Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions

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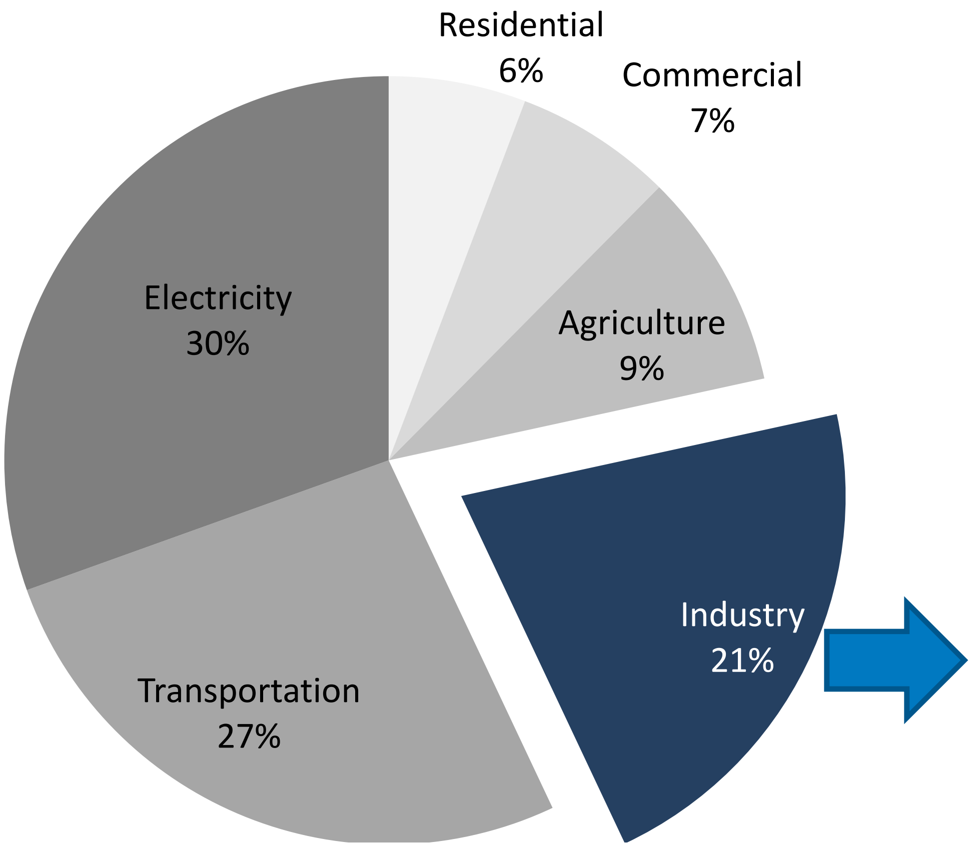
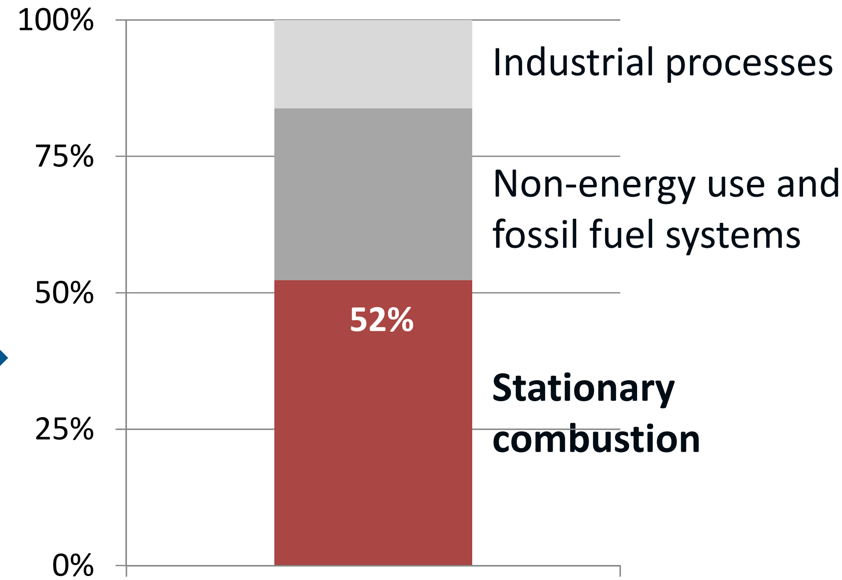
Context: U.S. Greenhouse Gas Emissions



