

# Market Assessment of Waste Heat Recovery Solutions in India





## Market Assessment of Waste Heat Recovery Solutions in India

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## Foreword

The industrial sector in India is the largest contributor to Greenhouse Gas (GHG) emissions consuming close to 41% of the total final energy consumption. According to International Energy Agency (IEA), the sector witnessed an exponential growth in terms of the total final energy consumption in the last two decades growing from 35,68,153 TJ in 2020 to a staggering 12,000,000 TJ in 2022. With rapid urbanization and economic development, the energy consumption in the sector is expected to grow rapidly in near future. Indian industries heavily rely on fossil fuels, with coal being the dominant source, accounting for approximately 55% of the country's energy needs.

With growing environmental concerns and urgent need to secure energy sources for future, adoption of energy efficient technologies and processes has almost become inevitable across sectors, predominantly in the industrial sector. While precise quantification remains challenging, studies consistently indicate that a substantial portion of industrial energy consumption, ranging from 20% - 50%, is dissipated as waste heat. This represents a significant untapped energy resource. Waste Heat Recovery (WHR) has emerged as a pivotal strategy to enhance industrial energy efficiency. By capturing and utilizing the otherwise wasted energy, industries can significantly curtail energy costs, reduce emissions, and improve overall operational performance leading to profitability.

The report provides a comprehensive assessment of the waste heat recovery technologies in select industrial sectors comprising of both large industries and MSME sectors. A bucket of economically viable and replicable waste heat technologies has been shortlisted based on desk review and stakeholders' consultation. These technologies when implemented can lead to consolidated energy saving of 0.55 to 1.07 million tonne of oil equivalent (MTOE) leading to GHG emission reduction in the range of 2.35 to 4.67 million tCO<sub>2</sub> within a period of 5 years. The accelerated adoption of these technologies can lead to monetary savings of INR 700 to INR 1300 crore with an investment in the range of INR 2000 to INR 4000 Crore over a period of 5 years.

The report provides a comprehensive analysis of selected WHR technologies, including a rigorous evaluation of their technological maturity, market dynamics, and potential business models for large and MSME sectors. By identifying high-impact technologies and developing a strategic deployment roadmap, the study supports EESL's efforts to promote energy efficiency and advance India's climate action objectives.

We extend our sincere appreciation to the United Nations Environment Programme (UNEP) for supporting this important study and International Institute for Energy Conservation (IIEC) for their support as a Co-executing agency in shaping this study. Together, we look forward to advancing this important agenda and supporting India's journey towards a more energy-efficient and climate-resilient industrial future.

(Vishal Kapoor)

Chief Executive Officer

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## Preface

Waste Heat Recovery (WHR) is crucial in the industrial sector because it significantly boosts energy efficiency, reduces operational costs, minimizes environmental impact, and enhances the lifespan of equipment. The current study presents a comprehensive market assessment of Waste Heat Recovery (WHR) technologies to support the strategic scale-up of industrial energy efficiency in India. Commissioned under the GEF-6 project "Creating and Sustaining Markets for Energy Efficiency," supported by United Nations Environment Programme (UNEP), implemented by Energy Efficiency Services Limited (EESL), jointly with International Institute for Energy Conservation (IIEC),

The study conducts a detailed evaluation of the key WHR technologies within prioritized industrial sectors to inform the development of a go-to-market strategy for EESL. The primary objective of the study is to identify technologies and approaches that offer the highest potential for energy savings and emissions reduction at scale. Given the diversity of WHR options, the study applies a structured assessment framework that evaluates technologies based on effectiveness, scalability, sectoral relevance, and heat sources.

The report covers nine priority sectors including five energy-intensive industries under the Bureau of Energy Efficiency's Perform, Achieve, and Trade (PAT) scheme, and four Micro, Small, and Medium Enterprises (MSME) sectors with significant waste heat generation. Through extensive stakeholder consultations, the study identifies a suite of WHR technologies with strong sectoral applicability, analyzes their energy and emissions reduction potential, and explores their replication feasibility.

To offer a perspective on the market potential for WHR technologies, the analysis also includes three distinct future scenarios, projecting adoption rates and impacts under varying industry and policy conditions a Low (Business-as-Usual) scenario, a medium scenario, and high scenario. These scenarios help estimate the market transformation potential and the contribution which WHR technologies can make to India's industrial decarbonization goals.

This report is envisaged to serve as a ready reckoner for policymakers, industries, technology providers, and financial institutions to design, implement, and scale up WHR programs leading to enhanced energy efficiency and reduced emissions contributing to the sustainable roadmap for India's industrial growth.

  
(Prashant Kumar)  
CGM & Head CDP

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## Acknowledgment

The report "Market Assessment of Waste Heat Recovery Solutions (WHRs) in India" is a crucial step toward exploiting the significant role of waste heat recovery (WHR) technologies in advancing India's Nationally Determined Contributions (NDC) goals, particularly within the industrial sector. Formulating a national program strategy for the large-scale deployment of WHR technologies across the sector is essential. By harnessing the substantial untapped energy conservation potential within waste heat streams across various industries, these technologies can make a meaningful contribution to India's climate agenda.

We express our deep gratitude to the International Institute for Energy Conservation (IIEC) for initiating this study under the GEF project led by United Nations Environment Programme (UNEP) and providing valuable guidance during its execution.

A special acknowledgment is extended to Dr. Ashok Kumar, DDG, Bureau of Energy Efficiency (BEE), who provided his expert opinion on the WHR technology.

We also sincerely thank the numerous industry stakeholders, experts, and institutional partners who participated in the consultation process. Their practical inputs, sectoral knowledge, and willingness to share operational insights played a vital role in ensuring the relevance and applicability of the recommendations presented in this report.

Finally, we express our sincere appreciation to the team from Deloitte Touche Tohmatsu India LLP for their unwavering commitment and consistent efforts in bringing this report to fruition. We also extend our gratitude to all individuals whose collective dedication has been vital in advancing our objectives in this significant field.

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## Executive Summary

The report "Market Assessment of Waste Heat Recovery solutions (WHRS) in India" delves into the critical role of waste heat recovery (WHR) technologies in propelling India's energy efficiency and sustainability agenda. By exploiting the substantial untapped energy conservation potential embedded within waste heat streams across diverse industrial sectors, India has a unique opportunity to bolster energy security, enhance economic competitiveness, and significantly contribute to its decarbonization efforts.

India has positioned itself as a global climate leader through its ambitious commitments. At the 26<sup>th</sup> Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change in November 2021, the nation pledged to achieve **net zero emissions by 2070**. Moreover, India's updated Nationally Determined Contributions (NDCs) under the Paris Agreement were enhanced to reduce **emissions intensity of its GDP by 45% by 2030** compared to 2005 levels. This target is underpinned by a robust policy framework aimed at global decarbonization.

Further demonstrating its commitment to energy transition, India has proactively committed within the G20 framework to **doubling the rate of improvement in energy efficiency by 2030**. These far-reaching goals underscore the imperative for innovative solutions to accelerate decarbonization and achieve net zero targets. Among these, technologies capable of capturing and reusing waste heat from industrial processes hold significant promise for reducing energy consumption and greenhouse gas emissions.

While precise quantification remains challenging, studies consistently indicate that a substantial portion of industrial energy consumption, ranging from 20% - 50% is dissipated as waste heat. This represents a significant untapped energy resource. Waste Heat Recovery (WHR) has emerged as a pivotal strategy to enhance industrial energy efficiency. By capturing and utilizing the otherwise wasted energy, industries can significantly curtail energy costs, reduce emissions, and improve overall operational performance leading to profitability. Such measures align with India's broader sustainability goals and contribute to its economic competitiveness.

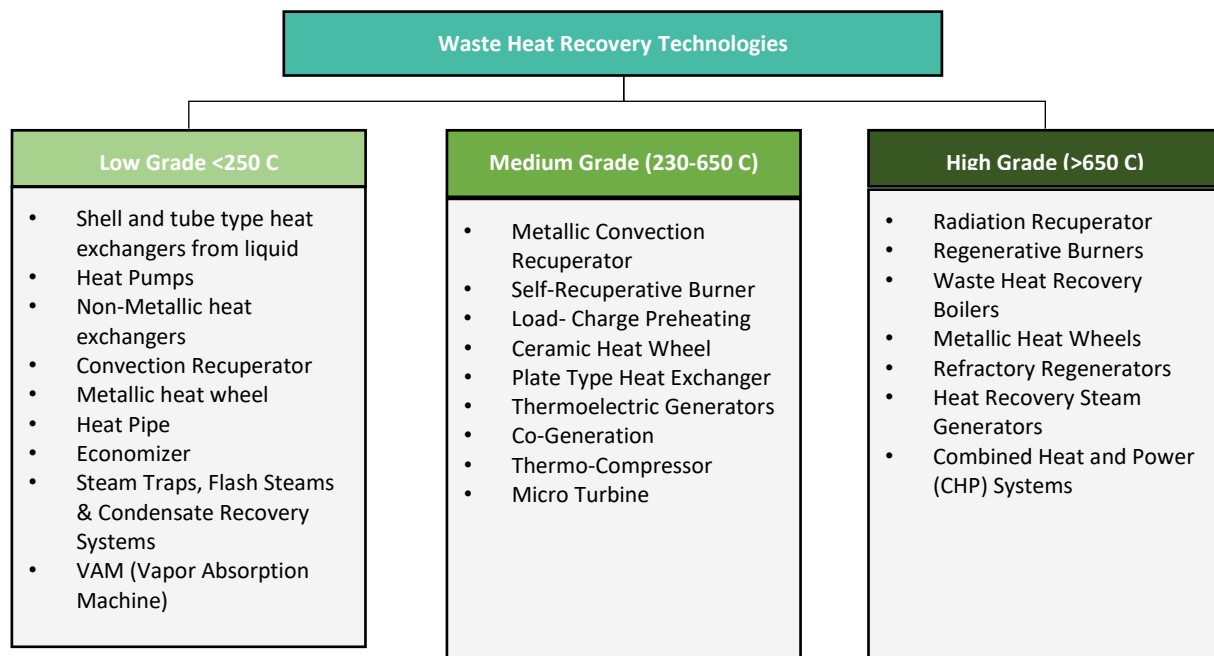
This study conducts a comprehensive analysis of various WHR technologies within prioritized industrial sectors to inform the development of a strategic go-to-market plan for Energy Efficiency Services Limited (EESL) to advance large-scale adoption of WHR technologies across these sectors. The primary objective is to identify the most impactful technologies and strategies for maximizing energy savings and emissions reductions. Given the wide array of available WHR technologies, a carefully structured approach is essential to pinpoint those with the greatest potential for emissions abatement and scalability.

The approach adopted in this study involves a comprehensive evaluation of various WHR technologies based on their effectiveness, scalability, and alignment with EESL's vision and mission. This includes assessing technologies that demonstrate significant potential for emission reduction and are suitable for large-scale deployment within an Energy Service Company (ESCO) framework. A key element of this strategy is sector prioritization, ensuring that selected technologies are tailored to specific industries where they can achieve optimal results.

This study undertakes an in-depth assessment of a wide range of WHR technologies across prioritized industrial sectors. The selected sectors include five energy-intensive industries already part of the Bureau of Energy Efficiency's Perform, Achieve and Trade (PAT) scheme, along with four Micro, Small, and Medium Enterprises (MSME) sectors exhibiting high levels of waste heat availability from their processes.

Through extensive stakeholder consultations, the study identifies a suite of WHR technologies suitable for diverse industrial applications in the prioritized sectors. The report provides a detailed analysis of each selected technology, covering its sectoral applicability, potential energy savings, emissions reduction capabilities, and feasibility for replication. To offer a forward-looking perspective on the market potential for WHR technologies, the analysis also includes three distinct future scenarios, projecting adoption rates and impacts under varying industry and policy conditions a Low (Business-as-Usual) scenario, a Medium scenario, and High scenario<sup>1</sup>.

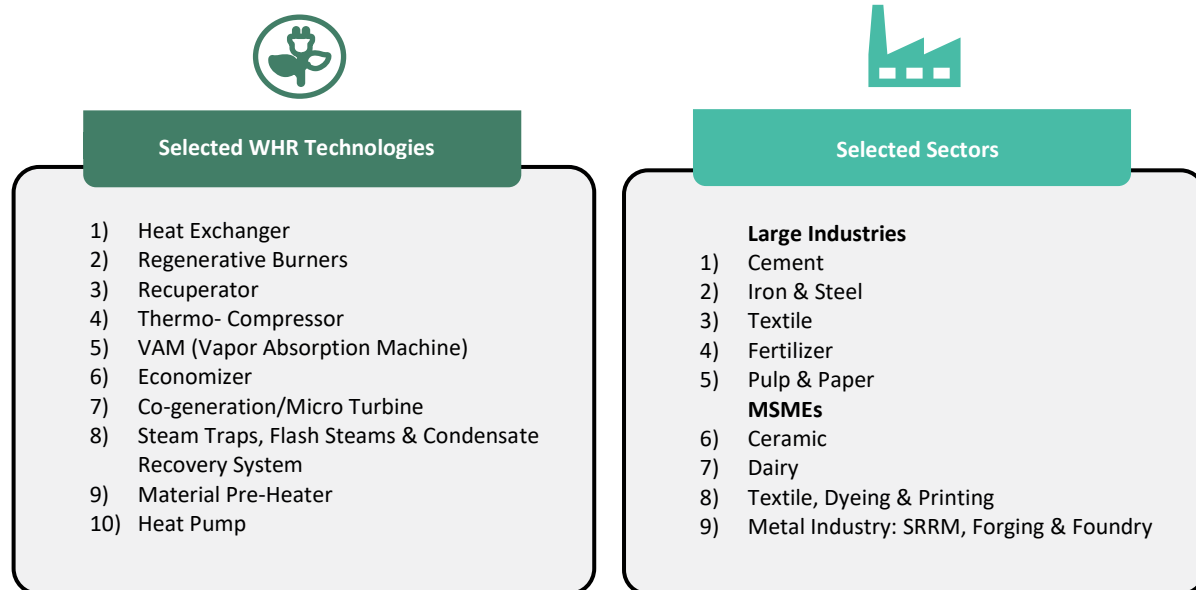
The following exhibit outlines the most common waste heat recovery technologies derived from different process streams and methods currently employed across various industries:



**Figure 1: Waste Heat Recovery Technologies**

<sup>1</sup> These scenarios represent the current state, moderate increase and widespread adoption of waste heat recovery technologies and implementation within industries.

The list of shortlisted technologies and priority sectors are summarized in the exhibit below:



**Figure 2: Selected WHR Technologies and Priority Sector**

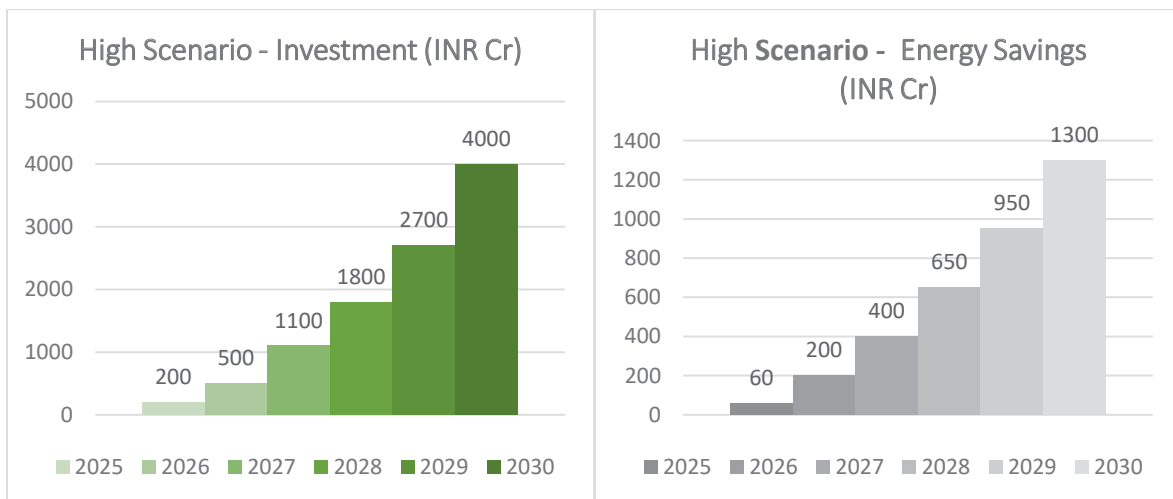
The table provides a quantitative projection of the potential for selected waste heat recovery (WHR) technologies within key demand sectors in India, analyzed across three scenarios: low, medium, and high:

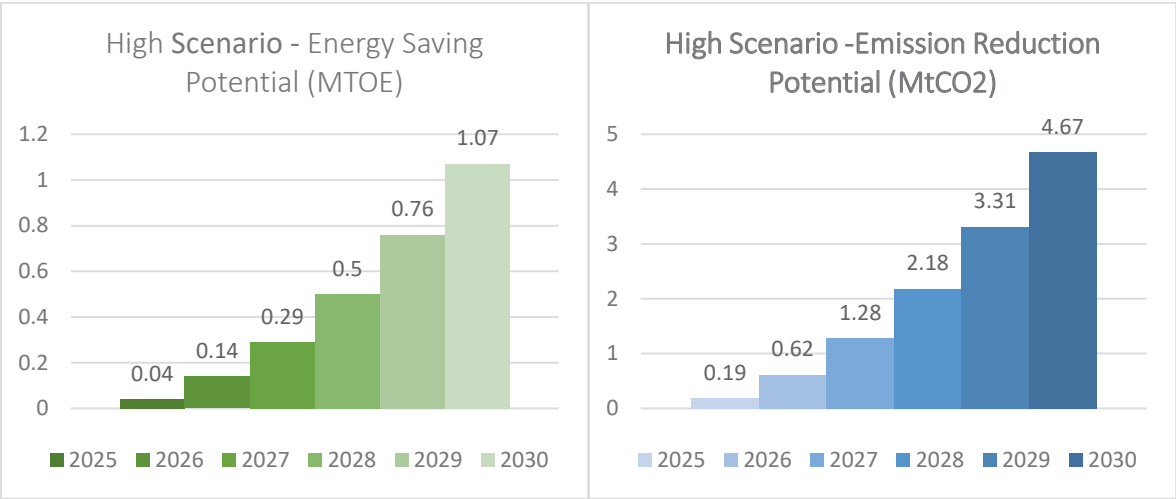
Energy Saving Potential (MTOE)	2025	2026	2027	2028	2029	2030
<b>Low</b>	0.02	0.07	0.15	0.26	0.39	0.55
<b>Medium</b>	0.03	0.11	0.22	0.38	0.57	0.81
<b>High</b>	0.04	0.14	0.29	0.50	0.76	1.07
Emission Reduction Potential (MtCO <sub>2</sub> )	2025	2026	2027	2028	2029	2030
<b>Low</b>	0.10	0.31	0.65	1.10	1.67	2.35
<b>Medium</b>	0.15	0.47	0.96	1.63	2.48	3.50
<b>High</b>	0.19	0.62	1.28	2.18	3.31	4.67
Energy Savings (INR Cr)	2025	2026	2027	2028	2029	2030
<b>Low</b>	30	100	200	350	500	700
<b>Medium</b>	50	150	300	500	750	1000
<b>High</b>	60	200	400	650	950	1300
Investment (INR Cr)	2025	2026	2027	2028	2029	2030
<b>Low</b>	80	300	550	900	1400	2000
<b>Medium</b>	120	400	800	1350	2050	3000
<b>High</b>	200	500	1100	1800	2700	4000

**Table 1: Energy saving potential for selected waste heat recovery (WHR) technologies.**

- Under the business-as-usual, low scenario, WHR is estimated to save approximately **0.55 million tonnes of oil equivalent (MTOE)** cumulatively by **2030**, leading to reduction in GHG emission by **2.35 million tonnes (MtCO<sub>2</sub>)** with an investment of approximately **2000 Cr INR**. The total monetary savings estimated to be leveraged through this intervention is **700 Cr INR**.
- Under the medium scenario, WHR is estimated to save approximately **0.81 million tonnes of oil equivalent (MTOE)** cumulatively by **2030**, leading to reduction in GHG emission by **3.5 million tonnes (MtCO<sub>2</sub>)** with an investment of approximately **3000 Cr INR**. The total monetary savings estimated to be leveraged through this intervention is **1000 Cr INR**.
- Under the high scenario, WHR is estimated to save approximately **1.07 million tonnes of oil equivalent (MTOE)** cumulatively by **2030**, leading to reduction in GHG emission by **4.67 million tonnes (MtCO<sub>2</sub>)** with an investment of approximately **4000 Cr INR**. The total monetary savings estimated to be leveraged through this intervention is **1300 Cr INR**.

