Office of Energy Efficiency & Renewable Energy
Advanced Manufacturing Office

U.S. DEPARTMENT OF ENERGY

Industrial Thermal Process Intensification

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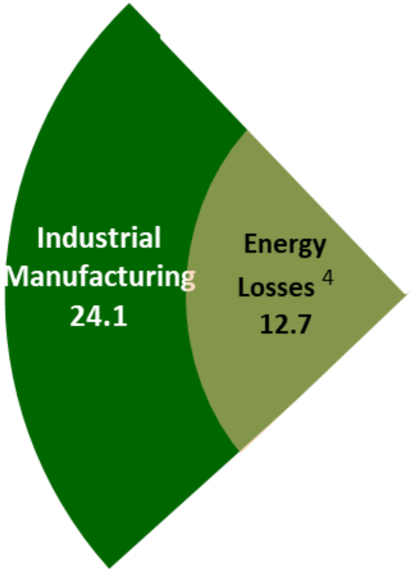
Opportunity Space for Manufacturing

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

Manufacturing Goods



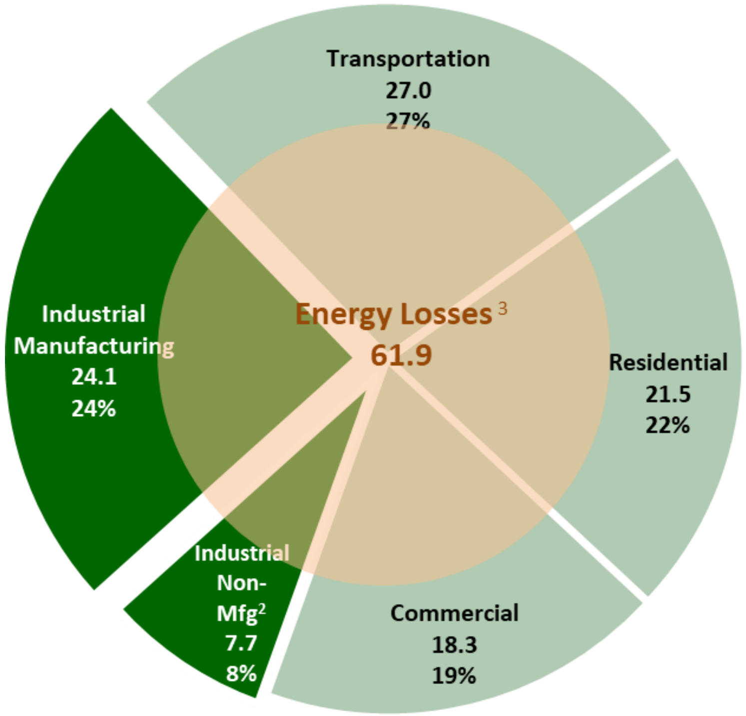
Data for 2014

More efficient manufacturing reduces energy losses

More efficient manufacturing enables technologies that improve energy use throughout the economy:

