Production Line Heat Recovery Systems

Project Number ET23SWG0014

GAS EMERGING TECHOLOGIES PROGRAM (GET)

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Acknowledgements

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Disclaimer

Executive Summary

This Gas Emerging Technologies (GET) project focused on researching production line heat recovery technologies available for industrial baking processes in California. In addition to an evaluation of different commercially available heat recovery products, the project gathered the insights of subject matter experts (SMEs) in respect to their likelihood of implementing this type of technology in their operation, as well as an analysis of the prevalence of heat recovery measures across the state of California. This study investigated the potential for implementation of heat recovery systems that can result in energy efficiency and reduced emissions for the production line in industrial baking processes.

The project consisted of a combination of SME interviews, and an analysis of implementation measures related to heat recovery in the Food and Beverage sector in the state of California. The attributes of heat recovery systems in the Food and Beverage sector were investigated, including commercially available products, applications, implementation advantages and challenges, and case studies. The project consisted of the three steps outlined below.

Step 1: Literature review, which sought to gather extensive information on an overview of the heat recovery technology, the state of heat recovery practices in industrial baking processes, commercially available heat recovery systems, and case studies of energy efficiency in industrial baking operations.

Step 2: Conducting a survey targeting SMEs in the industrial baking industry to gauge their knowledge of heat recovery systems, the state of their operations, their potential motivations for implementing this technology, the challenges they foresee in that implementation, and overall, their likelihood to adopt this technology.

Step 3: Conducting Industrial Assessment Center (IAC) Data Analysis of assessment recommendations related to heat recovery technologies to determine the prevalence of heat recovery-related measures in the Food and Beverage sector in the U.S. and California, to determine the implementation rate of heat recovery related measures in California and compare them with other states, to compile measure costs and energy cost savings of heat recovery-related measures implemented in the Food and Beverage sector. Calculate the estimated payback for each of them and analyze the energy-saving potential and payback period of heat recovery-related measures implemented in bakeries.

Project Goal: The goal of this study was to gather market data on production line heat recovery systems for industrial baking processes to provide an understanding of potential for implementation, and related drivers and barriers for this technology.

Technology Description: This study included analyzing commercially available production line heat recovery systems, which have the potential to increase operational energy efficiency by reusing the excess heat generated in industrial baking processes. Four (4) different commercially available products were analyzed and compared to obtain thorough information on best-available products.

Key Project Findings

- SME interviews revealed the need for heat recovery systems in industrial baking operations due to the excess heat generated in these processes, which currently constitutes waste exhaust heat and could otherwise be used to enhance energy efficiency.
- The most significant barriers for implementation of heat recovery systems in industrial baking operations are financial constraints associated with equipment installation and potential safety issues.
- The top drivers for heat recovery systems implementation include cost savings in sites' energy bills and government incentives which could facilitate their adoption of the technology.
- There is a need for advertising/education regarding the benefits of heat recovery systems to members of the industry, as seen in the relatively low knowledge held by representatives of the industry in their responses to the survey.
- Implementation of heat recovery-related measures in California is 14.7%, which is below the national average implementation rate of 20.8%, as per an analysis of all the IAC centers in the U.S.

Project Recommendations

The Study Team offers the following recommendations based on the findings:

- One of the most effective ways to encourage adoption is through the expansion of financial support mechanisms. Government and utility-sponsored incentives can play a pivotal role in offsetting the upfront costs that many bakeries identify as a primary barrier. These incentives, when clearly communicated and easily accessible, can significantly improve the return on investment and reduce the perceived financial risk.
- There is a need to raise awareness within industry given that many stakeholders remain unfamiliar with the capabilities and benefits of modern heat recovery systems.

- Developing a strategy to align economic incentives with environmental goals, equipping industry stakeholders with the knowledge and tools they need and fostering a supportive ecosystem that encourages innovation and investment in energy efficiency.

Introduction: Production Line Heat Recovery

Heat production is a critical component of industrial energy conservation, addressing the substantial energy loss observed in various processes. This loss, estimated between 20% and 50%, manifests as waste heat in hot exhaust gases, warmed cooling, and heat dissipated from equipment surfaces and products. In the context of onsite industrial energy, primarily derived from fossil fuel combustion, there is a prevailing trend of transfering heat to the environment rather than optimizing its use in the manufacturing process, resulting in significant enegery waste [1].

As industries globally recognize the advantages of waste heat recovery, it becomes essential to explore its application in sectors with unique energy challenges. The baking industry, a cornerstone of global food production, faces significant challenges in managing energy consumption due to diverse operations ranging from mixing and proofing to baking and cooling. The sector's reliance on fossil fuels, particularly natural gas, poses economic and environmental challenges, contributing to carbon emissions and adverse environmental impacts.

Understanding and addressing these challenges is crucial for the baking industry's long-term viability, aligning with global energy efficiency and environmental objectives. Shifting towards sustainable and efficient energy practices not only safeguards the economic health of bakeries but also plays a pivotal role in reducing the industry's environmental footprint.

Currently, the state of energy efficiency in bakeries is characterized by increasing energy prices that co-exist with general corporate trends towards environmental sustainability. Bakeries can implement certain strategies that can aid them in their goals of dealing with high energy prices as well as maintiaining environmental sustainability at the forefront of their processes. One of the primary issues to address is the energy inefficiencies derived from heat that is produced by their production processes and is left unused.

Assessment Objectives

The objectives of conducting this market study on production line heat recovery systems are listed below.

A. The primary objective of this research is to gather valuable insights and information to assess the feasibility, potential benefits, and market demand for implementing a heat recovery system in the production line setting.

B. The study focuses on the baking industry, which is an industry with substantial energy use and, mainly, energy losses due to unused exhaust heat.

C. The research aims to quantify potential energy savings, and improvements in production efficiency while incorporating potential challenges such as technical integration, regulatory compliance, and initial investment concerns.

D. The study involves up to six (6) Subject Matter Expert (SME) Interviews to gather more information about industry's likelihood to adopt heat recovery systems, their concerns regarding the systems, and potential challenges and opportunities related to their implementation.

Background: Heat Recovery in Commercial Baking

Commercial baking involves intricate processes that utilize various equipment to transform raw ingredients into the final baked goods. The primary sources of heat generation in this industry are ovens. Understanding this source of heat is crucial to acknowledging the potential for harnessing excess heat through recovery systems.

The implementation of effective heat recovery systems is significantly linked to the understanding of the traditional methods of heat generation in baking. In traditional baking processes, heat is often supplied directly through electrical resistance or gas burners, resulting in the continuous production of byproducts such as CO_2 and water within the baking chamber. The periodic evacuation of these combustion products becomes necessary, presenting a challenge in managing the temperature and composition of exhaust gases. Moreover, the efficiency of heat transfer is influenced by factors like the oven's size, geometry, and heating mode, alongside the physical properties of the baked products.

This inherent challenge in conventional baking processes underscores the importance of exploring innovative solutions for heat recovery. Notably, in tunnel-type multizone baking ovens, the efficiency of energy utilization is relatively high, ranging from 50% to 70% for gas ovens and 60% to 70% for electric ovens [2].

To put this into perspective, a sample bakery in California, for instance, annually consumes about 6,035,380 kBtu and emits approximately 730 Metric Tons of CO_2 annually [3] which is equivalent to the average annual CO_2 emissions of roughly 80 households. Addressing the complexities of traditional heat generation is essential for achieving sustainable and efficient practices in the commercial baking industry such as integrating advanced heat recovery systems.

Advantages of Heat Recovery in Commercial Baking

Incorporating heat recovery systems into bakery operations yields a highly favorable scenario, effectively addressing the challenges outlined earlier [4]:

1. Energy Efficiency: Capturing and repurposing heat, particularly through advanced heat recovery systems, significantly reduces therm usage in bakery operations. This strategic approach optimizes energy use, leading to streamlined and cost-effective operations. The recovered heat can be effectively utilized to enhance the efficiency of various heating processes within the facility. This translates into tangible energy savings, contributing to reduced operational costs.
2. Environmental Sustainability: The reduction in therm consumption achieved through innovative heat recovery measures corresponds to a decrease in greenhouse gas emissions. By incorporating advanced technologies that enhance energy efficiency and reduce reliance on conventional energy sources, bakeries can significantly lower their carbon footprint. These advancements contribute not only to energy savings but also to a substantial reduction of up to 20% in CO_2 emissions within the baking process [5]. This aligns with eco-friendly practices, positioning bakeries as environmentally responsible entities. Not only does this contribute to sustainable business practices, but it also proactively positions bakeries ahead of potential environmental regulations, showcasing a commitment to environmental stewardship.
3. Cost Savings: While the initial investment in implementing advanced heat recovery systems may seem substantial, the long-term financial benefits are considerable. By significantly reducing therm usage, forward-thinking bakeries can make a financially prudent move, particularly in the face of rising energy prices. The potential for full payback within a moderate timeframe, typically three to five years [6], underscores the economic viability of such investments. Furthermore, the continued savings throughout the system's operational life, often exceeding 20 years, compound the economic advantages and contribute to a robust return on investment. [7]

4. Enhanced Process Control: Beyond energy savings, the improved control offered by advanced heat recovery systems directly translates into consistently well-baked goods. This is achieved by maintaining optimal baking conditions through the efficient use of recovered heat. Additionally, the enhanced process control minimizes product waste due to uneven baking conditions, contributing to both operational efficiency and cost-effectiveness. Reducing product wastage further contributes to the overall savings and positively impacts the bakery's production quality goals.

After reviewing the positive aspects related to the implementation of heat recovery systems in baking, it is essential to acknowledge and address the challenges associated with these innovative systems since they can present practical and technical challenges that demand careful consideration.

