Market Outlook

Waste Heat to Power:

Global Market Outlook

March 2023

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Table of Contents

Chapter 1: Market Outlook 1
Market Snapshot 1
Chapter 2: Executive Summary 4
Chapter 3: Market Overview 10
Industry Landscape 10
Market Dynamics 11
Market Drivers 11
Market Restraints 14
Pricing Analysis 16
Macroeconomic Factors of Waste Heat Recovery Market 17
Impact of the COVID-19 Pandemic 17
Impact of the Russia-Ukraine War 18
Patent Analysis 19
Chapter 4: Emerging Technologies/Market Opportunities 22
Technology Background 22
Opportunities in Waste Heat Recovery Industry 24
Waste Heat Recovery Technologies 24
Heat Exchangers 24
Load Preheating 25
Power Generation 25
Direct Electrical Conversion Devices 28
Echogen Heat Engine Technology 29
Case Studies 31
Chapter 5: Thermal and Biological Waste-to-Energy Management 33
Thermal Waste-to-Energy 33
Biological Waste-to-Energy 35
Anaerobic Digestion 35
Bio-Hydrogen 35
Mechanical Biological Treatment 35
Physical Waste-to-Energy 36
Chapter 6: Market Breakdown by Application and End-Use 38
Global Market for Waste Heat Recovery Systems, by Application 38
Global Market for Waste Heat Recovery Systems, by End-Use 40
Chapter 7: Market Breakdown by Region 43
Global Market for Waste Heat Recovery Systems, by Region 43
North America 45
Europe 47
Asia-Pacific 48
Rest of the World 50

Chapter 8: Competitive Landscape 53
Company Market Share Analysis for Waste Heat Recovery Systems 53
Recent Key Developments 55
Chapter 9: Company Profiles 57
Chapter 10: Project Scope and Methodology 81
Overview 81
Scope of Report 81
Study Goals and Objectives 81
Methodology 82
Geographic Breakdown 83
Analyst's Credentials 87
Related BCC Research Reports 87
About BCC Research 88
About BCC Research 89
BCC Custom Research 89
BCC Membership 89

Additional segmentations and data sets available upon request. Email custom@bccresearch.com.

List of Tables

Summary Table: Global Market for Waste Heat Recovery Systems, by Region, Through 2027 ($ Millions) 7
Table 1 Technology Cost Comparison for Power Generation, 2021 ($/kWh) 16
Table 2 Waste Heat to Power Costs, 2021 ($/kWh) 16
Table 3 Waste Heat Recovery Systems Patents, 2017–2022 19
Table 4 Examples of Waste Heat Sources and End-Uses 23
Table 5 Comparison of Power Generating Cycles for Waste Heat Recovery 30
Table 6 Project Snapshot 31
Table 7 Global Market for Waste Heat Recovery Systems, by Application, Through 2027 ($ Millions) 39
Table 8 Global Market for Waste Heat Recovery Systems, by End-Use, Through 2027 ($ Millions) 41
Table 9 Global Market for Waste Heat Recovery Systems, by Region, Through 2027 ($ Millions) 44
Table 10 North American Market for Waste Heat Recovery Systems, by Application, Through 2027 ($ Millions) 46
Table 11 North American Market for Waste Heat Recovery Systems, by End-Use, Through 2027 ($ Millions) 47
Table 12 European Market for Waste Heat Recovery Systems, by Application, Through 2027 ($ Millions) 48
Table 13 European Market for Waste Heat Recovery Systems, by End-Use, Through 2027 ($ Millions) 48
Table 14 Asia-Pacific Market for Waste Heat Recovery Systems, by Application, Through 2027 ($ Millions) 49
Table 15 Asia-Pacific Market for Waste Heat Recovery Systems, by End-Use, Through 2027 ($ Millions) 50
Table 16 Rest of the World Market for Waste Heat Recovery Systems, by Application, Through 2027 ($ Millions) 51
Table 17 Rest of the World Market for Waste Heat Recovery Systems, by End-Use, Through 2027 ($ Millions) 51
Table 18 Global Waste Heat Recovery Systems Market Shares, by Leading Suppliers, 2021 (%) 53
Table 19 Global Waste Heat Recovery Systems Market, Recent Key Developments, 2017–2022 55
Table 20 ABB Ltd.: Company Financial Highlights, 2019–2021 ($ Millions) 58
Table 21 Climeon AB: Company Financial Highlights, 2019–2021 ($ Millions) 61
Table 22 Dürr Aktiengesellschaft.: Company Financial Highlights, 2019–2021 ($ Millions) 62
Table 23 Enertime SA: Company Financial Highlights, 2019–2021 ($ Millions) 64
Table 24 General Electric Co.: Company Financial Highlights, 2019–2021 ($ Millions) 66
Table 25 IHI Corp.: Company Financial Highlights, 2020–2022 ($ Millions) 68
Table 26 John Wood Group Plc: Company Financial Highlights, 2019–2021 ($ Millions) 70
Table 27 Mitsubishi Heavy Industries, Ltd.: Company Financial Highlights, 2020–2022 ($ Millions) 72
Table 28 Ormat Technologies, Inc.: Company Financial Highlights, 2019–2021 ($ Millions) 74
Table 29 Siemens AG: Company Financial Highlights, 2019–2021 ($ Millions) 76
Table 30 Thermax Ltd.: Company Financial Highlights, 2020–2022 ($ Millions) 78

List of Figures

Figure A Waste Heat Recovery Components 4
Figure B Waste Heat Recovery Cycle 6
Summary Figure: Global Market Shares of Waste Heat Recovery Systems, by Region, 2021 (%) 8
Figure 1 Global Waste Heat Recovery Market Trends, 2021–2027 ($ Millions)........ 10
Figure 2 Waste Heat Recovery With Rankine Cycle........ 26
Figure 3 Process Flow of Organic Rankine Cycle System 27
Figure 4 Kalina Cycle Heat Engine........ 28
Figure 5 Echogen Supercritical CO_2 Cycle........ 29
Figure 6 Global Market Shares of Waste Heat Recovery Systems, by Application, 2021 (%) 39
Figure 7 Global Market Shares of Waste Heat Recovery Systems, by End-Use, 2021 (%) 41
Figure 8 Global Market for Waste Heat Recovery Systems, by Region 43
Figure 9 Global Market Shares of Waste Heat Recovery Systems, by Region, 2021 (%)........ 44
Figure 10 Global Market Shares of Waste Heat Recovery Systems, by Region, 2027 (%)........ 45
Figure 11 ABB Ltd.: Revenue Share, by Business Segment, 2021 (%)........ 58
Figure 12 Dürr Aktiengesellschaft.: Revenue Share, by Business Segment, 2021 (%)........ 62
Figure 13 General Electric Co.: Revenue Share, by Business Segment, 2021 (%)........ 67
Figure 14 IHI Corp.: Revenue Share, by Business Segment, 2021 (%) 68
Figure 15 John Wood Group Plc: Revenue Share, by Business Segment, 2021 (%) 70
Figure 16 Mitsubishi Heavy Industries Ltd.: Revenue Share, by Business Segment, 2022 (%)........ 72
Figure 17 Ormat Technologies, Inc.: Revenue Share, by Business Segment, 2021 (%) 74
Figure 18 Siemens AG: Revenue Share, by Business Segment, 2021 (%) 77
Figure 19 Thermax Ltd.: Revenue Share, by Business Segment, 2021 (%) 79
Figure 20 Research Methodology Applied in the Analysis of the Global Market for Waste Heat Recovery Systems 83

Chapter 1

Market Outlook

Chapter 1: Market Outlook

Market Snapshot

Market Size

Overall, the global waste heat recovery system market stood at $57.7 billion in 2021 and should reach $89.0 billion by 2027.

CAGR

The waste heat recovery system market is expected to witness a compound annual growth rate (CAGR) of 8.0% from 2022 to 2027.

Regional Segment

Asia-Pacific contributes to 36.0% of the global market in terms of value, followed by Europe and North America.

Market Drivers

- Increasing Need for Energy Security.
- Carbon Footprint Reduction.
- Rising Industrial Processing.
- Emergence of APAC as a Major Hub for Waste Heat Recovery Systems.

Top Vendors

- Mitsubishi Heavy Industries, Ltd.
- Siemens AG.
- IHI Corp.
- ABB Ltd.
- General Electric Co.

Market Challenges

- Technical Barriers.
- Business Barriers.
- Inaccessibility/Transportability.
- High Cost.

Chapter 2

Executive Summary

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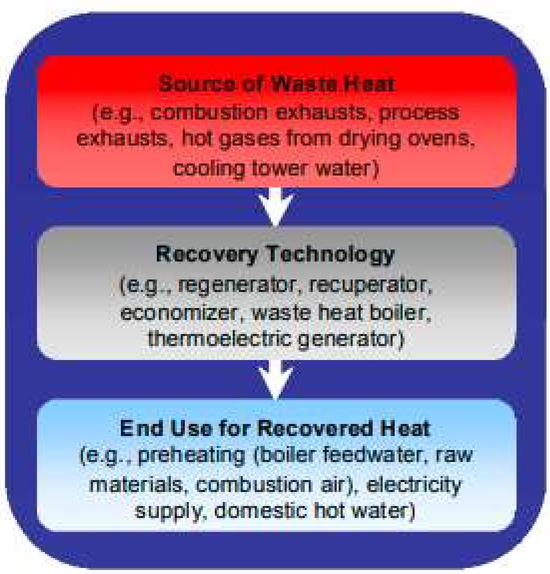
Chapter 2: Executive Summary

Waste heat recovery is the process of capturing heat discarded by an existing thermal process and using that heat to generate power. Heat recovery technologies frequently reduce the operating costs for facilities by increasing their energy productivity. Energy intensive processes such as those occurring at refineries, steel mills, glass furnaces, and cement kilns all release hot exhaust gases and waste streams that can be harnessed with well-established technologies to generate electricity.

Waste heat comes from a variety of sources, such as heated products leaving industrial operations, hot equipment surfaces, and hot combustion gases released into the atmosphere. It is estimated that as much as 20 to 50% of industrial energy consumption is ultimately discharged as waste heat. Even though some waste heat losses from industrial processes are unavoidable, facilities can minimize these losses by upgrading the effectiveness of their equipment or implementing a waste heat recovery system.

The global market for waste heat recovery systems was estimated to be $57.7 billion in 2021. The waste heat recovery system market is projected to grow at a CAGR of 8.0% and is forecast to reach $89.0 billion by 2027. Waste heat recovery comprises capturing and recovering the waste heat in industrial operations to generate mechanical or electrical work. Preheating combustion air, electricity generation, preheating furnace loads, absorption cooling, and space heating are a few examples of uses for waste heat. The major factors driving the waste heat recovery market across the globe include the demand for energy conservation, cohesive government policies, high efficiency, and technological advancement.

Figure A
Waste Heat Recovery Components



Source: U.S. Department of Energy

Waste heat that has been captured and utilized can replace expensive fuels or energy without emitting any emissions. There are numerous solutions available for redirecting waste heat to a useful end-use. Existing technologies can be upgraded to increase recovery, widen application restrictions, and boost economic viability. However, even though waste heat recovery offers major environmental and energy savings advantages, its application is largely influenced by economics and perceived technological hazards.

The temperature of the waste heat source has a significant impact on how effectively waste heat recovery generates electricity. In general, medium- to high-temperature waste heat sources (i.e., higher than 500°F) have been the only ones that allow for the economically viable generation of power from waste heat. This limit is starting to be lowered by new technologies like Organic Rankine Cycles (ORCs), and future developments in alternative power cycles will make it economically feasible to generate electricity at even lower temperatures.

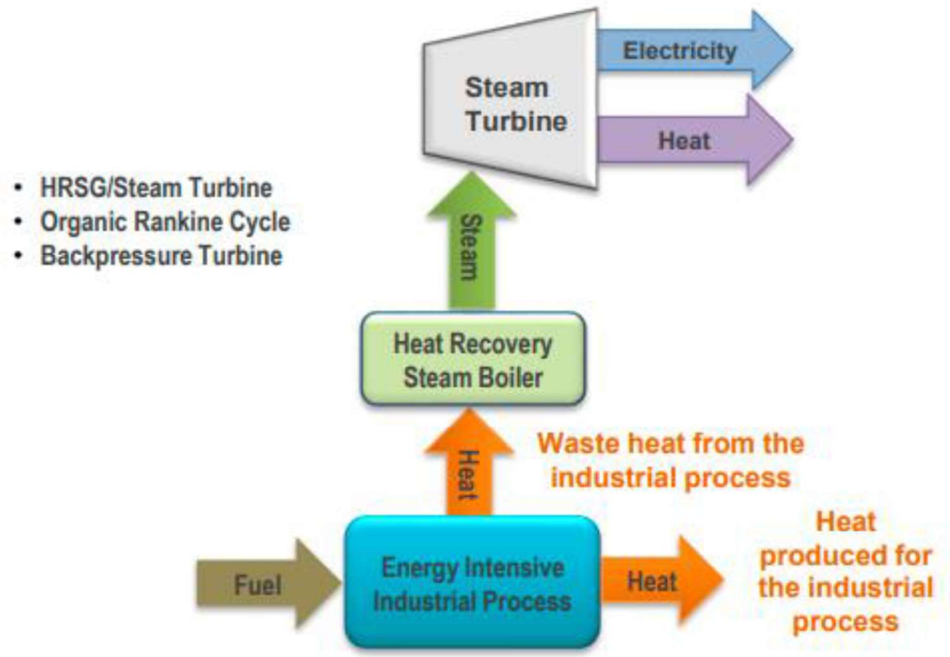
Applications of waste heat recovery that are economically viable typically rely on collecting waste heat from combustion exhaust streams that have temperatures above 500°F. The calcining of materials (such as cement, lime, alumina, and petroleum coke), melting of metals and glass, heating of petroleum fluids, thermal oxidizers, and exothermic synthesis processes are examples of industrial processes that generate these temperatures. Low temperature applications are also widely applicable, and ORC systems can be cost-effective in regions with high electricity costs or waste heat recovery incentives.

