Guidehouse

Playbook for Decarbonizing Process Heat in the Food and Beverage Sector

Heat Pumps and Electric Boilers as Enabling Technologies

July 2023

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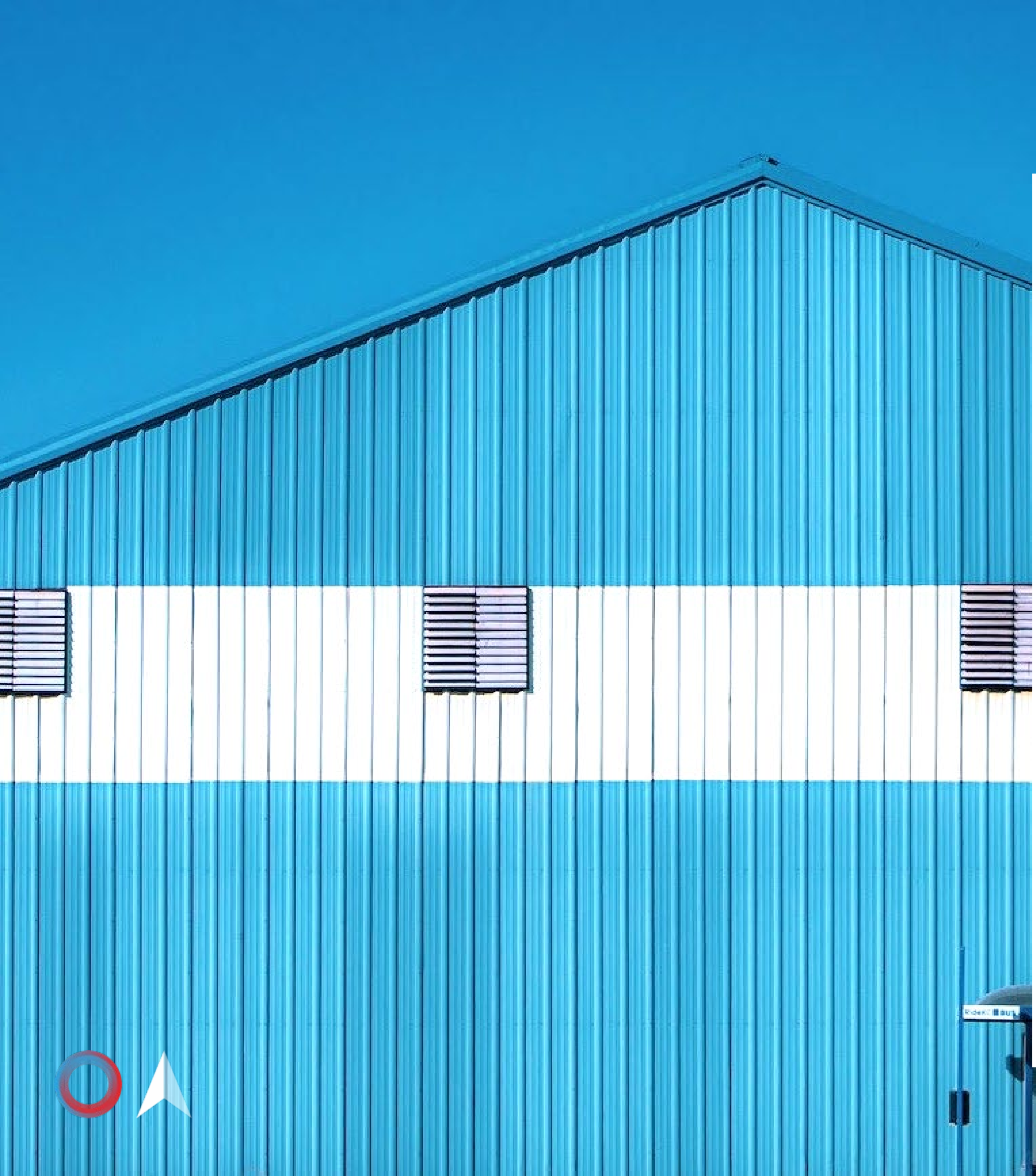


Introduction

Motivation, Scope, Executive Summary, and How to Use this Playbook

Motivation for Developing This Playbook

In the US, food and beverage processing and manufacturing is the fourth largest sector of industrial heat emissions, following refineries, chemicals, and iron and steel. According to RTC's *Renewable Thermal Vision Report*, 97% of the heat in this sector is in the low-temperature range, (<130º C), which can be decarbonized on an accelerated timeline with solar thermal and electrification technologies, particularly heat pumps.

The RTC *Vision Report* estimates that the sector can phase out coal and petroleum by 2030 and natural gas by 2035. By 2050, electrification will be able to provide more than 85% of the process heat in the sector, most of which is from heat pumps. Building on the *Vision Report* analysis to accelerate the decarbonization of the food and beverage sector, and to build the knowledge base for heat pump as a critical decarbonization solution more broadly, the Renewable Thermal Collaborative developed this playbook to review the potential for and barriers to heat pump deployment, and to provide recommendations for market and policy stakeholders so that they can overcome technology, market, and policy barriers, and scale the adoption of heat pumps and electric boilers to decarbonize process heat in the food and beverage sector.

The playbook is part of RTC's broader efforts to drive industrial electrification, among other solutions. Solar thermal energy with battery storage is another promising solution for the food and beverage sector, particularly in solar resource-rich regions such as the US Southwest. Learn more about RTC's Solar Thermal Technology Assessment and thermal storage work.

Renewable Thermal Vision Report

Industrial Electrification

Thermal Energy Storage

The Value of this Playbook

This playbook provides a guide for heat pump implementation as an enabler for food and beverage sector decarbonization

As an Energy Buyer

- Understand and assess energy use and emissions profile to prioritize decarbonization actions
- Understand what external factors dictate electrification as a priority and which internal and external stakeholders enable implementation
- Become familiar with the benefits and challenges of electrification technology implementation and be able to contribute to internal and external communications (See Technologies)
- Become familiar with relevant state and federal policies so you can contribute to internal and external communication (See Market Overview)
- Understand steps, practical implementation considerations, and success factors for deploying heat pumps effectively (See Approach to Deployment for technical approach and Developing an Implementation Plan for organizational approach)
- Identify actions that align with market and policy conditions required for scaling heat pumps and electric boilers to decarbonize operations

As a Solutions Provider

- Understand the barriers that potential industrial heat pump and electric boiler customers face
- Become familiar with the landscape for current case studies and best practice standards to guide potential customers (See Approach to Deployment and Examples of Heat Pump Application)
- Understand which collaborations with research organizations would help improve industrial heat pump implementations
- Understand policies and resources to improve domestic workforce development around heat pump training and certifications for HVAC professionals
- Understand the policy and incentive frameworks around process heat electrification and how to develop guidance for lawmakers

As a Policymaker

- Understand the decarbonization opportunities that can be secured through addressing process heat in the food and beverage sector
- Understand short-term strategies and tradeoffs for electrification and consider nuanced positions that favor long-term benefits
- Understand what technical and cost barriers are impeding heat pump and electric boiler adoption and how to overcome them
- Understand what factors will catalyze public/private partnerships for heat pump application research, development, and demonstration projects
- Advocate for policy frameworks to reduce technical and financial barriers to process heat electrification
- Advocate for policy frameworks that can accelerate economic and workforce needs for heat pump deployment at scale

To jump to hands-on recommendations for heat pump implementation, see Pathways for Enabling Technology Implementation

Executive Summary

Food and beverage processing in the US emits the equivalent of 92 million metric tons of carbon dioxide per year, with process heat and boiler use responsible for 28% and 21% of these fuel emissions, respectively. Over the past five years, as renewable energy contributions to the electrical grid have increased, emissions from electricity use have decreased. At the same time though, fuel emissions have increased. The temperature range of process heat in food and beverage processing is creates a unique and significant opportunity for heat pump and electric boiler deployment.

States with high GHG emissions from fuel for food and beverage processing include Iowa, Illinois, and California. Collectively, they generate more than 26 million metric tons of carbon dioxide annually—over 28% of the national total. Environmental policies that apply to food and beverage manufacturers vary greatly among states, with more stringent regulations associated with lower GHG emissions.

The effective deployment of heat pumps for food and beverage processing involves the optimization of process heat requirements by reducing setpoints, de-steaming processes, and leveraging heat recovery. Thermal mapping exercises, including the characterization of heat sources and heat sinks, and conducting pinch analyses, are useful for identifying potential heat pump applications.

Heat pumps can be effectively deployed in a variety of common food and beverage manufacturing processes, including drying, CIP, and pasteurization, leading to higher efficiencies and potential cost savings, despite continued barriers to widespread adoption.

Barriers to adoption include lack of operational track record, project costs, grid infrastructure limitations, and utility pricing structures. Addressing these barriers requires collective action and collaboration from energy buyers in the food and beverage industry, industry associations and coalitions, and policymakers.

A wide range of factors, from electrical infrastructure to space availability, should be considered when selecting heat pumps for specific manufacturing applications. Technologies that reduce the need for process heat or produce it with clean electricity, such as electric boilers and heat pumps, could further decarbonize food and beverage processing. **Policy interventions that can help drive rapid adoption of these technologies include reforms of electricity markets, support for developing the domestic heat pump market, and support for research and demonstration projects.**

Practical technical steps and recommendations for tackling barriers prepare energy buyers for implementation following **four key phases: 1) target setting and internal and external stakeholder engagement, 2) onsite techno-economic assessment, 3) development of detailed design for projects, and 4) implementation of solution and lessons learned.**

This playbook provides energy buyers, solution providers, and policymakers with an understanding of the US policy landscape, as well as technical implementation considerations, reference to existing tools, case studies, and pathways to decarbonizing process heat using heat pumps and electric boilers. Cross-sector collaboration and collective action are critical for scaling adoption and implementation of these technologies to advance decarbonization in the food and beverage sector.

Playbook Scope and Methodology

Aims

This playbook aims to:

- Assess major technology, market, and policy barriers to adoption of heat pumps and electric boilers
- Recommend priority actions for each stakeholder group so that they can leverage opportunities with heat pumps and electric boilers to decarbonize process heat in the food and beverage sector
- Provide corporate energy buyers a set of concrete, actionable recommendations on how to switch to heat pumps and electric boilers at their facilities to reduce GHG emissions and realize a cleaner energy supply

Scope

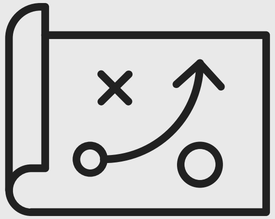
This playbook focuses on:

- The US food and beverage industry, with specific examination of California, Illinois, and Iowa (52% of the sector's emissions)
- Heat pumps and electric boilers for process heat
- Food and beverage manufacturing process heat below 100° C, with specific focus on drying, cleaning-in-place (CIP), and pasteurization

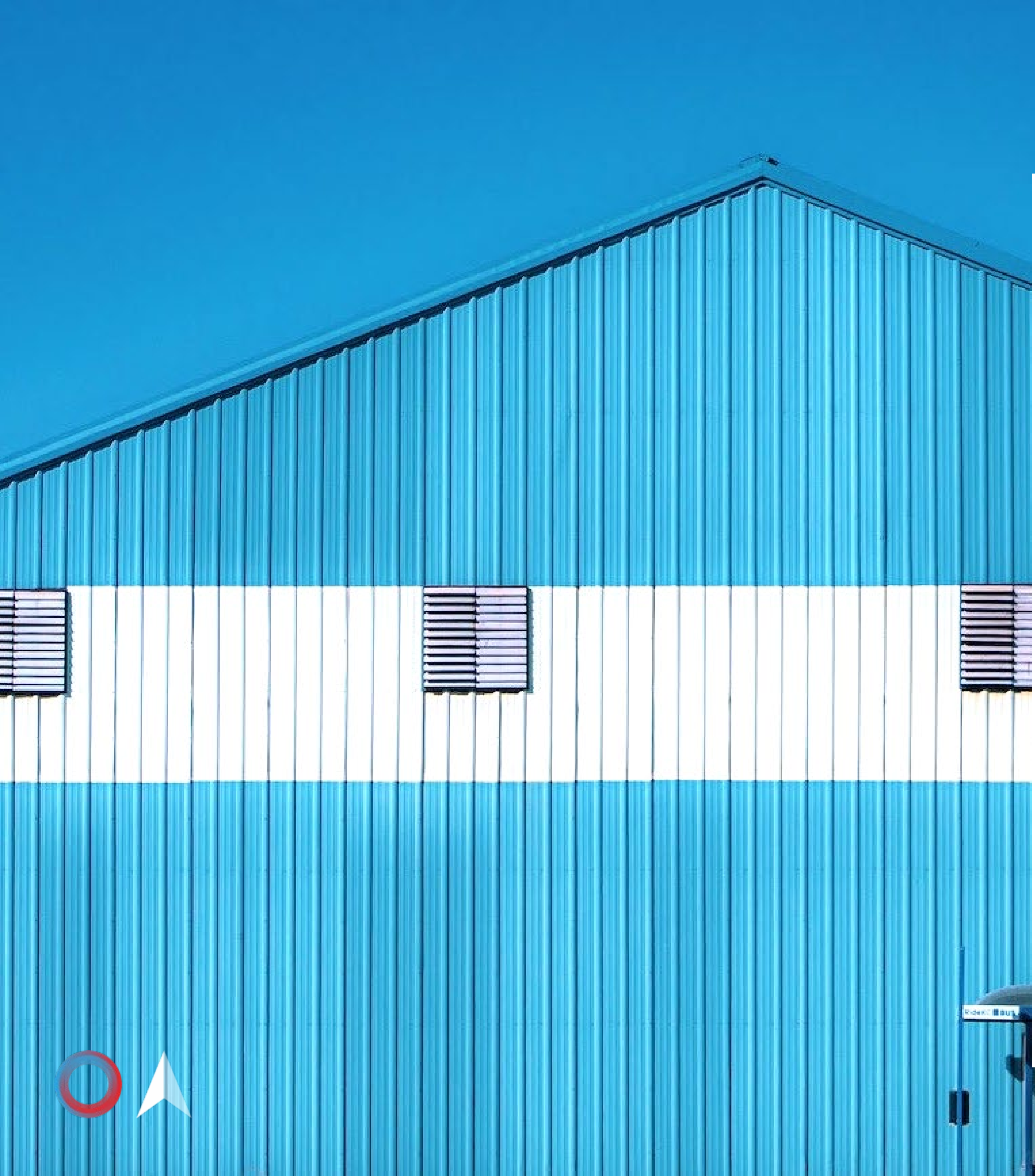
Methodology

This playbook was developed by:

- Quantifying, at a high-level, the emissions and energy use for the main food and beverage sector processes, by subsector, region, temperature range, and process type
- Reviewing federal policy landscape and incentives as well as state incentives in Iowa, Illinois, and California
- Characterizing the technology maturity of heat pumps and electric boilers and applicability for the selected processes and temperature ranges
- Reviewing the general market and commercial barriers preventing widespread adoption of the selected technologies and specific situations or barriers in Iowa, Illinois, and California
- Gathering inputs from energy buyers and solutions providers through the Renewable Thermal Collaborative (RTC) food and beverage working group
- Identifying low hanging fruit pathways for the adoption of heat pumps and electric boilers and their potential impact to reduce Scope 1 emissions in the food and beverage sector processing steps



This playbook is intended to provide key market and policy stakeholders strategies for overcoming technology, market, and policy barriers, and help them scale the adoption of heat pumps and electric boilers to decarbonize process heat in the food and beverage sector.