Challenges of Heat Recovery in Commercial Baking

While the integration of heat recovery systems in commercial baking holds considerable advantages, bakeries encounter practical and technical challenges that warrant attention [8] [9]:

1. Technical Complexity: The installation of heat recovery systems introduces a substantial level of technical intricacy. Successful integration hinges on seamlessly aligning these systems, preferably during active oven use. Striking the right balance, where the system captures heat effectively without interfering with core oven functions or baking processes, demands a nuanced understanding of existing oven technology. Involving experts becomes essential to tailor installations such as temperature and heat mismatch, where high-temperature exhaust gases need to be efficiently transferred and utilized in systems that may require lower temperatures.
2. Initial Investment and return on investment (ROI) Calculation: Financial considerations loom large for bakeries considering heat recovery systems, encompassing both the upfront costs and the challenge of calculating ROI. This calculation varies for each business, contingent on factors such as bakery size, energy market fluctuations, and the efficiency of the installed system. The capital investment and payback period are important metrics to consider, as implementing a heat recovery system involves upfront costs that need careful assessment against the potential energy savings over time.
3. Maintenance and Operational Integration: Sustaining optimal performance of heat recovery systems necessitates regular maintenance. For bakeries, the inherent risk of downtime during tasks like cleaning and troubleshooting is a significant concern. Time sensitivity in production schedules underscores the need for a meticulous maintenance plan that minimizes disruptions. Additionally, the maintenance of heat recovery systems can be complex due to the presence of particulate matter,

corrosive elements, and contaminants, requiring specialized knowledge and equipment.

4. Space Constraints: Limited space in many commercial bakeries poses a challenge for integrating additional equipment like heat recovery systems. Depending on design and size, these systems may require substantial space. Some systems offer flexibility in installation locations, accommodating indoor or outdoor setups, on roofs, next to buildings, or in less confined spaces. The space and installation constraints may be exacerbated when retrofitting systems into existing spaces.
5. Concerns related to Consistent Baking Quality: Consistency is paramount in the baking industry. While the introduction of a heat recovery system can improve consistency, the new system cannot disrupt the delicate balance of temperature and humidity crucial for impeccable baking results. Perception of potential negative impacts could hinder system installation as the process requires fine-tuning and close monitoring to maintain a stable oven environment, preventing any deviations that could compromise product quality. Variability and load fluctuations in the baking process further emphasize the need for careful system design to ensure consistent baking quality.
6. Compliance with Regulations: Installation of major equipment, including heat recovery systems, demands strict adherence to health, safety, and environmental regulations in food production facilities. Navigating the complexity of these regulations and ensuring compliance adds a layer of complexity and time consumption to the implementation process. Compliance becomes particularly critical when considering the potential environmental impacts of the system.
7. Adapting to Different Oven Types and Sizes: Bakeries employ a diverse range of ovens, each with unique characteristics. Designing a heat recovery system that works effectively across this spectrum, accommodating everything from small convection ovens to large tunnel ovens, requires a blend of ingenuity and technical expertise. Adapting to different oven types and sizes becomes a challenge, especially when considering the variability and load fluctuations experienced during the baking process, impacting the heat recovery system’s performance and efficiency.

Current State of Energy Efficiency in Bakeries

The prevailing state of energy efficiency in bakeries unfolds against the backdrop of soaring energy prices and a heightened corporate focus on environmental sustainability. In addressing these challenges, industry experts like Dave Watson (subject matter expert for baking and snack engineering in Austin Company) and Nico Roesler (sales manager at Reading Bakery Systems) advocate for a holistic approach to energy conservation, particularly tailored to bakeries reliant on heat-intensive processes and natural gas usage. [10]

Central to this strategy is a meticulous examination of energy consumption, with Watson emphasizing the crucial first step of measuring usage. Common inefficiencies in bakeries are identified through comprehensive energy audits.

Unique to the bakery industry are energy-saving strategies that revolve around oven efficiency, recognized as pivotal means to curtail energy costs. Adjusting oven schedules, capturing waste heat, and optimizing exhaust settings are highlighted as effective methods for ovens that predominately utilize natural gas. Roesler emphasizes the significance of controlling the oven's exhaust settings to regulate energy use efficiently, noting that waste heat can be repurposed for applications like preheating water or combustion air, aligning with the imperative for sustainability.

Maintenance practices emerge as a critical aspect of ensuring the seamless operation of natural gas-powered equipment. Regular lubrication of conveyor chains, gearboxes, and other components, coupled with routine inspections by qualified technicians, becomes essential to sustain optimal energy performance over time.

Dave Watson highlights a notable trend in oven technology evolution, indicating a growing preference for hybrid models that initiate with direct gas-fired (DGF) elements and culminate in convection. This shift towards hybrid ovens is recognized for its substantial efficiency improvements. Despite the theoretical considerations surrounding all-electric ovens, the baking industry continues demonstrating a steadfast commitment to utilizing natural gas. This enduring preference is attributed to factors such as the historical volatility of energy markets and the long-term nature of investments in oven technology [10]. This sets the stage for a detailed exploration of specific heat recovery systems tailored for the baking industry.

The understanding of current conditions in the baking industry allows for a further investigation into the specific applications where heat recovery systems play a crucial role. By addressing existing energy efficiency, the implementation of precise solutions tailored to meet the distinctive demands of commercial baking can be laid out.

Applications of Heat Recovery Technologies in Bakeries

Heat recovery systems in bakeries efficiently capture wasted energy, especially during baking and proofing. In a bakery setting, specific applications of heat recovery are listed in table 1 below [4] [6] [11]:

Table 1: Application of heat recovery techniques in baking processes

Heat Recovery Process	Description	Application
Oven Exhaust Heat Recovery	The baking process in commercial ovens generates a substantial amount of heat, and the exhaust gases expelled from these ovens carry valuable thermal energy.	Heat recovery systems capture the heat from oven exhaust gases, typically though heat exchangers, and repurpose it for various applications within the bakery.
Prover Heating	Provers facilitate the proofing of fermentation of dough before baking. This process often requires controlled heating.	Waste heat recovered from other bakery processes, such as oven exhaust, can be directed towards prover heating, contributing to energy efficiency and reducing the need for additional heating sources.
Water Heating	Hot water is a crucial resource in bakeries for various purposes, including dough preparation and equipment cleaning.	Heat recovery systems can transfer excess thermal energy to heat water for these purposes, minimizing the need for separate water-heating systems and reducing energy costs
Space Heating	Maintaining a comfortable temperature in the bakery space is essential for both working conditions and product quality.	Recovered heat can be utilized for space heating, ensuring a conducive working environment without relying solely on conventional heating methods.
Combined Heat and Power (CHP) Systems	Some bakeries may opt for more advanced systems that generate electricity and useful heat concurrently.	Waste heat recovery can contribute to Combined Heat and Power (CHP) systems for large bakeries, where the recovered energy powers electrical equipment and simultaneously provides thermal energy for various bakery processes.*

Heat Recovery Process	Description	Application
Air Pre-heating	Involves warming the combustion air before it enters the oven burners, improving overall combustion efficiency.	Recovered waste heat can be directed to preheat the combustion air, reducing the energy required for baking and enhancing the efficiency of the baking process. **

* Feasibility may need to be checked as it may not be permitted under EE programs.
** Could make reaching low NOx levels more challenging.

Literature Review Findings

The understanding of the specific systems that make the heat recovery applications previously mentioned possible is imperative to gauge the contributions of these technologies to energy efficiency in the baking industry. Therefore, the systems are listed as follows:

1. Roof-Top Heat Exchanger from Manufacturer A: A promising solution for energy concerns in commercial baking, this system offers minimal downtime, turnkey solutions, easy maintenance, customization, flexibility, durability, and quality assurance. [4] Some of the featured characteristics of this system are:
   - Minimal Downtime: Designed for minimal disruption, the installation process is streamlined, demanding less than 30 minutes of operational downtime for bakery ovens during roof-top installation. The quick setup involves fitting a specialized chimney tee section with an integrated bypass damper. Once operational, the bypass damper is closed, directing exhaust through the heat modules for efficient air-to-water heat transfer, ensuring swift installations with minimal downtime.
   - Turnkey Solution: The system stands as a comprehensive heat recovery unit (HRU), encompassing heat exchanger modules, dampers, plumbing, and controls. With utilities, supply and return pipes, and power as the only requirements from the bakery, the system presents itself as a turnkey solution, simplifying the implementation process.
   - Easy Maintenance: Facilitating hassle-free maintenance, the system incorporates features such as the integrated bypass and easily accessible heat modules through access panels. This allows for servicing without operational downtime, ensuring continuous functionality and efficiency.

- Customization and Flexibility: Tailored to meet diverse bakery needs, the system offers adaptability to various oven types and sizes. This customization ensures a versatile solution that can seamlessly integrate into different baking setups.
- Durability: Constructed with stainless steel and designed for roof installation on skids, the system prioritizes long-term efficiency and ease of service. The robust materials and skid-mounted configuration contribute to its durability, making it a reliable investment for sustained performance.
- Quality Assurance: The system incorporates precise controls to guarantee that heat recovery does not compromise baking quality. This commitment to maintaining product consistency ensures that the benefits of energy efficiency and sustainability do not come at the expense of the final baked goods, providing quality assurance that is crucial in the baking industry.

Figure 1: The Roof-Top Heat Exchanger System from Manufacturer A.

2. Heat Recovery System A: Compact air-to-water heat recovery unit with an integrated bypass function efficiently captures and repurposes hot flue gas, offering user-friendly control, cost-effectiveness, environmentally conscious, and efficient circulation. In various industrial settings, including bakeries, valuable energy is often discarded as hot flue gas expelled directly through chimneys. The Heat Recovery System A offers an effective remedy, capturing and repurposing the excess energy for heating purposes, resulting in cost savings and environmental benefits. [11] Some of the most significant characteristics of this system are:
   - Compact and Efficient: The system is a compact air-to-water heat recovery unit with an integrated bypass function, meticulously crafted to extract energy from hot flue gas. Its efficiency is centered around the core heat exchanger, which

adeptly harnesses the heat from the passing flue gas, ensuring optimal utilization of energy.

- Bypass Functionality: A distinctive feature of this system is its integrated bypass function, allowing for the automatic circulation of excess heat energy around the heat exchanger. This ensures that even the energy that cannot be immediately utilized is efficiently managed, enhancing the overall effectiveness of the heat recovery process.
- User-Friendly Control: The system has a controller that serves as the system's command center, overseeing the bypass damper, central heating pump, and mixing valves. This intuitive control mechanism guarantees that the circulation of heat occurs precisely when needed, optimizing energy usage and contributing to the system's user-friendly design.
- Cost-Effective and Environmentally Conscious: By capturing and reusing up to 95% of energy that would otherwise be wasted, the system stands as a cost-effective solution for industries seeking both financial savings and environmental responsibility. Reducing the expulsion of hot flue gas directly into the atmosphere aligns with sustainability goals, making it an environmentally conscious choice.
- Efficient Circulation: The entire system is engineered to ensure efficient and targeted circulation, thanks to the intelligent control system. This ensures the heat recovery process operates seamlessly, delivering consistent results without unnecessary energy consumption.