The Steam Rankine Cycle (SRC), which uses waste heat to generate steam in a waste heat boiler that drives a steam turbine, is the most widely used method for producing electricity from waste heat. One of the earliest and most adaptable prime mover technologies is the steam turbine. Systems with heat recovery boilers and steam turbines run like a Rankine cycle thermodynamically. The working fluid (in this case, water) in the SRC is first pumped to a high pressure before going into a heat recovery boiler. Hot exhaust heat vaporizes the pressurized water, which is then expanded to drop temperature and pressure and produce mechanical power that can power an electric generator. The heat is then removed from the system by condensing the low-pressure steam back into a liquid in a condenser under vacuum conditions. The cycle then resumes with the condensate from the condenser being returned to the pump.

In Organic Rankine Cycles (ORC) heat engines, alternative working fluids with higher efficiencies are used at lower heat source temperatures. In contrast to water, organic working fluids used in ORCs have a higher vapor pressure, larger molecular mass, and higher mass flow. Higher turbine efficiency than in an SRC is made possible by these properties when combined. Steam systems are only suitable for heat sources above 500°F, whereas ORC systems can be used for waste heat sources as low as 300°F. More recently, pipeline compressor heat recovery applications have used ORCs to generate electricity in geothermal power plants, which can be used by several facilities.

Another Rankine cycle is the Kalina cycle, which extracts energy from the heat source more effectively by employing a fluid that is a mixture of water and ammonia. The Kalina cycle is 15 to 25% more efficient than ORCs at the same temperature level and has an operational temperature range that can accept waste heat at temperatures of 200°F to 1,000°F. In geothermal power plants, where the hot fluid is frequently below 300°F, Kalina cycle systems are becoming more and more prevalent.

Figure B
Waste Heat Recovery Cycle



Source: U.S. Department of Energy

Advantages of Rankine power cycles:

- Utilize heat from existing thermal processes, which would otherwise be wasted to produce electricity.
- Important resource for vastly increasing industrial energy efficiency.
- Providing a source of pollution-free power.
- Theoretically, Kalina systems are the most efficient. They are typically appropriate for large power systems of several MWs or greater due to their complexity.
- ORC systems are well suited for using air-cooled condensers; thus, they are suitable for applications like pipeline compressor stations without access to water.
- SRC systems are the most familiar to industry and are in general economically preferable when the source heat temperature exceeds 800°F.

Cost effectiveness and capability to increase overall operational efficiency are major motivators of the waste heat recovery systems. It is estimated that around two-thirds of the energy used to generate electricity is wasted in the form of heat discharged to the atmosphere and there is considerable energy loss in the distribution of electricity to the end users. As a result, there is imminent demand for waste heat recovery technologies across the globe. The on-site electricity generation effectively captures the wasted heat to provide useful thermal energy such as steam or hot water that can be used for space heating, cooling, industrial processes, etc.

The increasing energy demands in the APAC region is expected to offer the most opportunity for the waste heat recovery systems market. APAC is expected to contribute the highest to the global waste heat recovery systems market followed by Europe. APAC is also an emerging market due to rising demand for natural sources of energy, favorable government policies, and rising adoption of waste heat recovery technologies in industrial processing. The government policies on energy conservation and green energy in the European region are encouraging the waste heat recovery market in the region. The European Union as well as individual countries have set targets to reduce carbon emissions by minimizing the use of fossil fuel. For instance, the cement industry in Turkey uses about 18% of the country's industrial energy. A 141.5 MW installed power waste heat recovery system was put into operation between 2011 and 2020. However, according to the government, another 128.5 MW of comparable capacity needs to be constructed. The increase in energy efficiency and use of alternative fuels are effective solutions to achieve the targets.

The COVID-19 pandemic has wreaked havoc on the worldwide industrial sector. Market development has been impeded by a lack of demand and a large demand-supply mismatch. Furthermore, the global delay of industrial growth projects, particularly in the construction and oil & gas sectors, due to national lockdown, will reduce production capacity. Moreover, due to the COVID-19 dilemma, several developing nations are on the verge of bankruptcy. However, in the post-pandemic era, the global waste heat to power market is anticipated to grow at a healthy growth rate. Government funding for various research projects to bolster the use of waste heat to power technologies has also pushed business growth.

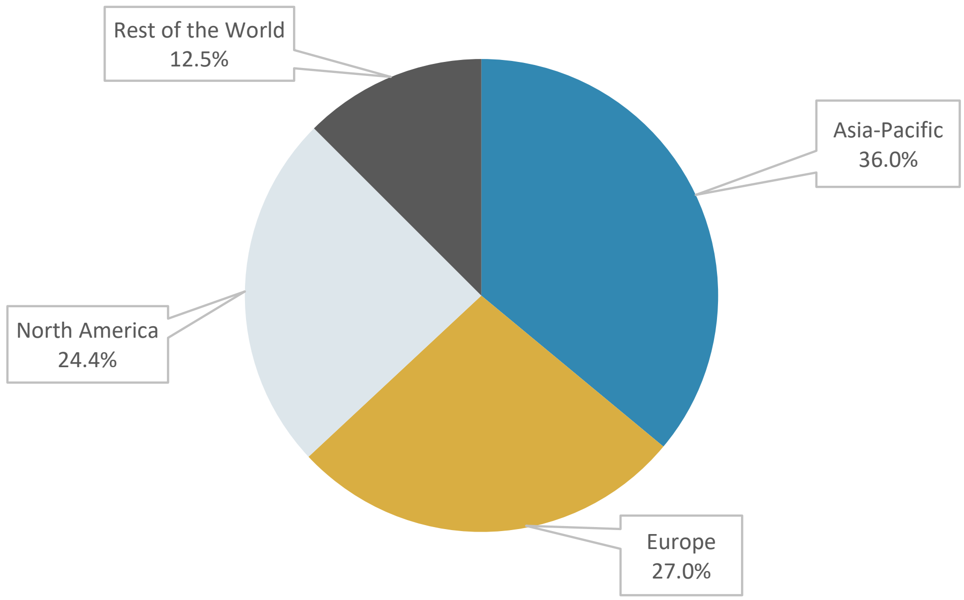
Summary Table:
Global Market for Waste Heat Recovery Systems, by Region, Through 2027
($ Millions)

Region	2021	2022	2027	CAGR% 2022-2027
North America	14,103.6	14,845.2	22,070.1	8.3
Asia-Pacific	20,797.7	22,128.4	34,635.8	9.4
Europe	15,586.7	16,220.6	22,755.3	7.0
Rest of the World	7,219.2	7,398.4	9,531.1	5.2
Total*	57,707.2	60,592.6	88,992.2	8.0

*Note: Totals in this report's tables and figures might not match exactly because of rounding.

Source: BCC Research

Summary Figure:
Global Market Shares of Waste Heat Recovery Systems, by Region, 2021
(%)



Source: BCC Research

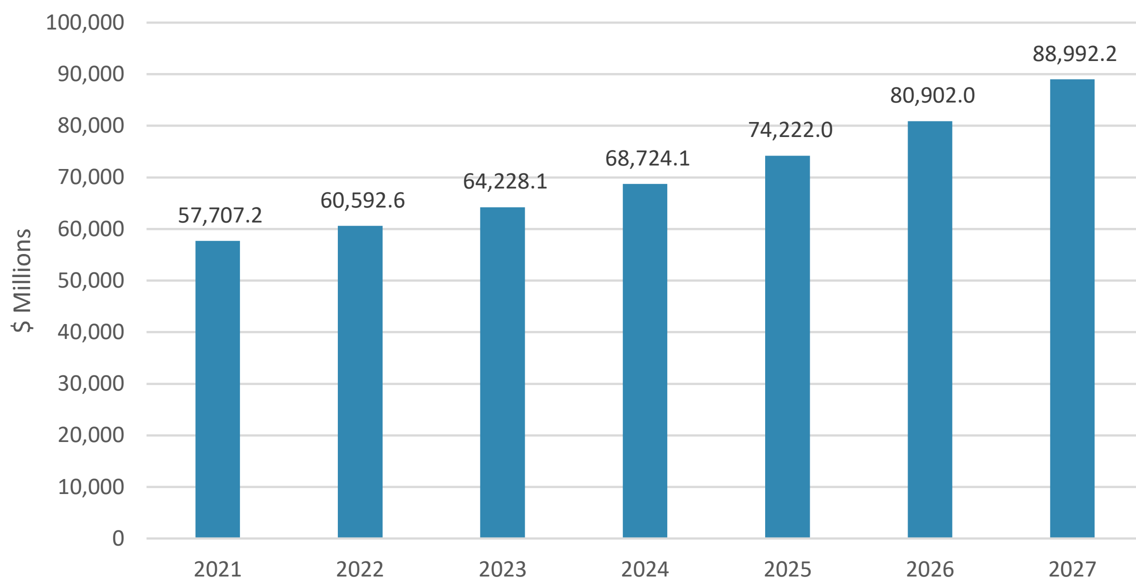
Chapter 3

Market Overview

Chapter 3: Market Overview

Industry Landscape

Figure 1
Global Waste Heat Recovery Market Trends, 2021–2027
($ Millions)



Source: BCC Research

Waste heat recovery is gaining status as an important component of integrated waste management strategies in which it plays the role of an alternative strategy to relieve the pressure on primary energy generation. The added benefit of waste heat recovery over other waste management strategies is the potential for the extraction of energy. A major portion of this energy is used by the plant itself for its internal energy requirements; the remainder is supplied to other end-use sectors.

Energy and its sources have always been a crucial part of society. An unprecedented change in the consumption of energy resources has been observed over the last 15 years. The major factors for this change include high growth in the renewable energy market, new capacity, and high growth rates in developing countries. Impressive growth has been seen in unconventional resources and technologies for other forms of energy resources, such as waste heat recovery systems. This has reduced the price of resources, increased economic growth, and reduced GHG emissions.

With the rising concerns about global warming and the growing trend of fuel price increases over the past few decades, engineering businesses are faced with the problem of lowering greenhouse gas emissions and enhancing the effectiveness of their sites. In this regard, one of the main areas of research to cut fuel consumption, lower harmful emissions, and increase production efficiency has been the use of waste heat recovery systems in industrial processes.

Major manufacturing sectors are aggressively implementing waste heat recovery to reduce their reliance on conventional energy sources and generate their own electricity to cut operating expenses. Additionally, ongoing technological developments like waste heat recovery with an Organic Rankine Cycle will further encourage market expansion.

Currently, one of the most significant untapped areas in the world is the recovery of industrial waste heat: A potential of roughly 51 TWh/year, or 16% of the industry's annual fuel energy use, is thought to exist in France alone. This energy is discharged as waste heat when temperatures rise above 100°C. This heat can be recovered to be used to generate electricity, mechanical energy, and thermal energy at low cost and without CO_2 emissions. The choice of heat recovery methods and techniques is greatly influenced by important elements including the type, quantity, and compatibility of the heat source.

Market Dynamics

Market Drivers

Increasing Need for Energy Security

Concerns about energy affordability, security, and greenhouse gas emissions have increased interest in energy efficiency and grid demand reduction because of the predicted rise in global energy demand by 2030. In the United States, lawmakers are working to control GHG emissions via market-based processes, efficiency initiatives, demand reduction strategies, and financial incentives. The majority of the world's electricity is produced by heat engines, which turn the heat produced by the combustion of fuel into mechanical energy and then into electricity. According to the U.S. DOE, 280,000 MW of waste heat that is released annually in the U.S. could be recycled to meet 20% of the country's electricity demands, reduce GHG emissions by 20%, and save $70–$150 billion in annual energy expenses.

The shift in the trend toward energy generation using renewable resources due to the depletion of conventional resources is expected to remain a key driving factor for the global waste heat recovery system market. Development of a sustainable, long-term solution to meet growing energy demand is one of the most defining issues of this era. Energy security may be defined as providing energy to all at affordable prices. The global energy industry has been witnessing volatility in the prices of key energy resources such as crude oil and natural gas. In addition, there is a large environmental risk associated with the use of such resources. Development of waste heat to power technologies has provided a new dimension to address the increasing energy demand.