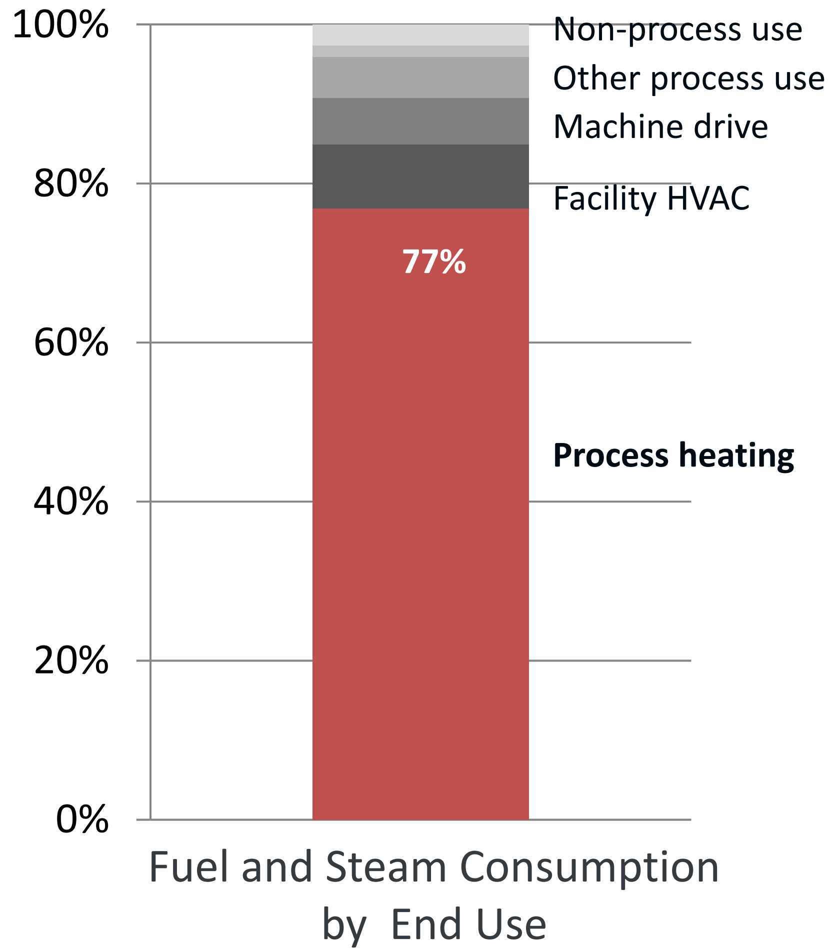
U.S. Greenhouse Gas (GHG) Emissions
in 2014
6,871 million metric tons CO_2-eq
($MMTCO_2e$)



Industrial Sector

Data source: U.S. EPA. 2016. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014.*

Context: U.S. Industrial (Manufacturing) Fuel and Steam by End Use



Data source: U.S. DOE. 2015. "Manufacturing Energy and Carbon Footprints (2010 MECS)"

Goal

Identify potential near zero-carbon energy sources for meeting the heat demands of the most significant GHG-emitting industries.

Analysis Outline

1. Determine the most significant GHG-emitting industries
2. Describe the thermal demand, process-heat temperatures, and related characteristics of the typical process/facility in each industry
3. Match heat demand characteristics to alternative, near zero-carbon heat supplies