- Transportation
- Buildings
- Energy Production and Delivery

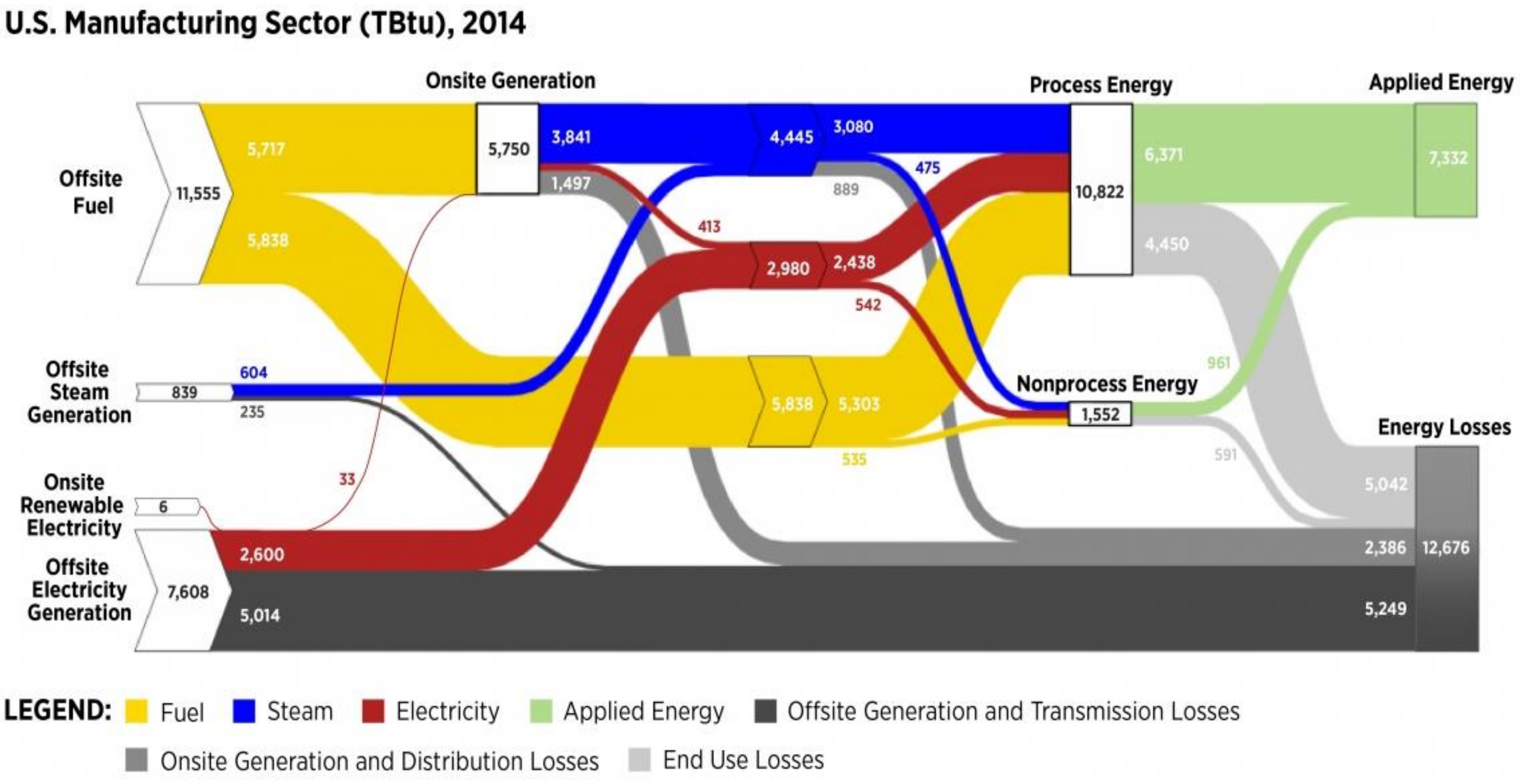
Use of Manufactured Goods



U.S. Energy Economy by Sector
98.5 quadrillion Btu, 2014 [1]

[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)

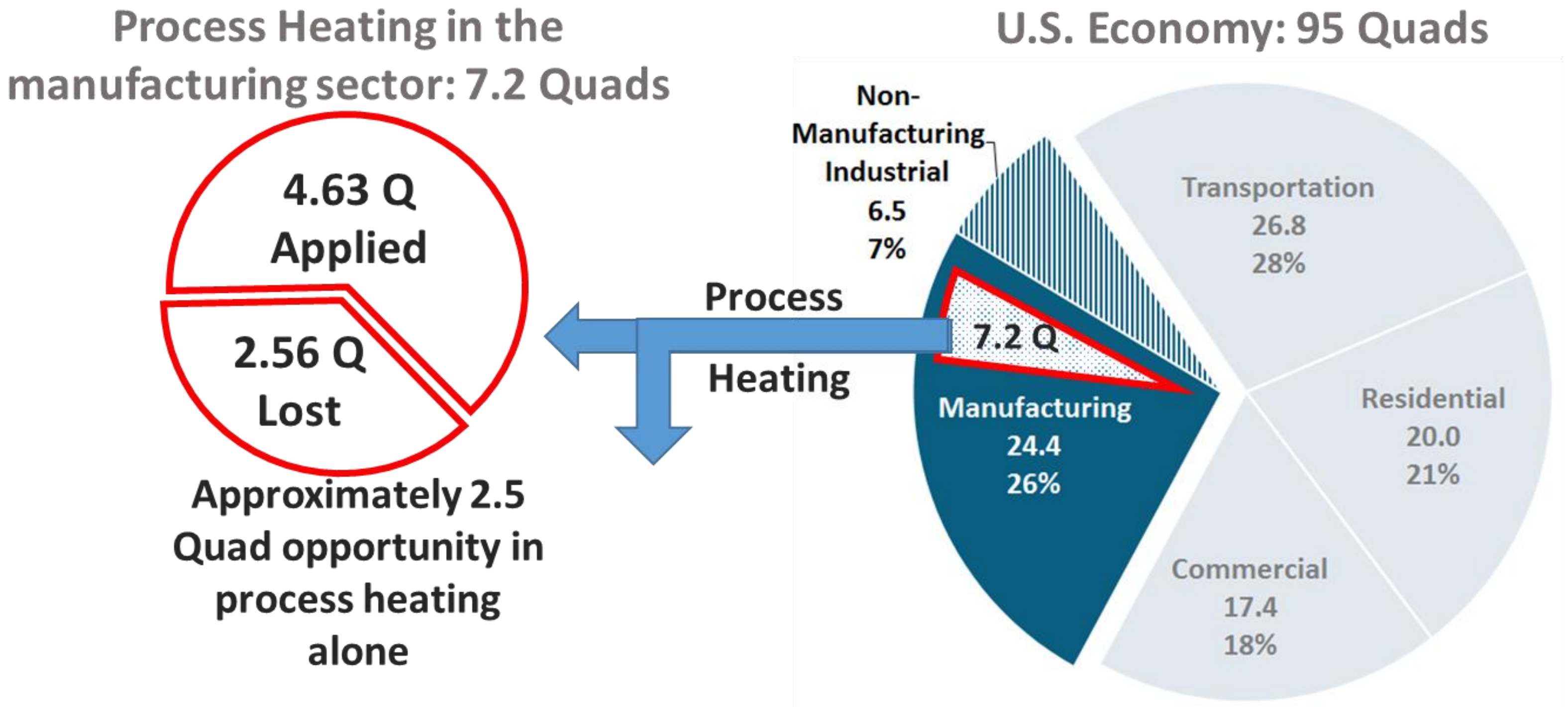
Sankey Diagram of Energy Flows in the U.S Manufacturing Sector