The Energy Council estimates that more than 2.5 billion people worldwide depend on traditional biomass for cooking and more than 1.5 billion people lack access to electricity. More than 65% of this population lives in Sub-Saharan Africa and South Asia. Moreover, lack of affordable energy results in more than four million premature deaths per year caused by household air pollution.

To overcome such challenges, governments across various nations have been adopting waste heat recovery technologies. Government policies are expected to help energy efficiency investment rise by

10% in 2021 to almost $300 billion. Governments, particularly across Asia-Pacific, have been working to reduce their carbon footprints whilst also catering to growing energy needs.

There has been an increase in the domestic manufacturing of chemicals, steel, and textiles in emerging and developing economies such as China, India, Brazil, and South Africa in recent years. In addition, the governments of countries such as India and China have implemented foreign direct investment (FDI) and are focusing on research and development (R&D) activities across several industries. The increase in disposable income and economic growth has led to the increase in energy demand globally, especially in non-OECD countries in Asia-Pacific and Latin America. Additionally, increased demand for sustainable and secure energy has further driven energy demand globally.

Carbon Footprint Reduction
The combustion of fossil fuels to generate electricity releases carbon into the atmosphere. The release of high levels of carbon is detrimental to the environment and human life. High carbon levels have spurred the development of alternative techniques, including waste heat recovery systems. There has been a drastic change in the worldwide mix of primary fuels used to generate electricity over the past several decades. Although coal continues to be the dominant fuel used for generating power, its share has either remained stagnant or declined continuously over the years. This decline has been offset by the rising demand for alternate energy sources that have become competitive to traditional sources of generating power over the last decade.

By reducing carbon emissions and recovering waste heat, one can decrease impact on the environment and improve the sustainability of energy production and consumption. For instance, the U.S. Department of Energy (DOE) provides funding and technical support for research and development of waste heat recovery technologies, as well as provides information and resources to help organizations implement waste heat recovery systems.

The Independent Electricity System Operator (IESO), a not-for-profit organization responsible for overseeing the electricity system in Ontario, Canada plays a key role in promoting and implementing waste heat recovery as part of its efforts to increase energy efficiency and reduce greenhouse gas emissions. The IESO recognizes the potential for waste heat recovery to improve energy efficiency and reduce emissions and has implemented several programs and initiatives to support its development and implementation. For example, the IESO’s Conservation First Framework provides funding and support for energy efficiency projects, including waste heat recovery, and the IESO’s Demand Response Program provides incentives for organizations to reduce their energy usage during times of high demand.

In addition, the IESO works with industry partners and stakeholders to encourage the development of new waste heat recovery technologies and to promote the use of existing technologies in various sectors. By promoting waste heat recovery, the IESO is helping to reduce carbon footprint, improve energy efficiency, and support a more sustainable energy system in Ontario.

Rising Industrial Processing
To support their industrial production, governments in both developed and emerging economies have been making a range of initiatives, including trade facilitation, policy interventions, environmental restrictions, technical developments, etc. The industrial sector accounted for 35% of all end-use energy consumption and 33% of all energy consumption in the United States in 2021, respectively, according to the U.S. Energy Information Administration. Increased WHP generation will result from the industrial

sector's expanding energy consumption. Therefore, the waste heat recovery systems market will rise as a result of expanding energy consumption in industrial processing.

The demand for waste heat recovery systems will surge throughout the APAC region because of rising investments in new industrial development projects and increased focus on introducing more energy-efficient technologies. Additionally, there are many significant manufacturing companies in the area, which will accelerate the installation of waste heat recovery units in these facilities. The Indian cement industry, according to the Indian Cement Manufacturers' Association, is comparable to Japan's in terms of energy use and adoption of green techniques. It consumes 100% of the slag produced by the steel industry and is the greatest consumer of fly ash from thermal power plants, both of which help lower the ratio of clinker to cement. The sector has increased its use of alternative fuels and raw materials and encouraged waste heat recovery-based power generation.

One of the biggest cement manufacturers in the world, Holcim, plans to cut its indirect emissions brought on by the purchase of energy, steam, and heat or cooling, by 65% by 2030 compared to 2018. To cut emissions by 500,000 t CO_2 annually, the business invested $108 million in waste heat recovery at six facilities in India. The grid's demand for electricity is also decreased by using waste heat from cement kilns to generate energy.

Emergence of APAC as a Major Hub for Waste Heat Recovery Systems
Recently, there have been a number of notable developments across Asia that together create a favorable climate for the development of new waste management infrastructure in the region. Some of these factors include the following:

- A generally more stable investment climate as exemplified by the recent upgrade of the Philippines to investment grade by both Fitch and Standard & Poor's. This more stable investment climate has led to more active involvement in project financing by regional/local banks, which have funds available to lend, and development banks such as ADB and JBIC.

- A greater focus by governments on energy efficient projects, including the setting of ambitious national targets for renewable energy production, including from waste heat recovery.

- The development of more sophisticated laws and regulations relating to the development and incentivization of energy efficient projects allowing greater certainty for developers.

- The development of more cohesive incentive schemes, including favorable tariffs, tax relief, and energy credits.

- Continuing concerns over energy security and supply in the region along with significant increases in energy demand are ensuring that the generation of sustainable energy will be welcomed.

- A shortage of effective and modern waste infrastructure together with rapid urbanization, justifying investment into the sector; increasing use of public, private partnerships (PPPs) to deliver economic and social infrastructure.

- A greater focus on Asia by internationally recognized and experienced developers keen to develop new markets.

Market Restraints

Technical Barriers

The heat recovery process itself is the main challenge for waste heat recovery systems. Each heat recovery scenario poses a different set of difficulties, despite the fact that the power producing equipment is commercially established and generally standardized.

The following are a few project-specific technological difficulties that have an impact on project economics:

- The waste heat sources at a plant are dispersed, challenging to gather, or come from batch or non-continuous processes.

- Low volume and seasonal operations minimize the waste heat recovery systems economic advantages.

- Chemical and/or mechanical impurities found in waste heat sources frequently affect the complexity, expense, and effectiveness of the heat recovery process.

- It is challenging or impossible to economically site waste heat recovery systems due to equipment designs and space constraints.

Business Barriers

Businesses could be hesitant to undertake projects with a reputation for risk, including energy recovery projects that fall outside of their core competencies. For capital-intensive waste heat recovery projects, these worries frequently result in project hurdle rates that are excessively high. Due to the fact that the expenditures of due diligence, permitting, and siting frequently diminish the returns, small projects (defined as those costing less than $5 million) can be extremely challenging to build. The risk that comes with funding projects with lengthy payback periods, particularly those that depend on erratic future fuel prices and fluctuating energy rates, has been made worse by the economic crisis.

It might be difficult to obtain bank financing for WHP projects since the systems can be technically challenging and mix the risk of power generation with the risk of the main company (i.e., there is no heat to recover if the plant shuts down). Additionally, end users are not generally knowledgeable about WHRS technologies or how to use them. Despite huge potential benefits, organizations are reluctant to adopt new, untested technology that may endanger current manufacturing processes.

High Cost

- Long payback periods: In some applications, the costs of auxiliary systems, heat recovery equipment, and design services result in lengthy payback periods. A number of industry subsectors with high-quality waste heat sources, including metal casting, are also known for their thin profit margins and fierce internal competition for scarce capital resources.

- Certain applications call for more expensive and sophisticated materials. High-temperature streams, streams with a lot of chemical activity, and exhaust streams that are cooled below condensation temperatures all call for expensive materials. As greater surface areas are needed for more effective, lower-temperature heat recovery systems, overall material costs per energy unit recovered rise.

- Corrosion, scaling, and fouling of heat exchange materials lead to higher maintenance costs and lost productivity.

- Equipment costs favor large- scale heat recovery systems and create challenges for small-scale operations.

Inaccessibility/Transportability

- Inaccessibility: Accessing and recovering heat from unusual sources is challenging, such as hot solid product streams (like ingots) and hot equipment surfaces (like the primary aluminum cells' sidewalls). Most melting furnaces, boilers, heaters, and other high temperature equipment must have egress/access around or above them due to safety and operating requirements.

- Transportability: Since many waste heat gaseous streams are released at atmospheric pressure, it is difficult to get them to and through machinery without using additional energy.

- Limited space: There are numerous facilities with constrained physical space to access waste heat streams (i.e., limited floor or overhead space).

Pricing Analysis

The price of the boiler or evaporator used for waste heat recovery, the cost of the SRC, ORC, or Kalina cycle used for power generation, and the price of the power conditioning and connecting equipment make up the entire cost of installing waste heat recovery systems. There are no fuel costs for waste heat projects. The soft costs related to planning, obtaining permits, and building the system would also be included in the overall cost. The installed costs of SRC, ORC, and Kalina cycle power systems are comparable, with differences more related to project size and site integration difficulty than system type. A preliminary estimate of the cost of generating power from WHP systems is shown in the table below.

Table 1
Technology Cost Comparison for Power Generation, 2021
($/kWh)

Cost Component	ORC	SRC
Installed Costs, $/kW	$1,900–$4,500	$1,200–$3,000
Waste Heat to Power Generation Cost		
Amortized Capital, $/kWh	$0.055–$0.125	-
O&M Costs, $/kWh	$0.009–$0.018	$0.005–$0.013
Total Power Cost, $/kWh	$0.060–$0.125	

Source: U.S. DOE, 2021.

Table 2
Waste Heat to Power Costs, 2021
($/kWh)

Technology	Cost Characteristic	Electric Capacity for WHP Technology				
		50–500 kW	500–1,000 kW	1–5 MW	5–20 MW	>20 MW
Steam Rankine Cycle	Installed Capital Cost, $/kW	$3,000	$2,500	$1,800	$1,500	$1,200
	O&M Costs, $/kWh	$0.013	$0.009	$0.008	$0.006	$0.005
Organic Rankine Cycle	Installed Capital Cost, $/kW	$4,500	$4,000	$3,000	$2,500	$2,100
	O&M Costs, $/kWh	$0.020	$0.015	$0.013	$0.012	$0.010

Source: ICF International

Macroeconomic Factors of Waste Heat Recovery Market

Impact of the COVID-19 Pandemic

Since its emergence the COVID-19 pandemic has become a public health threat. COVID-19, which has been confirmed in 213 nations and territories worldwide, was declared a pandemic by the World Health Organization in March 2020. Several countries, including China, India, France, Spain, Denmark, Italy, Austria, New Zealand, Poland, the U.K, and the Czech Republic, have enacted harsh restrictive measures despite the resulting economic slowdown. Over a third of the world's population was quarantined during this pandemic. While the outbreak has posed a threat to humans it has also strained businesses and organizations, including power, chemicals, data centers, petroleum, and their supply chain.

COVID-19 altered the course of many people's lives. One of the COVID-19 pandemic's repercussions was a drastic shift in worldwide energy generation and consumption. At first, global energy demand dropped dramatically because of the COVID-19 pandemic. For example, in the U.K. power demand typically declines by 10% to 20% on weekends over weekdays; but, during COVID-19, a similar decline was recorded throughout the week. Another example is the 2.9% reduction in power consumption in the U.S. in 2020 compared to 2019. These extraordinary events influenced power generation and trading activities globally.

The total energy demand declined by 2.5% in Q1 2020, and demand for coal and oil fell by nearly 8% and 5%, respectively, in the world. In 2020, the total energy demand fell by 4%, which is the most profound decline since World War II. Renewable energy was the only source that recorded demand growth, mainly due to its low operating costs and preferential access to electricity networks. However, energy operators in a few countries restricted renewable power generation and energy efficient technologies due to different structural challenges such as limited options for storing or exporting excess power, reduced demand-side flexibility as industrial plants operations went on hold or shut down, and inaccurate load forecasts due to lack of historical data on electricity demand during a pandemic. Various countries have implemented policy changes to address the concerns of renewable energy project delays and cancellations. However, the pandemic posed a risk to individual investors and small- to medium-sized firms operating in the energy market.

Electricity usage drastically decreased because of the COVID-19 outbreak. Governments worldwide were driven to curtail commercial activities to mitigate the coronavirus threat. As a result of COVID-19, lifestyles worldwide have been altered, with people preferring to stay at home and work from home whenever possible. As a result, home load demand increased significantly while commercial and industrial load demand decreased significantly. This devastation created new issues for the power sector's technical and financial activities. As a result, most utilities worldwide have implemented a disaster management strategy to address these continuous challenges/threats.

During the pandemic period several companies in the waste heat recovery landscape conducted their operations in a virtual work environment. Several companies used technical solutions to tune and control power plants remotely and thus avoid travel. However, the pandemic continued to have a negative impact on the waste heat recovery systems market, both order intake, revenues, and installation rate. The restrictions further affected the opportunities to develop new business and power plant projects.

Impact of the Russia-Ukraine War

The Russian invasion of Ukraine has hit the waste heat recovery system industry with supply disruptions and lowered demand. The long-term outlook remains unclear since there is no clarity on the scale of sanctions and whether companies suspending operations plan to return. The war has led to higher oil and natural gas prices worldwide during a moment when oil is already at a nine-year high. The problem with rising crude prices is that it will have a serious impact on inflation, and this impact will get passed through to energy-intensive modules, thereby affecting the whole world.

