

# **U.S. Manufacturing Energy Use and Loss: The Big Picture**

**Thursday May 22, 2014**

**Industrial Energy Technology Conference**

**Sabine Brueske    Ridah Sabouni**

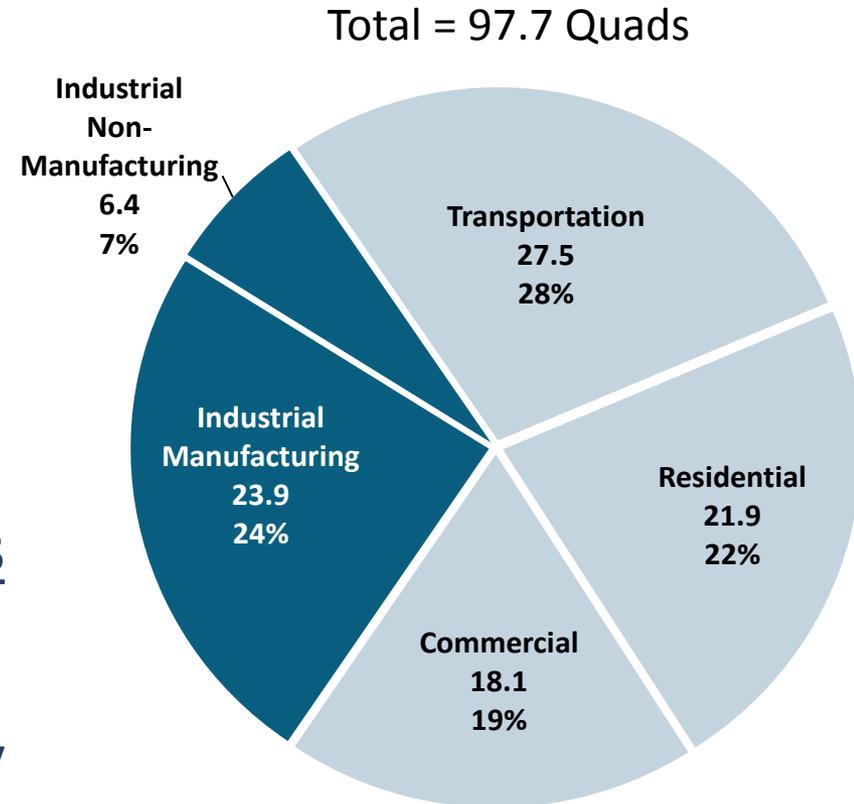


# Outline

- ▶ How Efficient is U.S. Manufacturing?
- ▶ Manufacturing Energy Use and Loss: The Big Picture
- ▶ Applied Energy by Sector
- ▶ Energy & Carbon Footprints
- ▶ Footprint Energy Analysis
  - Data Sources & Methodology
- ▶ Footprint Carbon Analysis
  - Data sources & Methodology
- ▶ Energy Flow (Sankey) Diagrams

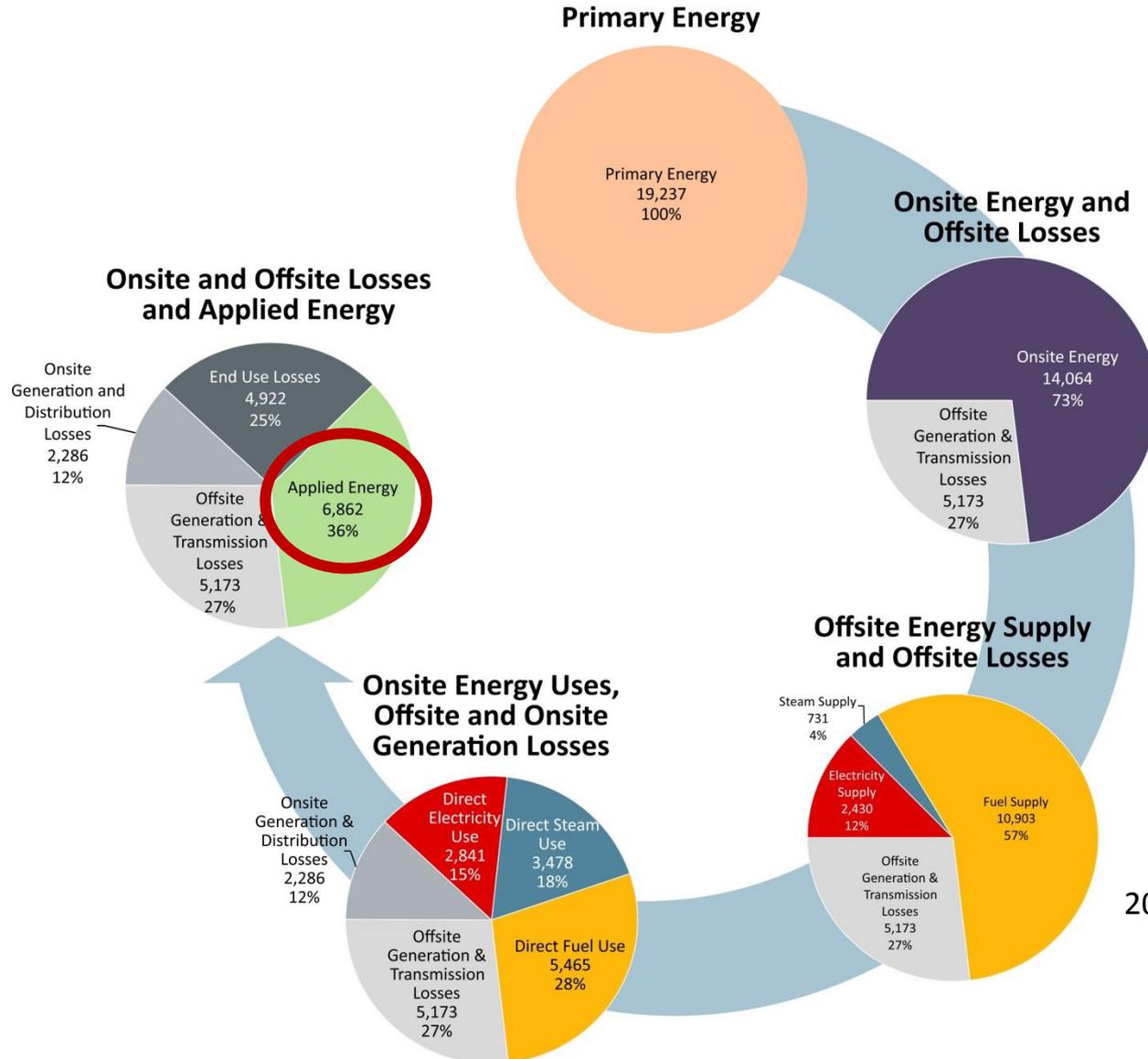
# How Efficient is U.S. Manufacturing?

- Manufacturing  $\approx$  one quarter of nation's energy consumption
- Which manufacturing sectors consume the most energy?
- Which cross-cutting processes consume the most energy?
- Where are the greatest energy losses incurred?



2010 Year Data  
EIA Annual Energy Review 2011  
EIA MECS 2010

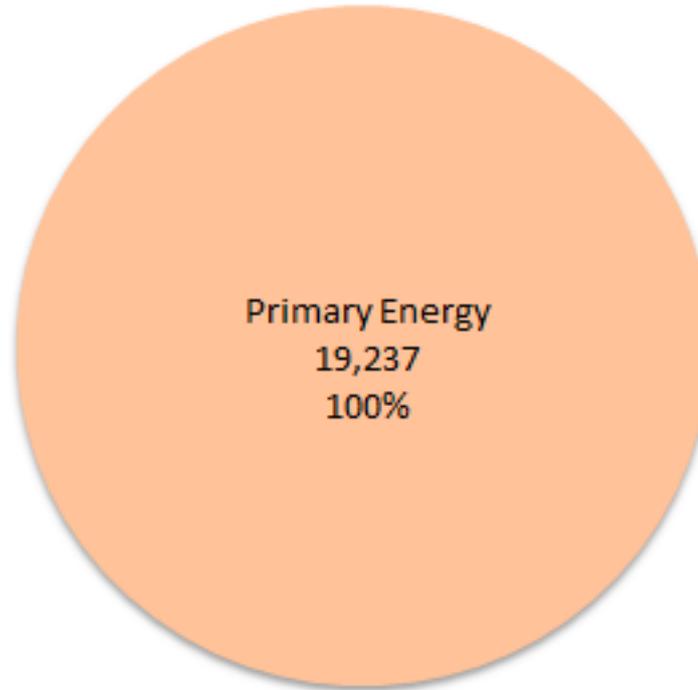
# U.S. Manufacturing Energy and Loss: The Big Picture



2010 Year Data (TBtu)  
EIA MECS 2010

# Primary Energy in the U.S. Manufacturing Sector

**19,237 TBtu**



2010 year data (EIA MECS, EIA AER)

7 TBtu of onsite, renewable electricity generation is included.

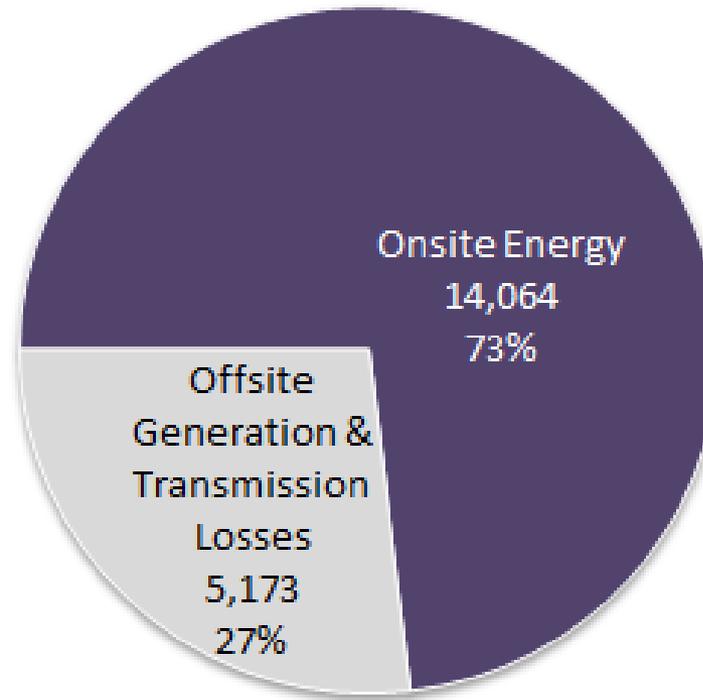
Feedstock energy is not included.

Slide 5/42

# Primary Energy in the U.S. Manufacturing Sector

## Onsite Energy and Offsite Losses

**19,237 TBtu**



2010 year data (EIA MECS, EIA AER)

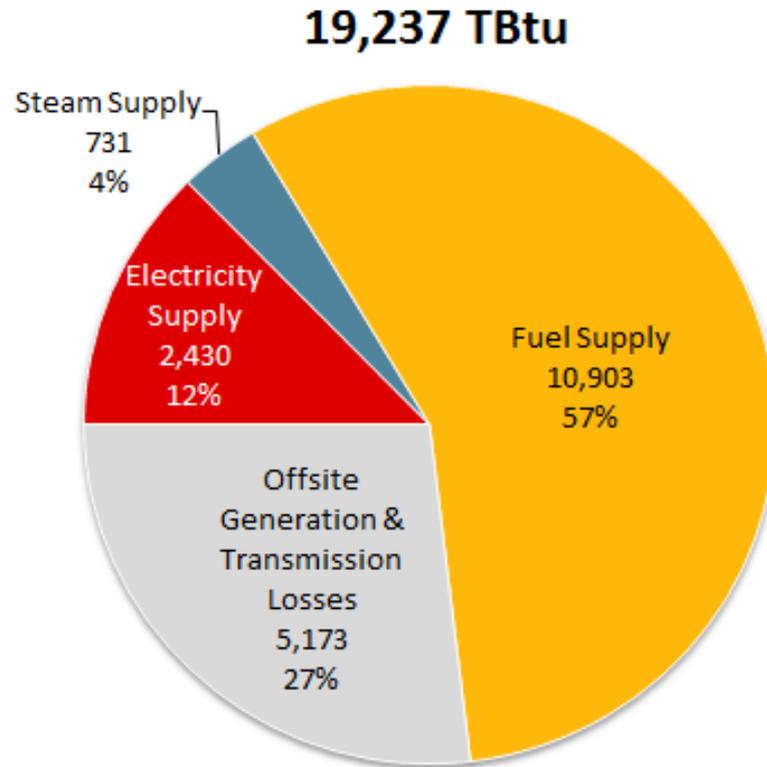
7 TBtu of onsite, renewable electricity generation is included.

Feedstock energy is not included.