These projections indicate that while the high scenario pathway demands greater initial investments, it offers a significantly greater return on investment in terms of energy savings and greenhouse gas reductions, contributing substantially to India's energy security and climate mitigation objectives.





**Figure 3: Waste Heat Recovery Potential**

In conclusion, this report provides a comprehensive analysis of selected WHR technologies, including a rigorous evaluation of their technological maturity, market dynamics, and potential business models for large and MSME sectors. By identifying high-impact technologies and developing a strategic deployment roadmap, the study supports EESL's efforts to promote energy efficiency and advance India's climate action objectives. The insights and recommendations presented aim to inform strategic decision-making and expedite the integration of WHR technologies within priority sectors, ultimately enhancing energy efficiency and sustainability across India.

To facilitate WHR technology deployment, we have formulated a tailored go-to-market strategy for EESL, with a focus on the Energy Service Company (ESCO) model. This approach emphasizes performance-based contracts that align EESL's interests with those of industrial clients, ensuring that energy savings are maximized. Through this model, EESL can establish long-term partnerships with industries, offering not only technology but also ongoing support to achieve substantial energy efficiency gains.

Additionally, digitalizing the business model via a comprehensive procurement portal will streamline processes and strengthen collaboration among stakeholders. This platform will enable transparent communication, efficient procurement, and effective project management, ensuring the swift and successful deployment of WHR technologies. By integrating the ESCO model with digital tools, EESL is well-positioned to drive impactful improvements in energy efficiency and sustainability, contributing significantly to India's broader climate action goals.





# Chapter 1- Background



# Chapter 1- Background

## 1.1 About the Project

The growing emphasis on sustainability and energy efficiency has spurred significant interest and investment in waste heat recovery technologies across industrial sectors worldwide. Waste heat, often generated as a byproduct of industrial processes, represents a substantial untapped resource that can be harnessed to reduce energy consumption, lower greenhouse gas emissions, and enhance overall operational efficiency.

In recent years, advancements in waste heat recovery systems, coupled with regulatory incentives aimed at reducing carbon footprints, have accelerated the adoption of these technologies. Industries ranging from manufacturing and power generation to oil & gas and chemical processing are increasingly integrating waste heat recovery solutions into their operations to achieve environmental compliance, operational cost savings, and competitive advantage.

The purpose of this report is to conduct a comprehensive market assessment of waste heat recovery technologies. The assessment will encompass a detailed analysis of market trends, technological advancements, regulatory frameworks, and key industry drivers influencing the adoption and growth of waste heat recovery systems. By examining market dynamics and emerging opportunities, the report aims to provide stakeholders with actionable insights into market potential, competitive landscape, and strategic considerations for implementing waste heat recovery projects.

### Through this project, we seek to explore:

- The current market size and growth projections for waste heat recovery technologies.
- Key technological innovations and advancements driving market expansion.
- Regulatory policies and incentives shaping market dynamics and influencing adoption rates.
- Sector-specific applications and case studies highlighting successful implementations of waste heat recovery systems.
- Challenges and barriers hindering widespread adoption and potential mitigation strategies.
- Market opportunities and emerging trends in waste heat recovery (WHR), such as the integration of renewable energy, the incorporation of WHR systems with digital technologies and the Internet of Things (IoT), and the coupling of WHR systems with energy storage solutions.

By synthesizing these insights, the report aims to equip decision-makers, industry professionals, investors, and policymakers with the necessary information to capitalize on the growing opportunities in the waste heat recovery market. Ultimately, the findings will contribute to fostering a more sustainable and efficient industrial landscape, aligning with global efforts towards mitigating climate change and achieving energy transition goals.

The scope of work encompasses three main components.

Firstly, the **Technology Assessment** will help analyze existing and potential WHR solutions in different sectors and processes, considering factors such as temperature classification, source variability, and

industry applicability. This will be further streamlined by conducting a low carbon technology analysis and identifying potential for WHR based on sectors and processes.

Secondly, the **Market Scanning** will assess current market potential, map relevant stakeholders, evaluate policy frameworks, and draw lessons from past projects. Based upon that standard templates have been created for selected sectors and technologies.

Lastly, the **Program Strategy** shall include analysis of the market such as- market drivers, barriers etc. and will define EESL's role, recommend WHR technologies, identify target user groups, develop business models and financing options, establish Monitoring & Verification protocols, propose after-sales services, devise market outreach strategies, and outline WHR deployment benefits. It shall also include the digitalization of the business model by developing a portal.

## 1.2 Project Objective

The "Creating and Sustaining Markets for Energy Efficiency" project, supported by GEF-6, aims to reduce greenhouse gas emissions in India by promoting energy efficiency technologies, particularly in the industrial sector. Recognizing that 20 to 50% of industrial energy consumption is lost as waste heat, the project focuses on Waste Heat Recovery (WHR) systems as a critical solution. By capturing and repurposing this excess heat, industries can enhance their energy efficiency, decrease reliance on purchased fuels, and significantly lower their carbon footprint. Through this comprehensive market assessment conducted by Deloitte and the International Institute for Energy Conservation (IIEC), EESL seeks to develop a national program for WHR systems, fostering sustainable industrial practices and supporting India's environmental goals. India's burgeoning economy demands a resilient and sustainable energy supply. Energy efficiency has emerged as a pivotal strategy to address this challenge. By reducing energy consumption, industries can not only lower operational costs but also contribute significantly to environmental protection. Prioritizing energy efficiency is therefore imperative for building economic resilience, safeguarding energy security, and advancing India's sustainability goals.

Waste heat recovery (WHR) offers a promising avenue to further optimize energy utilization. The industrial sector, a major energy consumer, presents a substantial opportunity for emissions reduction through WHR. Advanced technologies capable of capturing and recovering waste heat hold the potential to significantly curtail energy consumption and greenhouse gas emissions. By harnessing these innovations, India can accelerate progress towards its climate targets while strengthening its energy security and economic competitiveness.

This project aims to conduct a comprehensive market assessment of WHR systems in the Indian industrial sector. By identifying key opportunities, challenges, and potential solutions, the project will support the development of a robust national WHR program. Specific objectives include:

- **Quantifying the waste heat potential:** Accurately estimating the amount of waste heat generated across various industrial sectors in India. Recent studies indicate that the industrial sector accounts for a significant portion of the country's total energy consumption, with a substantial amount of this energy being wasted. By quantifying this potential, the project will provide a solid foundation for evaluating the economic and environmental benefits of WHR.
- **Identifying suitable WHR technologies:** Assessing the availability and applicability of different WHR technologies to various industrial processes. This includes evaluating factors such as

technology maturity, cost-effectiveness, efficiency, and environmental impact. Given the diverse range of industrial processes and waste heat characteristics, a comprehensive analysis of technology options is essential to identify the most suitable solutions for different applications.

- **Analyzing market potential and barriers:** Evaluating the market size, growth potential, and key drivers for WHR adoption in India. This includes identifying target industries with the highest potential for WHR implementation, as well as assessing the regulatory, financial, and technological barriers hindering wider adoption. By understanding these factors, the project will contribute to developing effective strategies to overcome challenges and accelerate market growth.
- **Developing a business model for WHR deployment:** Exploring viable business models for promoting WHR adoption, such as energy service companies (ESCOs), public-private partnerships (PPPs), and government incentives. This includes developing financial mechanisms to support upfront investment and risk mitigation. By identifying effective business models, the project will facilitate the replication and scaling up of successful WHR projects.
- **Building capacity and awareness:** Raising awareness about the benefits of WHR among industry stakeholders, policymakers, and the public. This includes organizing workshops, training programs, and knowledge-sharing initiatives to promote the adoption of WHR technologies. By building capacity and fostering collaboration, the project will contribute to creating a supportive ecosystem for WHR development in India.





# Chapter 2- Introduction to Waste Heat Recovery

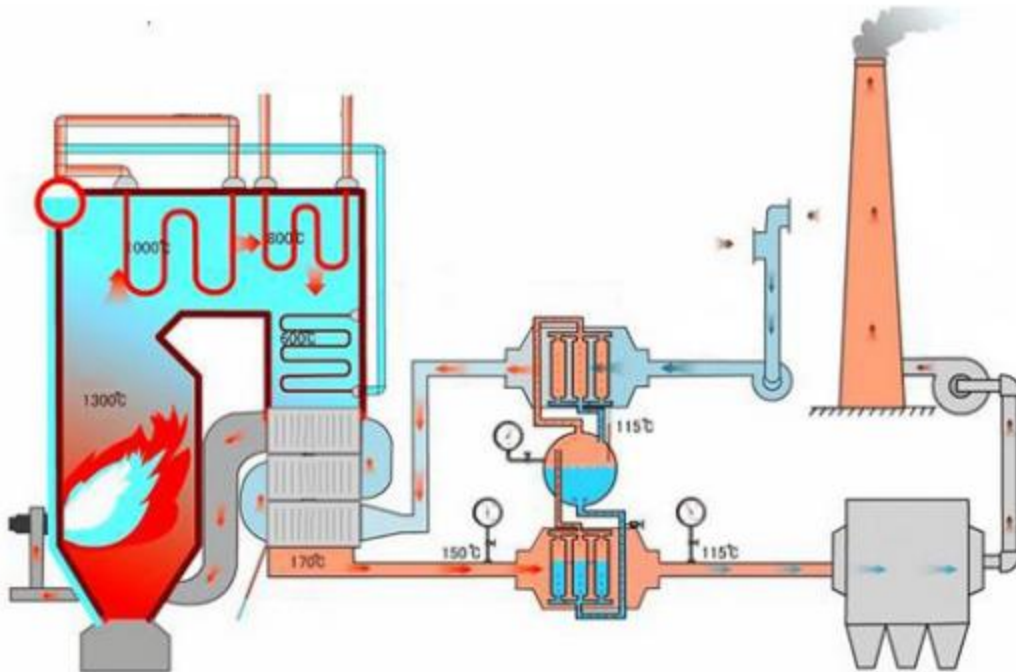


## Chapter 2- Introduction to Waste Heat Recovery.

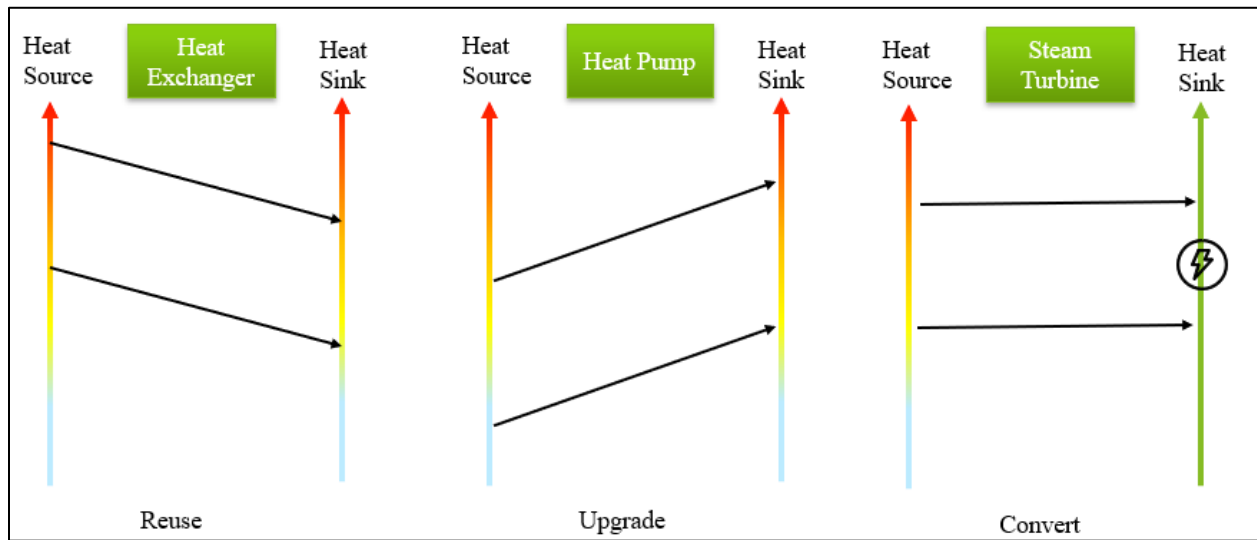
### 2.1 What is waste heat recovery?

Industrial processes generate substantial quantities of unutilized thermal energy often referred to as waste heat. This heat originates from various sources, including high- temperature exhaust gases discharged to the environment, heated products exiting processes, and heat radiating from equipment surfaces. While the precise amount of waste heat remains a subject of ongoing research, estimates suggest it could represent 20-50% of total industrial energy consumption<sup>1</sup>. Although some waste heat losses are inherent to industrial operations, several upgradations can be made to minimize the heat losses. These improvements can take the form of enhancing energy efficiency or installing waste heat recovery technologies. WHR involves capturing and re-utilizing waste heat for various purposes within the industrial setting, including electricity generation, preheating combustion air or furnace loads, absorption cooling, and space heating.

The adoption of WHR technologies frequently leads to reduced operational costs for facilities by boosting their overall energy productivity. While many WHR technologies are well- established and proven in their effectiveness, a combination of market and technical barriers impedes their widespread application. A comprehensive investigation into industrial waste heat generation, current recovery practices, and the existing barriers is crucial to identifying promising opportunities for WHR implementation and pinpointing technological advancements needed. Such an analysis would be instrumental in guiding decision – makers towards prioritizing research efforts aimed at promoting enhanced industrial energy efficiency.

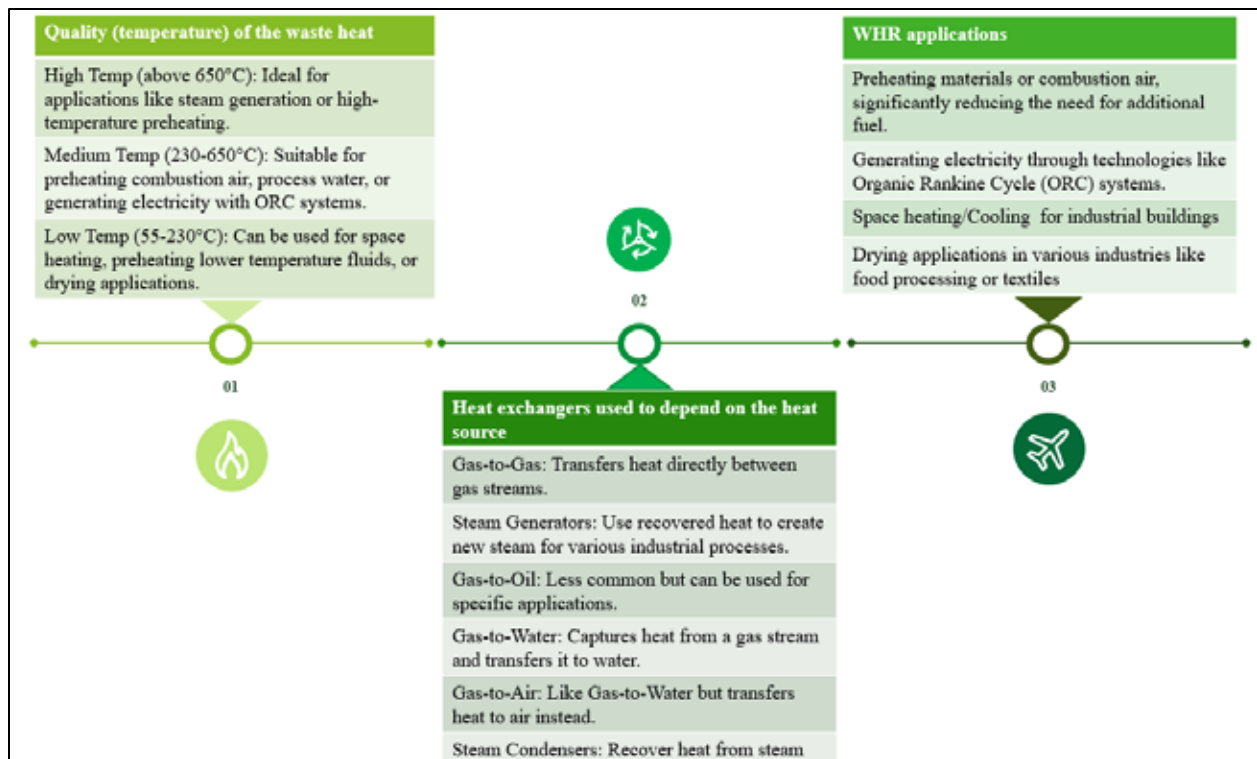


**Figure 4: Process of Waste Heat Recovery (Source- Furnace Flue Gas Waste Heat Boiler)**



**Figure 5: Key approach for waste heat recovery.**

Furthermore, WHR systems optimize industrial processes by providing a reliable heat source, thereby improving process efficiency and productivity. Major factors to be consider for a WHR system is given in the figure below.



**Figure 6: Factors to be considered in WHR system.**

The table below summarizes some of the key sources of waste heat in industrial process which can be re-utilized mostly in the form of heat or electricity leading to significant improvement of the efficiency of the industrial process leading to reduced energy consumption.

Heat source	Quality
Heat in flue gases	The higher the temperature, the greater the potential value for heat recovery
Heat in vapour streams	As above but when condensed, latent heat also recoverable
Heat stored in products leaving the process	Quality depends upon temperature.
Convective and radiant heat lost from exterior of preheats equipment	Low grade – if collected may be used for space heating or air preheats.
Heat in gaseous and liquid effluents leaving process	Poor if heavily contaminated and thus requiring alloy heat exchanger

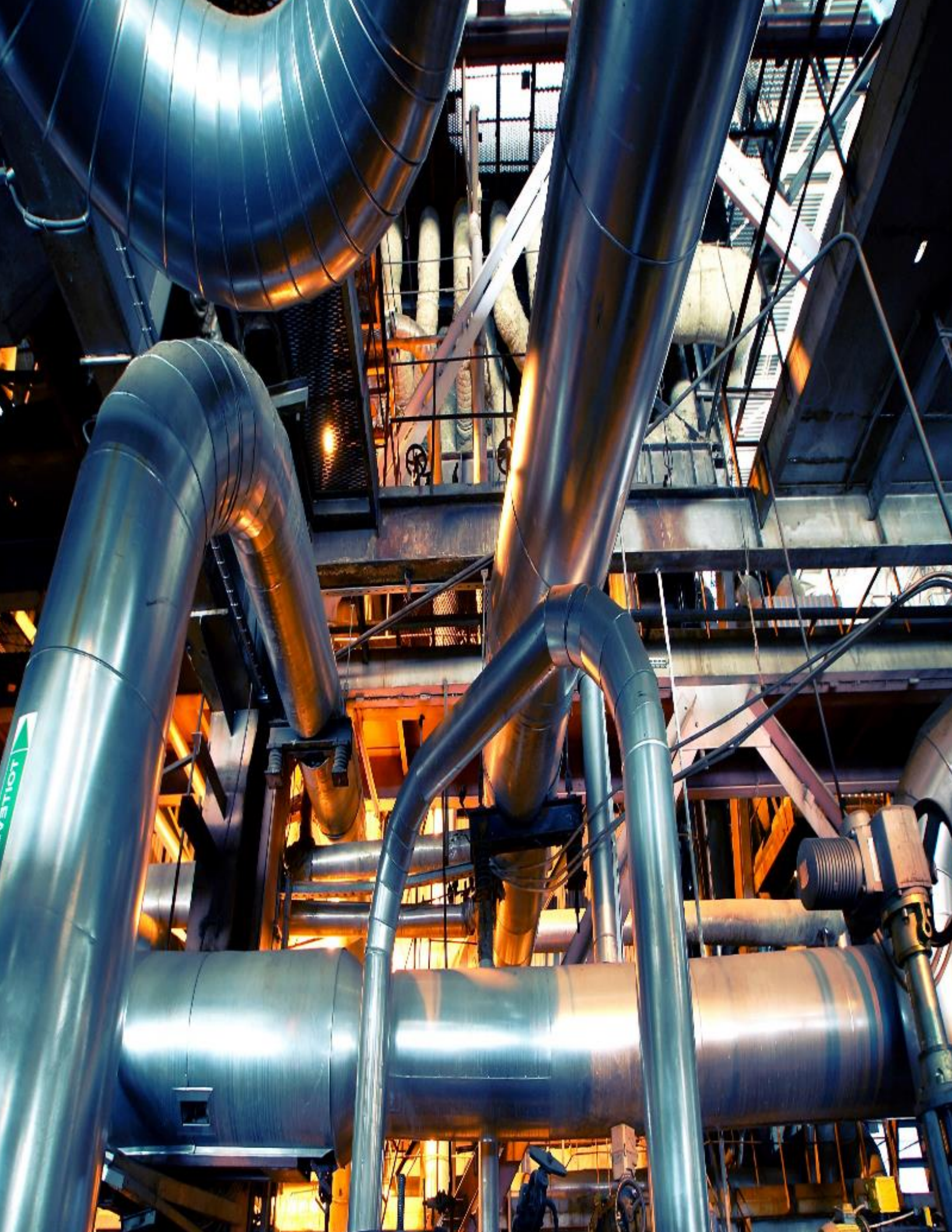
**Table 2: Waste heat source and quality**

Below table presents a comprehensive overview of typical process temperatures across key industrial sectors. By examining the temperature profiles of industries such as glass manufacturing, cement production, iron and steel, aluminum, petroleum refining, power generation etc, this analysis highlights the significant thermal energy potential embedded within these processes. These elevated temperatures represent a substantial opportunity for waste heat recovery (WHR) technologies to capture and utilize otherwise wasted energy, contributing to improved energy efficiency, reduced greenhouse gas emissions, and enhanced overall industrial sustainability.