Many industrial processing companies and raw materials suppliers are withdrawing their operations from Russia, which is impacting the waste heat recovery market. The industry is also likely to be hit with logistics problems, as most international shipping companies, such as Maersk, MSC, and others, face delays in moving goods in and out of Russia. The war, among other things, puts the world's food and energy security in jeopardy, contributes to rising inflation because of a spike in commodity prices, and disrupts supply chains, all of which have negative effects on businesses and limit the growth of the global economy, which has not yet fully recovered from the worldwide COVID-19 pandemic.

The Ukraine war has already proved to be the biggest shock for the Russian economy since the collapse of the Soviet Union. As many as 400 Western companies have suspended their operations in the country, citing reputational risks and logistics issues. Some energy producers also joined the trend, as the demand in some segments looks alarming. For instance, recently Siemens AG announced to quit the Russian market due to war in Ukraine, taking a $630.2 million hit to its business during the second quarter of 2022. The company previously halted new business and deliveries into the country after the invasion. Moreover, in April 2022, the Danish turbine manufacturer Vestas said it will withdraw fully from the Russian market over the country's invasion of Ukraine.

An increase in energy costs has been caused by a global lack of oil supply. Oil prices began to rise prior to the invasion due to a faster recovery of the world's demand than its supply, and due to the slow recovery of the world's field production following COVID-19. However, after Russia's invasion of Ukraine, oil prices soared to over $100 per barrel. 13% of the oil and 17% of the gas produced globally come from Russia. Russia provides 25% and 40% of the oil and gas that is used in Europe annually. Due to the inflexibility of the energy supply and logistical challenges, Chinese and Indian economies have gained a certain degree of negotiating power when acquiring Russian energy resources. A decrease in the supply of oil to Europe has forced Russia to look for alternative means of redirecting its energy flows to the other emerging economies such as China and India, at a discounted price. However, given Russia's limited capacity to export both oil and gas to East and South Asia, the possibilities for diverting oil and gas flows from the European market to Asia remain unclear.

Patent Analysis

The tables below provide a summary of patents related to waste heat recovery systems. Several patent databases (FPO, Scopus, Elsevier, DWPI) were reviewed before formulating the analysis. Several companies hold waste heat recovery systems patents.

Table 3
Waste Heat Recovery Systems Patents, 2017–2022

Inventor/Assignee	Publication Date	Publication No.	Patent Title/Abstract
Ford Global Technologies LLC	Jan 11, 2022	CN108005811B	Waste heat recovery for power generation and engine warm-up.
Enhanced Energy Group LLC	July 05, 2022	CA2890484C	Cycle turbine engine power system.
Sunamp Ltd.	July 05, 2022	US20200217518A1	Energy storage systems.
Cummins Inc.	Aug 17, 2021	US11092069B2	Rankine cycle waste heat recovery system and method with improved EGR temperature control.
Saudi Arabian Oil Co.	July 27, 2021	US11073050B2	Kalina cycle-based conversion of gas processing plant waste heat into power.
Mitsubishi Power Ltd.	Jan 20, 2021	EP2103339B1	Exhaust gas treating method and apparatus.
Mitsubishi Heavy Industries Ltd.	Oct 15, 2020	US20200325799A1	Waste heat recovery system, gas turbine plant provided with same, waste heat recovery method, and installation method for waste heat recovery system.
Mack Trucks Inc.	May 06, 2020	EP2593645B1	Waste heat recovery system with partial recuperation.
Claudio Filippone	May 07, 2020	US20200141353A1	Waste heat recovery and conversion.
Combined Energies LLC	May 05, 2020	US10644338B2	Dynamically responsive high efficiency CCHP system.
Mitsubishi Power Ltd.	Nov 19, 2019	US10480411B2	Waste heat recovery device, gas turbine plant provided with same, and waste heat recovery method.
Bitzer U.S. Inc.	May 09, 2018	US20180216500A1	Heat energy distribution systems and methods for power recovery.
Graco Minnesota Inc.	Nov 15, 2018	AU2017208348B2	Waste heat recovery system for pumping system.
Modine Manufacturing Co.	June 26, 2018	US10006311B2	Waste heat recovery system and method of operating the same.
Nissan Motor Co., Ltd.	Nov 21, 2018	EP2762690B1	Engine waste heat utilization device.
Matrix Industries Inc.	Dec 06, 2018	US20180351069A1	Thermoelectric devices and systems.
Echogen Power Systems Delaware Inc.	Jan 09, 2018	US9863287B2	Heat engine system with a supercritical working fluid and processes thereof.
Cummins Intellectual Property Inc.	July 11, 2017	US9702289B2	Reversible waste heat recovery system and method.
Cummins Intellectual Property Inc.	May 02, 2017	US9638067B2	Rankine cycle waste heat recovery system.

Inventor/Assignee	Publication Date	Publication No.	Patent Title/Abstract
Ormat Technologies Inc.	Aug 30, 2017	EP2561188B1	Organic motive fluid-based waste heat recovery system.
Eberspaecher Exhaust Technology GmbH and Co., KG	May 03, 2017	EP2525052B1	Heat recovery unit.

Source: BCC Research, Google patents, United States Patent and Trademark Office

Chapter 4

Emerging Technologies/
Market Opportunities

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Chapter 4: Emerging Technologies/ Market Opportunities

Technology Background

The minimization and recovery of waste heat represents a substantial opportunity to boost productivity and save energy costs. Additionally, since energy-intensive machinery can be run at a reduced intensity, this could result in cheaper maintenance costs and higher equipment productivity. Reducing the cost of waste heat recovery technology should be a major factor in all R&D efforts. Only savings that have a "reasonable" payback period (three years) and minimal perceived hazards will convince industrial manufacturing firms to invest in waste heat recovery. The economic viability of traditional recovery technologies must be increased, and innovative technologies that can be applied to waste heat sources that aren't generally used for waste heat recovery must be promoted in order to support waste heat recovery and process integration.

Technologies that are currently being developed hold promise for more effective and unconventional waste heat recovery. For instance, recovering low- to medium-temperature waste heat has been successful using recently developed recovery technologies, such as the Kalina cycle.

Additionally, efforts are being made to develop small membrane condensers, which could improve latent heat recovery from exhaust gases. Research and development initiatives are also investigating direct conversion methods, like thermoelectric generating. Last but not least, there might be chances for novel technology to recover heat from sources that aren't usually thought of for heat recovery (e.g., losses from heated product streams and sidewall losses in aluminium cells).

To create more effective ways to produce power from waste heat, researchers have been working significantly towards technology optimization. Special flow expanders, such as twin-screw designs, can increase output in current Organic Rankine Cycle (ORC) systems across a wider range of operating circumstances. While high-grade waste heat can be used to produce power by spinning turbines (such as in a steam engine), low-grade waste heat can also be used successfully and cheaply through the Organic Rankine Cycle (ORC). This makes use of specialised heat transfer fluids that can boil even at very low temperatures. Worldwide, there are numerous instances of successful ORC installations in the cement, glass, and metal industries.

Typical sources of waste heat and recovery options are listed in the table below:

Table 4
Examples of Waste Heat Sources and End-Uses

Waste Heat Sources	Uses for Waste Heat
Combustion Exhausts:	Combustion air preheating
• Glass melting furnace	Boiler feedwater preheating
• Cement kiln	Load preheating
• Fume incinerator	Power generation
• Aluminum reverberatory furnace	Steam generation for use in:
• Boiler	• power generation
Process off-gases:	• mechanical power
• Steel electric arc furnace	• process steam
• Aluminum reverberatory furnace	Space heating
Cooling water from:	Water preheating
• Furnaces	Transfer to liquid or gaseous process streams
• Air compressors	
• Internal combustion engines	
Conductive, convective, and radiative losses from equipment:	
• Hall-Hèroult cells	
Conductive, convective, and radiative losses from heated products:	
• Hot cokes	
• Blast furnace slags	

Source: BCC Research

Condensation and corrosion brought on by chilling exhaust gases below their dew point temperature present a significant obstacle to low temperature heat recovery from exhaust gases. Condensation heat recovery has far greater initial and ongoing expenditures, which are typically not justified by the energy savings they provide. Despite being commercially available, condensing economizers have up to three times the capital expenses of conventional boilers. Alternative technologies are being developed that could be more affordable, such as transport membrane condensers. Development potential may include low-cost approaches to the chemical deterioration of heat exchanger materials, improved heat transfer efficiency, and low-temperature heat recovery.

Opportunities in Waste Heat Recovery Industry

- Develop low cost, novel materials for resistance to corrosive contaminants and to high temperatures.
- Develop economic recovery systems that can be easily cleaned after exposure to gases with high chemical activity.
- Economically scale down heat recovery equipment and reduce relative costs for small-scale operations.
- Develop novel heat exchanger designs with increased heat transfer coefficients, especially in gas-to-gas and gas-to-liquid heat exchangers.
- Develop processes that avoid introducing contaminants into process off-gases, thereby enabling easier heat transfer from exhaust gases.
- Develop new working fluids that can efficiently recover low temperature heat.
- Develop low-cost methods for cleaning exhaust gases.
- Reduce the cost, technical, and product control challenges of process specific feed preheating systems (e.g., batch/cullet preheating in the glass industry).
- Develop new heat recovery technologies such as solid-state generation.

Waste Heat Recovery Technologies

Heat Exchangers

The most typical application of heat exchangers is to transfer heat from combustion exhaust gases to combustion air entering a furnace. Less energy must be provided by the fuel since preheated combustion air enters the furnace at a higher temperature. Recuperators, furnace regenerators, burner regenerators, rotary regenerators, and passive air preheaters are examples of common technologies used for air preheating.

Recuperator

In medium- to high-temperature applications like soaking or annealing ovens, melting furnaces, afterburners, gas incinerators, radiant tube burners, and reheat furnaces, recuperators recover exhaust gas waste heat. Radiation, convection, or a mix of both may be the basis for recuperators.

Regenerator

Furnace Regenerator

In regenerative furnaces, hot and cold air alternately flow through two brick “checkerwork” chambers. The temperature of the bricks rises when combustion exhausts move through one chamber because they absorb heat from the combustion gas. After that, the airflow is changed so that the combustion air entering the furnace passes through the hot checkerwork, which conducts heat.

Rotary Regenerator/Heat Wheel

Similar to fixed regenerators, rotary regenerators work by alternating the flow of hot and cold gases through the regenerator while storing heat in a porous medium. Rotary regenerators use a rotating porous disc positioned over two parallel ducts, one containing the hot waste gas and the other containing cool gas. They are also known as air preheaters and heat wheels.

Passive Air Preheaters

Gas-to-gas heat recovery devices called passive air preheaters are used in low- to medium-temperature applications where it’s important to avoid cross-contamination between gas streams. Applications include secondary recovery from furnaces, recovery from conditioned air, gas turbine exhaust, steam boilers, and ovens.

Regenerative/Recuperative Burners

A self-recuperative burner uses heat exchange surfaces built into the burner body to recover energy from the exhaust flue gas as it passes through the burner. Self-regenerative burners work in pairs similarly to a regenerative furnace by directing exhaust gases through the burner body and into a casing made of refractory material.

Finned Tube Heat Exchangers/Economizers

A round tube with fins that increase surface area and heat transfer rates makes up the finned tube. Hot gases passing through the tubes heat the liquid as it runs through them.

Waste Heat Boilers

The two-pass boiler is a type of waste heat boiler that produces steam from medium- to high-temperature exhaust gases. When waste heat is insufficient to generate the appropriate amount of steam, additional burners or an afterburner can be added to increase steam output. The steam can be utilized for power generation or process heating.

Load Preheating

Any efforts to utilize waste heat leaving a system to warm up the load entering the system are referred to as load preheating. The most typical instance is boiler feedwater preheating, where hot combustion exhaust gases are used to transfer heat to the water entering the boiler through an economizer.

Power Generation

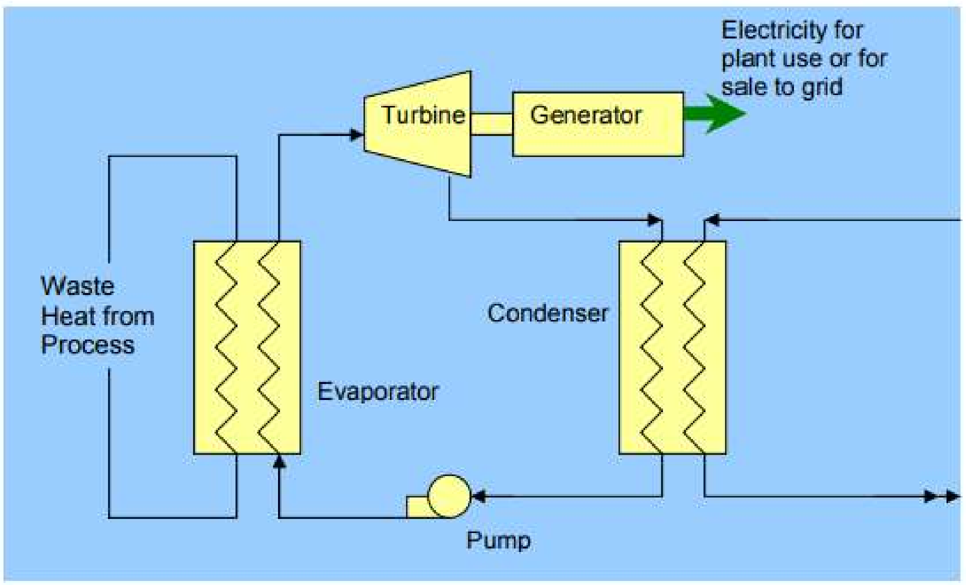
In order to produce electricity from waste heat, boilers’ waste heat is often used to generate mechanical energy, which subsequently powers an electric generator. Although these power cycles are well-established, new technologies, such as thermoelectric and piezoelectric generation, are being developed that can produce energy directly from heat.

