Analysis for Industrial Decarbonization: A National View

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Industry Decarbonization Pillars

Carbon intensity

- Process efficiency
- **Fuel switching**
- Feedstock substitution

Electrification
Solar for process heat
Hydrogen

Energy intensity

- Process efficiency
- Waste heat recovery

Use intensity

- Demand reduction (reuse, remanufacturing)
- Material substitution

Cresko (2020)

Electrification

Electrification

- NREL Electrification Futures Study (EFS) explored the impacts of widespread electrification in all U.S. economic sectors https://www.nrel.gov/analysis/electrification-futures.html
- Project conducted without assumptions for decarbonization
- For industry, literature and anecdotal evidence pointed to **productivity or profitability** benefits as the primary drivers of new technology adoption: improved product quality, higher throughput, reduced scrap and labor costs
- Created an adoption heuristic to approximate this behavior
  - Limited or no benefits (e.g., electric boilers)
  - Moderate benefits (e.g., resistance heating)
  - Large benefits (e.g., induction melting)

McMillan (2018)

EFS Approach for Industry: Sector and Tech Selection

Table 13. Industrial Subsectors and End Uses Relevant to Electrification Scenarios

Industrial Subsector	End Use	Representative Electrotechnology
All manufacturing industries and agriculture	Building HVAC	Industrial heat pump
	Machine drive	Electric machine drive
Food, chemicals, transportation equipment, plastics, and other manufacturing	Process heat	Electric boiler
Food	Process heat	Industrial heat pump
Chemicals	Process heat	Resistance heating
		Industrial heat pump
Glass and glass products	Process heat	Direct resistance melting (electric glass melt furnace)
Primary metals	Process heat	Induction furnace
Transportation equipment	Process heat	Induction furnace
Plastic and rubber products	Process heat	Resistance heating
	Process heat	Infrared processing
Other manufacturing	Process heat	Resistance heating
Other wood products and printing and related support	Process heat: curing	Ultraviolet curing

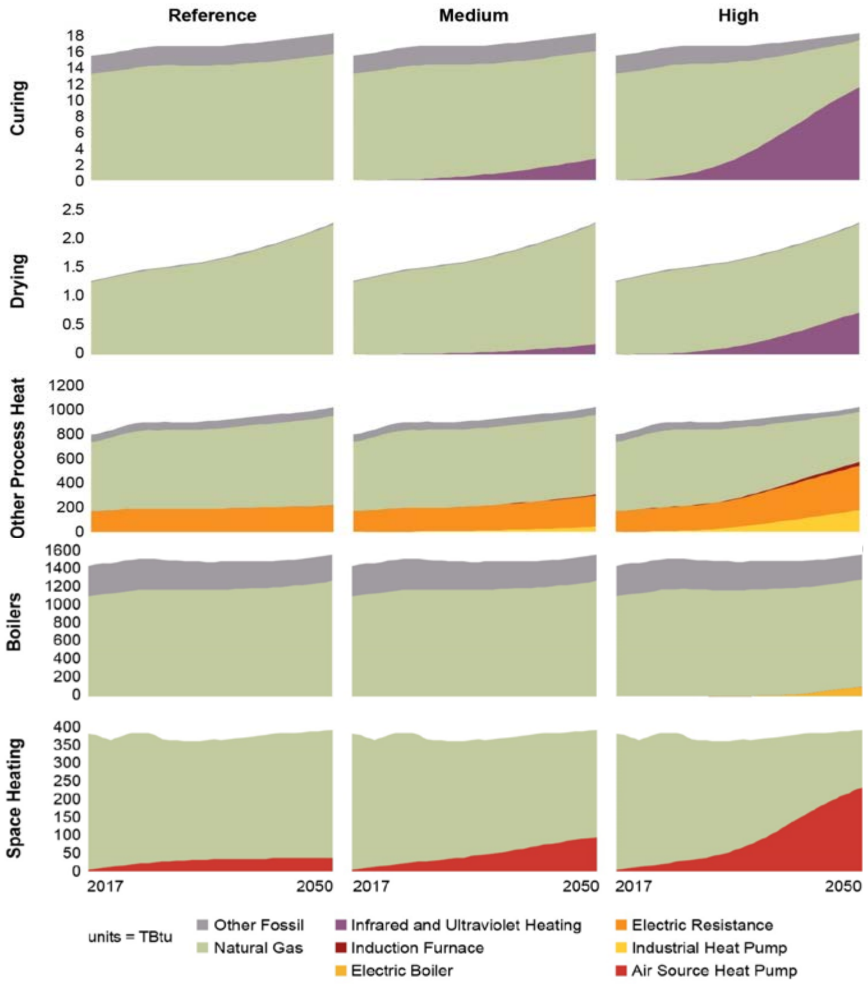
McMillan (2018)

Industry Scope

- **Excluded:** iron and steel processes, cement, lime, petroleum refining, and pulp and paper processes
- Included industries and end uses account for 43% of industry fuel energy use.
- Extent of electrification ultimately depends on **stock turnover** and **adoption** assumptions.

