and click “send”
QTR 2015 Chapter Outline

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14. Action Agenda and Conclusions; Web-Appendices

Web Appendices
Chapter Outline

1. Introduction
2. Unit Operations
   - Process Heating Systems
   - Motor-Driven Systems
   - Innovative New Manufacturing Approaches
3. Facility Systems
   - Onsite Generation and Energy Management
   - Waste Heat Recovery
   - Data and Automation in Manufacturing
4. Beyond the Plant Boundaries
   - Recyclability and Design for Re-Use
   - Sustainable Manufacturing (energy and resource utilization)
   - Advanced Materials Manufacturing
   - Critical Materials and Critical Material Alternatives
   - Manufactured Goods with Life Cycle Energy Impacts
5. Conclusions
Snapshot of Industry and Manufacturing

Definitions:

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

<table>
<thead>
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<tbody>
<tr>
<td>Manufacturing Share of GDP</td>
<td>Industrial Energy Consumption 30.9 Quads</td>
</tr>
<tr>
<td>Manufacturing Payroll</td>
<td>Industrial Energy Expenditures $226 billion</td>
</tr>
<tr>
<td>Manufacturing Exports</td>
<td>Manufacturing Facilities ~300,000</td>
</tr>
<tr>
<td>Manufactured Goods Trade Balance*</td>
<td>Manufacturing R&amp;D Expenditures (2011) $201 billion</td>
</tr>
<tr>
<td>Advanced Technologies Trade Balance</td>
<td>Manufacturing sector direct employment 12 million</td>
</tr>
</tbody>
</table>
| U.S. Manufacturing Share of World Output 18% | * Does not include crude oil, but does include some petroleum products. Adjusted for re-exports.
Manufacturing in the United States

Is a key driver of our economy, energy productivity\(^1\) and innovation.

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

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

Approach:

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

\(^1\) Energy productivity and competitiveness issues will be addressed in more-depth in Chapter 11 of the QTR

\(^2\) Historically DOE has communicated industrial energy use/opportunities in terms of site energy use; little precedent for materials flows, cross-sector impacts, economics & competitiveness.
Industry and Manufacturing Energy Use

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

2012 Data

Industry: 31 Quads

Fuel mix shows diverse nature of industry energy use

U.S. Economy: 95 Quads

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

Energy Use by Fuel Type ...

Non-manufacturing: 6.5 Quads

Manufacturing: 24.4 Quads

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

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

...and by Subsector...

U.S. Manufacturing (no feedstocks)
19.2 Quads

- Chemicals: 22%
- Petroleum Refining: 18%
- Forest Products: 16%
- Other Manufacturing: 5%
- Iron and Steel: 8%
- Fabricated Metals: 3%
- Transportation Equipment: 3%
- Plastics: 3%
- Computers and Electronics: 3%
- Aluminum: 2%
- Glass: 2%
- Cement: 2%
- Machinery: 1%
- Textiles: 1%
- Foundries: 1%

Non-Manufacturing Industrial
6.5 Quads
7%

Transportation
26.8 Quads
28%

Residential
20.0 Quads
21%

Commercial
17.4 Quads
18%

2012 Data

U.S. Economy: 95 Quads


Source: AMO Manufacturing and Carbon Footprints. Feedstock energy not included
...to “Applied” Energy, revealing opportunities.

U.S. Manufacturing (no feedstocks)
19.2 Quads

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

System Highlights: Bottom-up assessment of technologies

U.S. Manufacturing Sector (TBtu), 2010

Legends:
- Fuel
- Steam
- Electricity
- Applied Energy
- Offsite Generation and Transmission Losses
- Onsite Generation and Distribution Losses
- End Use Losses

Note: 1 quad = 1,000 TBtu
System Highlights: Opportunity Space Impacted by Manufacturing

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

Industrial Systems
31 quads

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

Example: Petroleum Refining

- Refining Industry ~4 quads
- Petro continuously ~26 TBtu
- Facility Steam ~5 TBtu

Production/Facility Systems
Equipment, process flow, and energy strategies that comprise a goods-producing facility.