Technologies for generating power via mechanical work include:

Steam Rankine Cycle

The most popular method for creating electricity from waste heat includes turning that heat into steam, which powers a steam turbine. The most effective method for recovering waste heat from exhaust streams with temperatures above approximately 650-700°F (340-370°C) is the conventional Steam Rankine Cycle. However, steam cycles lose their cost-effectiveness at lower waste heat temperatures because producing low pressure steam necessitates larger equipment. Therefore, the Organic Rankine Cycle or Kalina cycle, which utilize fluids with lower boiling point temperatures than steam, are better suited for low-temperature heat recovery applications.

Figure 2
Waste Heat Recovery With Rankine Cycle

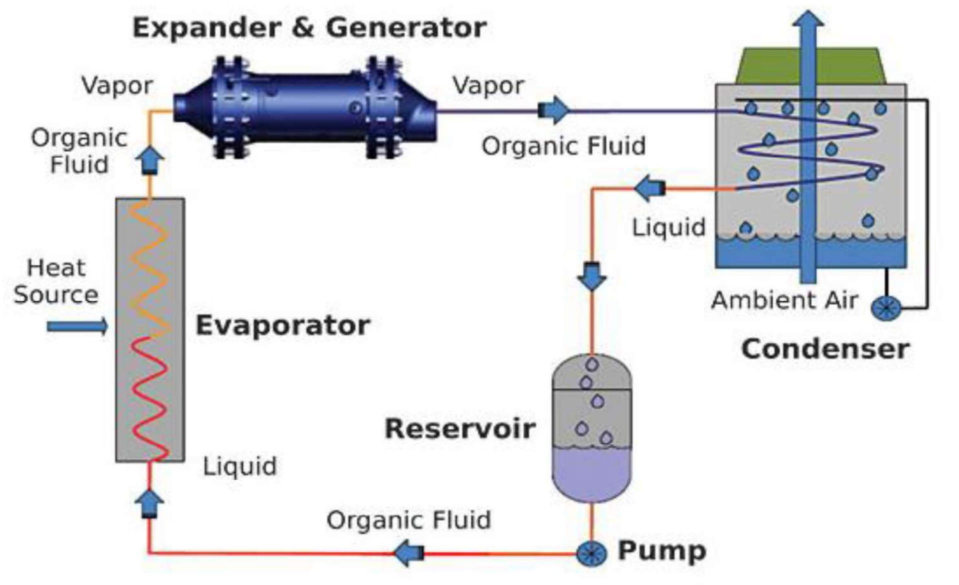


Source: The Office of Energy Efficiency and Renewable Energy (EERE)

Organic Rankine Cycle

In contrast to the steam Rankine cycle, the Organic Rankine Cycle (ORC) uses an organic working fluid. There are a number of alternatives, including silicon oil, propane, haloalkanes (such as "freons"), isopentane, isobutane, p-Xylene, and toluene, which have a lower boiling point and higher vapor pressure than water. Because of this, waste heat temperatures can potentially be as low as 150°F, allowing the Rankine cycle to function at much lower temperatures. The fluid being utilized will determine the temperature range that is best for ORCs because different temperatures will affect a fluid's efficiency depending on its thermodynamic parameters.

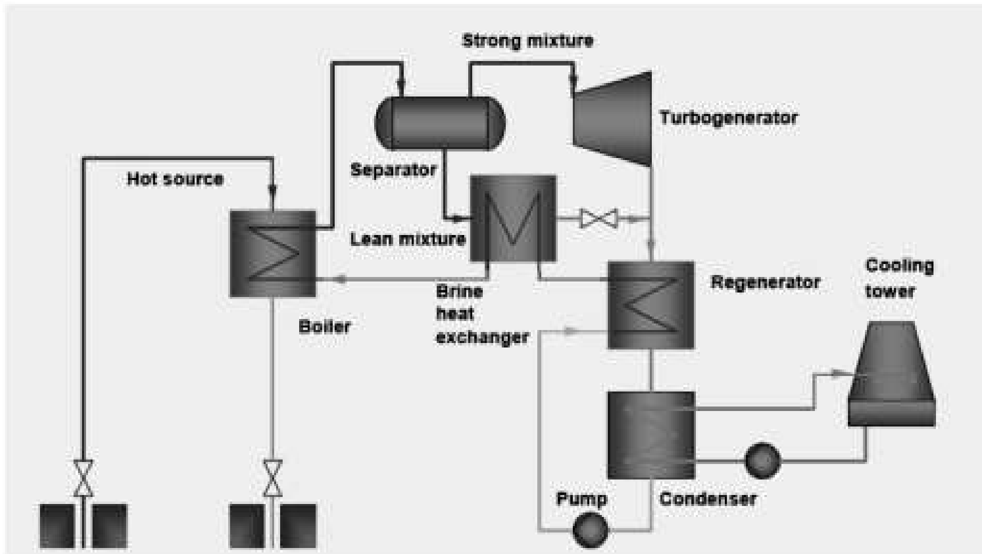
Figure 3
Process Flow of Organic Rankine Cycle System



Source: Process Heating

Kalina Cycle
A mixture of ammonia and water serves as the working fluid in the Kalina cycle, a version of the Rankine cycle. The temperature profile during boiling and condensation is a significant distinction between cycles using single fluids and cycles using binary fluids. The temperature stays constant during boiling for single-fluid cycles (such as steam or organic Rankine). The temperature of the working medium, such as water, gradually rises to boiling point as heat is given to it; after that, the temperature stays constant until all of the water has evaporated. Contrarily, the temperature of a binary mixture of water and ammonia (each of which has a distinct boiling point) will rise as it evaporates. This enables better thermal matching between the condenser's cooling medium and the waste heat source. This leads to much higher energy efficiency for these systems.

Figure 4
Kalina Cycle Heat Engine



Source: ICF International

Direct Electrical Conversion Devices

Thermoelectric Generation

When exposed to a temperature differential, thermoelectric (TE) materials, which are semiconductor solids, allow for the direct generation of electricity. The Seebeck effect is a phenomenon that occurs when two different semiconductor materials are exposed to a heat source and a heat sink. It provides the basis for these systems. By using electricity on various semiconductors, TE materials can also be utilized to cool or heat up.

Piezoelectric Power Generation

Low-temperature waste heat (200–300°F [or 100–150°C]) can be converted to electrical energy using the piezoelectric power generation (PEPG) method. Vibrations in the environment act as mechanical energy that piezoelectric devices convert to electrical energy. By utilizing oscillatory gas expansion, a piezoelectric thin-film membrane can produce a voltage.

Thermionic Generation

Thermionic devices function similarly to thermoelectric devices; however, instead of using the Seebeck effect like thermoelectric devices do, they use thermionic emission. These devices use a temperature differential to propel the flow of electrons from a metal to a metal oxide surface across a vacuum.

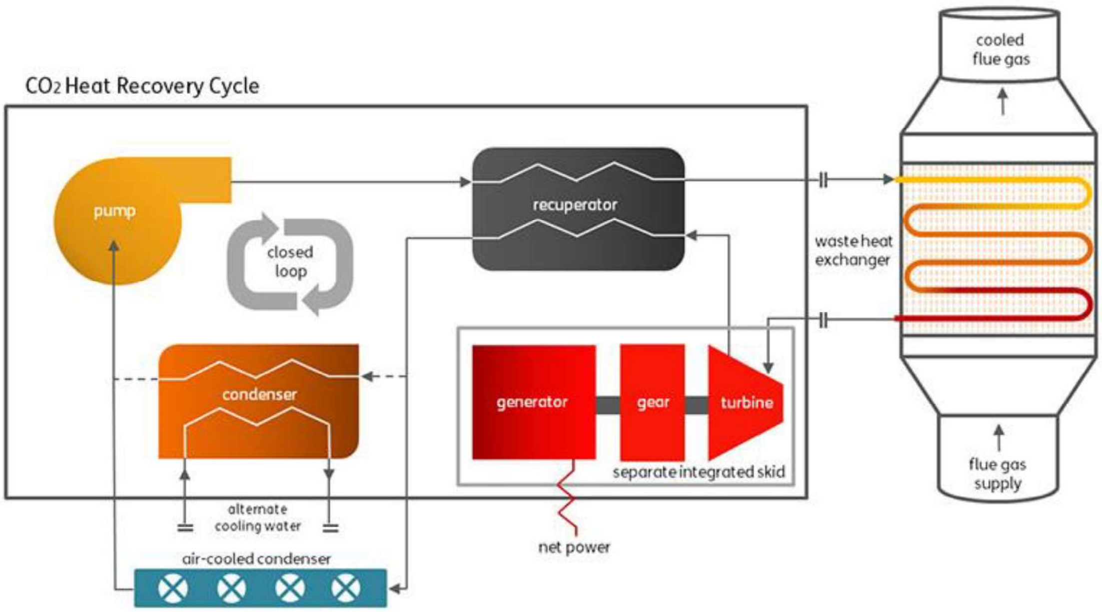
Thermophotovoltaic (TPV) Generator

Electricity can be produced using TPV generators to transform radiant energy. In these systems, a heat source, an emitter, a radiation filter, and a PV cell are all present (like those used in solar panels). Electromagnetic radiation is produced while the emitter warms up. The PV cell transforms this radiation into electricity.

Echogen Heat Engine Technology

The breakthrough thermal engine technology is based on a waste heat to power cycle using supercritical carbon dioxide ($ScCO_2$) as the working fluid. $ScCO_2$ is environmentally benign, non-toxic, with favorable heat and mass transport properties. The higher energy density of $ScCO_2$ reduces system component size and cost, and provides significant advantages regarding system efficiency, footprint, and ease of installation. Carbon dioxide as a working fluid for power generating cycles has many advantages. It is inexpensive, non-flammable, and abundant in nature. Due in part to its relative high working pressure, a carbon dioxide system can be built that is much more compact than systems using other working fluids.

Figure 5
Echogen Supercritical CO_2 Cycle



Source: Echogen

A key advantage of the Echogen technology is the use of supercritical CO_2 as a working fluid for heat recovery and power generation. A supercritical fluid is a substance at a temperature and pressure above its critical temperature and pressure. The critical point represents the highest temperature and pressure at which the substance can exist as a vapor and liquid in equilibrium.

Table 5
Comparison of Power Generating Cycles for Waste Heat Recovery

Parameter	ECHOGEN $ScCO_2$ Power Cycle	Organic Rankine Cycle	Steam Rankine Cycle
Source Temp Range (F)	400 to greater than 1,200	180 to 550	650+
Working Fluid	Supercritical carbon dioxide	HCFC, HFC or volatile hydrocarbons	Treated water
Working Fluid Attributes	Non-corrosive, non-toxic, non-flammable, thermally stable	Limited temperature range, flammable	Requires treatment to reduce corrosion & mineral deposition

Source: BCC Research

The Echogen $ScCO_2$ cycle holds great promise in providing a flexible, efficient, low-cost system for waste heat recovery from a wide variety of applications. The small size of sCO_2 turbomachinery, the simplicity of the exhaust heat exchanger, and the potential to operate in entirely water-free environments result in reduced plant footprint and simplified and flexible installation and operation.

