Energy Bandwidth Studies
May 22, 2014

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Purpose of presentation:

Present the results of and the analysis surrounding the 2014 Chemical, Petroleum Refining, and Pulp Paper, and Iron and Steel Energy Bandwidth Studies

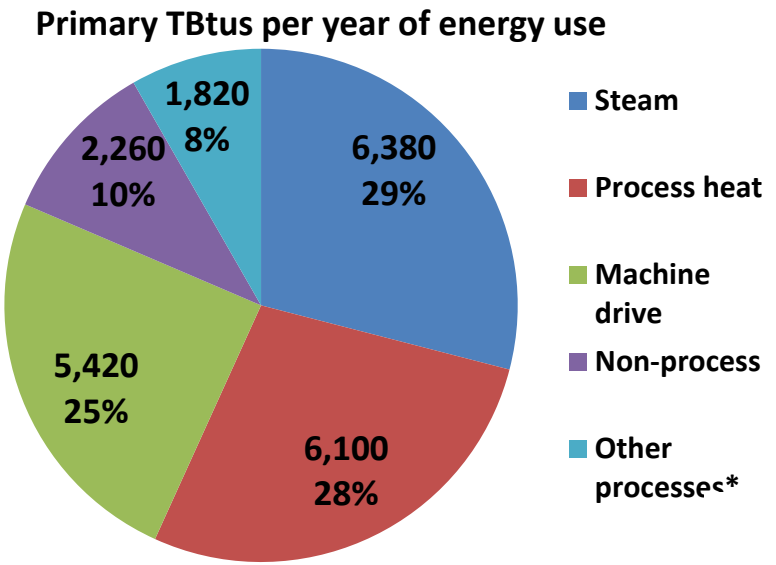
Outline

1. DOE AMO energy analysis efforts – evolving perspective
2. “Energy Bandwidth” – what does this mean?
3. Prior bandwidth studies
4. Four new bandwidth studies, 2014
5. Bandwidth analysis methodology
6. Bandwidth results
7. Using the results

United States Manufacturing Industry

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

Manufacturing and Advanced Manufacturing

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

"There is a close connection between R&D and manufacturing in many of the emerging sectors ……. R&D engineers may have to stay close to manufacturing to develop new strategies for making processes more efficient. The tighter integration of innovation and production may also present opportunities to bring design closer to end users, as advanced manufacturing technologies make it possible to produce higher-value goods at lower volume."*Professor Suzanne Berger, co-chair of MIT's Production in the Innovation Economy (PIE)*

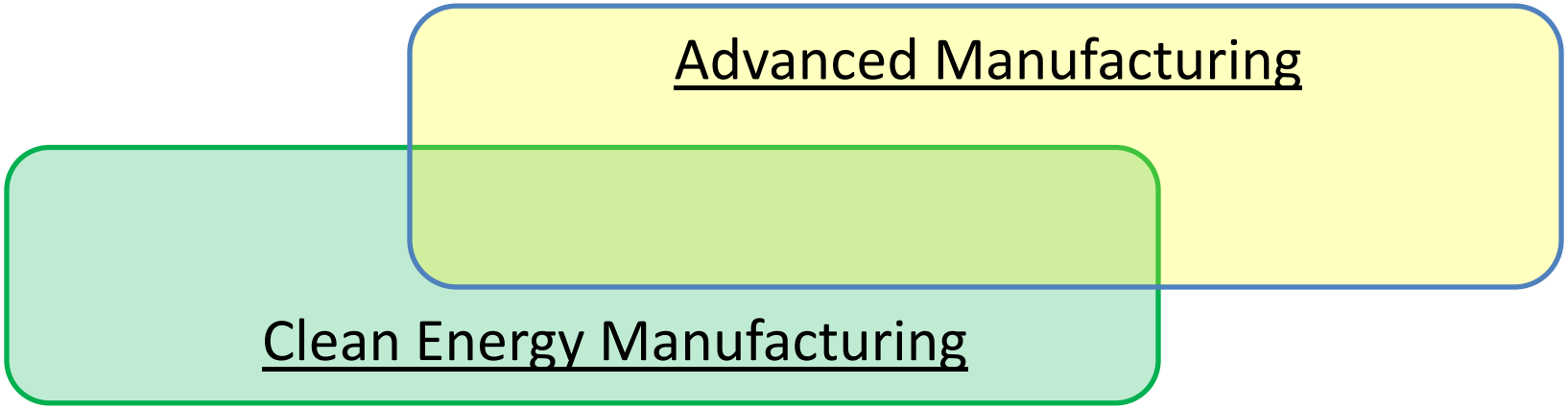
"Advanced Manufacturing involves both: new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies."

President's Council of Advisors on Science and Technology,
"Report to the President on Ensuring America's Leadership in Advanced Manufacturing," June 2011

Advanced Manufacturing and Clean Energy at DOE

Clean Energy Manufacturing
Making things such that environmental impact is reduced in the making, use, or disposal of the product made.

Advanced Manufacturing
Making things in a manner such that technology provides a competitive advantage over the practices widely in use.



Advanced Manufacturing Office – Focus on Technologies

Technologies and Materials

Existing

- Technologies and materials that already exist and no further improvements are required

Emerging

- Technologies and materials that are incrementally improving their performance and are under continuing improvement

Advanced

- New generation technologies and materials that offer “breakthrough” performance advancements

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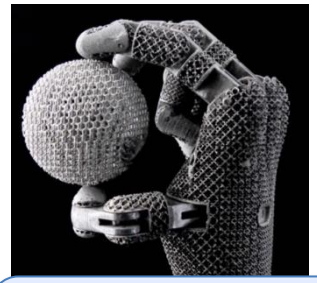
EERE's Clean Energy Manufacturing Initiative (CEMI)

1. Increase U.S. competitiveness in the production of clean energy products

Products that generate clean energy

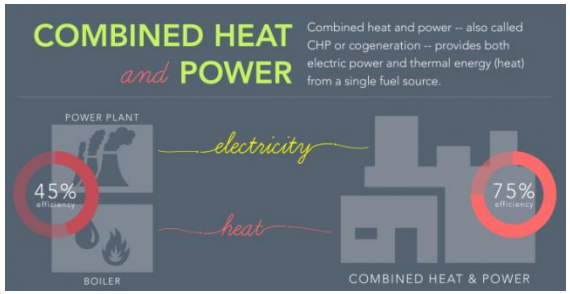
Products that save energy and increase efficiency

2. Increase U.S. manufacturing competitiveness across the board by increasing energy productivity and use of clean and low-cost fuels and feedstocks



Advanced Manufacturing Technologies

Industrial Energy Efficiency



Combined Heat & Power

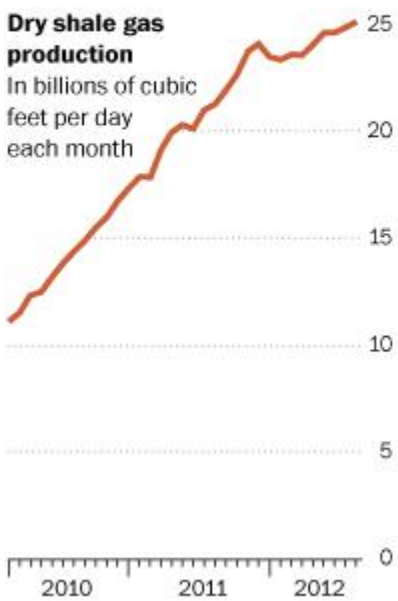
Low-Cost Natural Gas

Drivers affecting US Manufacturing

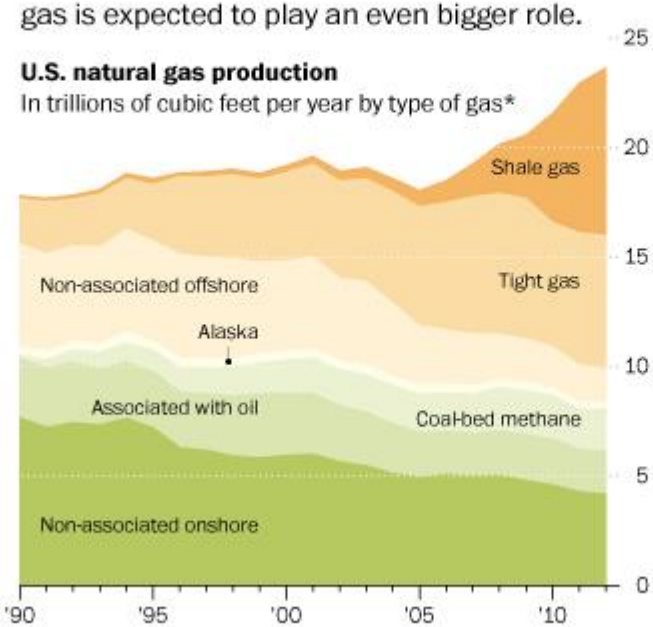
"For the foreseeable future, thanks to the recovery of vast U.S. underground gas deposits of shale, natural gas is likely to remain 50 to 70 percent cheaper in the U.S. than in Europe and Japan," said a recent report by the Boston Consulting Group. That will translate into significantly lower costs for electricity generation, for fuel used to power industrial plants and for feedstock used across many industrial processes."

The new boom: Shale gas fueling an American industrial revival,
Washington Post, November 15, 2012

Shale gas production has more than doubled since January 2010.

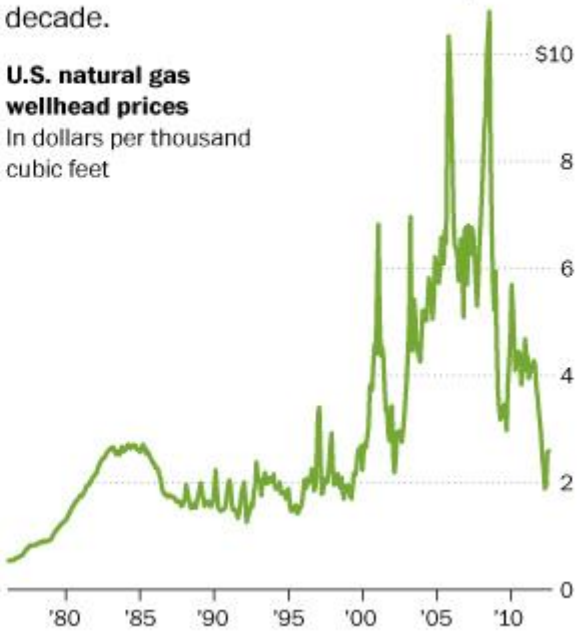


This has helped increase overall U.S. natural gas production, despite flat to declining production in traditional gas fields. In the future, shale gas is expected to play an even bigger role.



*2011 and 2012 are estimates.

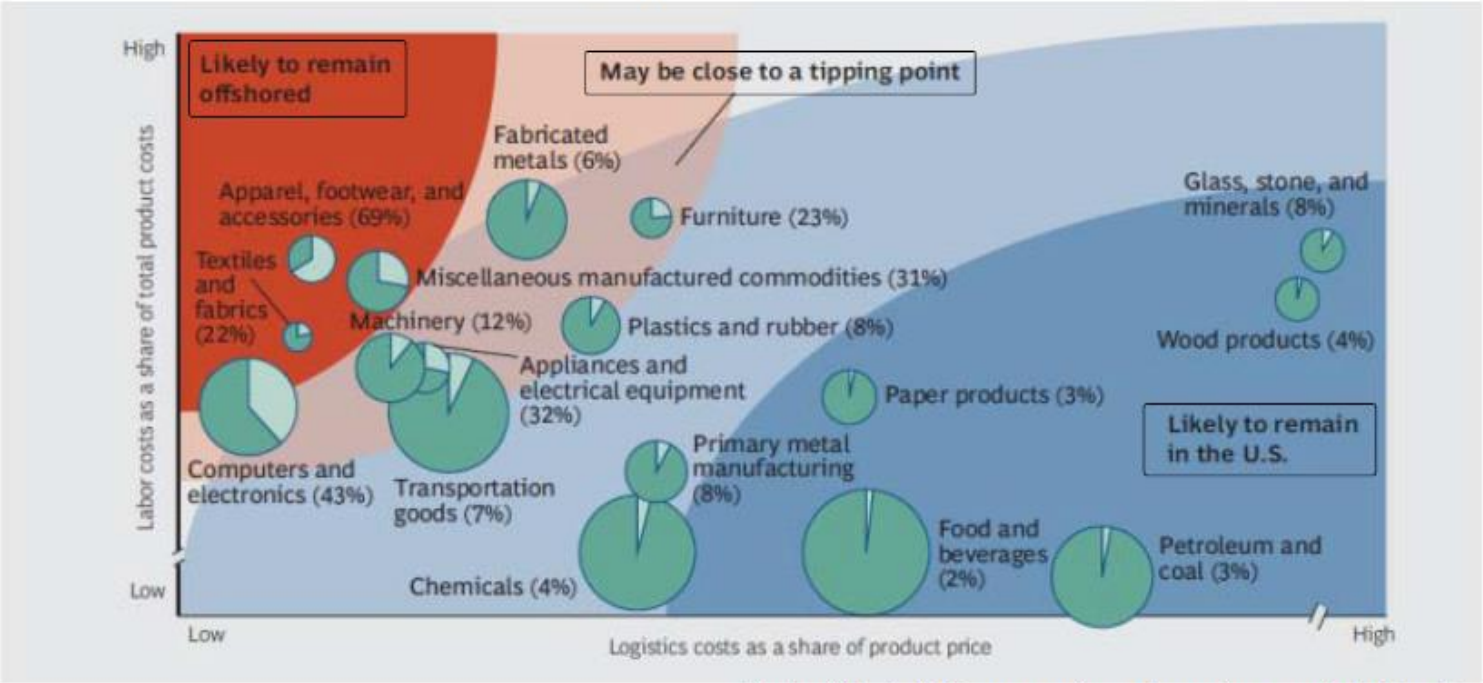
Natural gas wellhead prices crashed in April. They have recovered somewhat but remain near the lowest level in the past decade.