Analysis (1): GHG Emissions

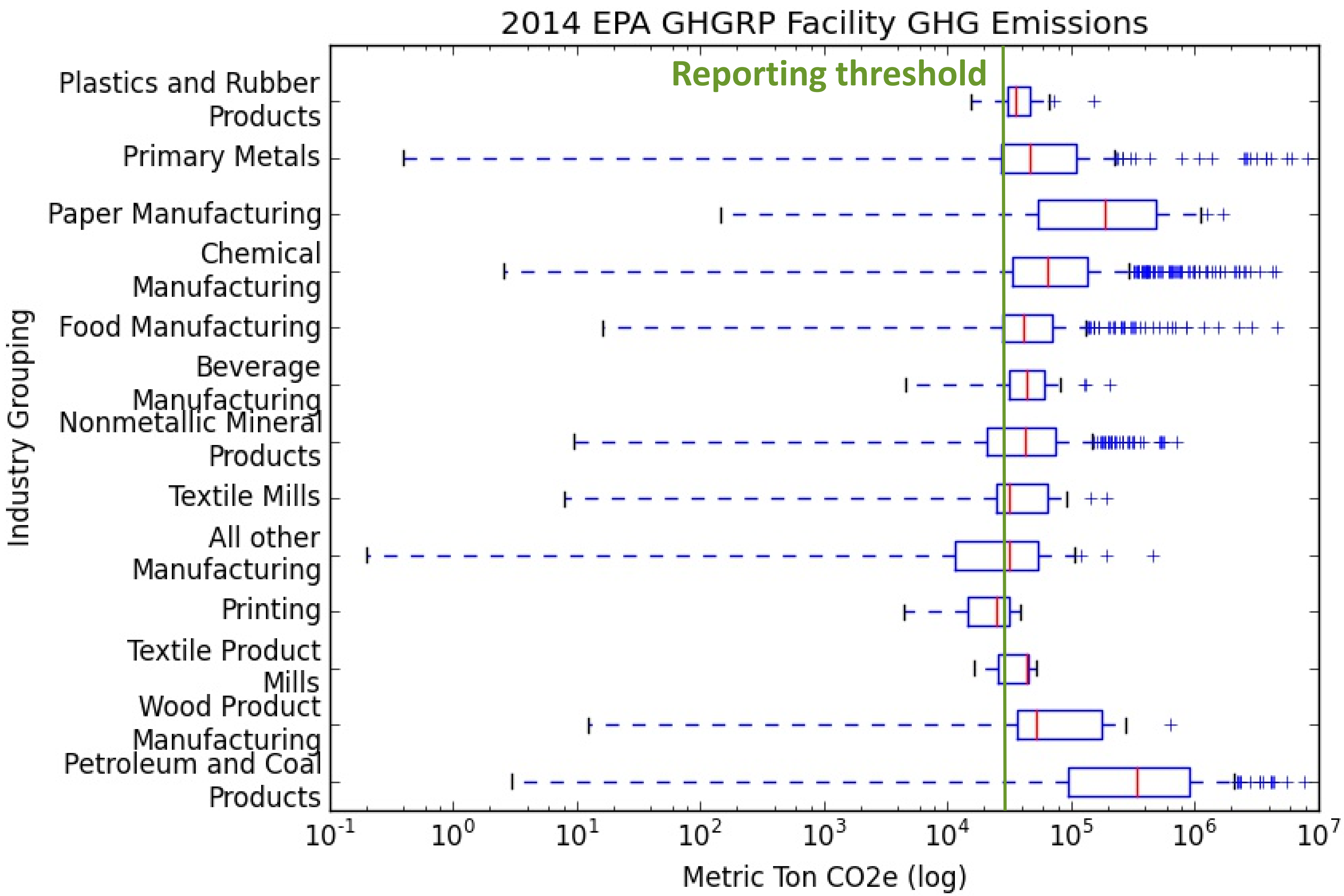
Most significant GHG-emitting industries?

- U.S. EPA's Greenhouse Gas Reporting Program (GHGRP)
  - Mandatory for facilities >25,000 metric tons CO_2e (not only manufacturers and power plants)
  - Reporting began in 2010
  - 8,080 reporting facilities
  - Emissions reported in 2014 account for ~50% of U.S. GHG inventory total (66% of reported from power plants)
  - Online database

Analysis (1): GHG Emissions

- Sample EPA GHGRP database attributes (Subpart C: Stationary Combustion)
    - GHG type
    - Reporting method
    - Fuel type
    - Combustion unit type (e.g., calciner, oven, kiln, **other**)
    - Combustion unit name
    - Facility name
    - Facility location (state, city, lat, long)
    - Industrial classification (6-digit North American Industrial Classification System [NAICS] code)
    - Parent company
- Plus API, machine-readable data