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

Thermal Opportunity

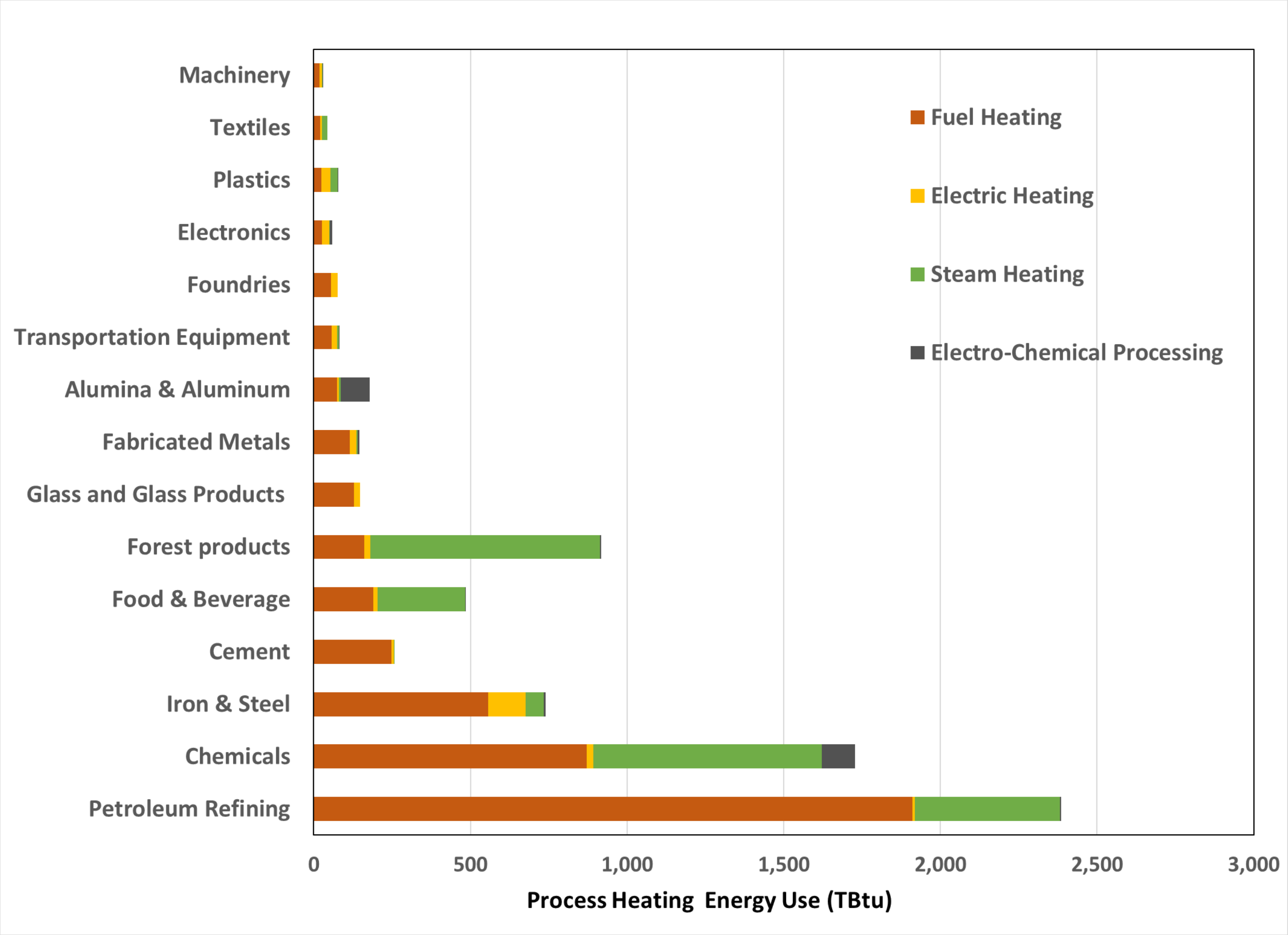
Process Heating Energy Use/Loss in the U.S. Economy



