# Industrial Processes Needing High Heat- An Overview

Vinod Narayanan
University of California- Davis

UC Solar Thermal Symposium
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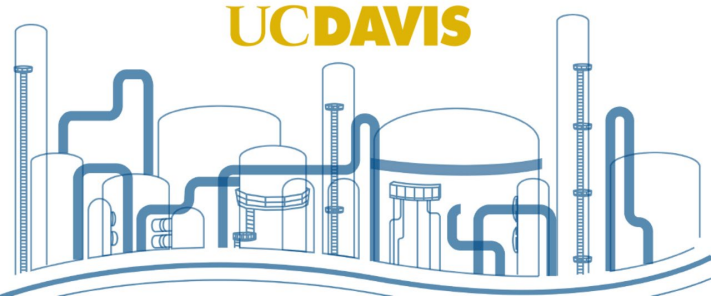


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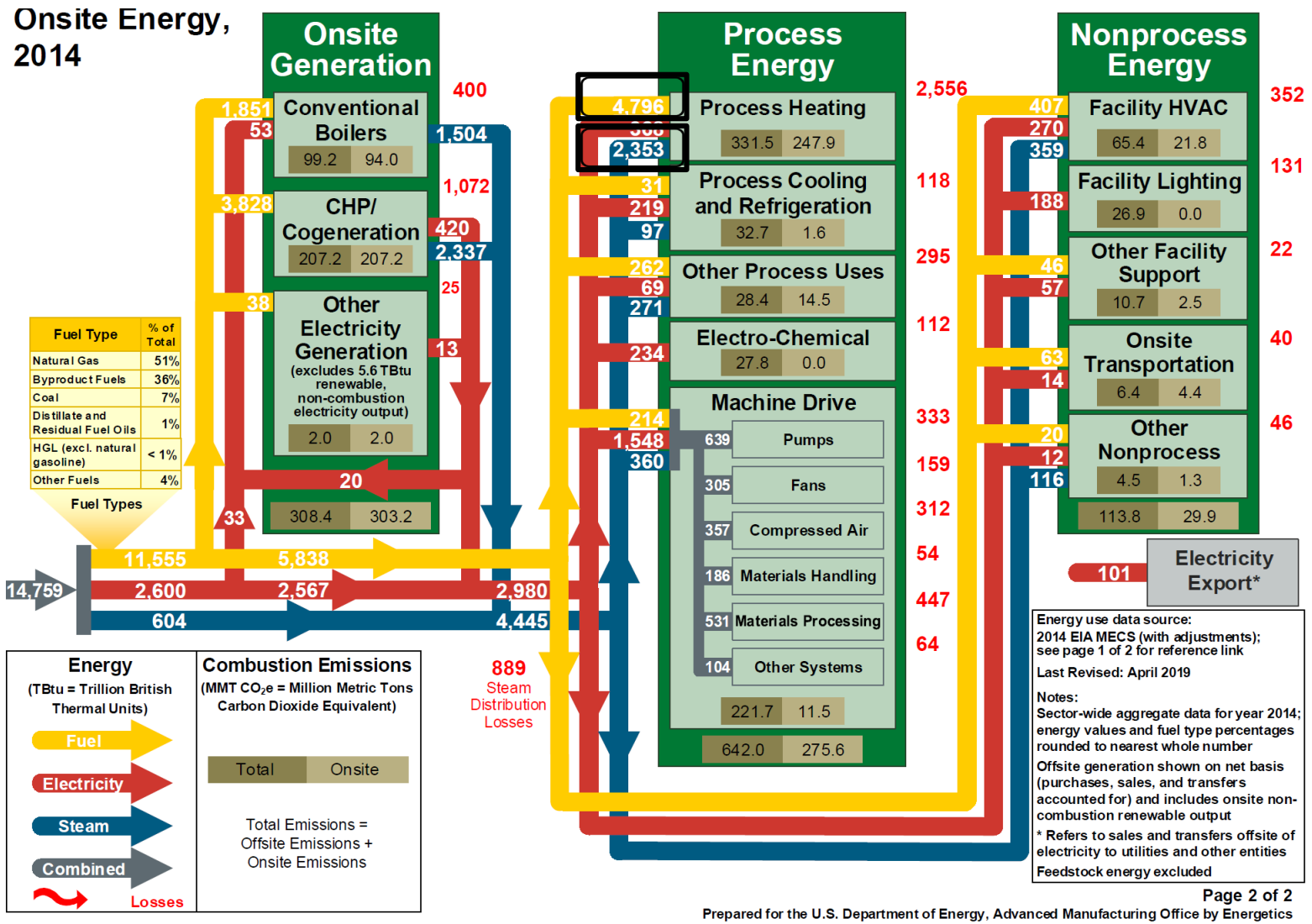
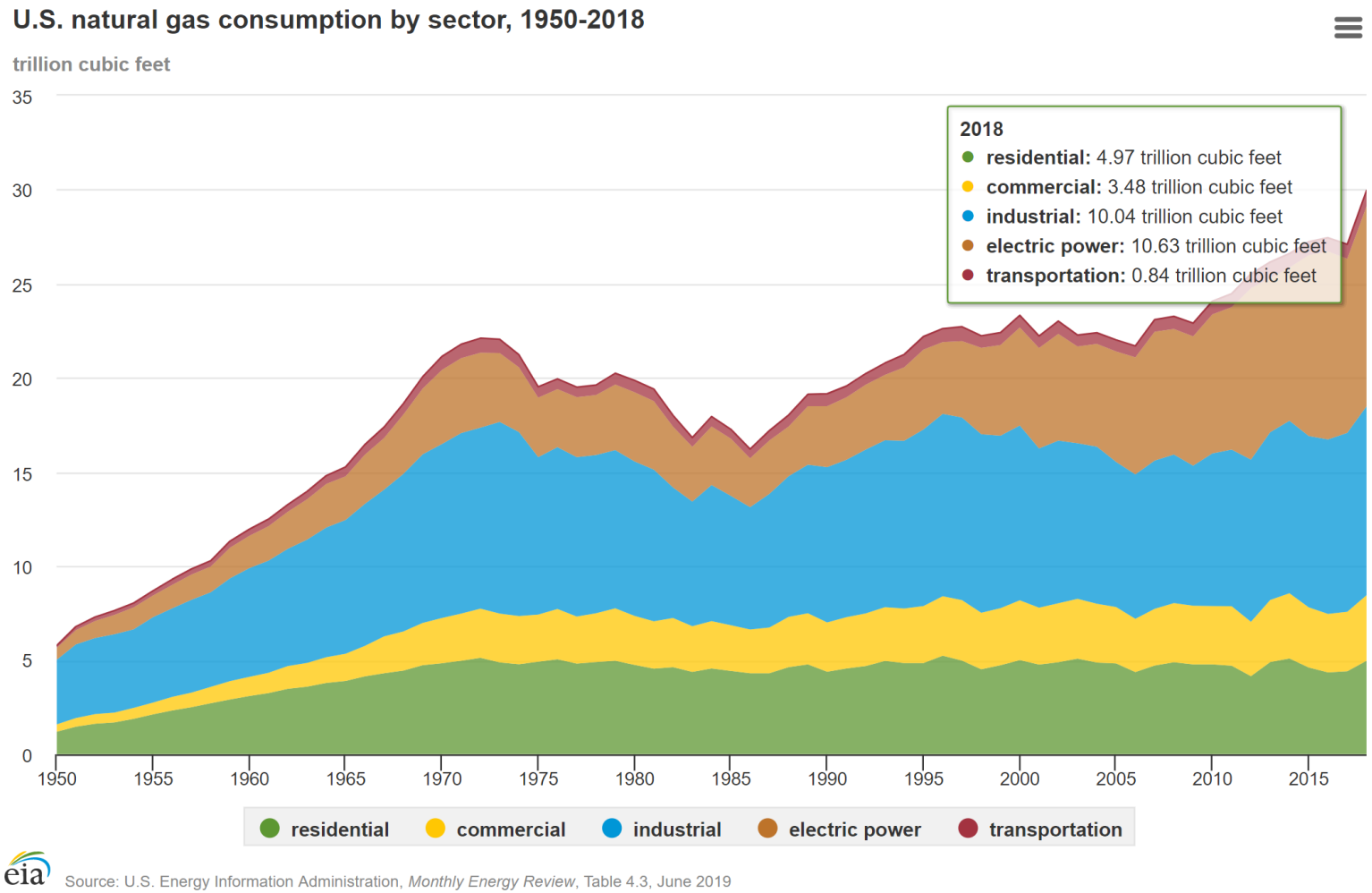
# Setting the stage- US Manufacturing Energy Consumption (2014 MECS)