Sources: Lippman Consulting, U.S. Energy Information Administration. The Washington Post. Published on November 14, 2012, 8:00 p.m.

US-based Manufacturing Opportunities are Increasing

Manufacturing Opportunities for Selected Industries



Pie charts illustrate U.S. consumption and percentage supplied by imports.

- High-level analysis indicates increasing domestic manufacturing opportunities across multiple sectors.

Source: Boston Consulting Group. (March 2012). "Made in America, Again. U.S. Manufacturing Nears the Tipping Point – Which Industries, Why, and How Much." Data from U.S. Department of Transportation, U.S. Census Bureau, and U.S. Bureau of Economic Analysis.

Advanced Manufacturing Office (AMO): Structure

R&D Projects

- Manufacturing Efficiency – Broadly Applicable
- Efficiency – for Energy Intense Processes
- Cross-cutting – for Clean Energy Manufacturing Technologies

R&D Facilities

- Manufacturing Efficiency – Broadly Applicable
- Cross-cutting – for Clean Energy Manufacturing Technologies

Technical Assistance

- Manufacturing Efficiency – Broadly Applicable

http://energy.gov/eere/amo/advanced-manufacturing-office

Advanced Manufacturing Office (AMO): Goals

R&D Projects

- Develop technologies to reduce the life-cycle energy consumption of affected manufactured goods by 50% within 10 years of the start of each development effort

R&D Facilities

- Establish 8 Clean Energy Manufacturing Innovation Institute(s) by 2017 to demonstrate advanced materials and processes technologies, leading to commercialization.

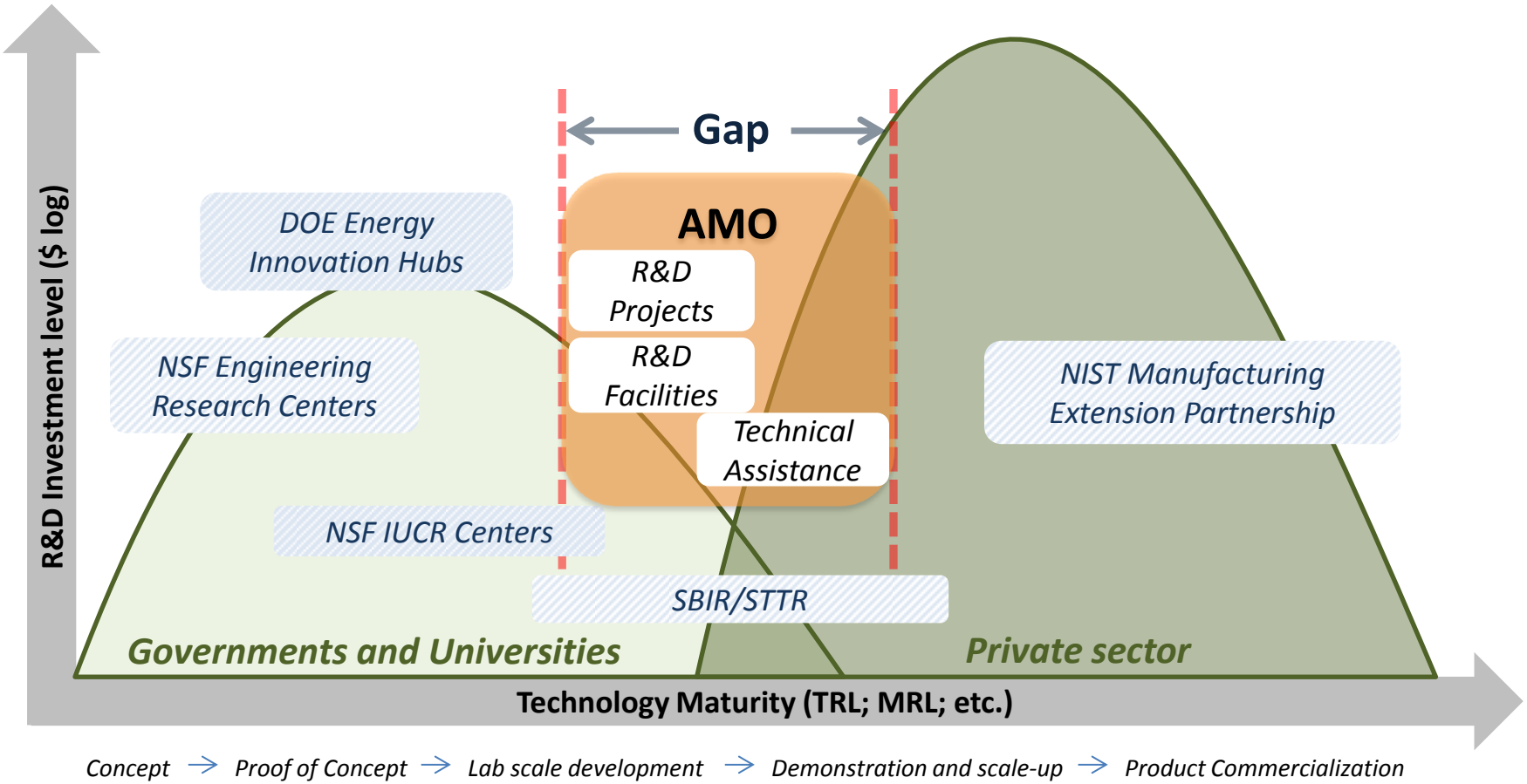
Technical Assistance

- Reduce manufacturing energy intensity by 25% over ten years
- Support achievement of 40 GW of new combined heat and power (CHP) by 2020

*Source: *DOE FY 2014 Congressional Budget Request, page EE-187 and EE-200,*
http://energy.gov/sites/prod/files/2013/04/f0/Volume3_1.pdf

The "missing middle"

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



AMO Targets Investments in High Impact Technologies

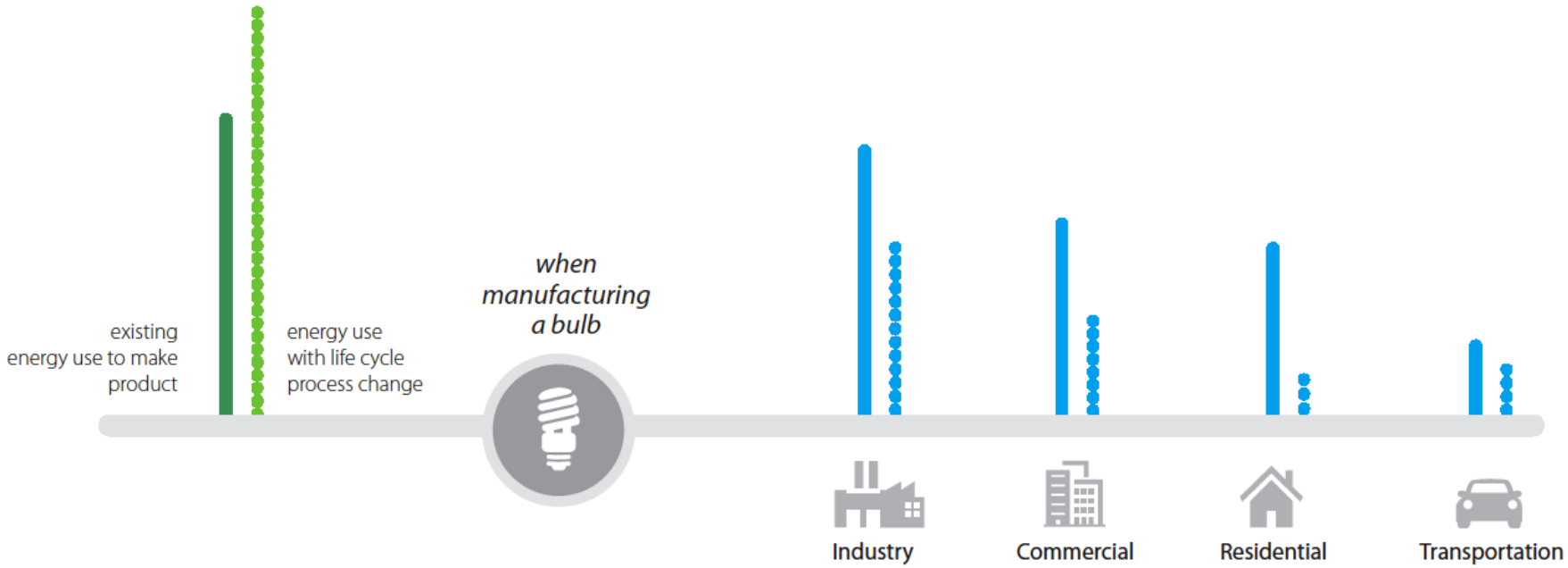
- **Transformative:** Results in significant change in the life-cycle impact (energetic or economic) of manufactured products

- **Pervasive**: Creates 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**: Represents a competitive/strategic capability for the United States

- **Significant in Clean Energy Industry**: Has a quantifiable *energetic* or *economic* value, embodied energy, economic (increase in value-added, increase in export value, increase in jobs created)

Life cycle approach to better understand system-wide impacts



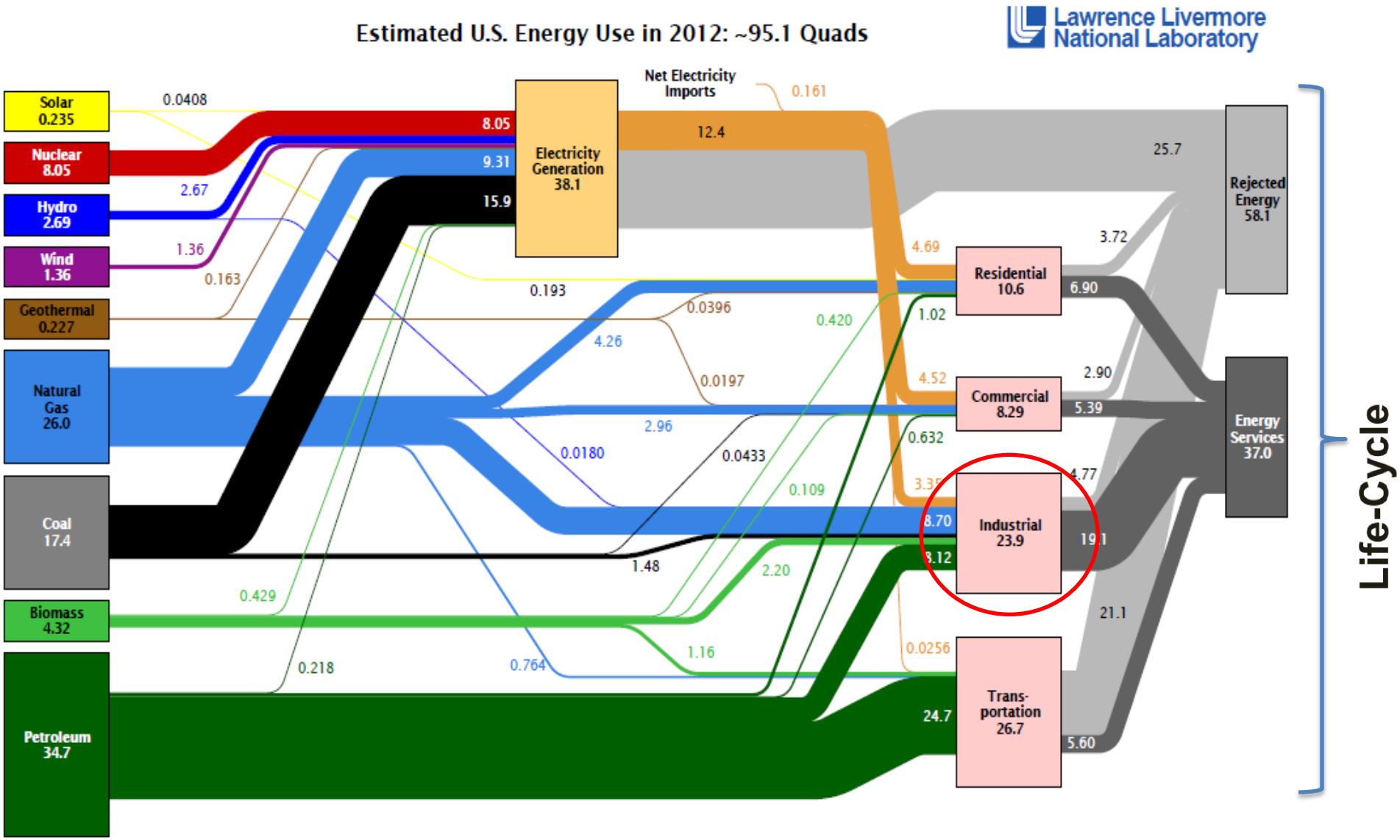
Energy Use in Manufacturing Process

New products or processes may lead to change in energy use in manufacturing sector.