Case Studies

Table 6
Project Snapshot

Project	Application /Industry	Capacity	Equipment	Fuel Type	Thermal/ Electrical Use	Installation Year	Environmental Benefits
Waste heat to power and process heat, Port Arthur, TX	Petroleum Refining	5 MW	Waste heat recovery boilers; back pressure steam turbine	Waste heat	Steam and electricity generation	2005	CO_2 emissions reduced by 159,000 tons/year
Flare Gas to Electricity Bakken, ND	Oil and Gas Extraction	65 kW	ElectraTherm Organic Rankine Cycle Power + hot water boiler	Flare Gas	Electricity generation	2015	CO avg% reduction: 89.1 NOx avg% reduction: 48.1 VOC avg % reduction: 92.8
Williams Ignacio Gas Plant Durango, CO	Oil and Gas Extraction	6.2 MW	Steam turbine	WHP	Waste heat from turbines drives centrifugal compressors	1984, upgraded 2014	Nitrogen oxides (NOx) reduced 88% Carbon oxides (CO) reduced 48% Volatile organic compounds (VOC) reduced 82% Particular matter (PM) reduced 59%
Northern Border Pipeline St. Anthony, ND	Midstream	5.5 MW	Organic Rankine Cycle, Ormat	Waste Heat	Electricity generation	2006	27,600 tons of CO2 34,500 kg of NOx 124,200 kg of SO2

Source: BCC Research

Chapter 5

Thermal and Biological Waste-to-Energy Management

Chapter 5: Thermal and Biological Waste-to-Energy Management

Thermal Waste-to-Energy

In recent years, the surge in the size of the global population has resulted in an increase in the volume of municipal solid waste. Currently, about three-fourths of the total waste is dumped in landfills, which not only requires the use of huge amounts of land but also has adverse effects on the environment as it emits greenhouse gases in excess, including methane in equal proportions. Dramatic population growth, rising levels of affluence, rapid urbanization, and conventional resource scarcity are expected to drive the establishment of waste-to-energy technologies. These technologies are expected to promote low carbon footprints in the renewable energy segment in comparison to landfill gas emitted. Not only is the landfill method environmentally harmful, but it also requires tremendous investment and is not cost-effective in comparison to waste-to-energy technologies. Unlike landfilling, non-thermal waste-to-energy technologies do not require separation or treatment of inorganic waste.

Thermal waste-to-energy (WTE) technologies can process both organic and inorganic waste, which gives them a competitive edge over other renewable energy technologies. Political support and environmental regulations are expected to have a positive influence on the overall market over the next few years. Public opposition to incineration technologies is still a major concern for widespread deployment of thermal waste-to-energy technologies. However, recent developments in these technologies are expected to create attractive market opportunities for waste-to-energy technology providers. The major technologies include gasification, thermal depolarization, pyrolysis, and plasma arc gasification. The solid char, gases, and oils left from pyrolysis and thermal gasification can also be utilized as feedstock for chemicals production and other applications.

Most of the energy generated from waste via thermal technologies is done through incineration. Incineration is a thermal processing method used for reducing solid wastes volume and extracting energy. Solid wastes are converted into liquid, gaseous conversion products under high temperature (in the range of 800°C to 1,000°C). The resultant substance is recovered from the process in the form of heat energy. MSW can be directly burned in a waste-to-energy incinerator as a fuel with minimum processing, in a process generally termed as mass-burn. Heat generated from the combustion process is then used to convert water into steam, which is further used to power steam-turbine generators and produce electricity. Depending on the heat supply, the generated energy is either converted into heat, which generally happens in North European countries, into heat and electrical power or only electricity. However, the various pollutants and ash produced during incineration are expected to remain a key challenge to overcome for market participants.

Conventional incinerator technology is provided in three main types of processes:

- Grate combustion.
- Fluidized bed combustion.
- Oscillating kiln technology.

Grate combustion, also called stoker combustion, consists of waste being introduced in a moving grate where it is combusted. The unburned materials along with other bottom ash are collected in a wet discharger. The gas then passes through a steam boiler operating at a temperature of approximately 400°C and a pressure of 40 bars and produces electricity via steam turbine. Flue gases along with other pollutants are cleaned subsequently with wet or dry flue gas treatment and ash collection methods. Waste in grate combustion need not be pretreated except for a few pieces that pass through a simple crusher. In comparison to other combustion technologies, grate combustion provides a flexible solution. Moving grates or grate combustion is the most widely used thermal technology in comparison to other conventional thermal technologies.

On the other hand, fluidized bed combustion technology consists of particle-sized waste that is introduced in an air stream with a floating bed of sand. In view of efficient heat transfer, this conventional thermal WTE technology might operate at lower temperatures. Ash loaded flue gases pass through dry ash collection and the steam boiler section. Generally, waste is pretreated by reduced particle size and a stable quality of waste is required. The technology is only meant for homogenous waste treatment such as industrial and sewage sludge.

Some of the major factors driving this technology include:

- Intense mass and heat transfer compared with other thermal technologies.
- Minimal mechanical moveable parts, which results in less wear and tear and ultimately reduces maintenance cost.

The rotary kiln is the most stagnant technology among the conventional thermal WTE technologies used worldwide. Rotary kilns are mainly used for industrial and hazardous waste treatment, and they are rarely used for municipal solid waste. The rotary kiln is rarely used alone and is generally combined with a moving grate. The largest rotary kiln WTE thermal plant is based in Taiwan with a capacity of 900 tons per day.

Pyrolysis is the breakdown of waste in the absence of air. In this process, waste is heated in high temperatures, which are generally above 300°C, by an external source of energy, without the addition of oxygen or steam. The intermediate products produced during the process include pyrolysis oil, char, and syngas. There are typically two types of pyrolysis processes used globally, slow pyrolysis and flash pyrolysis. Slow pyrolysis is carried out in a drum or stationary kiln and produces syngas and tar. Flash pyrolysis is a process that produces pyrolysis oils by the means of condensation of gases into liquids. One of the most important attributes of pyrolysis oils is their acid nature. Flash pyrolysis is typically used on biomass streams. Slow pyrolysis is usually followed by combustion of the gases and chars with subsequent electricity generation in a boiler and a steam turbine; flue gas cleaning is carried out via conventional processes.

Plasma-arc waste-to-energy technology uses a plasma-arc torch to generate high temperatures (13,000°F). This extreme heat helps in breaking down waste and forms syngas and slag as a by-product, which is used in construction or road asphalt. The syngas produced through plasma arc technology can be converted into a variety of marketable fuels such as natural gas, ethanol, and hydrogen. It can also be used to generate electricity directly. Plasma converters have the ability to consume a variety of waste generated, including steel, concrete, and toxic chemicals.

Biological Waste-to-Energy

Biological WTE technologies have been gaining market share due to the limitations associated with the use of thermal technologies. Anaerobic digestion produces biogas from a solid fraction called digestate and organic waste. Based on quality, the residual solid digestate can be recycled as soil amendments or fertilizer. The global increase in energy consumption, depleting fossil fuel reserves and the means to utilize alternative energy resources are expected to drive the biological waste-to-energy technology market over the next four years. This technology has evolved mainly in the industrialized countries of Europe such as Germany, Belgium, Denmark, and France. Anaerobic digestion is generally carried out in four steps:

- Hydrolysis.
- Fermentation.
- Acidification.
- Methane formation.

Anaerobic Digestion

Anaerobic digestion is a natural biological process that is carried out by a large number of bacteria that work together in the absence of air. These bacteria grow by undergoing several steps of biological treatment in which organic matter is converted into methane and carbon dioxide. Anaerobic digestion differs from aerobic degradation in terms of biochemical processes involved as well as the outputs.

Bio-Hydrogen

Bio-hydrogen is hydrogen gas produced by biological technologies. Biological methods to produce hydrogen include two different pathways. First is the direct biochemical conversion of sugars by chemotrophic or phototrophic microorganisms to hydrogen. The second biological route to produce hydrogen is the conversion of biomass to biogas by anaerobic fermentation and later by conversion of the methane in the biogas to hydrogen. Combinations of biohydrogen and biomethane are also becoming active research areas within WTE technologies.

Thermochemical transformation of biomass to hydrogen-rich gas has also been achieved from which hydrogen is separated. Although commercial-scale production of bio-hydrogen is yet to be realized, industrial plants for fermentative hydrogen production are being proposed. These plants can be based on thermophilic, dark, and/or photo-fermentation. The fermentation of biomass to hydrogen is manifested through a multi-enzyme biochemical reaction by a group of bacteria (i.e., Rhodobacter sphaeroides, Enterobacter cloacae, and Clostridium butyricum). Conversion of biohydrogen to electricity is being achieved by proton exchange membrane fuel cell (PEMFC) technology.

Mechanical Biological Treatment

Mechanical biological treatment (MBT) as part of waste management processes has evolved to reduce the quantity and volume of organic waste sent to landfills and to increase the potential recovery of resources from the waste. As the name suggests, MBT consists of two main components, mechanical treatment, and biological treatment. Mechanical treatment of waste includes sorting, classification, and pretreatment activities before the waste is led to biological treatment. Mechanical recovery facilities (MRFs) play an important role in this integrated approach. Biological processes involved include composting and anaerobic digestion. A large number of permutations and combinations are possible for MBT and the final configuration of any MBT plant is influenced by the following factors:

- Quantity of waste treated.
- Type of output required.
- Economic, technical, commercial, and regulatory factors.

Physical Waste-to-Energy

Refuse-derived fuel (RDF) is the most common physical technology available in the global market. RDF is a common term used to describe fuel generated from waste undergoing the production process after sorting and bailing complex mechanical treatments. Recycling and combustion materials such as metals and glass are mechanically removed, and the residual material may be sold in the form of pellets, logs, or bricks. RDF can be used to generate electricity and/or heat individually or with conventional sources of fuel or coal.

Chapter 6

Market Breakdown
by Application and End-Use

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Chapter 6: Market Breakdown by Application and End-Use

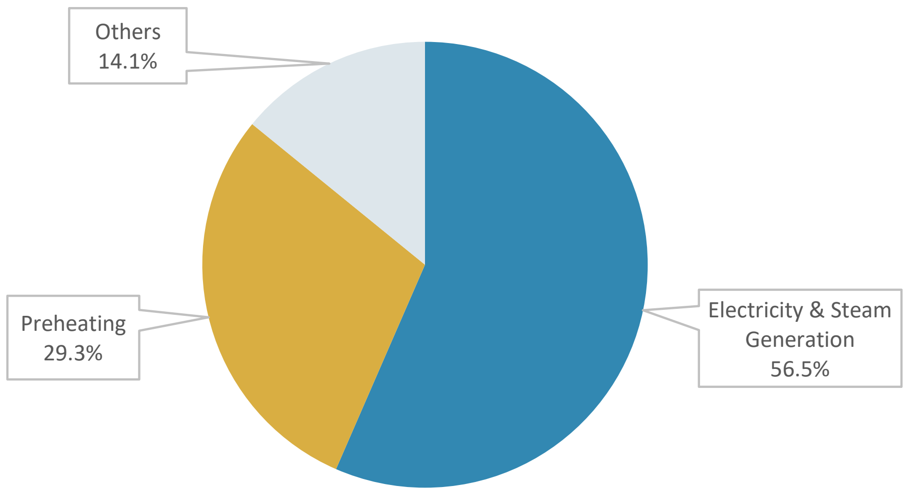
Global Market for Waste Heat Recovery Systems, by Application

The global market for waste heat recovery systems by application consists of pre-heating, electricity & steam generation, and others such as space heating, chilling etc. The deployment of WHRS for power and steam generation will be driven by rising electricity costs as well as ongoing efforts to minimize GHG emissions. The demand for onsite power generation is increasing and improving plant efficiency is a major focus. These two aspects are among the main drivers of market growth.

If not captured and used to generate emission-free renewable-equivalent power, waste heat is released to the atmosphere through stacks, vents, flares, and mechanical equipment. Among other energy-intensive industrial operations, steel mills, refineries, glass furnaces, and cement kilns all produce hot waste streams and exhaust gases that can be used to produce electricity using well-established technology. It decreases auxiliary energy use, pollutants, and equipment size.

The preheating of combustion air, furnace loads, boiler feed water, and space heating are the main uses of waste heat recovery systems. The most common uses for waste heat in the metal casting industry are preheating charge material and preheating combustion air. The U.S. Department of Energy claims that combustion air preheat can boost furnace efficiency by up to 50%. Furthermore, by preheating combustion exhaust gases, it may be possible to do away with the requirement for extra space heating apparatus, which would lower capital and operating expenses. These patterns show a plausible market scenario for waste heat recovery systems.

Figure 6
Global Market Shares of Waste Heat Recovery Systems, by Application, 2021
(%)



Source: BCC Research

Table 7
Global Market for Waste Heat Recovery Systems, by Application, Through 2027
($ Millions)

Application	2021	2022	2027	CAGR% 2022-2027
Electricity & Steam Generation	32,632.1	34,072.6	48,638.6	7.4
Preheating	16,919.3	18,101.1	29,051.4	9.9
Others	8,155.8	8,418.9	11,302.2	6.1
Total	57,707.2	60,592.6	88,992.2	8.0

Source: BCC Research

Global Market for Waste Heat Recovery Systems, by End-Use

In 2021, the petroleum refinery sector held the largest market share. Thermal cracking, catalysis, distillation (fractionation), and treatment are primary procedures performed in petroleum refineries. Many of these activities involve exothermic reactions, which also produce heat, and therefore consume a lot of energy. The heat recovered from one operation is used in other processes in today's fully integrated refineries. Many processes nevertheless continue to produce high-quality waste heat that may be used to generate electricity. The exhaust from petroleum coke calciners is one illustration. Petroleum coke is heated to 2,400°F, and the exhaust temperature as it leaves the calciner is usually between 900°F and 1,000°F.