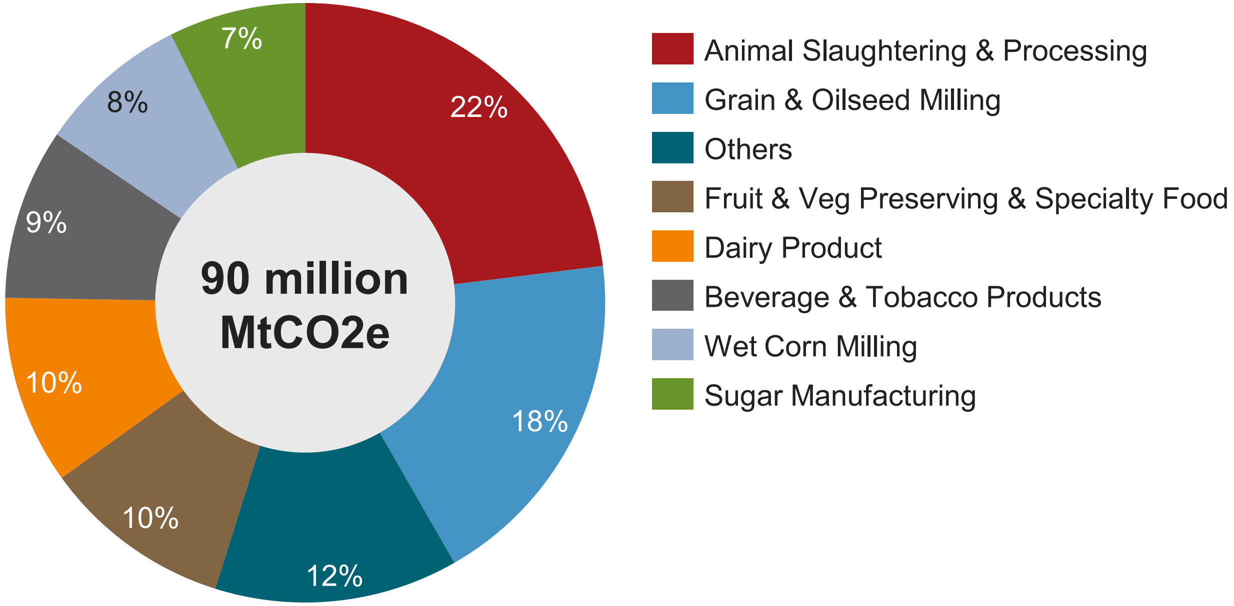


Current State

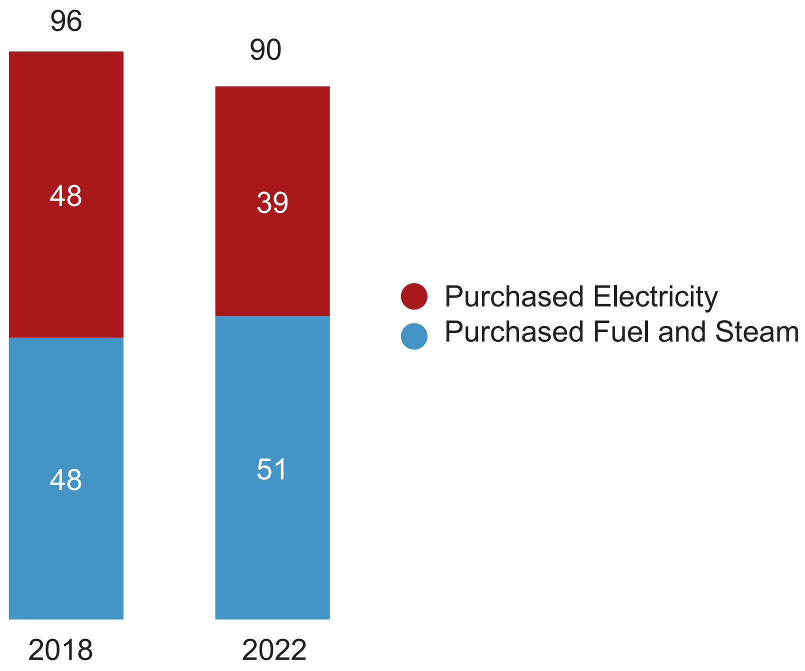
Scope 1 Internal Operations' Greenhouse Gas Emissions from Food & Beverage Processing

Internal Operations: US Food and Beverage Sector Greenhouse Gas Emissions

2022 US Food and Beverage Processing GHG Scope 1 & 2 Emissions by Sub-Sector (in Million tCO2e)[1]



US Food and Beverage Processing Scope 1 & 2 GHG Emissions by Energy Use (in Million tCO2e)[1]



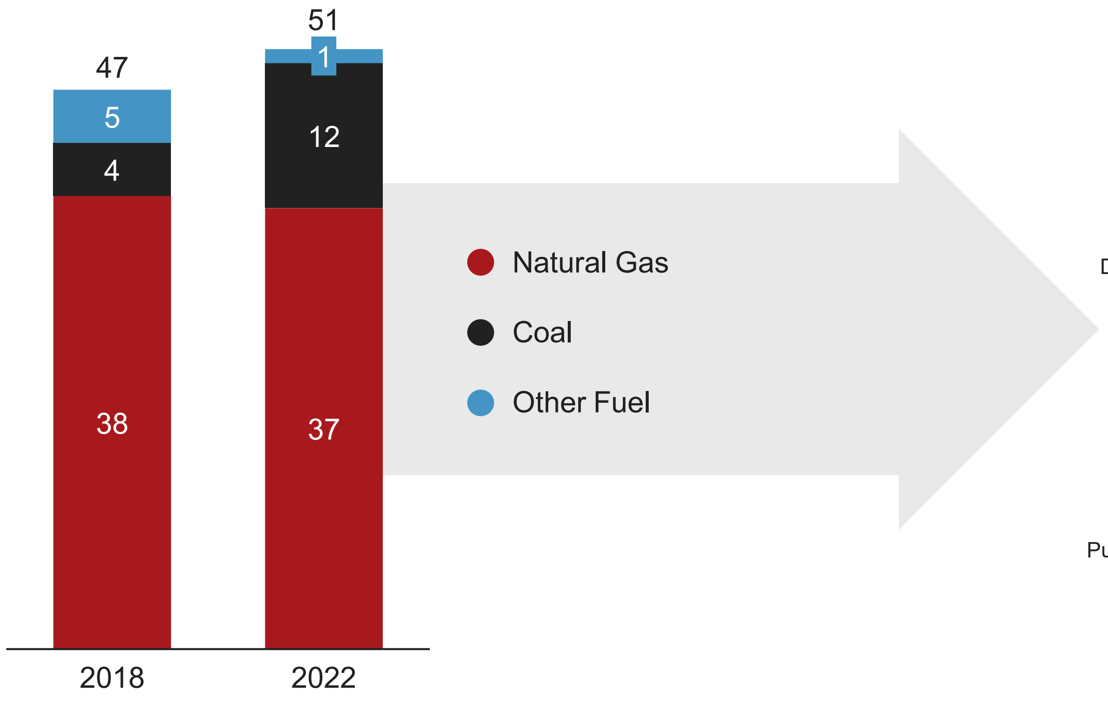
Source: Estimated based on U.S. Energy Information Administration, *Annual Energy Outlook 2023 Table 25. Food Industry Energy Consumption*, 2023., MECS, "Fuel Consumption, 2018,", Dec 2018.

Thermal Emissions from Food and Beverage Sector

Steam generation and direct fuel use in process heating (thermal emissions) are responsible for **~80% of emissions** from fuel use in food and beverage processing. **Process heating and thermal losses** alone contributes to **71%** of all **fuel use emissions**.

Emissions Breakdown Based on Fuel Usage

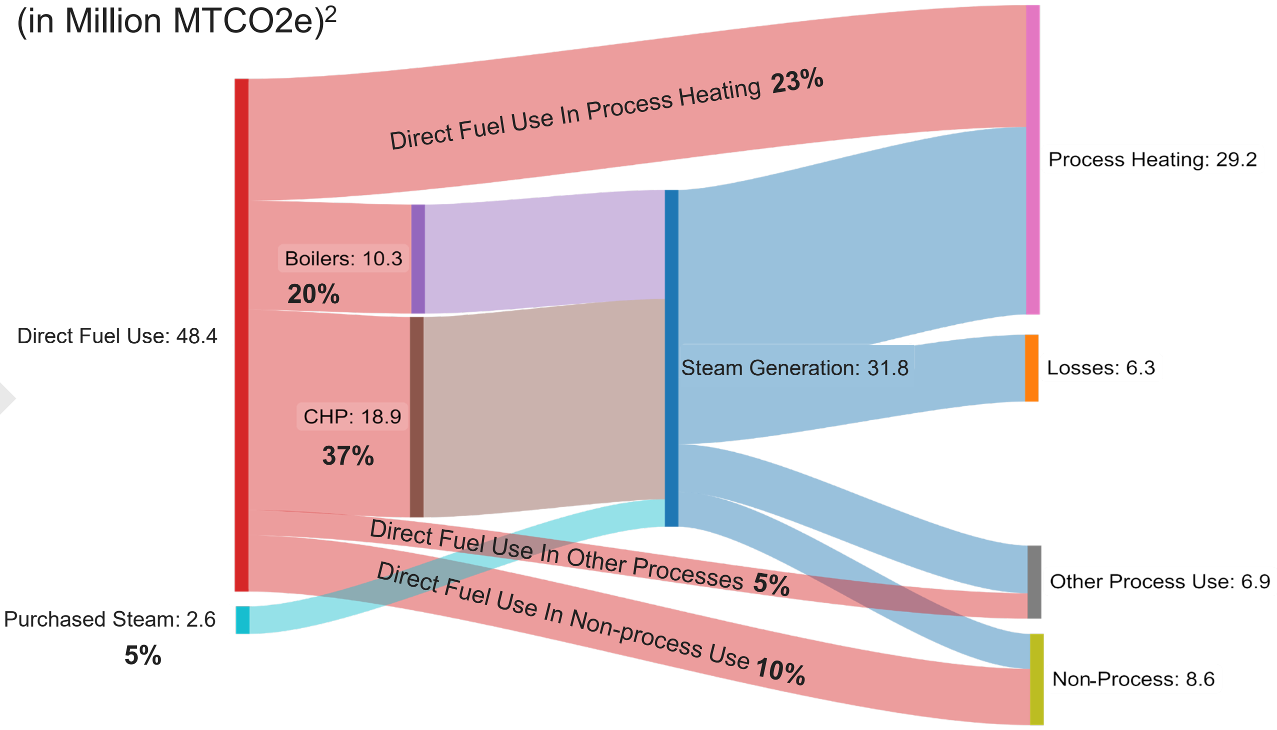
(in Million MTCO2e)[1]



Source: Estimated based on U.S. Energy Information Administration, *Annual Energy Outlook 2023 Table 25. Food Industry Energy Consumption*, 2023., MECS, "Fuel Consumption, 2018 Dec 2018.

Emissions Breakdown Based on Energy End Use

(in Million MTCO2e)[2]

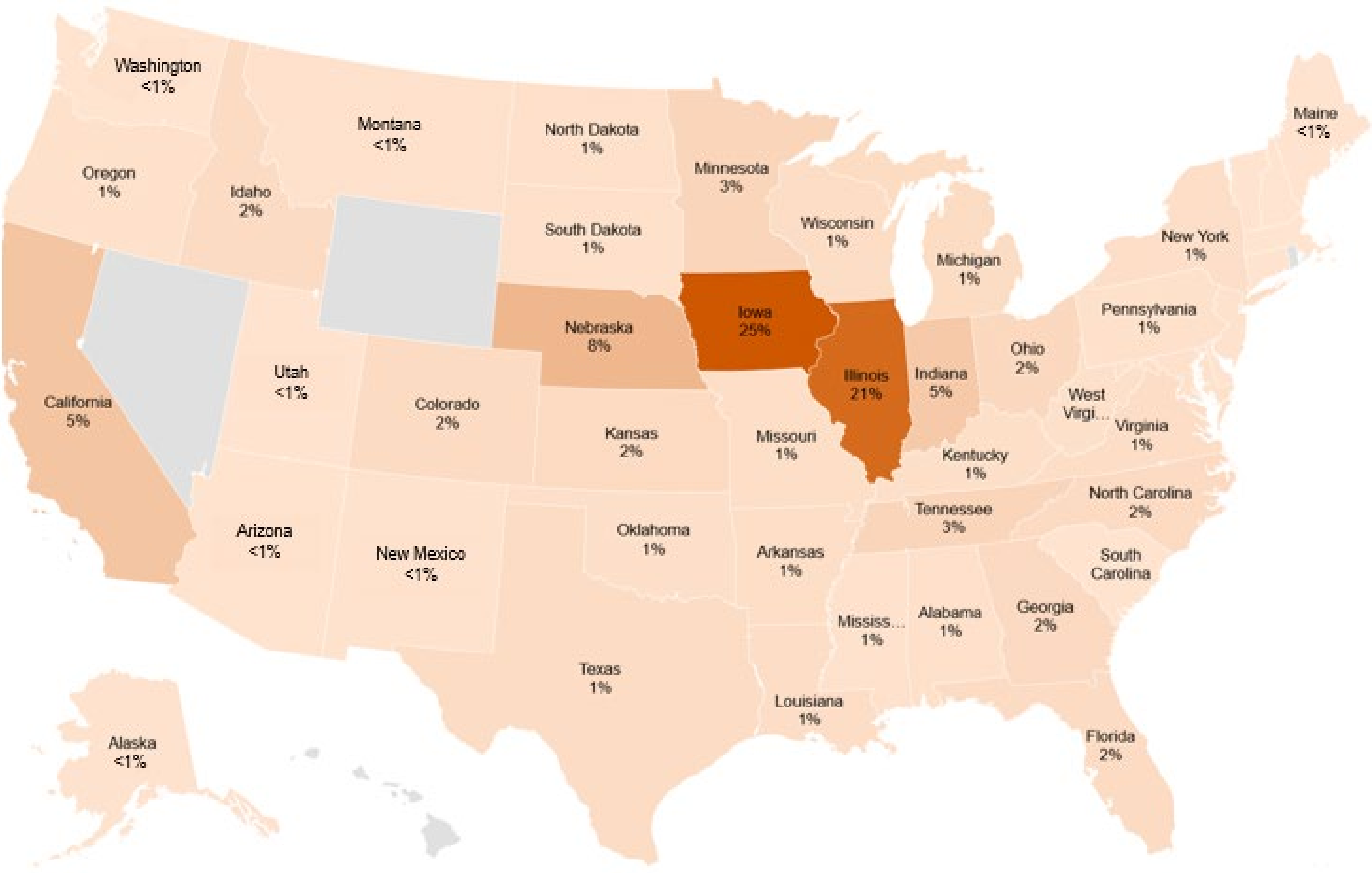


Source: % Breakdown of emissions from MECS, "Manufacturing Energy and Carbon Footprint, Sector: Food & Beverage", February 2021,

*These charts exclude electricity emissions.