Energy Use in Environment

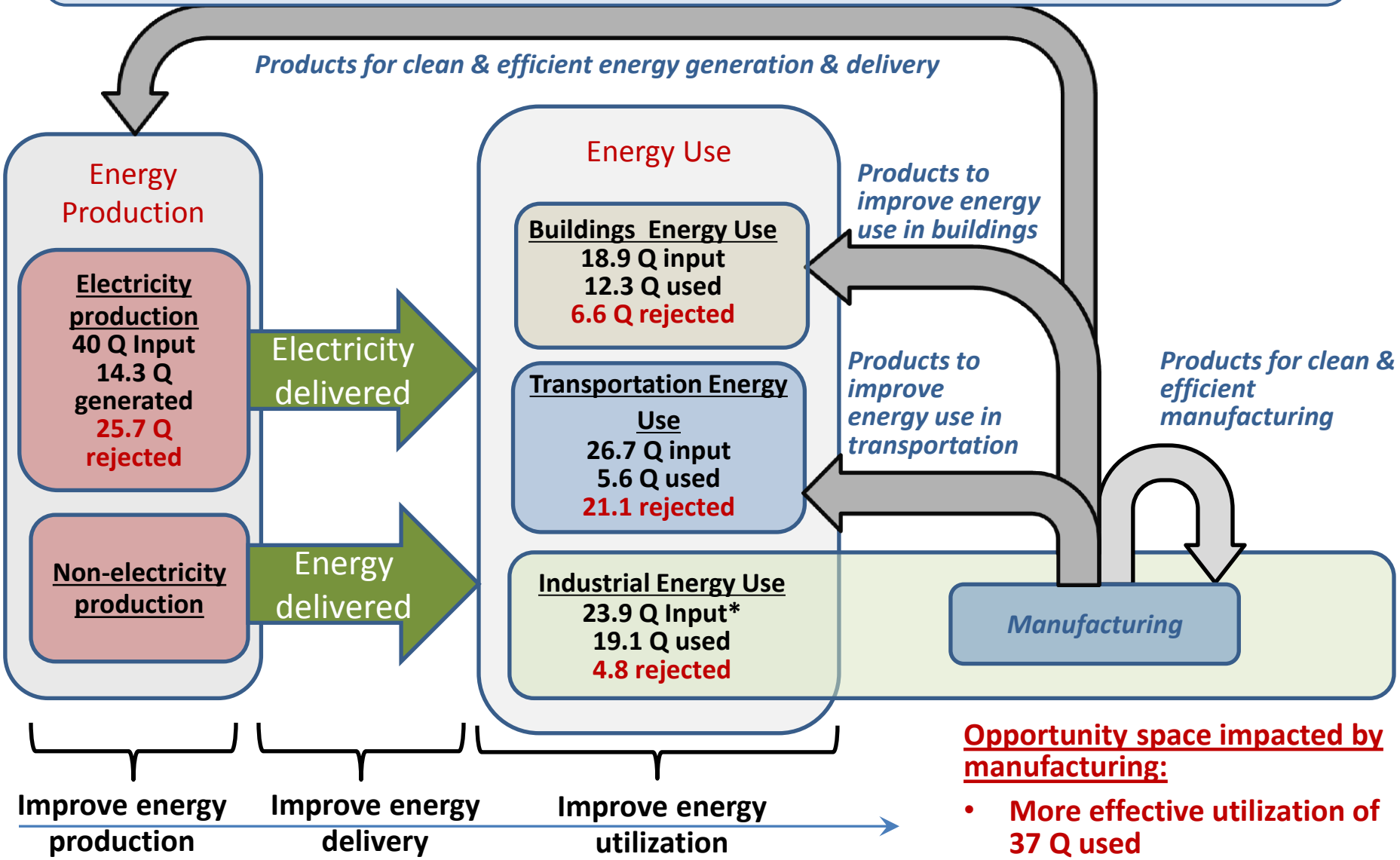
Change occurs in energy use across sectors as a result of deployment of new product.

Flow of Energy through the U.S. Economy



Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

The opportunity space: economy-wide energy impacts resulting from clean energy manufacturing.



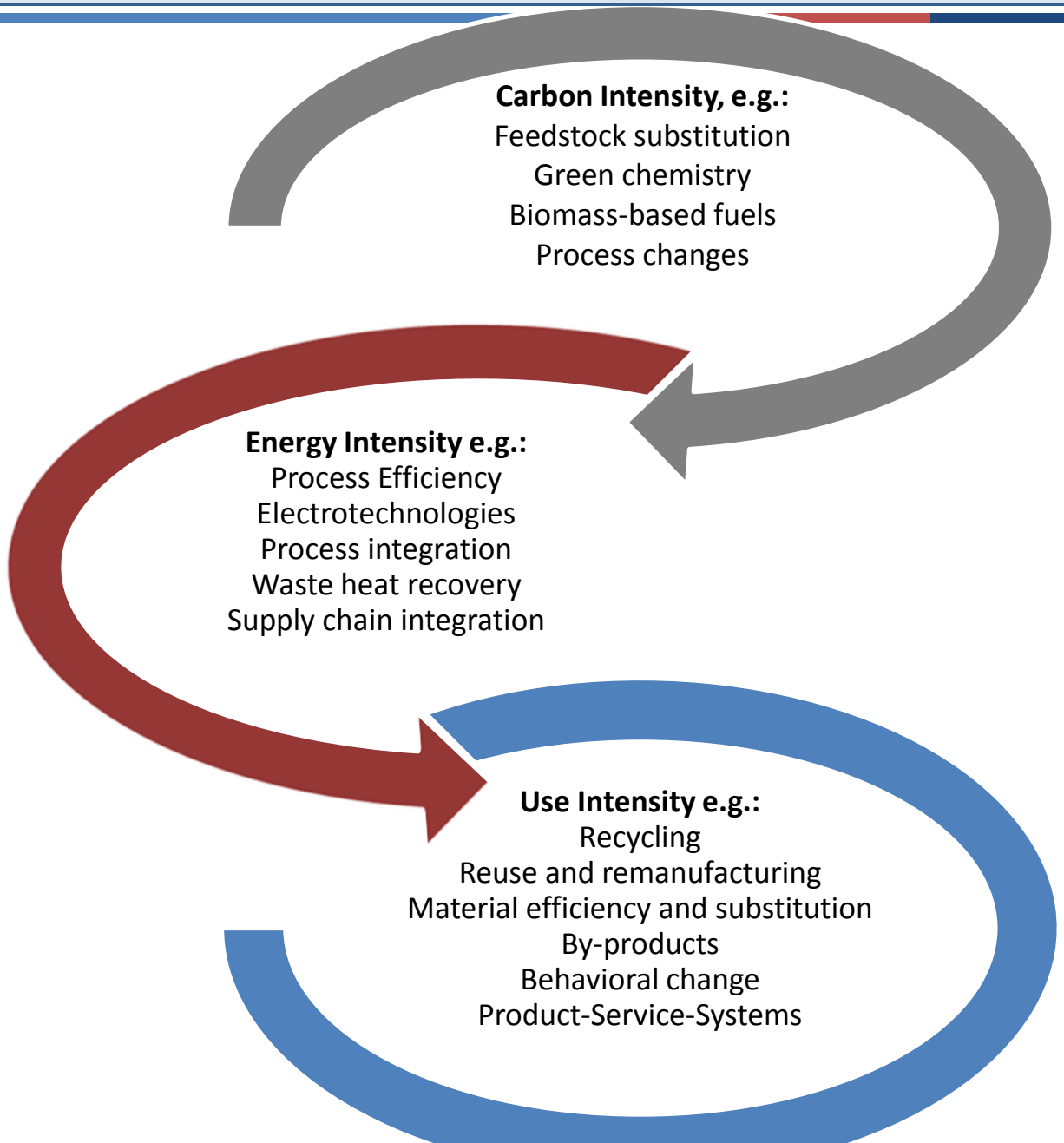
Opportunity space impacted by manufacturing:

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

* >30% is feedstock

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

System Approach – What affects the system?

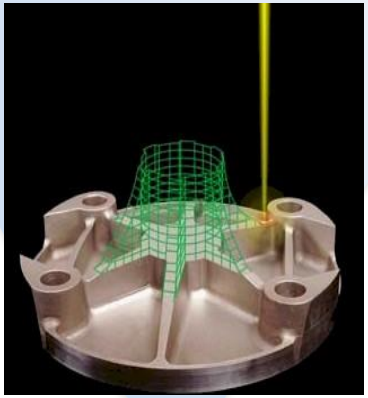


Drivers to reduce energy & emissions through the product lifecycle

Economy-wide lifecycle energy impacts – starts with technology

Industry Energy Use

- Dramatically increased buy:fly for complex components
- Less process heating



AeroMet process. Boeing, Northrup Grumman, NavAir W. Coblenz, DARPA/DSO 2000

Lifecycle Impact

Non-Industry Energy Use

- Lighter components
- Novel, energy-efficient designs

Reduces material use and costs by up to 90%

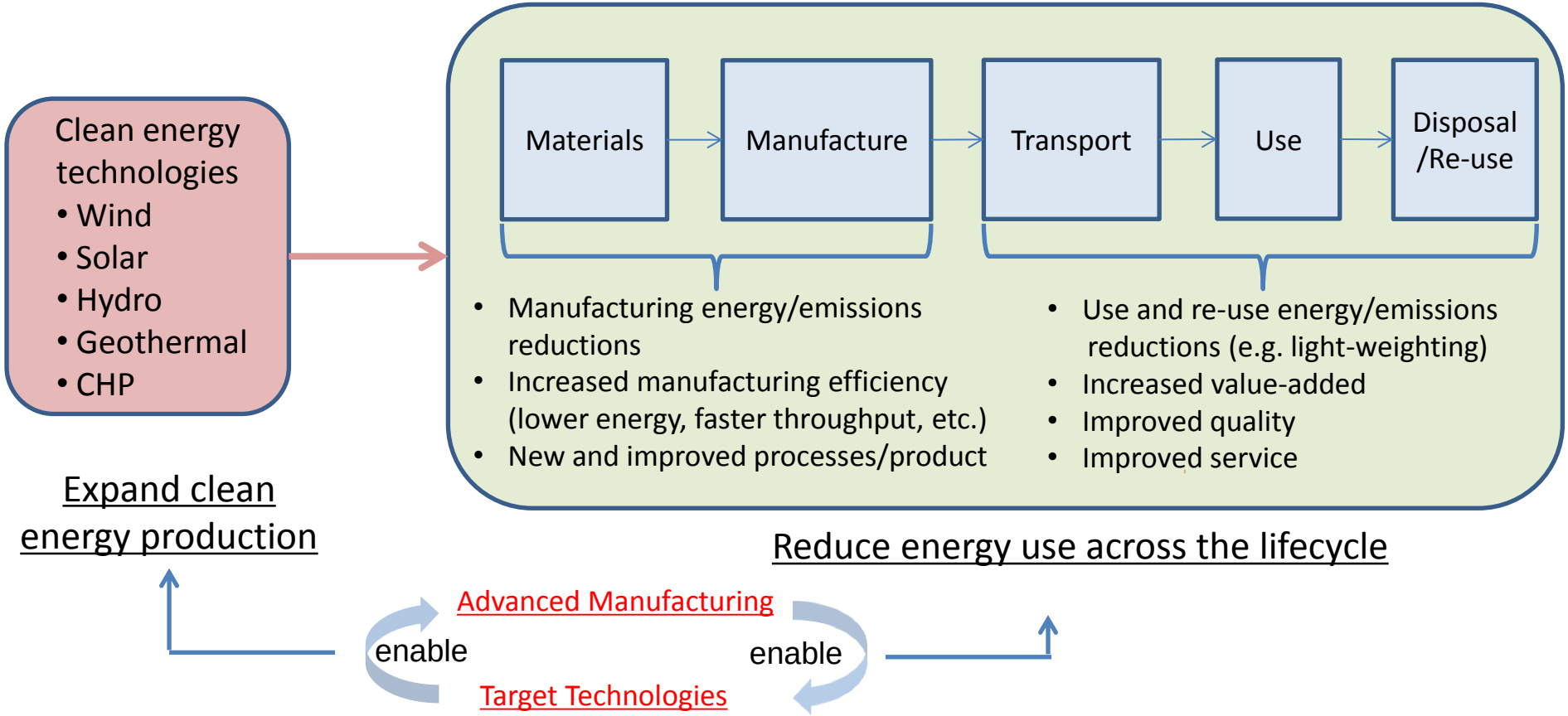
Source: The Economist. www.economist.com/node/18114221

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

– Robert McEwan GE

Economy-wide lifecycle energy impacts – starts with technology

- Identify opportunities for manufacturing impacts in clean energy production and use.
- Target timely, high-impact, foundational clean energy technologies with the potential to transform energy use and accelerate their introduction into the US economy.



