Industry Decarbonization Pillars

Carbon intensity
- Process efficiency
- Fuel switching
- Feedstock substitution

Energy intensity
- Process efficiency
- Waste heat recovery

Use intensity
- Demand reduction (reuse, remanufacturing)
- Material substitution

Cresko (2020)

Electrification
- Solar for process heat
- Hydrogen
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](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)
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
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?

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

- Conventional boiler, CHP; hot water (<90°C)
- Conventional boiler, CHP, process heat
- Conventional boiler, CHP; hot water (<90°C)
- Conventional boiler (steam and hot water)
- Conventional boiler, CHP, process heat

Solar Technologies

- Flat plate collector (w/ water storage)
- Parabolic trough collector (w/wo 6-hr thermal energy storage)
- Linear Fresnel, direct steam generation
- Ambient heat pump (HP) (w/ water storage)
- Electric boiler
- Resistance heater
- Waste heat recovery HP (WPRHP)

7 solar “technology packages”

McMillan et al. (2021a)
Frequency of Solar Heat Fully Meeting Process Heat Demand

- Flat plate collector, with storage
- PV + Electric boiler
- Parabolic trough collector, with storage
- Parabolic trough collector, no 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

Note: color bins are different per technology

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 CO₂ 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
- Direct reduction ironmaking (H2DRI)
- Ammonia
- Synthetic hydrocarbons (e.g., methanol)
- Biofuels

## Combustion
- Natural gas blending (typically 5-20% H2 [Melaina et al. 2013])
- Pure H2
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’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])