Slide 6/42

# Primary Energy in the U.S. Manufacturing Sector

## Offsite Energy Supply and Offsite Losses



2010 year data (EIA MECS, EIA AER)

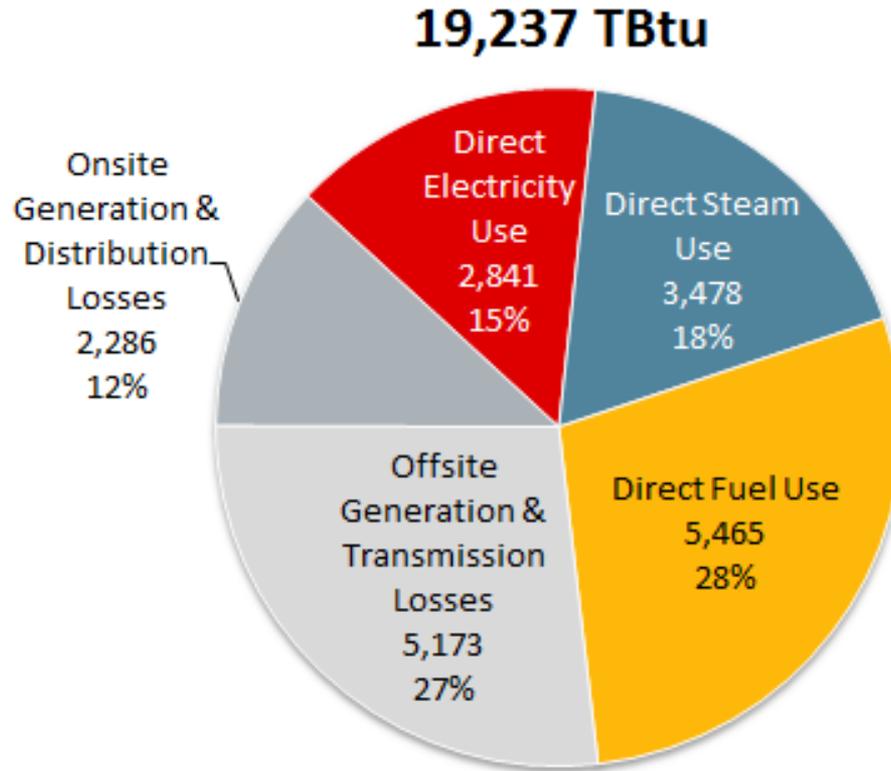
7 TBtu of onsite, renewable electricity generation is included.

Feedstock energy is not included.

Slide 7/42

# Primary Energy in the U.S. Manufacturing Sector

## Onsite Energy Uses, Offsite and Onsite Generation Losses



2010 year data (EIA MECS, EIA

7 TBtu of onsite, renewable electricity generation is included.

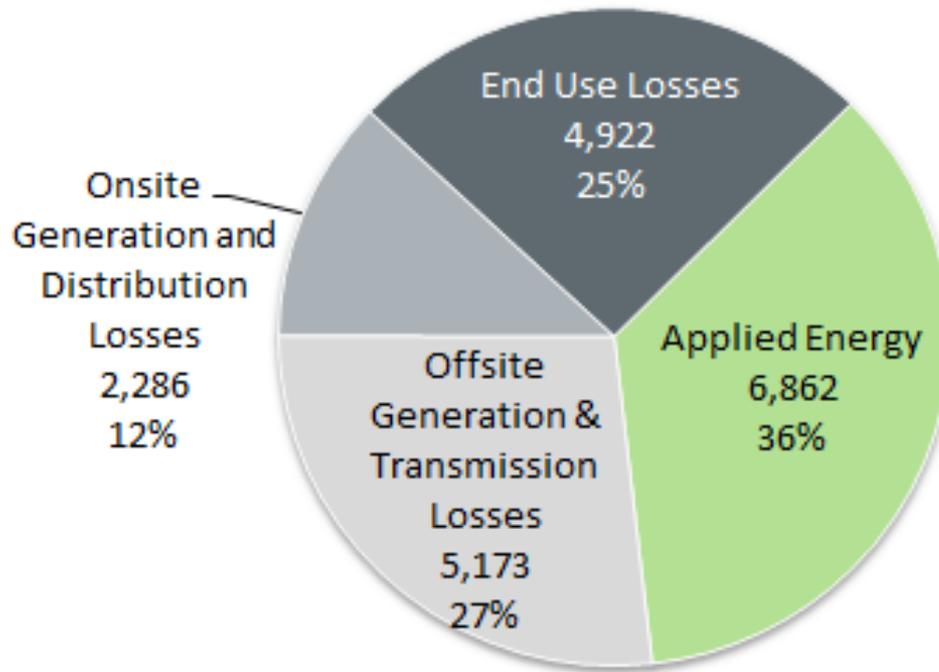
Feedstock energy is not included.

Slide 8/42

# Primary Energy in the U.S. Manufacturing Sector

## Onsite and Offsite Losses and Applied Energy

**19,237 TBtu**



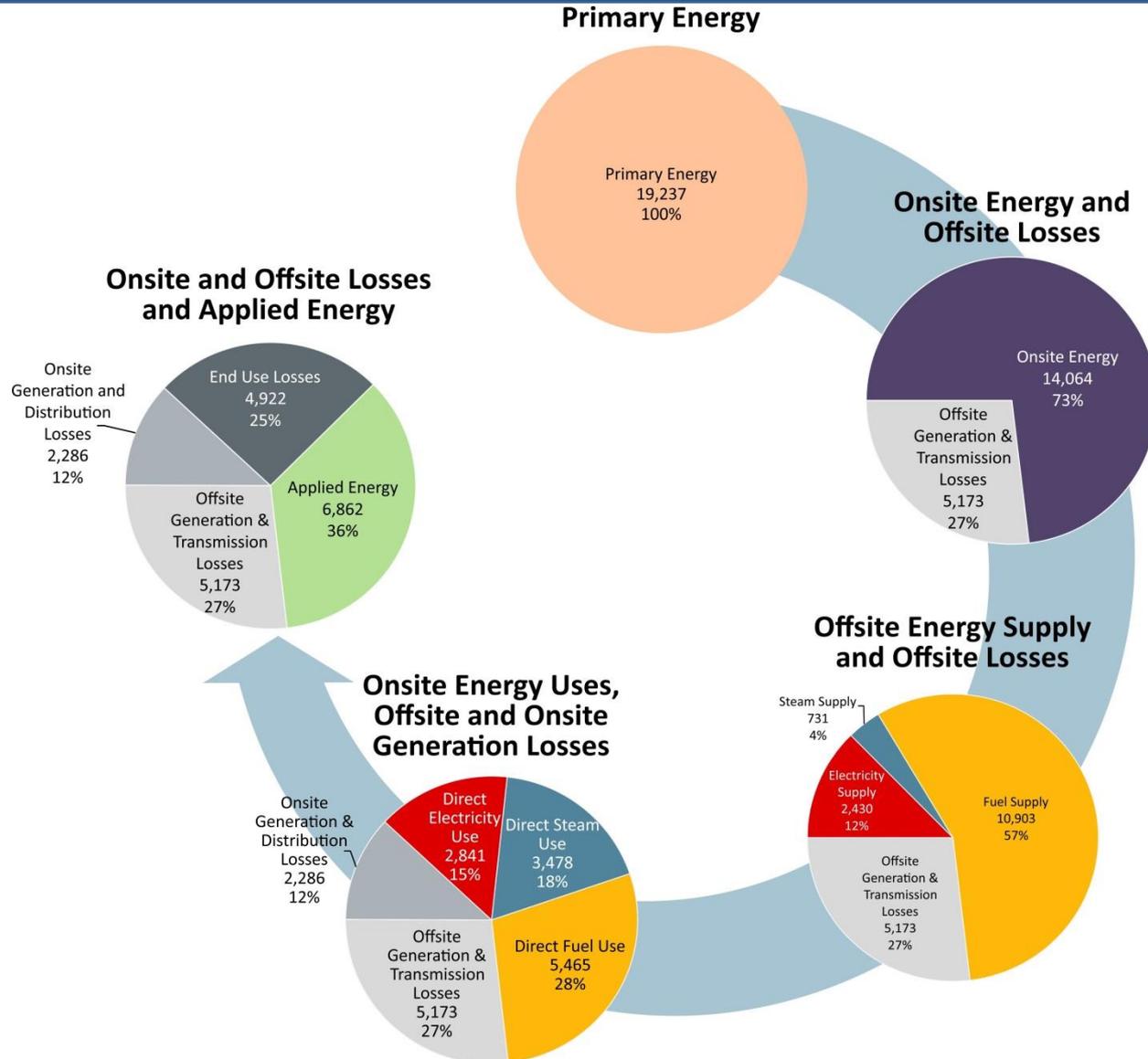
2010 year data (EIA MECS, EIA AER)

7 TBtu of onsite, renewable electricity generation is included.

Feedstock energy is not included.

Slide 9/42

# U.S. Manufacturing Energy and Loss: The Big Picture

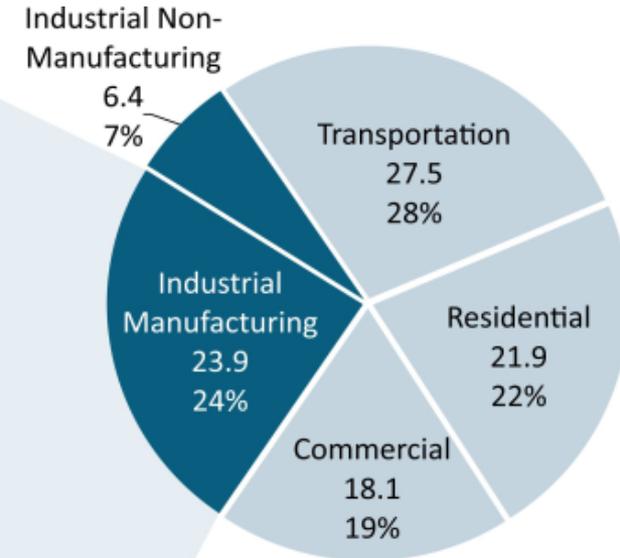


# Manufacturing Sectors with Associated Energy and Carbon Footprints

	Manufacturing Sector	NAICS Code
1	Alumina and Aluminum	3313
2	Cement	327310
3	Chemicals	325
4	Computers, Electronics, Electrical Equipment	334, 335
5	Fabricated Metals	332
6	Food and Beverage	311, 312
7	Forest Products	321, 322
8	Foundries	3315
9	Glass and Glass Products	3272, 327993
10	Iron and Steel	3311, 3312
11	Machinery	333
12	Petroleum Refining	324110
13	Plastics and Rubber Products	326
14	Textiles	313, 314, 315, 316
15	Transportation Equipment	336
16	All Manufacturing	31 - 33

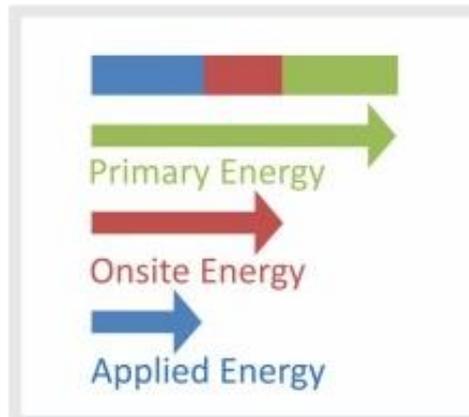
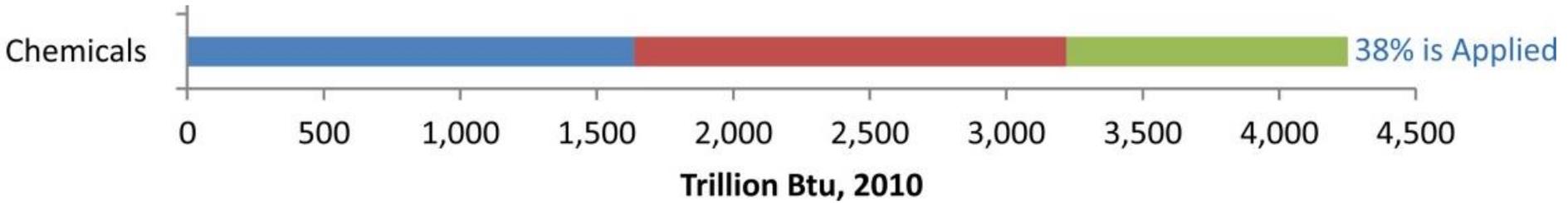
# U.S. Manufacturing Sectors