Illustrative

Economy-wide lifecycle energy impacts – starts with technology

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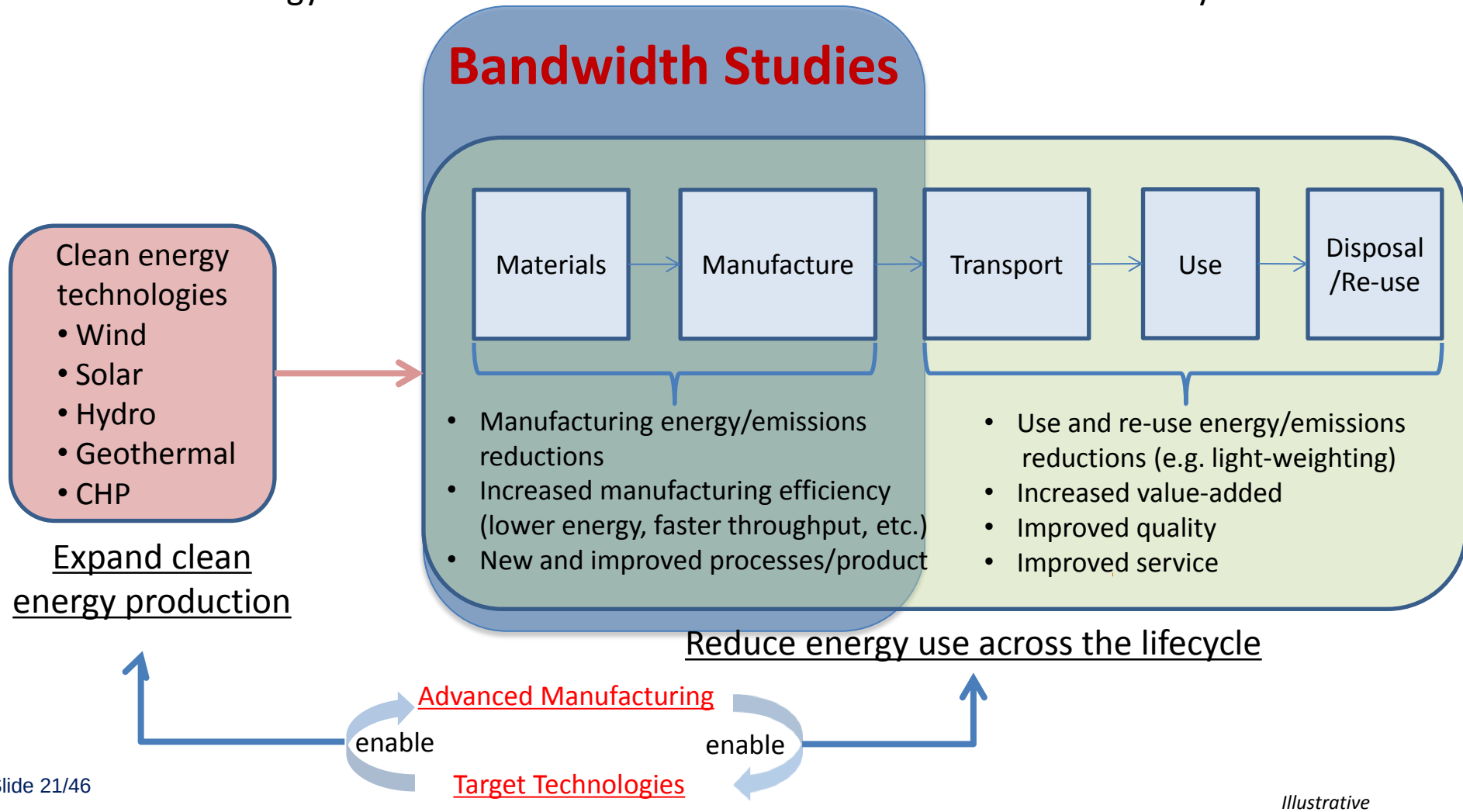


Illustrative

Big Industrial End Users are Important

Aluminum Materials Flows – U.S. and Canada, 2009 Billions of Pounds

btu/lb	primary	secondary
Current average	26,000	2,200
Practically achievable	20,000	925
Current savings potential	6,000 btu/lb Process improvement	1,275
Theoretical minimum	10,200	510

23,800 btu/lb Materials shift

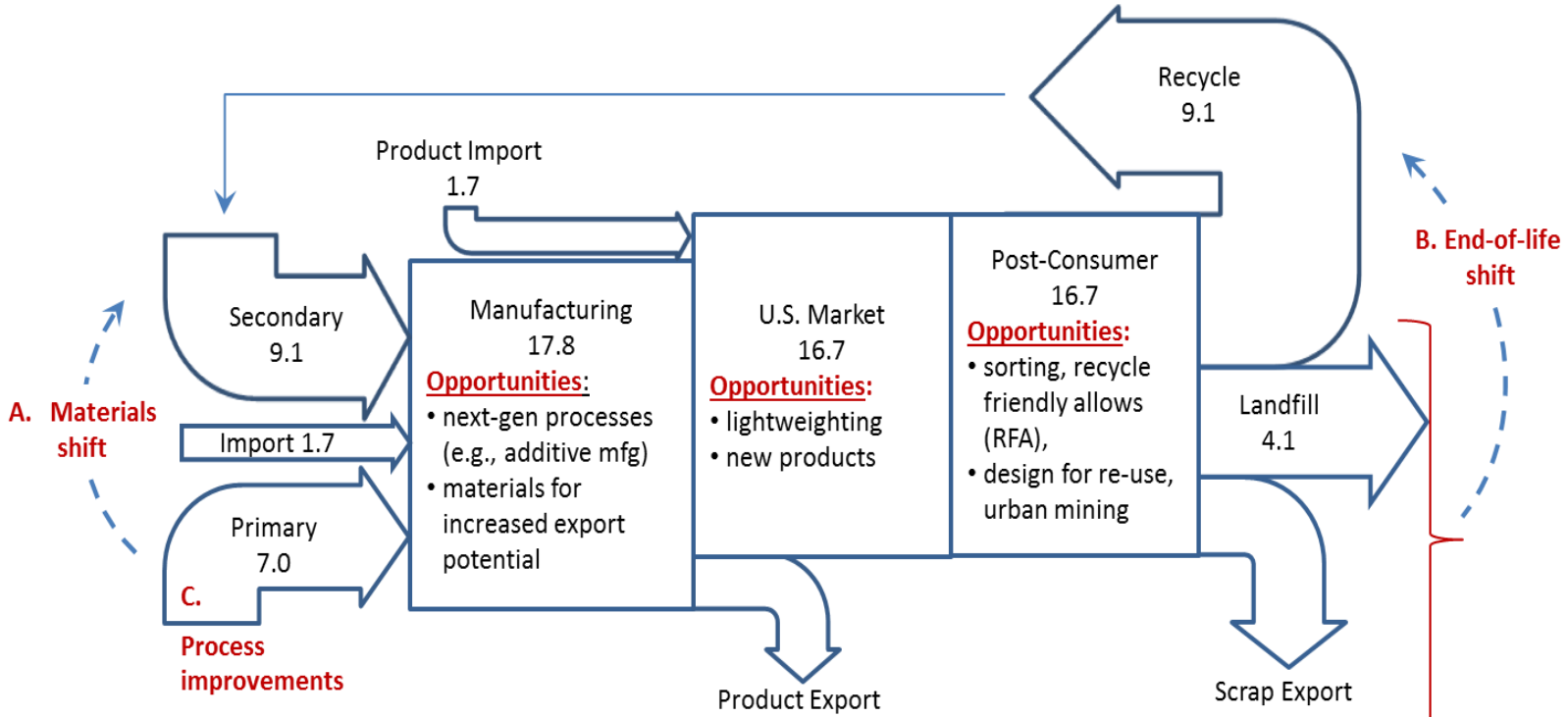
Key Opportunities:

A. Materials shift - Technologies to enable increase in secondary aluminum use by manufacturing sector.

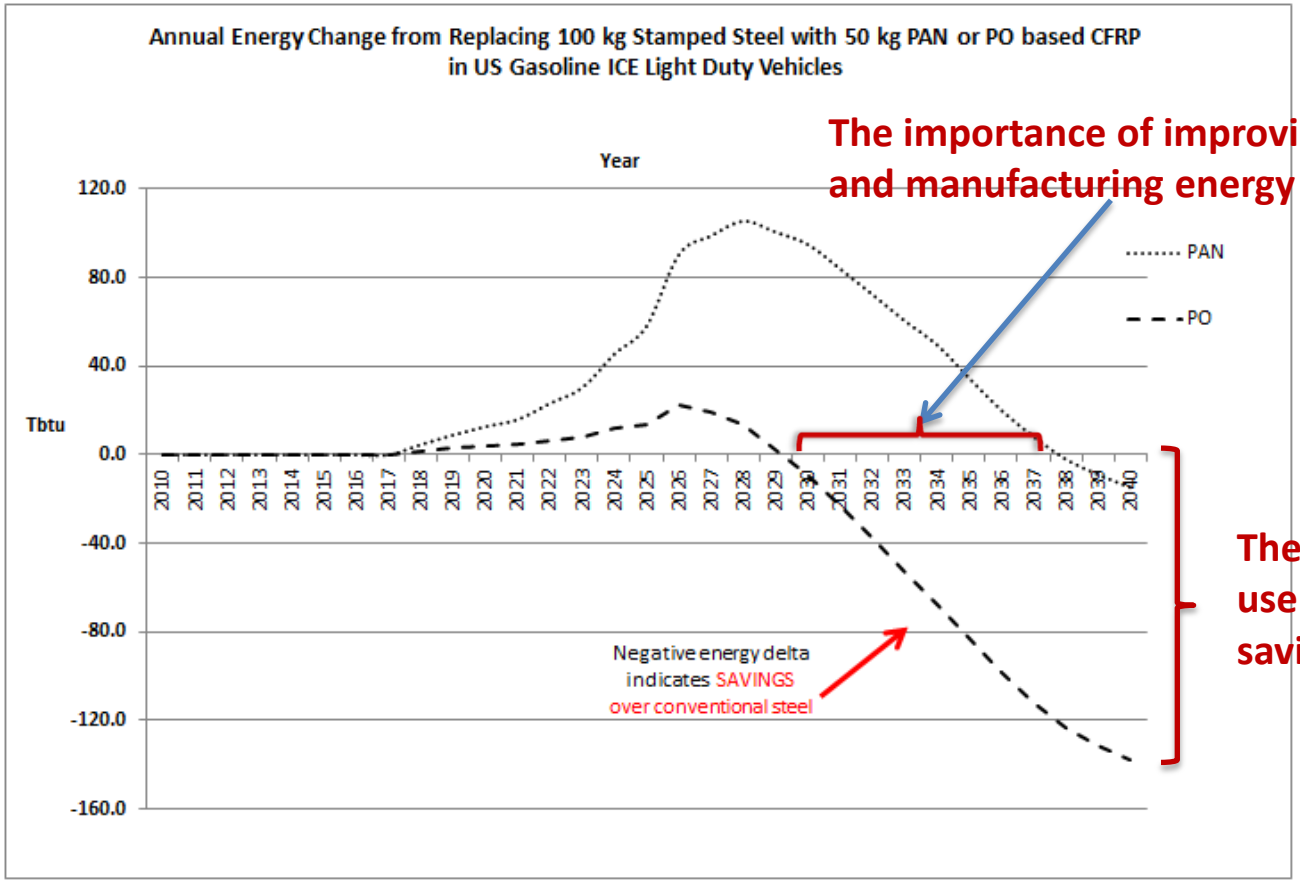
B. End-of-life shift - Technologies to enable greater capture and use of 7.6 billion pounds aluminum (landfill + scrap export).

C. Process improvements- Technologies to improve primary aluminum processing.

New opportunities throughout the system – in materials design, product design, manufacturing, use and re-use.



Energy Consumption Savings from Lightweighting Carbon Fiber Reinforced Plastics (CFRP) vs. Steel; *Improved CF (polyolefin) vs. current CF (polyacrylonotrile)*



- Per vehicle savings of 2600 MJ per PAN vehicle and 11,500 MJ per PO vehicle
- Net energy impact of PO (dashed line) in US LDV fleet also compared with PAN (dotted line)
- Significantly greater materials and manufacturing energy investment with PAN – net energy savings temporally delayed and lesser magnitude

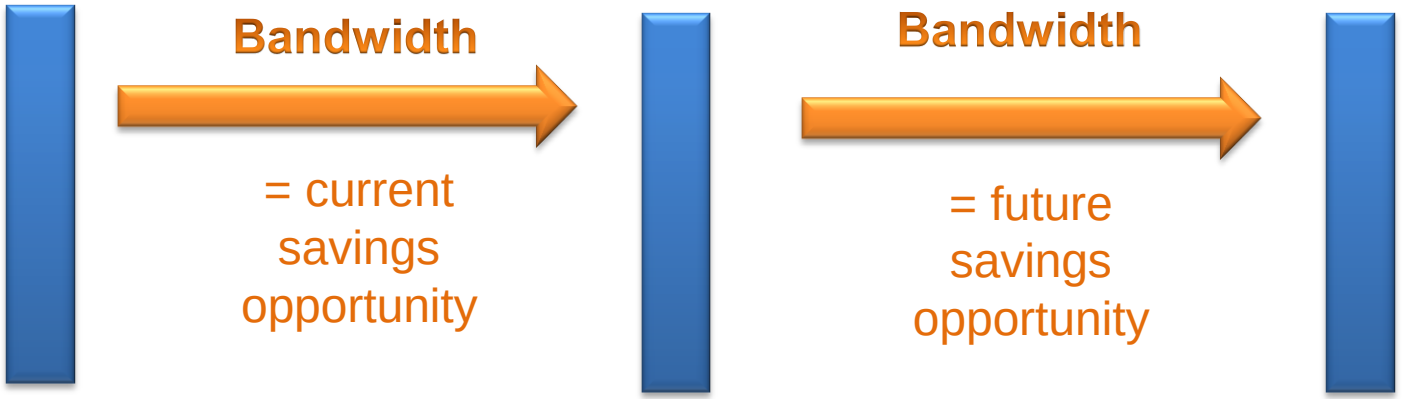
“Energy Bandwidth”

Energy Bandwidth = comparison of energy consumption for defined industrial process areas to determine bandwidths of technical energy savings opportunity

… **technical energy savings opportunity**

These bands of energy consumption and bandwidths of opportunity are useful for identifying and prioritizing areas of focus.