Industry	Typical process temperatures
Cement Manufacturing	Rotary cement kilns 1300 to 1500 °C
Iron and Steel Manufacturing	Coke Oven Gas 800-1000°C, Basic Oxygen Furnace (BOF) 1600-1700°C, Electric Arc Furnace (EAF) reaching up to 3000°C, BF/BOF Slag 1400-1600°C
Textile	Fiber processing 100°C to 200°C, Dyeing and finishing 80°C to 120°C, Heat setting 180°C to 220°C
Aluminium Production	Primary Aluminium Production (Smelting) 950-980°C, Secondary Aluminium Production (Recycling) 650°C to 750°C Aluminium Processing (Casting, Extrusion, Rolling) 650°C to 750°C Heating for Extrusion or Rolling 300°C to 600°C.
Fertilizer	Ammonia production 400°C -600°C, Urea production 180°C to 200°C, Phosphoric acid production typically around 250°C, Granulation & Drying 100°C to 200°C
Glass Manufacturing	Glass melting 1400 to 1600 °C
Industrial Boiler and Furnace	Industrial Boilers 300°C to 800°C, Industrial Furnaces often exceeding 1000°C
Petroleum Refinery	Crude Oil Distillation: Atmospheric 300°C to 400°C, Vacuum up to 450°C ; Conversion Processes : Catalytic cracking 450°C to 550°C, Hydrocracking 350°C to 450°C, Coking can exceed 550°C; Reforming 450°C to 550°C, Hydrotreating 200°C to 450°C
Power Generation	Steam turbines 300°C to 600°C, Gas turbines exceeding 800°C, Nuclear power plants exceeding 300°C.
Chemical	Inorganic chemical reactions, polymerization 200°C to 450°C

**Table 3: Typical process temperatures in different industrial sectors**





# Chapter 3- Technology Assessment



## Chapter 3- Technology Assessment

### 3.1 Introduction

With an increasing focus on energy efficiency and sustainability, Waste Heat Recovery (WHR) systems are gaining importance in industrial operations. As industries work to reduce carbon footprints and optimize energy use, understanding the array of WHR solutions is crucial. This report analyzes current WHR systems across various sectors and explores emerging technologies globally.

The report includes market segmentation of WHR systems based on temperature grades (high, medium, low), sources, applications, technologies, components, and costs. It also examines WHR integration with renewable energy solutions, emphasizing synergies with low-carbon options like solar and geothermal energy.

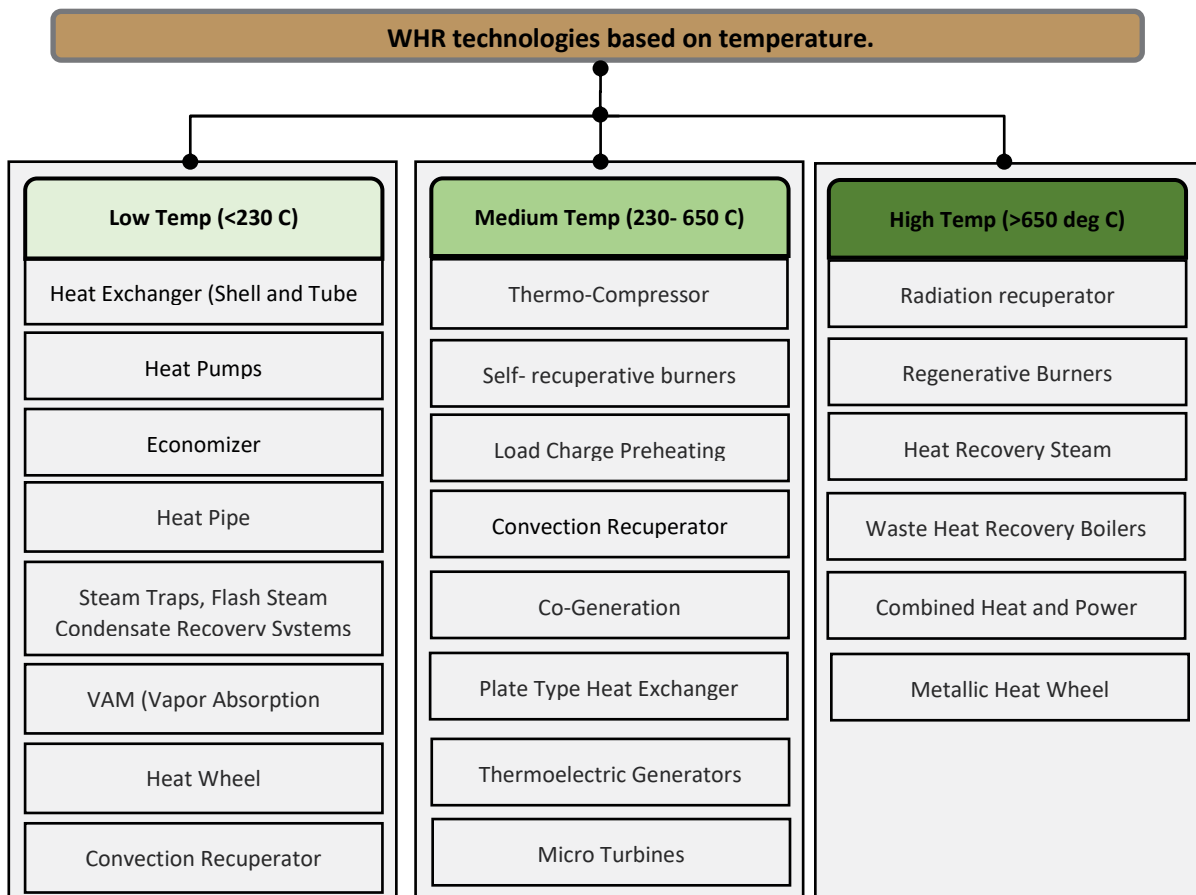
Additionally, the report reviews relevant technical standards, both Indian and international, to ensure WHR systems meet quality and compliance benchmarks. Through this analysis, stakeholders gain insights to make informed decisions on adopting and advancing WHR technologies, fostering a more sustainable industrial landscape.

### 3.2 Assessment by Temperature

#### Temperature-Based Assessment

Temperature is a critical factor in Waste Heat Recovery (WHR) technology selection, as it influences both the efficiency and applicability of recovery systems across various industries. WHR technologies are typically categorized by temperature grades—high, medium, and low—which determine the suitable equipment and methods for capturing and repurposing waste heat. This section provides an overview of WHR technologies aligned with specific temperature ranges, examining the capabilities and limitations of commonly used systems. By assessing technologies based on temperature, industries can make informed decisions on optimizing energy savings and enhancing sustainability efforts in line with their operational needs.

The figure below shows typical WHR technologies segregated by temperature, providing a clear framework to guide industries in optimizing energy savings and advancing sustainability efforts.

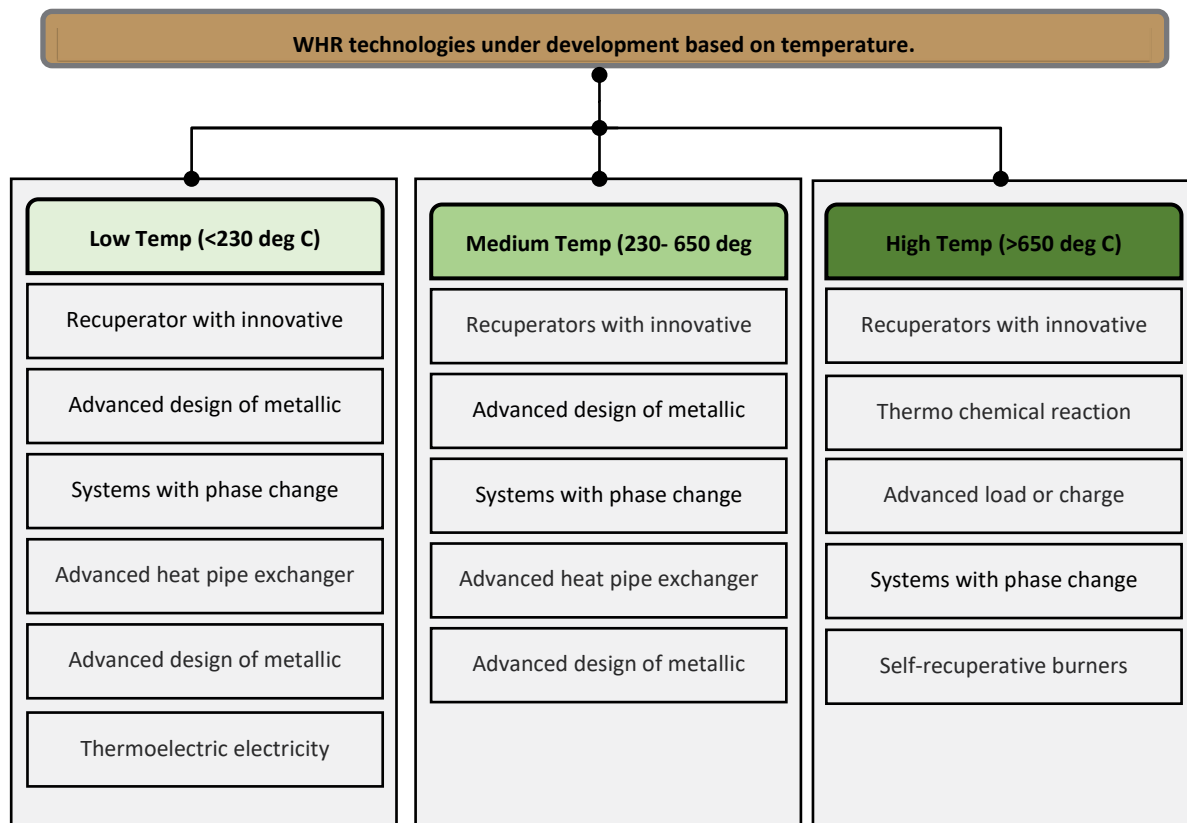


**Figure 7: Commonly used WHR technologies by Temperature Range**

### **R&D and emerging technologies based on temperature.**

A range of emerging WHR technologies is under development in laboratories and pilot projects worldwide, with progress largely driven by local energy costs, availability, and the support of government or funding agencies. Key areas of innovation in WHR include:

- i. Conversion of waste heat into flexible and transportable energy sources, such as electricity.
- ii. Recovery of heat from high-temperature gases that are laden with contaminants like particulates, combustibles, and condensable vapors (organic, metallic, or non-metallic materials).
- iii. Extraction of heat from sources below 120°C, which has traditionally been challenging.
- iv. Recovery of heat from low- to medium-temperature exhaust gases or air with high moisture content, enabling the capture of latent heat from water vapor



**Figure 8: WHR technologies, under development or demonstration by temperature range. [2]**

### 3.3 Assessment by Source

The feasibility of recovering waste heat is largely contingent upon its temperature profile, which can vary significantly across different industrial processes. Waste heat sources encompass a broad spectrum, ranging from low-temperature cooling water at 40-90 °C to high-temperature sources, such as flue gases from glass melting furnaces, exceeding 1320 °C. For effective waste heat recovery, it is essential that the temperature of the waste heat source is higher than that of the heat sink, with a greater temperature differential contributing to increased overall efficiency.

This temperature differential is critical in two key areas:

- a) The rate of heat transfer per unit surface area of the heat exchanger.
- b) The maximum theoretical efficiency in converting thermal energy from the heat source into another form, such as electricity.

The temperature range of the waste heat also dictates the choice of materials for constructing heat exchangers, as different materials are required to withstand various temperature extremes.

Furthermore, waste heat sources are classified into low-, medium-, and high-quality categories based on their temperature ranges, with each category offering distinct advantages for recovery and necessitating the use of specific technologies.

The main goal of waste heat recovery (WHR) systems is to maximize energy savings by capturing and reusing waste heat. High-temperature WHR systems (649°C and above) are primarily used in energy-intensive industries such as steel, cement, and chemicals, where they offer significant potential for on-site power generation through technologies like the Organic Rankine Cycle (ORC).

Medium-temperature WHR systems, operating between 232–650°C, are commonly applied in district heating, cooling, and industrial process heating, where thermal energy demand is substantial. Implementing these systems requires careful design, integration expertise, and skilled personnel to manage their complexity and impact on industrial processes.

In large industries, WHR systems are further classified by the temperature range of the waste heat they capture. The figure below shows typical WHR technologies segregated by waste heat sources:

Temp Range	Waste heat Sources	Temp (°C)	Advantages	Recovery Methods/Technologies
<b>High (&gt;650 °C)</b>	Nickel Refining Furnace	1370-1650	<ul style="list-style-type: none"> <li>• High Quality energy available for diverse range of end uses with varying temperature requirements.</li> <li>• High efficiency power generation</li> <li>• High heat transfer rate per unit area</li> </ul>	<ul style="list-style-type: none"> <li>• Combustion air preheat.</li> <li>• Steam generation for process heating or mechanical/electrical work.</li> <li>• Furnace load preheating</li> <li>• Transfer to med-low temperature processes</li> </ul>
	Steel Electric Arc	1370-1650		
	Basic Oxygen furnace	1200		
	Aluminum Reverberatory	1100-1200		
	Copper Refining furnace	760-820		
	Steel refining furnace	930- 1040		
	Copper reverberatory furnace	900-1090		
	Fume Incinerators	650-1000		
	Glass melting furnace	1300-1540		
Coke oven	650- 1000			
<b>Medium (230-650 °C)</b>	Steam Boiler exhaust	230-480	<ul style="list-style-type: none"> <li>• More compatible with heat exchanger materials</li> <li>• Practical for power generation</li> </ul>	<ul style="list-style-type: none"> <li>• Combustion air preheat.</li> <li>• Steam/power generation.</li> <li>• Organic rankine cycle for power generation</li> <li>• Furnace Load preheating</li> <li>• Transfer to low temperature processing</li> </ul>
	Gas turbine exhaust	370-540		
	Reciprocating engine exhaust	320-590		
	Heat treating furnace	430-650		
	Drying & baking ovens	230-590		
	Cement Kiln	430-620		
Exhaust Gases exiting recovery devices in gas-fired boilers	70-230	<ul style="list-style-type: none"> <li>• Large quantities of low temperature</li> </ul>	<ul style="list-style-type: none"> <li>• Space Heating</li> </ul>	

<b>Low ( &lt;230 °C )</b>	Process Steam condensate	50-90	heat contained in numerous product steams	<ul style="list-style-type: none"> <li>• Domestic water heating</li> <li>• Upgrading via heat pump to increase temp for end use</li> <li>• Organic Rankine Cycle</li> </ul>
	Cooling water from- furnace doors	30-50		
	Cooling water from- annealing furnaces	70-230		
	Cooling water from- air compressors	30-50		
	Cooling water from- AC and refrigeration condensers	30-40		
	Drying baking and curing ovens	90-230		
	Hot processed liquids/Solids	30-230		

(Source- Waste Heat Recovery: Technology and opportunities in US)

**Table 4: Waste heat sources and related recovery opportunity**

In conclusion, assessing waste heat recovery by source is vital to identifying the most effective technologies for capturing and repurposing waste heat across industries. By understanding the temperature profiles and unique characteristics of each waste heat source, industries can optimize system selection, improve energy efficiency, and reduce emissions. This source-based approach ensures that WHR systems are tailored to meet specific operational needs, ultimately driving cost savings and supporting broader sustainability goals.

### 3.4 Assessment by End-Use and Application

#### By End-Use

Industrial processes generate considerable waste heat, often released into the environment, representing untapped potential for energy savings and environmental improvement. Waste Heat Recovery Systems (WHRS) capture and repurpose this waste heat, enhancing overall efficiency across various applications.

For instance, in boiler systems, WHRS can preheat feedwater using hot exhaust gases, reducing the energy required to reach operational temperatures and optimizing fuel consumption. Additionally, WHRS enable waste heat transfer to other processes within a facility. For example, hot exhaust gases from a furnace can preheat air for a drying oven, eliminating the need for a dedicated burner and reducing fossil fuel dependence.

Below are typical end-use applications of recovered waste heat and their sources.

(Source- Waste Heat Recovery: Technology and Opportunity in US Industry)

Waste heat sources	End-Use
1) Combustion exhausts: <ul style="list-style-type: none"> <li>a) Glass melting furnace.</li> <li>b) Cement kiln</li> <li>c) Fume Incinerator</li> <li>d) Aluminum reverberatory furnace</li> <li>e) Boiler</li> </ul>	1) Combustion air preheating 2) Boiler feedwater preheating 3) Load preheating. 4) Transfer to liquid or gaseous process streams. 5) Steam Generation <ul style="list-style-type: none"> <li>a) Power generation</li> </ul>

2) Process off-gases. a) Steel electric arc furnace b) Aluminum reverberatory furnace 3) Cooling water from a) Furnaces b) Air compressors	b) Mechanical power c) Process steam. 6) Space Heating
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**Table 5: End-Use Examples with Sources**

**Breakdown of Common Waste Heat Recovery System (WHRS) End-Uses:**

- **Combustion Air Preheating:** Boosts furnace efficiency by up to 50% and reduces capacity needs for thermal devices, leading to capital cost savings.
- **Preheating:** WHRS can preheat combustion air, boiler feedwater, or process fluids, cutting energy use. Widely used in steel, cement, and chemical industries.
- **Power Generation:** High-temperature WHRS integrated with Organic Rankine Cycle (ORC) systems generate electricity for on-site use or grid feed-in, benefiting industries with high waste heat production.
- **Steam Generation:** WHRS can produce low-pressure steam for various processes, potentially replacing dedicated boilers and reducing fuel consumption, popular in food, textile, and paper industries.
- **Space Heating:** Waste heat can be used for heating industrial buildings or district heating systems, reducing reliance on conventional methods and energy costs.
- **Heat Transfer to Process Streams:** WHRS transfers heat directly to process streams via heat exchangers, tailored to specific industrial processes.

**End-Use Applications for WHR Technologies:**

- **Power Generation:** High-temperature waste heat can generate electricity through steam and ORC systems, used in cement, steel, and food industries.
- **Industrial Process Heat:** Waste heat is used in preheating, drying, and evaporation, improving efficiency in cement, chemical, textile, and food sectors.
- **Space Heating and Cooling:** Waste heat is suitable for district heating and absorption chillers, cutting emissions and fossil fuel reliance.
- **Cogeneration (CHP):** Waste heat supports industrial CHP, providing electricity and process heat simultaneously, enhancing energy efficiency.
- **Additional Applications:** Desalination and aquaculture benefit from waste heat, improving water production and aquaculture environments.