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%

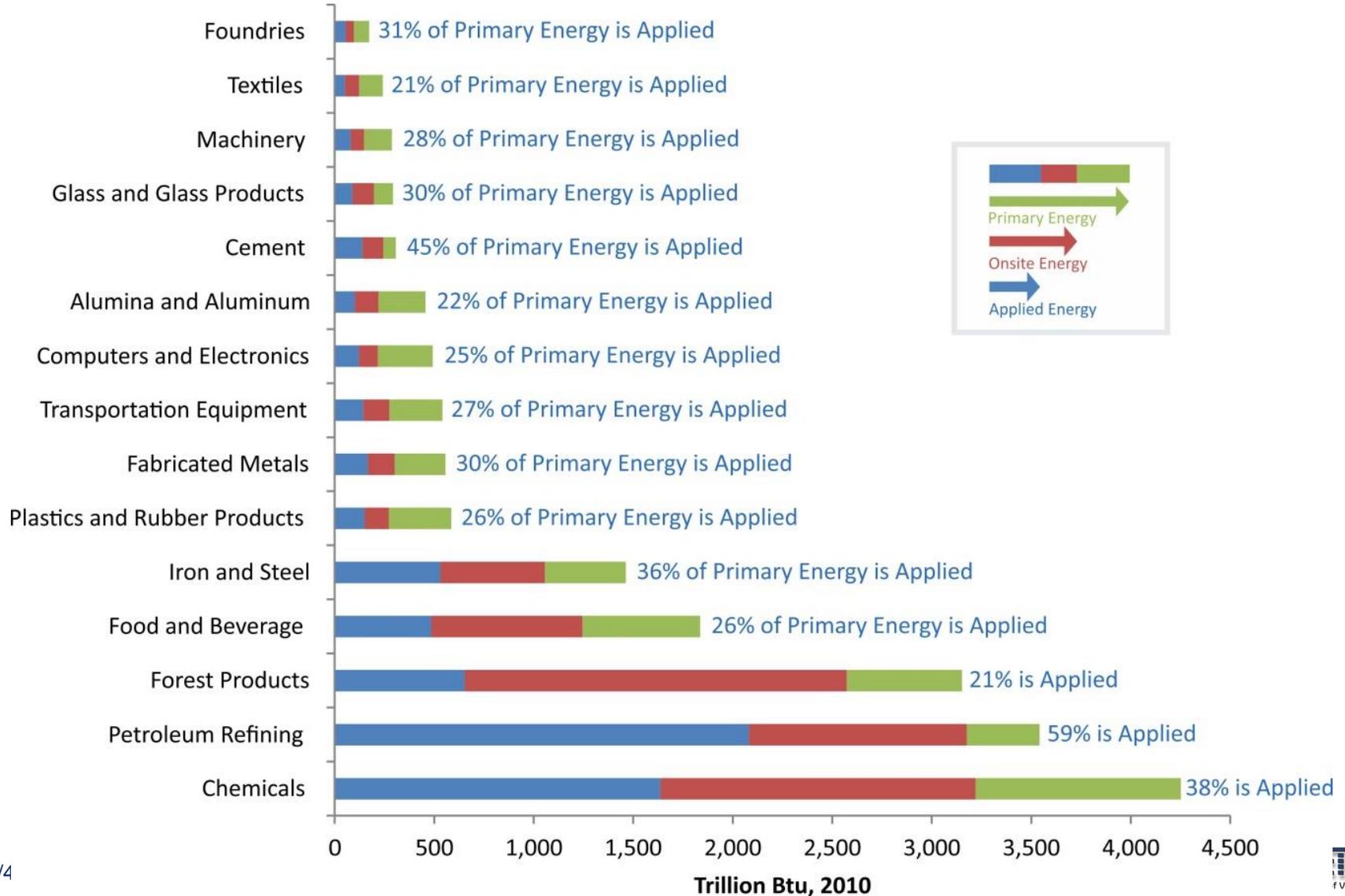


Total U.S. Energy  
Consumption  
= 97.7 Quads

# Applied Energy by Manufacturing Sector

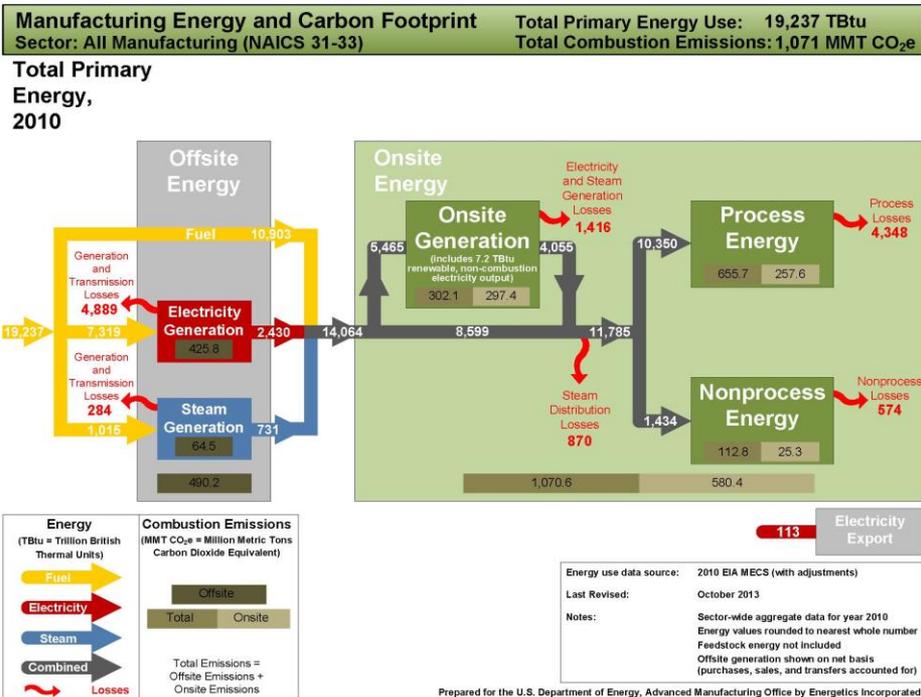


# Applied Energy by Manufacturing Sector

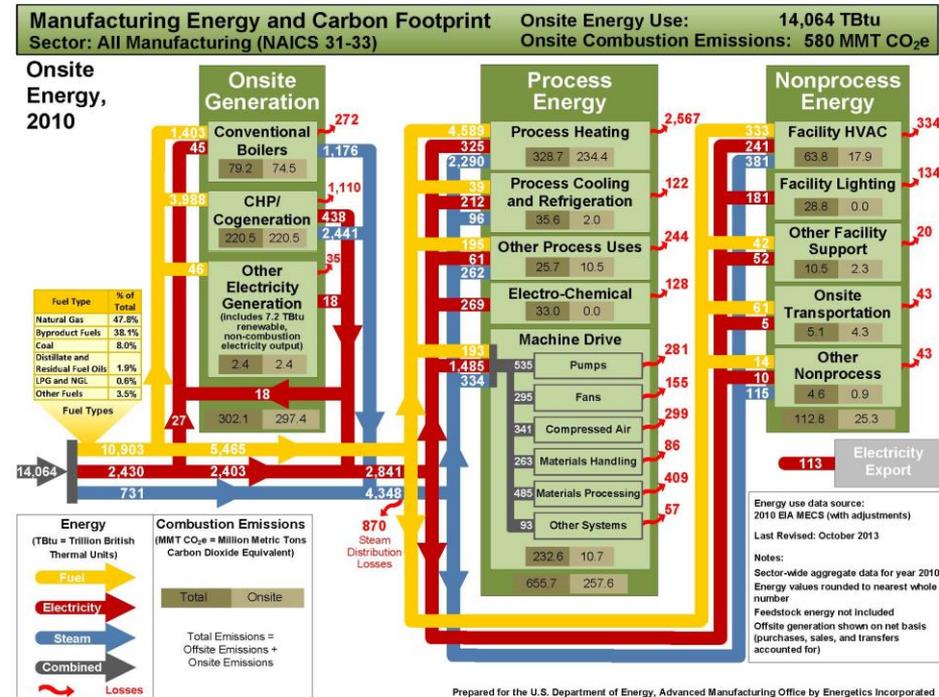


# Manufacturing Energy and Carbon Footprint

## Onsite and offsite energy use and GHG emissions



## Only onsite energy use and GHG emissions



<http://energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2010-mecs>

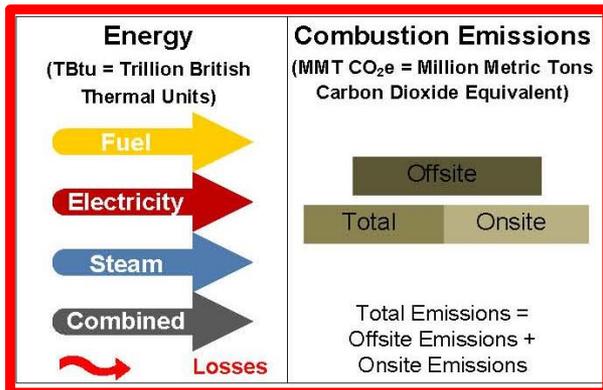
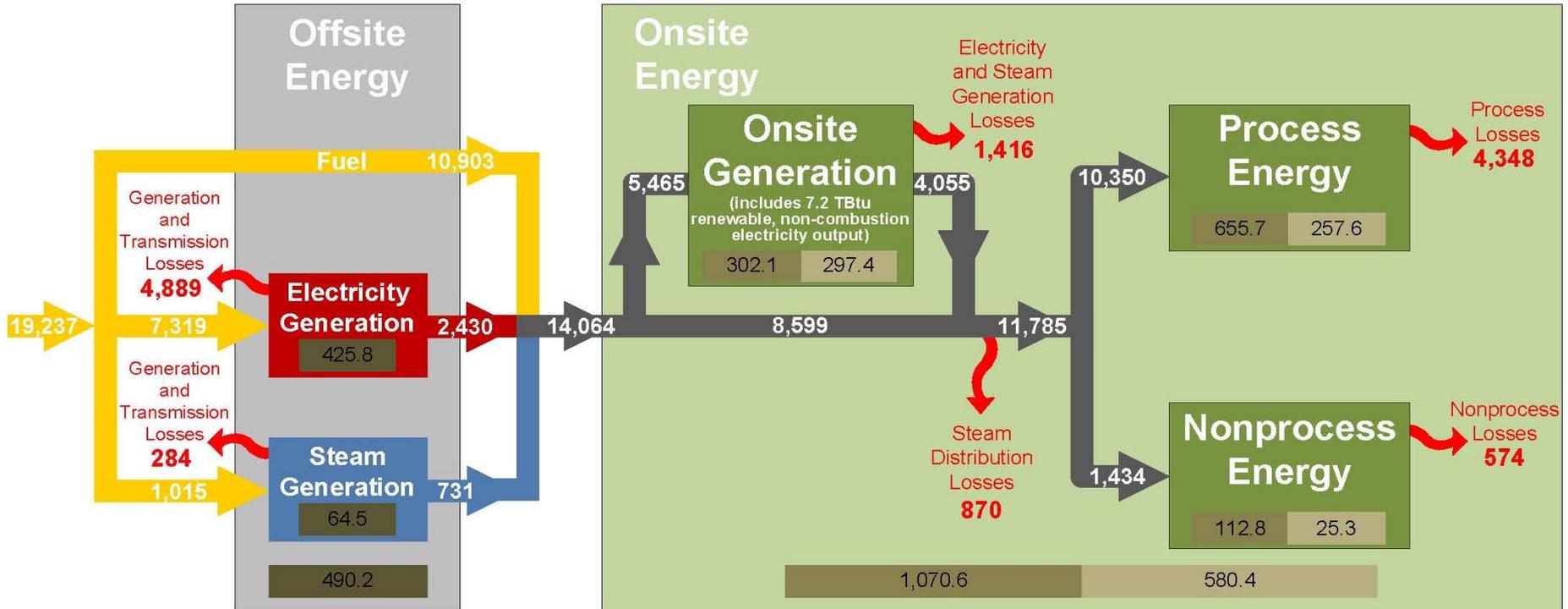
Or, just Google "Energy Footprint"!