- Petroleum Refinery ~26 TBtu
- Facility Steam ~5 TBtu

Manufacturing Systems/Unit Operations
Equipment used for manufacturing process and nonprocess unit operations.

- Atmospheric Distillation Unit ~4 TBtu
- Hydro-cracker ~2 TBtu
- Catalytic Reformer ~3 TBtu

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

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

Energy Production

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

U.S. Energy Economy 95 quads

Note: 1 quad = 1,000 TBtu
# System Highlights: Bottom-up assessment of technologies

## Supply-Chain Systems

<table>
<thead>
<tr>
<th>Example: Petroleum Refining</th>
<th>Example: Chlorine Production</th>
<th>Example: Additive Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refining Industry</td>
<td>Chemicals Industry</td>
<td>Fabricated Metal Prod. Industry</td>
</tr>
<tr>
<td>~4 quads</td>
<td>~6 quads</td>
<td>~0.5 quads</td>
</tr>
</tbody>
</table>

## Production/Facility Systems

<table>
<thead>
<tr>
<th>Petroleum Refinery</th>
<th>Chlorine Plant</th>
<th>Powder Metallurgy Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>~26 TBtu</td>
<td>~4 TBtu</td>
<td>~&lt;1 TBtu</td>
</tr>
<tr>
<td>Facility Steam</td>
<td>Water Cooling System</td>
<td>Compressed Air System</td>
</tr>
<tr>
<td>~5 TBtu</td>
<td>~&lt;1 TBtu</td>
<td>~&lt;1 TBtu</td>
</tr>
</tbody>
</table>

## Manufacturing Systems/Unit Operations

<table>
<thead>
<tr>
<th>Atmospheric Distillation Unit</th>
<th>Hydrocracker</th>
<th>Catalytic Reformer</th>
<th>Electrolytic Cell</th>
<th>Drying Tower</th>
<th>Gas Compressor</th>
<th>CAD Modeler</th>
<th>3D Printer</th>
<th>Depowdering Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>~4 TBtu</td>
<td>~2 TBtu</td>
<td>~3 TBtu</td>
<td>~3 TBtu</td>
<td>&lt;1 TBtu</td>
<td>&lt;1 TBtu</td>
<td>~&lt;1 TBtu</td>
<td>~&lt;1 TBtu</td>
<td>~&lt;1 TBtu</td>
</tr>
</tbody>
</table>

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Note: 1 quad = 1,000 TBtu
Interdependency of Manufacturing Systems/Unit Operations and Production/Facility Systems

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

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

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

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

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

* Other processes include process cooling, refrigeration, electrochemical, and other non-thermal processes

Energy Use in Entire Manufacturing Sector

- **Steam:**
  - Nonprocess: 0.50
  - Other processes*: 0.36
  - Machine drive: 0.33
  - Process heating: 2.29
  - Total: 3.5 Quads

- **Electricity:**
  - Nonprocess: 0.49
  - Other processes*: 0.54
  - Machine drive: 1.48
  - Process heating: 0.32
  - Total: 2.8 Quads

- **Fuel:**
  - Nonprocess: 0.45
  - Other processes*: 0.23
  - Machine drive: 0.19
  - Process heating: 4.59
  - Total: 5.5 Quads
Technology Highlights – Energy Intensity Improvements

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

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

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

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The 2014 Iron and Steel Industry Energy Bandwidth Study explores the energy intensity of steel manufacturing by major process area.