- Fuel use is 4.5 times larger than electricity use
- NG is the predominant fuel
- Significant part of process heat is driven by steam
- Total emissions: 1064 MMT $CO_2e$ (16% of US total)

# Setting the stage- Natural Gas use in US




5 largest NG consuming states:
TX (14.3%)
CA (7.8%)
LA (5.9%)
FL (5.1%)
PA (4.7%)

Industrial processes used 10.04 trillion cubic feet (~34%) of natural gas 2018

# Setting the stage- Top thermal energy consumption industries (TBtu)

US*

| Subsector and Industry | Net Electricity | Natural Gas |
|---|---|---|
| Chemicals | 458 | 2496 |
| Petroleum and Coal Products | 167 | 1072 |
| Petroleum Refineries | 160 | 1000 |
| Primary Metals | 433 | 688 |
| Food | 247 | 572 |
| Other Basic Organic Chemicals | 57 | 474 |
| Iron and Steel Mills and Ferroalloys | 204 | 443 |
| Paper | 191 | 436 |
| Plastics Materials and Resins | 58 | 424 |
| Nitrogenous Fertilizers | 13 | 383 |

Western region accounts for ~12% of total industrial natural gas consumption

Western census region*

| Subsector and Industry | Net Electricity | Natural Gas |
|---|---|---|
| Petroleum and Coal Products | 26 | 261 |
| Petroleum Refineries | 25 | 249 |
| Food | 41 | 135 |
| Chemicals | 39 | 63 |
| Paper | 34 | 61 |
| Fruit and Vegetable Preserving and Specialty Food | 12 | 60 |
| Nonmetallic Mineral Products | 20 | 47 |
| Primary Metals | 47 | 35 |