# Manufacturing Energy and Carbon Footprint

Sector: All Manufacturing (NAICS 31-33)

Total Primary Energy Use: 19,237 TBtu  
 Total Combustion Emissions: 1,071 MMT CO<sub>2</sub>e

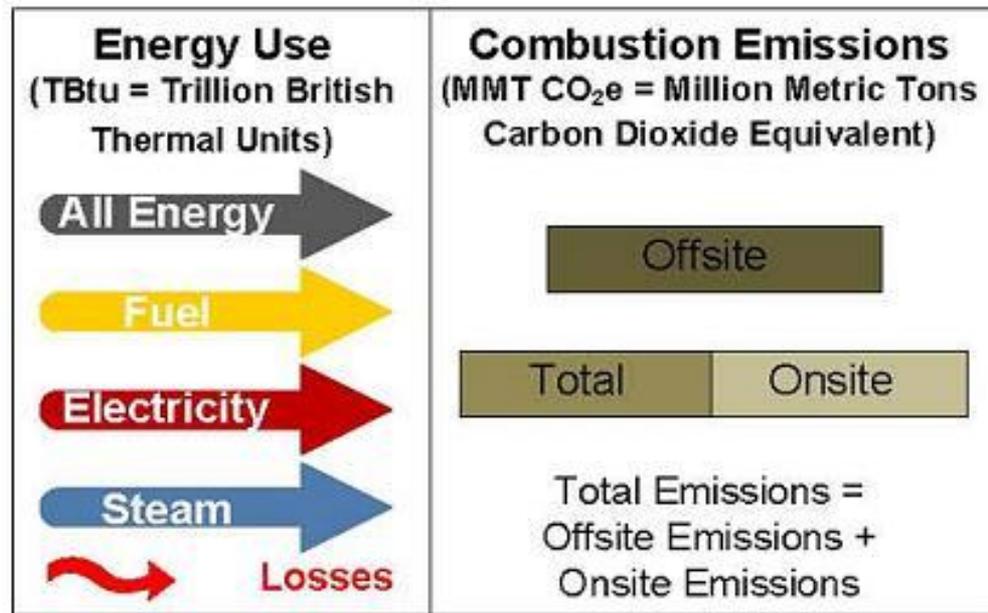
## Total Primary Energy, 2010



113 Electricity Export

Energy use data source: 2010 EIA MECS (with adjustments)  
 Last Revised: October 2013  
 Notes: Sector-wide aggregate data for year 2010  
 Energy values rounded to nearest whole number  
 Feedstock energy not included  
 Offsite generation shown on net basis (purchases, sales, and transfers accounted for)

# Footprint Legend

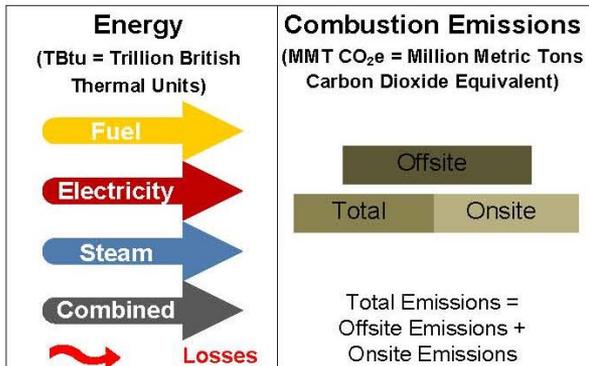
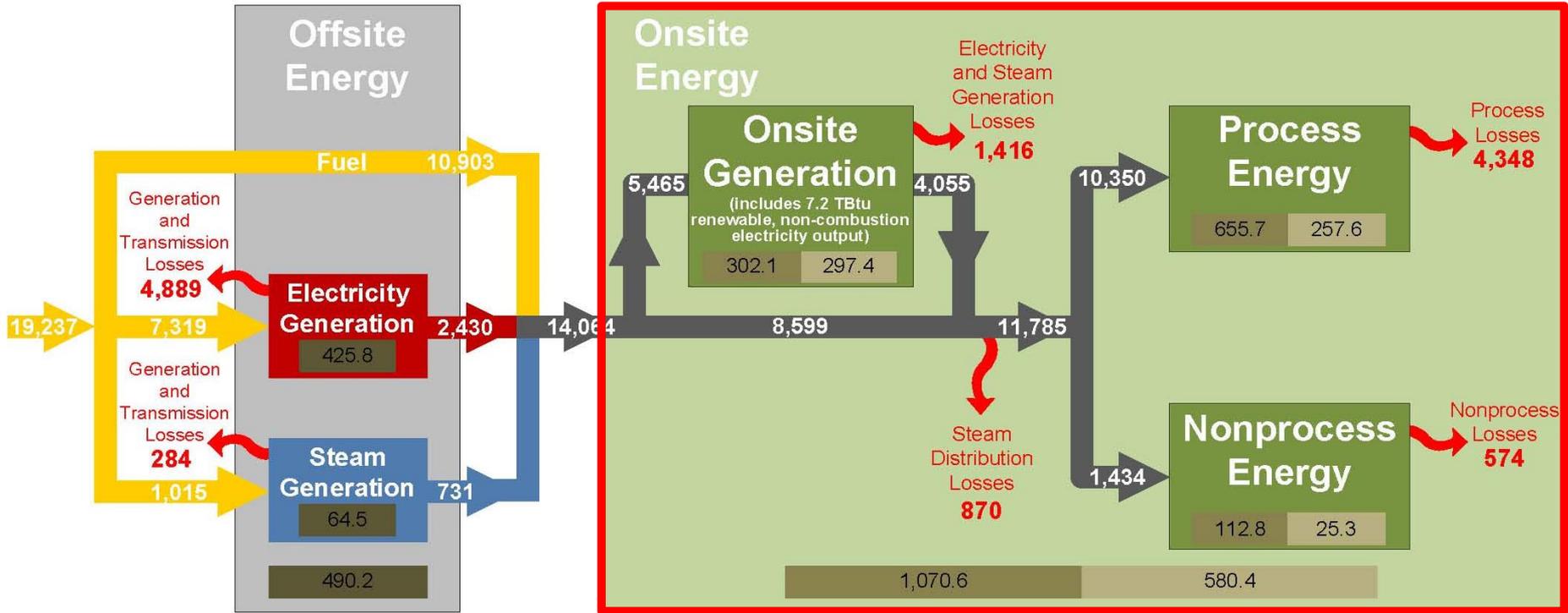


# Manufacturing Energy and Carbon Footprint

Sector: All Manufacturing (NAICS 31-33)

Total Primary Energy Use: 19,237 TBtu  
 Total Combustion Emissions: 1,071 MMT CO<sub>2</sub>e

## Total Primary Energy, 2010



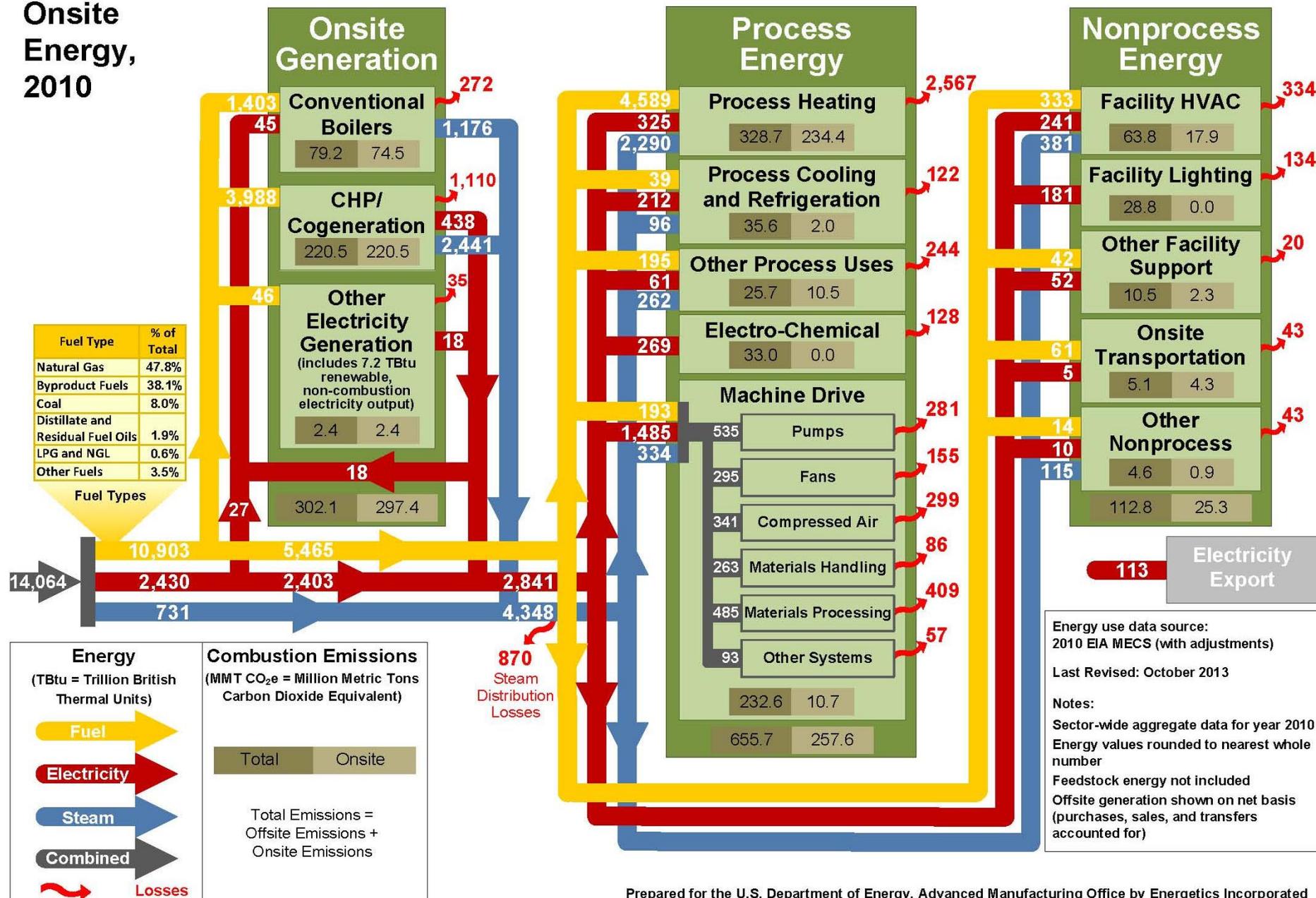
Energy use data source: 2010 EIA MECS (with adjustments)  
 Last Revised: October 2013  
 Notes: Sector-wide aggregate data for year 2010  
 Energy values rounded to nearest whole number  
 Feedstock energy not included  
 Offsite generation shown on net basis (purchases, sales, and transfers accounted for)

# Manufacturing Energy and Carbon Footprint

Sector: All Manufacturing (NAICS 31-33)

Onsite Energy Use: **14,064 TBtu**  
 Onsite Combustion Emissions: **580 MMT CO<sub>2</sub>e**

## Onsite Energy, 2010



Energy use data source:  
 2010 EIA MECS (with adjustments)

Last Revised: October 2013

Notes:  
 Sector-wide aggregate data for year 2010  
 Energy values rounded to nearest whole number  
 Feedstock energy not included  
 Offsite generation shown on net basis (purchases, sales, and transfers accounted for)

# Footprint Energy Analysis

# Energy Consumption Data Source: EIA MECS

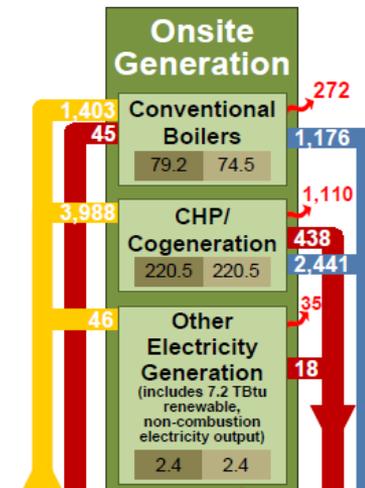
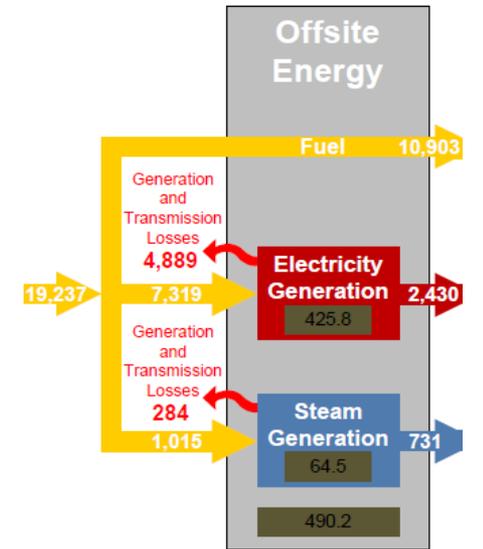


- National sample survey that collects information on the stock of U.S. manufacturing establishment, their energy-related building characteristics, and their energy consumption and expenditures.
  - 250,000 U.S. manufacturing plants
  - Statistical sample of approximately 15,500 establishments are surveyed representing 97% - 98% of U.S. manufacturing payroll and energy consumption
- MECS data released every four years
  - Past footprints (1998, 2002, 2006)
  - Current footprint (2010)