EFS Industry Results

- Most-significant growth for electrotechnologies with **productivity benefits**
- In the **High** scenario, electrotechnologies provide **63% of curing** needs, **32% of drying** services, and **56% of other process heating**
- High scenario driven by a 50% reduction in equipment lifetimes



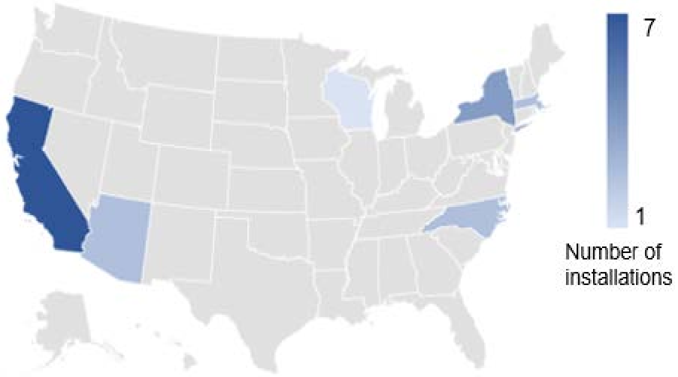
McMillan (2018)

Solar for Industrial Process Heat

Analysis Introduction

- Industrial process heat (IPH) is the transfer of heat to a material within a production process by convection, conduction, or radiation
- The potential to use of solar technologies (solar thermal and PV) for meeting IPH in the United States is an understudied and important topic
- The motivating research questions are:
    1. What are the geographic, temporal, and operational characteristics of IPH demand in the United States?
    2. What is the county-by-county **opportunity** to meet IPH demand with solar technologies?

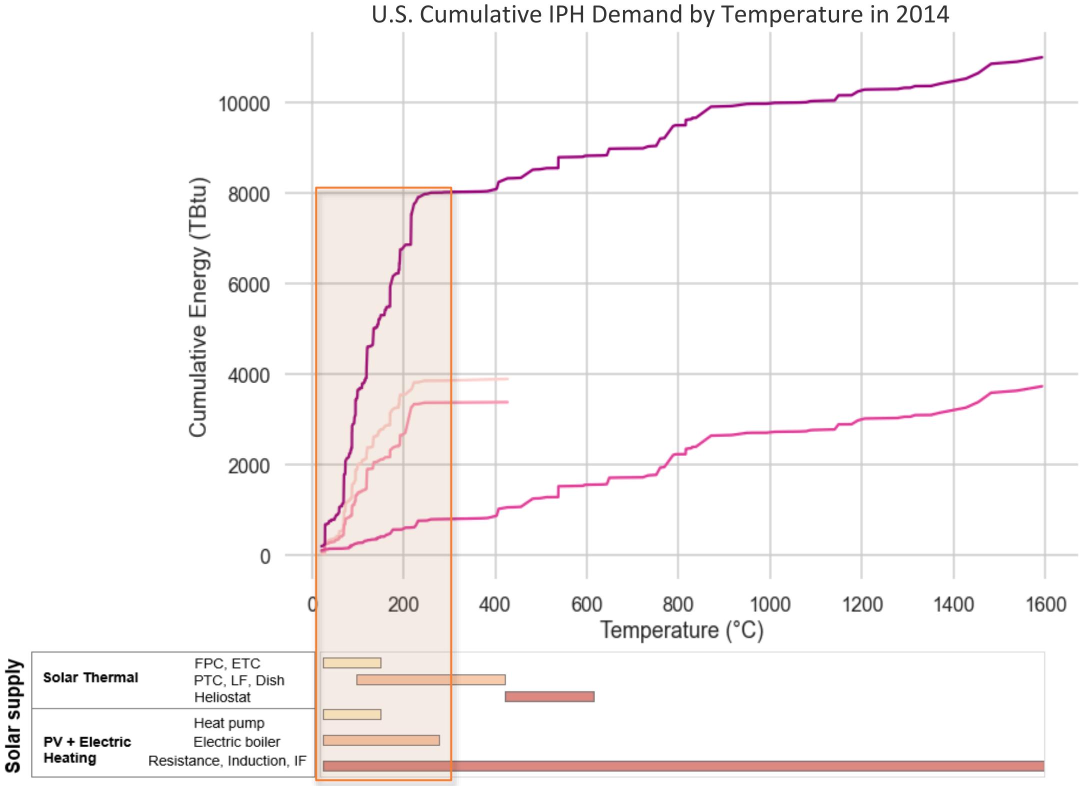
https://www.nrel.gov/analysis/solar-industrial-process-heat.html



Solar Process Heat Installations (2019)

McMillan et al. (2021a)

Why Solar for IPH?