Energy Bandwidth

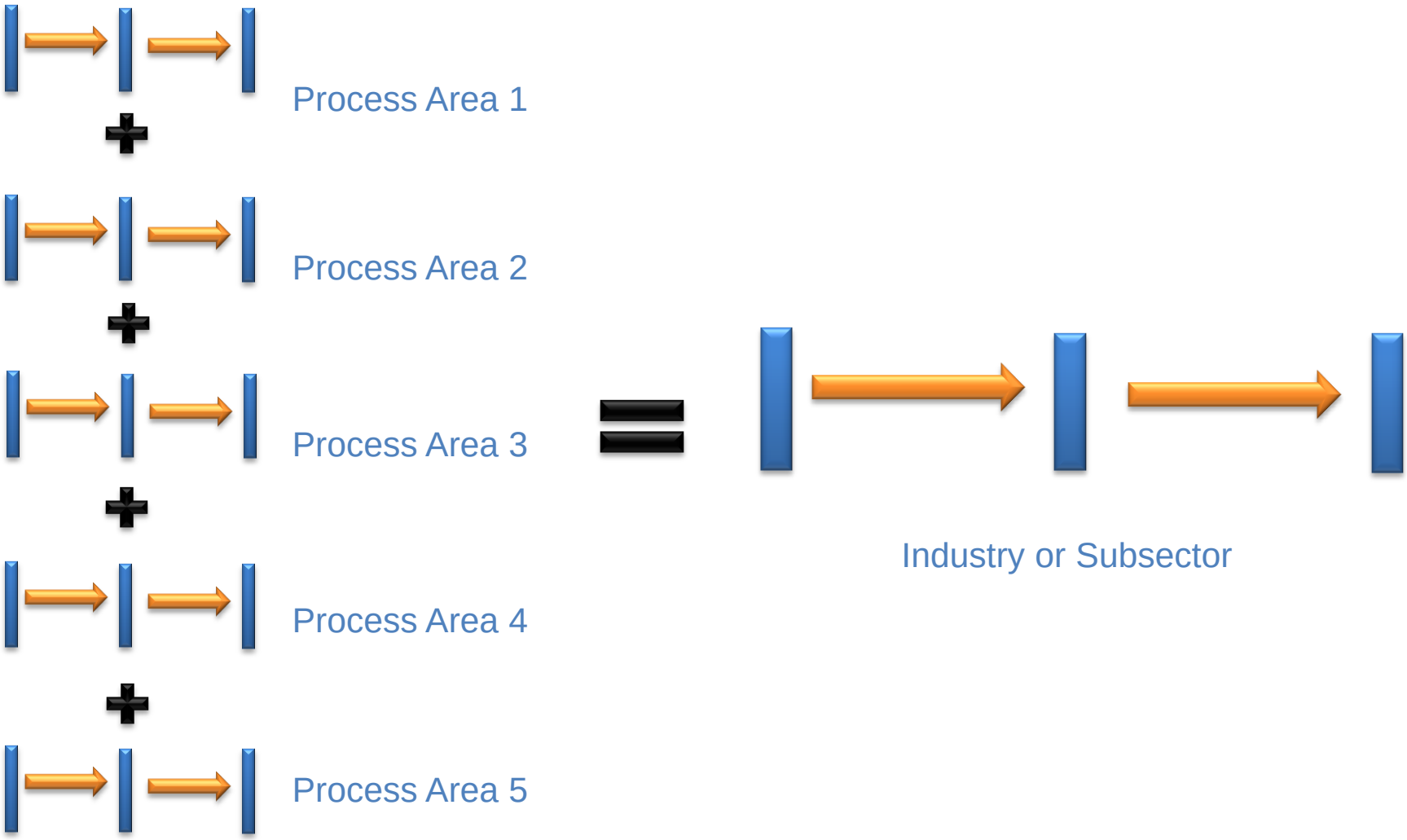


Current Average
Energy Consumption

State of the Art
Energy Consumption

Practical Minimum
Energy Consumption

Energy Bandwidth



October 2004

Steel Industry
Energy Bandwidth Study

Energetics, Inc.
for the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Industrial Technologies Program

October 2004

October 2006

Energy Bandwidth for Petroleum Refining Processes

Prepared by Energetics Incorporated for the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Industrial Technologies Program

October 2006

August 2006

REPORT for

American Institute of Chemical Engineers
(AIChE)

Pulp and Paper Industry
Energy Bandwidth Study

Prepared by

Jacobs
Greenville, South Carolina, USA
and
Institute of Paper Science and Technology (IPST) at
Georgia Institute of Technology
Atlanta, Georgia
August 2006

Project Number: 16CX8700

JACOBS

December 2006

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Chemical Bandwidth Study

Exergy Analysis: A Powerful Tool for Identifying Process Inefficiencies in the U.S. Chemical Industry

Industrial Technologies Program

DRAFT Summary Report
December 2006

Study conducted for the U.S. Department of Energy
by JVP International, Incorporated and Psage Research, LLC
Summary report prepared by Energetics Incorporated

Examples of Who Uses the Bandwidths

- **Environmental Defense Fund** - 2013 Less Carbon, More Innovation initiative factsheets www.lesscarbonmoreinnovation.org
- **National Academy of Sciences** - 2010 Real Prospects for Energy Efficiency in the United States, National Academy of Sciences, National Academy of Engineering, National Research Council
- **LBNL** - Assessment of Energy Efficiency Improvement - 2013 Petroleum Refining, 2013 Pulp and Paper, and others…
- **EPA** - rule making reference
- **Northwest Clean Air Agency** - referenced in preparing CO_2 emissions guidelines
- **DOE/EERE** - Industry Energy Futures (technical potential), Quadrennial Technology Review
- **DOE/AMO** - goal setting for Better Plants Program

Energy Bandwidth History

Sectors Studied		Original Bandwidth Publish Dates	Current, Uniform Bandwidth Analysis
1	Chemical	2006, 2011 (unpublished)	2014
2	Petroleum Refining	2006	2014
3	Iron and Steel	2004	2014
4	Pulp and Paper	2006, 2011 (unpublished)	2014
5	Aluminum	2007	planned
6	Cement	2010 draft	planned
7	Glass	2007	
8	Mining	2007	
9	Metalcasting	2004 (no savings)	
10	Other Manufacturing *		planned

Bandwidth Improvements

Past Bandwidth Studies

- Different base years
- Different definitions of measures and terminology
- Different authors and different SOW
- Different units
- Different presentation style

Inconsistent Results

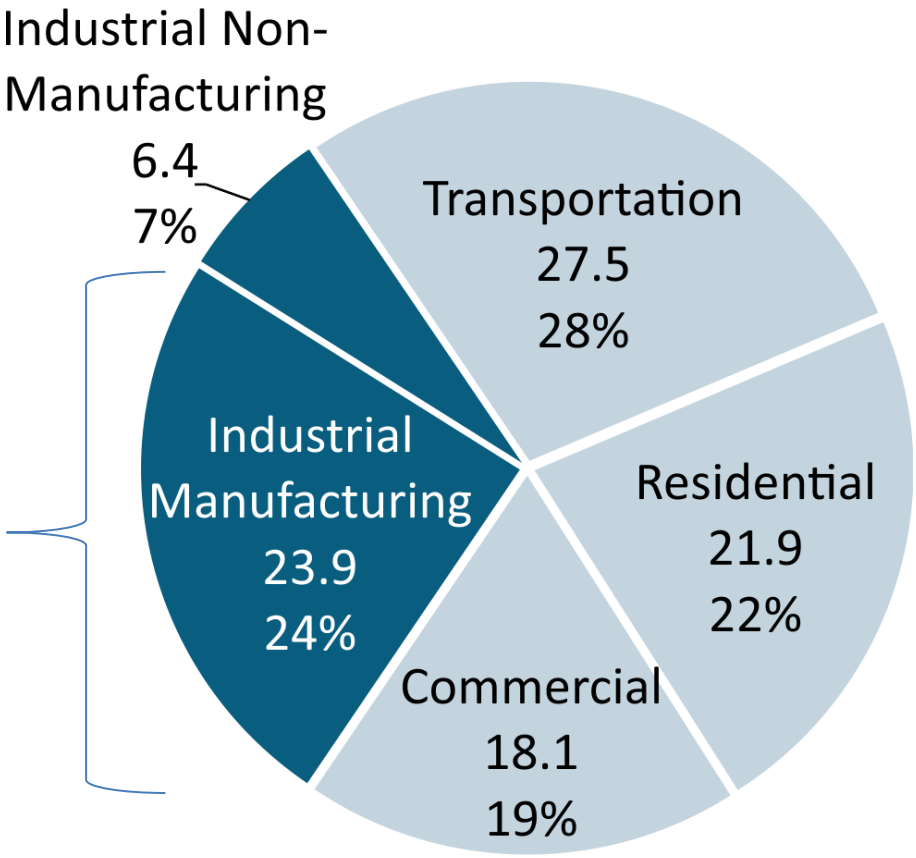
Current Bandwidth Studies

- Sources, assumptions, calculations standardized
- Standard units and reporting conventions
- Improved coverage of industry studied
- Savings measures sufficiently described
- Same look, format, presentation

Table of Contents

- Chapter 1 – Introduction, methodology
- Chapter 2 - Brief overview of sector, key process areas
- Chapter 3 - Production (2010)
- Chapter 4 – Current Average Energy Consumption
- Chapter 5 – State of the Art Energy Consumption
- Chapter 6 – Practical Minimum Energy Consumption
- Chapter 7 – Thermodynamic Minimum Energy Consumption
- Chapter 8 – Summary
- Appendices – Reference Lists, PM Intensities, PM Technology Weighting Factors, Graphics

Chemicals *	18%
Petroleum Refining *	15%
Forest Products *	13%
Food and Beverage	8%
Iron and Steel *	6%
Plastics and Rubber Products	2%
Fabricated Metals	2%
Transportation Equipment	2%
Computers and Electronics	2%
Alumina and Aluminum	2%
Cement	1%
Glass and Glass Products	1%
Machinery	1%
Textiles	1%
Foundries	1%
Remaining Manufacturing	4%
Feedstock Energy	19%

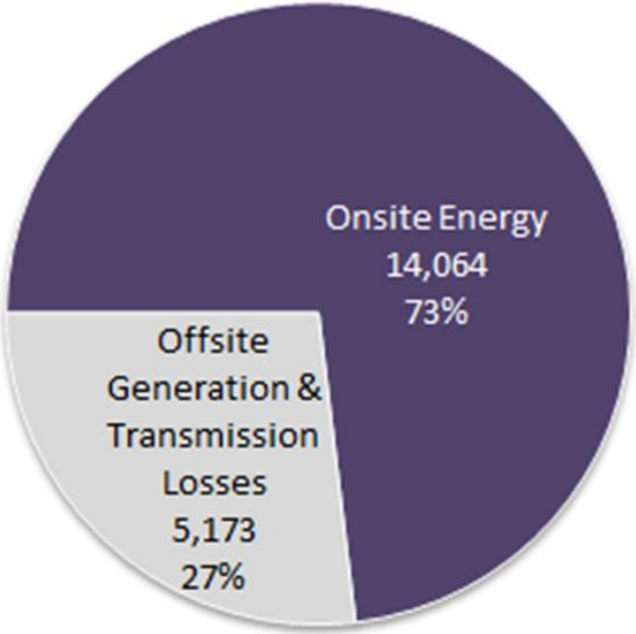


Industries Studied

Energy Consumption of Energy Bandwidth Sectors		
Sector		2010 Primary Energy, TBtu
Chemicals	NAICS 325	4,290
Petroleum Refining	NAICS 324110	3,555
Pulp and Paper	NAICS 322	2,559
Iron and Steel	NAICS 331111	1,359
Total for four sectors		11,763

Primary Manufacturing Energy Use

19,237 TBtu



Defined Processes Areas Studied, and Coverage

Key Process Areas Studied and Sector Coverage of these Areas		
Manufacturing Sector	Key Process Areas Studied	% of Sector-wide Onsite Energy Covered
Chemicals	74 Chemical Products and 15 Chemical Manufacturing Subsectors	(e.g., ethylene, chlorine, ammonia)
Petroleum Refining	9 Processes	(alkylation, atmospheric crude distillation, coking/visbreaking, FCC, hydrocracking, hydrotreating, isomerization, reforming, vacuum cru
Pulp and Paper	6 Processes and 2 Subsectors	(**pulp manufacturing** – liquor evaporation, pulping chemical prep, wood coking, bleaching, and **paper manufacturing** – drying, paper machine wet end)
Iron and Steel	6 Processes and 8 Sub-processes	(agglomeration, cokemaking, ironmaking, steelmaking (BOF, EAF), casting, rolling)

Definition of Bandwidth Measures

Current average (CA) – average energy intensity (Btu/unit) will be applied to the current annual unit production (units/year) to determine current average energy consumption (Btu/yr). Year 2010 was used in all reports.