Analysis (1): GHG Emissions

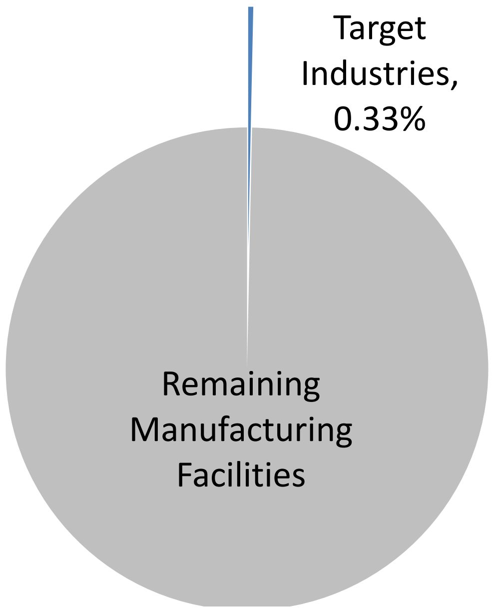


Analysis (1): GHG Emissions

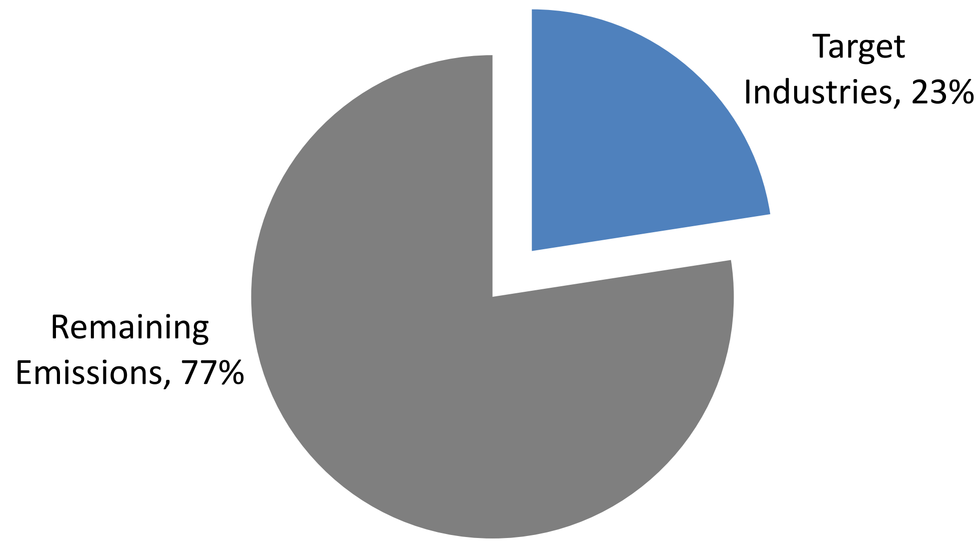
Industry Subsector	Target Industry	Number of Reporting Facilities	Facility Mean Emissions ($MMTCO_2e$)*	Total Emissions ($MMTCO_2e$)*	Fraction of Industrial Sector Emissions (%)*
Petroleum and Coal Products Manufacturing	**Petroleum Refineries**	141	0.882	124	8
Primary Metal Manufacturing	**Iron and Steel Mills**	115	0.440	51	3
Paper Manufacturing	**Paper (except Newsprint) Mills**	116	0.275	32	2
	Paperboard Mills	73	0.327	24	1.5
	Pulp Mills	30	0.395	12	0.7
Chemical Manufacturing	**All Other Basic Organic Chemical Manufacturing**	85	0.245	21	1.3
	Ethyl Alcohol Manufacturing	168	0.109	18	1.1
	Plastics Material and Resin Manufacturing	72	0.235	17	1.0
	Petrochemical Manufacturing	35	0.450	16	1.0
	Alkalies and Chlorine Manufacturing	11	1.223	13	0.8
	Nitrogenous Fertilizer Manufacturing	30	0.252	8	0.5
Food Manufacturing	**Wet Corn Milling**	24	0.744	18	1.1
Nonmetallic Mineral Product Manufacturing	**Lime Manufacturing**	49	0.201	10	0.6
Mining (Except Oil and Gas)	**Potash, Soda, and Borate Mineral Mining**	11	0.568	6	0.4
	Total	**960**	**0.385**	**369**	**23**