Solar technologies are well-matched to the temperature demands of IPH in the U.S.

But, what about temporal and geographic characteristics of IPH demands?

McMillan et al. (2021a)

Matching Solar Technologies with IPH Applications

Conventional IPH Technologies and Applications	Solar Technologies		
Conventional boiler, CHP; hot water (<90°C)	Flat plate collector (w/ water storage)		(1)
Conventional boiler, CHP, process heat	Parabolic trough collector (w/wo 6-hr thermal energy storage)		(2)
	Linear Fresnel, direct steam generation		(3)
Conventional boiler, CHP; hot water (<90°C)	Ambient heat pump (HP) (w/ water storage)	PV	(4)
Conventional boiler (steam and hot water)	Electric boiler		(5)
Conventional boiler, CHP, process heat	Resistance heater		(6)
Conventional boiler, CHP, process heat	Waste heat recovery HP (WPRHP)		(7)

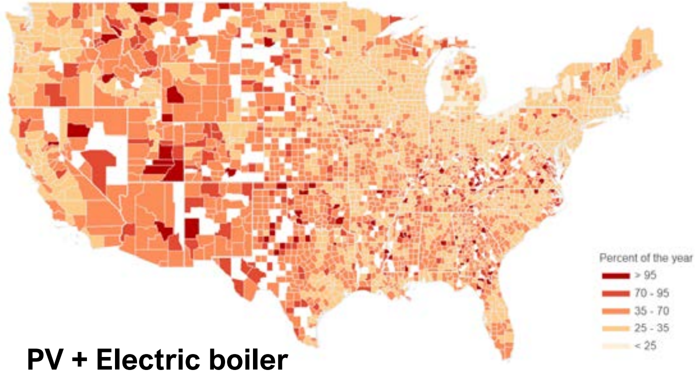
7 solar "technology packages"

Legend:
- Conventional IPH technology and application
- IPH electrotechnology
- Solar technology

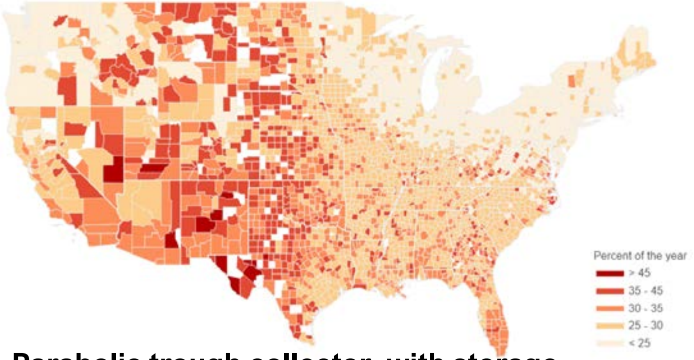
McMillan et al. (2021a)