Greenhouse Gas Emissions from Fuel by State

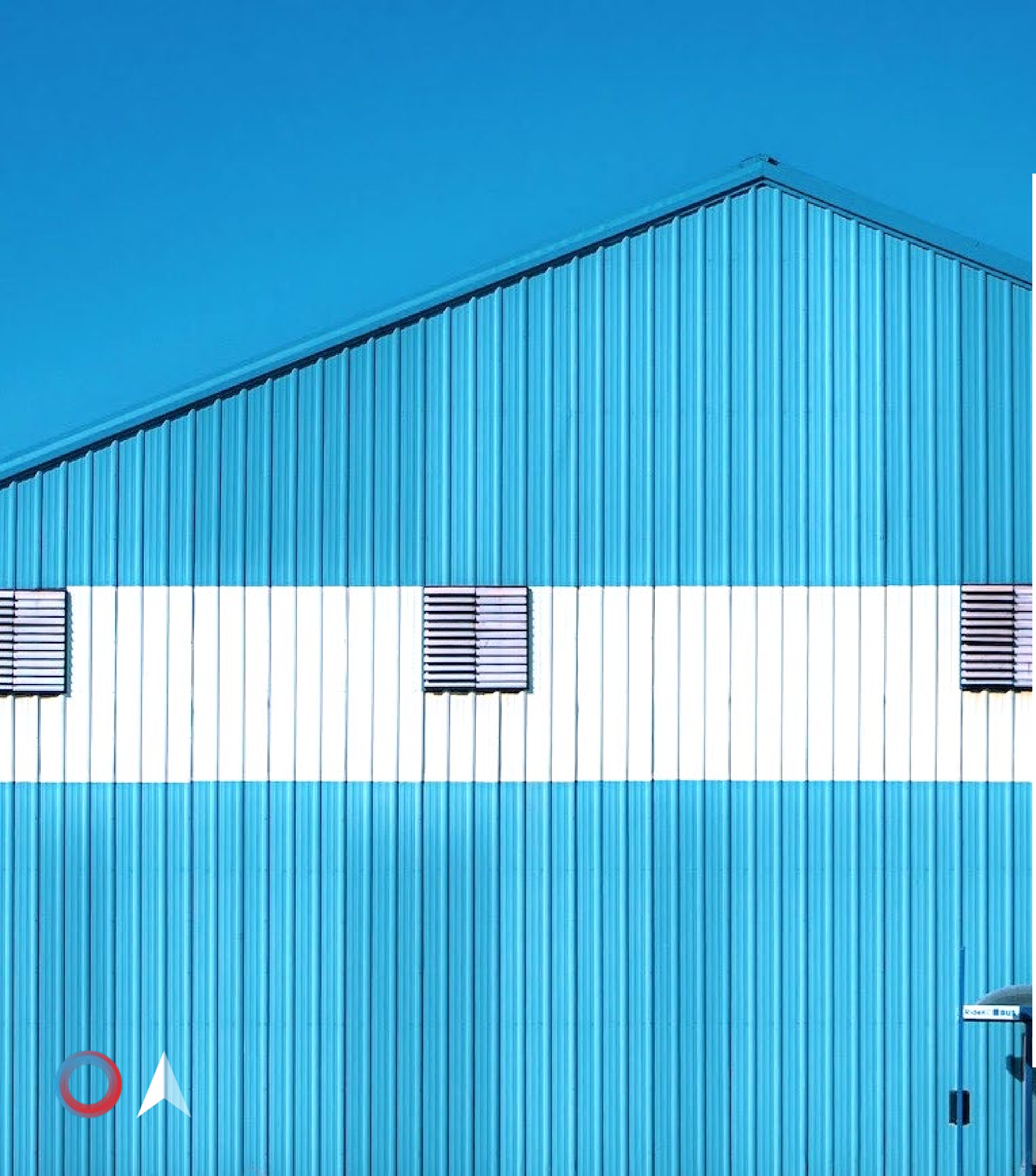
Food And Beverage Fuel Emissions By State in 2022 (% state contribution)[3]



65%

of US emissions from fuel use for food and beverage processing are concentrated in the top 5 states of Iowa, Illinois, Nebraska, California & Indiana

Source: Estimated using emissions contribution of individual states using EPA FLIGHT data (accessed April 2023). EPA FLIGHT data only covers facilities emitting >10,000 $MtCO_2e$. Values were scaled to match total USA food & beverage emissions.



Market Overview

Federal and State-Level Market Overview, with a Focus on California, Illinois, and Iowa

Food and Beverage Industry Insights: US

Market Overview

The food and beverage manufacturing industry provides important economic impacts for the US.

- Nationally, **the industry accounted for 1.5 million employees in 2021 out of roughly 11.2 million total manufacturing employees.**[4]
  - Food and beverage manufacturing is tied with transportation equipment manufacturing for the greatest number of employees (in manufacturing).
- California, Texas, and Illinois employed the most workers in 2021, with a combined 326,633 workers.[3]
- These states are correspondingly responsible for the highest revenue from food and beverage manufacturing, contributing to a combined $195.2 billion out of the industry's total $904.1 billion in sales in 2021.[3]

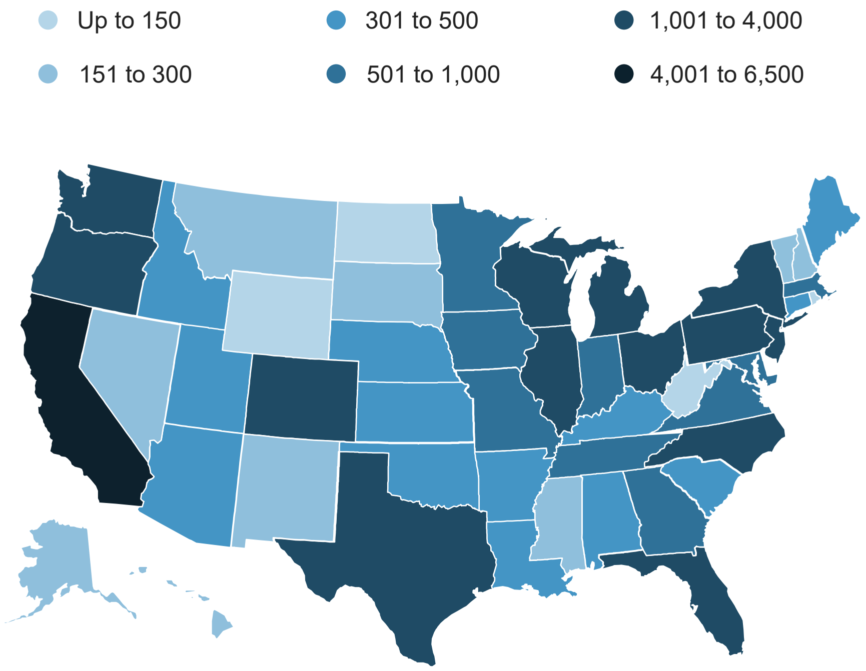
In 2020, there were 39,646 food and beverage processing plants in the US.[3]

Policy Landscape

The US is currently amid a decarbonization incentive boom.

- Thanks in large part to the Inflation Reduction Act (IRA) and the Infrastructure Investment and Jobs Act (IIJA), **large pools of incentive money are being deployed** to aid in decarbonization of all kinds. More clarity is needed on when industrial projects qualify for incentives, and eligibility should be expanded to cover additional use cases.
- At the state level**, there is space to advocate for strengthening of industrial electrification incentives**, especially as most heat pump incentives are specified for the residential market.
- Twenty states, including Illinois, have implemented performance-based regulation (PBR) to alter utility profit models in a way that **financially incentivizes strong performance** on metrics like reliability and sustainability.
- Some regions allow utilities to **negotiate directly with industrial clients** in order to secure better rates, typically in exchange for agreements on overload shifting or peak usage reductions.

Food and Beverage Manufacturing Plants: 2020



Source: USDA, Guidehouse Insights, using data from the U.S. Department of Commerce, Bureau of the Census, 2020 County Business Patterns

Food and Beverage Industry Insights: Focus on State-level

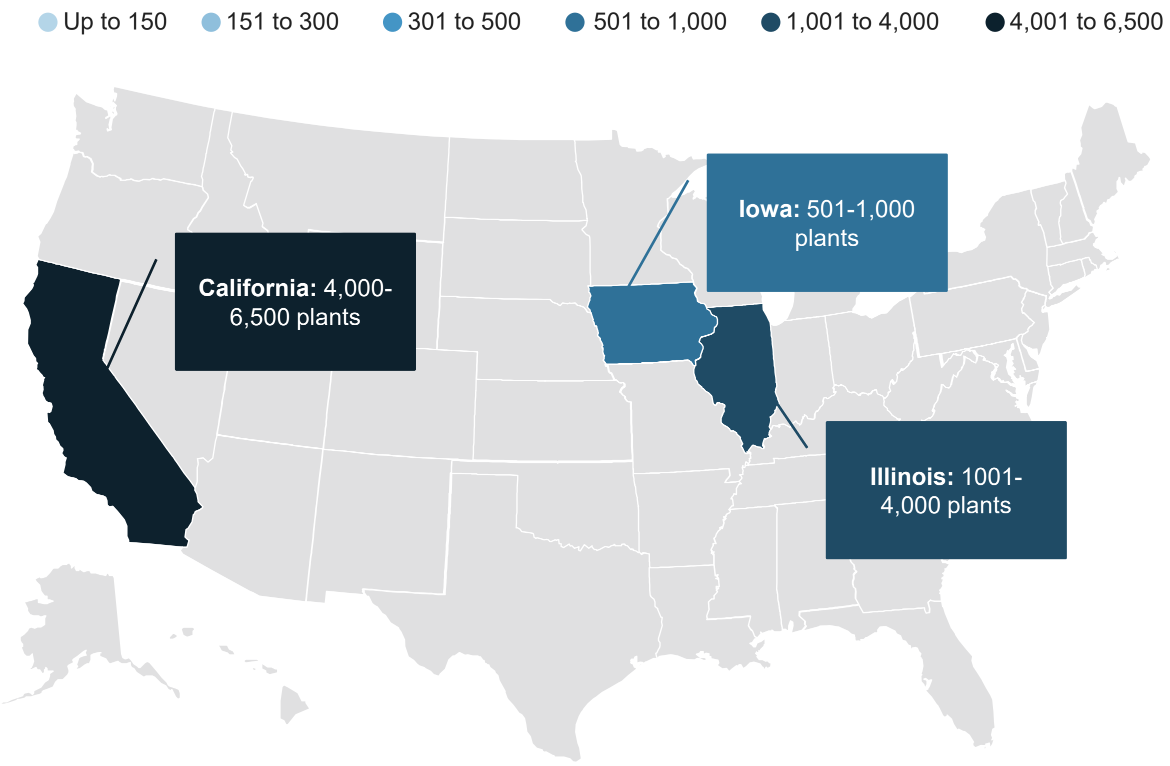
Large facilities by direct emissions are concentrated in several states

For large facilities[3] (i.e., those with direct emissions great than 10,000 metrics tonnes of CO2e per year), over 50% of US direct emissions from fuel use for food and beverage processing is concentrated in 5 states: Iowa, Illinois, Nebraska, California, and Indiana.

The next section examines the **market and policy landscape** for decarbonization at the **federal level** and state-level for **California, Illinois, and Iowa**.

Source: Estimated using emissions contribution of individual states using EPA FLIGHT data (accessed April 2023). EPA FLIGHT data only covers facilities emitting >10,000 MtCO2e. Values were scaled to match total USA food & beverage emissions as indicated in previous pages.

Food and Beverage Manufacturing Plants, State Highlights: 2020



Source: USDA, Guidehouse Insights, using data from the U.S. Department of Commerce, Bureau of the Census, 2020 County Business Patterns

Food and Beverage Industry Insights: California

Market Overview

California is known as a top food producing state in the US. **It grows over a third of the country's vegetables and two-thirds of its fruits and nuts.**[5]

- The state's top agriculture commodities include dairy products, almonds, grapes, pistachios, and cattle and calves, among others.

Food and beverage manufacturing in California provides important economic impacts for the state.

- In 2021, California employed 150,093 people in the food and beverage industry.[3]
- **The industry generated $84.7 billion in sales in 2021**.[3]

The state's top **manufactured** foods and beverages align with the food and beverages **grown** in California and include:

- Animal processing
- Dairy
- Fruits and vegetables
- Grain and oil seeds

The processes examined in Examples of Heat Pump Application are align with processes in manufacturing of these foods and beverage categories

Policy Highlights

California hosts a complex economic landscape of energy markets. A long running cap and trade program and aggressive decarbonization plan inform its policy landscape.

- California has published a plan to become net zero by 2045.[6]
  - This includes a **focus on decarbonizing industrial process heat with specific attention to electrification and solar thermal heat processes.**
  - California's plan notes that electrification of high heat processes remains a barrier and suggests that hydrogen or biogas/biomass may be needed in these cases.
- **California has a carbon emissions trading market which currently prices allowances at roughly $28/ton.**[7]
- California's ISO recently approved $7.3 billion in new transmission funding specifically to improve capacity for clean energy and aid state decarbonization efforts.
- In 2022, California launched the TECH Clean California program to invest $150 million into heat pump adoption.[8]
- California has worked with commercial partners to offer free heat pump training courses to HVAC certified workers.
- California has a 2022 ratemaking proposal (22-02-005) that would phase out ratepayer-funded energy efficiency for natural gas by 2030 for industrial uses with a viable alternative, potentially making electric alternatives more cost competitive.[9]

Food and Beverage Industry Insights: Illinois

Market Overview

Illinois is a top grower of corn, soybeans, cattle and calves, dairy, and poultry.

Manufacturing accounted for roughly 12% of the state's output in 2021.[9] Chemicals, food and beverage, and machinery manufacturing are the top three contributors to Illinois' manufacturing GDP.

- In 2021, Illinois employed 80,180 people in the food and beverage industry, ranking as the third highest employer for food and beverage workers nationally.[3]
- **The industry generated $44.6 billion in sales in 2021.[3]**

Food and beverage processing in the state economically strengthens urban areas.

Illinois is a leader in food processing research.

- The Institute for Food Safety and Health is a research consortium consisting of the U.S. Food and Drug Administration's Center for Food Safety and Applied Nutrition, Illinois Institute of Technology (IIT), and the food industry.
- Illinois is the top state for private food manufacturing R&D.

Policy Highlights

With a long running PBR program and a strong state-level decarbonization plan, Illinois is a national leader in climate policy. Industrial facilities in the state have support from both government and utility sectors for decarbonization efforts.

- Illinois passed the Climate and Equitable Jobs Act in 2021 which, among other things, mandates a 100% clean grid by 2045 and established funds for reducing energy transition barriers.[11]
- **Illinois instituted performance-based regulation (PBR) in 2011, one of the longest running PBRs in the US.**
  - Illinois' PBR is a policy action to make activities that advance goals like decarbonization more profitable for utilities than legacy business models. This is being used to achieve the states climate goals and cure market failures.
  - Stated goals of the Illinois PBR include goals to "maintain and improve service reliability and safety… [and] decarbonize utility systems at a pace that meets or exceeds State climate goals… [while making] **cost-effective investments that support achievement of Illinois' clean energy policies."**
- In 2022, ComEd published a Beneficial Electrification Plan which provides $100 million for electrification measures, including an undefined amount for industrial customers.[12]

Food and Beverage Industry Insights: Iowa

Market Overview

While the food and beverage manufacturing sector in Iowa is smaller than in California or Illinois, it still **ranks number four in the US in terms of sales and number nine in terms of number of employees.**

- In 2021, Iowa employed 53,052 people in the food and beverage industry.[3]
- **The industry generated $44.0 billion in sales in 2021.**[3]

Iowa's key food and beverage manufacturing sectors include animal slaughtering and processing, grain and oil seed processing, and animal food processing.