Figure 2: Manufacturer B's waste heat recovery system schematic. [12]

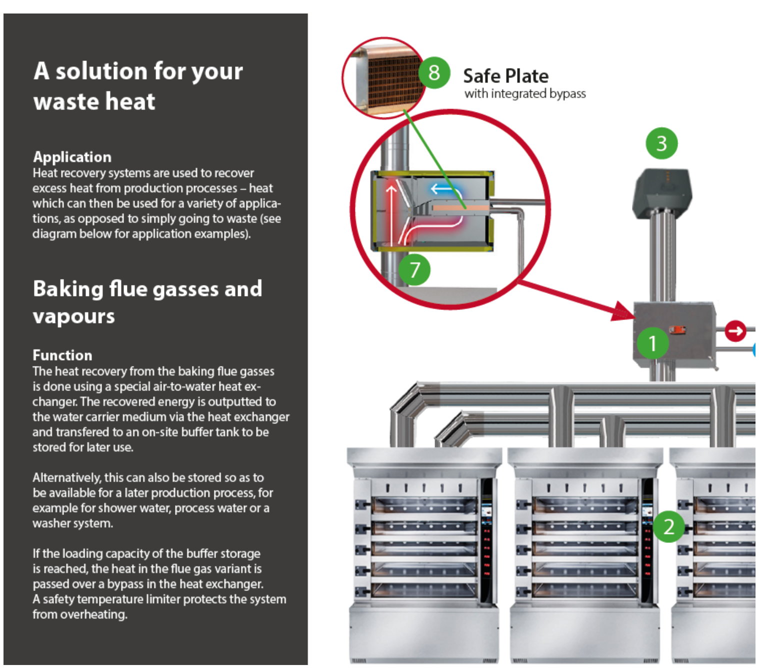
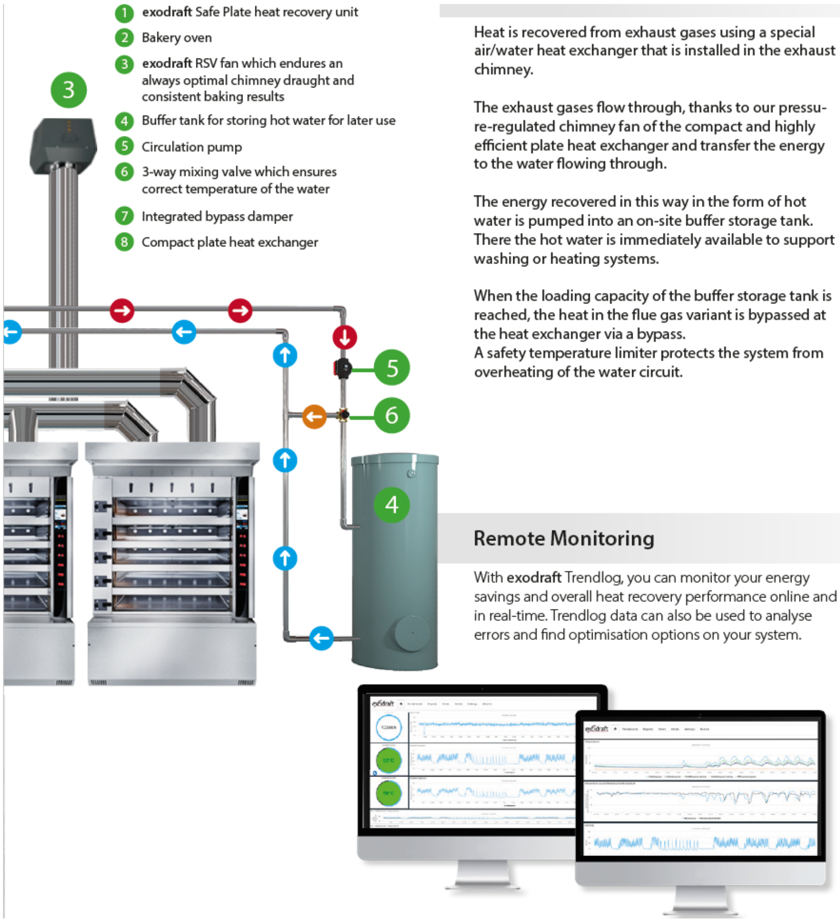


Figure 3: Manufacturer B's waste heat recovery system schematic. [12]



3. Manufacturer C's Equipment: Heat recovery solutions engineered specifically for the baking industry, offering a comprehensive approach to capturing and reusing waste heat from ovens. These systems recover thermal energy from both flue gas and steam—two major byproducts of baking—by processing them separately to maximize efficiency. They can reclaim a substantial amount of energy used in baking operations. This recovered energy can be redirected into building services, such as heating water or supporting Heating, Ventilation, and Air-Conditioning (HVAC) systems, significantly reducing energy costs and environmental impact. Designed for flexibility, Manufacturer C's systems are compatible with a wide range of ovens and scalable for bakeries of all sizes. They also help reduce chimney requirements, noise, and odors, making them ideal for urban or residential settings. There are two systems from Manufacturer C analyzed in this project:
    - Heat Recovery System B: Smart system that optimally utilizes hot gases and steam from multiple ovens, providing two temperature levels and directing surplus heat to a basket-washing system. Its consolidation of exhaust from

multiple ovens into one exhaust flue enhances energy savings and simplifies the overall system. [13]

- Heat Recovery System C: Designed to capture and utilize leftover heat from flue ga, the Heat Recovery System C warms up service water, supports heating systems, and reduces the need for chimneys. Its large flue gas heat exchanger recovers up to 70% of escaping flue as heat, contributing to increased combustion efficiency and short payback times. [14]

Figure 2: Manufacturer C's Heat Recovery System B.

Figure 3: Manufacturer C's Heat Recovery System C.

The Roof-Top Heat Exchanger, Heat Recovery System A, and Manufacturer C's Equipment offer distinct features and capabilities in addressing energy concerns within the baking industry. Table 2 provides a concise overview of their key attributes.

Table 2: Comparative table of heat recovery systems' characteristics.

Feature	Roof-Top Heat Exchanger	Heat Recovery System A	Manufacturer C's Equipment
Installation Downtime	Less than 30 minutes	Not specified	Not specified
Maintenance Efficiency	Integrated bypass, accessible heat modules	Integrated bypass function	Large flue gas heat exchanger, ease of servicing
Adaptability and Customization	Tailored to various oven types and sizes	Supports different applications	Supports different applications
Flue Gas Capture Efficiency	Not specified	Efficient Heat Exchanger	Large flue gas heat exchanger
User-Friendliness Control System Abilities	Controller capabilities	EHC20 controller	Not specified
Cost-Effective Heat Recovery	Not specified	Not specified	Reduced need for chimneys, potential cost savings
Environmental Considerations	Reduced emissions (not quantified)	Estimated 15-30% reduced emissions	Estimated 25% reduced emissions
Circulation Efficiency	Not specified	Efficient and targeted circulation	Increased combustion efficiency

Case Studies of Heat Recovery Systems

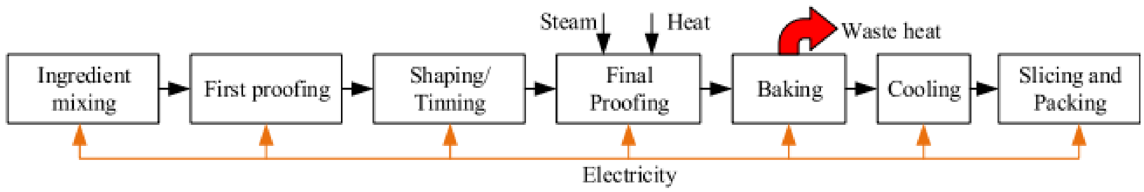
This section summarizes the findings from two (2) identified case studies that relate to strategies to increase energy efficiency in operational activities in industrial baking facilities.

[1] Waste Heat Recovery Integration Options for Commercial Bakeries in a thermos-economic-environmental Perspective

- **System Description:**
  This provides insights from a comprehensive case study by J.I. Chowdhury [15], which sheds light on waste heat recovery integration options for a commercial bakery in the United Kingdom. The study focuses on a specific bread manufacturing line, producing 2-2.5 tonnes per hour of bread, with each loaf weighing 800 grams. The energy-intensive processes of baking and proofing, particularly the waste heat generated by the

oven's exhaust gases, are the main focus of the investigation. Figure 5 depicts the flowchart of the commercial bread-making process.

Figure 4: Flowchart of commercial bread-making process.