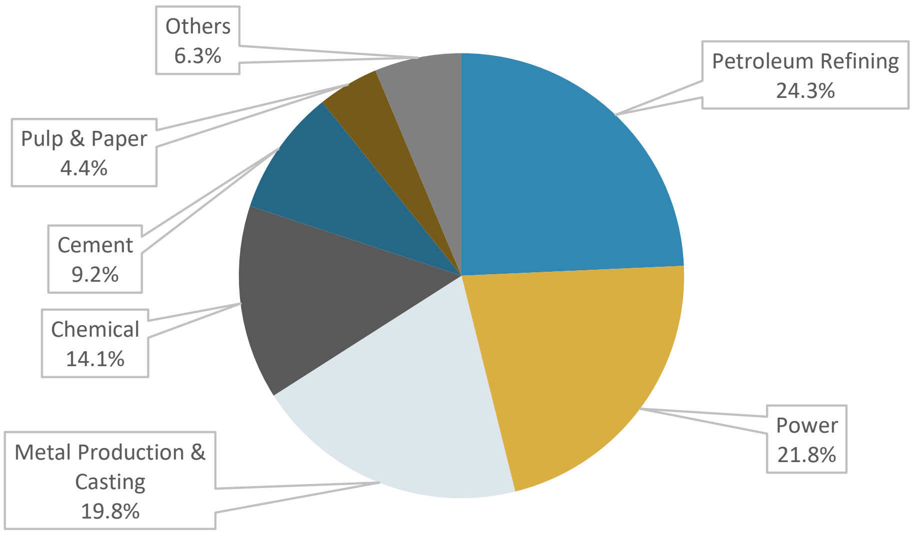
The chemical sector is the fastest growing end-use industry in WHRS market. There are several major segments of the industry in which high-temperature exhaust is released that could be recovered for power generation. For instance, industrial gases, alkalis and chlorine, cyclic crudes, and intermediates (e.g., ethylene, propylene, and benzene/toluene/xylene), plastics materials, synthetic rubber, synthetic organic fibers, and agricultural chemicals (i.e., fertilizers and pesticides) are some of the growing segments with high production rate.

Primary metals manufacturing involves a large number of high-temperature processes. For instance, there are several high-temperature heat recovery options available to steel mills. Waste heat from coke ovens, blast furnaces for making iron, and basic oxygen furnaces for making steel can all be recovered in integrated mills. The waste heat from electric arc furnaces can also be recovered. The Hall-Héroult cell exhaust and secondary melting processes in the aluminum sector have the ability to recover energy. Many different waste heat sources are used in metal foundries, including melting furnace exhaust, ladle preheating, core baking, pouring, shot blasting, cooling of castings, heat treating, and quenching.

In the metal fabrication industry, processes generating waste heat include metal preheating, heat treatment, cleaning, drying, and furnace heating. Cement, gypsum, alumina, soda ash, lime, and kaolin clay are all produced by the high-temperature calcining process in rotary kilns. High-temperature raw material melting, annealing, and tempering furnaces are all used in the glass industry. Therefore, there are a number of strong opportunities for waste heat recovery systems in this sector.

ORC systems could employ exhaust gases from landfills that run reciprocating internal combustion engines or turbines to provide more power. The waste heat produced by flaring could be used to power ORC systems at other landfills. There are a number of flared energy sources in oil and gas production that could utilize waste heat recovery systems.

Figure 7
Global Market Shares of Waste Heat Recovery Systems, by End-Use, 2021
(%)



Source: BCC Research

Table 8
Global Market for Waste Heat Recovery Systems, by End-Use, Through 2027
($ Millions)

End-Use	2021	2022	2027	CAGR% 2022-2027
Petroleum Refining	14,019.6	14,729.1	21,694.9	8.1
Metal Production & Casting	11,454.5	12,202.7	19,210.7	9.5
Power	12,587.4	13,103.1	18,410.0	7.0
Chemical	8,149.9	8,784.4	14,567.5	10.6
Cement	5,288.5	5,463.8	7,369.8	6.2
Pulp & Paper	2,566.8	2,629.0	3,375.8	5.1
Others	3,640.5	3,680.4	4,363.5	3.5
Total	57,707.2	60,592.6	88,992.2	8.0

Source: BCC Research

Chapter 7

Market Breakdown by Region

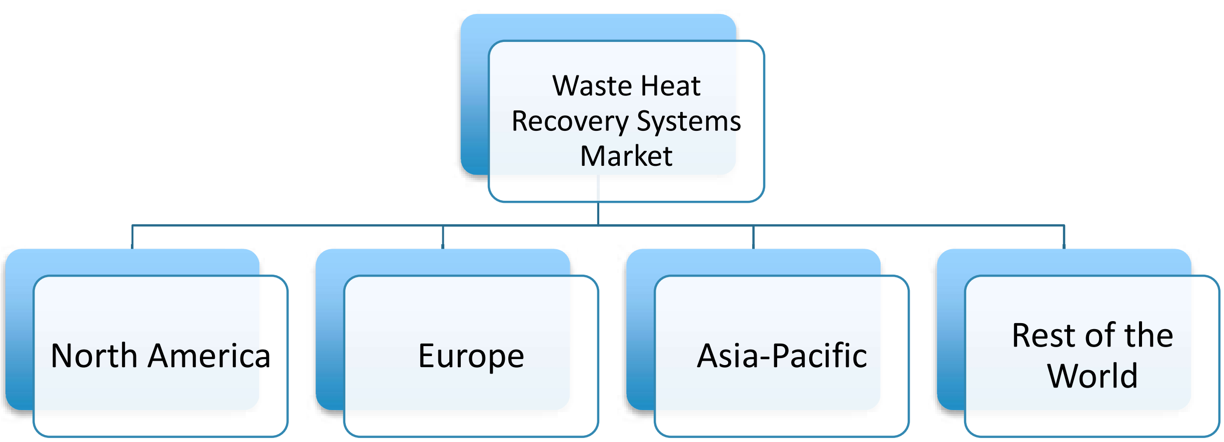
Chapter 7: Market Breakdown by Region

Global Market for Waste Heat Recovery Systems, by Region

The geographic analysis of the waste heat recovery systems market explains the current market scenario and future growth prospects across different regions, including North America, Europe, Asia-Pacific, and RoW (Latin America, Middle East, and Africa). The geography section of the report explores the main factors that drive the market in different regions and the impact that those factors are projected to have during the forecast period.

The energy efficient waste heat recovery systems market is primarily driven by rising crude oil prices, depleting coal reserves, uncertainty about nuclear energy, growing awareness of carbon footprints caused by the combustion of fossil fuels used in electricity generation, and the increasing applications of the technology in different industries. These factors are expected to fuel the demand of waste heat recovery globally as the technology can be used to generate electricity with zero carbon emissions. As waste heat sources are freely available, the cost of electricity generated via waste heat recovery units can be below the cost of electricity acquired from the grid. Moreover, the waste heat recovery systems market is seeing growing applications in various industries.

Figure 8
Global Market for Waste Heat Recovery Systems, by Region



Source: BCC Research

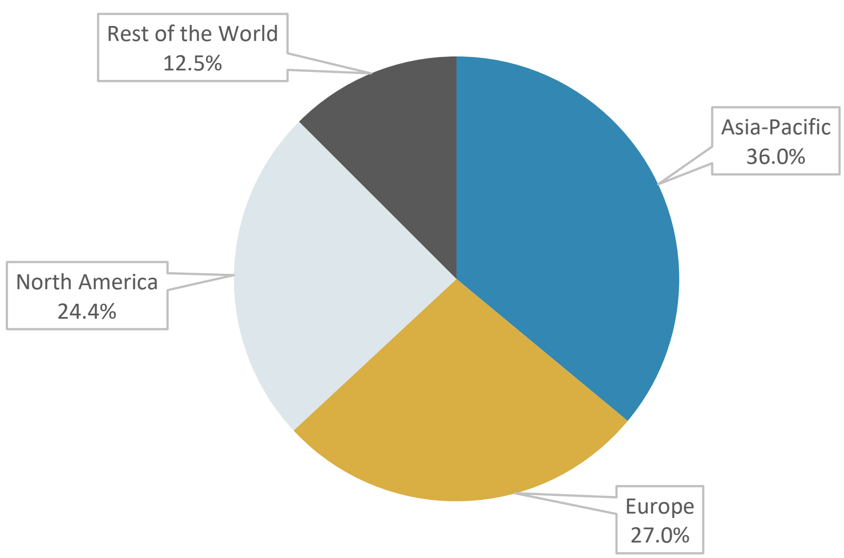
Table 9
Global Market for Waste Heat Recovery Systems, by Region, Through 2027
($ Millions)

Region	2021	2022	2027	CAGR% 2022-2027
North America	14,103.6	14,845.2	22,070.1	8.3
Asia-Pacific	20,797.7	22,128.4	34,635.8	9.4
Europe	15,586.7	16,220.6	22,755.3	7.0
Rest of the World	7,219.2	7,398.4	9,531.1	5.2
Total	57,707.2	60,592.6	88,992.2	8.0

Source: BCC Research

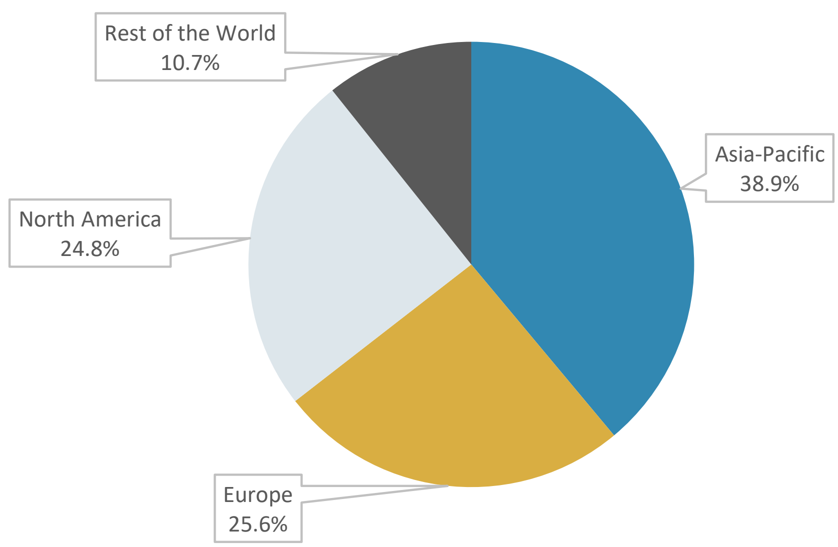
The North American and European waste heat recovery systems markets are regarded as mature markets. North America is considered a pioneer of waste heat recovery and has continuously innovated new technologies. The implementation of national and regional policies along with falling prices of waste heat recovery unit installation is expected to fuel the market in North America over the forecast period. Waste heat recovery system market growth in North America is being driven particularly by increasing installations in Louisiana, Texas and California, Indiana and Ontario, Canada.

Figure 9
Global Market Shares of Waste Heat Recovery Systems, by Region, 2021
(%)



Source: BCC Research

Figure 10
Global Market Shares of Waste Heat Recovery Systems, by Region, 2027
(%)



Source: BCC Research

North America

North America represented a mature, large, $14.1 billion market for waste heat recovery systems in 2021. It accounts for 24.4% of the global market and presents some lucrative opportunities in the chemical, petroleum refining, and power sectors. Growth is pegged at 8.3% per year through 2027. In North America, economic growth is driven by a strong increase in productivity, along with continuing population growth and immigration. The growing establishment of trade associations and other non-profit institutes in the U.S. played a key role in organizing the market. The North American region is home to the world's most proactive and technologically advanced industries. It is also a very receptive market for scientific research, perfecting the blend of government/academic/industry partnerships. The introduction of new standards and technologies, evolving regulatory requirements will have an impact on the waste heat recovery ecosystem.

North America has a considerable market for waste heat recovery systems due to rising demand for energy, cohesive government policies, and significant contributions from regional waste heat recovery systems companies. According to the U.S. Department of Energy (DOE), waste heat recovery systems have been adopted in 48 states with highest potential for new WHP in Texas, Louisiana, and California. The U.S. holds the largest share of the North American waste heat recovery systems market. Canada is growing rapidly due to the presence of major factories, cohesive government policies and so forth. Waste heat recovery systems in the North American region looks promising with the introduction of two new bills, the "Heat Efficiency through Applied Technology (HEAT) Act" and the "Clean Distributed Energy Grid Integration Act" by the Natural Resource Committee and the senate energy committee. These create lucrative opportunities for the WHRS market.

The U.S. leadership as the innovative producer of shale gas in recent years has established it as a possible catalyzer for global energy change. U.S. Energy Information Administration (EIA) has projected that the U.S.'s total natural gas consumption will rise to 31.6 Tcf by 2040 with 56% of the rise in natural gas production resulting from the upward development of shale gas. For the next decade, North America will remain the leader in terms of growth in the production of liquid hydrocarbons. Development of horizontal drilling and hydraulic fracturing technologies made a significant amount of unconventional hydrocarbon reserves in the U.S. Hence these factors will open growth opportunities for WHRS market players in the oil & gas sector.