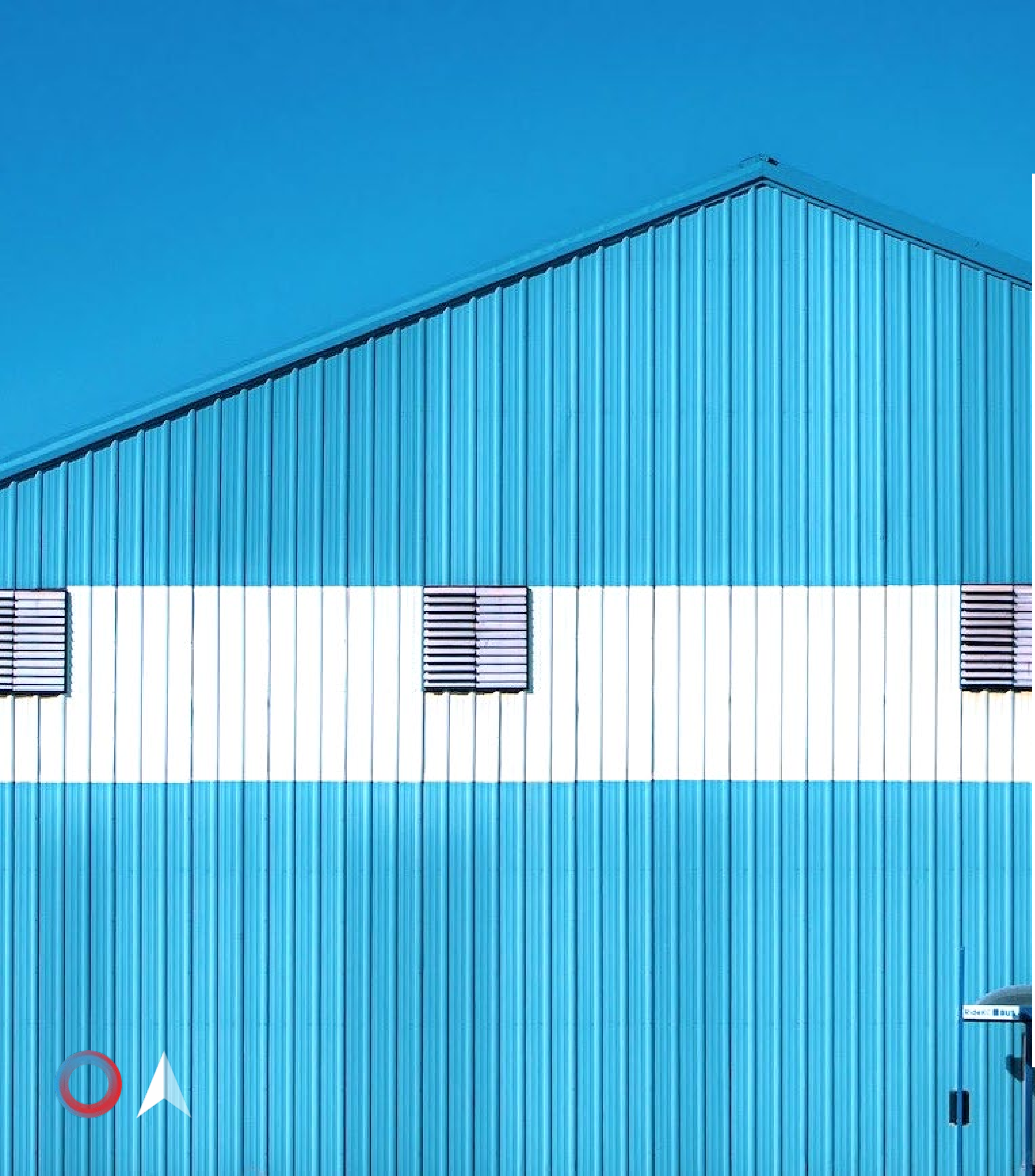
- Dairy products and fruit and vegetable processing represent a significantly smaller portion of the state's food and beverage industry.

Iowa actively courts food and beverage processors with pro-business policies and incentives.

Policy Highlights

Iowa takes a generally light touch approach to industrial and emissions regulations, which **limits both market constraints and electrification incentives.** While the latter are limited in the state, Iowa's high agricultural yields and wind energy potential give it strong potential for industrial decarbonization.

- While various cities in Iowa have implemented emissions reductions plans, the state as a whole does not have a comprehensive GHG reduction plan.
  - The State does have an emissions inventory program.
- Some private companies have begun utilizing corn stover (biomass left after harvest) for biogas production.
- **Some Iowa utilities have rebate programs in place for energy efficient grain dryers.**[13]



Scope 1 Greenhouse Gas Emission Reduction Technologies

Background on the Use of Heat Pumps and Electric Boilers, including their Benefits and Limitations Related to Food and Beverage Sector Greenhouse Gas Emission Reductions

Heat Pumps in Food and Beverage Processing

Heat pumps can provide an opportunity to abate emissions from process heating, which currently comprises of 23% of food and beverage processing emissions in the US

Principles of Operation

Heat pumps extract heat from a relatively low temperature heat source and compress a fluid to increase its temperature. They then deliver the heat where it is needed, often referred to as the **heat sink**.

In many applications, the initial low temperature heat source is air, water, or earth. However, in food and beverage processing, waste heat generated by chilling systems can also be utilized to efficiently produce hot air, water, or steam.

Heat Pump Benefits

Electric heat pumps powered by renewable energy do not emit GHG (though some industrial heat pumps are also driven by steam or natural gas). The coefficient of performance (COP) of electric industrial heat pumps can approach 4.0 (see grey box to the right).

Non-energy benefits of heat pumps for food and beverage processing include increased temperature control, the elimination of the risks associated with combustion of fuel sources, and operational cost savings (depending on the prices of fuel and electricity).

Common Electric Industrial Heat Pumps

- **Closed-cycle mechanical heat pumps** increase the temperature through mechanical compression of a refrigerant. Heat exchangers transfer heat at both the heat source and the heat sink.
- **Open-cycle mechanical vapor compression heat pumps** mechanically compress water vapor (usually from process steam) to increase temperature.

Heat Pump Limitations

Electric industrial heat pumps are not capable of meeting all food and beverage process heat needs. The temperature increases that can be achieved are limited (generally ~160° C), with degraded efficiency at high temperatures (~100° C).

Heat pumps are typically more expensive than fuel-burning heating technologies and installation may require upgraded electrical infrastructure.

The efficiency of a heat pump is expressed as the coefficient of performance (COP), which is the ratio of the heat power produced by the heat pump and the electric power it consumes:

$$\text{COP} = \frac{\text{heat output (w)}}{\text{electricity input (W)}}$$

Heat pumps are energy efficient because their COPs typically exceed 3.0, meaning that they produce more energy than they consume. A higher COP indicates better efficiency.

Electric Boilers in Food and Beverage Processing

Electric boilers can provide an opportunity to abate emissions from steam generation and boilers (20%) and part of current food and beverage processing emissions from CHP energy use, which represents 37% of food and beverage processing emissions in the US (see details on page 12)

Principles of Operation

Electric boilers use electricity for heating water to produce hot water or steam. In immersion boilers, the electricity heats resistance elements, which then heat the surrounding water. In electrode boilers, current flowing between submerged electrodes electrifies and heats the water.

Electric Boiler Benefits

Electric boilers are energy efficient, converting approximately 99% of the energy they consume into heat. When powered by renewable electricity, they do not emit GHG.

Electric boilers are simpler and cheaper to install and maintain than fuel-burning boilers, as less equipment is required. Electric boilers do not need combustion exhaust systems and they occupy substantially less space than traditional boilers. In some jurisdictions, permitting requirements are less onerous for electric boilers. Electric boilers are also far quieter than their alternatives, which can be important in some applications, such as when boilers are sited near occupied spaces.

Hybrid Electric Boilers

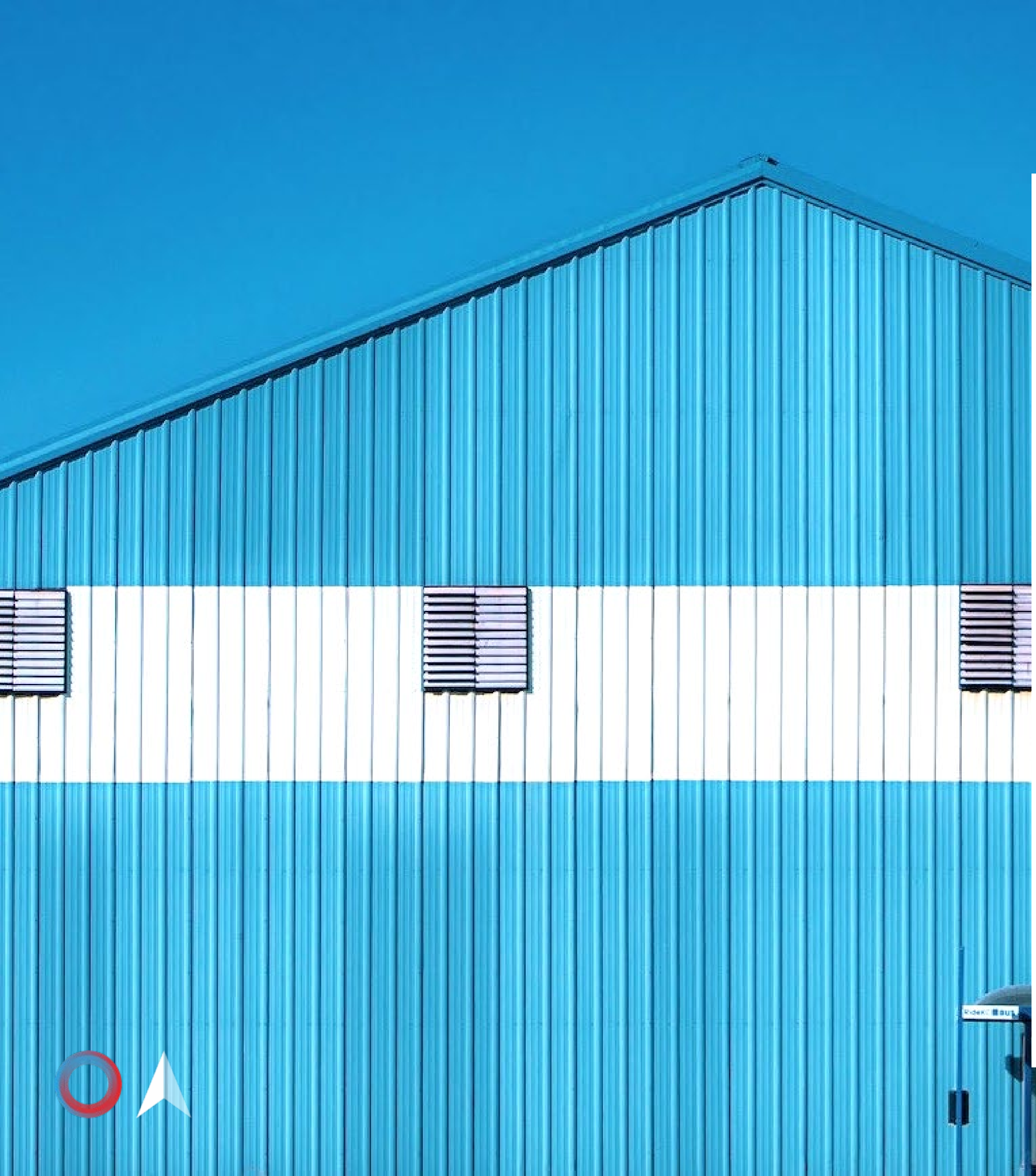
Hybrid electric boilers can produce hot water or steam from electricity and another fuel source. By using electricity during periods of high renewable power generation, renewable curtailment can be minimized. Users can elect to use another fuel source, such as natural gas, when electricity demand charges are high.

Electric Boiler Limitations

Electric boilers have high electrical demand and hence require larger infrastructure and grid connection capacity. With current power and fuel prices, they are more expensive to operate than traditional natural gas boilers in the US.

It is important to monitor water chemistry to prevent degradation of elements in immersion boilers. In electrode boilers, the water conducts electricity, which creates a risk of electrical shock.

Since hybrid boilers combine the functionality of electric and fuel boilers, they do not share many of the positive attributes of electric boilers, as they take up a lot of space, require exhaust systems, and are expensive.



Approach to Deployment – The Technical Perspective

Heat Pump Mapping, Setpoint Optimization, De-Steaming, and Heat Pump Evaluation and Selection

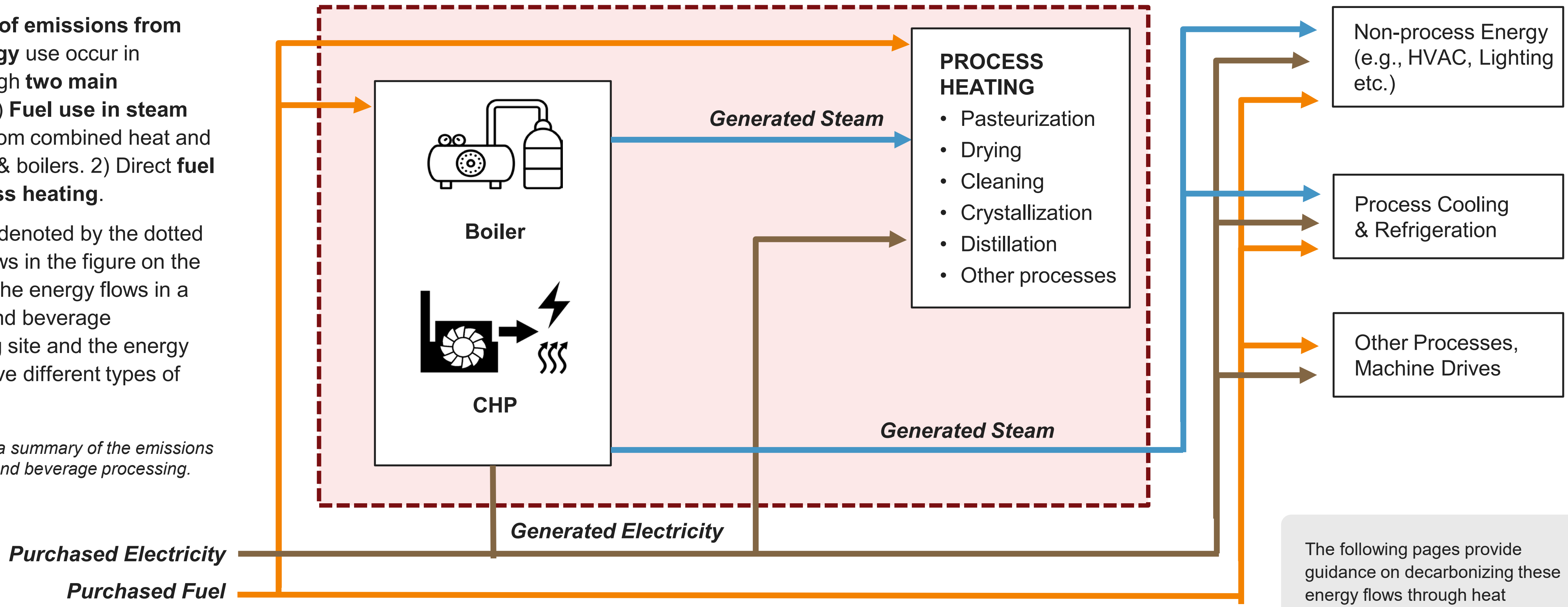
Overview of Energy Usage in Food & Beverage Processing

The **majority of emissions from thermal energy** use occur in industry through **two main processes**: 1) **Fuel use in steam generation** from combined heat and power (CHP) & boilers. 2) Direct **fuel use in process heating**.