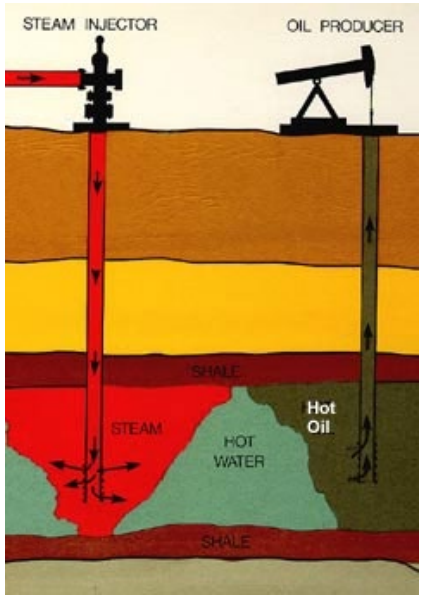
California**

| Subsector and industry | Net Electricity | Natural Gas |
|---|---|---|
| O&G extraction and mining support | 22.02 | 230.54 |
| Petroleum and coal products manufacturing | 28.90 | 184 |
| Chemicals | 1.34 | 39.3 |
| Food and beverage | 20.24 | 37.7 |
| Primary metals | 0.51 | 9.7 |

*Source for US and western region: 2014 MECS data
**Source for CA data: California Energy Commission, 2019, "Research Roadmap for Advancing technologies in California's Industrial, Agriculture and Water Sectors," Energy Research and Development division Final Project Report CEC-500-2019-016

# Oil and Gas Extraction (upstream)

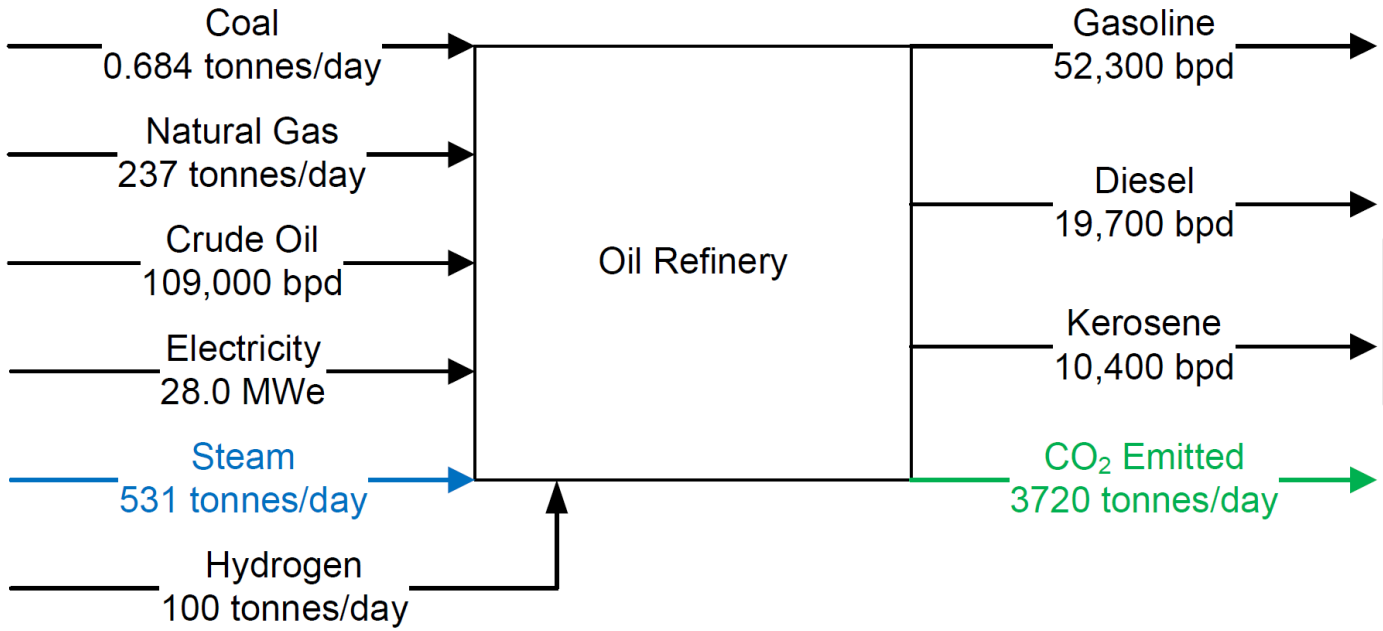
- driving pumps to extract hydrocarbons and to reinject water;
- Enhanced oil recovery- thermal injection (40% of CA oil)
- heating the output stream to allow separation of the oil, gas and water;
- powering compressors and pumps for transporting oil and gas through gathering pipelines to processing plants;
- driving turbines to generate the electricity and heat needed for on-site operations