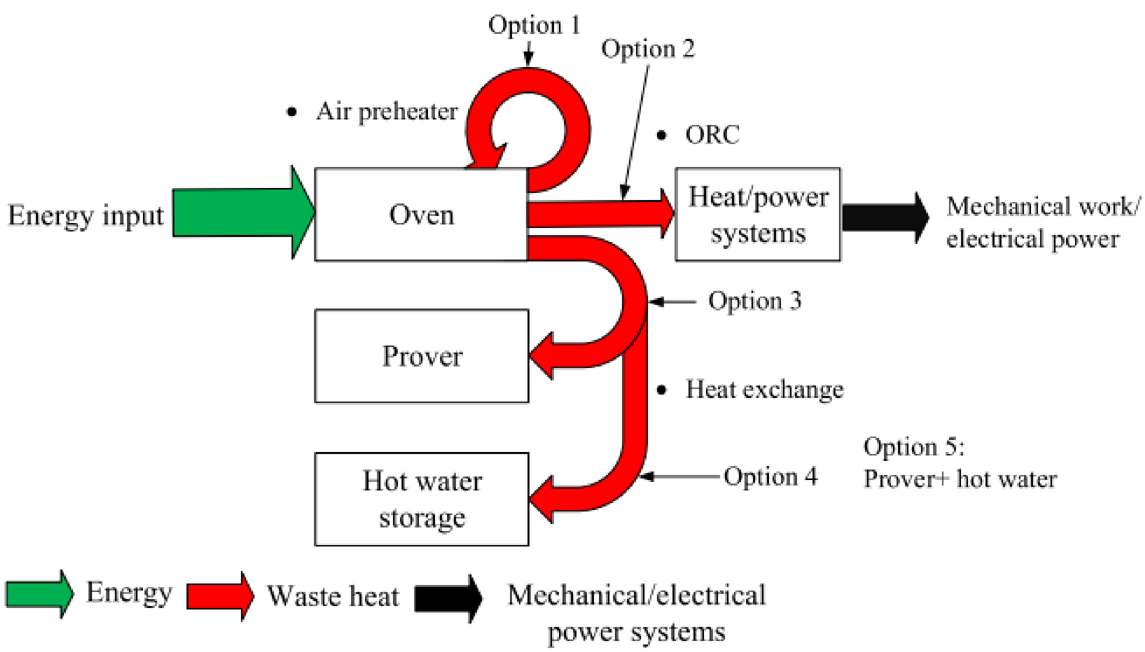


- **Waste Heat Recovery Options:**
  Commercial bakeries typically employ combustion air preheating for waste heat recovery. However, this study explores five distinct integration options for harnessing waste heat from oven exhaust gases:

1. Air preheating
2. Organic Rankine Cycle (ORC) - based electricity generation
3. Prover heating
4. Water heating
5. Combination of prover heating and hot water

This selection, depicted in Figure 7, provides a thorough understanding of the potential benefits and challenges associated with each option.

Figure 5: Selected waste recovery options for commercial bakeries.



- **Results and Discussions:**
  The evaluation of waste heat recovery options involve comprehensive simulations using Aspen Pluas and MATLAB, offering insights into technical, economic, and environmental impacts.

- **Technical Analysis:**
  Table 3 presents key technical parameters from baseline simulations, including heat exchanger areas (A) and thermodynamics works (W). Variations in heat exchanger sizes were observed based on system heating and pressure requirements, fluid types, and application specifics.

Table 3: Estimated parameters for various waste heat recovery options. [16]

WHR options	Estimated parameters (A = Area, W=Power)		
	Heat exchangers parameters	Pump parameters	Turbine parameters
Option 1: Air preheater for oven 1 heat exchanger	$A_{ap} = 4.81m^2$		
Option 2: ORC 3 heat exchangers (evaporator, recuperator, and condenser); 2 pumps; 1 turbine	$A_{evp} = 9.06m^2$ $A_{recp} = 1m^2$ $A_{con} = 12.48m^2$		$W_P = 2.68kW$, $W_T = 60.8kW$ $W_{cp} = 0.93kW$
Option 3: Prover heating 2 heat exchangers (air and steam)	$A_{air} = 0.33m^2$, $A_s = 0.38m^2$ $P_{air} = ambient$, $P_s = 1.2bar$ $T_{air} = 40C$, $T_s = 105C$		
Option 4: Hot water 1 heat exchanger; 1 pump	$A_{hw} = 0.96m^2$	$W_{p,hw} = 0.083kW$	
Option 5: Prover heating + hot water 3 heat exchangers (air, steam, hot water); 1 pump	Prover: $A_{pr,air} = 0.33m^2$, $A_{pr,s} = 0.38m^2$, Hot water: $A_{hw} = 1.78m^2$	$W_{p,hw} = 0.21kW$	

Table 4 details the techno-economic performance of different options, emphasizing their potential to recover up to 285 kW of waste heat from the oven. Notably, the air pre-heater outperformed alternatives, showcasing a remarkable fuel-saving potential of 161.9 tonnes/year (178.5 tons/year) or (9,318 MMBtu/year).

The ORC option, designed for electricity generation, exhibited lower annual cost savings ($66k/year) compared to other options. This was attributed to its lower heat-to-work conversion efficiency (21%).

Table 4: Techno-economic performances of different waste heat recovery options.

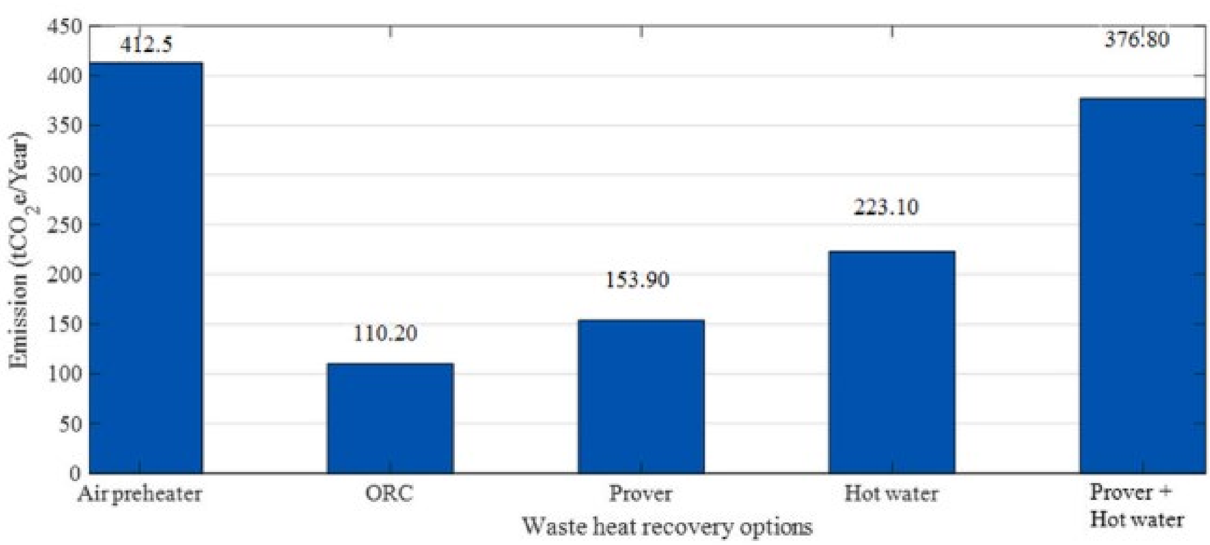
WHR options (Integration options)	Heat recovery	Fuel or electricity[a] saving/ year		Investment cost (WHR options only)	Payback period
	kW	(tonne or MWh)	($/year[b])	($)	(years)
Option 1: Air preheater (Oven + Air preheater)	286	161.93 t	93,594	71,631	0.77
Option 2: ORC (Oven + ORC)	286	428.93 MWh	66,157	304,040	4.59
Option 3: Prover heating (Oven + Prover heating)	120	61.10 t	35,317	104,000	2.94
Option 4: Hot water (Oven + Hot water)	164	87.57 t	50,613	64,886	1.28
Option 5: Prover heating + hot water (Oven + Prover heating + Hot water)	284	148.85 t	86,032	172,810	2

Currency conversion rate 1£ = 1.28 US$.

- Gas price £0.029/kWh, **Electricity price £0.1205/kWh for medium-sized industry (source Department of Business, Energy, and Industrial Strategy (BEIS) [17]).
- Yearly operation time: 7500 h.

- **Economic Viability and Environmental Impact:**
  Figure 8 illustrates emissions savings associated with various options, with the air pre-heater emerging as the most economically viable and environmentally friendly choice. Despite the ORC option lagging in emissions savings, its electricity generation potential, if stored and reused during peak times, could bring additional economic benefits.

Figure 6: Emissions savings with different waste heat recovery options.



While the air pre-heater stands out individually, the study emphasizes the benefits of integrating multiple options (e.g., options 3 and 4). Despite potentially longer payback periods due to increased investment costs, combined heat recovery integration options promise greater long-term benefits.

In conclusion, the study underscores the multifaceted nature of waste heat recovery, where technical, economic, and environmental considerations converge to inform optimal strategies for the commercial baking industry.

[2] Energy Cost Reduction at a Bakery Factory: A Heat Recovery Case Study [18]

- **Introduction:**
  Operational, a prominent player in energy-efficient solutions, undertook a project aimed at enhancing substantially and reducing operational costs for one of Spain's leading bakery manufacturers. The bakery, specializing in breadcrumb production for major food chain stores across Spain, operated multiple lines in its factory located in the North of Spain. Operational identified an opportunity to curtail gas consumption in the driers associated with the bakery lines by harnessing the waste heat generated by the ovens.

- **Implementation:**
  Operational's engineers conceptualized and implemented a Heat Recovery System, intricately linking the exhaust stacks of the ovens to the fresh air inlet of the driers. The ductwork, constructed with thermally insulated stainless steel, facilitates efficient heat transfer. A modulating damper system controls the distribution of hot air to the driers, ensuring optimal utilization. The system's logic, governed by a Programmable Logic Controller (PLC), incorporates key process data, with static pressure in the oven stack and duct temperature serving as pivotal regulatory factors.

- **System Components:**
  The integration involved components such as Bakery Factory Systems, Energy Cost Reduction materials, and Bakery Factory Ventilation, emphasizing a holistic approach to energy efficiency.

- **Results:**
  The implementation of yielded the results below:
  - A notable 3,000 Nm^3/h of exhaust air per oven, at a minimum temperature of 200°C, was effectively recycled to each drier.
  - Each drier experienced savings of over 100 kWh of thermal energy.
  - A 30% reduction in the overall gas consumption across the bakery lines.
  - Cumulatively, the project led to savings of 1,200 MWh (41,000 therms) of gas annually, translating to a reduction of 250 tons per year in CO_2 emissions, contributing positively to the bakery's environmental footprint.

Literature Review Conclusions

The literature review provided a comprehensive overview of heat recovery systems in the baking industry. It explored the principles, advantages, challenges, and specific systems, showcasing the industry's commitment to sustainable and efficient energy practices. As the baking sector navigates challenges, these innovative solutions pave the way for a more resilient and environmentally conscious future. The versatility of heat recovery technologies extends beyond baking. For instance, the heat recovery technology from Manufacturer B presented before has features that allow it to adapt to a diverse range of industries such as food and beverages, metal processing, paint and drying plants, heat treatment plants, cement production, aluminum industry, foundries, glass productions, paper mills, etc. Similarly, the roof-top heat exchanger from Manufacturer A, highlighted for its efficacy in the baking sector, finds potential applications in food and beverage, healthcare, industrial and processes, manufacturing, and pharmaceutical industries. This underscores the broad spectrum of industries that can benefit from implementing advanced heat recovery solutions, fostering sustainable practices across various sectors.