This scope is denoted by the dotted line. The arrows in the figure on the right indicate the energy flows in a typical food and beverage manufacturing site and the energy inputs that drive different types of processes.

See page 12 for a summary of the emissions sources in food and beverage processing.

Thermal Energy Flows in Food and Beverage Processing Facilities



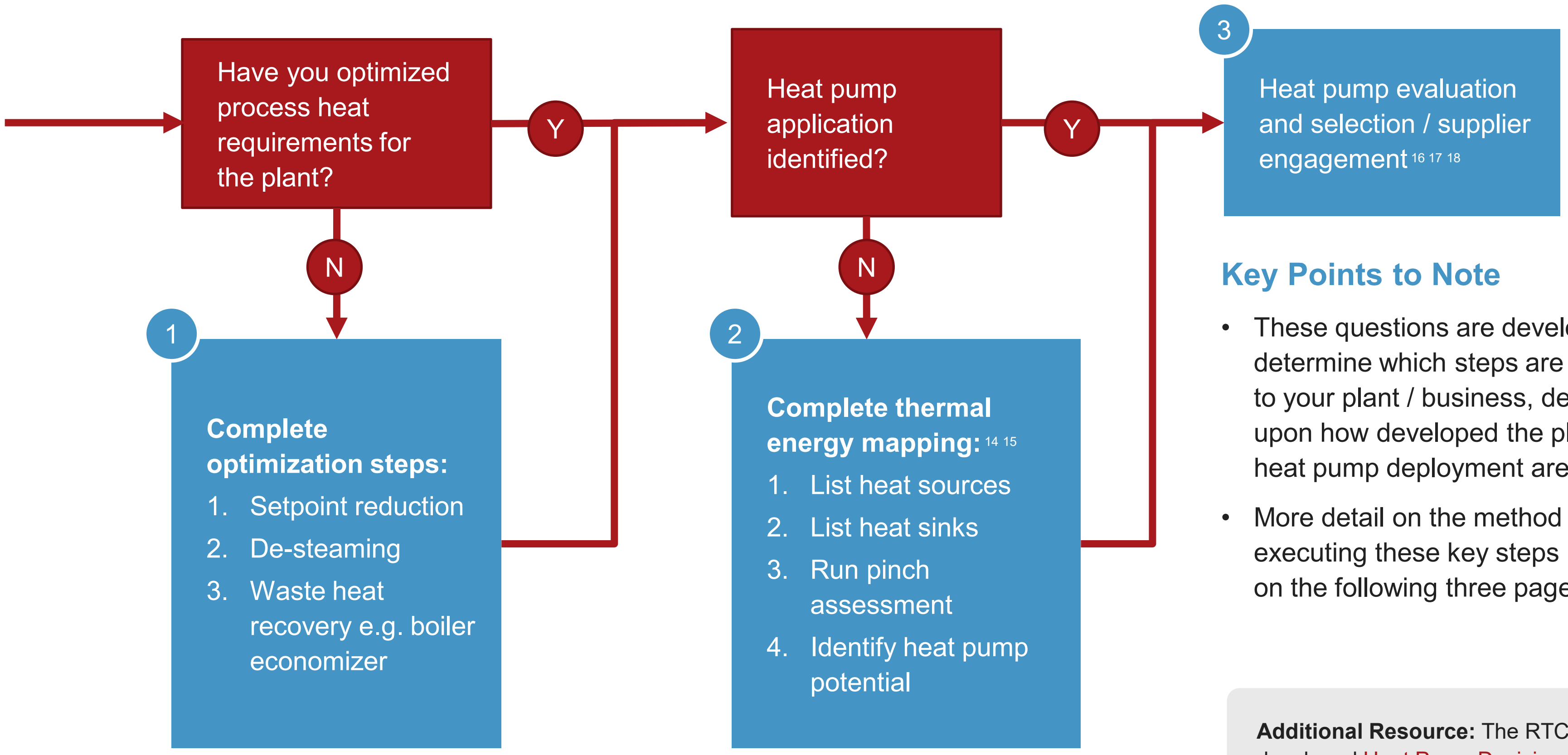
Source: *Guidehouse Technical Experts*

The following pages provide guidance on decarbonizing these energy flows through heat pumps.

Approach to Effective Heat Pump Deployment

As shown on the previous page, a heat pump could be deployed in several areas of process heat demand in the food and beverage industries.

This flow chart outlines the practical steps that should be followed.



Key Points to Note

- These questions are developed to determine which steps are applicable to your plant / business, depending upon how developed the plans for heat pump deployment are.
- More detail on the method for executing these key steps is shown on the following three pages.

Additional Resource: The RTC has developed Heat Pump Decision Support Tools that can further support Energy Buyers with evaluation and selection.[25]

Step 1: Optimization Steps to Reduce Heat Demand

Step Description

The three recommended optimization steps that should be performed prior to conducting a thermal energy assessment are: 1) setpoint optimization, 2) de-steaming potential, and 3) implement no-regret heat recovery.

Step Objectives

a) Ensure that thermal energy demand has been minimized where practically possible prior to assessing electrification opportunities.

b) Introduce some OPEX savings from these no-regret projects which can mitigate any increase in OPEX from electrification.

	SETPOINT OPTIMIZATION	DE-STEAMING POTENTIAL	WASTE HEAT RECOVERY
What is it?	• Reducing temperature setpoints for process heating and increasing setpoints for process cooling	• Transitioning from steam as a heating medium to hot water where there is sub-100° C requirement	• Implementing standalone heat recovery projects with good ROI (e.g., boiler flue gas economizer)
Why do it?	• Reduces thermal demand • Brings heating and cooling requirements closer together, reducing temperature lift and increasing scope for heat pump deployment	• Reduces inefficiencies in plant heat network • Enables heat pump deployment, since most commercialized applications deliver heat as hot water	• Reduces thermal demand • Improves efficiency • Delivers OPEX savings, which can be used to fund future electrification projects
How to do it?	• Engage with process teams to scrutinize current setpoints • Run trials if necessary to verify no product quality impact	• Requires engineering design, including potential redesign of heat exchangers given medium change	• Requires engineering design, including design of heat exchangers and controls

Practical Implementation Considerations

- **Stakeholder engagement.** Adjustments of setpoints, changing heating medium, or implementing heat recovery projects may have some production / product quality implications, so engaging closely with all relevant parties to gain sign off for approval is necessary.
- **Risk mitigation.** Related to the above point, outlining how any product quality risks can be eliminated or mitigated in implementation and operation will be important.
- **Align with strategy to ensure actions are no-regret.** Ensuring that any actions undertaken in this stage are aligned with any mid- or long-term strategies to avoid is important—for example, installing heat recovery that is mutually exclusive for heat pump deployment elsewhere in the plant.

Success Factors

- Alignment and collaboration between process, engineering, and sustainability functions
- Ready access to detailed energy and process data e.g., temperatures, flowrates, energy consumption in hourly granularity (or greater)

Step 2: Thermal Energy Mapping to Identify Heat Pump Applications

Step Description

Assessing heating and cooling requirements in a plant to assess and identify potential heat recovery and heat pump projects.

Step Objectives

a) Establish baseline thermal energy balance, b) understand opportunities for heat recovery, and c) understand opportunities for heat pump deployment.

1. IDENTIFY HEAT SOURCES	2. IDENTIFY HEAT SINKS	3. CONDUCT PINCH ANALYSIS	4. IDENTIFY HEAT PUMP POTENTIAL
• **Definition:** A heat source is a medium that requires cooling down/has latent heat. • **Examples:** Product/process cooling, exhaust from boiler / process equipment, refrigeration condensers, air compressor exhaust • **Requirements:** Compile list of heat sources, including temperature of heat source, target temperature, and amount of heat in BTU/h	• **Definition:** A heat sink is a medium that requires heating up. • **Examples:** Product/process heating, space heating, CIP, water heating • **Requirements:** Compile list of heat sinks including temperature of heat sink, target temperature and amount of heat in BTU/h	• **Definition:** Pinch analysis is a method to design and optimize heat exchanger networks but can be a useful tool for identifying potential heat pump applications, bridging the gap between heating and cooling streams. • **Requirements:** Separate guidance is available to understand steps for undertaking pinch analysis as part of heat pump review*	• **Requirements:** The outputs from the pinch assessment highlight areas where heat recovery may be possible; these should be assessed as to where heat pumps could be deployed to produce a short list of potential applications for further evaluation.
List of heat sources with temperatures and thermal outputs	List of heat sinks with temperatures and thermal inputs	Pinch analysis composite curves and calculations	Shortlist of potential heat pump applications for evaluation

Practical Implementation Considerations

- **List of heat sinks and sources should be exhaustive.** This exercise is most effective when all heat sources and sinks across the facility are considered, to maximize potential for heat recovery and heat pump deployment.
- **Matching heat sources to sinks.** The three key factors to consider are:
  1. **Quantity and quality.** The amount of available heat and temperatures between sources and sinks are drivers for feasibility and efficiency.
  2. **Intermittency.** Is the heat available constantly, or is it intermittent? Is the supply/demand profile constant or variable? The more matched the heat source to sink is, the better.
  3. **Locality.** The closer the heat source is located to the heat sink, the better, to mitigate the cost of pipework and thermal losses.

Success Factors

- Access to comprehensive process and utility data (e.g., temperatures, volumes, energy measurements for each stream).
- Software tools can support and guide pinch analysis, reducing administrative burdens (e.g., EINSTEIN).

Step 3: Heat Pump Evaluation and Selection Process

Step Description

The selection of a suitable heat pump is important for achieving optimal efficiency benefit, and thus OPEX savings.

Step Objectives

a) Ensure that a suitable heat pump is chosen for the required purpose, b) optimize efficiencies and OPEX savings, c) identify preferred heat pump supplier based on their techno-economic proposal, d) develop a pre-FEED* & identify relevant grants and funding schemes, e) Implement solution.

HEAT PUMP TECHNOLOGY	DESCRIPTION	COP RANGE	FOOD AND BEVERAGE EXAMPLE APPLICATIONS
Mechanical Compression	Involves the **use of mechanical compression of a working fluid to achieve temperature lift**. The working fluid is typically a common refrigerant. This can be a multistage system to achieve higher temperature lift.	1.6 - 5.8	• General: Used for heating process and cleaning water • Soft drink manufacturing: Used for the concentration of effluent
Absorption	Involves the **use of a two-component working fluid and the principles of boiling-point elevation** (the boiling point of a mixture is higher than the boiling point of the pure volatile component) **and heat of absorption to achieve temperature lift.**	0.5 - 3	• General: Used for chilling and cooling applications
Mechanical Vapor recompression (MVR)	Involves the **use of a mechanical compressor to increase the pressure and the temperature of waste vapor**.	10 - 30	• Brewery: Used for the concentration of waste liquid • Dairy: Used for the concentration of milk and whey
Thermal Vapor Recompression (TVR)	Involves the **use of energy in high pressure motive steam to increase the pressure of waste vapor** using a jet-ejector device.	10 - 30	• Wet corn milling: Used for the concentration of steep water and syrup

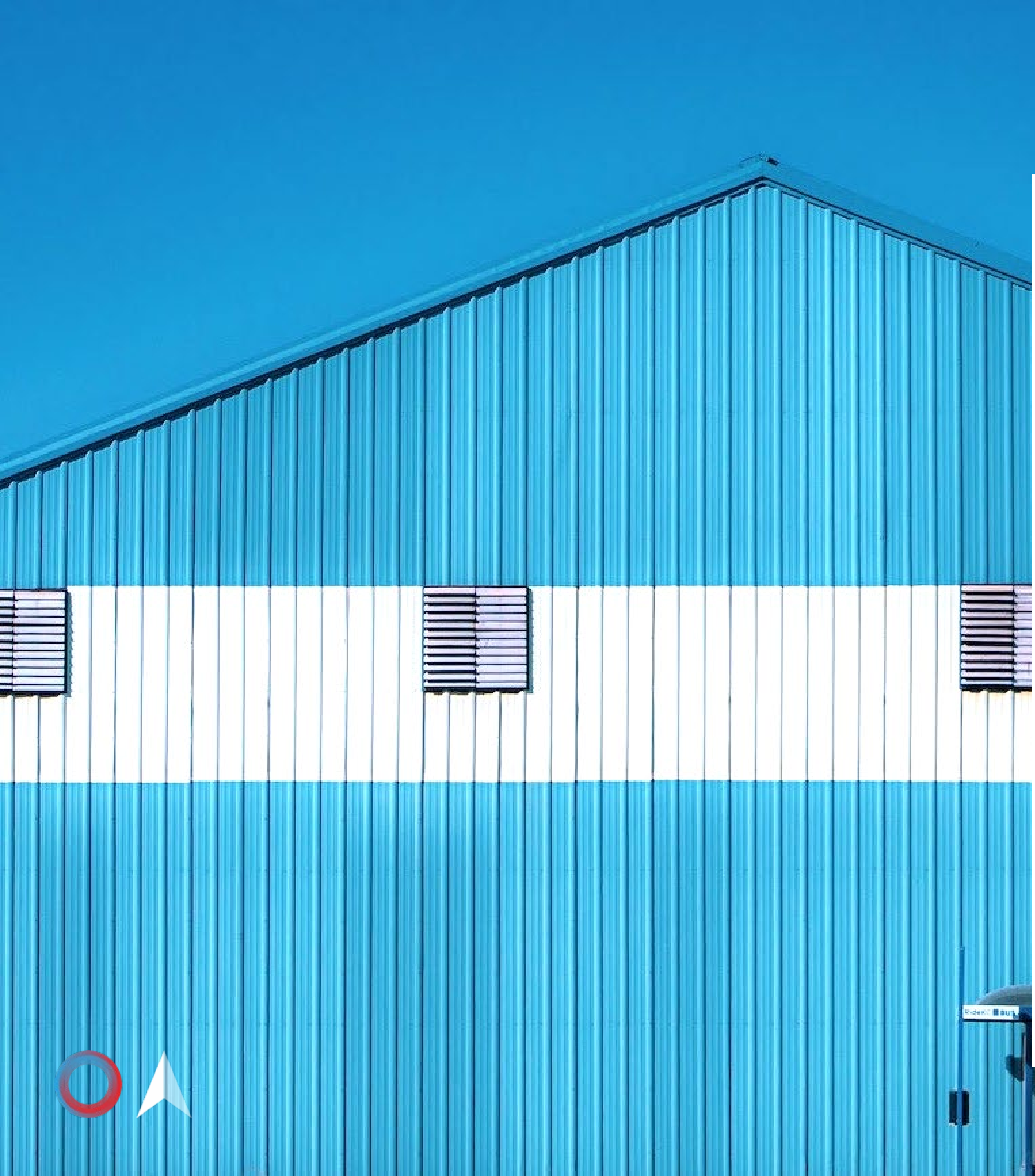
*Preliminary-Front End Engineering and Design

Practical Implementation Considerations

- **Space uptake.** Heat pumps can take up significant space in a manufacturing plant; this should be considered during the design phase.
- **Integration with existing systems.** The integration with existing heat source and sink can be difficult; it is important to select a qualified supplier.
- **Electricity price.** Electricity is significantly more expensive than gas in most markets. Power purchase agreements (PPAs) and onsite renewable electricity generation should be investigated to provide security against energy price fluctuations.
- **Thermal storage.** Investigate the potential benefits of installing thermal storage with heat pumps to deliver better demand management.