With these applications, WHR systems offer significant energy savings, cost reductions, and sustainability benefits. As technology advances, WHR's potential continues to expand, promising further efficiencies and environmental gains. High-energy industries like manufacturing, power generation, and oil and gas are ideal for WHR implementation, strengthening competitiveness and environmental stewardship.

### 3.5 Assessment by Technology including its component and costing.

Waste Heat Recovery Systems (WHRS) offer significant opportunities to optimize energy consumption and reduce environmental impact across various industries. However, to fully harness this market potential, a detailed understanding of its segmentation is essential. This analysis examines the WHRS market by segmenting it based on technology, component breakdown, and cost structures. By exploring the specific needs and cost considerations within each segment, stakeholders can formulate targeted strategies and identify profitable opportunities for WHRS deployment.

Name of technology	Brief	TRL	Components	Costing	Sector
Heat Exchanger	A system used to transfer heat between a source and a working fluid.	9	Heat transfer surface (Tube, plates), exhaust system.	~2-6 Lakh INR	Cross-Sectoral
Regenerative Burners	In regenerative temperature can go to 1000°C, resulting huge energy savings and improved furnace productivity. Applicable only for gas fired furnaces	9	Regenerator, Flue gas system, fans or blowers	~2-4 Lakh INR/ton	Cross-Sectoral
Recuperator	A recuperator is used to recover the waste heat, usually from the exhaust flue gas generated from furnace and use it to preheat the combustion air, thereby ensuring fuel saving and process efficiency	9	Heat exchanger, Flue gas systems, insulation	~1-2 Lakh INR/ton	Cross-Sectoral (thermal)
Thermo-compressor	Thermo-compressors are devices that compress low-pressure steam using high-pressure steam, allowing the repurposed steam to be converted into medium-pressure steam.	9	Compressor unit, Heat Exchanger, Flue gas systems, Condensate system	~1-2 Lakh INR/TR	Cross-Sectoral (thermal)
VAM (Vapor Absorption Machine)	Vapor Absorption Chiller (VAM) is a type of cooling machine that generates chilled water by utilizing a heat source instead of relying on electrical energy	9	Absorber, Generator, Heat Exchanger, Refrigerant	~60 Lakh INR/TR	Cross-Sectoral (thermal)
Economizer	Economizer is highly recommended to save fuel in thermal application by use of high heat content in flue gas to pre-heat water	9	Heat exchanger, Flue gas systems, Insulation	1 to 1.5 Lakhs/tons of boiler capacity	Cement (thermal)
Steam Traps, Flash Steams & Condensate Recovery	A set of systems and components designed to optimize steam utilization in industrial processes.	8	Valve mechanism, Flue Gas systems, Heat Exchanger, Storage tanks	~1 Lakh INR/m3 of flash steam	Cross-Sectoral (thermal)

Material Preheater	Use of waste flue gas to pre-heat the material and save fuel	8	Flue gas system, Insulation, Material feed system, Sensors, fans, or blowers	~1-2 Lakh INR/ton	Cross-Sectoral (thermal)
Heat Pumps	A heat pump is a device that can heat a building/utility by transferring thermal energy from the outside using the refrigeration cycle	9	Compressor, Heat Exchanger	~50-90 thousand INR /kW	Cross-Sectoral (thermal)
WHR Boilers	WHR Boiler is a system which recovers various kinds of waste heat generated from the production process of steel, chemical, cement etc and convert such recovered heat into useful and effective thermal energy	9	Heat Exchanger, Furnace, Economizer, Flue Gas System	~750 Lakh INR /MW	Cross-Sectoral (thermal)
Co-Generation/Microturbine	Cogeneration technology provides thermal and electrical energy both and it has higher efficiency compared to power generation plant.	9	Generator, Heat Exchanger, Flue Gas System, Combustor	~2- 4 Lakhs INR /kW	Cross-Sectoral
CO2 Turbine	CO2 Turbines are specialized turbines designed to operate using carbon dioxide as the working fluid.	6	Recuperator, Heater, Cooler, Turbine, Generator	~5-10 Cr INR	Cement and Iron and Steel
Combustion Control System for Boiler	Combustion control system in boiler provides effective monitoring of flue gas parameters, their temperature and pressure for complete combustion	7	N/A	N/A	Cross-Sectoral
Heat Exchanger in Kiln	The waste heat, which otherwise would escape in atmosphere may be recovered using appropriate heat exchanger to pre-heat water for use in utility or process	9	Heat exchanger	N/A	Cement (thermal)
Heat Exchanger- Low-Grade Waste Heat Recovery System (LGWHRS)	Waste heat even below 100 C is recovered by LGWHRS and can be used in the low temperature applications. These heat exchangers are specially designed for low-grade waste heat recovery.	8	Heat exchanger	N/A	Cross-Sectoral (thermal)
Air Preheater & Drying bed in furnace	Use of waste flue gas to pre-heat the material and save fuel	7	Flue gas system, Insulation, Material feed system, Sensors, fans or blowers	N/A	Cross-Sectoral (thermal)
Gas-fired Reheating Furnace with WHR System	A fully automated system ensures better control on temperature of metals in rolling mills, with efficient	7	N/A	N/A	Cross-Sectoral (thermal)

	combustion owing to the use of gas as fuel. In addition, the WHR system will save substantial energy by preheating the metal to the extent possible before reheating				
WHR for power generation	The WHR process is a fuel conservation measure where the heat from waste stream of gases is recovered to generate steam which in turn is used to drive turbine and generate power, instead of using conventional process of burning fuel	9	N/A	N/A	Cross-Sectoral (thermal)
Recuperative burner	A recuperative burner is the one where recuperator is an integral part of the burner, and the waste heat is recovered to pre-heat the combustion air, thereby ensuring substantial energy saving	9	N/A	N/A	Cross-Sectoral (thermal)
WHR in centrifugal compressor	The waste heat is recovered from each stage of compressor owing to losses in the form radiation loss and/or condensation heat and using them in pre-heating of boiler feedwater or process application	7	N/A	N/A	Textile

**Table 6: WHR technologies with potential savings & project costings as per consultation**

(Source- Secondary research & [BEEs Adeetie Portal](#))

### 3.6 Integration/Enhancing of WHR systems with low carbon solutions.

The urgent need to decarbonize the global economy has intensified the focus on renewable energy and energy efficiency. Waste heat recovery (WHR) systems, which capture and utilize thermal energy from industrial processes, are becoming essential in this transition. By integrating WHR with low-carbon solutions, industries can optimize energy use, reduce emissions, and enhance overall sustainability.

#### Integration with Renewable Energy Systems

Combining WHR with renewable energy sources creates a more resilient energy system. For instance, solar thermal energy can preheat working fluids in Supercritical CO2 (sCO2) systems, improving performance and reliability, especially in areas with variable solar radiation. Furthermore, excess electricity from wind and solar farms can power heat pumps that recover waste heat, increasing overall system efficiency and aiding grid stability.

The rising interest in renewable hydrogen production also provides opportunities for WHR integration. WHR systems can supply the necessary heat for the energy-intensive electrolysis process, reducing energy demands and improving hydrogen production economics.

## Synergy with Carbon Capture and Storage (CCS)

Integrating WHR with CCS creates a mutually beneficial relationship, as CCS generates significant waste heat that can be repurposed for preheating feedstocks or electricity generation. This reduces CCS energy consumption while enhancing the overall efficiency of industrial facilities. Moreover, WHR can provide the energy needed for CO<sub>2</sub> capture and compression, thus lowering the carbon footprint of CCS systems.

## Integration with Energy Storage Systems

Energy storage is vital for balancing intermittent renewable sources. By integrating WHR with energy storage systems, industries can enhance energy utilization and flexibility. Thermal energy storage (TES) can store recovered heat for later use, aligning energy supply with demand, especially in facilities with fluctuating loads. Additionally, power-to-heat applications can utilize excess renewable electricity to drive heat pumps for waste heat recovery, further optimizing energy consumption.

## Emerging Trends in WHR

To maximize the impact of WHR systems, several trends are gaining momentum:

**Digitalization and IoT:** Real-time monitoring and predictive maintenance enhance WHR performance.

**Advanced Materials:** New materials improve heat transfer efficiency and durability of heat exchangers.

**Integration with Building Energy Systems:** Waste heat recovery can also support heating and cooling needs in buildings, creating synergistic systems.

By embracing these trends, industries can unlock additional value from waste heat and contribute to a sustainable and efficient future.

In conclusion, integrating WHR with low-carbon solutions presents a promising pathway to achieving energy efficiency and reducing emissions. By leveraging the synergies between these technologies, industries can optimize resource utilization, enhance system performance, and contribute to a resilient and decarbonized energy landscape.

## 3.7 Technical Standards for WHRS

The implementation of Waste Heat Recovery Systems (WHRS) necessitates a thorough understanding of the intricate web of national and international standards governing their design, installation, operation, and maintenance. This multi-faceted approach ensures the safe, efficient, and compliant integration of WHRS into various industrial processes.

The Bureau of Indian Standards (BIS) is the national standards body responsible for developing and promoting standards in India. While BIS has adopted several international standards, there are specific Indian standards tailored to the country's industrial landscape and regulatory environment.

**Bureau of Indian Standards (BIS):** BIS develops and publishes Indian Standards (IS) covering various aspects of WHRS, including energy efficiency, performance evaluation, and safety.

**International Organization for Standardization (ISO):** ISO provides a global framework for WHRS standards, offering general principles and guidelines that can be adapted to the Indian context.

India has specific regulations governing the design, manufacture, and operation of pressure equipment and boilers. Key regulations include:

- **Indian Boiler Regulations (IBR):** These regulations govern the design, construction, installation, and operation of boilers and pressure vessels.
- **Pressure Equipment Safety Regulations (PESO):** PESO is responsible for the safety of pressure equipment in India, including design, manufacture, installation, and inspection.

Compliance with these regulations is essential for ensuring the safety and reliability of WHRS components.

The safety of WHRS installations is paramount. Beyond the regulatory framework, additional safety standards and guidelines need to be considered:

- **National Building Code of India (NBC):** This code provides guidelines for the installation and operation of WHRS systems in buildings.
- **Electrical Equipment Safety Standards:** Adherence to electrical safety standards is crucial for WHRS systems involving electrical components.
- **Occupational Safety and Health Standards:** Ensuring the safety of personnel working with WHRS is essential.

Below is compilation of various national & international standards for WHRS-

*(Source- ISO, ASME, BIS, CEN/EN websites)*

Standard	Description	Applicability to WHRS
IS 4800 (2015)	Code of Practice for Selection, Installation and Maintenance of Steam Traps	Selection, installation, and maintenance of steam traps in WHRS using steam.
IS 13512 (2014)	Code of Practice for Design and Installation of Steam Boilers	Pressure vessel design, material selection, and safety considerations for WHRS components.
IS 12271 (2017)	Code of Practice for Design and Installation of Heat Exchangers	Design considerations, materials selection, and fabrication practices for heat exchangers in WHRS.
ISO 11298 (Parts 1-4)	Road Vehicles - Tank Containers for Liquid Foodstuffs - Specifications and Testing	Material selection and pressure vessel design for WHRS utilizing food-grade fluids (indirect reference).
ISO 13485 (2016)	Medical Devices - Quality Management Systems - Requirements for Regulatory Purposes	Framework for quality management systems adaptable for WHRS manufacturing and service providers (indirect reference).
ISO 21905:2020 (en)	Gas turbine exhaust systems with WHR	Specifies requirements and gives recommendations for the design, materials of construction, modelling, controlling, fabrication, inspection, testing, installation, start-up and operation of industrial gas

		turbine (GT) exhaust systems with or without waste heat recovery unit
ISO 5168:2007	Heat exchangers- selection, design and construction	This standard offers guidance for selecting designing and installing and operating heat exchangers
ISO 14001:2015	Environment management systems	WHRS implementation is encourages as a strategy for energy efficiency and reduced environmental impact
ASME B31 Piping codes	Provides comprehensive guidelines for efficient fluid flow within WHRS	Pipe design, materials selection, fabrication, testing, and operation for piping.
ASME Boiler and Pressure Vessel Code (Sections I, VIII)	Provides comprehensive guidelines for pressure vessels and boilers.	Design, fabrication, inspection, and testing of pressure vessels in WHRS.
ASME PTC 4.4	Gas Turbine Heat recovery systems	Gas Turbine Heat recovery systems
ASME PTC 30	-	Air cooled heat exchangers
ASME PTC 12.5	-	Single Phase Heat exchangers
NFPA 85	Boiler and combustion system hazards	It is crucial for WHRS applications involving high temperature furnaces.
IS 2825	Boiler and pressure vessel code	This code aligns with principles from ASME boiler and pressure vessel code for manufacturing, materials, inspection and testing of pressure vessels used in WHRS in India
IS 16528: part 2007	Boilers and pressure vessel	This code aligns with principles from ASME boiler and pressure vessel code for manufacturing, materials, inspection and testing of pressure vessels used in WHRS in India

**Table 7: Indian and International Standards for WHRS**



# Chapter 4- Market Assessment



## Chapter 4- Market Assessment

### 4.1 Overview of the Market Assessment

In our comprehensive market assessment of the Waste Heat Recovery (WHR) sector in India, we undertook a detailed analysis to identify the market potential across various sectors and technologies. Our approach was multi-faceted, encompassing a thorough evaluation of the current market landscape, supply chain dynamics, and stakeholder mapping.

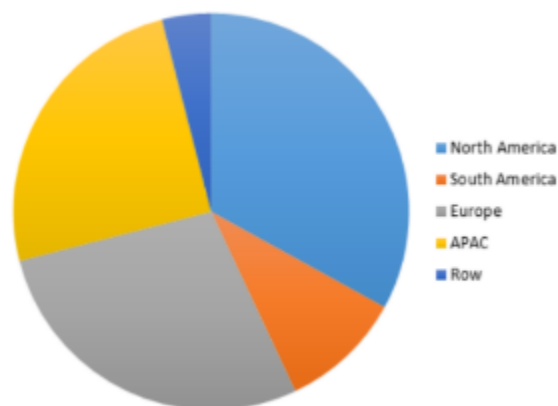
We focused on the identification of key sectors, distinguishing between large industries and Micro, Small, and Medium Enterprises (MSMEs) based on their potential for WHR implementation. By examining energy consumption patterns and waste heat generation, we determined where WHR technologies could be most effectively deployed to maximize energy savings and GHG emissions reductions.

Additionally, we analyzed different WHR technologies through a selection matrix that considered cost viability, available vendors, potential applications, and insights gained from secondary research. This matrix allowed us to assess the most suitable technologies for various industrial contexts, ensuring our recommendations are both practical and implementable.

Our assessment also included an exploration of market drivers and barriers to adoption, insights from previously implemented WHR projects by national and international agencies, and a review of the existing policy, institutional, and regulatory frameworks. This holistic approach not only highlights the current state of the WHR market in India but also provides actionable recommendations aligned with government policies and updated NDC commitments.

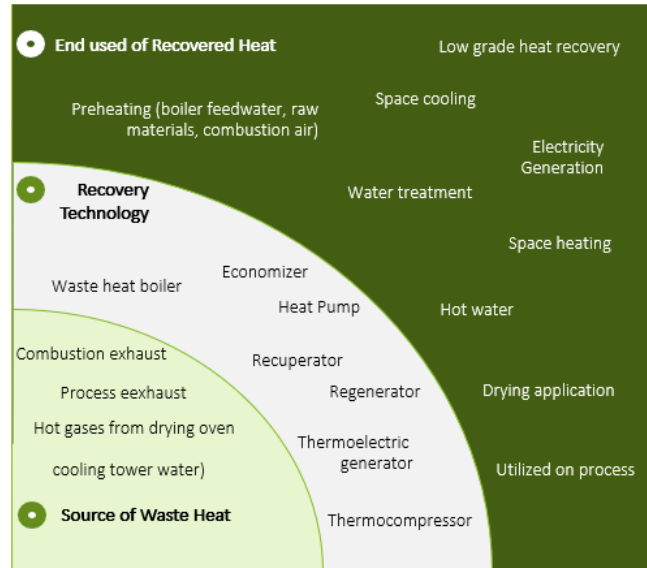
### 4.2 Global Waste Heat Recovery Market Potential

Global projections for the WHR market indicate substantial growth, with an estimated reach of USD 52.02 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 9.3% from 2023 to 2030 [1]. This optimistic trajectory is anticipated to resonate within India's market, signalling opportunities for exponential growth. Although specific data regarding India's WHR market size is not readily available, existing reports hint at a sizable market base with significant untapped potential. These indicators collectively underscore a lucrative opportunity for stakeholders to capitalize on the burgeoning demand for WHR solutions in India's industrial landscape. By application, Steam and electricity generation are expected to have the highest compound annual growth rate (CAGR) in the forecast period for the Waste Heat Recovery System Industry. By Industry Petroleum refining, Chemical, Cement and Metal production share the highest potential.



**Figure 9: Global waste heat recovery market by region.**

As illustrated recovering waste heat generated from industrial processes can unlock substantial energy savings and minimize environmental impacts. Industrial processes inherently generate substantial waste heat in the form of hot exhaust gases, chilled cooling water, and heated equipment surfaces. This represents a significant untapped thermal energy resource. Waste Heat Recovery (WHR) technologies are instrumental in capturing and repurposing this wasted energy for productive applications. By redirecting waste heat towards preheating processes or electricity generation, WHR significantly reduces overall fuel consumption, mitigating energy demand and enhancing sustainability.



**Figure 10:Essential component of WHR (Source, Technology, End Use)**

### 4.3 Indian Waste Heat Recovery Market Potential

The Indian waste heat recovery (WHR) market presents significant opportunities for enhancing energy efficiency across various sectors and technologies. With a substantial portion of industrial energy consumption being wasted as heat, the potential for recovery is immense, offering both economic and environmental benefits. Based on this study the Indian waste heat recovery market’s estimated monetary savings comes to be around USD ~1.18 billion, with an investment of USD ~3.5 billion by 2030.

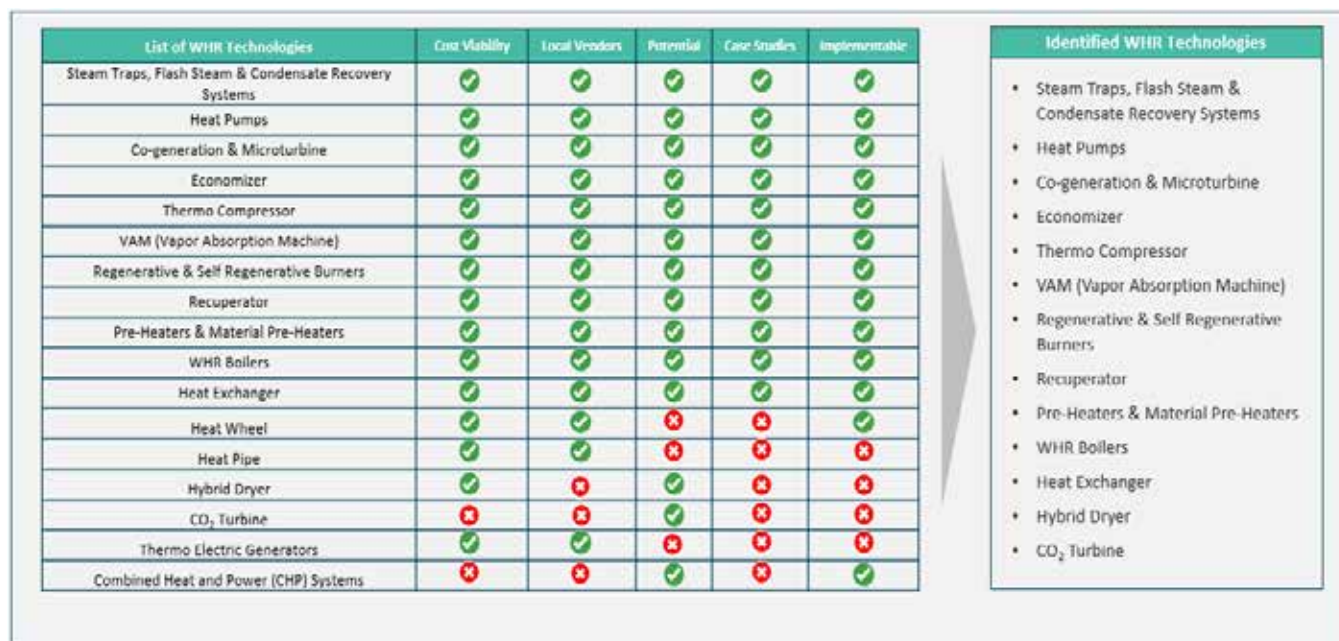
This section explores the market potential by dissecting it into specific sectors large and MSME, where the implementation of WHR technologies can lead to considerable energy savings. Additionally, we assess the potential by various technologies employed in waste heat recovery, highlighting important KPIs such as potential, GHG emission reduction, payback etc. By analyzing these dimensions, we aim to provide a comprehensive understanding of the WHR market potential in India, paving the way for targeted investments and strategic initiatives.