*Source:* DOE/AMO, Iron & Steel Industry Energy Bandwidth Study (2014)

*Note:* 1 quad = 1000 TBtu
Bandwidth Studies underway

**Chemicals, e.g.:**
- Advanced Distillation Technologies
- New Membranes (liquid, gas)
- New Catalysts

**Pulp and Paper, e.g.:**
- Black Liquor Gasification
- Directed Green Liquor Utilization
- New Fibrous Fillers

**Petroleum Refining, e.g.:**
- Thermal Cracking
- Progressive Distillation
- Dividing-wall Columns
- Improved Heat Integration

**Iron and Steel, e.g.:**
- Heat Recovery
- Slag Recycling
- Endless Rolling
- High Temperature Insulation Materials
Technology Highlights – Carbon Intensity Improvements

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

Agriculture, mining, construction: Opportunities for advanced engines, biofuels, etc.
Carbon capture and sequestration (CCS) technologies offer additional opportunities

Example analysis using the Buildings, Industry, Transport, Electricity Scenario (BITES) tool
### Technology Highlights – Use Intensity Improvements

<table>
<thead>
<tr>
<th>btu/lb</th>
<th>primary</th>
<th>secondary</th>
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<tr>
<td>Current</td>
<td>26,000</td>
<td>2,200</td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practically</td>
<td>20,000</td>
<td>925</td>
</tr>
<tr>
<td>achievable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>12,000</td>
<td>1,275</td>
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<tr>
<td>savings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>potential</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical</td>
<td>10,200</td>
<td>510</td>
</tr>
<tr>
<td>minimum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

**Carbon Intensity, e.g.:**
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- Feedstock substitution
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- Biomass-based fuels
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**Expanded Technology Opportunity Space:**
- **Materials Shift** – To enable increase of secondary aluminum by manufacturing
- **End-of-life shift** – To enable greater capture and use of landfill + scrap export
- **Systems-wide** – Materials & product design, manufacturing, use and re-use.

**Aluminum Materials Flows** – U.S. and Canada, 2009 Billions of Pounds
Case Study – Optimized Aircraft Bracket*

*“Average” conventional bracket 1.09 kg, “average” AM bracket 0.38 kg

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

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

Additive Manufacturing

Applications in Multiple Sectors

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

R&D Challenges

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

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

Case Study: Optimized Aircraft Bracket

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

Life-Cycle Energy Savings for Additive Manufactured Aircraft Bracket

Source: MFI and LIGHTEnUP Analysis
Note: 1 quad = 1 \times 10^9 MMBtu
Technology Highlights – Use Intensity Improvements

Additive Manufacturing

Applications in Multiple Sectors

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

Impacts from Aircraft Fleet-Wide Adoption of Additive Manufacturing

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Slow Adoption</th>
<th>Mid-Range Adoption</th>
<th>Rapid Adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>0.5</td>
<td>4.7</td>
<td>5.5</td>
</tr>
<tr>
<td>2040</td>
<td>42.0</td>
<td>45.9</td>
<td>24.9</td>
</tr>
<tr>
<td>2050</td>
<td>98.3</td>
<td>91.2</td>
<td>115.7</td>
</tr>
</tbody>
</table>

Scenario

- **Slow Adoption**
  - New aircraft only

- **Mid-Range Adoption**
  - New aircraft and new parts

- **Rapid Adoption**
  - New aircraft, new parts, and accelerated replacement

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

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


Note: 1 quad = 1,000 TBtu
• Carbon Fiber (CF) is currently ~ 5x more energy intensive than steel: savings accrue in the use phase
• Improved CF is ~ ½ energy intensity than PAN: 11,300 MJ/vehicle (PO) vs. 20,200 MJ/vehicle (PAN)
• Per vehicle savings over 13 yr, 250,000 km: 11,500 MJ per PO vehicle, 2600 MJ per PAN vehicle
• Penetration into US LDV fleet - Net energy impact of PO (dashed line) vs. PAN (dotted line): Significantly improved materials and manufacturing energy investment improves net energy footprint
Characteristics of Key Technologies

Opportunity for DOE to Invest in Technologies that are:

• **Transformative**: Result in significant change in the life-cycle impact (energetic or economic) of manufactured products

• **Pervasive**: Create value in multiple supply chains, diversifies the end use/markets, applies to many industrial/use domains in both existing and new products and markets

• **Globally Competitive**: Represent a competitive/strategic capability for the United States