Success Factors

- Sufficient onsite and offsite grid infrastructure; distribution network operators should be engaged as early as possible during the project.
- Selection of qualified heat pump supplier and installer.
- Education of operations staff on heat pump optimization.
- Grants, funds, and incentives to reduce upfront capital cost required. See page 37 for the expansion of addressing barrier 2, project cost.
- See Developing an Implementation Plan for the organizational approach to support technical steps.



Examples of Heat Pump Application

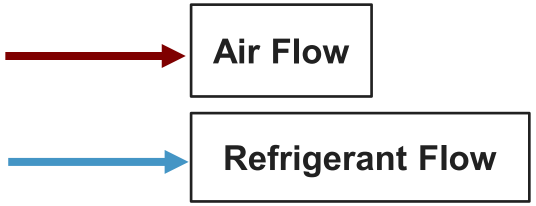
Overview of Applications and Case Studies for Drying, Cleaning-in-Place, and Pasteurization

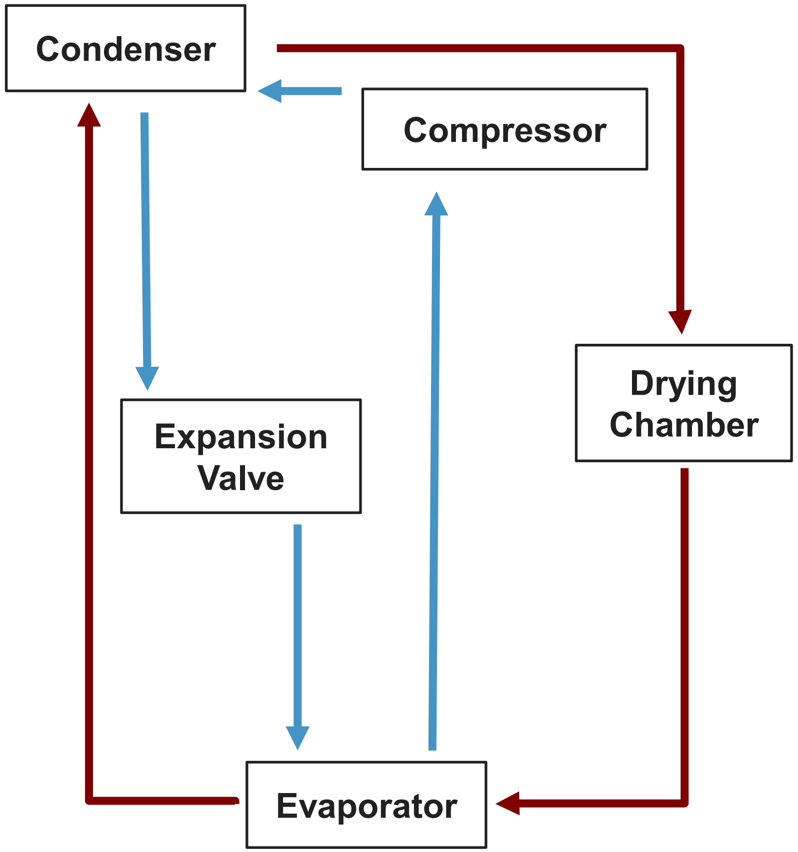
Drying Food with Heat Pumps to Remove Water

How Heat Pumps Can Support Drying

A typical heat pump dryer consists of a drying chamber, two heat exchangers (an evaporator and a condenser), a compressor, and an expansion valve.

As air passes through the drying chamber, it picks up moisture from the food. This humid air is then dehumidified by the evaporator. During dehumidification, the air is cooled to its dew point, resulting in water condensation. The heat that is released when the vapor condenses heats the refrigerant. The pressure of the refrigerant is then increased by the compressor, which further increases its temperature. The cooled and dehumidified air is sent from the evaporator to the condenser, which transfers the heat from the refrigerant to the air. The condenser sends this hot air to the drying chamber, as the pressure of the refrigerant is decreased as it passes through the expansion valve.





Research has demonstrated **positive outcomes of heat pump drying in food processing applications,**[18] including:

- Reduced product shrinkage
- Reduced energy consumption
- Reduced drying times
- Improved product appearance

See page 33 for a case study examining drying using heat pumps

Cleaning-in-Place with Heat Pumps

How Heat Pumps Can Be Used to Supply Heat to CIP Systems

Opportunities for heat pump use
Optional steps

Pre-rinse
This step removes most residue, dissolves sugars, and moistens equipment surfaces

Caustic wash
A hot (60° C - 85° C) alkaline detergent softens fats

Intermediate rinse
Fresh water rinses detergent from the equipment

Final rinse
Additional rinse to remove any remaining cleaning agents

Sanitizing rinse
A chlorine or peracetic acid sanitizer reduces bacterial growth

Push out
Residual product is pumped out of equipment

Acid wash
A hot (55° C - 65° C) acid solution dissolves protein residues and neutralizes pH

Air blow
Removes moisture from equipment

Heat pumps can provide temperatures up to 100 ° C and, therefore, act as the heat source for the highlighted processes.

See page 33 for a case study examining cleaning using heat pumps

Pasteurizing with Heat Pumps

How Heat Pumps Can Be Used for Pasteurization

Primarily applied to liquids, pasteurization uses heat to kill pathogens and increase the shelf life of foods and beverages. Though some foods are pasteurized with steam, exposure to much lower temperatures can effectively pasteurize many foods (see table for temperatures used in milk pasteurization).

Waste Heat Recapture

Most non-acidic foods need to be chilled after pasteurization. The cooling systems used to do this generate waste heat that can be recaptured to serve as the source heat for a heat pump.

Food is heated to a temperature ranging from 83° C to 100°+ C to kill pathogens

Food is chilled to ~4° C to prevent spoiling

Cooling system generates waste heat

Heat pump captures waste heat from cooling system

Food and Drug Administration Milk Pasteurization Specifications[19]

TEMPERATURE	TIME
Batch (Vat) Pasteurization	
83° C	30 minutes
Continuous Flow High-Temperature-Short-Time (HTST) Pasteurization	
72° C	15 seconds
Continuous Flow Higher-Heat-Shorter-Time (HHST) Pasteurization	
89° C	1.0 seconds
90° C	0.5 seconds
94° C	0.1 seconds
96° C	0.05 seconds
100° C	0.01 seconds
Ultra-Pasteurization (UP)	
83° C	30 minutes

Case Studies Related to Heat Pump Applications

Heat Pumps for Preheat Dryers

A dry milk plant in Denmark utilizes a hybrid heat pump to recover waste heat from the evaporation process and utilizes it to preheat dryers. Discharged wastewater at 40° C is utilized for this process.[21]

- **Process**: Drying
- **Heat Pump Capacity**: 1.25 MW
- **Heat Pump Type**: Hybrid NH3/H2O
- **Temperature Range:** Up to 85° C
- **COP:** 4.5
- **Repayment Period:** 2.3 years (1.5 years with energy grants included)
- **Maintenance Costs:** Approximately 2€ per MWh/heat
- **Annual Projected Energy Savings:** 7.2 GWh
- **Directly Replaced Natural Gas Boiler**

The owner reports a high degree of satisfaction with the heat pump installation. Thorough energy analysis was crucial as reduced consumption and direct heat exchangers had to be considered. While exceptionally time consuming, the savings found through this process more than paid for itself.

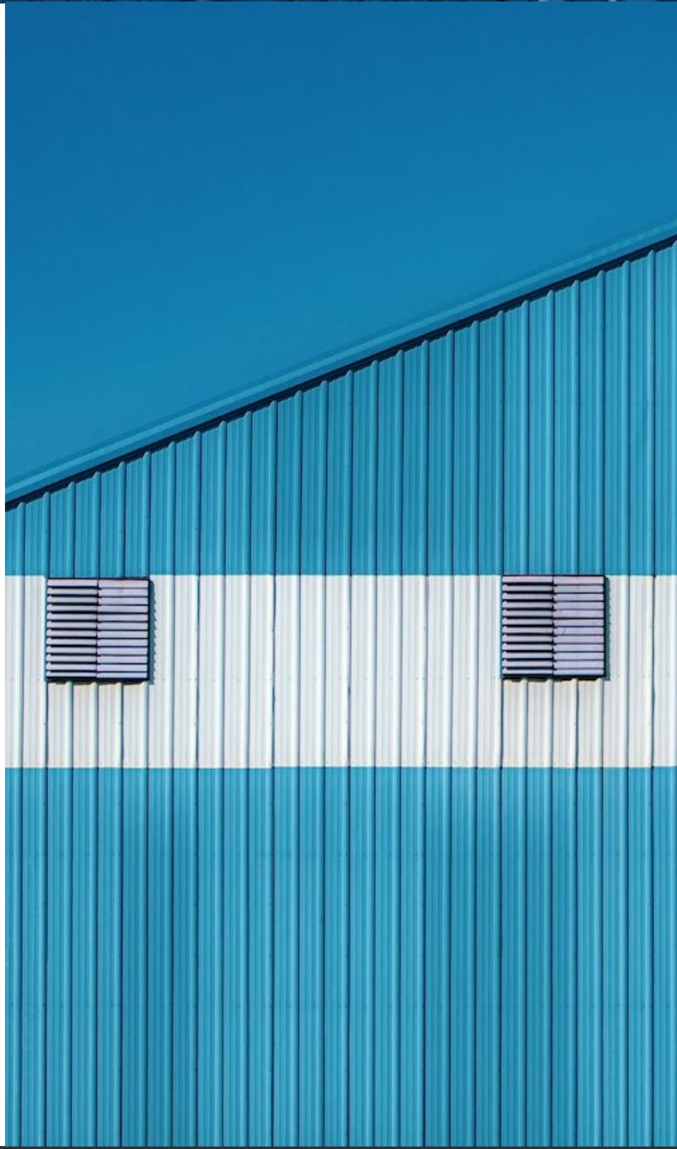
For additional case studies, refer to Case Studies – Renewable Thermal Collaborative

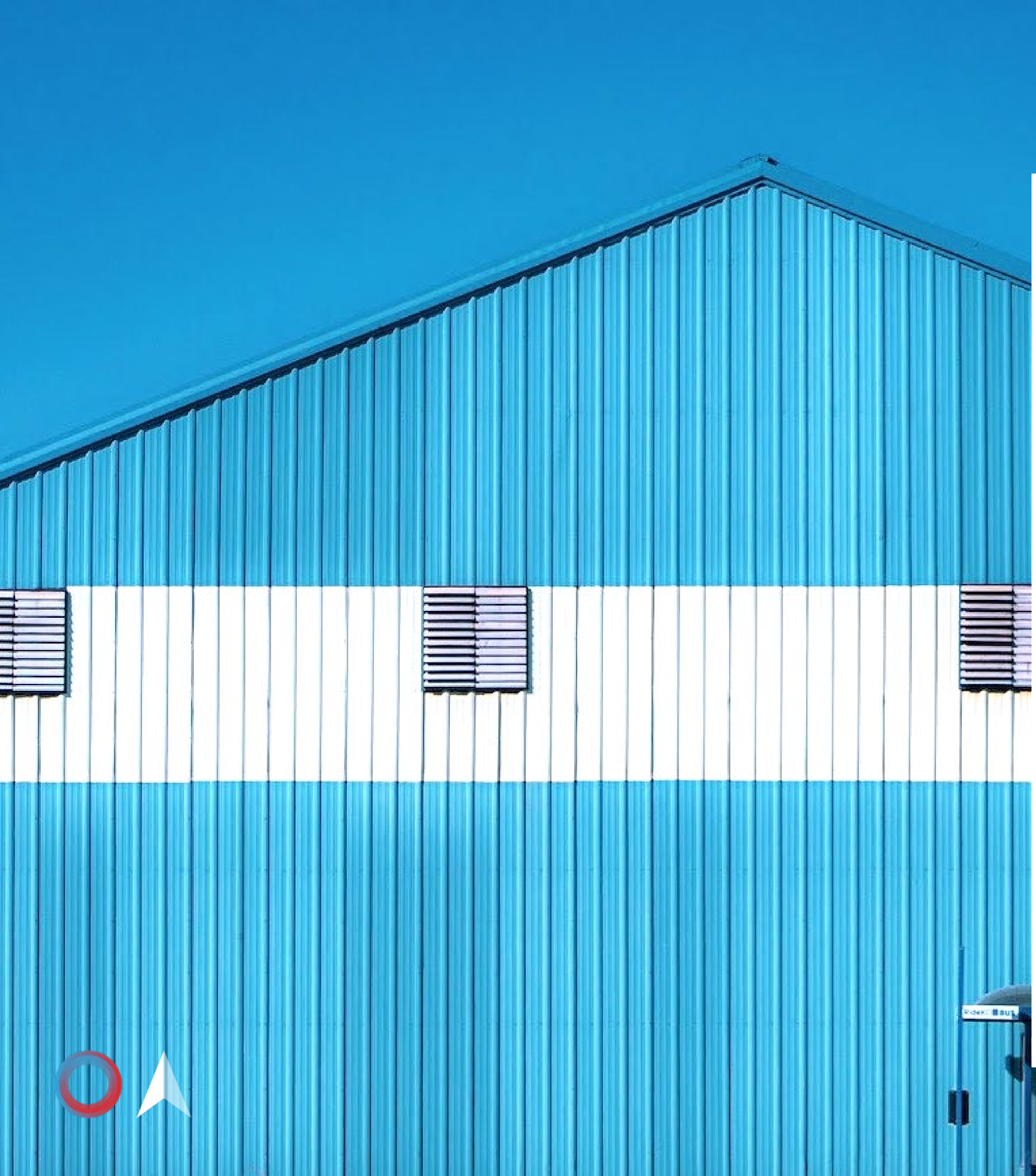
Heat Pumps for Water Heating and Cleaning

A meat packing facility in Austria specializing in processed meat products is utilizing an electrically driven compression heat pump to recover waste heat and utilize it for water and space heating applications.[21]

- **Process**: Space Heating, Cleaning, Others
- **Heat Pump Capacity**: 257 kW
- **Heat Pump Type**: Compression
- **Temperature Range:** Up to 55° C
- **COP:** 6.1
- **Repayment Period:** Unspecified
- **Maintenance Costs:** Unspecified
- **75% reduction in emissions**
- **Dual Condenser Units**: One for process heat and one for space heating

The manufacturer reports the client’s high satisfaction for the heat pump’s performance and operation. The unit meets roughly 50% of the daily heating need and replaces a 100% natural gas fired system. An adequate storage system of the maximum daily heat demand was also considered as a part of the project.





Pathways for Enabling Technology Implementation

Recommendations for Enabling Technology Adoption and Implementation for Energy Buyers, Solutions Providers, and Policymakers

Overview of Barriers to Adoption and Implementation

Industry participants identified lack of operational track record, cost, insufficient grid infrastructure, and utility pricing structures as the top barriers to heat pump and electric boiler adoption and implementation

	Barriers Identified*	Recommendations for Energy Buyers and Solutions Providers
1. Lack of Operational Track Record	The lack of information on long-term reliability, performance, and OPEX of heat pumps and electric boilers in industrial food and beverage processes is limiting adoption. This includes a lack of comparable case studies.	1.1: Seek partnerships with government agencies and research organizations to pilot equipment and showcase operational success. 1.2: Advocate for improvements to training and certification for heat pump installation and repair.
2. Project Cost	The cost of electrified equipment continues as a barrier to adoption. Lack of domestic suppliers and trained maintenance workers contribute to these higher costs.	2.1: Clarify to policymakers the importance of dedicating a portion of electrification funding to industrial applications. 2.2: Work with partners, both public and private, to obtain CAPEX funding.
3. Insufficient Grid Infrastructure	Infrastructure to support the requisite load of electrifying process heat is typically inadequate, including both distribution infrastructure and customer substation and internal wiring.	3.1: Utilize a plant capacity-needs projection to advocate for future grid improvements. 3.2: Invest in efficiency measures for existing systems. 3.3: Leverage the knowledge of external organizations.
4. Utility Pricing Structures	Currently utility demand tariffs are structured in such a way that drawing load during peak hours contributes to making electricity a non-competitive input fuel, compared to natural gas.	4.1: Support measures that reform electric cost structures for industrial customers, especially those that incentivize clean energy use.