# Offsite and Onsite Energy Generation Losses

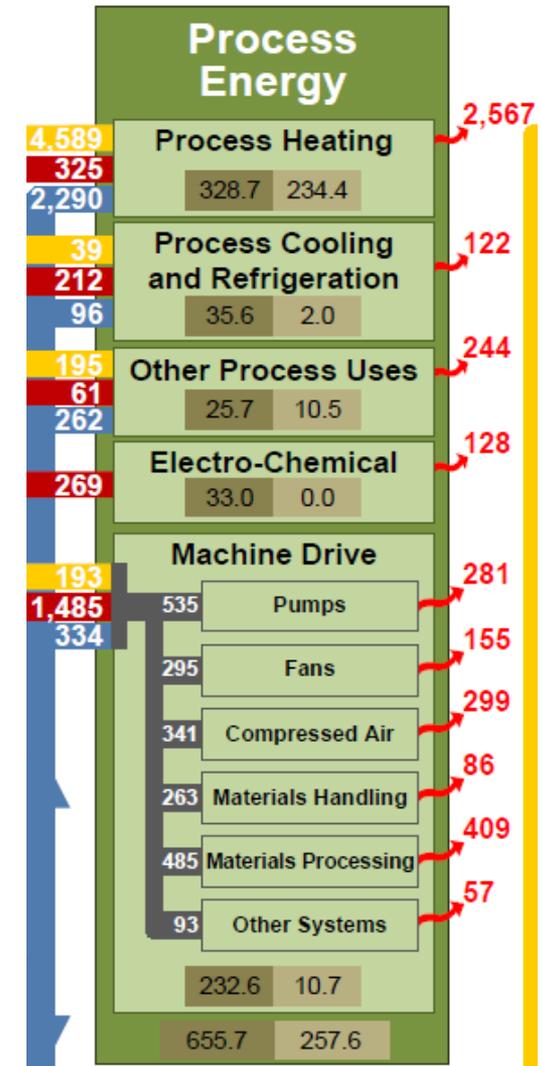
	Energy System	Percent Energy Lost
<b>Offsite Generation</b>	Offsite electricity generation and transmission (grid)	66.8%
	Offsite steam generation	20%
	Offsite steam transmission	10%
<b>Onsite Generation</b>	Onsite steam generation (conventional boiler)	18% to 22% <i>(varies, sector dependent)</i>
	Onsite CHP/cogeneration	18% to 29% <i>(varies, sector dependent)</i>
	Onsite steam distribution	20%

All loss factors are sourced, referenced and peer reviewed. In some cases, an analysis was performed in order to more accurately derive sector-specific loss factors based on several published sources.



# Process Energy Losses

Energy System	Percent Energy Lost
Process heating	18% to 72% <i>(varies, sector dependent)</i>
Process cooling and refrigeration	35%
Electro-chemical	35% to 60% <i>(varies, sector dependent)</i>
Other processes	Fuel: 70% Electricity: 5% Steam: 40%
Machine drive (shaft energy)	Fuel: 63% Electricity: 6% to 8% <i>(varies, sector dependent)</i> Steam: 60% (steam)
Machine driven systems	Pumps: 40% Fans: 40% Compressed air: 85% Materials handling: 15% Materials processing: 80% Other systems: 52%

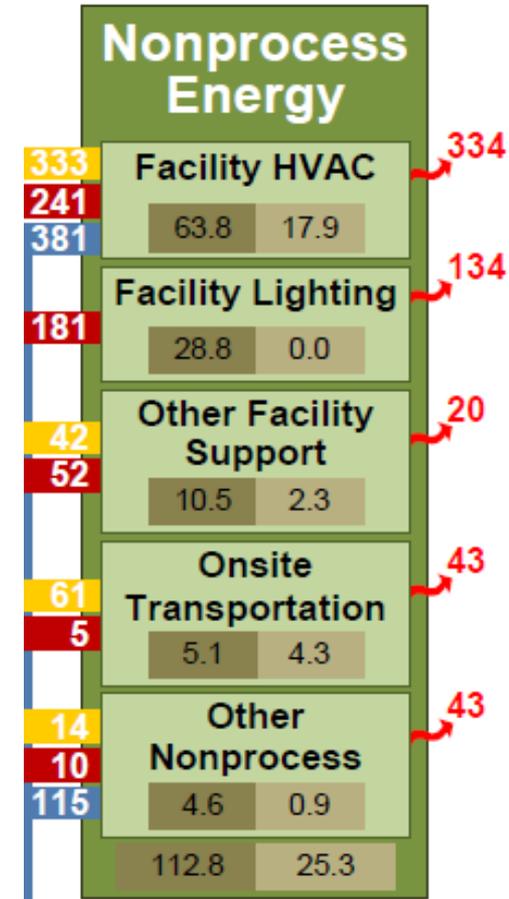


All loss factors are sourced, referenced and peer reviewed. . In some cases, an analysis was performed in order to more accurately derive sector-specific loss factors based on several published sources.

# Nonprocess Energy Losses

Energy System	Percent Energy Lost
Facility HVAC	35%
Facility lighting	74.1% to 74.6% (varies, sector dependent)
Other facility support	Fuel: 35% Electricity: 10%
Onsite transportation	65%
Other nonprocesses	Fuel: 35% Electricity: 33% Steam: 30%

All loss factors are sourced, referenced and peer reviewed. . In some cases, an analysis was performed in order to more accurately derive sector-specific loss factors based on several published sources.

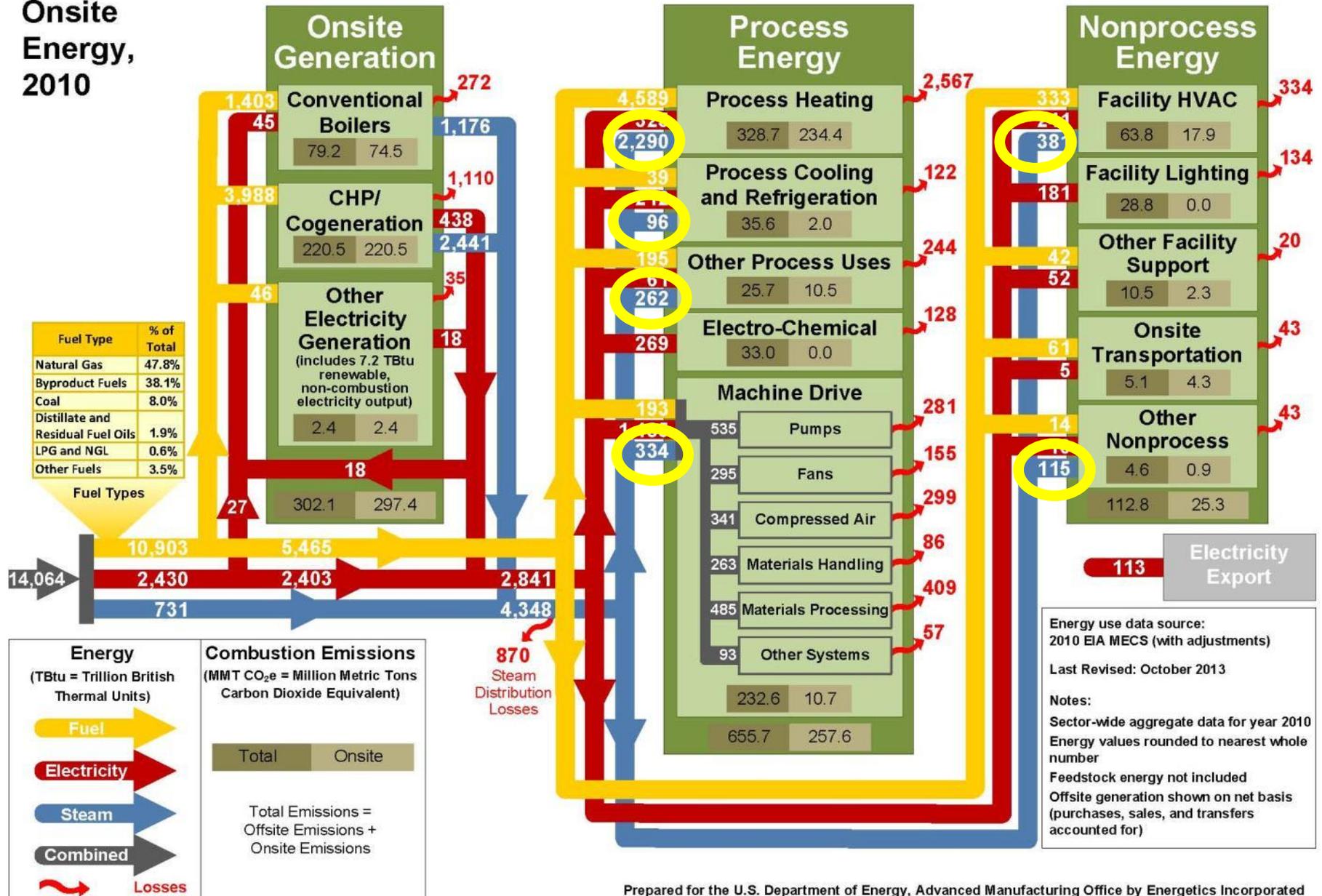


# Manufacturing Energy and Carbon Footprint

## Sector: All Manufacturing (NAICS 31-33)

Onsite Energy Use: **14,064 TBtu**  
 Onsite Combustion Emissions: **580 MMT CO<sub>2</sub>e**

### Onsite Energy, 2010



# Steam End Use Distribution

Sector	Steam end use allocation					
	Process heating	Machine drive	Process cooling/ refrigeration	Other process uses	Facility HVAC	Other nonprocess uses
Alumina and Aluminum	31%	13%	0%	27%	21%	7%
Cement	45%	6%	1%	16%	27%	6%
Chemicals	67%	10%	3%	8%	9%	4%
Computers, Electronics and Electrical Equipment	16%	0%	1%	7%	73%	4%
Fabricated Metals	35%	1%	1%	16%	46%	2%
Food and Beverage	69%	4%	5%	8%	10%	3%
Forest Products	70%	9%	2%	5%	9%	4%
Foundries	13%	15%	0%	9%	60%	3%
Glass and Glass Products	5%	5%	0%	22%	63%	5%
Iron and Steel	46%	7%	0%	8%	38%	1%
Machinery	24%	29%	1%	7%	37%	1%
Petroleum Refining	66%	16%	2%	10%	4%	2%
Plastics and Rubber Products	71%	1%	0%	7%	18%	3%
Textiles	63%	2%	2%	10%	21%	2%
Transportation Equipment	27%	2%	7%	9%	53%	2%
All Manufacturing	66%	11%	2%	7%	11%	3%

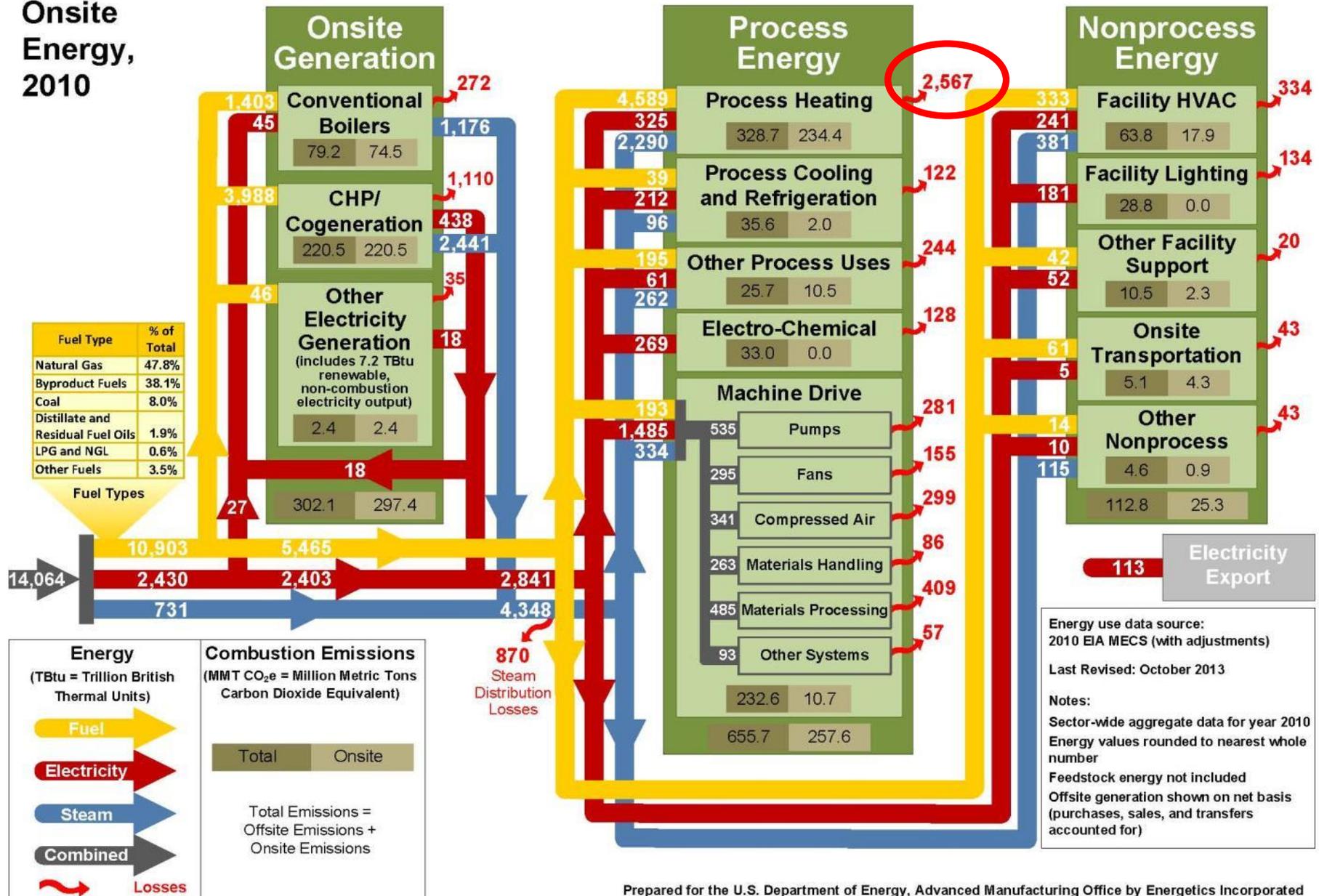
Source: Steam Working Group, 2012

# Manufacturing Energy and Carbon Footprint

## Sector: All Manufacturing (NAICS 31-33)

Onsite Energy Use: **14,064 TBtu**  
 Onsite Combustion Emissions: **580 MMT CO<sub>2</sub>e**