Source: EIA Monthly Energy Review, Aug 2014; AEO 2014

- **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.

Energy Used for Thermal Processing



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

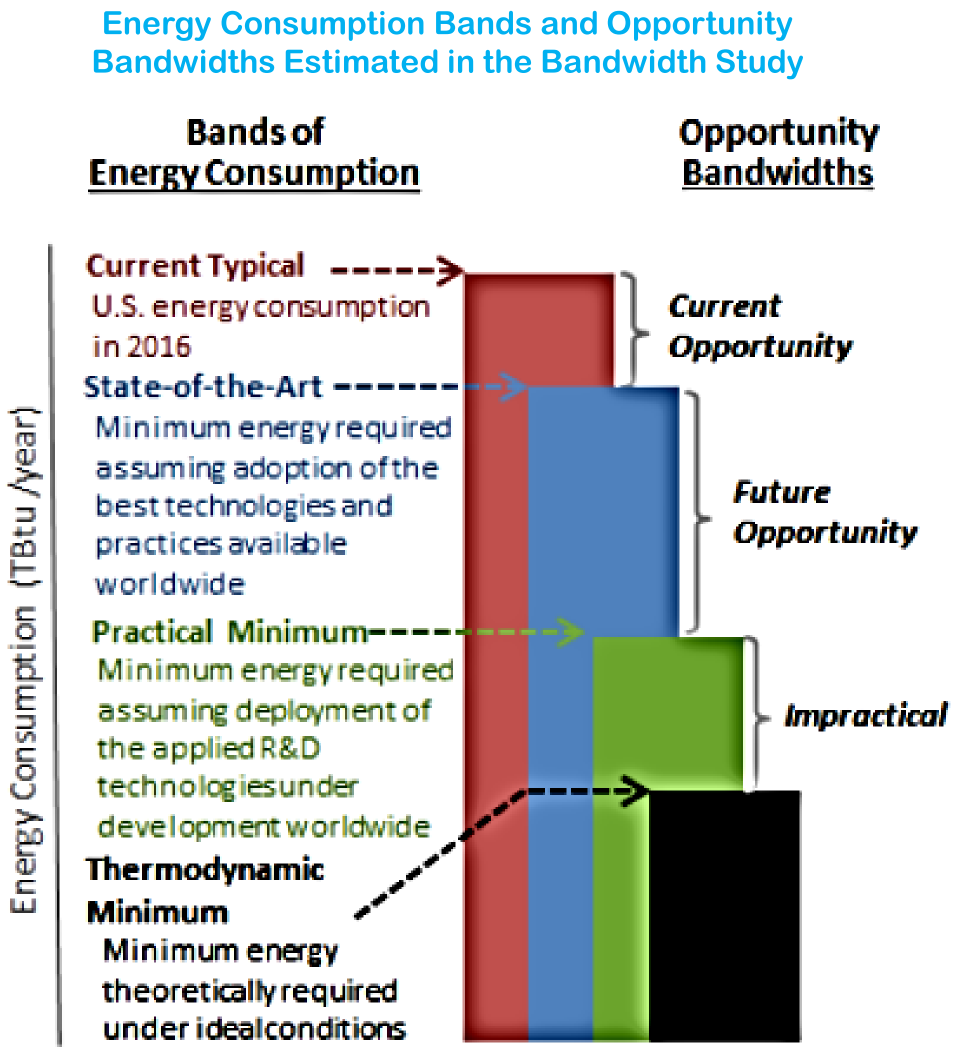
Source: EIA MECS 2014

Type of Thermal Processes Used for Eight Large Energy Consuming Industries

Thermal Process Step	Iron & Steel	Petroleum Refining	Chemical Industry	Glass	Aluminum	Pulp & Paper	Food Processing	Cement
Calcining	[High]		[High]		[High]	[High]		[High]
Curing and forming			[Low]					
Drying			[Medium]			[Low]	[Low]	
Fluid heating		[Medium]	[Medium]			[Low]	[Low]	
Heat treating (metal & nonmetal)	[Medium]			[Medium]	[Medium]			
Metal and non-metal reheating	[High]				[Medium]			
Metal and non-metal melting	[High]			[High]	[Medium]			
Other heating - processing			[Medium]					
Reactive thermal processing	[High]	[Medium]	[Medium]					
Smelting, agglomeration, etc.	[High]		[Medium]					
Steam generation	[Medium]	[Medium]	[Medium]		[Medium]	[Medium]	[Medium]	

