Industrial Thermal Process Intensification

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joe.cresko@ee.doe.gov

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Opportunity Space for Manufacturing

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

More efficient manufacturing reduces energy losses

More efficient manufacturing enables technologies that improve energy use throughout the economy:
- Transportation
- Buildings
- Energy Production and Delivery

Data for 2014

1. Energy consumption by sector from EIA Monthly Energy Review, 2018
2. Industrial non-manufacturing includes agriculture, mining, and construction
3. US economy energy losses determined from LLNL Energy Flow Chart 2014 (Rejected Energy), adjusted for manufacturing losses
4. Manufacturing energy losses determined from DOE AMO Footprint Diagrams (2014 data)
Thermal Opportunity

Process Heating Energy Use/Loss in the U.S. Economy

• **7 Quads opportunity space.** Process heating accounts for a sizable fraction of total U.S. energy use, and more direct energy use than any other energy consuming processes in manufacturing. Currently process heating is 95% fossil fuel based.

• **95% fossil fuel based.** Traditional industrial (thermal) processes can be inefficient, difficult to control and result in materials and products with compromised quality and performance.

• **> 1 Quad potential.** Assuming half of the energy lost in current process heating operations can be avoided, this represents a > 1% reduction in the total energy used in the U.S. economy.
In the U.S., the total energy consumed for thermal processing in these 8 industries is roughly 95% the total energy consumed for thermal processing in all U.S. industries.
# Type of Thermal Processes Used for Eight Large Energy Consuming Industries

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<td>Curing and forming</td>
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<td>Drying</td>
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<td>Fluid heating</td>
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<td>Heat treating (metal &amp; nonmetal)</td>
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<td>Metal and non-metal reheating</td>
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<td>Metal and non-metal melting</td>
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<td>Other heating - processing</td>
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<td>Reactive thermal processing</td>
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<td>Smelting, agglomeration, etc.</td>
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<td>Steam generation</td>
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## Temperature Range

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<tr>
<th>Temperature Range</th>
<th>Color</th>
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<tbody>
<tr>
<td>Low Temperature (&lt;800°F)</td>
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<td>Medium Temperature (800 to 1400°F)</td>
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<tr>
<td>High Temperature (&gt;1400°F)</td>
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</table>
Energy bandwidth studies of U.S. manufacturing sectors serve as general data references to help understand the range (or bandwidth) of potential energy savings opportunities.

The consistent methodology used in the bandwidth studies provides a framework to evaluate and compare energy savings potentials within and across manufacturing sectors at the macro-scale.

Energy Intensity

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

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

- Use Intensity e.g.: Circular economy, Design for Re-X (recycling, reuse and remanufacturing), Material efficiency and substitution

Technical Energy Savings Opportunities:

- Chemicals: Impractical Opportunity (2023), Future Opportunity (1176), Current Opportunity (764)
- Petroleum Refining: Impractical Opportunity (1793), Future Opportunity (793), Current Opportunity (420)
- Iron and Steel: Impractical Opportunity (228), Current Opportunity (239), Future Opportunity (150)
- Pulp and Paper: Current Opportunity (464), Future Opportunity (147)

Note: 1 quad = 1000 TBtu

https://www.energy.gov/eere/amo/energy-analysis-data-and-reports
MCPI Taxonomy

Modular Chemical Process Intensification (MCPI)

- Modular Processing
  - Parallel Modular
  - Unitary Modular
  - Centralized
  - Distributed

Equipment
- Equipment for Carrying Out Chemical Reactions
- Equipment for Operations not Involving Chemical Reactions

Methods
- Multifunctional Reactors
- Hybrid Separations
- Alternative Energy Sources
- Other Methods

Examples
- Gas compression
- Chloralkali
- Gas-to-Liquids Distillation

Gaps / Opportunities
- Understanding risks, cost, RAM
- Module Standardization
- Flexibility of assets
- Sensors, controls, automation