Background- Industrial Assessment Center (IAC) Data Analysis:

The industrial market data exists across various resources, including the IAC Database, California Energy Data and Reporting System (CEDARS) Claims, Program Implementation Plans for Industrial Programs in California, Market Studies, Impact Evaluation, and California Public Utilities Commission (CPUC) Potential and Goal Studies. The most robust of these data sources is the Industrial Assessment Center (IAC) Database. The IAC Program is administered by the U.S. Department of Energy. It operates through a network of university-based centers and provides free energy assessments to small and medium-sized manufacturers across the country. IACs conduct American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Level II assessment of the client's facility and provide an in-depth assessment of the industrial facility with a list of efficiency measures with estimated costs, estimated energy savings, and a return on investment. Centers then contact each participating manufacturer six (6) to nine (9) months later to gather more information about implementing recommendations. As of 2023, there are thirty-nine (39) IACs across the country, with four (4) active centers in California at San Francisco State University, San Jose State University, University of California – Irvine, and San Diego State University [19].

Objectives:

The objectives of conducting IAC Data Analysis of assessment recommendations related to heat recovery technologies are:

a. Determine the prevalence of heat recovery-related measures in the Food and Beverage sector in the U.S. and California.

b. Summarize measure costs and energy cost savings information per North American Industry Classification System (NAICS) and Standard Industrial Classification (SIC) codes.

c. Determine the implementation rate of heat recovery related measures in California and compare them with other states.

d. Compile measure costs and energy cost savings of heat recovery-related measures implemented in the Food and Beverage sector. Calculate the estimated payback for each of them.

e. Analyze the energy-saving potential and payback period of heat recovery-related measures implemented in bakeries.

IAC Data Analysis:

IAC assessments data is publicly available on the IAC website [19]. The database consists of information about measure costs, energy cost savings, sector type, and implementation status for about 21,285 assessments and 158,622 recommendations at the end of Q1 2024. IAC data for heat recovery-related measures recommended after 2010 is pulled out from the database for this comprehensive analysis.

In the IAC database, assessment recommendations are categorized as per End Product, State and NAICS codes. The food and beverage sector encompasses the recommendations for industries/end products, including (but not limited to) bakeries, tortillas, chips, almonds, frozen vegetables, and beverages. Table 5 compiles the information about assessments performed in California and related to the food and beverage sector. About 9% of the total assessments are on the food and beverage sector in California.

Table 5: Preliminary Information about IAC Assessments in California (since 2010)

Number of total energy assessments performed in California	321
Number of assessments in Food and Beverage Sector	30
% Assessments in Food & Beverage Sector	9%

Tables 6 and 7 represent information about IAC assessments related to heat recovery and bakeries. About twenty-six (26) recommendations from the Food and Beverage sector/category are related to heat recovery. However, the data indicates that the number of recommendations for the bakeries is significantly low.

Table 6: Preliminary Information about IAC Assessments related to heat recovery and the Food & Beverage sector

Total number of assessment recommendations in CA after 2010	3,000
Number of recommendations related to heat recovery	101
Total number of recommendations in Food and Beverage End Products (in CA after 2010)	291
Number of heat recovery-related recommendations in the Food and Beverage sector (in CA after 2010)	26

Table 7: Preliminary information about IAC Assessments related to bakeries

Number of recommendations for bakeries in the U.S.	12
Average therms consumption of the above facilities	486,570
Number of recommendations for bakeries in CA	1

Appendix III summarizes the data regarding implementation status and costs, natural gas savings, and payback period for recommendations related to heat recovery in the Food and Beverage sector. The average natural gas savings for twenty-six (26) recommendations are 4,160 MMBTU, and the average energy cost savings are $25,191. Furthermore, the estimated payback period ranges from 0.58 to 6.53 years for all the assessments. The average payback period for the twenty-six (26) recommendations is 2.46 years.

Table 8 illustrates the implementation rates of heat recovery-related measures in the U.S. and California. The average implementation rate for 101 recommendations is 14.7%, whereas the average implementation rate for all the IAC centers in the U.S. is 20.8%. Figures 9 and 10 illustrate the year-on-year comparison of implementation rates in CA and state-wise comparison of implementation rates in the U.S., respectively. The number of recommendations related to heat recovery was highest in the year 2023 in California. The average implementation rate of heat recovery-related measures is the highest in Missouri (MO) state (compared to states noting more than 100 heat recovery-related recommendations since 2010).

Table 8: Implementation rate of heat recovery-related measures in the U.S. and CA

	AR Code 2.24- All Heat Recovery related measures- CA			
FY	Number of measures	Imp Status Known	Implemented	% Imp Rate
2011	8	8	1	12.5
2012	12	12	3	25.0
2013	10	10	2	20.0
2014	5	5	1	20.0
2015	11	11	1	9.1
2016	10	10	0	0.0
2017	2	2	0	0.0
2018	2	2	0	0.0
2019	3	3	0	0.0
2020	2	2	1	50.0
2021	3	3	1	33.3
2022	2	1	0	0.0
2023	22	7	1	14.3
Average Implementation Rate- CA				14.7%
Overall Average Implementation Rate- US				20.8%

Figure 7: Implementation rates of heat recovery related measures in CA (Since 2010)

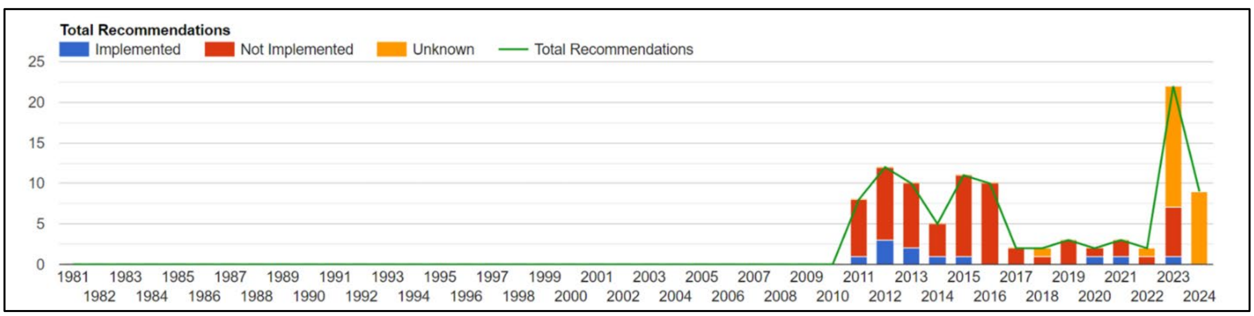


Figure 8: Implementation rates of heat recovery-related measures in the U.S. (Since 2010)

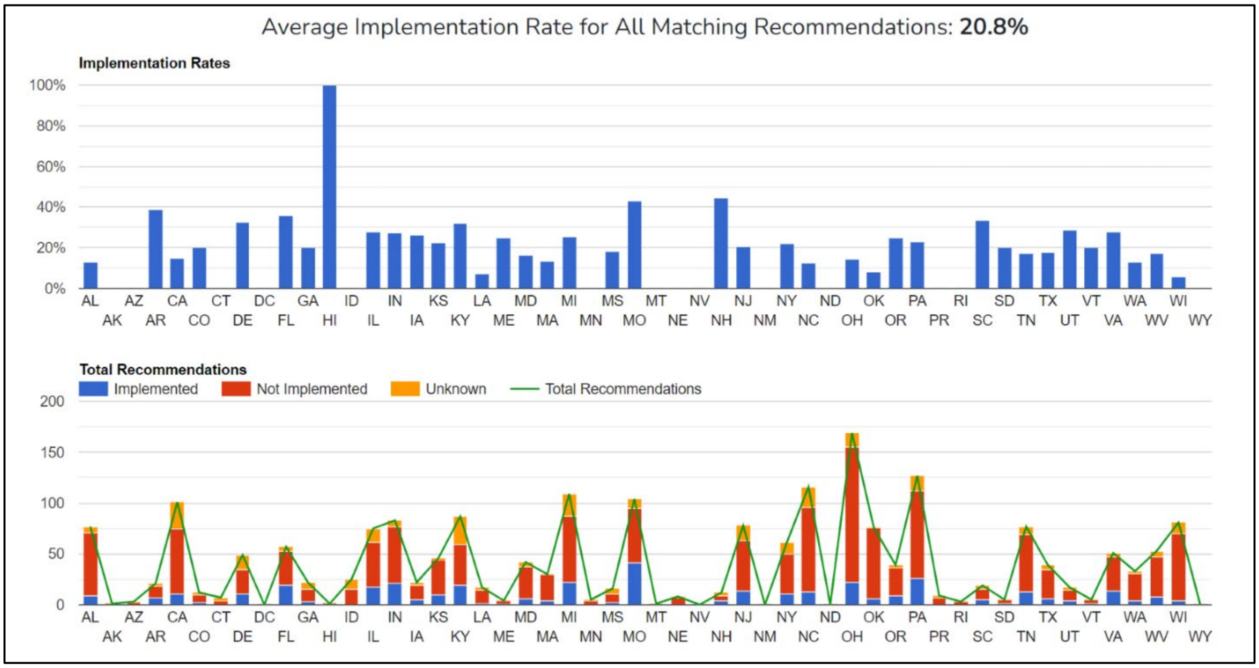


Table 9 illustrates the summary of assessment recommendations for bakeries in the U.S. IAC audits have been conducted in about 12 bakeries in the U.S. since 2010. Out of them, heat recovery-related recommendations were made for 4 bakeries. Table 10 illustrates the summary of heat recovery-related recommendations: implementation costs, natural gas savings, and estimated payback period.

Table 9: Summary: IAC assessment recommendations for bakeries in the U.S.