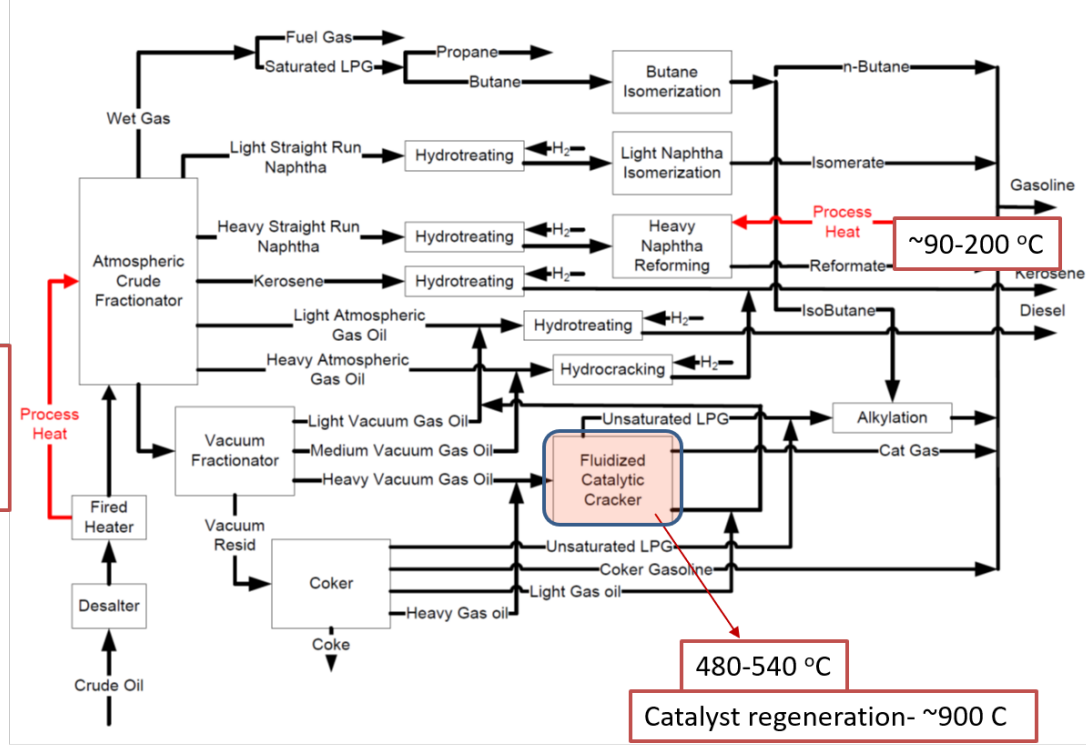

Solar Enhanced Oil recovery could displace 20% of NG use for EOR in CA: Kern County 21Z Solar Project (GlassPoint Solar)

Sources:
IPIECA, 2013, Saving Energy in the oil and gas industry

# Petroleum Refining (Downstream)




Typical refinery energy and product flows



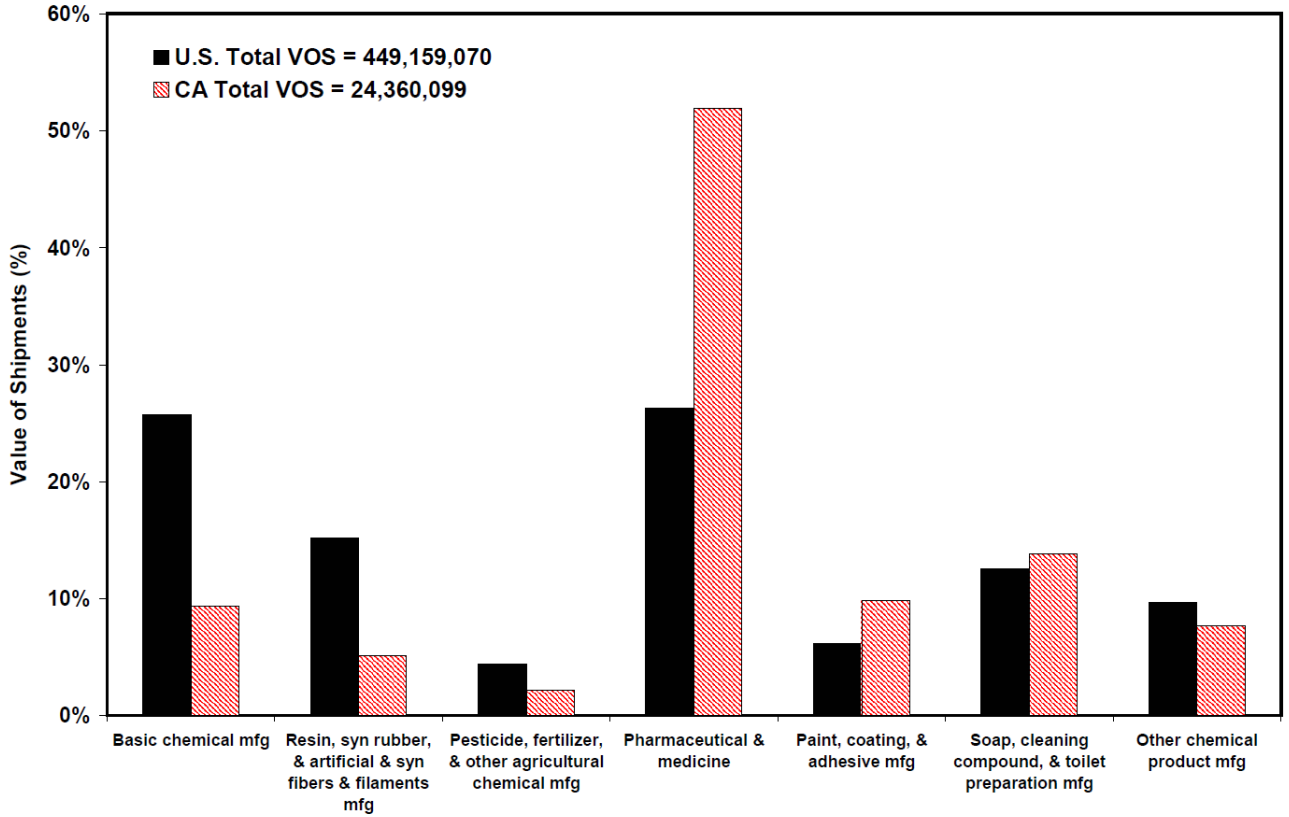

Source: Appendix - McMilan et al., 2016, Generation and use of thermal energy in the US Industrial Sector and Opportunities to Reduce its Carbon Emissions, NREL/TP-6A50-66763, INL/EXT-16-39680

- Fractional distillation
- Rearrangement of HC molecules- Conversion of paraffins to aromatics (dehydrogenation and aromatization), longer chains to aromatics and branched HCs (isomerization); goal- higher octane value, longer chains broken into smaller molecules (cracking)