Temperature Range	Color
Low Temperature (<800°F)	[light yellow]
Medium Temperature (800 to 1400°F)	[orange-yellow]
High Temperature (>1400°F)	[red]

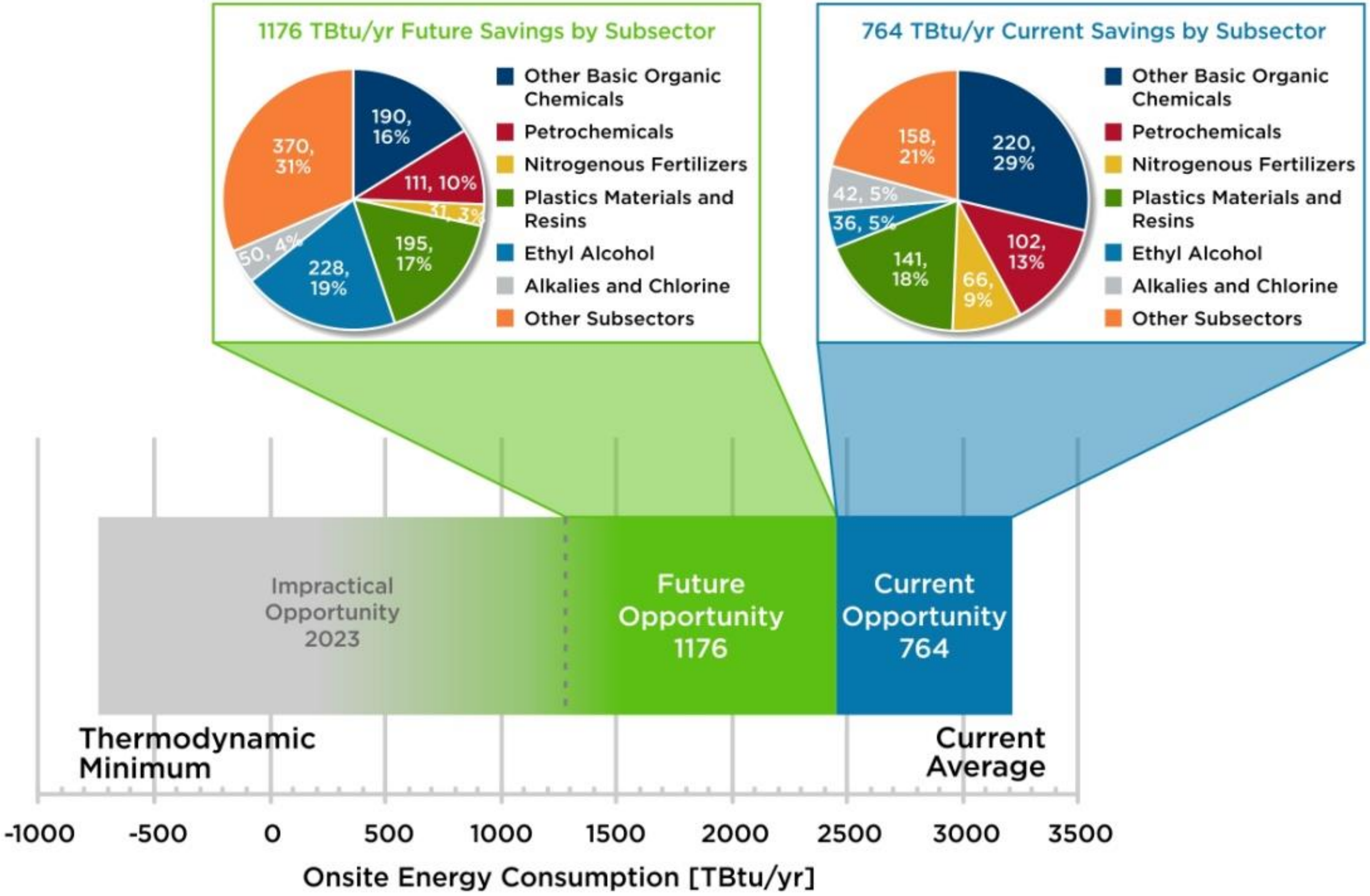
Manufacturing Energy Bandwidth Studies



- 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

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

Bandwidth Study Example – Chemicals



2015 Bandwidth Study: Chemicals

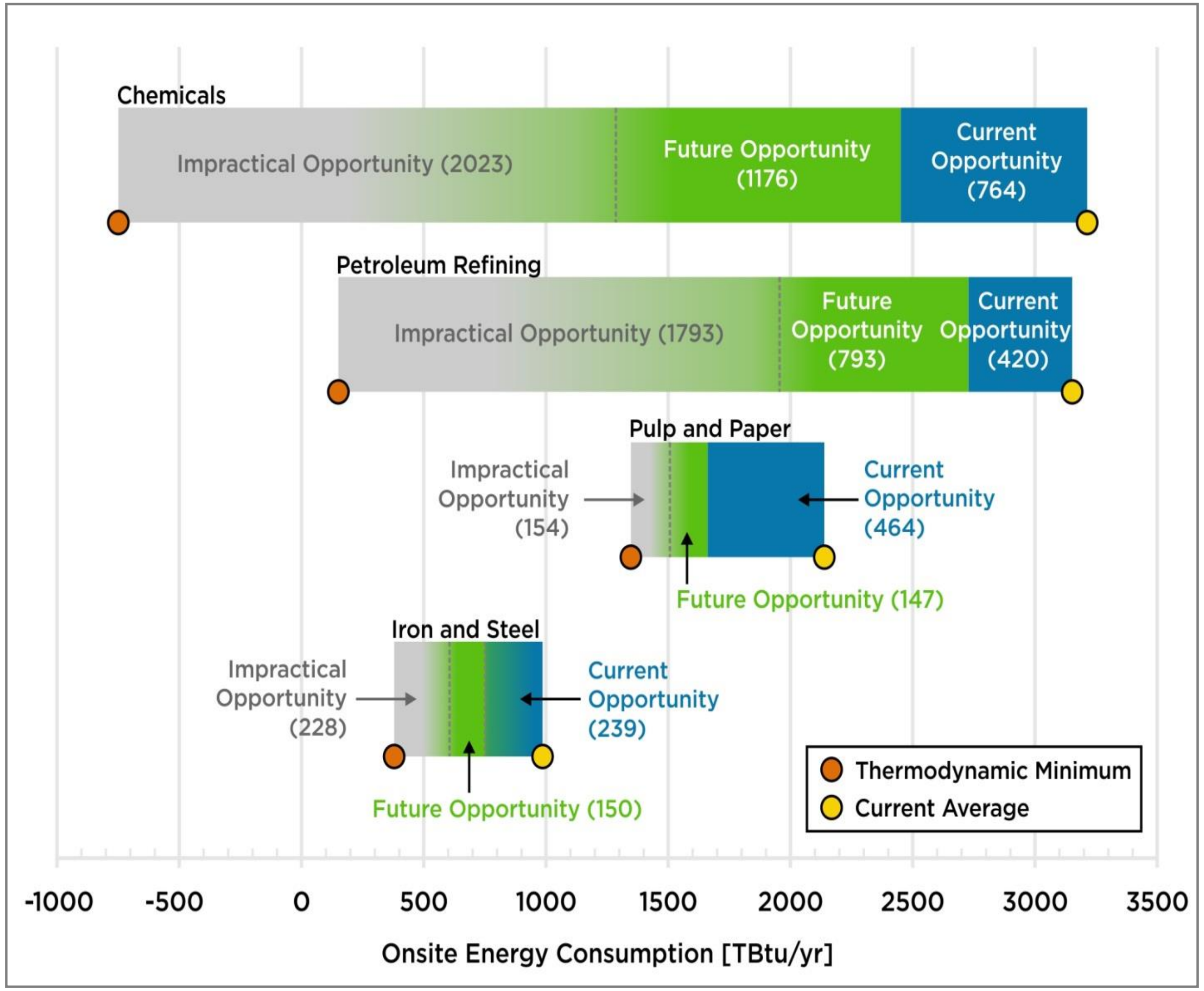
Energy Intensity

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

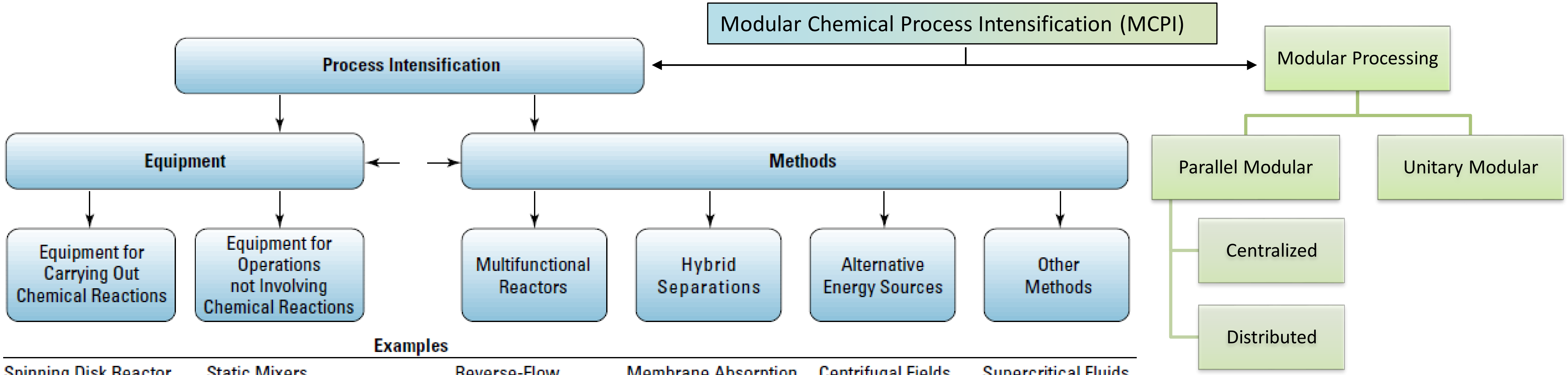
Technical Energy Savings Opportunities:



Source: DOE/AMO, Energy Bandwidth Studies (2015)
Note: 1 quad = 1000 TBtu

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

MCPI Taxonomy



Examples