ID	FY	SIC	NAICS	State	Products	Implementation Status
AM0660	2014	2045	311812	TX	Bakery mixes	NA
AS0490	2020	2051	311812	AZ	Bakery Products	NA
BD0396	2011	2051	311812	IL	Bakery goods	N
CO0703	2015	2051	311812	CO	Bakery Products	NA
CO0704	2015	2051	311812	CO	Bakery Products	NA
CO0715	2015	2051	311812	CO	Bakery Products	NA
MZ0156	2014	2045	311813	MO	Bakery Products	I
OK0912	2015	2051	311812	OK	Bakery Products	N
SF0412	2012	2051	311812	CA	Bread and Other Bakery products	NA
SU0347	2013	2033	311421	NY	Bakery Products	NA

ID	FY	SIC	NAICS	State	Products	Implementation Status
UD0900	2014	3556	333241	OH	Bakery Equipment	I
UL2203	2022	2051	311812	KY	Bakery products	NA

Table 10: Summary Table: Heat recovery related recommendations for bakeries in U.S.

ID	FY	Implementation Status	Implementation Cost ($)	Natural Gas Savings (MMBTU)	Energy Cost Savings ($)	Payback Period (yrs)
BD0396	2011	N	$ 3,000	4,274	$ 18,092	0.17
MZ0156	2014	I	$ 4,400	1,159	$ 2,886	1.52
OK0912	2015	N	$ 60,000	2,056	$ 10,628	5.65
UD0900	2014	I	$ 2,500	66	$ 607	4.12

Market Assessment Survey

The selected methodology to conduct a market assessment on the potential for implementation of production line heat recovery systems included the involvement of SMEs in a survey with the intention of gauging their interest in adopting this kind of technology in their production processes, as well as the potential barriers.

The objective of the interviews as part of this market assessment is to gain insights from various stakeholders on aspects of production line heat recovery systems and associated technologies, technology usage understanding, market environment, and energy savings potential. The focus of these SME interviews was centered around the understanding of current industry practices for excess heat management, knowledge of available heat recovery systems, likelihood of adopting heat recovery systems, energy efficiency, and market usage.

The survey was designed to be answered by a variety of stakeholders that would serve as a representative sample of the baking industry in the state of California. The interview was sent to 10 different organizations, and the target number of participants was 4 organizations. Table 11 contains the summary of response rates and interview participation. Refer to Appendix A for the detailed interview questionnaire. The individual SME responses and information on the interviewees can be found in Appendix B.

Table 11: Summary of organization response rate.

Number of organizations contacted	Number of organizations that responded	Target number of interviews	Actual participation	Response rate	Participation rate
10	6	4	6	60%	100%

Market Findings

This section summarizes the key findings of the interviews:

1. The SMEs indicated heat sources in their production processes include: 50% of the sites have boilers as their main heat source, 17% have ovens, and 33% have a combination of ovens and boilers.
2. The entirety of the SMEs interviewed indicated that there is a need in their production processes to manage the excess heat generated. One third of the sites use cooling towers, one third use ventilation, and the other third use a combination of both cooling towers and ventilation to manage excess heat generated.
3. The familiarity of SMEs with heat recovery systems observed in this survey indicates that there is a general lack of knowledge of these systems. One of the SMEs indicated not to be familiar with these systems, and the rest of them indicated to be slightly, somewhat, or moderately familiar with them.
4. The implementation of heat exchangers to capture excess heat from production processes seems to be required based on the responses from SMEs; however, 50% of the interviewees indicated that they have not considered implementing systems to recover excess heat. This indicates some understanding of the required systems but illustrates little interest in pursuing the installation of them.

The answers to the questions in the survey indicate that there is a gap in heat recovery processes in the industry which is currently not being fulfilled. All SMEs indicate that there is excess heat that is being generated in their processes, and their answer to this heat is to dispose of it as opposed to reusing it to make their processes more efficient. Among the SMEs interviewed, half of them have not considered implementing systems that could address heat recovery in the food and beverage industry; furthermore, this reluctance to implementing systems could be based on the lack of knowledge commonly held by industry as per their responses to the survey. This presents a market opportunity to implement technologies that address heat recovery in production processes in the food and beverage industry.

Implementation Challenges

The most significant challenge SMEs identified for the implementation of heat recovery systems in their production operations is the financial constraints associated with adopting this new technology—83% of the interviewees noted this as their main challenge, and 50% of the total number of interviewees mentioned operational disruptions as another challenge they anticipate. One out of the six interviewees stated being unsure of the challenges they could face by implementing heat recovery systems.

The initial investment required for the implementation of heat recovery systems is a challenge identified by SMEs as observed in their responses to the survey. Furthermore, 50% of the interviewees indicated that they would be willing to invest less than $50,000 in a heat recovery system. Additionally, they indicated a low degree of likelihood of investing in a heat recovery system within the next 2 years. The remaining 50% of interviewees suggested they would be willing to make an initial investment between $50,000 and $100,000 for heat recovery systems. Overall, interviewees indicated a relatively high degree of likelihood to invest in a heat recovery system within the next 2 years.

SMEs suggested that safety measures are an important aspect that has the potential to influence their decision to implement heat recovery systems. A total of 83% of the interviewees noted that they would require at least 3 safety measures that would need to be implemented to ensure efficient and safe heat recovery; the remaining 17% of interviewees suggested a total of 2 safety measures that would need to be in place for them to adopt the systems.

The challenges indicated by the SMEs provide guidelines for best practices that would enhance the chances of organizations in industry implementing heat recovery systems. As observed in the responses, financial constraints are a significant barrier to address for the industry to be willing to invest in heat recovery systems, Table 12 contains a summary of the different challenges for adopting heat recovery systems that SMEs noted. More effort in advertising the potential energy savings deriving from these systems, which could offset the initial investments, may incentivize representatives in industry to adopt the suggested technology. Similarly, understanding the safety measures SMEs want in heat recovery systems can inform best-practice guidelines, helping reassure industry stakeholders and encourage adoption.

Table 12: Distribution of responses regarding challenges for heat recovery systems adoption

Challenges	Org1	Org 2	Org 3	Org 4	Org 5	Org 6
Financial constraints	X	X		X	X	X
Operational disruptions		X		X		X
Unsure			X			

Potential Incentives for System Implementation

Cost savings are one of the main drivers for incentivizing organizations to implement heat recovery systems as seen in their responses to the survey. Regarding the importance of cost savings associated with heat recovery systems, 67% of the interviewees indicated that these are extremely important, 17% noted that they are somewhat important, and the remaining 16% indicated that they are neutral to potential cost savings from heat recovery systems implementation.

The answers of SMEs related to environmental sustainability show that this is a relatively low priority for them since 50% of the interviewees suggested it is somewhat important, 17% deem it to be extremely important, 17% answered it is slightly important, and the remaining 16% indicated that they are neutral to environmental sustainability.

Energy efficiency in production processes is an aspect that SMEs consider to be of relatively low importance for their adoption of heat recovery systems since 50% of the interviewees mentioned that energy efficiency is slightly significant, 33% stated it is moderately significant, and 17% believe energy efficiency is not significant at all for their overall production processes.

All the SMEs indicated that reduction in their energy bills associated with the energy savings achieved through heat recovery is the best way to quantify energy savings. Additionally, 67% of the interviewees also indicated that "kWh saved" would be another way to quantify energy savings.

Government incentives are a significant aspect that can incentivize industries to implement heat recovery systems as per the answers given by SMEs. 50% of the interviewees indicated that government incentives have a high impact (~>50%) on their potential to adopt heat recovery systems, and the remaining 50% suggested that these have a significant impact (~>25%).

The answers to the questions related to the potential ways to increase the likelihood of industry adopting heat recovery systems in their production processes are contained in Figures 11-13. These figures show that long-term overall cost savings are the key incentive for implementing heat recovery systems. The implementation of these systems has, mainly, three aspects—cost savings, environmental impacts, and energy efficiency. Based on the responses to the survey, energy efficiency in the production process, as well as environmental sustainability are considerably less important to SMEs than cost savings. Therefore, it could yield the most benefits to bring the SMEs' attention to the cost savings associated with heat recovery systems. Additionally, it is observed that incentives could influence the likelihood of industry members implementing heat recovery systems.

Figure 9: Distribution of answers to the importance of cost savings in decision-making.

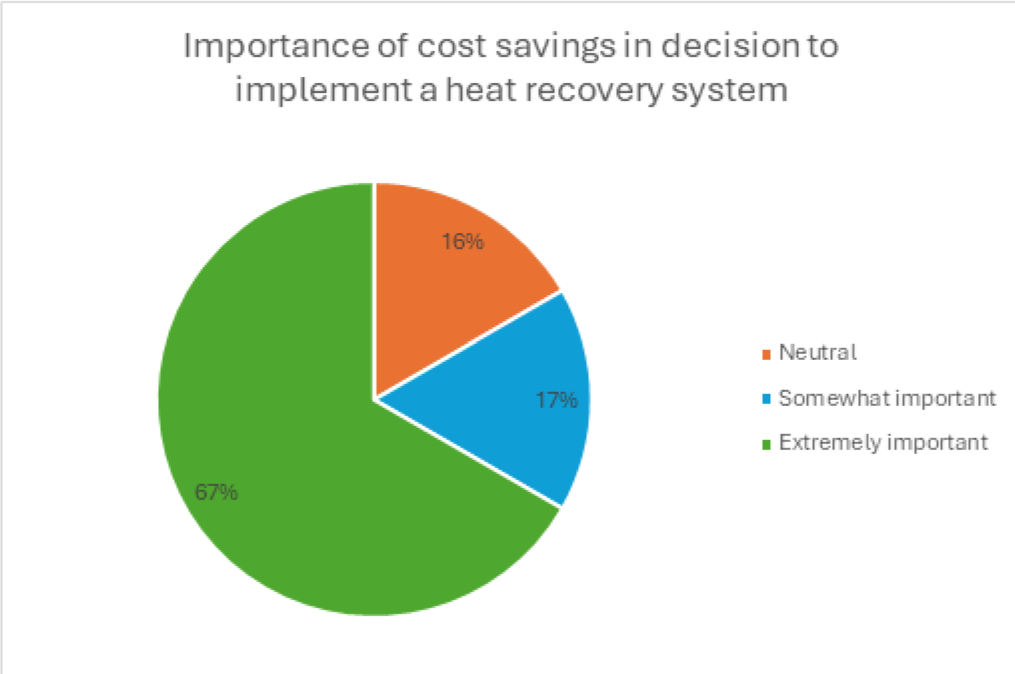


Figure 10: Distribution of answers to the importance of environmental sustainability in decision-making.