# Chemical Manufacturing (2004 data)

CA chemicals industry (2000)

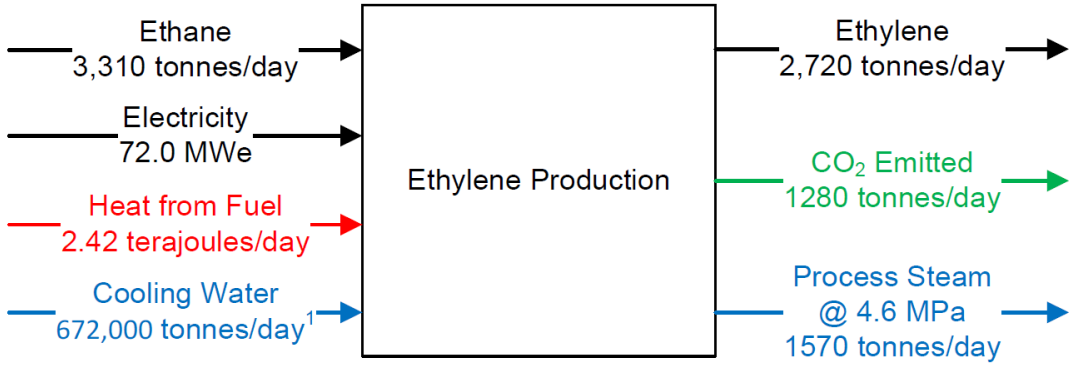
| SIC | Sector | Natural Gas (TBtu) | Electricity (GWh) | Primary Energy (TBtu) |
|---|---|---|---|---|
| **281** | Inorganic Chemicals | 5.28 | 1397 | 15.6 (32%) |
| **282** | Plastics & Synthetics | 1.34 | 155 | 2.5 (5%) |
| **283** | Drugs | 2.07 | 878 | 8.6 (18%) |
| **284** | Soap & Cleaners | 0.43 | 154 | 1.6 (3%) |
| **285** | Paints | 0.04 | 64 | 0.5 (1%) |
| **286** | Organic Chemicals | 0.11 | 44 | 0.4 (1%) |
| **287** | Agricultural Chemicals | 0.15 | 68 | 0.7 (1%) |
| **289** | Other | 0.54 | 141 | 1.6 (3%) |
| | Unclassified | 9.15 | 1008 | 16.6 (38%) |
| **Total** | | **19.13** | **3909** | **48.13** |

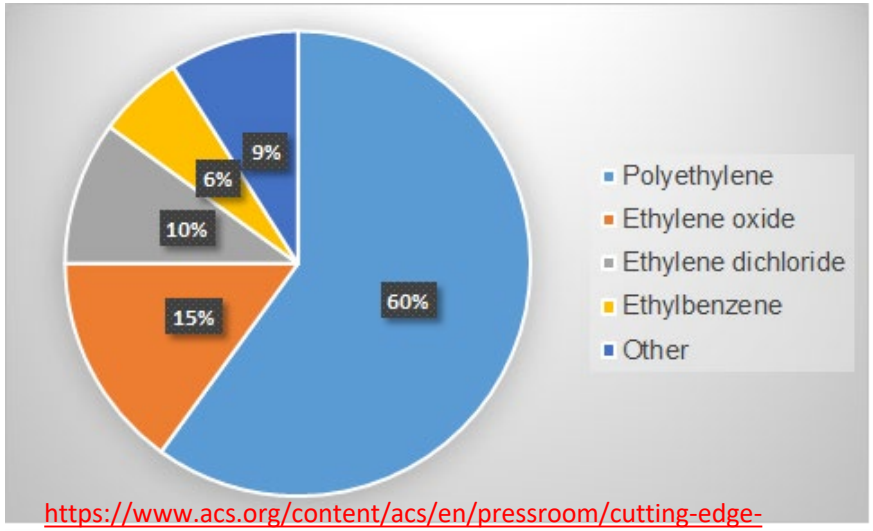



- Chemical processing -Two main steps-
  - Primary synthesis
  - Separation and purification (fractional distillation)
- 40% of heat in chemical plants is delivered using steam
- Final products- soaps, cleaners, bleach, cosmetics, dyes, pharmaceuticals, plastics
- Intermediate products – plastics, rubber, textiles, apparel, paper
- CA- pharmaceuticals, soaps and cleaners, inorganic chemicals make up 75% of CA industry