Equipment for Carrying Out Chemical Reactions	Equipment for Operations not Involving Chemical Reactions	Multifunctional Reactors	Hybrid Separations	Alternative Energy Sources	Other Methods
Spinning Disk Reactor	Static Mixers	Reverse-Flow Reactors	Membrane Absorption	Centrifugal Fields	Supercritical Fluids
Static Mixer Reactor (SMR)	Compact Heat Exchangers	Reactive Distillation	Membrane Distillation	Ultrasound	Dynamic (Periodic) Reactor Operation
Static Mixing Catalysts (KATAPAKs)	Microchannel Heat Exchangers	Reactive Extraction	Adsorptive Distillation	Solar Energy	
Monolithic Reactors	Rotor/Stator Mixers	Reactive Crystallization		Microwaves	
Microreactors	Rotating Packed Beds	Chromatographic Reactors		Electric Fields	
Heat Exchange (HEX) Reactors	Centrifugal Adsorber	Periodic Separating Reactors		Plasma Technology	
Supersonic Gas/Liquid Reactor		Membrane Reactors			
Jet-Impingement Reactor		Reactive Extrusion			
Rotating Packed-Bed Reactor		Reactive Comminution			
		Fuel Cells			

Examples

Gas compression	Gas-to-Liquids
Chloralkali	Distillation

Gaps / Opportunities

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

Four Pillars of Thermal PI – Examples from RAPID's Portfolio




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

Alternative Thermal Processing

Manufacturing Supply Chain for Modular Solar-Thermochemical Conversion

Additive manufacturing and modular designs for distributed, solar-driven reforming of natural gas to hydrogen

Pacific Northwest NATIONAL LABORATORY

Oregon State University

STARS Technology Corporation

SoCalGas

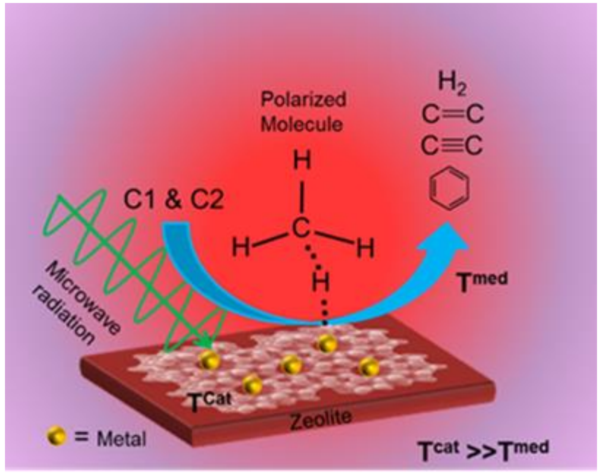
Alternative Energetics for Hydrocarbon Upgrading

A viable reactor and catalysts for direct conversion of lower alkanes to aromatics using selective microwave heating