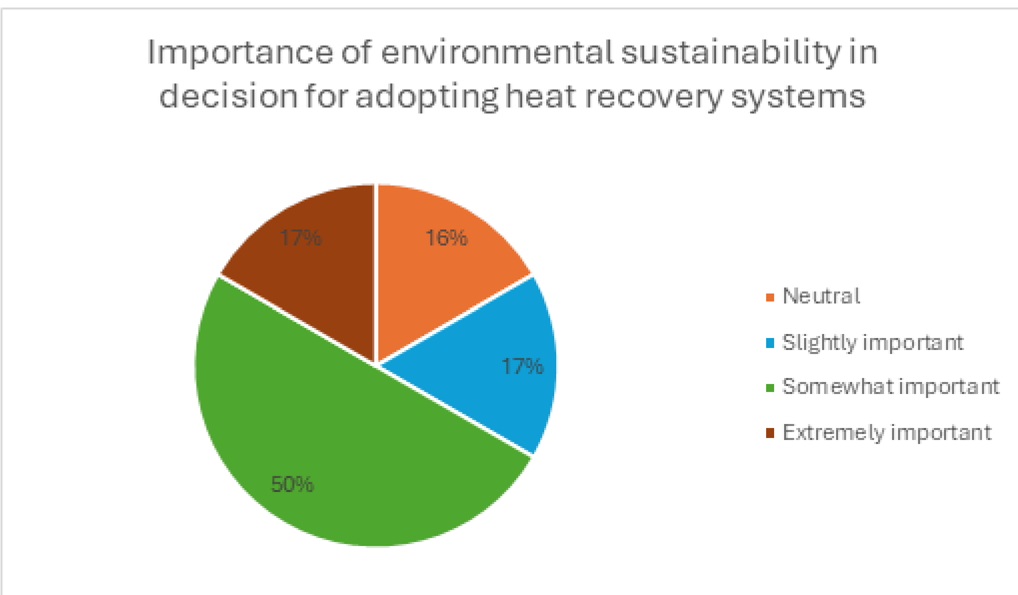
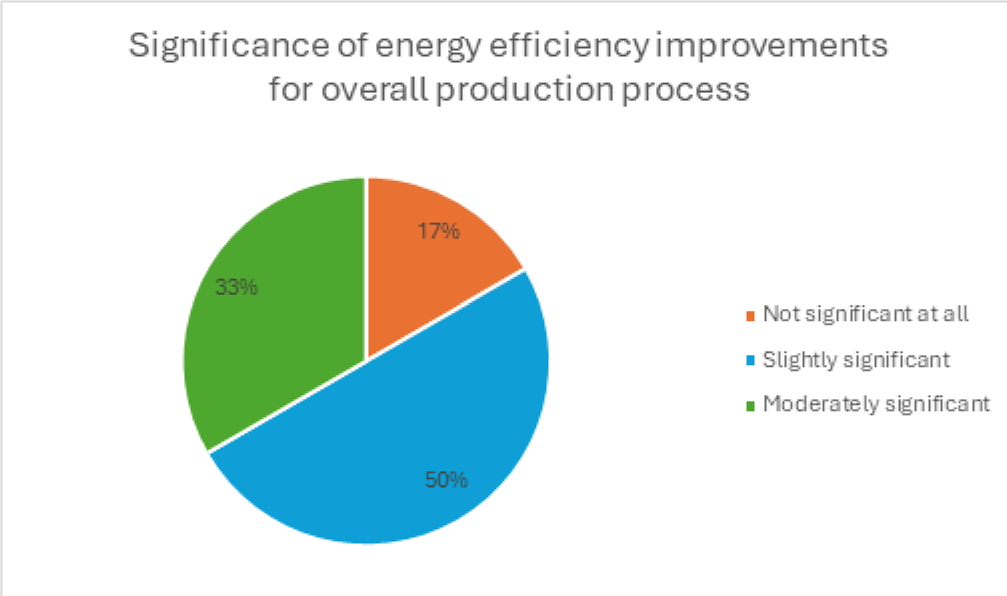


Figure 11: Distribution of answers to the importance of energy efficiency in decision-making.



Conclusions

This study has shown that production line heat recovery systems represent a promising opportunity for improving energy efficiency and reducing greenhouse gas emissions in the industrial baking sector. Through a combination of literature review, case studies, SME interviews, and data analysis, it became clear that a significant amount of thermal energy is currently wasted in baking operations, particularly from ovens and boilers, despite the availability of technologies capable of capturing and reusing this heat.

The analysis of commercially available systems, including rooftop heat exchangers and integrated flue gas recovery units, demonstrated that these technologies can achieve meaningful reductions in both energy consumption and CO_2 emissions, with some systems offering up to 30% energy savings and payback periods as short as two to five years. However, despite these benefits, adoption in California remains below the national average, suggesting that the market is underdeveloped and that barriers to implementation persist.

Incentives are a significant aspect that can push industries to implement heat recovery systems as per the answers given by SMEs. 50% of the interviewees indicated that government incentives have a high impact on their potential to adopt heat recovery systems, and the remaining 50% suggested that these have a significant impact.

Interviews with subject matter experts revealed that while there is a clear recognition of the need to manage excess heat, many facilities have not yet considered or implemented heat recovery systems. This hesitation is largely driven by financial concerns, operational uncertainties, and a general lack of awareness about the available technologies and their benefits. While environmental sustainability and energy efficiency are acknowledged, they are not the primary motivators for adoption. Instead, cost savings and the availability of government incentives emerged as the most influential factors in decision-making.

Overall, the findings underscore a disconnect between the technical potential of heat recovery systems and their current market penetration. Bridging this gap will require targeted outreach, financial support mechanisms, and continued demonstration of the economic and operational viability of these systems in real-world bakery settings.

Recommendations

To bridge the gap between the demonstrated potential of heat recovery systems and their limited adoption in the industrial baking sector, a multifaceted approach is necessary. The findings of this study suggest that while the technical and environmental benefits of these systems are well-established, their implementation is often hindered by financial, operational, and informational barriers. Addressing these challenges requires a coordinated effort that combines financial incentives, education, and strategic demonstration.

One of the most effective ways to encourage adoption is through the expansion of financial support mechanisms. Government and utility-sponsored incentives can play a pivotal role in offsetting the upfront costs that many bakeries identify as a primary barrier. These incentives, when clearly communicated and easily accessible, can significantly improve the return on investment and reduce the perceived financial risk.

Equally important is the need to raise awareness within industry. Many stakeholders remain unfamiliar with the capabilities and benefits of modern heat recovery systems. Targeted outreach and education campaigns can help demystify the technology and build confidence among potential adopters. These efforts should be complemented by the development of best practice guidelines that address safety, integration, and maintenance, ensuring that bakeries can implement these systems with minimal disruption to their operations.

Ultimately, the path forward involves aligning economic incentives with environmental goals, equipping industry stakeholders with the knowledge and tools they need and fostering a supportive ecosystem that encourages innovation and investment in energy efficiency. By taking these steps, the industrial baking sector in California and beyond can move toward a more sustainable and cost-effective future.

Appendices

Appendix I. SME Interview Questions

Note: *These questions were modified depending on the manufacturer or specialist interviewed to reflect their product and expertise. The specific questions asked to each SME can be found in the interview notes in Appendix II.

1. How familiar are you with heat recovery systems in food and beverage production lines?
2. What types of heat sources do you currently have in your production process?
3. Have you considered implementing heat exchangers to capture waste heat from processes?
4. How do you currently manage excess heat generated during production?
5. What challenges do you foresee in integrating a heat recovery system into your production line?
6. Could heat recovery be most effective in specific production stages?
7. What safety measures would you implement to ensure efficient and safe heat recovery?
8. How would you quantify the energy savings achieved through heat recovery?
9. What initial investment would you be willing to allocate for implementing a heat recovery system
10. How significant do you consider energy efficiency improvements for your overall production process?
11. How likely are you to invest in energy efficiency technologies within the next two years?
12. How important are cost savings in your decision to implement a heat recovery system?
13. How would you rate the potential impact of government incentives on your decision to adopt heat recovery systems?
14. How important is environmental sustainability in your decision-making process for adopting new technologies?
15. Could you please provide data on gas usage to help us estimate the amount of gas used in your production process?

Appendix II. Raw SME Responses

Interviewee 1

Date of interview: 12/27/2024

Interview Questions and Responses:

1. How familiar are you with heat recovery systems in food and beverage production lines?
   a. Somewhat familiar.
2. What types of heat sources do you currently have in your production process?
   a. Boilers.
3. Have you considered implementing heat exchangers to capture waste heat from processes (If yes, please specify the types of heat exchangers that have been considered)?
   a. Yes.
4. How do you currently manage excess heat generated during production?
   a. Cooling towers.
5. What challenges do you foresee in integrating a heat recovery system into your production line?
   a. Somewhat familiar.
6. Could heat recovery be most effective in specific production stages? If so, which stages?
   a. Yes, at chilling systems.
7. What safety measures would you implement to ensure efficient and safe heat recovery?
   a. Regular maintenance, automated monitoring systems, and safety protocols.
8. How would you quantify the energy savings achieved through heat recovery?
   a. kWh saved, and reduction in energy bills.
9. What initial investment would you be willing to allocate for implementing a heat recovery system
   a. Between $50,000 and $100,000.
10. How significant do you consider energy efficiency improvements for your overall production process?
    a. Slightly significant.
11. How likely are you to invest in energy efficiency technologies within the next two years?
    a. Somewhat likely.

12. How important are cost savings in your decision to implement a heat recovery system?
    a. Extremely important.
13. How would you rate the potential impact of government incentives on your decision to adopt heat recovery systems?
    a. Significant impact.
14. How important is environmental sustainability in your decision-making process for adopting new technologies?
    a. Neutral.
15. Could you please provide data on gas usage to help us estimate the amount of gas used in your production process?
    a. I would need to review billing.