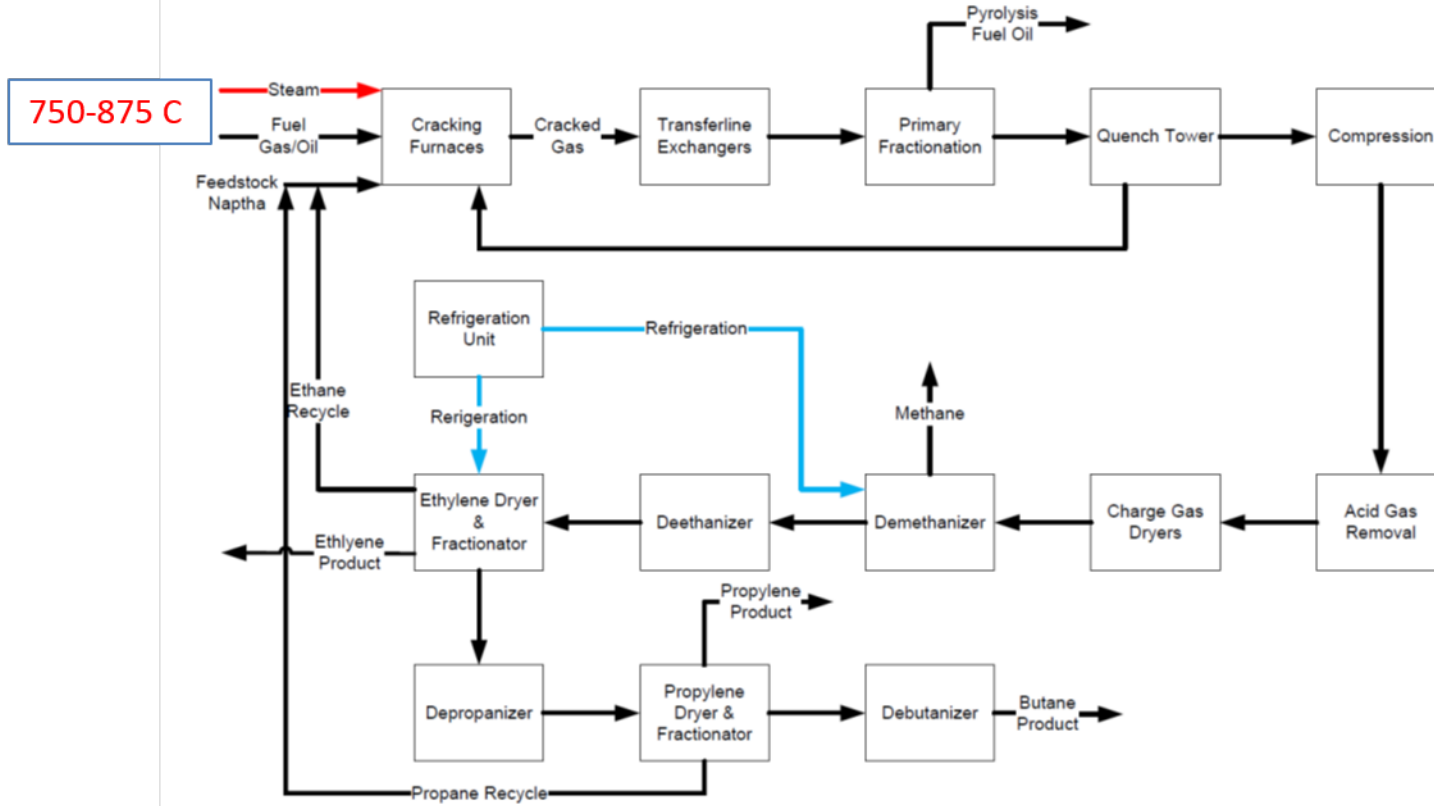
C. Garitsky, E. Worrell, 2004, Profile of the Chemicals Industry in California- California Industries of the Future Program, LBNL 55668

# Petrochemicals



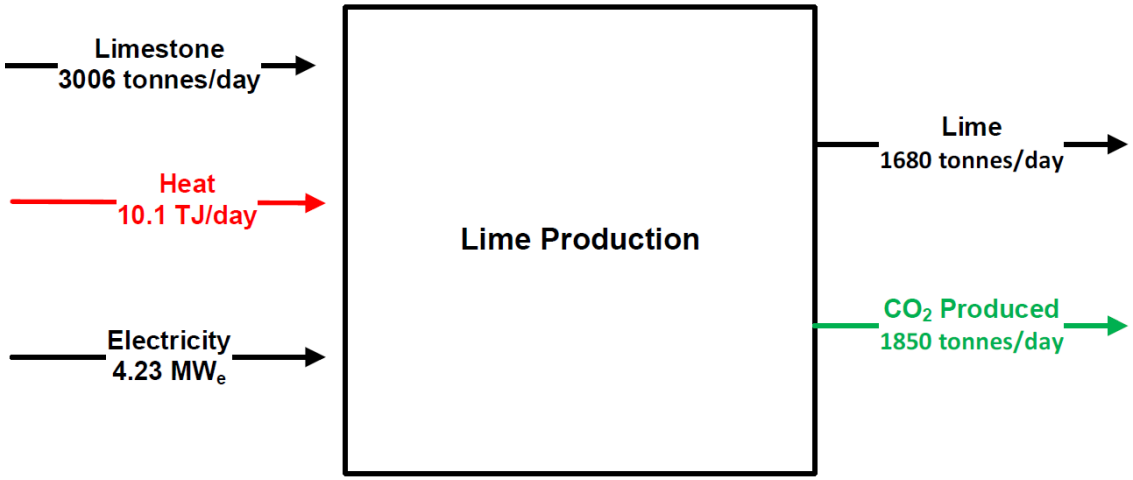

https://www.acs.org/content/acs/en/pressroom/cutting-edge-chemistry/beyond-the-ethylene-steam-cracker.html