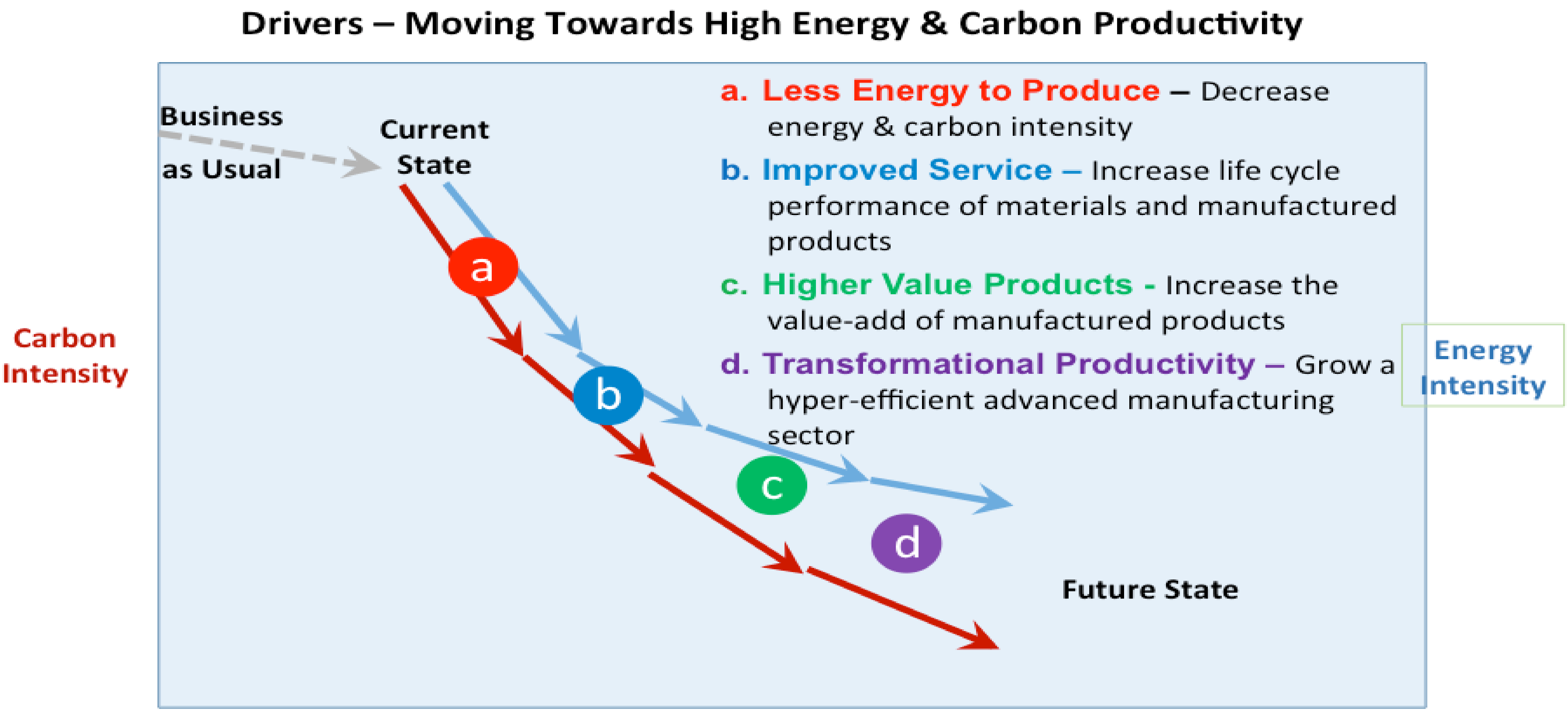
West Virginia University

NATIONAL ENERGY TECHNOLOGY LABORATORY

University of Pittsburgh



What is Potential to Decouple Thermal Operations in Mfg.?



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

	High Temperature Metals	High Temperature Non - Metallic Minerals	Low/Medium Temperature Processing	Hydrocarbon Processing Industry
Session 0 - Plenary Session (November 5th at Noon – 3:00 pm ET)				
Pillar 1 & 2 – Transformative Low Thermal Budget and Alternative Thermal Processing	Session1 November 9 (Noon to 2:00 pm ET)	Session 2 November 12 (Noon to 2:00 pm ET)	Session 3 November 16 (Noon to 2:00 pm ET)	Session 4 November 20 (Noon to 2:00 pm ET)
Pillar 3 – Transformative Supplemental Technologies	Session 5 - Dec 2nd (Noon to 3:00 pm ET)			
Pillar 4 – Waste Heat Management Technologies	Session 6 - Dec 9th (Noon to 3:00 pm ET)			