Interviewee 2

Date of interview: 01/25/2025

Interview Questions and Responses:

1. How familiar are you with heat recovery systems in food and beverage production lines?
    a. Moderately familiar.
2. What types of heat sources do you currently have in your production process?
    a. Ovens and boilers.
3. Have you considered implementing heat exchangers to capture waste heat from processes (If yes, please specify the types of heat exchangers that have been considered)?
    a. No.
4. How do you currently manage excess heat generated during production?
    a. Cooling towers and ventilation.
5. What challenges do you foresee in integrating a heat recovery system into your production line?
    a. Unsure.
6. Could heat recovery be most effective in specific production stages? If so, which stages?
    a. Yes, at production.
7. What safety measures would you implement to ensure efficient and safe heat recovery?
    a. Regular maintenance, automated monitoring systems, and safety protocols.

8. How would you quantify the energy savings achieved through heat recovery?
    a. kWh saved, reduction in energy bills, and improvement in energy efficiency.
9. What initial investment would you be willing to allocate for implementing a heat recovery system
    a. Between $50,000 and $100,000.
10. How significant do you consider energy efficiency improvements for your overall production process?
    a. Moderately significant.
11. How likely are you to invest in energy efficiency technologies within the next two years?
    a. Very likely.
12. How important are cost savings in your decision to implement a heat recovery system?
    a. Neutral.
13. How would you rate the potential impact of government incentives on your decision to adopt heat recovery systems?
    a. Significant impact.
14. How important is environmental sustainability in your decision-making process for adopting new technologies?
    a. Extremely important.
15. Could you please provide data on gas usage to help us estimate the amount of gas used in your production process?
    a. Yes.

Interviewee 3

Date of interview: 01/30/2025

Interview Questions and Responses:

1. How familiar are you with heat recovery systems in food and beverage production lines?
    a. Moderately familiar.
2. What types of heat sources do you currently have in your production process?
    a. Ovens and boilers.
3. Have you considered implementing heat exchangers to capture waste heat from processes (If yes, please specify the types of heat exchangers that have been considered)?
    a. Yes, thrush heat exchangers.

4. How do you currently manage excess heat generated during production?
   a. Ventilation.
5. What challenges do you foresee in integrating a heat recovery system into your production line?
   a. Operational disruptions and financial constraints.
6. Could heat recovery be most effective in specific production stages? If so, which stages?
   a. N/A.
7. What safety measures would you implement to ensure efficient and safe heat recovery?
   a. Regular maintenance, automated monitoring systems, and safety protocols.
8. How would you quantify the energy savings achieved through heat recovery?
   a. Reduction in energy bills and improvement in energy efficiency percentages.
9. What initial investment would you be willing to allocate for implementing a heat recovery system
   a. Less than $50,000.
10. How significant do you consider energy efficiency improvements for your overall production process?
    a. Slightly significant.
11. How likely are you to invest in energy efficiency technologies within the next two years?
    a. Somewhat likely.
12. How important are cost savings in your decision to implement a heat recovery system?
    a. Extremely important.
13. How would you rate the potential impact of government incentives on your decision to adopt heat recovery systems?
    a. Significant impact.
14. How important is environmental sustainability in your decision-making process for adopting new technologies?
    a. Somewhat important.
15. Could you please provide data on gas usage to help us estimate the amount of gas used in your production process?
    a. Unknown.

Interviewee 4

Date of interview: 01/15/2025

Interview Questions and Notes:

1. How familiar are you with heat recovery systems in food and beverage production lines?
   a. Somewhat familiar.
2. What types of heat sources do you currently have in your production process?
   a. Boilers.
3. Have you considered implementing heat exchangers to capture waste heat from processes (If yes, please specify the types of heat exchangers that have been considered)?
   a. Yes, an economizer.
4. How do you currently manage excess heat generated during production?
   a. Cooling towers.
5. What challenges do you foresee in integrating a heat recovery system into your production line?
   a. Financial constraints and operational disruptions.
6. Could heat recovery be most effective in specific production stages? If so, which stages?
   a. Yes, heating systems and cooling systems.
7. What safety measures would you implement to ensure efficient and safe heat recovery?
   a. Regular maintenance, safety protocols, and automated monitoring systems.
8. How would you quantify the energy savings achieved through heat recovery?
   a. kWh saved, reduction in energy bills, and improvement in energy efficiency.
9. What initial investment would you be willing to allocate for implementing a heat recovery system
   a. Between $50,000 and $100,000.
10. How significant do you consider energy efficiency improvements for your overall production process?
    a. Moderately significant.
11. How likely are you to invest in energy efficiency technologies within the next two years?
    a. Somewhat likely.

12. How important are cost savings in your decision to implement a heat recovery system?
    a. Extremely important.
13. How would you rate the potential impact of government incentives on your decision to adopt heat recovery systems?
    a. High impact.
14. How important is environmental sustainability in your decision-making process for adopting new technologies?
    a. Somewhat important.
15. Could you please provide data on gas usage to help us estimate the amount of gas used in your production process?
    a. Yes, 250,000 deca therms.

Interviewee 5

Date of interview: 08/05/2024

Interview Questions and Responses:

1. How familiar are you with heat recovery systems in food and beverage production lines?
    a. Slightly familiar.
2. What types of heat sources do you currently have in your production process?
    a. Boilers.
3. Have you considered implementing heat exchangers to capture waste heat from processes (If yes, please specify the types of heat exchangers that have been considered)?
    a. No.
4. How do you currently manage excess heat generated during production?
    a. Ventilation and Cooling towers.
5. What challenges do you foresee in integrating a heat recovery system into your production line?
    a. Financial constraints.
6. Could heat recovery be most effective in specific production stages? If so, which stages?
    a. Yes, cooking.
7. What safety measures would you implement to ensure efficient and safe heat recovery?
    a. Safety protocols, regular maintenance, and automated monitoring systems.

8. How would you quantify the energy savings achieved through heat recovery?
   a. kWh saved and reduction in energy bills.
9. What initial investment would you be willing to allocate for implementing a heat recovery system
   a. Less than $50,000.
10. How significant do you consider energy efficiency improvements for your overall production process?
    a. Slightly significant.
11. How likely are you to invest in energy efficiency technologies within the next two years?
    a. Somewhat unlikely.
12. How important are cost savings in your decision to implement a heat recovery system?
    a. Extremely important.
13. How would you rate the potential impact of government incentives on your decision to adopt heat recovery systems?
    a. High impact.
14. How important is environmental sustainability in your decision-making process for adopting new technologies?
    a. Slightly important.
15. Could you please provide data on gas usage to help us estimate the amount of gas used in your production process?
    a. Yes, 680,000 Therms per year.

Interviewee 6

Date of interview: 08/05/2024

Interview Questions and Responses:

1. How familiar are you with heat recovery systems in food and beverage production lines?
   a. Not familiar at all.
2. What types of heat sources do you currently have in your production process?
   a. Ovens.
3. Have you considered implementing heat exchangers to capture waste heat from processes (If yes, please specify the types of heat exchangers that have been considered)?
   a. No.

4. How do you currently manage excess heat generated during production?
   a. Ventilation.
5. What challenges do you foresee in integrating a heat recovery system into your production line?
   a. Financial constraints and operational disruptions.
6. Could heat recovery be most effective in specific production stages? If so, which stages?
   a. No.
7. What safety measures would you implement to ensure efficient and safe heat recovery?
   a. Regular maintenance and safety protocols.
8. How would you quantify the energy savings achieved through heat recovery?
   a. Reduction in energy bills.
9. What initial investment would you be willing to allocate for implementing a heat recovery system
   a. Less than $50,000.
10. How significant do you consider energy efficiency improvements for your overall production process?
    a. Not significant at all.
11. How likely are you to invest in energy efficiency technologies within the next two years?
    a. Neither likely nor unlikely.
12. How important are cost savings in your decision to implement a heat recovery system?
    a. Somewhat important.
13. How would you rate the potential impact of government incentives on your decision to adopt heat recovery systems?
    a. High impact.
14. How important is environmental sustainability in your decision-making process for adopting new technologies?
    a. Somewhat important.
15. Could you please provide data on gas usage to help us estimate the amount of gas used in your production process?
    a. N/A.

Appendix III. Summary Table–Implementation status and costs, natural gas savings and payback period

ID	IMP Statu	Implementation Cost ($)	Natural Gas Savings (MMBTU	Energy Cost Savings ($)	Payback Period (yrs)
SD0434	NO	$ 4,751	635	$ 4,279	1.11
SD0436	NO	$ 22,700	4,764	$ 26,197	0.87
SD0450	NO	$ 25,000	1,730	$ 8,500	2.94
SD0481	NO	$ 25,200	10,685	$ 22,759	1.11
SD0490	NO	$ 5,480	254	$ 1,842	2.98
SD0559	NO	$ 37,900	2,899	$ 21,481	1.76
SD0585	NO	$ 12,000	4,507	$ 11,628	1.03
SF0398	NO	$ 212,500	15,908	$ 136,531	1.56
SF0399	NO	$ 101,238	8,275	$ 42,675	2.37
SF0404	NO	$ 20,358	776	$ 3,982	5.11
SF0411	NO	$ 3,965	539	$ 2,723	1.46
SF0419	NO	$ 35,328	1,008	$ 5,628	6.28
SF0420	NO	$ 9,543	217	$ 1,461	6.53
SF0422	NO	$ 10,283	1,370	$ 9,464	1.09
SF0429	NO	$ -	37,718	$ 228,512	0.00
SF0470	YES	$ 11,844	816	$ 5,546	2.14
SF0471	NO	$ 50,144	3,034	$ 25,853	1.94
SF0481	NO	$ 10,000	1,372	$ 7,601	1.32
SF0485	NO	$ 14,174	583	$ 3,513	4.03
SF0486	NO	$ 22,499	4,504	$ 21,035	1.07
SF0492	NO	$ 45,338	3,241	$ 17,145	2.64
SF0508	NO	$ 6,155	88	$ 1,181	5.21
SF0539	NO	$ 6,004	123	$ 1,211	4.96
SF0573	NO	$ 960	119	$ 1,654	0.58
SF0594	UNKNOWN	$ 9,100	424	$ 5,385	1.69
SF0595	UNKNOWN	$ 32,818	2,583	$ 37,173	0.88

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