State of the Art (SOA) – represents deployment of global best plant technologies and practices economically viable today (TRL 8-9)

Practical Minimum (PM) – includes deployment of all known technologies in research and development today globally, encompassing DOE TRL (2-7)

Thermodynamic Minimum (TM) – the theoretical minimum energy needed to produce the end products analyzed

Analysis Methodology

Energy consumption =

Energy Intensity x 2010 production

Btu/lb x lbs/year = Btu/year

Uniformity issues addressed:

- Boundary issues, feedstock excluded
- LHV vs HHV

Results provided a process level and sector-wide

Appendix A1 Master Chemicals Table, by Chemical Name

Table A1a Master Chemicals Table by Chemical Name

NAICS Code	Chemical	2010 Production [million lbs]	Energy Intensity [Btu/lb]				Calculated Onsite Energy [TBtu/year]			
			CA	SOA	PM Lower Limit	TM[a]	CA	SOA	PM Lower Limit	TM
325199	Acetic Acid	4,366	2,552	1,978	1,204	436	11	9	5	2
325199	Acetic Anhydride	1,798	2,785	2,450	578	-2,045	5	4	1	-4
325199	Acetone	3,178	7,717	4,299	2,073	-1,143	25	14	7	-4
325199	Acrylic Acid	2,723	9,009	7,883	4,073	-1,792	25	21	11	-5
325199	Acrylonitrile	2,505	626	-2,021	-3,286	-5,516	2	-5	-8	-14
325188	Aluminum Sulfate	1,906	1,250	1,094	608	-156	2	2	1	0
325311	Ammonia	22,691	5,847	3,138	2,402	414	133	71	55	9
325311	Ammonium Nitrate	15,166	341	39	21	-502	5	1	0	-8
325312	Ammonium Phosphates (Other)	3,053	323	283	66	-240	1	1	0	-1
325311	Ammonium Sulfate	5,729	4,000	3,500	1,849	-706	23	20	11	-4
325192	Aniline	2,348	-980	-1,120	-1,489	-2,093	-2	-3	-3	-5
325110	Benzene	13,274	7,868	5,288	2,812	-69	104	70	37	-1
325192	Bisphenol A	1,610	9,410	8,234	4,885	-491	15	13	8	-1
325110	Butadiene	3,484	7,868	5,288	2,534	-505	27	18	9	-2
325110	Butylenes	2,110	1,677	989	681	-502	4	2	1	-1
325188	Calcium Carbonate	24,282	2,046	1,069	1,043	100	50	26	25	2
325188	Calcium Chloride	2,204	3,882	3,396	981	-2,465	9	7	2	-5
325199	Caprolactam	1,530	13,185	-344	-345	-366	20	-1	-1	-1
325182	Carbon Black	3,415	3,845	1,935	1,861	-803	13	7	6	-3
325120	Carbon Dioxide	17,365	320	280	-1,587	-3,854	6	5	-28	-67
325181	Chlorine	21,465	6,578	5,116	4,882	3,086	141	110	105	66

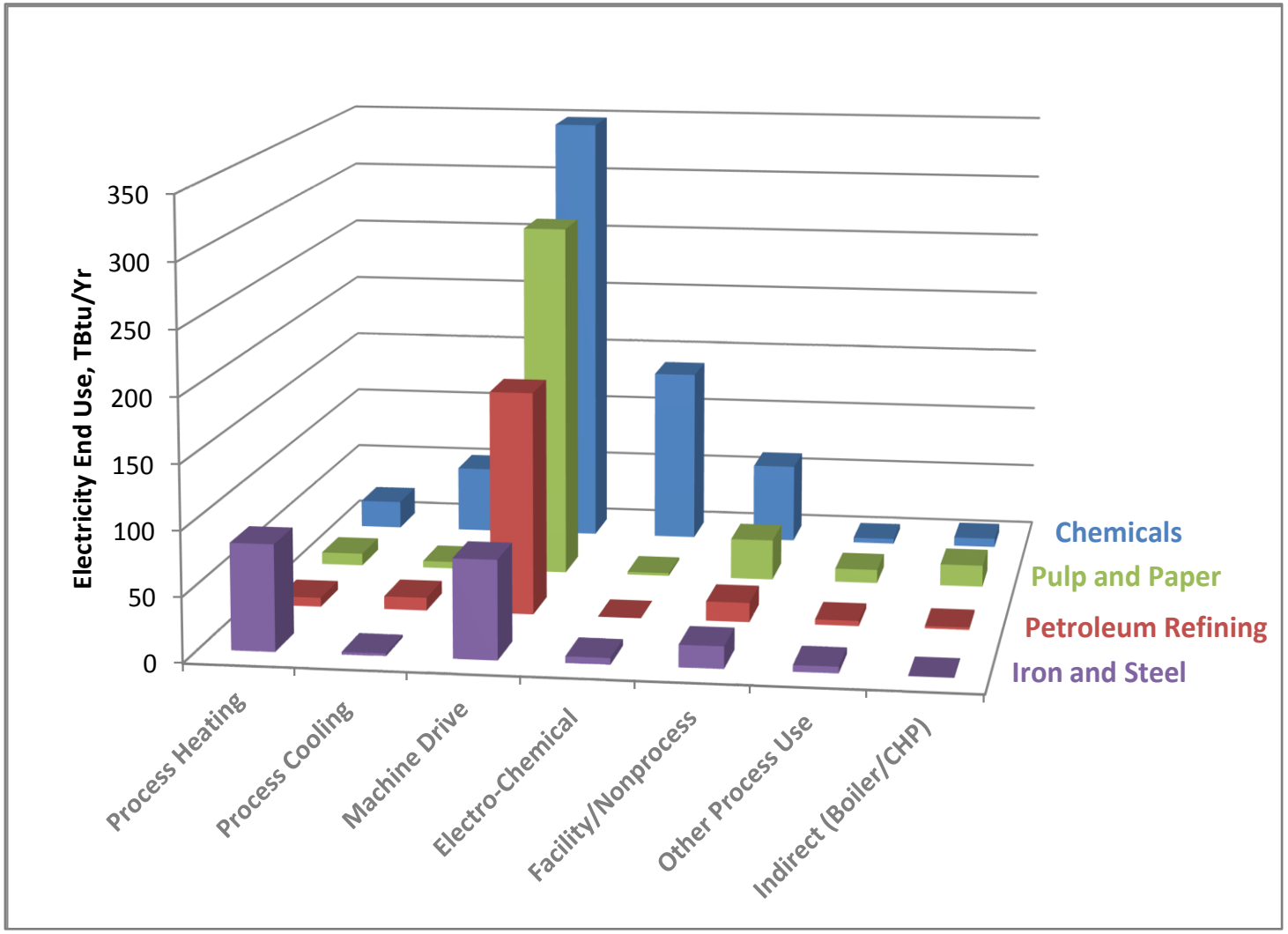
Calculation of Savings %

Savings % is calculated as <u>absolute savings</u> – where Thermodynamic Minimum Consumption is the absolute minimum (versus zero).

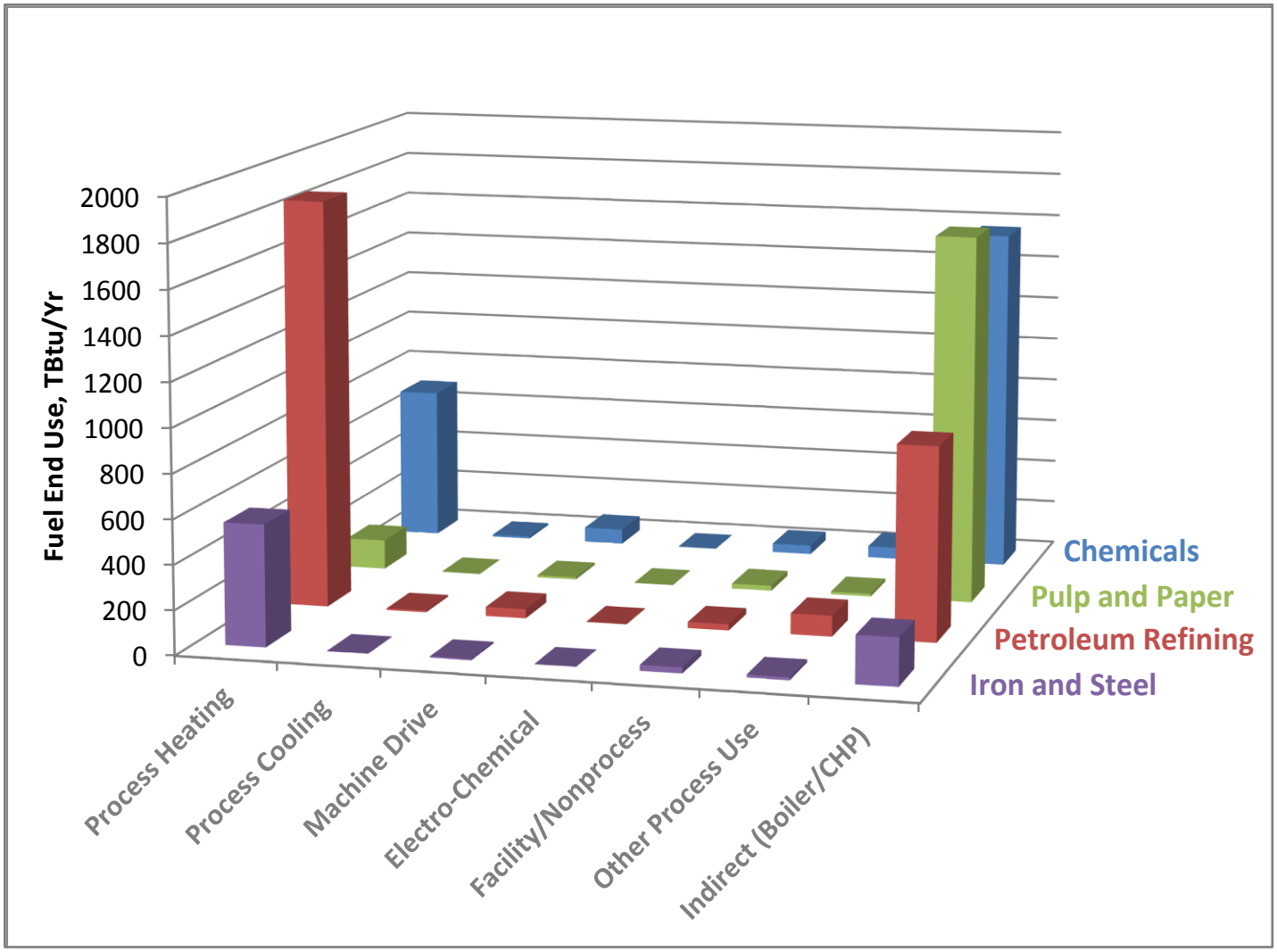
$$SOA\ Savings\ \% = \frac{CA - SOA}{CA - TM} \qquad PM\ Savings\ \% = \frac{CA - PM}{CA - TM}.$$

	Manufacturing Process Area or Subsector	Primary Energy	Current Average Energy	State of the Art Energy	SOA Savings % **	Practical Minimum Energy	PM Savings % **
Chemicals	Other Basic Organics	728	634	414	28%	224-414	28-53%
	Petrochemicals	636	568	466	21%	355-466	21-43%
	Plastics Materials & Resins	620	462	321	18%	126-321	18-42%
	Ethanol	371	307	271	9%	43-271	9-64%
	Alkalies and Chlorine	299	224	182	21%	132-182	21-47%
	Other Basic Inorganics	398	214	*	16%	*	16-47%
	Nitrogenous Fertilizers	198	166	100	40%	69-100	40-59%
	Industrial Gases	238	96	83	6%	8-83	6-37%
	Cyclic Crudes & Intermediates	73	52	43	6%	(-21)-43	6-53%
	Phosphatic Fertilizers	45	35	31	7%	7-31	7-46%
	Carbon Black	16	13	7	41%	6-7	41-43%
	Subtotal	3,622	2,771	1,917	19%	948-1,917	19-50%
	All Other NAICS 325	667	451				
	NAICS 325 Total	**4,290**	**3,222**	**2,458**	**19%**	**1,282-2,458**	**19-50%**
Petroleum Refining	Alkylation	101	90	80	9%	56-80	9-30%
	Atm. Crude Distillation	676	604	522	20%	314-522	20-70%
	Coking & Visbreaking	127	114	101	11%	66-101	11-42%
	Fluid Catalytic Cracking	374	334	289	17%	243-289	17-35%
	Hydrocracking	95	85	74	9%	57-74	9-22%
	Hydrotreating	437	390	333	9%	252-333	9-21%
	Isomerization	49	44	39	11%	25-39	11-43%
	Reforming	312	279	246	17%	188-246	17-46%
	Vacuum Crude Distillation	250	223	192	23%	135-192	23-64%
	Subtotal	2,420	2,163	1,877	14%	1,336-1,877	14-40%
	All Other NAICS 324110	1,135	1,013				
	NAICS 324110 Total	**3,555**	**3,176**	**2,756**	**14%**	**1,963-2,756**	**14-40%**
Pulp and Paper	Paper Drying	617	430	319	37%	254-319	37-59%
	Paper Machine Wet End	308	190	124	65%	124	65%
	Liquor Evaporation	201	178	153	35%	114-153	35-89%
	Pulping Chemical Prep	111	104	81	39%	72-81	39-54%
	Wood Cooking	151	129	103	76%	95-103	76-100%
	Bleaching	80	72	50	53%	50	53%
	Subtotal	1,469	1,103	830	45%	709-830	45-65%
	All Other NAICS 322 and Powerhouse	1,090	1,007				
	NAICS 322 Total	**2,559**	**2,110**	**1,646**	**61%**	**1,499-1,646**	**61-80%**
Iron and Steel	Agglomeration - sintering	9	8	7	17%	6-7	17-72%
	Cokemaking	37	36	31	22%	18-31	22-91%
	Ironmaking, blast furnace	351	337	329	9%	280-329	9-64%
	Steelmaking, BOF	28	20	(-10)	72%	(-12)-(-10)	72-77%
	Steelmaking, EAF	256	101	88	33%	67-88	33-46%
	Casting	28	16	4	74%	3-4	74-79%
	Rolling, hot	282	219	136	38%	106-136	38-52%
	Rolling, cold	143	85	39	55%	31-39	55-63%
	Subtotal	1,133	821	625	39%	501-625	39-63%
	All Other NAICS 331111	226	178				
	NAICS 331111 Total	**1,359**	**999**	**760**	**39%**	**609-760**	**39-63%**