In our analysis of Waste Heat Recovery (WHR) technologies, we employed a selection matrix as a pivotal tool to systematically evaluate and compare various options. The importance of this matrix lies in its ability to provide a structured framework that facilitates informed decision-making. By considering multiple criteria—such as cost viability, available vendors, potential applications, and insights from secondary research—we were able to create a comprehensive overview of the technologies currently available in the market.

Our approach to developing the selection matrix involved several key steps. First, we identified a range of WHR technologies applicable to different industrial sectors. Next, we gathered data on each technology's cost-effectiveness, examining both initial investment and long-term operational savings. We also researched the vendor landscape to identify reputable suppliers and their offerings.

To ensure a well-rounded assessment, we included potential applications for each technology, which allowed us to match them with specific industry needs. Insights from secondary research enriched our understanding of market trends and user experiences, providing a robust context for our evaluations. This

comprehensive methodology not only enhances the reliability of our findings but also ensures that our recommendations are tailored to the unique requirements of various industrial contexts, paving the way for practical and successful implementations of WHR systems.



**Figure 11: Selection Matrix for Technologies**

### Analysis of Low-Medium and High Scenario

For the estimation of the market scenario, we have developed three distinct scenarios—Low, Medium, and High—representing varying levels of adoption and implementation potential for Waste Heat Recovery (WHR) technologies across Indian industrial sectors. These scenarios are based on market potential, considering the current landscape, sector-specific challenges, and expected trends over the next five years.

#### **Low Scenario:**

In this scenario, WHR technology adoption progresses slowly, with limited market growth. Industrial sectors show moderate interest, constrained by factors such as limited awareness, financial constraints, and operational challenges. Consequently, the market potential grows at a slow and steady pace, with minimal improvements in technology implementation over the next five years.

#### **Medium Scenario:**

The medium scenario reflects a moderate acceleration in WHR adoption, driven by increasing awareness, technological advancements, and evolving regulations. Adoption rates rise steadily, leading to significant market expansion over the next five years compared to the low scenario.

#### **High Scenario:**

In the high scenario, we envision rapid WHR adoption, supported by strong regulatory frameworks, increased industry commitment to sustainability, and higher financial investments in energy-efficient

technologies. This results in faster adoption rates and widespread technology implementation across various sectors within the next five years.

The market potential and projections for each WHR technology and sector in this study were derived from secondary research, stakeholder consultations with sector experts, and discussions with technology suppliers, providing a robust foundation for estimating the future growth of WHR technologies in India's industrial sectors.

### 4.3.1 Market assessment based on Sectors.

The waste heat recovery (WHR) market is experiencing robust growth as industries grapple with escalating energy costs and stringent environmental regulations. Sectors such as cement, steel, textiles, fertilizers, aluminum, and MSMEs are at the forefront of adopting WHR technologies to optimize energy efficiency and reduce greenhouse gas emissions.

Advanced WHR solutions, including heat exchangers, recuperators, and waste heat recovery boilers (WHRB) are driving this transformation. By capturing and repurposing waste heat, these technologies are not only enhancing operational efficiency but also contributing significantly to broader sustainability goals.


The subsequent sections will delve deeper into the energy-saving potential and investment requirements for typical WHR technologies across the aforementioned sectors under low, medium and high scenarios. By quantifying the potential benefits and investment needs, this analysis aims to provide a clear understanding of the economic and environmental implications of WHR implementation in these industries.

#### Large Sector


The waste heat recovery (WHR) market is poised for significant growth, particularly within large, hard-to-abate sectors such as steel, cement, Textile, fertilizer, and paper manufacturing. These industries, characterized by their high energy consumption and substantial waste heat generation, face increasing pressure to reduce carbon emissions and enhance energy efficiency amid tightening regulations and shifting market dynamics. As companies seek to meet sustainability goals and optimize operational costs, the integration of WHR technologies offers a viable solution for capturing and repurposing waste heat, ultimately driving both economic and environmental benefits. Below is the sectoral outlook for the identified selected large sectors:

##### i. Cement Industry

Particular	Details
Sector	Cement Industry
Description	India ranks as the world's second largest cement producer. According to PAT cycle-VII A regulations, 174 cement plants in the country were notified as Designated Consumer, each with a minimum energy consumption of 30,000 TOE for integrated Cement Unit and 10,000 TOE for Grinding Unit. [16]

	<p>Typical sources of waste heat for both old and small-sized shaft furnace types of units and plants that use the dry process are as follows:</p> <ul style="list-style-type: none"> <li>• Clinker cooling air ranges from 180°-480°C [2] and can be utilized with Waste Heat Recovery (WHR) technologies to preheat air for steam generation and heating with minimal R&amp;D.</li> <li>• Exhaust gases from preheaters, containing CO<sub>2</sub> and kiln combustion byproducts at 150°C to 260°C [2], are mixed with cooling air and their heat is recovered through heat recovery units.</li> <li>• Kiln and precalciner surfaces, with temperatures between 260°C and 430°C [2], have limited effective heat recovery methods, leading to potential redesigns for better insulation and reduced heat loss.</li> </ul>		
Applicable Technology	<ul style="list-style-type: none"> <li>• Waste Heat Recovery Boiler</li> <li>• VAM (Vapor Absorption Machine)</li> </ul>		
Product/Process Photographs			
GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.376 MtCO <sub>2</sub>	Medium: 0.750 MtCO <sub>2</sub>	High: 1.127 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.079 MTOE	Medium: 0.158 MTOE	High: 0.237 MTOE
Waste Heat Streams	Stack Exhausts from Cement Kiln		
Total Monetary Savings (in INR Cr)	Low: ~75-100 INR Cr	Medium: ~175-200 INR Cr	High: ~250-300 INR Cr
Total Investment Required* (in INR Cr)	Low: ~350-400 INR Cr	Medium: ~700-750 INR Cr	High: ~1050-1100 INR Cr
ROI* (in years)	3.5-4 years		


**ii. Iron and Steel Industry**

Particular	Details		
Sector	Iron and Steel Industry		
Description	<p>India stands as the third largest steel producer globally. Under PAT cycle-VII A regulations, 168 iron and steel plants in India are designated consumer, each with an energy consumption of at least 20,000 TOE. [16]</p> <p>Steel industry can be divided into three areas of waste heat in an integrated steel plant.</p> <p>In steel production, various processes generate significant waste heat.</p> <p>Blast furnaces produce high-temperature blast air (1,066°C to 1,122°C) and waste heat in blast furnace gas (BFG), which can be utilized or recovered from hot BFG, moisture removal, and flared BFG. Coke ovens generate waste heat from hot coke discharge, hot coke oven gas (815°C), and exhaust gases, with opportunities for heat recovery from clean boiler flue gases.</p> <p>Reheating and heat-treating furnaces at rolling and finishing areas use mixed fuels and generate waste heat from exhaust gases, furnace radiation, and unutilized heat from rolled steel shapes, offering potential for increased heat recovery.</p>		
Applicable Technology	<ul style="list-style-type: none"> <li>• Waste Heat Recovery Boiler</li> <li>• Recuperator</li> <li>• Co-generation</li> <li>• Regenerative Burners</li> <li>• Vapor Absorption Machine</li> <li>• Raw Material Preheaters</li> </ul>		
Product/Process Photographs			
GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.873 MtCO <sub>2</sub>	Medium: 1.234 MtCO <sub>2</sub>	High: 1.586 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.204 MTOE	Medium: 0.288 MTOE	High: 0.368 MTOE

Waste Heat Streams	<ul style="list-style-type: none"> <li>• Sinter exhaust from cooler</li> <li>• Blast furnace gas.</li> <li>• Coke Oven Gas</li> <li>• Blast Furnace hot stove.</li> <li>• BOF exhaust</li> <li>• Reheat exhaust from hot rolling.</li> <li>• Rotary Kiln - DRI</li> <li>• EAF Furnace</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~250-300 INR Cr	Medium: ~350-400 INR Cr	High: ~450-500 INR Cr
Total Investment Required* (in INR Cr)	Low: ~850-900 INR Cr	Medium: ~1150-1200 INR Cr	High: ~1400-1500 INR Cr
ROI* (in years)	3.0- 3.5 years		


### iii. Textile Industry

Particular	Details
Sector	Textile Industry
Description	<p>India ranks as the third largest textile exporter globally. Under PAT cycle-VII A regulations, 168 textile plants in India, each with an energy consumption of at least 3,000 TOE, have been designated as key consumers. [16]</p> <p>In the textile industry, significant energy savings can be achieved through waste heat recovery. Steam exhaust from dyeing and finishing processes, along with hot exhaust air from drying, can be captured and reused to preheat incoming water or air, enhancing energy efficiency. Additionally, flue gases from steam boilers, which contain residual heat, can be recovered using economizers or heat exchangers to preheat feedwater or generate additional steam, reducing fuel consumption and improving boiler efficiency.</p> <p>In the textile industry, waste heat recovery can significantly enhance energy efficiency. Low-grade heat from dye effluent (80-100°C), sinter exhaust (130-150°C), and blowdown water (140-160°C) can be recovered using heat exchangers and condensate recovery systems, achieving energy savings of 10-15%. Medium-grade heat from flue gases (300-350°C) in dyeing processes is efficiently utilized with economizers. The sector's potential for energy savings lies in optimizing these recovery methods, which can lead to reduced energy consumption and lower operational costs across various processes.</p>
Applicable Technology	<ul style="list-style-type: none"> <li>• Economizer</li> <li>• Heat Exchanger</li> <li>• Heat Pump</li> <li>• Micro Turbine</li> <li>• Steam Traps, Flash Steam &amp; Condensate Recovery Systems</li> </ul>


Product/Process Photographs			
GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.170 MtCO <sub>2</sub>	Medium: 0.254 MtCO <sub>2</sub>	High: 0.339 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.035 MTOE	Medium: 0.053 MTOE	High: 0.070 MTOE
Waste Heat Streams	<ul style="list-style-type: none"> <li>• Stenter exhaust</li> <li>• Condensate from Jet Dyeing Machine</li> <li>• Water from dyeing machine to ETP</li> <li>• Flue gas from Boilers/ Thermal Fluid Heater</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~50-75 INR Cr	Medium: ~90-120 INR Cr	High: ~120-150 INR Cr
Total Investment Required* (in INR Cr)	Low: ~100-160 INR Cr	Medium: ~200-250 INR Cr	High: ~300-350 INR Cr
ROI* (in years)	2.5-3 years		

#### iv. Fertilizer Industry

Particular	Details
Sector	Fertilizer Industry
Description	<p>The India contributes to 16.81% share of global Fertilizer production. With a minimum energy consumption threshold of 30,000 TOE, 37 Fertilizer plants in India were notified as Designated Consumers under PAT cycle-VII A. [16]</p> <p>In the fertilizer industry, significant energy savings can be achieved through waste heat recovery across various processes. High-temperature flue gases from ammonia synthesis and sulfuric acid production, along with reaction heat from urea synthesis, can be recovered using heat exchangers and economizers to improve plant efficiency. Heat from cooling systems in granulation and hot exhaust air from drying can be captured to pre-heat materials or water, and boiler</p>

	<p>flue gases can be recovered to pre-heat feedwater or generate additional steam. These methods enhance energy efficiency and reduce operational costs.</p> <p>In the fertilizer sector, waste heat recovery methods offer notable energy savings. High-grade flue gases from ammonia synthesis (1,000-1,500°C) can be recovered using WHR boilers, achieving 10-15% savings. Low-grade heat from steam reforming process gases and condensate tanks (100-150°C) can be captured using vapor absorption machines and condensate recovery systems, providing savings of 5-15%. Additionally, heat pumps can recover low-grade heat from chillers (100-150°C) for savings of 15-30%. These techniques highlight significant potential for improving energy efficiency and reducing costs in fertilizer production.</p>		
Applicable Technology	<ul style="list-style-type: none"> <li>• WHR Boilers</li> <li>• Steam Traps, Flash Steam &amp; Condensate Recovery</li> <li>• VAM (Vapor Absorption Machine)</li> </ul>		
Product/Process Photographs			
GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.265 MtCO <sub>2</sub>	Medium: 0.318 MtCO <sub>2</sub>	High: 0.354 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.089 MTOE	Medium: 0.106 MTOE	High: 0.118 MTOE
Waste Heat Streams	<ul style="list-style-type: none"> <li>• Flue gases from Ammonia Synthesis</li> <li>• Process gases from Steam Reforming</li> <li>• Condensate tank from Steam Reforming</li> <li>• Flash steam</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~30-50 INR Cr	Medium: ~40-60 INR Cr	High: ~60-80 INR Cr
Total Investment Required* (in INR Cr)	Low: ~75-100 INR Cr	Medium: ~90-120 INR Cr	High: ~100-150 INR Cr
ROI* (in years)	2-2.5 years		

**v. Paper and Pulp Industry**

Particular	Details
Sector	Paper and Pulp Industry
Description	<p>India's paper industry contributes 3.7% to global paper production. Under PAT cycle-VII A regulations, 48 pulp and paper plants in India, each consuming at least 30,000 TOE of energy, have been notified as designated consumers. [16]</p> <p>In the paper industry, waste heat recovery can significantly enhance energy efficiency. High-temperature flue gases from boilers and exhaust gases from pulp digestion can be recovered using economizers and heat exchangers to pre-heat feedwater and cooking chemicals. Hot air from drying processes and heat from chemical reactors can be reused to pre-heat incoming air or water. Additionally, heat from condensate and exhaust in steam generation, as well as from dryer sections in paper machines, can improve overall efficiency by reducing energy requirements for subsequent processes.</p> <p>The paper and pulp sector can significantly benefit from waste heat recovery technologies. Low-grade heat streams, such as flash steam from chemical pulping, deaerators, and boilers (80-120°C), can be efficiently recovered using methods like steam traps, thermo compressors, and heat pumps, offering energy savings of 5-30%. Medium-grade steam from power generation (350-400°C) can be captured using high-pressure co-generation systems, yielding similar savings. Heat recovery from effluent treatment and paper machines also contributes to improved efficiency. Overall, these technologies enhance energy efficiency and reduce operational costs, demonstrating considerable potential for energy savings in the sector.</p>
Applicable Technology	<ul style="list-style-type: none"> <li>• Economizer</li> <li>• Heat Pumps</li> <li>• Steam Traps, Flash Steam &amp; Condensate Recovery</li> <li>• Thermo Compressor</li> </ul>
Product/Process Photographs	

GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.455 MtCO <sub>2</sub>	Medium: 0.609 MtCO <sub>2</sub>	High: 0.775 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.095 MTOE	Medium: 0.127 MTOE	High: 0.161 MTOE
Waste Heat Streams	<ul style="list-style-type: none"> <li>• Paper Machine</li> <li>• Returned Chilled Water from Deaerator</li> <li>• High pressure steam from Power Generation Plant</li> <li>• Effluents from ETP</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~100-120 INR Cr	Medium: ~150-175 INR Cr	High: ~175-200 INR Cr
Total Investment Required* (in INR Cr)	Low: ~250-300 INR Cr	Medium: ~350-400 INR Cr	High: ~450-500 INR Cr
ROI* (in years)	2.5-3.0 years		

## MSME Sector

The waste heat recovery (WHR) market is increasingly gaining traction within micro, small, and medium enterprises (MSMEs), which represent a vital segment of the global economy. These businesses, often operating on tighter margins, face unique challenges related to energy efficiency and sustainability, making the effective utilization of waste heat a critical opportunity. As MSMEs across sectors such as Ceramic, Dairy, Textile, SRRM processing, and manufacturing seek to reduce operational costs and enhance their environmental performance, the adoption of WHR technologies emerges as a practical solution. This market assessment will delve into the current landscape of WHR implementation within the MSME sector, highlighting the barriers, opportunities, and innovative practices that can drive the transition toward greater energy efficiency and sustainability.

The subsequent table provides a detailed analysis of the energy savings, emissions reductions, and investment requirements associated with WHR implementation in these sectors, underscoring the potential for significant energy efficiency gains and environmental benefits within the MSME landscape.


### i. Ceramic Sector

Particular	Details
Sector	Ceramic Industry
Description	The ceramic MSME cluster in India is highly energy-intensive, primarily due to the high temperatures required for kilns and drying processes. Despite this, there is significant potential for improving energy efficiency through waste heat recovery. Technologies like recuperators for kilns and heat exchangers for dryers can substantially cut energy use, but adoption remains limited due to high initial costs and lack of awareness. Enhanced support and investment in these technologies

	<p>could reduce energy consumption and operational costs, fostering greater sustainability in the sector.</p> <p>In the ceramic MSME cluster, raw materials like clay and quartz are wet-ground in ball mills to create a homogeneous slurry, which is then spray-dried to reduce moisture from 35-40% to 5-6% using hot flue gases at 550-600°C. The dried product is pressed into tiles, which are further dried to 2-3% moisture, often utilizing hot air from kiln cooling zones. After glazing, the tiles undergo final firing in kilns at 1100-1150°C, primarily using natural gas, though some units use hot air from gasifiers. Finished tiles are sized and calibrated, while vitrified tiles undergo polishing, consuming 40-45% of the plant's electricity. [5]</p> <p>In the ceramic MSME sector, waste heat recovery technologies can significantly improve energy efficiency. Tunnel kilns and roller kilns generate low-grade exhaust flue gases at 200-250°C, with recuperators capturing this heat, yielding typical energy savings of 2-5% for tunnel kilns and 15-20% for roller kilns. Spray dryers produce exhaust gases at 100-120°C, where pre-heaters can recover this low-grade heat, achieving energy savings of 12-18%.</p>		
Applicable Technology	<ul style="list-style-type: none"> <li>• Recuperator</li> <li>• Heat Pumps</li> </ul>		
Product/Process Photographs			
GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.024 MtCO <sub>2</sub>	Medium: 0.037 MtCO <sub>2</sub>	High: 0.049 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.008 MTOE	Medium: 0.012 MTOE	High: 0.016 MTOE
Waste Heat Streams	<ul style="list-style-type: none"> <li>• Exhaust flue gas from Roller Tunnel Kiln</li> <li>• Exhaust flue gas from Shuttle Kiln</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~10-15 INR Cr	Medium: ~15-20 INR Cr	High: ~20-25 INR Cr
Total Investment Required* (in INR Cr)	Low: ~30-40 INR Cr	Medium: ~40-50 INR Cr	High: ~55-70 INR Cr


ROI* (in years)	2.5-3.0 years
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## ii. Dairy Sector