### Onsite Energy, 2010



## Process Heating Losses

Sector	Percent of Process Heating Energy Lost
Chemicals; Plastics and Rubber Products	23%
Food and Beverage; Textiles	56%
Forest Products	72%
Petroleum Refining	18%
Iron and Steel; Alumina and Aluminum; Foundries	46%
Glass and Glass Products	55%
Cement	40%
All Manufacturing Average  (also used for the following sectors where there is insufficient data: Computers, Electronics, and Electrical Equipment; Fabricated Metals; Machinery; and Transportation Equipment)	36%

Source: Process Heating Working Group, 2012

# Footprint Carbon Analysis

# Carbon Analysis Methodology

- The methodology used to calculate GHG emissions is based on EPA's Mandatory Greenhouse Gas Reporting Rule
- GHG emissions are reported as CO<sub>2</sub>-equivalent and consist of combustion-related emissions of:
  - carbon dioxide (CO<sub>2</sub>)
  - methane (CH<sub>4</sub>)
  - nitrous oxide (N<sub>2</sub>O)
- Carbon emissions are calculated for each manufacturing sector by multiplying total energy consumption in each sector by the respective GHG emission factor for each fuel type



# Fuel GHG combustion emission factors (kg CO<sub>2</sub>e per million Btu)

Fuel Type	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	Total GHG	Source
Agricultural Byproducts	118.17*	0.800	1.252	2.05	[a]
Coal (Industrial Sector)	93.91	0.275	0.477	94.66	[a]
Distillate Fuel Oil No. 2	73.96	0.075	0.179	74.21	[a]
Kerosene	75.20	0.075	0.179	75.45	[a]
LPG (energy use)	62.98	0.075	0.179	63.23	[a]
Natural Gas (pipeline weighted average)	53.02	0.025	0.030	53.07	[a]
Electricity Generation (offsite)	173.85	0.086	0.770	174.70	[c]
Steam Generation (offsite)	88.18	0.205	0.179	88.56	[d], [a]
Petroleum Coke	102.41	0.075	0.179	102.66	[a]
Pulping Liquor/Black Liquor	94.40*	0.063	0.596	0.66	[a]
Residual Fuel Oil No. 6	75.10	0.075	0.179	75.35	[a]
Still Gas	66.72	0.075	0.179	66.97	[a]
Waste Oils, Tars, and Waste Materials	74.49	0.075	0.179	74.74	[b], [a]
Wood and Wood Residuals	93.80*	0.800	1.252	2.05	[a]

\* Only CH<sub>4</sub> and N<sub>2</sub>O emissions are considered from biomass fuels; CO<sub>2</sub> emissions from biomass fuel combustion (also known as biogenic CO<sub>2</sub>) are not included in the total GHG emission factor because the uptake of CO<sub>2</sub> during biomass growth results in zero net emissions over time.

#### Sources:

[a] Federal Register/Vol. 74, No. 209/Friday, October 30, 2009/Part 98, Tables C-1, C-2, and A-1 (EPA Mandatory Reporting Rules)

[b] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2012, Annex 2. Tables A-32, A-33, A-35, data for 2010.

[www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Annex-2-Emissions-from-Fossil-Fuel-Combustion.pdf](http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Annex-2-Emissions-from-Fossil-Fuel-Combustion.pdf)

[c] EPA Emissions & Generation Resource Integrated Database (eGRID). eGRID2012 Version 1.0 [www.epa.gov/cleanenergy/egrid](http://www.epa.gov/cleanenergy/egrid) (adjusted to reflect losses in transmission)

[d] EIA - Voluntary Reporting of Greenhouse Gases, 2010 Appendix N, "Emission Factors for Steam and Chilled/Hot Water" p 171:

[http://www.eia.gov/survey/form/eia\\_1605/pdf/Appendix%20N\\_20110128.pdf](http://www.eia.gov/survey/form/eia_1605/pdf/Appendix%20N_20110128.pdf)

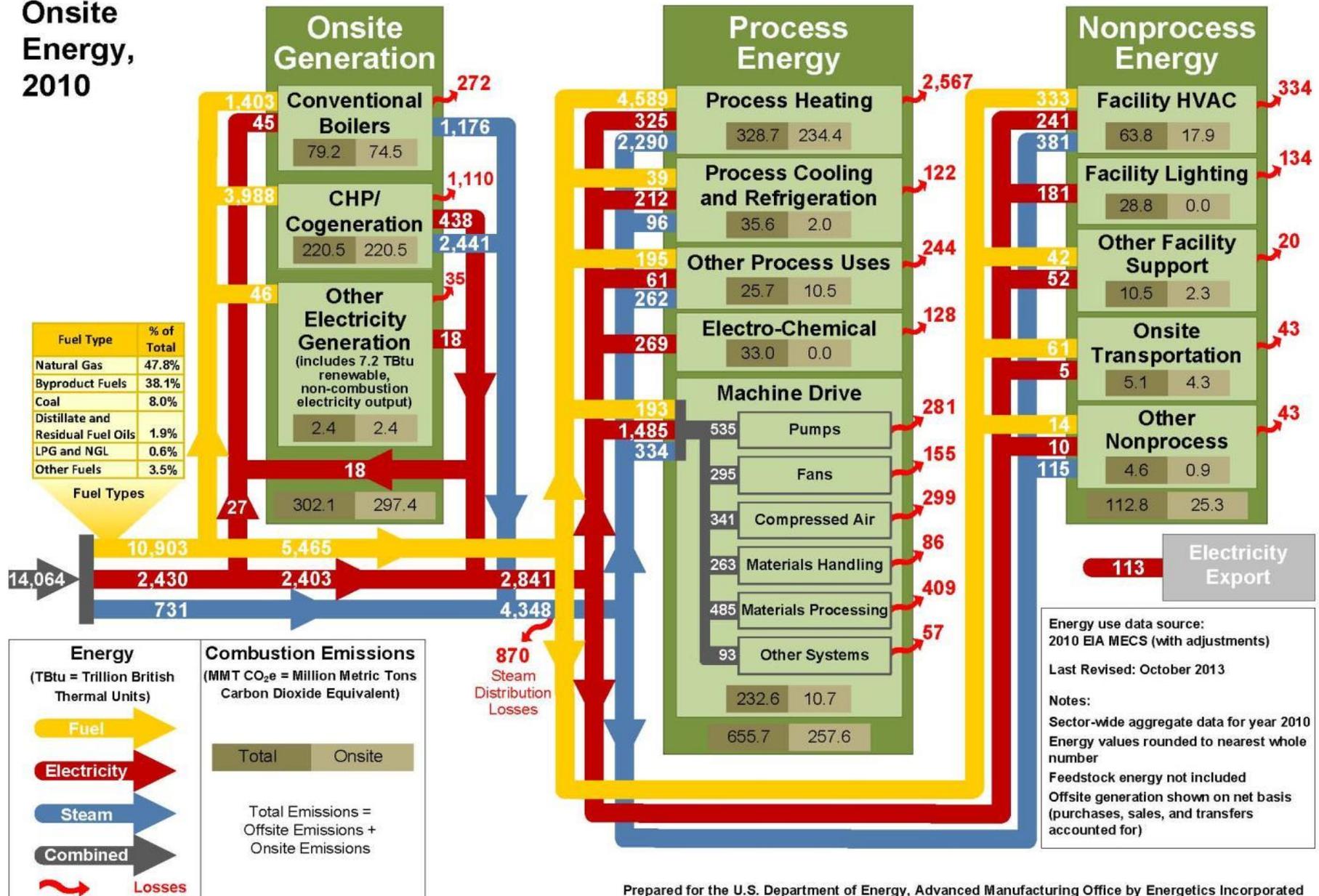


# Manufacturing Energy and Carbon Footprint

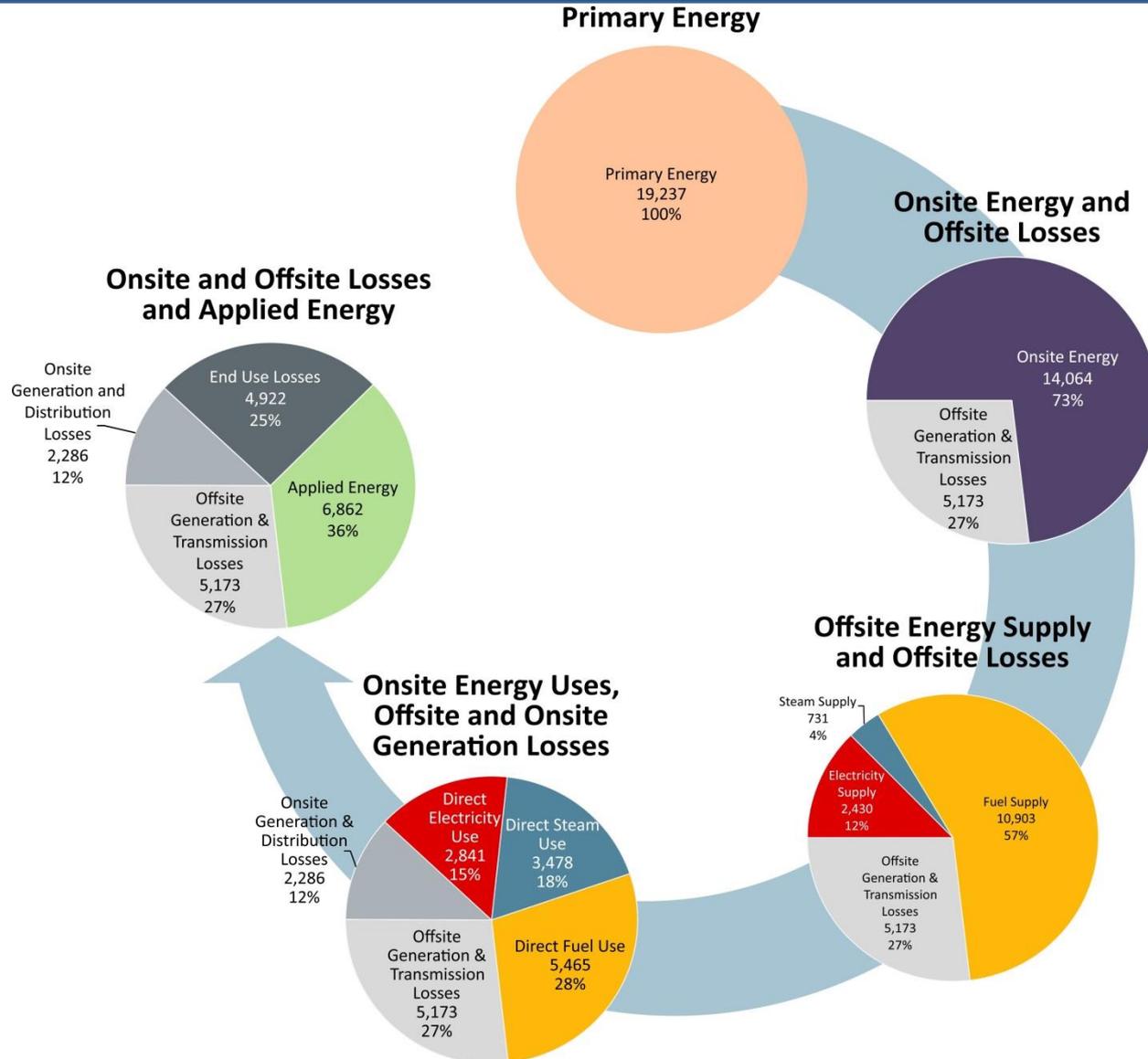
## Sector: All Manufacturing (NAICS 31-33)