• **Significant in Clean Energy Industry**: Have a quantifiable energetic or economic value (increase in value-added, increase in export value, increase in jobs created)
Industry & Manufacturing Technology Assessments

1. Thermoelectric Materials, Devices, and Systems
   • Thermoelectric materials (bismuth telluride, lead telluride, etc.), including high-ZT materials
   • Waste heat recovery equipment
   • Thermoelectric generation of electricity

2. Wide Bandgap Power Electronics
   • Opportunities for silicon carbide (SiC) and gallium nitride (GaN) to replace silicon (Si) in power electronics
   • Applications including AC adapters, data centers, and inverters for renewable energy generation

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

4. Critical Materials
   • Permanent magnets for wind turbines and electric vehicles
   • Phosphors for energy efficient lighting
   • Supply diversity and global material criticality

5. Roll-to-Roll Processing
   • Roll-to-roll (R2R) applications such as flexible solar panels, printed electronics, thin film batteries, and membranes
   • Deposition processes such as evaporation, sputtering, electroplating, chemical vapor deposition, and atomic layer deposition
   • Metrology for inspection and quality control of R2R products
6. Process Heating
   • Fuel, electricity, steam, and hybrid process heating systems
   • Sensors and process controls for process heating equipment
   • Process heating energy saving opportunities, e.g. waste heat recovery, non-thermal drying, and low-energy processing

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

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

9. Advanced Sensors, Controls, Modeling and Platforms
   • Smart systems and advanced controls
   • Advanced sensors and metrology, including power/cost sensors and component tracking across the supply chain
   • Distributed manufacturing
   • Predictive maintenance
   • Product customization
   • Cloud computing and optimization algorithms
Industry & Manufacturing Technology Assessments

10. Flow of Materials through Industry (Sustainable Manufacturing)
   • Supply chain issues, from resource extraction to end of life (life cycle analysis)
   • Mechanisms for reducing material demand, such as lightweighting, scrap reduction, recycling, and increased material longevity
   • Design for re-use / recycling

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

12. Waste Heat Recovery
   • Waste heat recovery technologies, including recuperators, recuperative burners, stationary and rotary regenerators, and shell-and-tube heat exchangers
   • Major waste heat sources such as blast furnaces, electric arc furnaces, melting furnaces, and kilns
   • Opportunities for low, medium, and high-temperature waste heat recovery
13. Materials for Harsh Service Conditions

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

14. Next Generation Materials and their Manufacture

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

These assessments, separate from the main report, will contain the data and analysis that supports the technology discussion in the chapter. They will be available on the web.
Systems Approach to Manufacturing Technology Assessments

Critical Materials

Thermoelectric Materials, Devices and Systems

Wide Bandgap Power Electronics

Materials for Harsh Service Conditions

Next Generation Materials and their Manufacture

Additive Manufacturing

Composite Materials

Roll-to-Roll Processing

Process Intensification

Process Heating

Advanced Sensors, Controls, Modeling and Platforms

Waste Heat Recovery

Combined Heat and Power

Flow of Materials through Industry (Sustainable Manufacturing)
## Findings: Systems-of-Systems Approach to Manufacturing Energy Use Reveals Economy-Wide Opportunities

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

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

Some Key Technology and System Assessment/Analysis

Issues & Questions

• What technology and system improvements and innovations will result in the greatest *economy-wide* impacts?

• What are the most impactful opportunities to leverage abundance of domestic natural gas?

• What timely investments could potentially enable U.S. leadership and open markets?

• What is the appropriate balance between deployment of current SOA vs investment in next-generational technologies?

Findings will *not* suggest regulatory and market policy recommendations
Public Input

Thanks for your participation!

- You are encouraged to submit questions using GoToWebinar’s “Questions” functionality. The moderators will respond, via audio broadcast, to as many appropriate questions as time allows.

- If you have questions or comments that cannot be addressed during the webinar, email them to DOE-QTR2015@hq.doe.gov
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