Particular	Details		
Sector	Dairy Industry		
Description	<p>In the dairy MSME cluster, energy consumption is high due to processes like pasteurization, cooling, and evaporation. Significant waste heat is generated from these processes, including hot exhaust gases and cooling system heat. This waste heat can be recovered using technologies such as heat exchangers and economizers to pre-heat incoming milk or water, thereby improving energy efficiency and reducing fuel costs. Implementing waste heat recovery systems can lead to substantial savings and enhanced operational efficiency in dairy operations.</p> <p>In the dairy MSME sector, waste heat recovery opportunities include condensate from boilers, refrigerant exhaust from cooling systems, and heat from chiller compressors. Typical temperatures of these waste heat streams are around 70-80°C, classifying them as low-grade. Heat recovery methods such as condensate recovery systems, heat exchangers, and heat pumps can preheat boiler feedwater and improve energy efficiency. Implementing these technologies can achieve energy savings of 7-30%, enhancing both cost-effectiveness and operational efficiency.</p>		
Applicable Technology	<ul style="list-style-type: none"> <li>• Economizer</li> <li>• Micro Turbine</li> <li>• Heat Pumps</li> <li>• Steam Traps, Flash Steam &amp; Condensate Recovery</li> </ul>		
Product/Process Photographs			
GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.017 MtCO <sub>2</sub>	Medium: 0.026 MtCO <sub>2</sub>	High: 0.034 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.006 MTOE	Medium: 0.010 MTOE	High: 0.013 MTOE
Waste Heat Streams	<ul style="list-style-type: none"> <li>• Condensate in Boiler</li> <li>• Boiler Feed Water</li> </ul>		

	<ul style="list-style-type: none"> <li>Flue gas exhaust from Boiler</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~5-10 INR Cr	Medium: ~10-15 INR Cr	High: ~15-20 INR Cr
Total Investment Required* (in INR Cr)	Low: ~15-20 INR Cr	Medium: ~20-30 INR Cr	High: ~30-40 INR Cr
ROI* (in years)	2.0-3.0 years		


### iii. Textile (MSME) Sector

Particular	Details
Sector	Textile (MSME)
Description	<p>Textile dyeing and printing processes are energy-intensive, involving various stages where waste heat recovery can significantly enhance efficiency. In dyeing, high-temperature dye effluents and exhaust gases from equipment like jet dyeing machines and steners are prevalent. The waste heat from these streams, typically ranging from 80-150°C, can be recovered using heat exchangers to preheat incoming water or air, potentially saving 10-15% of energy. Dyeing processes also utilize medium-grade heat from flue gases in thermic fluid heaters, which can be efficiently captured through economizers.</p> <p>Printing processes also present opportunities for heat recovery. During drying, hot air is generated and can be reused to reduce energy consumption in subsequent stages. Heat recovery systems, including economizers and heat exchangers, are crucial in capturing and utilizing this low-grade heat.</p>
Applicable Technology	<ul style="list-style-type: none"> <li>Economizer</li> <li>Steam Traps, Flash Steam &amp; Condensate Recovery Systems</li> <li>Heat Exchanger</li> <li>Micro Turbine</li> </ul>
Product/Process Photographs	

GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.106 MtCO <sub>2</sub>	Medium: 0.144 MtCO <sub>2</sub>	High: 0.212 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.022 MTOE	Medium: 0.030 MTOE	High: 0.044 MTOE
Waste Heat Streams	<ul style="list-style-type: none"> <li>• Dye Effluent from Jet Dyeing Machine</li> <li>• Flue gas from Thermal Fluid Heater/Boiler</li> <li>• Bleached water</li> <li>• Condensate from Jet Dyeing Machine</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~30-40 INR Cr	Medium: ~40-50 INR Cr	High: ~60-75 INR Cr
Total Investment Required* (in INR Cr)	Low: ~60-80 INR Cr	Medium: ~90-100 INR Cr	High: ~120-150 INR Cr
ROI* (in years)	2.0-2.5 years		

#### iv. Metal Industry (SRRM, Forging & Foundry)

Particular	Details
Sector	SRRM- Secondary Steel Re-Rolling Mills/ Forging and Foundry
Description	<p>Steel re-rolling mills process steel billets or ingots into finished products like bars and sections. The primary stages include reheating billets in furnaces, rolling them into shape, and cooling them. Energy consumption in these mills is significant, with reheating furnaces being the largest energy consumer due to the high temperatures required (around 1,200–1,300°C) for metal processing.</p> <p>In terms of energy efficiency, steel re-rolling mills have substantial potential for waste heat recovery (WHR). Exhaust gases from reheating furnaces, typically at 600–800°C, can be captured and utilized with recuperators or heat exchangers to pre-heat incoming air or water, leading to significant energy savings. Additionally, the heat from the cooling process can also be harnessed to improve overall efficiency.</p> <p>By adopting WHR technologies, steel re-rolling mills can achieve considerable reductions in energy consumption and operational costs. Implementing advanced systems for recovering waste heat from both reheating and cooling processes can result in energy savings of 15–25%, showcasing the sector’s potential for improved sustainability and cost efficiency.</p> <p>Forging &amp; Foundry- The foundry and forging MSME industry in India faces significant energy consumption challenges, primarily due to the high energy requirements for melting furnaces, heating billets, and forging processes. Energy-intensive operations such as melting in induction or arc furnaces and maintaining high temperatures for forging contribute to substantial energy use. However, there is considerable potential for waste heat recovery (WHR) to enhance efficiency. Technologies like recuperators</p>

	for furnace exhaust gases, heat exchangers for cooling systems, and heat recovery from casting processes can substantially reduce energy consumption and operational costs in this sector.		
Applicable Technology	<ul style="list-style-type: none"> <li>• Regenerative Burners (SRRM)</li> <li>• Recuperator (SRRM, Forging &amp; Foundry)</li> </ul>		
Product/Process Photographs			
GHG emission Reduction (in million tCO <sub>2</sub> )	Low: 0.073 MtCO <sub>2</sub>	Medium: 0.140 MtCO <sub>2</sub>	High: 0.213 MtCO <sub>2</sub>
Energy Saving Potential (in million TOE)	Low: 0.016 MTOE	Medium: 0.030 MTOE	High: 0.047 MTOE
Waste Heat Streams	<ul style="list-style-type: none"> <li>• Flue gas from Re-Heating Furnace (SRRM), Exhaust Gas (Forging &amp; Foundry)</li> </ul>		
Total Monetary Savings (in INR Cr)	Low: ~30-45 INR Cr	Medium: ~50-75 INR Cr	High: ~90-120 INR Cr
Total Investment Required* (in INR Cr)	Low: ~50-90 INR Cr	Medium: ~90-120 INR Cr	High: ~130-180 INR Cr
ROI* (in years)	1.0-2.5 years		

### 4.3.2 Market assessment based on technologies.


The waste heat recovery (WHR) market is rapidly evolving, showcasing a diverse range of technologies designed to capture and repurpose thermal energy from industrial processes. Key technologies driving this market include recuperators, WHR boilers, economizers, heat exchangers, regenerative burners, steam traps, flash steam recovery systems, vapor absorption machines (VAMs), and thermos-compressors. Recuperators and economizers enhance process efficiency by preheating incoming air or fluids, reducing fuel consumption. WHR boilers convert waste heat into useful energy carriers like steam or hot water for power generation, process heating, or space heating. Heat exchangers optimize thermal energy transfer between fluids, while regenerative burners and VAMs recover and reuse waste heat in

high-temperature processes. Additionally, steam traps, flash steam recovery systems, and thermocompressors optimize steam systems to prevent energy losses and improve heat recovery efficiency.

This market assessment aims to analyze the current landscape of WHR technologies, highlighting their versatility and adaptability across various industrial sectors. By understanding the unique characteristics and needs of different industries, tailored WHR solutions can lead to substantial energy savings, reduced greenhouse gas emissions, and enhanced overall system performance. The following analysis will explore the replication potential of these technologies and identify opportunities for widespread adoption and impact assessment.



### i. Recuperators

Particular	Details
Technology	Recuperator
Typical Working Principle	<p>A recuperator is a heat exchanger that transfers heat from one fluid to another, typically in a counterflow arrangement, to improve energy efficiency:</p> <ul style="list-style-type: none"> <li>• Collect waste heat: A hot fluid, such as exhaust gases, enters the recuperator from one side.</li> <li>• Heat exchange: The hot fluid passes over heat exchanger surfaces and transfers its heat to a cold fluid, such as air or water.</li> <li>• Heat transfer: The cold fluid absorbs the heat and exits the recuperator from the other side, ready to be used in a different process or system.</li> </ul>
Typical Applications	<p>Recuperators are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• Air handling systems: Recuperators are positioned in the supply and exhaust air streams to recover waste heat and preheat air entering the combustion system.</li> <li>• Industrial processes: Recuperators are used in the exhaust gases of industrial processes to recover waste heat.</li> <li>• Automotive engines: Recuperators are used to transfer heat from one fluid to another without the need for intermediary thermal storage</li> </ul>
Applicable Sector	<ul style="list-style-type: none"> <li>• Ceramic</li> <li>• Iron &amp; Steel</li> <li>• Steel Re-rolling Mill</li> </ul>
Benchmarks Properties & Relevant standards (if any)	IS 12392 (for Design, Manufacture and Testing of Metallic Recuperators)
Advantages of the process/technology over available technologies	<p>Recuperators are advantageous because they:</p> <ul style="list-style-type: none"> <li>• Have a straightforward design.</li> <li>• Can be used in a variety of industrial and technical scenarios.</li> <li>• Prevent cross-contamination.</li> <li>• Can be up to 92% efficient.</li> <li>• Require little maintenance.</li> </ul>

	<ul style="list-style-type: none"> <li>• Don't have parts that consume electricity</li> </ul>		
Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	10-25%		
Other benefits (if any)	<p>A recuperator has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• Increase on flame temperature.</li> <li>• Helps improving combustion efficiency thereby improving yield.</li> <li>• Enhances life of refractory and insulation</li> <li>• Helps maintain furnace draught</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.044 MTOE	Medium: 0.067 MTOE	High: 0.091 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.144 MtCO <sub>2</sub>	Medium: 0.227 MtCO <sub>2</sub>	High: 0.312 MtCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~50-70 INR Cr	Medium: ~80-100 INR Cr	High: ~110-150 INR Cr
Total Investment Required* (in INR Cr)	Low: ~130-160 INR Cr	Medium: ~200-250 INR Cr	High: ~300-320 INR Cr
ROI* (in years)	2.5-3.5 years		

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## ii. Regenerative Burners

Particular	Details
Technology	Regenerative Burners
Typical Working Principle	<p>Regenerative burners are advanced combustion systems designed to enhance the efficiency of industrial heating processes. By capturing and reusing waste heat from exhaust gases, these burners optimize fuel consumption and reduce emissions, making them an essential component in energy-intensive industries.:</p> <ul style="list-style-type: none"> <li>• <b>Heat Storage:</b> Regenerative burners utilize a heat exchanger to store waste heat from exhaust gases in a ceramic or metallic medium.</li> <li>• <b>Cycle Operation:</b> The system alternates between two chambers; one absorbs heat from flue gases while the other preheats the combustion air using the stored heat.</li> <li>• <b>Combustion Process:</b> Preheated air is mixed with fuel, resulting in more efficient combustion due to the higher temperature of the incoming air</li> <li>• <b>Energy Recovery:</b> The cycle repeats, maximizing heat recovery and improving the overall thermal efficiency of the burner.</li> </ul>
Typical Applications	<p>Regenerative Burners are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• <b>Metal Melting Furnaces:</b> Utilized in industries where high-temperature processes are essential.</li> </ul>
Applicable Sector	<ul style="list-style-type: none"> <li>• Iron &amp; Steel</li> <li>• Steel Re-rolling Mill</li> </ul>
Advantages of the process/technology over available technologies	<p>Regenerative Burners are advantageous because they:</p> <ul style="list-style-type: none"> <li>• They are energy efficient.</li> <li>• Can be used in a variety of industrial and technical scenarios.</li> <li>• Lower emissions as utilizing waste heat results in less GHG emission.</li> <li>• Require little maintenance.</li> <li>• Don't have parts that consume electricity</li> </ul>
Product/Process Photographs	<div style="display: flex; justify-content: space-around;">   </div>

TRL Level	8-9		
Energy Saving Potential* (in %)	10-25%		
Other benefits (if any)	<p>A regenerative burner has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• Regenerative burners can achieve thermal efficiencies of 90% or higher.</li> <li>• Helps improving combustion efficiency thereby improving yield</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.016 MTOE	Medium: 0.023 MTOE	High: 0.029 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.050 MtCO <sub>2</sub>	Medium: 0.076 MtCO <sub>2</sub>	High: 0.102 MtCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~10-20 INR Cr	Medium: ~20-30 INR Cr	High: ~30-40 INR Cr
Total Investment Required* (in INR Cr)	Low: ~30-50 INR Cr	Medium: ~50-75 INR Cr	High: ~75-100 INR Cr
ROI* (in years)	2.5-3.0 Years		

### iii. Waste Heat Recovery Boilers


Particular	Details
Technology	Waste Heat Recovery Boilers
Typical Working Principle	<p>A waste heat recovery boiler is designed to capture and utilize excess thermal energy from industrial processes, converting it into useful steam or hot water for energy efficiency:</p> <ul style="list-style-type: none"> <li>• Heat Capture: Waste Heat Recovery boilers capture excess thermal energy from exhaust gases and processes.</li> <li>• Heat exchange: The captured heat is transferred to a working fluid, which is circulated through a heat exchanger within the boiler.</li> <li>• Steam Generation: As the working fluid heats up, it converts into steam.</li> </ul>
Typical Applications	<p>Waste Heat Recovery Boilers are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• Power Generation: Used in combined cycle power plants to utilize exhaust heat from gas turbines.</li> <li>• Industrial Heating: Applied in Industries where waste heat can be used for preheating, drying or other thermal processes.</li> </ul>

	<ul style="list-style-type: none"> <li>District Heat Systems: Provides Steam or hot water for heating in residential or commercial buildings.</li> </ul>		
Applicable Sector	<ul style="list-style-type: none"> <li>Iron &amp; Steel</li> <li>Cement</li> <li>Fertilizer</li> </ul>		
Advantages of the process/technology over available technologies	<p>Waste Heat Recovery Boilers are advantageous because they:</p> <ul style="list-style-type: none"> <li>Significantly reduce fuel consumption by recovering and reusing waste heat, leading to lower operational costs</li> <li>Can be used in a variety of industrial and technical scenarios.</li> <li>Enhance overall system efficiency, often resulting in a higher output of useful energy for the same input of fuel.</li> </ul>		
Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	10-25%		
Other benefits (if any)	<p>A waste heat recovery boiler has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>Overall energy efficiency of industrial operations</li> <li>Efficiently uses waste heat in the flue gas to generate power.</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.205 MTOE	Medium: 0.310 MTOE	High: 0.413 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.939 MtCO <sub>2</sub>	Medium: 1.432 MtCO <sub>2</sub>	High: 1.921 MtCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~250-300 INR Cr	Medium: ~400-450 INR Cr	High: ~500-600 INR Cr
Total Investment Required* (in INR Cr)	Low: ~900-1000 INR Cr	Medium: ~1400-1500 INR Cr	High: ~1900-2000 INR Cr

ROI* (in years)	3.0 – 3.5 Years
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#### iv. Steam Traps, Flash Steam and Condensate Recovery Systems


Particular	Details
Technology	Steam Traps, Flash Steam and Condensate Recovery Systems
Typical Working Principle	<p>A <b>steam trap</b> is a mechanical device used in steam systems to manage the flow of steam and condensate, ensuring efficient operation, and minimizing energy loss.</p> <ul style="list-style-type: none"> <li>• <b>Condensate Removal:</b> Steam traps automatically remove condensate (the liquid formed when steam cools) from the steam system while preventing the escape of steam.</li> <li>• <b>Pressure Differential:</b> The trap operates based on pressure differentials, allowing it to open and close in response to the presence of steam</li> </ul> <p><b>Flash steam</b> refers to the steam that is generated when high-pressure condensate is allowed to expand or "flash" into a lower pressure environment.</p> <ul style="list-style-type: none"> <li>• <b>Condensate Expansion:</b> When high-pressure condensate is released into a lower pressure area, it expands rapidly, converting some of the liquid into steam.</li> <li>• <b>Heat Recovery:</b> This flash steam can be captured and utilized for heating or other processes, effectively recovering energy that would otherwise be wasted.</li> </ul> <p><b>Condensate recovery systems</b> are designed to collect and reuse condensate in steam systems, enhancing energy efficiency and reducing water consumption.</p> <ul style="list-style-type: none"> <li>• <b>Condensate Collection:</b> The system captures condensate from steam processes and transfers it to a storage tank or directly back to the boiler.</li> <li>• <b>Pumping and Treatment:</b> Condensate may be pumped and treated to remove impurities before being reused in the steam system.</li> </ul>
Typical Applications	<p>Steam Traps, Flash Steam and Condensate Recovery Systems are used in a variety of applications, including:</p> <p>Steam Traps</p> <ul style="list-style-type: none"> <li>• <b>Heating Systems:</b> Used in building heating systems to remove condensate from radiators and steam heating coils.</li> <li>• <b>Power Generation:</b> Utilized in steam turbines and heat exchangers to manage condensate and improve overall efficiency.</li> </ul> <p>Flash Steam</p> <ul style="list-style-type: none"> <li>• <b>Energy Recovery Systems:</b> Used in condensate recovery systems to capture and utilize flash steam for heating or power generation.</li> <li>• <b>Industrial Heating:</b> Employed in various manufacturing processes that require steam, allowing for efficient energy use.</li> </ul> <p>Condensate Recovery Systems</p>

	<ul style="list-style-type: none"> <li>• <b>Industrial Processes:</b> Used in manufacturing plants to recover and reuse steam condensate, improving overall efficiency.</li> <li>• <b>HVAC Systems:</b> Employed in building heating and cooling systems to recover condensate from steam heating equipment.</li> </ul>		
Applicable Sector	<ul style="list-style-type: none"> <li>• Fertilizer</li> <li>• Dairy</li> <li>• Pulp and Paper</li> <li>• Textile</li> <li>• Textile Dyeing (MSME)</li> </ul>		
Advantages of the process/technology over available technologies	<p>Steam Traps, Flash Steam and Condensate Recovery Systems are advantageous because they:</p> <ul style="list-style-type: none"> <li>• Have a straightforward design.</li> <li>• Can be used in a variety of industrial and technical scenarios.</li> <li>• Are energy efficient</li> <li>• Require little maintenance.</li> </ul>		
Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	10-20%		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.07 MTOE	Medium: 0.09 MTOE	High: 0.11 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.26 MtCO <sub>2</sub>	Medium: 0.35 MtCO <sub>2</sub>	High: 0.43 M tCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~30- 40 INR Cr	Medium: ~ 40- 60 INR Cr	High: ~ 60- 80 INR Cr
Total Investment Required* (in INR Cr)	Low: ~75-100 INR Cr	Medium: ~ 100-120 INR Cr	High: ~ 120-140 INR Cr
ROI* (in years)	2- 3 years		

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#### v. Raw Material Preheater

Particular	Details
Technology	Raw Material Preheater
Typical Working Principle	<p>A material preheater is an industrial device designed to raise the temperature of raw materials before they enter a processing system, enhancing efficiency and improving the quality of the final product:</p> <ul style="list-style-type: none"> <li>• <b>Heat Exchange:</b> The preheater transfers heat from a hot medium (such as exhaust gases or steam) to the incoming raw materials through direct or indirect heat exchange methods.</li> <li>• <b>Material Flow:</b> Raw materials are conveyed through the preheater, where they are subjected to the heat transfer process, raising their temperature to the desired level.</li> <li>• <b>Controlled Environment:</b> The system can be adjusted to maintain optimal temperature and flow rates, ensuring uniform heating and efficient operation.</li> </ul>
Typical Applications	<p>Material Preheater are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• Used to preheat raw materials like limestone and clay before they enter the kiln, improving combustion efficiency and reducing energy consumption.</li> <li>• Applied in the heating of ores or scrap metal before smelting, improving melting efficiency and reducing energy costs.</li> </ul>
Applicable Sector	<ul style="list-style-type: none"> <li>• Iron &amp; Steel</li> </ul>
Benchmarks Properties & Relevant standards (if any)	-
Advantages of the process/technology over available technologies	<p>Material Preheaters are advantageous because they:</p> <ul style="list-style-type: none"> <li>• By raising material temperatures before processing, preheaters reduce the energy required for subsequent operations, leading to lower operational costs.</li> <li>• Material preheaters can be designed to accommodate various materials and processes, making them versatile solutions in multiple industries.</li> </ul>

Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	10-20%		
Other benefits (if any)	<p>A material preheater has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• Improve boiler efficiency.</li> <li>• Easy to install.</li> <li>• Low energy consumption</li> <li>• Enhance the heat transfer</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.045MTOE	Medium: 0.08 MTOE	High: 0.12 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.22 MtCO <sub>2</sub>	Medium: 0.40 MtCO <sub>2</sub>	High: 0.59 M tCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~30- 40 INR Cr	Medium: ~ 60-80 INR Cr	High: ~ 90- 110 INR Cr
Total Investment Required* (in INR Cr)	Low: ~80-100 INR Cr	Medium: ~ 125-175 INR Cr	High: ~ 200- 250 INR Cr
ROI* (in years)	2- 3 years		

vi. Co- Generation & Micro Turbine


Particular	Details
Technology	Co -Generation & Micro Turbine
Typical Working Principle	<p>Micro turbines represent a cutting-edge technology in distributed energy generation, providing an efficient and flexible solution for both electricity and heat production (Co-generation). These compact systems utilize natural gas or renewable fuels to generate power, while also recovering waste heat for various applications:</p> <ul style="list-style-type: none"> <li>• <b>Gas Compression:</b> Micro turbines compress incoming air before it enters the combustion chamber.</li> <li>• <b>Combustion:</b> The compressed air is mixed with fuel and ignited, producing high-pressure exhaust gases.</li> <li>• <b>Turbine Operation:</b> The exhaust gases expand through a turbine, generating mechanical energy that can be used for electricity or direct mechanical applications.</li> <li>• <b>Heat Recovery:</b> Waste heat from the exhaust can be recovered for cogeneration applications, improving overall efficiency.</li> </ul>
Typical Applications	<p>Micro Turbine are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• <b>Distributed Power Generation:</b> Ideal for small-scale power generation in remote areas or on-site applications.</li> <li>• <b>Combined Heat and Power (CHP):</b> Used in applications requiring both electricity and heat, such as hospitals or industrial plants.</li> </ul>
Applicable Sector	<ul style="list-style-type: none"> <li>• Iron &amp; Steel</li> <li>• Pulp &amp; Paper</li> <li>• Textile</li> <li>• Textile (Dyeing MSME)</li> <li>• Dairy (MSME)</li> </ul>
Benchmarks Properties & Relevant standards (if any)	-
Advantages of the process/technology over available technologies	<p>Micro Turbines are advantageous because they:</p> <ul style="list-style-type: none"> <li>• Ideal for small-scale power generation in remote areas or on-site applications.</li> <li>• Can be used in a variety of industrial and technical scenarios.</li> <li>• Used in applications requiring both electricity and heat, such as hospitals or industrial plants.</li> <li>• Cogeneration systems can achieve efficiencies of 70-90%, significantly reducing fuel consumption.</li> </ul>

Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	15-30%		
Other benefits (if any)	<p>A Co-Generation &amp; Micro Turbine has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• Micro turbines can achieve efficiencies of over 80% when used in cogeneration applications.</li> <li>• Small footprint makes them suitable for space-constrained applications.</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	<p>Low: 0.011 MTOE (Co-Generation)</p> <p>Low: 0.024 MTOE (Micro Turbine)</p>	<p>Medium: 0.017 MTOE (Co-Generation)</p> <p>Medium: 0.036 MTOE (Micro Turbine)</p>	<p>High: 0.021 MTOE (Co-Generation)</p> <p>High: 0.05 MTOE (Micro Turbine)</p>
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	<p>Low: 0.025 MtCO<sub>2</sub> (Co-Generation)</p> <p>Low: 0.107 MtCO<sub>2</sub> (Micro Turbine)</p>	<p>Medium: 0.04 MtCO<sub>2</sub> (Co-Generation)</p> <p>Medium: 0.160 MtCO<sub>2</sub> (Micro Turbine)</p>	<p>High: 0.05 MtCO<sub>2</sub> (Co-Generation)</p> <p>High: 0.213 MtCO<sub>2</sub> (Micro Turbine)</p>
Total Monetary Savings (in INR Cr)	<p>Low: ~10-20 INR Cr (Co-Generation)</p> <p>Low: ~30-50 INR Cr (Micro Turbine)</p>	<p>Medium: ~15-20 INR Cr (Co-Generation)</p> <p>Medium: ~50-70 INR Cr (Micro Turbine)</p>	<p>High: ~20-25 INR Cr (Co-Generation)</p> <p>High: ~75-100 INR Cr (Micro Turbine)</p>
Total Investment Required* (in INR Cr)	<p>Low: ~20-30 INR Cr (Co-Generation)</p> <p>Low: ~110-130 INR Cr (Micro Turbine)</p>	<p>Medium: ~30-40 INR Cr (Co-Generation)</p> <p>Medium: ~175-200 INR Cr (Micro Turbine)</p>	<p>High: ~40-50 INR Cr (Co-Generation)</p> <p>High: ~225-275 INR Cr (Micro Turbine)</p>
ROI* (in years)	2- 3 years		

**vii. Heat Exchanger**


Particular	Details
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Technology	Heat Exchanger
Typical Working Principle	<p>A heat exchanger is a device used to transfer heat between two or more fluids without mixing them. They are essential in various industrial processes, HVAC systems, and power generation applications, enhancing energy efficiency and temperature control:</p> <ul style="list-style-type: none"> <li>• <b>Heat Transfer Mechanism:</b> Heat exchangers operate on the principle of conduction and convection, where thermal energy is transferred from a hot fluid to a cold fluid through a separating wall or surface.</li> <li>• <b>Flow Arrangement:</b> Fluids can flow in different configurations, including counterflow (opposite directions), parallel flow (same direction), or crossflow (perpendicular), depending on the design and application.</li> <li>• <b>Surface Area:</b> The efficiency of a heat exchanger is influenced by its surface area, with larger areas facilitating greater heat transfer between fluids.</li> </ul>
Typical Applications	<p>Heat Exchanger are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• <b>HVAC Systems:</b> Used for heating and cooling air or water in buildings, improving indoor climate control and energy efficiency.</li> <li>• <b>Industrial processes:</b> Heat exchanger in Recuperators and regenerators are used in the exhaust gases of industrial processes to recover waste heat.</li> <li>• <b>Power Generation:</b> Employed in steam power plants to transfer heat from combustion gases to water, generating steam for turbines.</li> </ul>
Applicable Sector	<ul style="list-style-type: none"> <li>• Textile</li> <li>• Textile Dyeing MSME</li> </ul>
Benchmarks Properties & Relevant standards (if any)	-
Advantages of the process/technology over available technologies	<p>Heat Exchangers are advantageous because they:</p> <ul style="list-style-type: none"> <li>• By recovering and reusing heat, heat exchangers significantly reduce energy consumption and operational costs.</li> <li>• Can be used in a variety of industrial and technical scenarios.</li> <li>• Many heat exchangers are designed to be compact, saving space in facilities while maintaining high thermal performance.</li> </ul>

Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	10-25%		
Other benefits (if any)	<p>A heat exchanger has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• They enable better temperature regulation in industrial processes, enhancing product quality and consistency.</li> <li>• Heat exchangers can be tailored to various applications and fluids, making them adaptable to a wide range of industries and processes.</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.02 MTOE	Medium: 0.025 MTOE	High: 0.03 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.08 MtCO <sub>2</sub>	Medium: 0.11 MtCO <sub>2</sub>	High: 0.16 M tCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~20- 40 INR Cr	Medium: ~ 40-60 INR Cr	High: ~ 60- 80 INR Cr
Total Investment Required* (in INR Cr)	Low: ~50-70 INR Cr	Medium: ~ 80-100 INR Cr	High: ~ 120- 150 INR Cr
ROI* (in years)	2- 3 years		

### viii. Thermo Compressors


Particular	Details
Technology	Thermo Compressors

<p>Typical Working Principle</p>	<p>A thermo compressor is a device that uses thermal energy to compress and transfer vapor, primarily in refrigeration and air conditioning systems. They enhance efficiency by recycling waste heat and are commonly used in industrial processes where heat recovery is essential:</p> <ul style="list-style-type: none"> <li>• <b>Heat Input:</b> The thermo compressor utilizes a heat source (such as steam or hot water) to vaporize a working fluid, often refrigerant.</li> <li>• <b>Vapor Compression:</b> The vapor produced is then compressed using the thermal energy provided, increasing its pressure and temperature.</li> <li>• <b>Heat Exchange:</b> The high-pressure vapor is directed to a heat exchanger where it can transfer heat to a cooling medium or process fluid.</li> </ul>
<p>Typical Applications</p>	<p>Thermo Compressors are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• Used in industrial refrigeration systems to enhance cooling efficiency by reusing waste heat from other processes.</li> <li>• Integrated into district heating systems to enhance the efficiency of heat distribution through recycling waste heat. Applied in industries such as food processing and chemical manufacturing to provide heating while reducing energy costs.</li> </ul>
<p>Applicable Sector</p>	<ul style="list-style-type: none"> <li>• Pulp and Paper</li> </ul>
<p>Benchmarks Properties &amp; Relevant standards (if any)</p>	<p>-</p>
<p>Advantages of the process/technology over available technologies</p>	<p>Thermo Compressors are advantageous because they:</p> <ul style="list-style-type: none"> <li>• Thermo compressors significantly reduce energy consumption by reusing waste heat, leading to lower operational costs.</li> <li>• By increasing the pressure and temperature of the vapor, they improve the overall efficiency of refrigeration and heating systems.</li> </ul>
<p>Product/Process Photographs</p>	
<p>TRL Level</p>	<p>8-9</p>
<p>Energy Saving Potential* (in %)</p>	<p>10-25%</p>

Other benefits (if any)	<p>A Thermo Compressor has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>Utilizing waste heat reduces reliance on conventional energy sources, leading to lower greenhouse gas emissions.</li> <li>They can be adapted to various industrial applications, making them versatile solutions for enhancing energy efficiency.</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.013 MTOE	Medium: 0.02 MTOE	High: 0.03 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.06 MtCO <sub>2</sub>	Medium: 0.09 MtCO <sub>2</sub>	High: 0.13 M tCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~20- 30 INR Cr	Medium: ~ 30-50 INR Cr	High: ~ 40- 60 INR Cr
Total Investment Required* (in INR Cr)	Low: ~40-60 INR Cr	Medium: ~ 70-80 INR Cr	High: ~ 90- 120 INR Cr
ROI* (in years)	2-2.5 Years		

#### ix. Heat Pumps


Particular	Details
Technology	Heat Pumps
Typical Working Principle	<p>A heat pump is a versatile device that transfers thermal energy from one location to another, providing heating, cooling, and hot water for residential and industrial applications. By using a small amount of energy, heat pumps can move large amounts of heat:</p> <ul style="list-style-type: none"> <li><b>Heat Absorption:</b> The heat pump absorbs heat from a low-temperature source (such as air, water, or ground) using a refrigerant that evaporates at low temperatures.</li> <li><b>Compression:</b> The vaporized refrigerant is then compressed by a compressor, increasing its pressure and temperature.</li> <li><b>Heat Release:</b> The high-temperature refrigerant passes through a heat exchanger (condenser), where it releases heat to the target space (indoor area or hot water tank) while condensing back into a liquid.</li> </ul>
Typical Applications	<p>Heat Pumps are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>Used in homes to provide efficient heating in winter and cooling in summer, often as part of HVAC systems.</li> <li>Utilized in industrial applications for process heating, drying, and other temperature-sensitive operations.</li> </ul>

Applicable Sector	<ul style="list-style-type: none"> <li>• Textile</li> <li>• Ceramic (MSME)</li> <li>• Dairy (MSME)</li> <li>• Pulp and Paper</li> </ul>		
Benchmarks Properties & Relevant standards (if any)	IS 12392 (for Design, Manufacture and Testing of Metallic Recuperators)		
Advantages of the process/technology over available technologies	<p>Heat Pumps are advantageous because they:</p> <ul style="list-style-type: none"> <li>• Capable of both heating and cooling, heat pumps serve multiple functions, making them a cost-effective solution for year-round temperature control.</li> <li>• While the initial installation may be higher than traditional systems, the lower operational costs over time lead to savings on energy bills.</li> </ul>		
Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	10-25%		
Other benefits (if any)	<p>A heat pump has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• An efficient alternative to ACs</li> <li>• Are energy efficient.</li> <li>• Require little maintenance.</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.016 MTOE	Medium: 0.023 MTOE	High: 0.031 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.08 MtCO <sub>2</sub>	Medium: 0.11 MtCO <sub>2</sub>	High: 0.15 M tCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~20- 40 INR Cr	Medium: ~ 40-50 INR Cr	High: ~ 50- 60 INR Cr

Total Investment Required* (in INR Cr)	Low: ~60-80 INR Cr	Medium: ~ 90-110 INR Cr	High: ~ 130- 140 INR Cr
ROI* (in years)	2.5-3 years		


#### x. Vapor Absorption Machine (VAM)

Particular	Details
Technology	Vapor Absorption Machine (VAM)
Typical Working Principle	<p>A vapor absorption machine (VAM) is an energy-efficient system used for cooling or heating, relying on a refrigerant and an absorbent to transfer heat. VAMs are commonly utilized in air conditioning and refrigeration applications, especially in industrial settings where waste heat is available:</p> <ul style="list-style-type: none"> <li>• <b>Absorption:</b> The vapor absorption process begins with a refrigerant (often ammonia or water) evaporating in the evaporator, absorbing heat from the environment and providing cooling.</li> <li>• <b>Absorbent Interaction:</b> The vaporized refrigerant is absorbed by a liquid absorbent (such as lithium bromide), forming a solution that captures the refrigerant vapor.</li> <li>• <b>Heat Addition:</b> The solution is then heated in a generator, causing the refrigerant to vaporize again and separate from the absorbent, which is returned to the absorber.</li> </ul>
Typical Applications	<p>VAMs are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• Used in large-scale air conditioning systems, particularly where waste heat is available from industrial processes or power plants.</li> <li>• Employed in chilling applications for food processing, chemical manufacturing, and other industries that require precise temperature control.</li> <li>• Utilized in systems designed to recover waste heat from processes, improving overall energy efficiency.</li> </ul>
Applicable Sector	<ul style="list-style-type: none"> <li>• Iron &amp; Steel</li> <li>• Fertilizer</li> <li>• Cement</li> </ul>
Benchmarks Properties & Relevant standards (if any)	-
Advantages of the process/technology over available technologies	<p>VAMs are advantageous because they:</p> <ul style="list-style-type: none"> <li>• VAMs can utilize low-grade waste heat or solar energy, significantly reducing the consumption of electricity or fossil fuels for cooling.</li> <li>• By leveraging waste heat, operational costs are often lower compared to conventional electric chillers.</li> <li>• VAMs minimize greenhouse gas emissions by using renewable energy sources and reducing reliance on traditional cooling methods.</li> </ul>

Product/Process Photographs			
TRL Level	8-9		
Energy Saving Potential* (in %)	10-25%		
Other benefits (if any)	<p>A VAM has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• Works with any thermal source</li> <li>• Lesser moving parts resulting in quiet operation</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.04 MTOE	Medium: 0.06 MTOE	High: 0.07 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.14 MtCO <sub>2</sub>	Medium: 0.19 MtCO <sub>2</sub>	High: 0.23M tCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~30- 40 INR Cr	Medium: ~ 40-60 INR Cr	High: ~ 60- 70 INR Cr
Total Investment Required* (in INR Cr)	Low: ~80-100 INR Cr	Medium: ~ 130-150 INR Cr	High: ~ 180- 200 INR Cr
ROI* (in years)	2.5-3.0 years		

#### xi. Economizer

Particular	Details
Technology	Economizer
Typical Working Principle	An economizer is a heat recovery device designed to improve the energy efficiency of heating systems, particularly in boilers and industrial processes. It captures waste heat from flue gases and utilizes it to preheat incoming water or air:

	<ul style="list-style-type: none"> <li>• Heat Recovery: The economizer captures heat from the flue gases produced during combustion in a boiler or furnace.</li> <li>• Heat Exchange: This waste heat is transferred to a secondary fluid (usually water) that is being fed into the boiler, raising its temperature before it enters the combustion chamber.</li> <li>• Increased Efficiency: By preheating the water, the economizer reduces the amount of fuel needed to reach the desired temperature, enhancing overall system efficiency.</li> </ul>
Typical Applications	<p>Economizer are used in a variety of applications, including:</p> <ul style="list-style-type: none"> <li>• Boiler Systems: Commonly used in industrial boilers to recover heat and improve thermal efficiency, leading to lower fuel consumption.</li> <li>• HVAC Systems: Employed in heating, ventilation, and air conditioning systems to preheat air or water, improving energy efficiency.</li> <li>• Power Plants: Used in power generation facilities to recover heat from exhaust gases, increasing the overall efficiency of the plant.</li> </ul>
Applicable Sector	<ul style="list-style-type: none"> <li>• Dairy</li> <li>• Textile</li> <li>• Textile Dyeing MSME</li> <li>• Paper and Pulp</li> </ul>
Benchmarks Properties & Relevant standards (if any)	-
Advantages of the process/technology over available technologies	<p>Economizers are advantageous because they:</p> <ul style="list-style-type: none"> <li>• Economizers can significantly reduce fuel consumption, leading to lower operating costs and increased energy efficiency.</li> <li>• Can be used in a variety of industrial and technical scenarios.</li> <li>• The initial cost of installing an economizer is often offset by the long-term savings on fuel and energy costs.</li> </ul>
Product/Process Photographs	
TRL Level	8-9
Energy Saving Potential* (in %)	10-25%

Other benefits (if any)	<p>An economizer has the following additional benefits apart from reduction in fuel consumption:</p> <ul style="list-style-type: none"> <li>• Increases efficiency of the boiler</li> <li>• Reduces heat losses due to flue gas emissions.</li> <li>• By optimizing operating temperatures, economizers can help prolong the lifespan of boilers and other heating equipment by reducing thermal stress.</li> </ul>		
Estimated Energy Savings* (cumulative for 5 years), in Million TOE	Low: 0.05 MTOE	Medium: 0.07 MTOE	High: 0.09 MTOE
Estimated GHG Emission Reduction* (cumulative for 5 years), in Million tCO <sub>2</sub>	Low: 0.25 MtCO <sub>2</sub>	Medium: 0.33 MtCO <sub>2</sub>	High: 0.4 M tCO <sub>2</sub>
Total Monetary Savings (in INR Cr)	Low: ~50- 70 INR Cr	Medium: ~ 70-90 INR Cr	High: ~ 90- 110 INR Cr
Total Investment Required* (in INR Cr)	Low: ~120-140 INR Cr	Medium: ~ 160-180 INR Cr	High: ~ 200- 220 INR Cr
ROI* (in years)	2.0-2.5 years		

## 4.4 Indian Waste Heat Recovery Market Composition

The composition of the Indian waste heat recovery (WHR) market involves a variety of key stakeholders, including government agencies, policy makers, donor organizations, financial institutions, and industry participants. Each of these groups plays a crucial role in facilitating the growth and implementation of WHR technologies. Understanding their interactions and contributions is essential for developing effective strategies to enhance energy efficiency initiatives and overcome existing challenges in the market. This section will explore the roles of these stakeholders and assess the current policy framework, providing recommendations for future improvements.