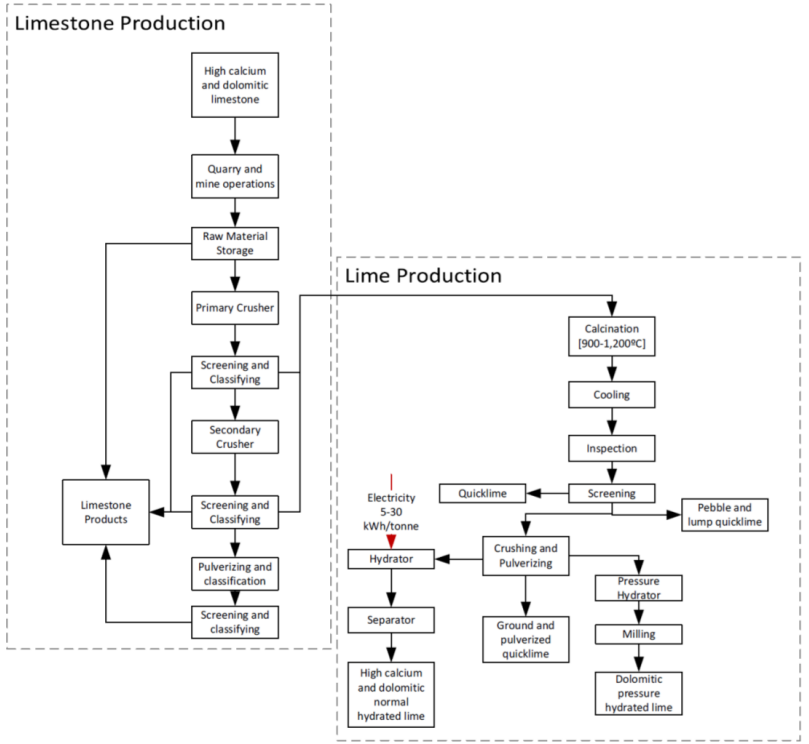



Feedstock for polyethylene (~60% used for this); rest used in ethylene glycol, industrial ethanol, …

Source: Appendix - McMilan et al., 2016, Generation and use of thermal energy in the US Industrial Sector and Opportunities to Reduce its Carbon Emissions, NREL/TP-6A50-66763, INL/EXT-16-39680

# Lime (CaO) production



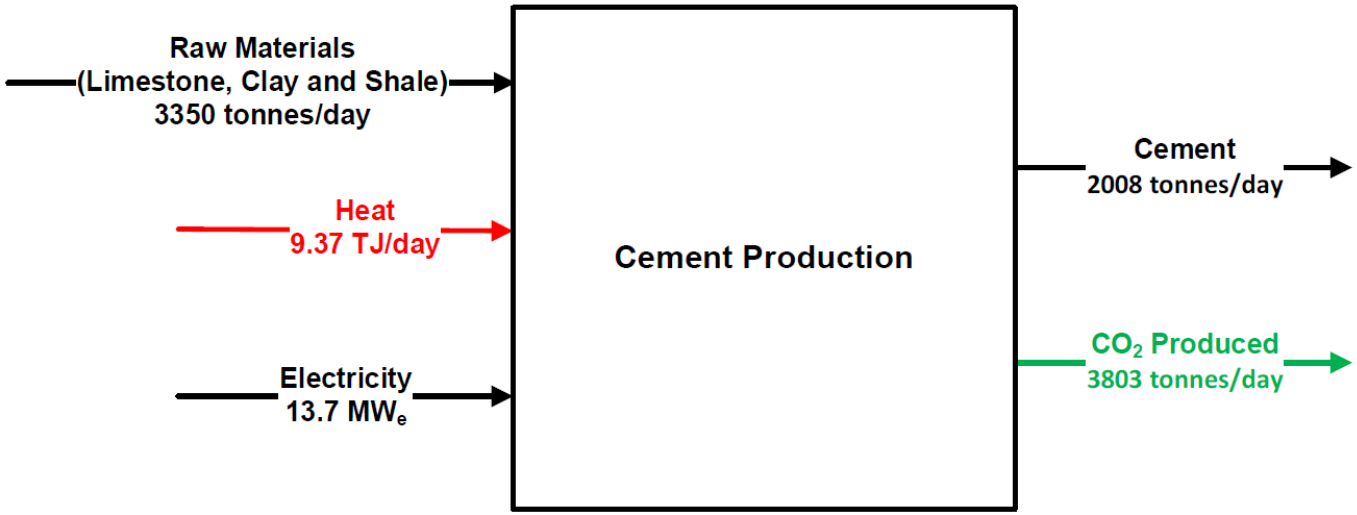

$CaCO_3$ (s)→ CaO (s)+$CO_2$ (g)

$CaCO_3.MgCO_3$+ heat --> 2$CO_2$ + CaO.MgO (dolomitic lime)

Source: Appendix - McMilan et al., 2016, Generation and use of thermal energy in the US Industrial Sector and Opportunities to Reduce its Carbon Emissions, NREL/TP-6A50-66763, INL/EXT-16-39680

- Lime is used as an alkaline agent
- Iron and steel, pulp and paper, treatment of flue gas and water; key ingredient of cement
- Large rotary kiln at 900-1200 ºC (endothermic)