Onsite Energy Use: **14,064 TBtu**  
 Onsite Combustion Emissions: **580 MMT CO<sub>2</sub>e**

### Onsite Energy, 2010

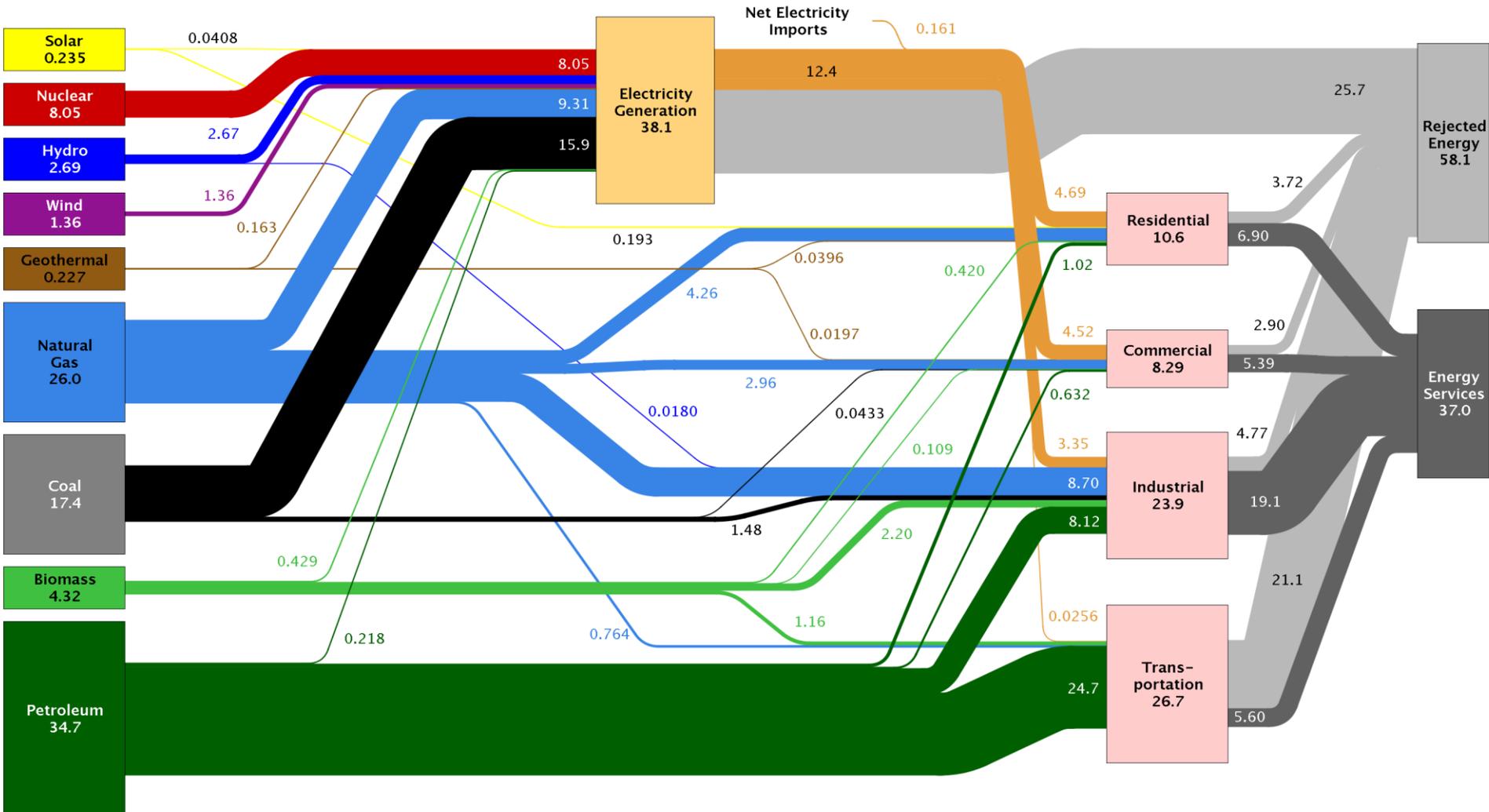


# U.S. Manufacturing Energy and Loss: The Big Picture



# Energy Sankey Diagrams

# Estimated U.S. Energy Use in 2012: ~95.1 Quads

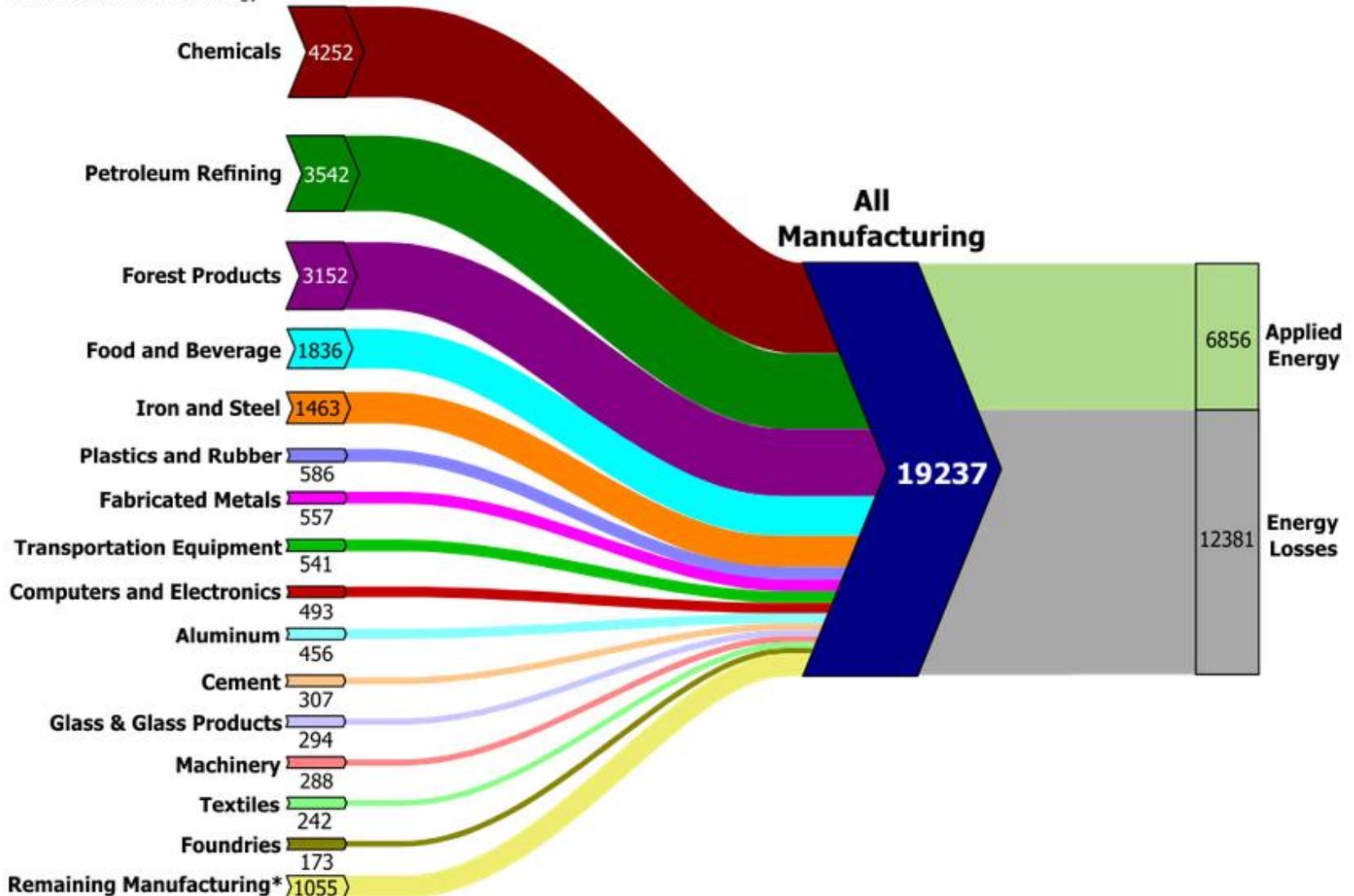


Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only 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

# Full Sector U.S. Manufacturing Energy Sankey Diagram

PRIMARY ENERGY (TBTU), 2010

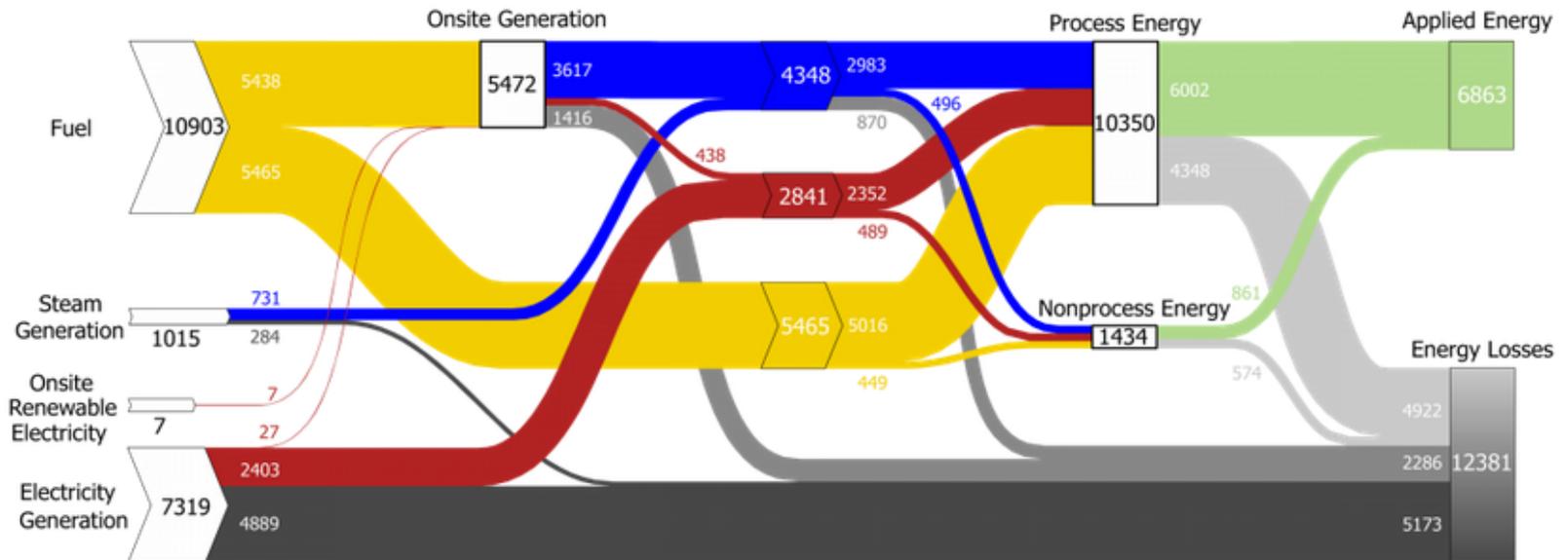
*Excludes feedstock energy*



# Full Sector U.S. Manufacturing Energy Sankey Diagram

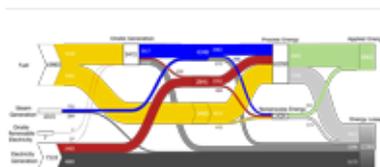
ALL MANUFACTURING PRIMARY ENERGY (TBTU), 2010

FULL SECTOR

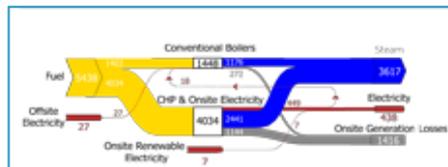


LEGEND:

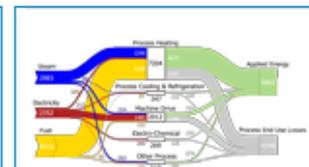
- Fuel
- Steam
- Electricity
- Applied Energy
- Offsite Generation and Transmission Losses
- Onsite Generation and Distribution Losses
- End Use Losses