### 4.4.1 Key Stakeholders

The successful implementation of Waste Heat Recovery Systems (WHRS) depends on the collaborative efforts of a diverse group of stakeholders within the industrial landscape. At the forefront are the industries and associations, who stand to gain the most from WHRS through reduced energy consumption, cost savings and an enhanced environmental footprint. Governments play a crucial role by providing financial incentives, regulations, and promoting WHRS adoption through industry awareness campaigns. Technology providers, OEMs, vendors are instrumental in developing innovative, cost-effective WHRS solutions tailored to specific industrial needs. Think tanks also play a vital role by equipping the workforce with the necessary skills for WHRS design, operation, and maintenance. We have identified key stakeholders which are industry specific and will be beneficial for the upscaling of the WHRS market. Below is the depiction of the key players:

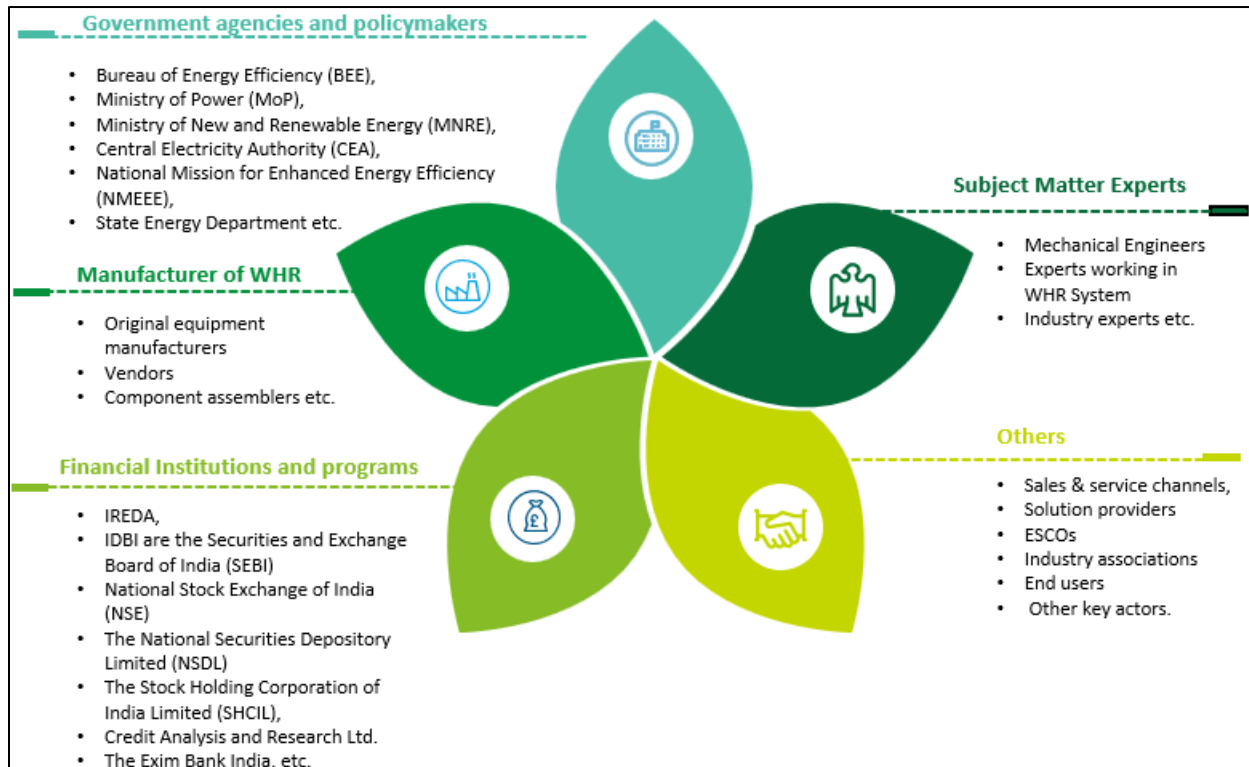
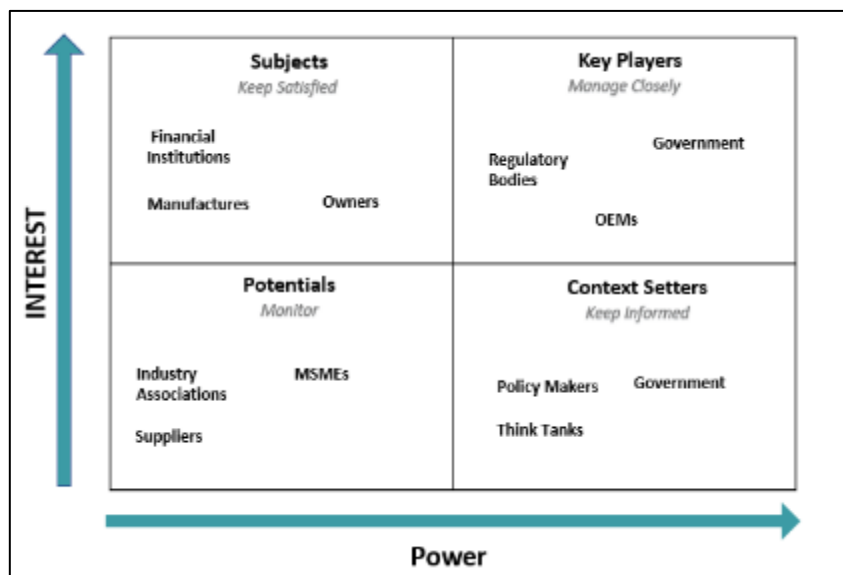


Figure 12: Mapping of Key Stakeholders



**Figure 13: Power Matrix for Key Stakeholders**

#### 4.4.2 Government Agencies and Policy Makers

The Indian government has taken significant strides in promoting energy efficiency and sustainable development. To facilitate the growth of the waste heat recovery (WHR) market, several government agencies and policymakers have been instrumental in shaping the regulatory and policy landscape. The Bureau of Energy Efficiency (BEE) serves as the nodal agency for enhancing energy efficiency across various sectors in India. BEE has undertaken several initiatives to promote WHR technologies, including providing financial incentives, technical assistance, and capacity building programs. Additionally, the Ministry of New and Renewable Energy (MNRE) has played a crucial role in supporting the integration of WHR with renewable energy sources, creating a synergistic approach to energy generation.

Furthermore, state-level pollution control boards and electricity regulatory commissions have been actively involved in promoting WHR adoption through policies and regulations. These agencies have implemented measures to encourage industries to adopt energy-efficient practices, including WHR, to reduce emissions and improve overall environmental performance. While the Indian government has made substantial progress in fostering a conducive environment for WHR, further policy refinements and financial incentives are necessary to accelerate the widespread adoption of these technologies. -

Sector	Key Ministries	Key Agencies	Key Policies and Initiatives	Key Associations
Cement	Ministry of Power, Ministry of Environment, Forest and Climate Change	Bureau of Energy Efficiency (BEE), Central Pollution Control Board (CPCB)	Perform, Achieve and Trade (PAT) scheme, Energy Conservation Building Code (ECBC), National Mission for	Cement Manufacturers Association of India (CMA)

			Enhanced Energy Efficiency (NMEEE)	
Iron & Steel	Ministry of Steel, Ministry of Power	BEE, CPCB, Ministry of Environment, Forest and Climate Change	PAT scheme, Steel Industry Energy Efficiency Roadmap, National Clean Air Programme (NCAP)	Indian Iron and Steel Association (IISA)
Textile	Ministry of Textiles, Ministry of Power	BEE, Ministry of Environment, Forest and Climate Change	Perform, Achieve and Trade (PAT) scheme, Technology Upgradation Fund Scheme (TUFS), National Textile Policy, Energy Conservation Building Code (ECBC)	The Cotton Textiles Export Promotion Council (TEXPROCIL), The Synthetic and Rayon Textiles Export Promotion Council (SRTEPC)
Aluminum	Ministry of Mines, Ministry of Power	BEE, CPCB, Ministry of Environment, Forest and Climate Change	PAT scheme, National Aluminum Policy, Energy Conservation Building Code (ECBC)	Aluminum Association of India (AAI)
Fertilizer	Ministry of Chemicals and Fertilizers, Ministry of Power	BEE, CPCB, Department of Fertilizers	Perform, Achieve and Trade (PAT) scheme, National Fertilizer Policy,	Fertilizer Association of India (FAI)
Pulp & Paper	Ministry of Environment, Forest and Climate Change, Ministry of Power	BEE, CPCB	Perform, Achieve and Trade (PAT) scheme, Energy Conservation Building Code (ECBC)	Indian Paper Manufacturers Association (IPMA)

**Table 8: Key stakeholders for WHRS in India**

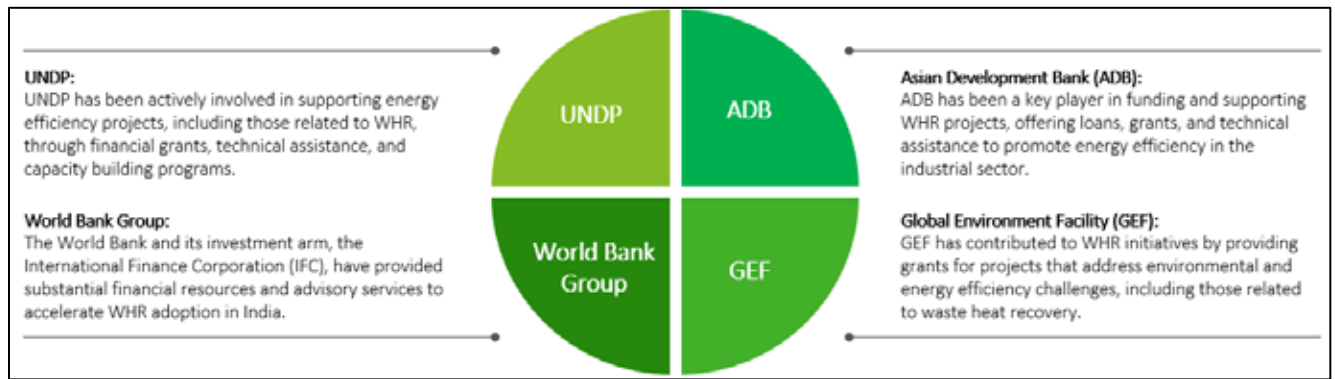
### 4.4.3 Donor Agencies and Financial Institutions Catalyzing WHR

#### Adoption

The adoption of waste heat recovery (WHR) technologies across diverse sectors, including cement, steel, textiles, aluminum, fertilizers, pulp and paper, and MSMEs, has been significantly influenced by the support of various donor agencies and financial institutions. These organizations have played a pivotal role in advancing WHR initiatives through financial assistance, technical expertise, and policy advocacy.

#### Key Development Partners

Several international and domestic organizations have been instrumental in promoting WHR in India:



**Figure 14: Key Development Partners**

## Domestic Financial Institutions

Indian financial institutions have also played a crucial role in supporting WHR projects:



**Figure 15: Domestic Financial Institutions**

## Government Policy and Regulatory Support

The Government of India, through the Ministry of Power and other relevant agencies, has implemented various policies and initiatives to promote energy efficiency and WHR adoption. The Perform, Achieve, and Trade (PAT) scheme, for instance, has encouraged industries to improve energy efficiency, including through the adoption of WHR technologies.

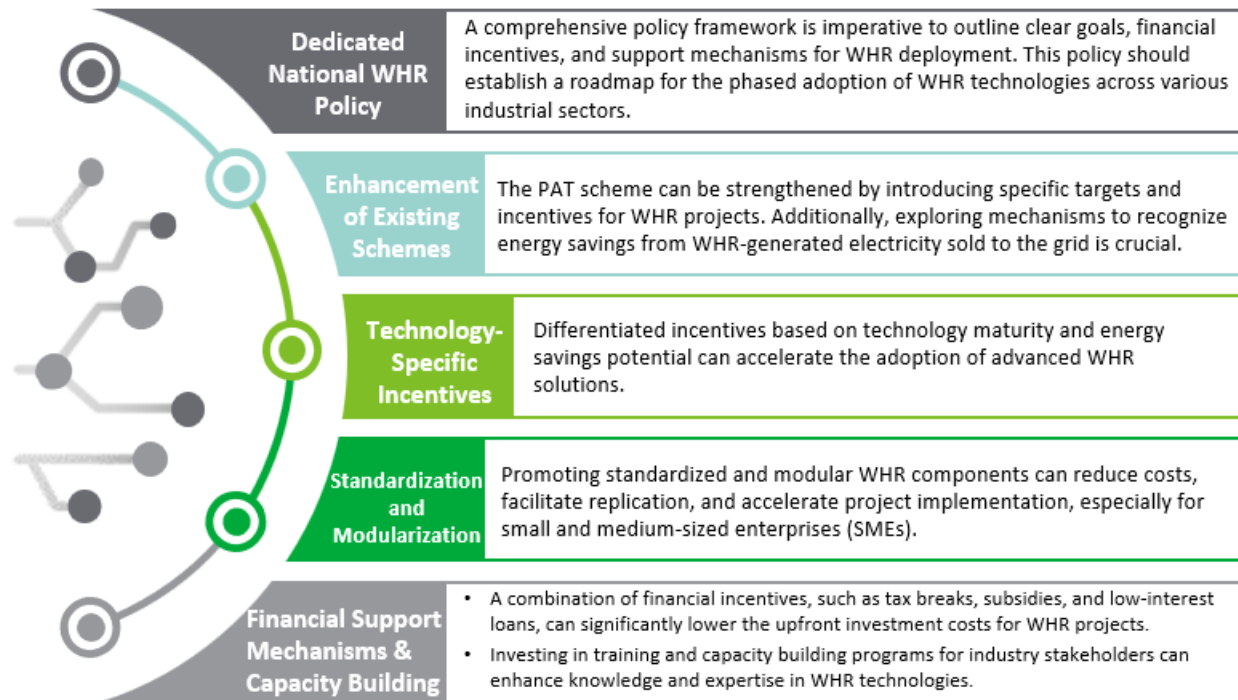
The combined efforts of these donor agencies, financial institutions, and government bodies have been instrumental in creating a conducive environment for WHR adoption in India. However, further policy refinements and financial incentives are necessary to accelerate the widespread implementation of WHR technologies across different sectors.

#### 4.4.4 Existing Policy Assessments and Recommendations

The widespread adoption of Waste Heat Recovery Systems (WHRS) hinges on a supportive policy environment that incentivizes investment, addresses regulatory challenges, and fosters innovation. While India has made strides in promoting energy efficiency, a comprehensive and targeted policy framework for WHR is still evolving.

The Perform, Achieve and Trade (PAT) scheme, while impactful in driving overall energy efficiency, does not explicitly incentivize WHR technologies. The scheme's focus on energy savings within organizational boundaries limits its applicability to WHR projects that generate electricity for captive consumption. This constraint hampers the adoption of WHR systems that produce electricity for sale to the grid.

To fully unlock the potential of WHR, the following policy recommendations are proposed:



**Figure 16: Policy Recommendations**

By implementing these policy measures, India can create a favorable environment for WHR adoption, leading to substantial energy savings, reduced emissions, and enhanced industrial competitiveness.





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- 15) [Enhancing Energy Efficiency through Industry Partnership \(PAT- MoP, BEE\)](#)

## Annexure

### a. Manufacturers & OEMs

S.No	Name of the vendor	Contact Person	Phone No	Email ID
1	Refined Structures & Heat Control Unit	Mr. V. K. Sharma	9829060615	<a href="mailto:refinefurnace@gmail.com">refinefurnace@gmail.com</a>
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9	Turbo Tech Precision Engineering Pvt Ltd	Mr. Dinesh Kumar	9545350044	<a href="mailto:dineshkumar@turbotechindia.com">dineshkumar@turbotechindia.com</a>
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11	Econotherm	Mr. Chander Kamra	9819536221	<a href="mailto:kamracp@gmail.com">kamracp@gmail.com</a>
12	Triveni Turbines	Mr. Apurva Bose	8147623794	<a href="mailto:apurva.bose@triveniturbines.com">apurva.bose@triveniturbines.com</a>
13	Hindware	Mr. Rajeev Gupta	9711303889	<a href="mailto:rajeev.gupta@hindware.com">rajeev.gupta@hindware.com</a>
14	Enviropol	Mr. Rajesh Verma	9818393844	<a href="mailto:ceo@enviropolengineers.in">ceo@enviropolengineers.in</a>

## b. Abbreviations

Abbreviations	Full form
ASME	American Society of Mechanical Engineers
BAT	Best Available Technologies
BEE	Bureau of Energy Efficiency
BF	By-product Fuel
BFG	Blast Furnace Gas
BIS	Bureau of Indian Standards
BOF	Basic oxygen furnace
CAGR	Compound Annual Growth Rate
CEN	European Committee for Standardization
CFM	Cubic feet per minute
CHP	Combined Heat and Power
CMA	Cement Manufacturer's Association
DTEC	Direct Thermal Energy Conversion
DOE	Department of Energy
EAF	Electric arc furnace
EESL	Energy Efficiency Services Limited
EIA	Energy Information Administration
EN	European Norms/ European Standards
EPA	Environmental Protection Agency
ETP	Energy Technology Perspectives
GoI	Government of India
HRSG	Heat recovery steam generator
HVAC	Heating, ventilation, and air-conditioning
IEA	International Energy Agency
IIEC	International Institute for Energy and Conservation
ISO	International Organizations for Standardization
ISSSC	Indian Iron and Steel Sector Skills Council
LGWHRS	Low Grade Heat Recovery System
MECS	Manufacturing Energy Consumption Survey
MoP	Ministry of Power
MSME	Micro, Small and Medium Enterprises
NBFC	Non-Banking Financial Institutions
NCCBM	National Council on Cement and Building Materials
NMEEE	National Mission for Enhanced Energy Efficiency
ORC	Organic Rankine cycle
PAT	Perform Achieve Trade
PSU	Public Sector Undertaking
PV	Photovoltaic
RC	Rankine cycle
SEC	Specific Energy Consumption
SME	Small Medium Enterprise
SPV	Special Purpose Vehicle
SRC	Steam Rankine cycle
rpm	Revolutions per minute
R/R	Regenerative & recuperative
scf	Standard cubic foot

TEG	Thermoelectric generators
TOE	Tonne of oil equivalent
TPH	Tonnage per hour
TRL	Technology Readiness Levels
UTPRERAK	Unnat Takniki Pradarshan Kendra
WHP	Waste heat to power
WHR	Waste Heat Recovery
WHRS	Waste Heat Recovery Systems

## c. Glossary

Air to fuel ratio	In a combustion process, the ratio of the air supply flow rate to the fuel supply flow rate when measured under the same conditions.
Absorption chiller	A type of air-cooling device that uses absorption cooling to cool interior spaces.
Available heat	The gross quantity of heat released within a combustion chamber minus both the dry flue gas loss and the moisture loss. It represents the quantity of heat remaining for useful purposes (and to balance losses to walls, openings, and conveyors).
Burner Capacity	The maximum heat output (in Btu per hour) released by a burner with a stable flame and satisfactory combustion.
By-product fuel	Materials having calorific value, which are generated as a by-product in manufacturing and production processes. For example – black liquor, wood chips, bio-gas, etc.
Cleanliness of exhaust gases	The quality of exhaust gases from industrial heating processes. It depends on many factors related to the operation and design of heating equipment. For example, the presence of highly corrosive fluxing agents (e.g., chlorides, fluorides, etc.), particulates (e.g., metal oxides, carbon or soot particles, fluxing materials, slag, aluminum oxide, magnesium oxide, manganese), and combustibles (e.g., CO, H <sub>2</sub> , hydrocarbons) affect the cleanliness of exhaust gases.
Combustion air	All of the air supplied through a burner other than that used for atomization.
Electrolysis	A chemical change in a substance that results from the passage of an electric current through an electrolyte
Flue gas	All gases—combustion gases, products of combustion (e.g. water vapor), excess oxygen, nitrogen, etc.—that leave a furnace, recuperator, or regenerator, by way of the flue.
Heat source	A medium or process from which heat may be extracted. For heat transfer to occur between a source and recipient, the source must always be at a temperature higher than the recipient.
Heat waste	Energy in the form of heat rejected or lost from a process, which may be recovered or reused in another process providing it is of sufficient quality (i.e., hot enough and there is a use for it).
Latent heat	Heat absorbed or given off by a substance without changing its temperature, as when melting, solidifying, evaporating, condensing, or changing crystalline structure.
Lower heating value (l <sub>h</sub> v)	The gross heating value minus the latent heat of vaporization of the water vapor formed by the combustion of hydrogen in the fuel.
Phase change	The process of changing from one physical state (solid, liquid, or gas) to another, with a necessary or coincidental input or release of energy.
Rankine cycle	An idealized thermodynamic cycle that converts sensible heat into mechanical work. The Rankine cycle that is an ideal standard for comparing performance of heat-engines, steam power plants, steam turbines, and heat pump systems that use a condensable vapor as the working fluid; efficiency is measured as work done divided by sensible heat supplied.
Recuperator	Equipment that uses hot flue gases to preheat air for combustion. The flue gases and airflow are in adjacent passageways so that heat is transferred from the hot gases, through the separating wall, to the cold air.
Regenerator	A cyclic heat interchanger, which alternately receives heat from gaseous combustion products and then transfers heat to air before combustion.
Reverberatory furnace	A reverberatory furnace is a metallurgical or process furnace that isolates the material being processed from contact with the fuel, but not from contact with combustion gases.





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