Frequency of Solar Heat Fully Meeting Process Heat Demand

Flat plate collector, with storage

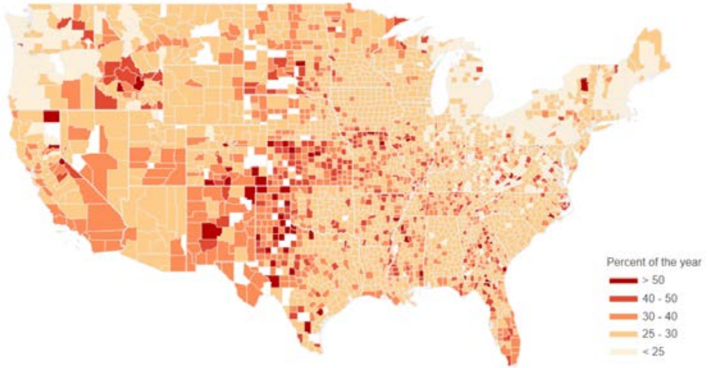


Parabolic trough collector, no storage

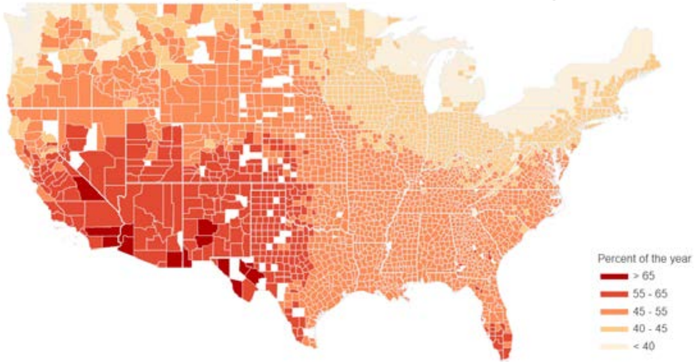


Note: color bins are different per technology

PV + Electric boiler



Parabolic trough collector, with storage



- Based on hourly solar fraction: when the solar fraction is 1 or greater, solar heat can fully meet demand
- Maps show how often during the year that solar heat is fully meeting demand in the county

McMillan et al. (2021a)

Conclusions for Solar for IPH Analysis

- First national level analysis for the U.S., conducted at the county level
- Solar thermal and PV heat technologies can meet many temperature needs; nearly 25% of 2014 IPH demand
- Most counties have sufficient available land, although site-specific details matter
  - On average only 5% of land is needed
  - However, site assessment for individual facilities is needed to determine economic viability
- **Key insight:** All CONUS states can readily benefit from solar heat technologies, and meet a large portion of their IPH demand
- **Key insight:** possible for heating technologies to reduce CO_2 emissions by ~15%
- **Key insight:** thermal energy storage is a key for solar IPH success

Interactive map of results: https://nrel.carto.com/u/gds-member/builder/51943617-62eb-4241-8b30-c943fce85692/embed

McMillan et al. (2021a)

Hydrogen

Hydrogen

Feedstock	Combustion
• Direct reduction ironmaking (H2DRI) • Ammonia • Synthetic hydrocarbons (e.g., methanol) • Biofuels	• Natural gas blending (typically 5-20% H2 [Melaina et al. 2013]) • Pure H2

Hydrogen: Combustion

Most industrial gas heating equipment could be retrofitted to operate on pure H2, but there are several key challenges (Durusut et al. 2019):

Technical

- **Food ovens**: Are generally custom made. H2 could impact strict product quality standards.
- **Kilns**: concerns about impact of changes in flue gas composition, particularly with higher moisture content
- All equipment
  - Increased NOx emissions
  - Convective heat transfer: lower air requirement reduces the gas volume available to transfer heat
  - Hydrogen burner development
  - Leakage risks and embrittlement of piping and fittings

Environment, safety & health

- Explosive atmosphere regulations- cost and space

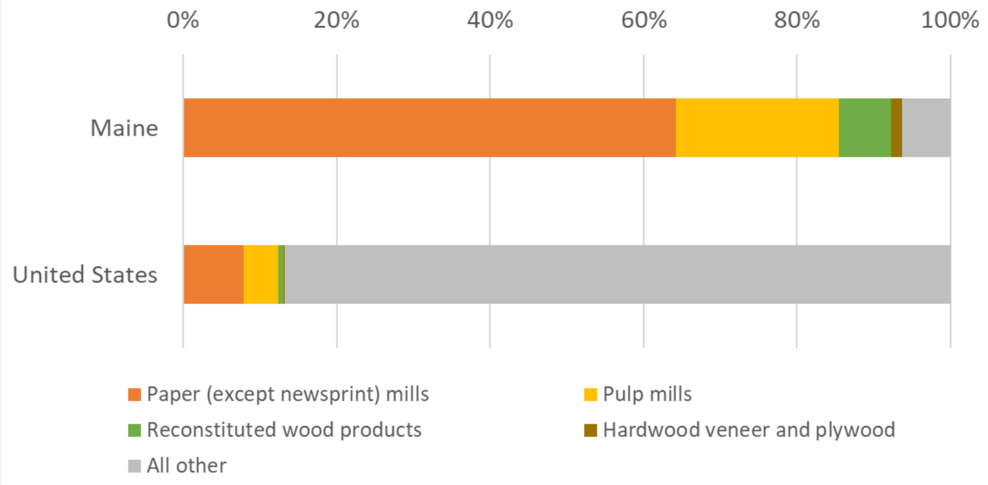
Resources & site

- Staff training
- Demonstration and implementation resources
- Hidden costs: downtime/shutdown

Maine in National Context

Maine in National Context

- Maine's industry composition is very different from U.S., but process heat remains important
- Electrification (infrared dryers) or solar thermal could be used in drying processes
- Use of biomass byproducts changes economics and environmental impacts of fuel switching
- How could these differences become opportunities?



Comparison of industry composition of estimated process heat demand (data from McMillan [2019])

Q&A

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