* Includes emissions from biomass combustion

Analysis (1): GHG Emissions



Facility Count in 2014

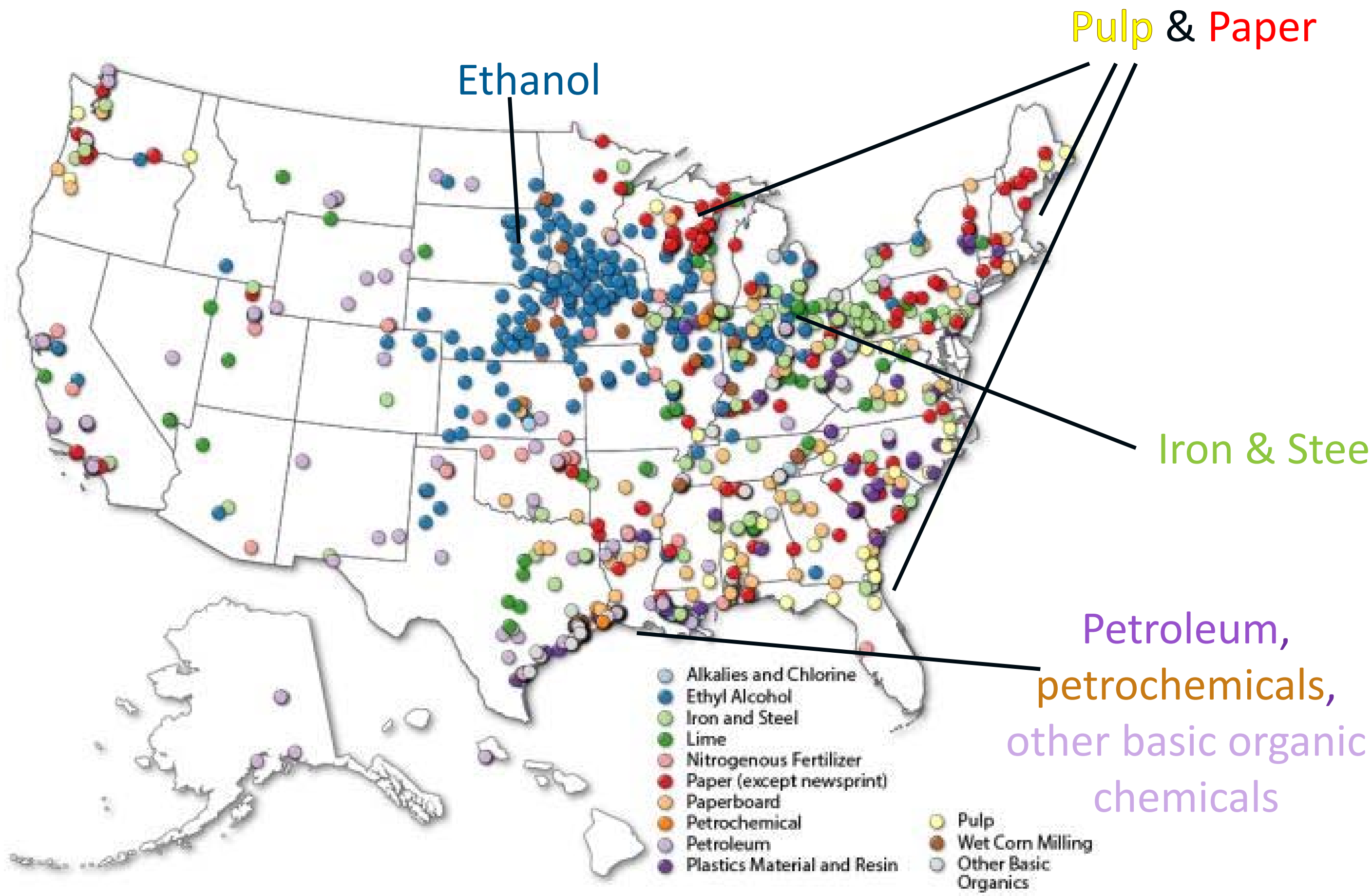


Industrial Sector GHG Emissions in 2014

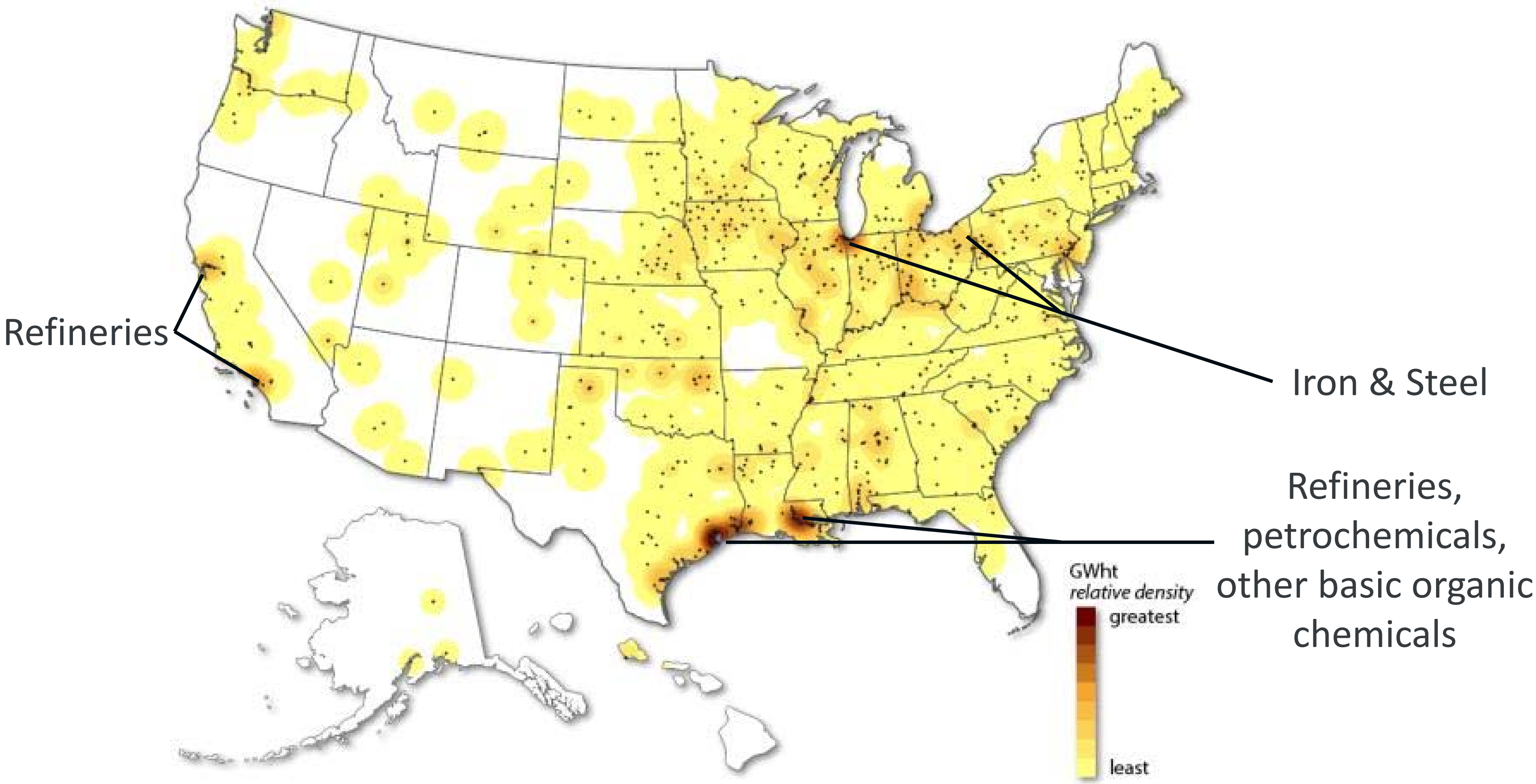
Combustion GHGs from **<0.5%** of manufacturing facilities accounted for nearly **25%** of industrial sector total emissions (**5%** U.S. total) in 2014

Manufacturing facility count: U.S. Census Bureau. 2014 Census Business Patterns.

Analysis (1): Locations of Target Industry Facilities



Analysis (1): Target Industry Process Heat Use



Analysis (2): Unit Processes

- Process flow diagrams were then developed for the “typical” process in each of the 14 target industries, e.g.
  - Iron & Steel: blast-furnace/basic oxygen furnace, integrated mill
  - Pulp mills: sulfate (“kraft”) process
  - All other basic organic chemicals: methanol
  - Petrochemical manufacturing: ethylene
  - Plastic materials and resins: PE and PET
- Identified material and energy (including process temperatures) flows
- Based on existing INL analysis, Kirk-Othmer, other relevant literature

Analysis (3): Alternative Heat Supplies

Assessing potential alternative heat supplies includes:

1. Size, temperature, and dependability of heat supply
2. Heat-transport distance and distribution of the thermal working fluid
3. Heat-transfer media
4. Existing or new heat exchangers and heat transfer into reaction processes