Adapted from Stankiewicz and Moulijn, "Chemical Engineering Progress," ©2000 American Institute of Chemical Engineers.
# Four Pillars of Thermal PI – Examples from RAPID’s Portfolio

<table>
<thead>
<tr>
<th>Low-Thermal Budget Transformative Technologies</th>
<th>Alternative Thermal Processing</th>
<th>Transformative Supplemental Technologies</th>
<th>Waste Heat Management Technologies</th>
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<tbody>
<tr>
<td>Technologies that may use alternate energy sources while offering disruptive changes in the current production methods.</td>
<td>Technologies that use alternate source of energy in manufacturing processes while maintaining the current production methods.</td>
<td>Emerging energy-efficiency and supplemental technologies that reduce thermal demand</td>
<td>Emerging waste heat reduction, recycle, and recovery options</td>
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<tr>
<td>- Electrolysis and Electrodialysis</td>
<td>- Induction and resistance furnaces</td>
<td>- Smart IoT devices for system optimization</td>
<td>- High temperature heat pumps</td>
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<td>- UV applications for disinfection</td>
<td>- Microwave and RF heating pre-heaters</td>
<td>- Smart manufacturing (Digital twin, AI and Predictive Process Controls)</td>
<td>- Thermal energy storage</td>
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<tr>
<td>- Ultrasound/RF processing for drying</td>
<td>- Hybrid fuel systems</td>
<td>- Flexible, modular manufacturing and operations design</td>
<td>- Recuperators, regenerators and economizers for non-traditional applications</td>
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<tr>
<td>- Hydrogen based production of ammonia, methanol, etc.</td>
<td>- Solar thermal systems</td>
<td>- Advanced materials for thermal systems</td>
<td>- Thermoelectric devices, heat pipes, etc.</td>
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<tr>
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<td>- Waste heat to power, District heating, desalination, green-house heating, etc.</td>
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</table>
Manufacturing Supply Chain for Modular Solar-Thermochemical Conversion
Additive manufacturing and modular designs for distributed, solar-driven reforming of natural gas to hydrogen

Alternative Energetics for Hydrocarbon Upgrading
A viable reactor and catalysts for direct conversion of lower alkanes to aromatics using selective microwave heating
What is Potential to Decouple Thermal Operations in Mfg.?

Drivers – Moving Towards High Energy & Carbon Productivity

- **a. Less Energy to Produce** – Decrease energy & carbon intensity
- **b. Improved Service** – Increase life cycle performance of materials and manufactured products
- **c. Higher Value Products** - Increase the value-add of manufactured products
- **d. Transformational Productivity** – Grow a hyper-efficient advanced manufacturing sector
Thanks!

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Thermal Process Intensification: 
Transforming the Way Industry Uses Thermal Process Energy
November 5 - December 9, 2020

https://www.orau.gov/2020thermal

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<thead>
<tr>
<th>High Temperature Metals</th>
<th>High Temperature Non-Metallic Minerals</th>
<th>Low/Medium Temperature Processing</th>
<th>Hydrocarbon Processing Industry</th>
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<tbody>
<tr>
<td>Session 0 - Plenary Session (November 5th at Noon – 3:00 pm ET)</td>
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<tr>
<td><strong>Pillar 1 &amp; 2 – Transformative Low Thermal Budget and Alternative Thermal Processing</strong></td>
<td>Session 1</td>
<td>Session 2</td>
<td>Session 3</td>
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<td>November 9 (Noon to 2:00 pm ET)</td>
<td>November 12 (Noon to 2:00 pm ET)</td>
<td>November 16 (Noon to 2:00 pm ET)</td>
<td>November 20 (Noon to 2:00 pm ET)</td>
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<td><strong>Pillar 3 – Transformative Supplemental Technologies</strong></td>
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<td>Session 5 - Dec 2(^{nd}) (Noon to 3:00 pm ET)</td>
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<td><strong>Pillar 4 – Waste Heat Management Technologies</strong></td>
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<td>Session 6 - Dec 9(^{th}) (Noon to 3:00 pm ET)</td>
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