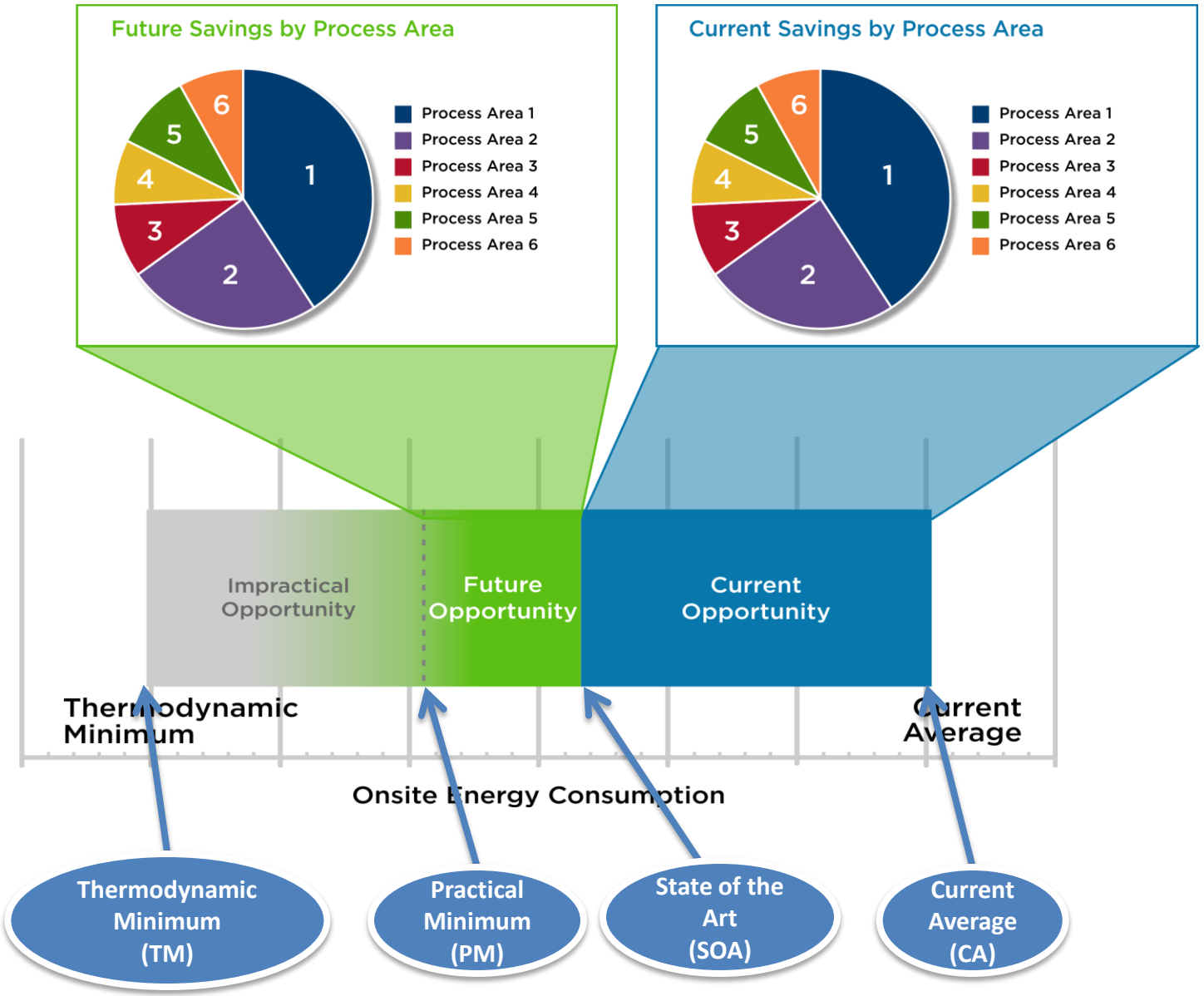
Current Average - Electrical End Us by Sector



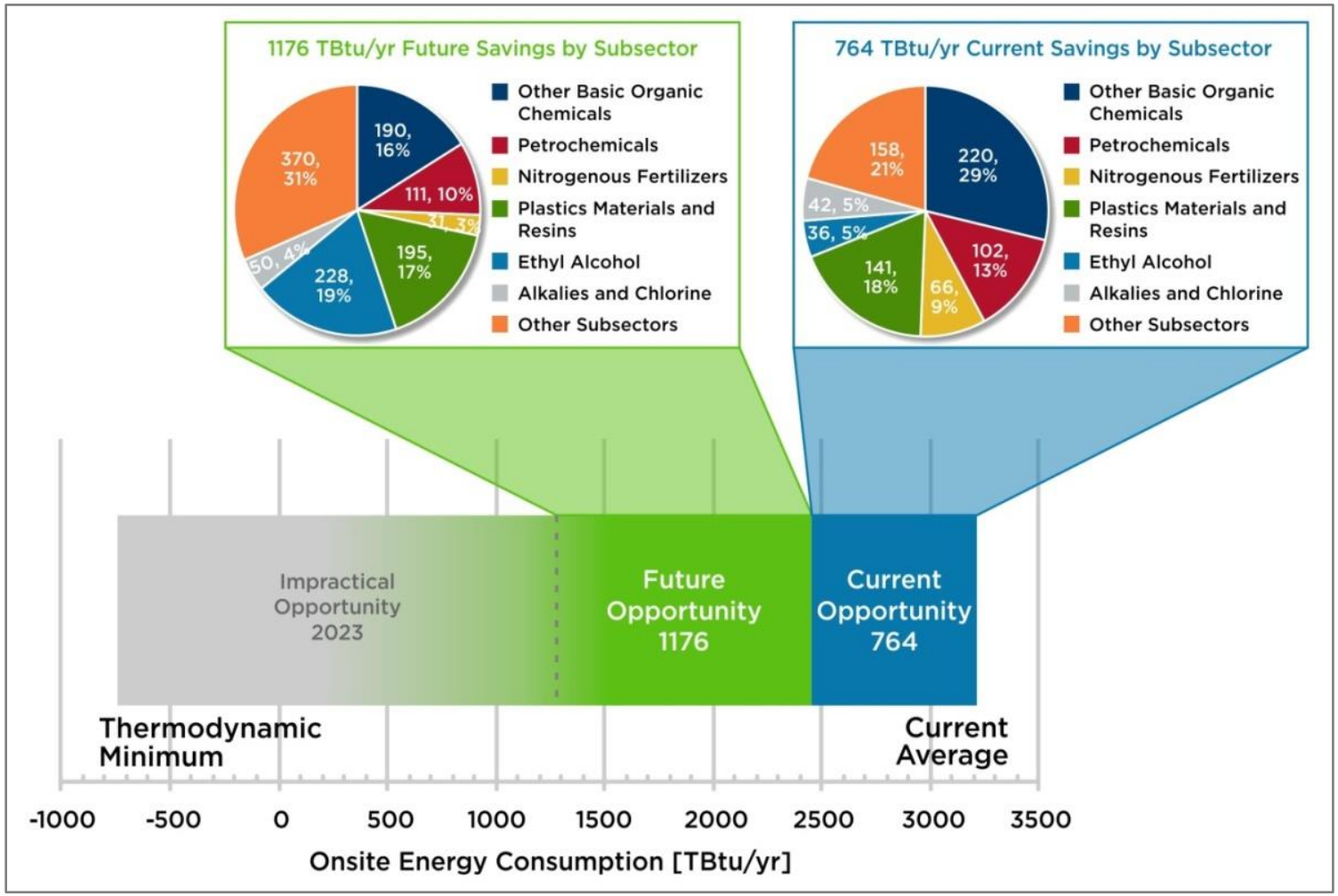
Current Average - Fuel End Use by Sector