Analysis (3): Alternative Heat Supplies

Heat matching with industrial demands

1. **Geothermal**
   - Current use for demands < 150°C; enhanced geothermal for demands approaching 200°C
   - Most favorable sources located in western U.S.
2. **Solar industrial process heat (SIPH)—concentrating and nonconcentrating collectors**
   - SIPH (e.g., parabolic trough and linear Fresnel): Current use in small applications (0.1 – 100 MW_t) for 150 – 300°C, in wide range of industries
   - Higher temperature (1,100°C upper limit assumed) applications assumed for other concentrating technologies (e.g., central receiver)
   - Need to match insolation at industrial facility location
3. **Small modular nuclear reactors (SMRs)**
   - Current development for 30 – 1,000 MW_t thermal capacity, providing heat between 300 – 850°C
   - Number of SMRs may be limited to siting and licensing restrictions

Analysis (3): Alternative Heat Supplies

- Roughly estimated alternative heat supply potential for the identified industries
- **More rigorous, detailed analyses identified as research opportunities**
- Demand-supply matching based on:
  - **Temperature:** typical process temperature requirement and assumed supply temperature above
  - **Heat demand:** Average daily heat demand by process and assumed supply unit size (smallest SMR module of 150 MWt; SIPH size limit of 250 MWt)
- Did not consider resource availability or site permitting, heat transfer losses, heat recuperation opportunities, combining alt. heat supplies.

Analysis (3): Alternative Heat Supplies

Alternative Heat Supply	Assumed Applicable Temperature (ºC)	Potential Heat Supply in PJ/year (TBtu/year)	Applicable Industries
Geothermal	150	70 (66)	Wet corn milling
SIPH (concentrating and nonconcentrating)	<1,000	1,480 (1,403)	Petroleum refineries, chemical industries, ethyl alcohol, plastic materials and resins, alkali and chlorine, potash, and soda and borate mining
SMRs	300 - 850	1,480 (1,403)	Same as SIPH
Hydrogen (feedstock)	NA	15,851 metric tons/day	Refineries, iron & steel, plastic materials & resins
Target industry heat use	5,824 PJ/year (5,520 TBtu/year).		
Hydrogen production	~27,400 metric tons/day (current production for feedstock)		

Analysis Opportunities (sample)

1. **Detailed cost comparison and technical assessment:** potential for heat delivery and GHG reductions from SMR, SIPH, and geothermal resources vs. fossil fuels combustion.
2. **Case-specific heat application design studies:** evaluate heat integration and capital and operating cost expenses.
3. **Heat-transfer tests:** hot gases, organic heat-transfer fluids, and other heat-transfer media, including energy deposition in existing process reaction vessels and heat exchangers.

Analysis Opportunities (sample, con't)

4. **Techno-economic evaluation of heat boosting:** may consider heat-topping options—e.g., electrical heating, hydrogen combustion, and chemical heat pumps
5. **Feasibility of retrofitting existing CHP power turbines:** with SMR, SIPH, and geothermal heat-supply sources.
6. **Scale and cost of thermal storage:** e.g., steam accumulators, molten-salt heat reservoirs, process-specific/custom-designed eutectic salt or adsorption/desorption energy storage media.
7. **Opportunities for energy parks**: Manufacturing centers may already be suitable. New growth may embrace energy parks surrounding renewable and nuclear energy sources with relatively low operating costs.

Conclusions

1. **In 2014 less than 0.5% of all U.S. manufacturing facilities** were responsible for nearly 25% of industrial GHG emissions (5% of U.S. total emissions)
2. **SMR technologies** are expected to be well-matched to the scale of demand of oil refineries, pulp/paper manufacturing, methanol, fertilizer plants, among others.
3. **SIPH applications** can potentially supply heat to the majority of the industrial applications analyzed. Specific examples include chlor-alkali plants, ethylene and other chemical production plants, and food processing plants.
4. **Geothermal energy** could provide thermal energy to food processing plants and to plants that use lower temperature heat to concentrate and/or dry process feedstocks and products.

Conclusions

5. **Heat recuperation and temperature boosting** are important thermal energy management concepts that may benefit SMR, SIPH, and geothermal energy sources
6. **Hybrid thermal/electricity generation** may help balance hourly, daily, and/or seasonal electrical cycles.
7. **Thermal energy storage** that matches clean energy delivery with thermal load schedules may be required for intermittent or batch plant operations.
8. **Electrification** warrants further consideration. Direct electrical heating is technically feasible, but could add to grid response dynamics and challenges.
9. **Hydrogen production** for use as a substitute fuel gas and feedstock could reduce industry GHG emissions.

Final Report and Data Sets

- Final report will be available from INL & NREL
- Data sets on calculated facility-level heat use available from NREL Data Catalog (also searchable from OpenEI.org and data.gov)

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Thank you

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