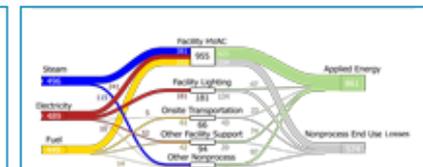
Full Sector



Onsite Generation



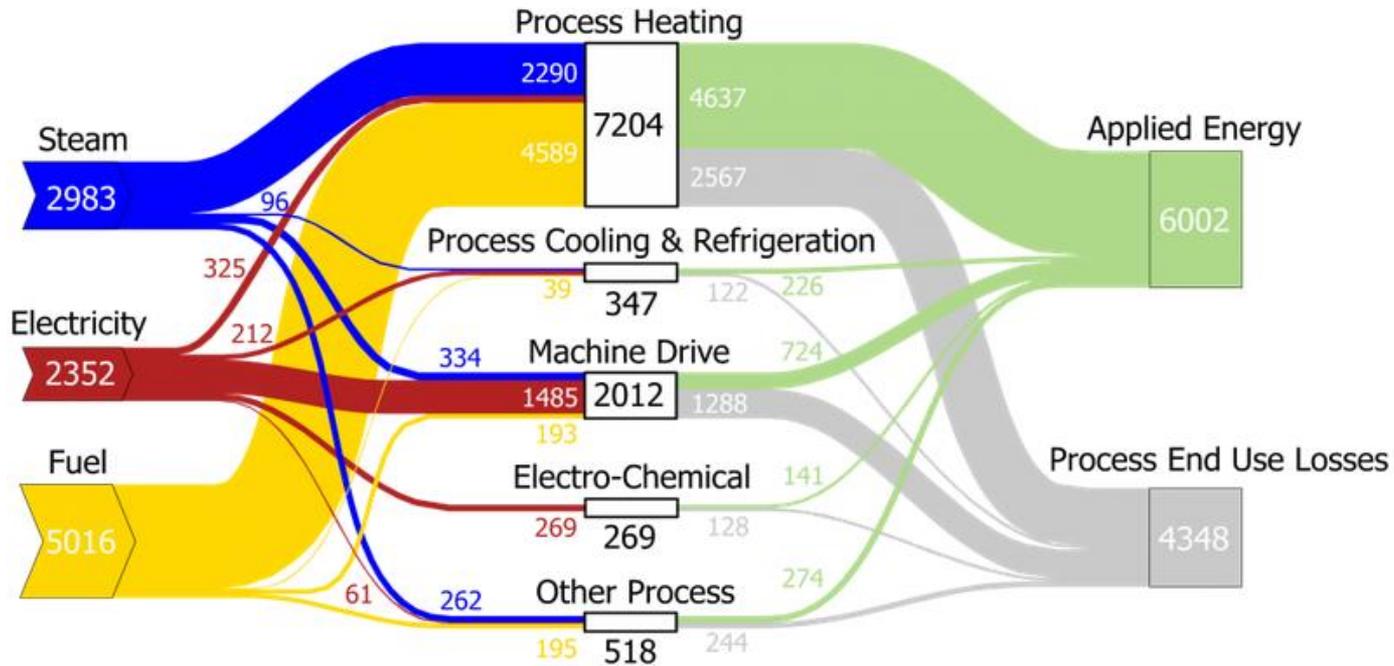
Process Energy



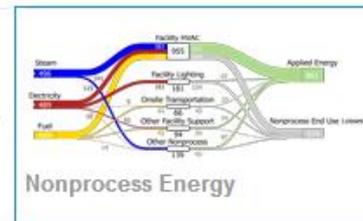
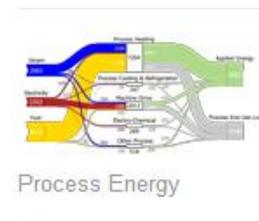
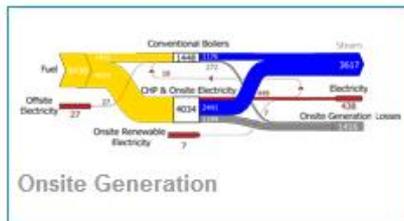
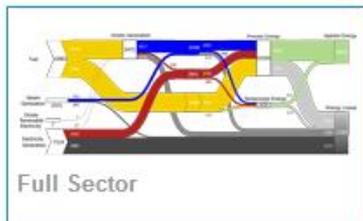
Nonprocess Energy

# Process Energy U.S. Manufacturing Energy Sankey Diagram

ALL MANUFACTURING ONSITE ENERGY (TBTU), 2010  
 PROCESS ENERGY



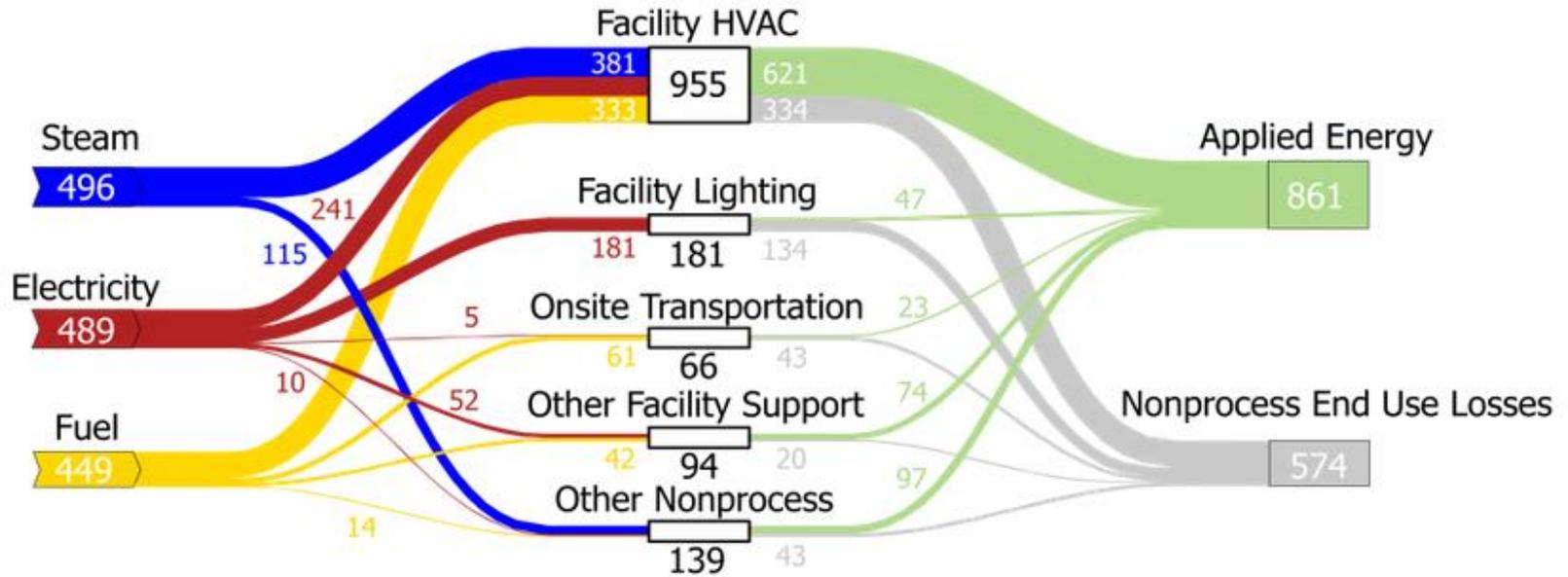
LEGEND: Fuel Steam Electricity Applied Energy End Use Losses



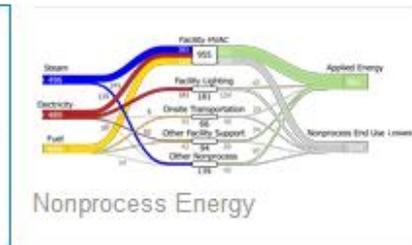
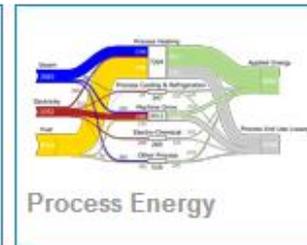
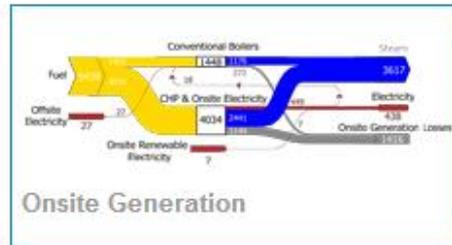
# Nonprocess Energy U.S. Manufacturing Energy Sankey Diagram

ALL MANUFACTURING ONSITE ENERGY (TBTU), 2010

NONPROCESS ENERGY



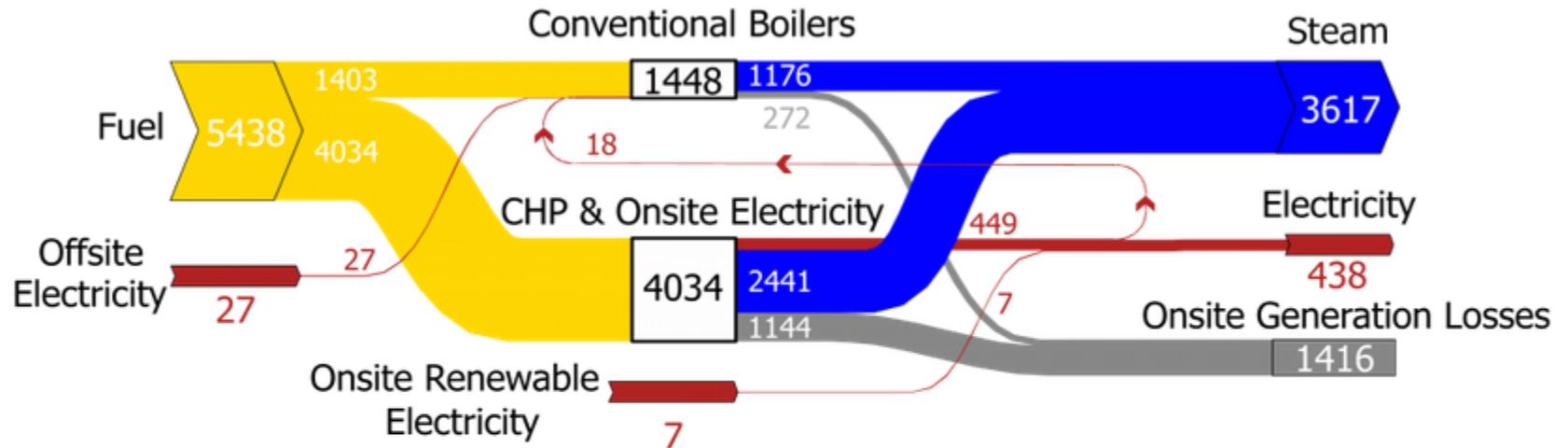
LEGEND: Fuel Steam Electricity Applied Energy End Use Losses



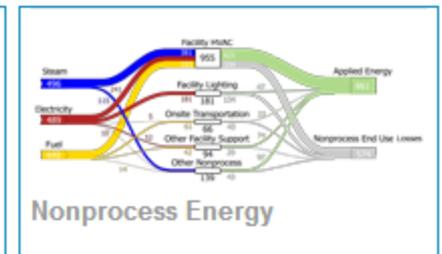
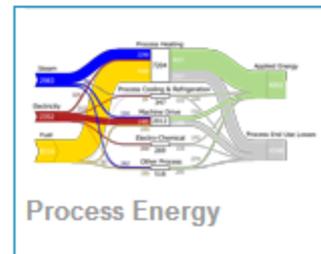
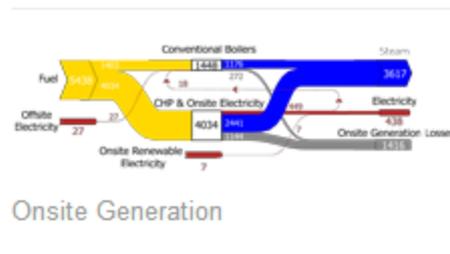
# Onsite Generation Energy Sankey Diagram for U.S. Manufacturing

ALL MANUFACTURING ONSITE ENERGY (TBTU), 2010

ONSITE GENERATION



LEGEND: Fuel Steam Electricity Onsite Generation Losses



# Conclusions

- Including both offsite and onsite losses:  
Primary energy applied = 36%  $\left(\frac{\text{Applied Energy Output}}{\text{Primary Energy Input}}\right)$
- Only including onsite losses:  
Onsite energy applied = 49%  $\left(\frac{\text{Applied Energy Output}}{\text{Onsite Energy Input}}\right)$ 
  - What is the opportunity? These are overall losses, not recoverable opportunity
- What is the overall loss in your plant? This same kind of analysis can be applied at plant or corporate level
- Sankey diagrams: Method to visualize significant energy uses and losses in a more user-friendly format
- More study needed:
  - Better understand shifts in time
  - Better understand process heating losses
  - Regional differences

# Acknowledgments

DOE/AMO Staff, EIA staff (Bob Adler and Tom Lorenz), ORNL and LBNL staff for Sankey diagram feedback, Tom Wenning, Greg Harrell, and Bob Bessette for boiler efficiency feedback and the Energetics team (Sabine Brueske, Chris Gillespie, Nancy Gonzales, Keith Jamison, Caroline Kramer, Ridah Sabouni, Yannick Tamm)

# Thank you!

## Questions?