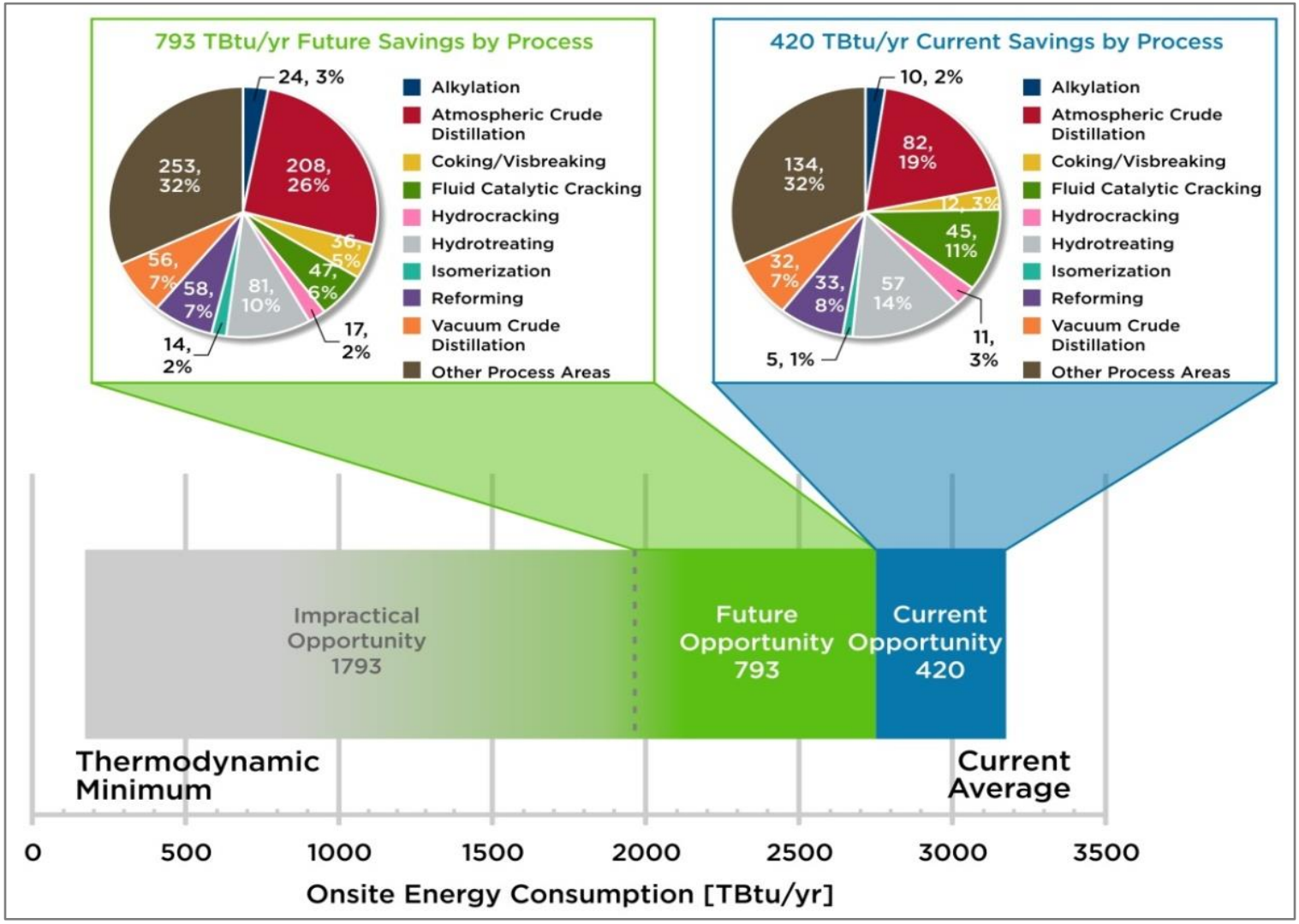
Summary Figure Explanation



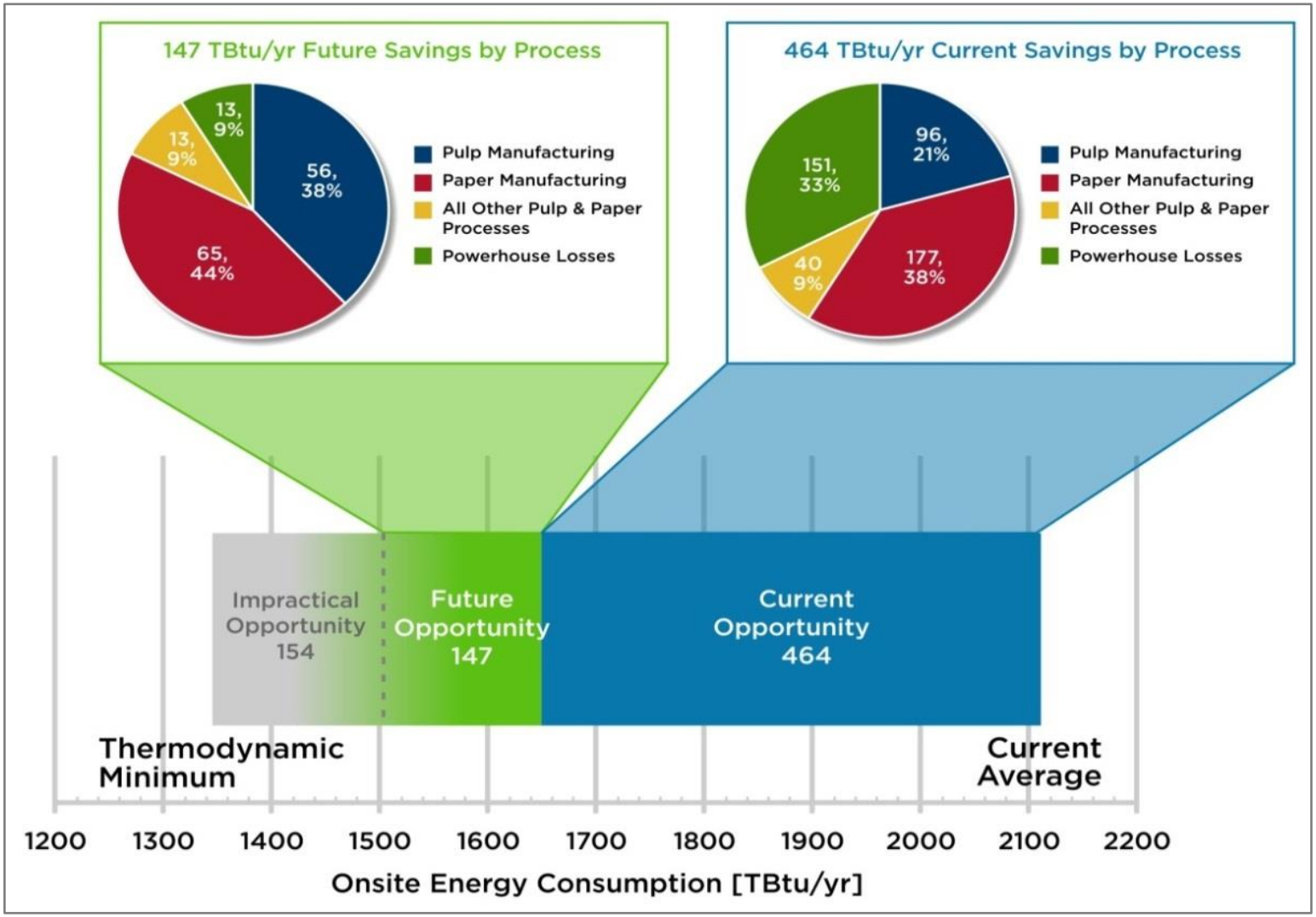
Chemical Bandwidth Summary



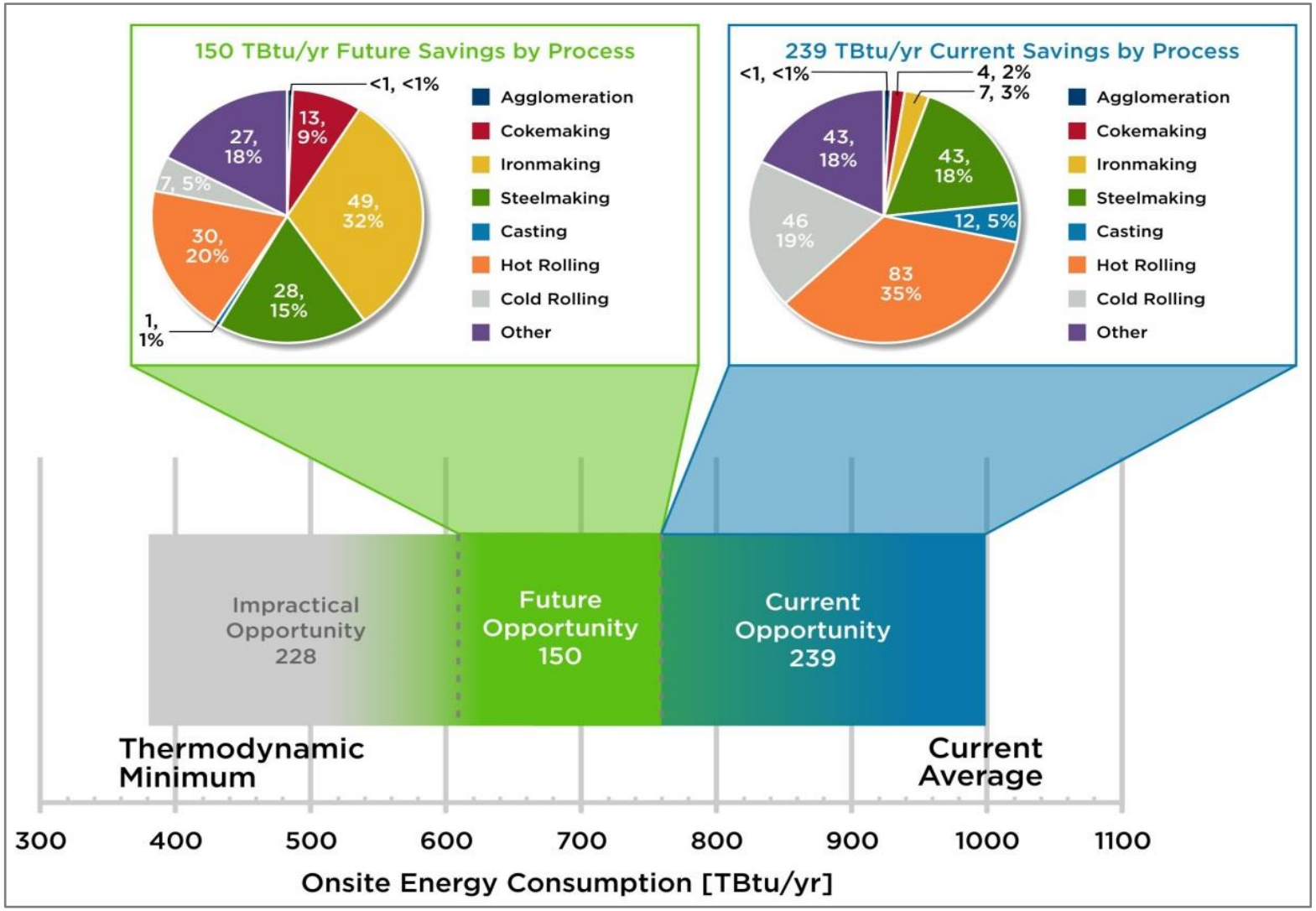
Petroleum Refining Bandwidth Summary



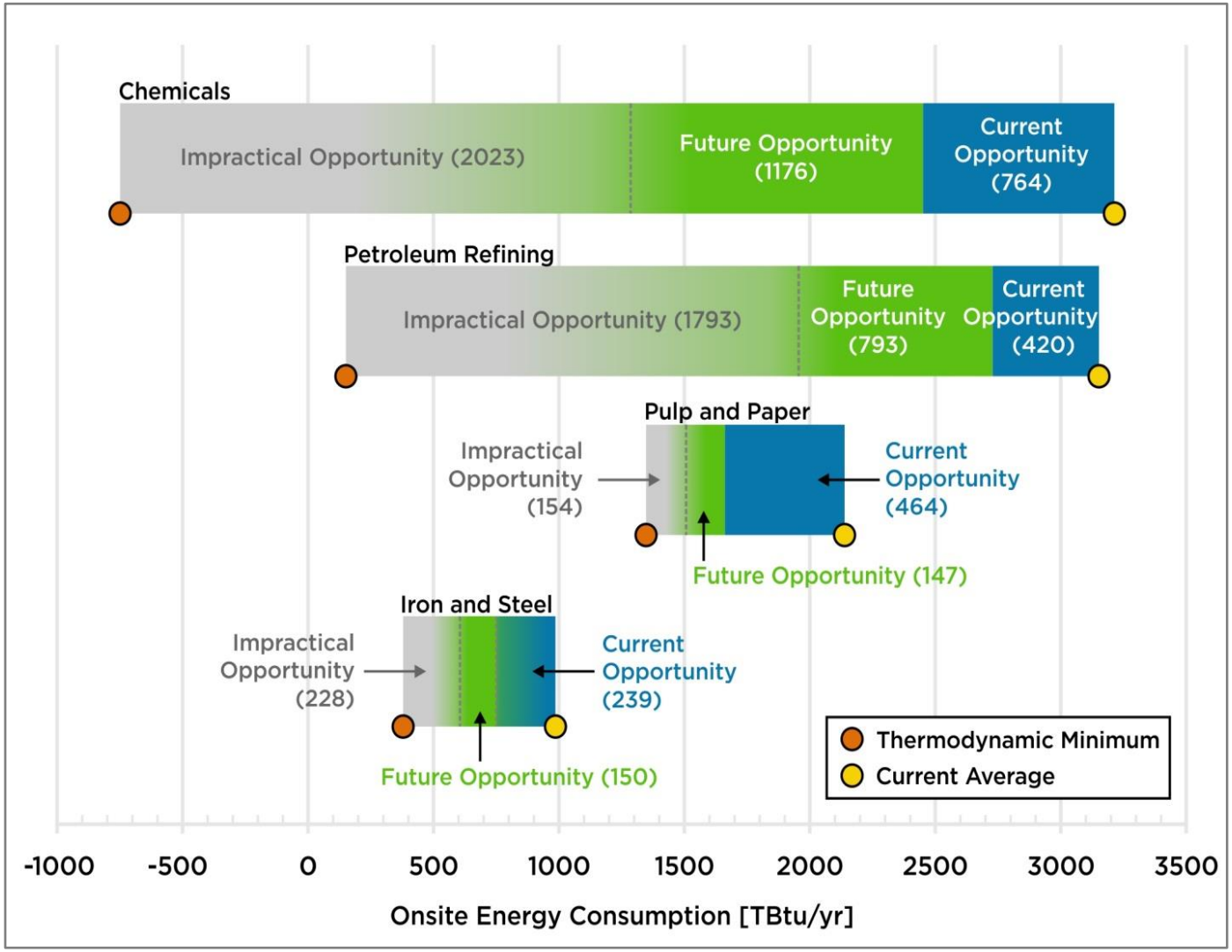
Pulp and Paper Bandwidth Summary



Iron and Steel Bandwidth Summary



Combined Bandwidth Summary



Select R&D Technologies Included

Chemicals

- Advanced Distillation Technologies
- New Membranes (liquid, gas)
- New Catalysts

Petroleum Refining

- Thermal Cracking
- Progressive Distillation
- Dividing-wall Columns
- Improved Heat Integration

Pulp and Paper

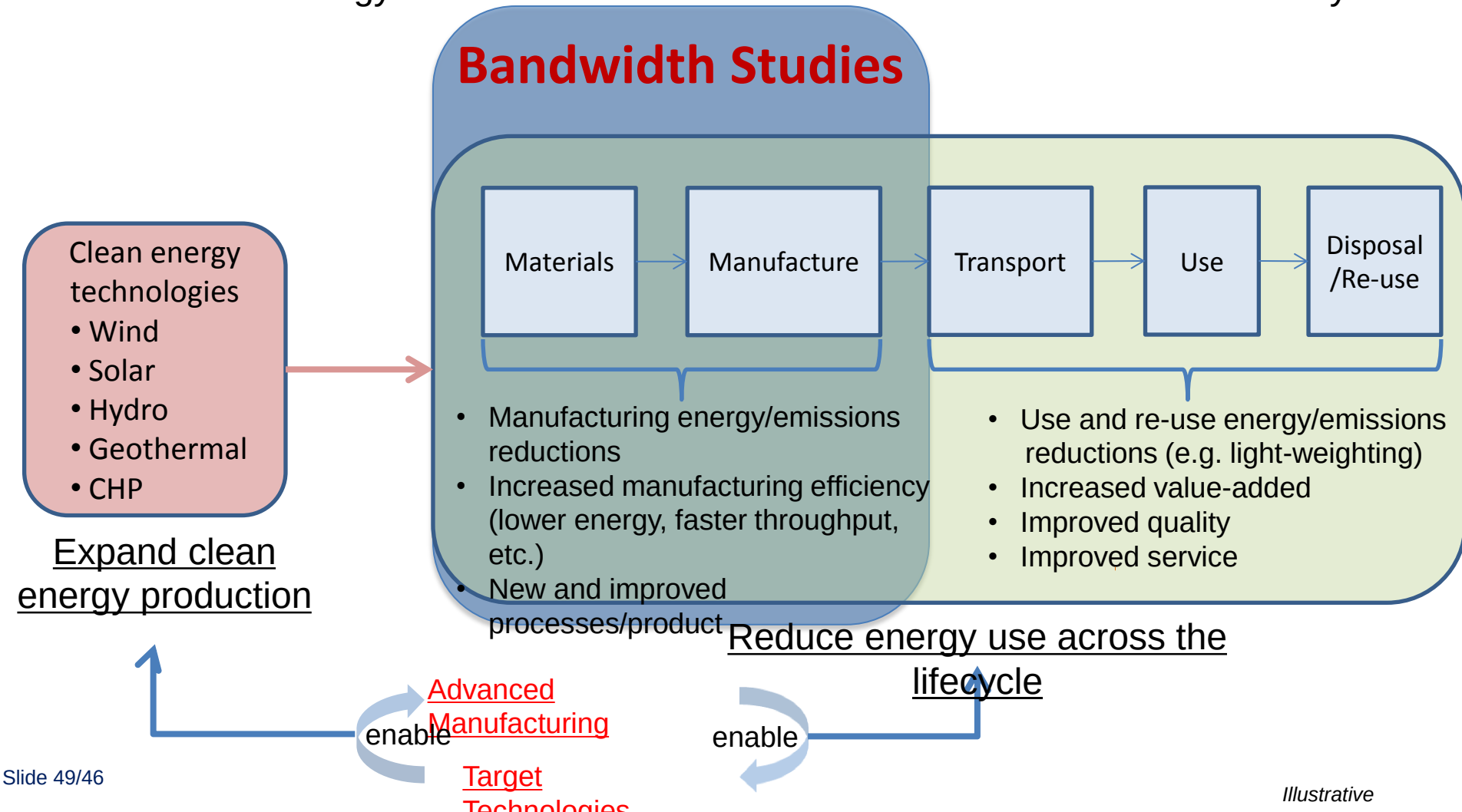
- Black Liquor Gasification
- Directed Green Liquor Utilization
- Condebelt Drying
- New Fibrous Fillers

Iron and Steel

- Heat Recovery
- Slag Recycling
- Endless Rolling
- High Temperature Insulation Materials

Economy-wide lifecycle energy impacts – starts with technology

- Identify opportunities for manufacturing impacts in clean energy production and use.
- Target timely, high-impact, foundational clean energy technologies with the potential to transform energy use and accelerate their introduction into the US economy.



Illustrative

Thank you!

Questions/Discussion