*Barriers were identified and ranked utilizing primary research interviews with industry participants as well as secondary research sources

A deep dive into each barrier and an expansion on recommendations to energy buyers, solutions providers, and policy makers follows in subsequent pages

Barrier 1: Lack of Operational Track Record

The Need for More Domestic Case Studies

The lack of case studies surrounding the use of electric boilers, and especially heat pumps in the US food and beverage industry, is widely noted and creates a knowledge gap about operational performance. Without a deep well of knowledge to draw from, plant managers are reluctant to adopt these decarbonization measures as any outages could have significant financial ramifications. Other unknowns are how factors like unit sizing and refrigerant choices effect real world operations. This reluctance ultimately poses a barrier to the growth of the domestic industrial heat pump market. Lack of knowledge also affects the maintenance and repair market because local technicians are not always capable of installing and repairing these units. In some past cases, international technicians were flown in so they could service units.

The most direct way to address this knowledge gap is by increasing the amount of domestic research on industrial heat pump integration. Academic and government research organizations, such as the U.S. Department of Energy National Laboratories, are well-positioned to conduct such pilots and trials. While international case studies exist, conducting studies in the US will ensure that the results are directly applicable to domestic market conditions. Using the results from these trials to improve content related to heat pumps in HVAC training and certification programs is critical.

Recommendations for Energy Buyers and Solutions Providers

Helping address the knowledge gap in the installation, operation, and repair of heat pumps is one of the most actionable opportunities RTC members can take. Partnerships to trial industrial heat pumps can fill the knowledge gap while granting sponsoring companies financial and operational support over the length of the trial.

1.1: Seek partnerships with government agencies and research organizations to pilot equipment and showcase operational success.

- Volunteer to collaborate on supported field tests of industrial heat pumps and electric boilers with agencies like the U.S. Department of Energy National Laboratories.
- Share the outcomes of these case studies with policymakers and industry players. Make clear what solutions are needed to further reduce barriers to deployment.

1.2: Advocate for improvements to training and certification for heat pump installation and repair.

- Utilize the results of case studies to advocate for changes to HVAC training curricula and certification standards in order to equip domestic work forces to service these larger, industrial units.

Recommendations for Policymakers

As a primary driver of basic scientific research, the federal government can play a critical role in the development of process heat electrification case studies. Primarily through the U.S. Department of Energy National Laboratories, the government should work with academic and industry partners to conduct supported field tests of electrification technologies—particularly heat pumps.

1.1: Support industry partners willing to sponsor trials.

- The industry has shown broad interest in incorporating heat pumps into operations, but a lack of general operational insights dissuades potential adopters.
- While some companies are willing to volunteer to trial industrial heat pump applications, assurances of financial and logistical assistance could spur the process.
- Potential volunteers fear possible down time and loss of use due to failure of the yet untested industrial heat pump integrations. Adequate support in the event of an incident may help stimulate the research process.
- Published case studies of any findings are critical, including detailed accounts of operational performance.

State Highlight: The California Energy Commission has undertaken research on industrial heat pumps in the past, focusing on recovery of low-grade waste heat for low pressure steam applications[26]

Barrier 2: Project Cost

Heat Pumps Remain a Considerable Expense

For several reasons, the cost of electrified process heat solutions continues to be high in the US both in CAPEX and OPEX. The current lack of a sufficient domestic industrial heat pump production capability and a trained service personnel pool often leads interested buyers to purchase units made internationally. Depending on the available trained workforce, these companies may also have to fly in international engineers and technicians to service units. A lagging domestic market for these units also means less price competition among fewer vendors.

Existing incentive and rebate programs for heat pumps focus predominately on the residential market. Those that do specify eligibility for industrial customers often dedicate a small proportion of the over-all funds to these project types. While the IRA and IIJA have dedicated a considerable amount of funding to heat pumps in general, specifics on eligibility for industrial projects remain slim. As guidelines develop for spending the funds the bills allocate, industrial heat pump applications may be able to access a considerable portion of them.

Today's US industrial heat pump market is underdeveloped, understaffed, and underfunded. While changes in the focus of incentive spending can help correct this, collaborations among industry, government, and educational entities are required to grow a domestic market for the construction and servicing of these units.

Recommendations for Energy Buyers and Solutions Providers

Potentially, large pools of public funding are available to energy buyers for electrifying process heat, but qualification specifics are either unclear or dedicate little to industrial applications. Working with policymakers to clarify the importance of decarbonizing process heat to over all climate goals can help clarify this situation.

2.1: Clarify to policymakers the importance of dedicating a portion of electrification funding to industrial applications.

- Advocate for clarity on and inclusion of industrial heat pump units in existing and future public funding for modernization and decarbonization.
- Develop plant decarbonization plans and projections to aid in communication with policymakers.

2.2: Work with partners, both public and private, to obtain CAPEX funding.

- Utilize the knowledge of solutions providers and industry groups to locate available public funding sourced in a particular jurisdiction.

Recommendations for Policymakers

The current US industrial heat pump market is nascent. Scaling up the country's domestic production capability for these units is critical, as is incentivizing HVAC technicians to train on the installation and repair of heat pump systems.

2.1: Scale up production.

- Eligibility for industrial heat pumps should be considered for inclusion in tax credit programs like 48C and 45X. Additionally, eligibility for funding through the IRA/IIJA should be considered and clarified to energy buyers.
- The DOE should continue its efforts to develop a national heat pump roadmap that can guide market growth, reduce costs for all participants, and prioritize economic benefits for US-based actors.

2.2: Train domestic maintenance and repair.

- Policies should be adopted to incentivize existing licensed HVAC professionals to acquire heat pump training, whether through offsetting training fees, travel stipends, or making information access more convenient.

State Highlight: California has worked to develop a network of free heat pump training programs with corporate partners. Classes are available to HVAC trained workers, with some including remote learning components. (See page 17)

Barrier 3: Insufficient Grid Infrastructure

Electrification Requires More Grid Capacity

A frequently expressed barrier to the adoption of process heat electrification solutions is the lack of sufficient infrastructure to deliver the required electrical load. Since a full electric retrofit may increase a facility's load profile severalfold, upgrades are frequently required to the wiring and substation. Improvements to nearby transmission infrastructure may also be needed to meet heightened load demand. These transmission upgrades are not in the industrial customer's direct control and can be slow to permit and expensive to build. Current back orders and supply chain issues in the electrical equipment space further compound this challenge.

This significant barrier requires long-term, high level planning processes from ISOs/RTOs with assistance from utility companies and state-level commissions. While the importance of bolstering transmission infrastructure is clearer now than it has ever been, individual energy buyers have few direct actions they can take to expedite the process. ISOs and RTOs continually consider transmission expansion projects, but the process takes years and is significantly constrained by the available financial resources. While a renewed focus on transmission line planning, funding, and permitting has seen recent successes in Washington and at the ISO/RTO level, grid constraints will likely continue to be an impediment to process heat decarbonization for some time.

Recommendations for Energy Buyers and Solutions Providers

While energy buyers can do little to improve transmission capacity directly, they can still play a role in the process. Primarily, buyers should advocate for needed transmission improvements during public comment periods.

3.1: Utilize a plant capacity needs projection to advocate for future grid improvements.

- Develop an estimate of the total capacity required to meet process heat electrification goals.
- Use this estimate to advocate for future transmission improvement through ISO/RTO and utility commission transmission study comment periods.

3.2: Invest in efficiency measures for existing systems.

- Work with solutions providers to improve efficiency that might create room inside existing load constraints.
- Identify opportunities for improving the efficiency of legacy systems that reduce overall emissions intensity.

3.3: Leverage the knowledge of external organizations.

- Partner with groups that focus on electric grid and market issues, such as the Clean Energy Buyers Association and Renewable Thermal Collaborative working groups.

Recommendations for Policymakers

The power to alleviate the transmission capacity issue rests across several public entities. Federal agencies, state assemblies, and ISOs/RTOs should place added emphasis on transmission planning and funding.

3.1: Continue comprehensive study of future grid needs.

- DOE's Grid Deployment Office published a national study to identify grid needs to 2035.
- ISOs/RTOs should engage the DOE to ensure transmission planning processes are comprehensive.

3.2: Seek to expand financial and policy support for transmission capacity improvements.

- As transmission capacity remains a large barrier to decarbonization, funding for both direct development and planning processes will be a key policy step.
- Utilize the $2.5 billion DOE Transmission Facilitation Program[23] to improve transmission capacity and performance.
- Certain revisions to siting and permitting practices for transmission lines can streamline development.

State Highlight: $7.3B in spending was recently approved by CAISO for new transmission development specifically to help meet electrification and decarbonization goals (See page 17)

Barrier 4: Utility Pricing Structures

Utility Pricing Must Change to Meet New Goals

In many regions, utility demand tariffs are structured in such a way that drawing load during peak times dramatically increases the per unit cost of electricity. These tariff structures are also increasingly incongruent with decarbonization goals, as local solar generation capacity may exceed peak demand or transmission capacity and end up being curtailed. This is at odds with decarbonization goals when industrial and other clients could potentially utilize that zero-carbon energy.

Several attempts have been made to address barriers posed by utility pricing for industrial clients across the US. Some PUCs have developed fixed-rate structures for some or all of the typical per unit costs for industrial clients. TVA, for example, has 56 **direct serve** industrial customers who receive fixed fee structures and other incentives for utilizing more energy at off peak times. Many utilities, including PG&E and SoCal Edison, have programs for industrial clients that discount rates for reducing demand at peak time through various means. Utilities may also offer free consulting for analyzing a program's operational impact.

Seventeen states, including Illinois, have adopted laws that aim to shift utility profit models away from total energy sales and toward meeting performance targets like reliability and clean energy penetration. These laws are varied and complex but attempt to align business interests with legislative goals, such as addressing climate change.

Recommendations for Energy Buyers and Solutions Providers

As large users of electricity, industrial clients are valuable customers for utilities, so they have power to negotiate for programs that can reduce their overall electricity costs. As many states aim to meet aggressive decarbonization goals, the position of industrial facilities as high volume energy users lends weight to their voices during policy comment periods.

4.1: Support measures that reform electric cost structures for industrial customers, especially those that incentivize clean energy use.

- Be attentive to proceedings on electricity pricing policy and regulation, especially those at the PUC and RTO/ISO levels. Policies set there are highly impactful, though often see little engagement during their comment periods.
- Make clear to state level policymakers that electricity costs pose financial barriers to the adoption of electrification technologies. Advocate for policy redresses to these challenges.
- Become familiar with alternative energy pricing structures and advocate for their duplication in your jurisdiction.

Recommendations for Policymakers

Current methods for determining electrical prices for industrial customers are a barrier to electrification and increasingly at odds with decarbonization goals. Policymakers can enable more nuanced pricing structures that align utility business interests with industrial customers' decarbonization goals.

4.1: Encourage new rate structures for industrial users.

- Assess policy measures that incentivize utilities to work with industrial clients on alternative cost structures which lower the overall barrier of electricity cost to decarbonization efforts.
- Policies that incentivize use of electricity when renewable penetration is high and limit renewable curtailment should garner particular attention.

4.2: Explore credit programs to support electrification.

- Consider programs that offer financial credits in exchange for reductions in fossil fuel consumption, such as an electric bill credit per unit of natural gas use avoided.
- Ensure that incentives to industrial clients are paid in a timely manner to improve ROI calculations.

State Highlight: Illinois has a long history of utilizing state policy to incentivize utilities to conduct business in ways that meet policy goals like reliability and, recently, decarbonization (see page 18).

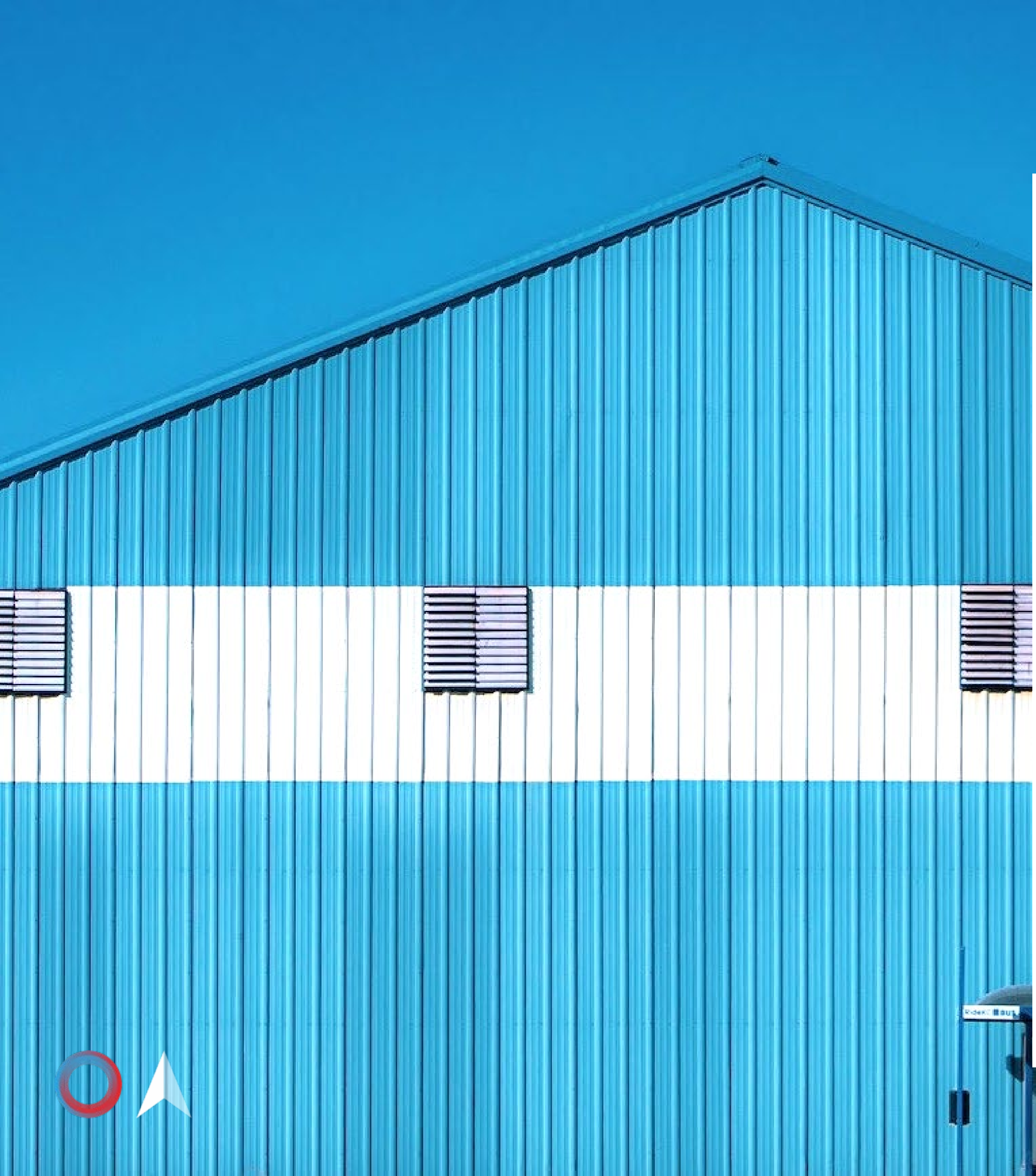
Developing an Implementation Plan for Energy Buyers

The table below provides a summary of steps for energy buyers to **implement heat pumps and electric boilers on site**. The external barriers and recommendations section (pages 35-39) provide insights for an improved implementation process.