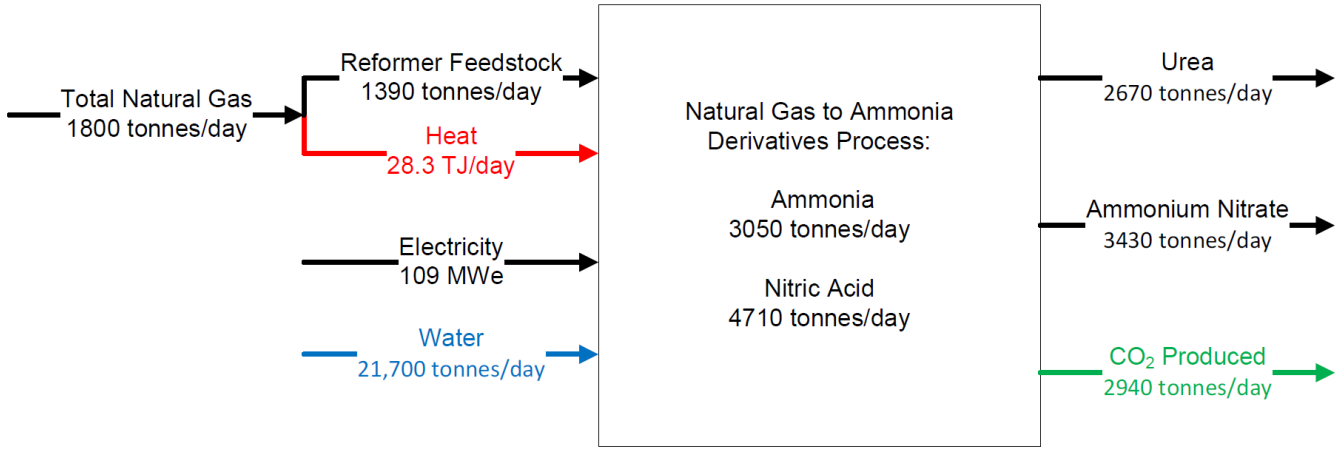
# Cement Production




- Grinding a mixture of limestone and clay or shale to make a fine "rawmix"
- Heating the rawmix to sintering temperature (up to 1,500°C) in a cement kiln – heat source at 1800-2000 C
- Kiln fired by combustion of coal, petroleum coke, heavy fuel oil, natural gas, landfill off-gas, and oil refinery flare gas (used tires!)
- Radiation heat transfer dominant
- Grinding the resulting clinker to make cement.

Source: Appendix - McMilan et al., 2016, Generation and use of thermal energy in the US Industrial Sector and Opportunities to Reduce its Carbon Emissions, NREL/TP-6A50-66763, INL/EXT-16-39680

# Fertilizer Production (Ammonia synthesis)

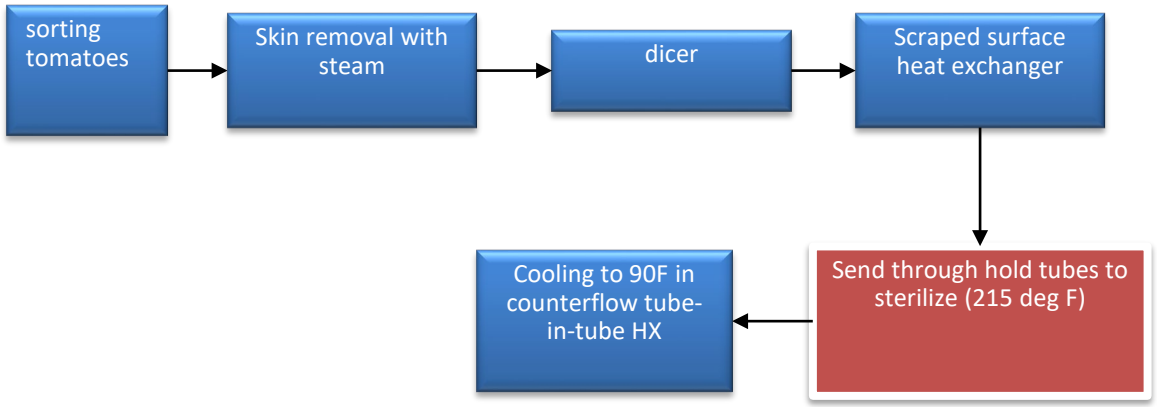



Typical fertilizer plant energy and product flows

- 9.4 million tons in US (2015); accounts for 88% of $NH_3$ use
- Constituents- natural gas- for $H_2$; air for $N_2$

Source: Appendix - McMilan et al., 2016, Generation and use of thermal energy in the US Industrial Sector and Opportunities to Reduce its Carbon Emissions, NREL/TP-6A50-66763, INL/EXT-16-39680

# Food Processes that Use Heat




| Pasteurization Type | Typical Product | Typical Storage | Temperature | Holding Time |
|---|---|---|---|---|
| **Batch, vat** | Milk | Refrigerated | 145°F (62.8°C) | 30 min |
| " | Viscous products, or products with more than 10% fat or added sweetener | " | 150°F (65.6°C) | 30 min |
| " | Egg nog, frozen dessert mixes | " | 155°F (68.3°C) | 30 min |
| **Continuous, high temperature short time (HTST)** | Milk | " | 161°F (71.7°C) | 15 sec |
| " | Viscous products, or products with more than 10% fat or added sweetener | " | 166°F (74.4°C) | 15 sec |
| " | Egg nog, frozen dessert mixes | " | 175°F (79.4°C) | 25 sec |
| " | " | " | 180°F (82.2°C) | 15 sec |
| Continuous, higher heat shorter time (HHST) | Milk | " | 191°F (88.3°C) | 1 sec |
| " | " | " | 194°F (90°C) | 0.5 sec |
| " | " | " | 201°F (93.8°C) | 0.1 sec |
| " | " | " | 204°F (96.2°C) | 0.05 sec |
| " | " | " | 212°F (100°C) | 0.01 sec |
| Continuous, Ultrapasteurization | Milk and cream | Refrigerated, extended storage | 280°F (137.8°C) | 2 sec |
| Aseptic, ultra high temperature (UHT) | Milk | Room temperature | 275-302°F (135-150°C) | 4-15 sec |
| Sterilization | Canned products | " | 240°F (115.6°C) | 20 min |

- Pasteurization & sterilization
- Concentration

# Concluding thoughts

- Can solar thermal displace a significant fraction of the NG needed for industrial needs?
- What are the competing technologies?
- Which application is the “lowest hanging fruit” for solar thermal?