	1 Target Setting, Internal and External Stakeholder Engagement	2 Onsite Techno-Economic Assessment	3 Development of Detailed Design For Projects	4 Implementation of Solution and Lessons Learned

KEY ACTIVITIES & RESOURCES	• **Engage internal teams** including engineering, operations, and procurement **to set a target** (e.g., Science-Based Targets) for abating Scope 1 and 2 emissions.
	• **Identify opportunities to motivate organisational stakeholders to prioritize decarbonization** (e.g., linking targets to bonuses, internal carbon pricing).
	• **Identify personnel responsible** for driving sustainability targets.
	• **Engage in working groups** led by the Renewable Thermal Collaborative:
	  • Electrification Working Group
	  • Policy Working Group
	  • Solar Thermal Working Group
	  • Thermal Storage Working Group
	  • GHG Accounting and Market Instrument Working Group
		• **Optimize site thermal demand** through de-steaming, heat recovery, and set point optimization.
		• **Perform thermal energy mapping** of operations.
		• **Identify site locations for heat pump and electric boiler implementation** based on a techno-economic assessment, available grid capacity, and the company's planned strategy.
		• **Develop a business case** for each project including impact of available grants and incentives.
		• See Approach to Deployment section for key steps.
			• **Develop pre-FEED design** for identified projects.
			• **Engage suppliers through RFI** and **RFP** stages and **select supplier** based on techno-commercial analysis of offers.
			• **Carry out project risk assessment** and **identify mitigation actions.**
			• **Evaluate onsite and offsite grid capacity** and **engage with DNO** to apply for any required grid upgrade. See recommendations for tackling Insufficient Grid Infrastructure.
			• Ensure **renewable energy contracts** are in place to attain decarbonization (e.g., RECs, PPAs).
			• **Apply for relevant federal and local grants/ funding schemes** to subsidize CAPEX. See recommendations for tackling Project Cost.
			• See Step 3 – Heat Pump Evaluation and Selection.
				• **Project sign off** and release Purchase Order from procurement.
				• **Onsite implementation** and **upskill employees** through training.
				• **Capture insights from pilot implementation to refine targets and inputs** for future projects.
				• See Approach to Deployment section for key steps.
				• Share outcome of operational successes to support training and certifications. See recommendations for tackling Lack of Operational Track Record.
				• Consider submitting case studies to the RTC through the Case Study Submission Form.

OUTCOME	**Company-Wide Sustainability Targets**	**Identify Pilot Sites to Implement Electrification Projects**	**Selected Supplier, Detailed Engineering Design, Capital Investment Plan Including Grants**	**Successful Implementation of Projects**



Looking Ahead

Emerging Technologies Focused on Reducing the Need for Process Heat and Other Electrification Measures

Looking Ahead: Emerging Technologies for Food and Beverage Processing

Reducing the Need for Process Heat

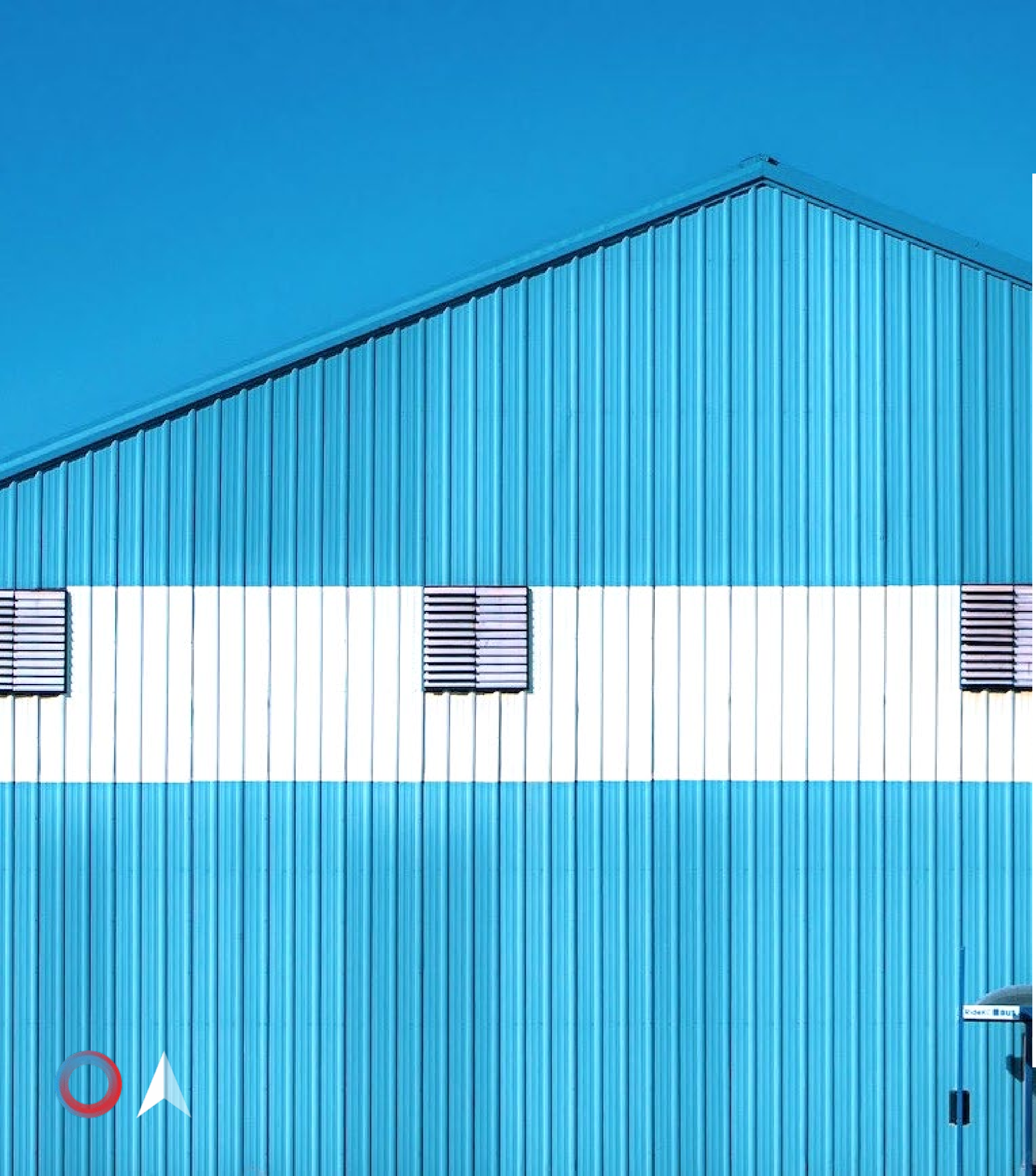
Reducing the process heat required to achieve food and beverage processing outcomes can promote decarbonization. Technologies and methods to facilitate reductions in the generation of process heat include:

- **Mechanical dewatering.** The use of filtration, centrifugal force, gravity, mechanical compression, and high velocity air can reduce the moisture content of foods prior to drying. Generally, each 1% reduction in food moisture reduces the energy the dryer consumes by 4%.
- **Solar air heating.** Air heated from the sun, rather than fuel, can be used to dry foods through convection. This technology is primarily used to preserve fruits and vegetables but is also used for spice, tea leaf, fish, and nut drying/roasting. Though operation is limited to daylight hours, operational costs are minimal, and the food is dried evenly.
- **Ultrasound drying.** Food can be exposed to ultrasound frequencies prior to or simultaneous with other drying processes to reduce drying time and temperature, which minimizes thermal degradation of food.
- **Ozone cleaning**. Ozone is a strong oxidant and potent disinfecting agent. Already used in bottled water processing, this method has potential applications in food surface hygiene, fruit, vegetable, meat, and seafood processing.
- **Ultraviolet (UV) pasteurization and sterilization.** UV pasteurization is most applicable to dairy, juice, and other beverages but has potential for controlling contamination in meats and shell egg surfaces. Many applications are still being tested and validated, but the technology's low capital and operating costs, as well as the superior resulting food product, make it an attractive emerging technology.
- **Pulsed electric field (PEF) technology.** Short pulses of high electric fields through foods can kill microorganisms and increase osmotic drying without producing heat. Applications of PEF include pasteurization and drying.
- **Process insulation**. Insulation decreases heat loss and, therefore, reduces the amount of heat that must be generated.

Other electrification measures

- **Ohmic heating.** This thermal processing method passes alternating electrical current through food products to generate heat internally. Ohmic heating is purported to produce a uniform, inside-out heating pattern that heats foods faster and more evenly than conventional outside-in heating methods. Pilot units are being field tested, but this technology is not yet ready for widespread use in food and beverage processing.
- **Induction heating of liquids.** By dissipating the energy generated when the secondary winding of a transformer is short circuited, induction heaters instantly impart heat to liquid circulating in a coil around the transformer core. Though highly efficient, induction heaters are expensive and still being piloted in the food and beverage industry.
- **Dielectric heating**. The use of microwave and/or radio frequencies can reduce drying time and increase product yields. Dielectric heating is primarily used for drying, but has potential applications in pasteurization, blanching, cooking, etc.

These technologies require additional R&D support.



Additional Resources

Additional Resources from the Renewable Thermal Collaborative

Additional Resources

Additional Resources from the Renewable Thermal Collaborative:

RTC Heat Pump Decision Support Tools: https://www.renewablethermal.org/heat-pump-decision-support-tools/

RTC Electrification Road Map: https://www.renewablethermal.org/electrification-road-map/

Industrial Electrification in U.S. States: https://www.renewablethermal.org/state-electrification-report/

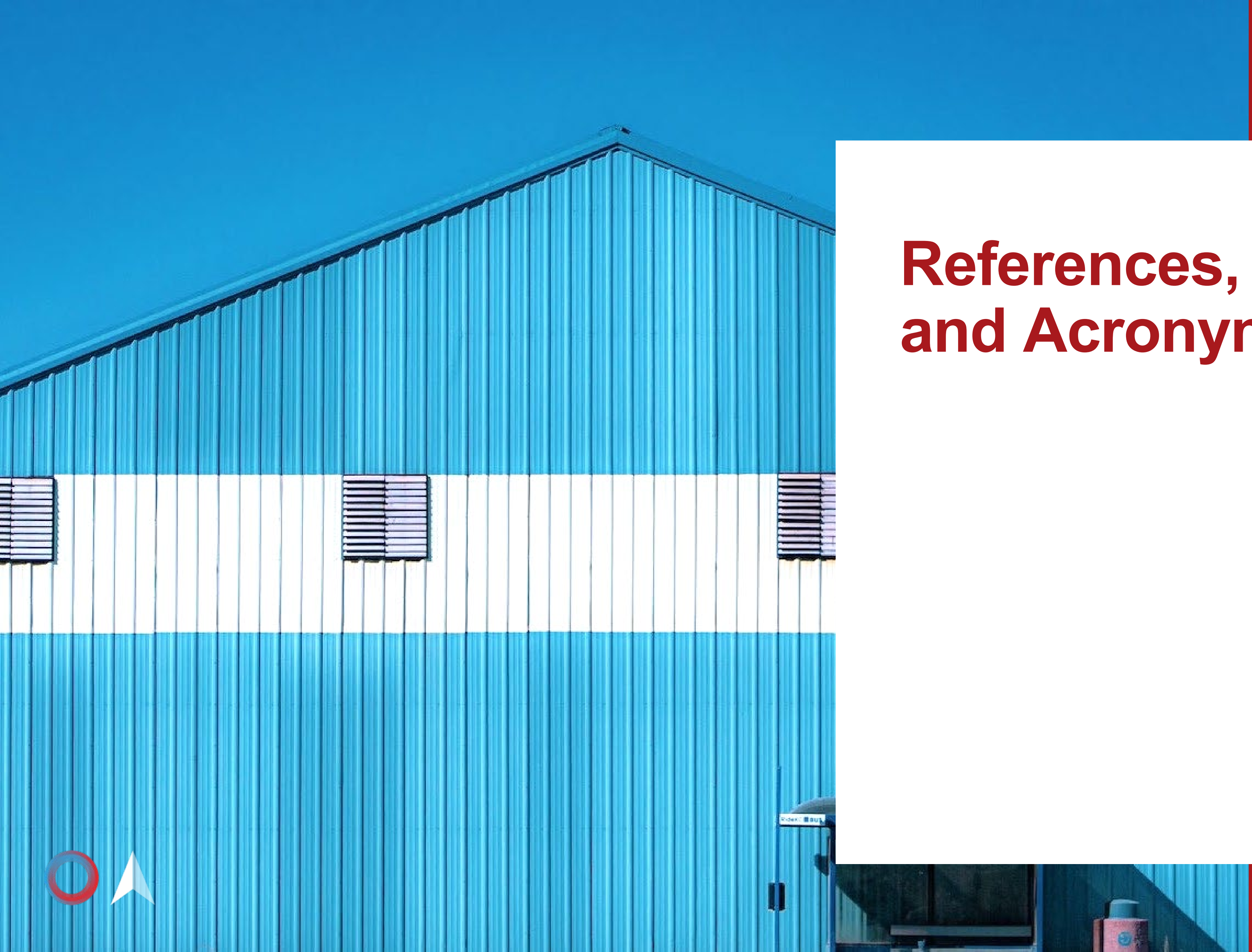
Electrifying U.S. Industry: A Technology- and Process-Based Approach to Decarbonization: https://www.renewablethermal.org/electrifying-us-industry/

For additional case studies, refer to **Case Studies – Renewable Thermal Collaborative**

Working groups led by the Renewable Thermal Collaborative:

- Electrification Working Group
- Policy Working Group
- Solar Thermal Working Group
- Thermal Storage Working Group
- GHG Accounting and Market Instrument Working Group

Please reach out to Cihang Yuan (cihang.yuan@wwfus.org) and Blaine Collison (blaine@dgardiner.com) about joining the RTC and these working groups.



References, Notes, and Acronym List

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Acronym List

BTU/h	British Thermal Units per Hour
CAPEX	Capital Expenditures
CHP	Combined Heat and Power
CIP	Cleaning-in-Place
COP	Coefficient of Performance
DNO	Distribution Network Operator
DOE	U.S. Department of Energy
GHG	Greenhouse Gas
HHST	Higher-Heat-Shorter-Time
HTST	High-Temperature-Short-Time
HVAC	Heating, Ventilation, and Air Conditioning
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
ISO	Independent System Operator
MTCO2e	Metric tons of carbon dioxide equivalent
MVR	Mechanical Vapor Recompression
OPEX	Operational Expenditure
PBR	Performance-Based Regulation
PEF	Pulsed Electric Field
PPA	Power Purchase Agreement
Pre-FEED	Preliminary-Front End Engineering and Design
PUC	Public Utility Commission
R&D	Research & Development
REC	Renewable Energy Certificate
RFI	Request for Information
RFP	Request for Proposal
ROI	Return on Investment
RTO	Regional Transmission Organization
TVR	Thermal Vapor Recompression
UP	Ultra-Pasteurization
UV	Ultraviolet