Additionally, high investment in the development of smart waste management systems technologies for waste management should fuel market growth. New technologies are expected to meet the requirements of the commercial sector arising from insufficient space and rising levels of carbon emissions.

Table 10
North American Market for Waste Heat Recovery Systems, by Application, Through 2027
($ Millions)

Application	2021	2022	2027	CAGR% 2022-2027
Electricity & Steam Generation	8,236.5	8,625.0	12,491.7	7.7
Preheating	4,054.8	4,349.6	7,073.5	10.2
Others	1,812.3	1,870.5	2,505.0	6.0
Total	14,103.6	14,845.2	22,070.1	8.3

Source: BCC Research

Table 11
North American Market for Waste Heat Recovery Systems, by End-Use, Through 2027
($ Millions)

End-Use	2021	2022	2027	CAGR% 2022-2027
Petroleum Refining	3,478.0	3,663.8	5,469.0	8.3
Metal Production & Casting	2,761.5	2,946.8	4,678.9	9.7
Power	3,105.6	3,242.2	4,621.5	7.3
Chemical	2,002.7	2,165.9	3,650.4	11.0
Cement	1,255.2	1,299.0	1,765.6	6.3
Pulp & Paper	564.1	577.5	737.1	5.0
Others	936.5	950.1	1,147.6	3.8
Total	14,103.6	14,845.2	22,070.1	8.3

Source: BCC Research

Europe

In terms of revenue, the industry was valued at $15.6 billion in 2021 and is forecast to reach $22.8 billion by 2027, with gains at 7.0% CAGR. Europe is the second-largest regional market, accounting for 27.01% of the global market. Being the hub of industrial manufacturing, Germany, France, and the U.K. have historically dominated the European market and will continue to do so. Companies focus on serving a large customer base and expanding production and distribution capabilities. Europe is currently experiencing weak economic growth, and the economic slowdown has severely affected government budgets, which, in turn, is affecting end-user markets.

Europe is one of the paradigm regions focused on waste-to-energy as an alternative energy source. Europe has a large number of waste heat recovery unit manufacturers. The European Union has stringent laws for many of these products. These directives provide opportunities to both existing and new entrants in European market to prosper. Thus, a positive regulatory environment and growing demand within European markets for energy conservation have improved industrial sustainability profiles. All manufacturers are striving to make breakthroughs in R&D programs to stay competitive in the market. The regional market is characterized by the presence of leading global players ABB Ltd., Aura GmbH, Climeon AB, Dürr AG, Econotherm, Exergy, and Siemens AG. These players cater to respective demands from industries around the world and most have supply chains in the region.

Table 12
European Market for Waste Heat Recovery Systems, by Application, Through 2027
($ Millions)

Application	2021	2022	2027	CAGR% 2022-2027
Electricity & Steam Generation	8,354.5	8,645.6	11,787.2	6.4
Preheating	5,167.0	5,466.4	8,294.3	8.7
Others	2,065.2	2,108.7	2,673.7	4.9
Total	15,586.7	16,220.6	22,755.3	7.0

Source: BCC Research

Table 13
European Market for Waste Heat Recovery Systems, by End-Use, Through 2027
($ Millions)

End-Use	2021	2022	2027	CAGR% 2022-2027
Petroleum Refining	3,896.7	4,058.4	5,716.1	7.1
Power	3,600.5	3,717.8	5,010.7	6.2
Metal Production & Casting	2,799.4	2,957.0	4,455.5	8.5
Chemical	2,517.3	2,682.9	4,207.5	9.4
Cement	1,223.6	1,249.0	1,581.5	4.8
Pulp & Paper	554.9	559.6	659.9	3.4
Others	994.4	995.9	1,124.1	2.5
Total	15,586.7	16,220.6	22,755.3	7.0

Source: BCC Research

Asia-Pacific

In terms of revenue, this regional industry was valued at $20.8 billion in 2021 and is forecast to reach $34.6 billion through 2027, with gains at 9.4% CAGR. Asia-Pacific is the fastest-growing market for waste heat recovery systems. The region is the world's industrial powerhouse. The region is a net energy importer, and its availability remains a primary concern. In Asia, the urban population constitutes approximately 45% of the total population. With rising consumer spending power in the region and high migration rates, there will be a greater demand alternate energy sources in the near future.

Supplemented by strong government incentive programs, the Asia-Pacific waste heat recovery systems market is expected to lead the market during the forecast period. Low prices, supportive government programs, mainly in the form of incentives, the launch of industry specific programs, and achievable numerical targets have tightened conditions for the global waste heat recovery market.

The anticipated shift of focus of the waste heat recovery market from Europe to the Asia-Pacific region is due to low overhead costs, which will lead to low-priced heat recovery units. China's regulations governing the emission of greenhouse gases, carbon dioxide, and other harmful pollutants have led to a demand for capturing waste heat emitted by end-use industries. Most leading manufacturers are subject to policy measures aimed at social transformation. India offers many benefits in terms of manufacturing. It has a large cohort of young laborers, stable governance, rich natural resources, and a desire for sustainable and responsible development. Key sectors in India that are expected to benefit the most from waste heat recovery industry implementation include petroleum, cement, chemical, pulp and paper, metalworking, etc.

Japan has been moving toward energy-saving equipment to cut costs and invest in future technology. Manufacturing facilities are mainly concentrated in Japanese cities and owners have strong trade partnerships with Southeast Asian economies. Chubu, Tohoku, and Shikoku are a few major regions that feature notable manufacturing bases. Also, the presence of several waste heat recovery unit suppliers in the region will support market growth in the coming years.

Table 14
Asia-Pacific Market for Waste Heat Recovery Systems, by Application, Through 2027
($ Millions)

Application	2021	2022	2027	CAGR% 2022-2027
Electricity & Steam Generation	11,521.9	12,192.7	18,564.8	8.8
Preheating	5,979.3	6,483.6	11,100.8	11.4
Others	3,296.4	3,452.0	4,970.2	7.6
Total	20,797.7	22,128.4	34,635.8	9.4

Source: BCC Research

Table 15
Asia-Pacific Market for Waste Heat Recovery Systems, by End-Use, Through 2027
($ Millions)

End-Use	2021	2022	2027	CAGR% 2022-2027
Metal Production & Casting	4,577.6	4,930.2	8,184.4	10.7
Petroleum Refining	4,879.1	5,195.7	8,167.1	9.5
Power	4,317.6	4,554.0	6,816.3	8.4
Chemical	2,791.0	3,049.3	5,396.3	12.1
Cement	2,059.0	2,157.5	3,117.2	7.6
Pulp & Paper	1,039.9	1,082.1	1,503.2	6.8
Others	1,133.5	1,159.5	1,451.2	4.6
Total	20,797.7	22,128.4	34,635.8	9.4

Source: BCC Research

Rest of the World

In terms of revenue, this regional industry was valued at $7.2 billion in 2021 and is forecast to reach $9.5 billion through 2027, with gains at a 5.2% CAGR. Demand for waste heat recovery in rest of the world is currently in a nascent stage. The region accounted for 12.5% of the share in the global market in terms of value. However, the region is expected to show incremental growth over the forecast period.

The waste heat recovery systems market growth may be seen on a long-term scale due to the availability of raw materials in Brazil and the decreasing cost of technology in the future. Brazil is the leading economy in this region and is home to several industrial manufacturing and mining industries. Latin America is coming out of a period of economic unrest with a slow increase in overall GDP. The proximity of the region to the U.S. plays an important role in its growth. This region is attractive to the industrial sector, due to its strategic advantages and trade agreements. Construction industry expansion in Brazil, Colombia, Peru, and Cuba, along with easy petrochemical trading with Middle East countries, is likely to drive the regional market. Growing oilfield chemicals demand due to expanding drilling and exploration activities are projected to positively influence the waste heat recovery industry.

The Middle East and Africa is an important strategic center for trade and commerce around the world, and it attracts a large pool of foreign investors. Increasing private sector activities, government spending, and low-interest rates in Saudi Arabia, UAE, and other GCC countries will support industrial development in the Middle East and Africa. Saudi Arabia's National Transformation Program insists on economic diversification. The Saudi Arabian government is taking initiatives to develop the domestic industry and encourage global manufacturers to establish local operations there, enabling the transfer of technology and skills. Saudi Arabia's National Renewable Energy Program (NREP) will be the mechanism for delivering the country's Vision 2030, which forecasts energy consumption to increase threefold between 2016 and 2030. Egypt is also repositioning itself as a regional energy leader with strong clean energy investment ambitions and is viewed as an example for neighboring countries across the Middle East and Africa. Despite the large renewable potential, penetration of waste heat recovery in

Africa's energy sector is still very low. However, declining equipment costs are expected to significantly increase waste heat recovery installations in Africa.

Table 16
Rest of the World Market for Waste Heat Recovery Systems, by Application, Through 2027
($ Millions)

Application	2021	2022	2027	CAGR% 2022-2027
Electricity & Steam Generation	4,519.2	4,609.2	5,794.9	4.7
Preheating	1,718.2	1,801.5	2,582.9	7.5
Others	981.8	987.7	1,153.3	3.1
Total	7,219.2	7,398.4	9,531.1	5.2

Source: BCC Research

Table 17
Rest of the World Market for Waste Heat Recovery Systems, by End-Use, Through 2027
($ Millions)

End-Use	2021	2022	2027	CAGR% 2022-2027
Petroleum Refining	1,765.8	1,811.1	2,342.7	5.3
Power	1,563.7	1,589.2	1,961.5	4.3
Metal Production & Casting	1,316.1	1,368.7	1,891.9	6.7
Chemical	838.9	886.3	1,313.4	8.2
Cement	750.8	758.3	905.5	3.6
Pulp & Paper	407.9	409.9	475.6	3.0
Others	576.1	574.9	640.5	2.2
Total	7,219.2	7,398.4	9,531.1	5.2

Source: BCC Research

Chapter 8

Competitive Landscape

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Chapter 8: Competitive Landscape

Company Market Share Analysis for Waste Heat Recovery Systems

Table 18
Global Waste Heat Recovery Systems Market Shares, by Leading Suppliers, 2021 (%)

Suppliers	Market Share (%)
Large producers (Mitsubishi Heavy Industries Ltd., IHI Corp., Siemens AG, General Electric Co., ABB Ltd., John Wood Group)	43-50
Second-tier producers (Dürr AG, Ormat Technologies, Climeon AB, Echogen, Exergy International)	32-42
Others	15-18

Source: Company websites, BCC Research

The waste heat recovery systems market is consolidated, with major players contributing over one-third of the total industry share. Global manufacturers operating in this market are targeting new product development and R&D investment as key development strategies. Some important trends include technological innovation and supplier consolidation. In developed nations like North America and Europe the need for environmentally friendly balancing power is very high. Moreover, companies in the region are looking forwards on selling heat power as a product, together with product-related services, as well as servicing and spare parts.

The waste heat recovery systems industry is relatively complex and diversified. It is comprised of a wide range of raw material suppliers. Manufacturers are either part of large, diversified companies or present some degree of vertical integration within the industry. To reduce its dependence on individual suppliers, market players strive for dual sourcing of each component. Several large tier companies own the design for all critical, non-standard components, thus further reducing the company's reliance on specific suppliers. Moreover, they strive to have long-term partnerships with global part manufacturers to access high-quality products.

In general, the manufacturers in this industry create considerable value and enjoy leverage over suppliers. Manufacturers in this industry are constantly positioning themselves to gain a competitive advantage via strategic alliances, mergers, and acquisitions. The waste heat recovery systems industry has been trying to diversify from high-volume applications to novel applications where the exhaust temperature is below 230°C. It is anticipated that, as the price of waste heat recovery units' installation approaches certain threshold levels, volume growth will continue to rise.

Most companies have adopted either a strategy of product differentiation via unique processing technology or a strategy of focus that is established on a product-type basis. Entry barriers are high. In some segments, such as petroleum refining, chemical, cement and metal fabrication, regulatory barriers like product testing and approval processes can be significantly high.

Dürr AG. contributed a major chunk of the total industry in 2021. The German based multinational has a leading market position through several strategic acquisitions aimed at increasing industry presence in different geographic locations. In October 2021, Dürr and Uniper jointly offered integrated solutions for waste heat recovery with ORC systems. Both partners see enormous potential for reducing energy consumption in various industrial settings and, thus, are making a significant contribution to decarbonization. Dürr AG has a strong market position and an efficient operational network.

Dürr AG has also been making substantial investments in expanding its geographic reach by setting up new R&D and manufacturing facilities. Furthermore, the company is also actively engaged in new product formulation. For instance, The Cyplan® ORC modules developed by Dürr are the most flexible and technologically sophisticated systems on the market in the < 500 kWel power range. Dürr's Cyplan® ORC technology covers a wide temperature range from 90°C to over 500°C. The high-temperature ORC modules work like electricity-generating heat exchangers, by using waste heat to generate additional electricity and providing useful heat.

IHI Corp. is another manufacturer in the global waste heat recovery systems market. Over the years, the company has established a network of experts, universities, colleges, and independent labs that perform R&D to generate intellectual property to further expand the role of waste heat recovery in new markets. This gives IHI Corp. the ability to lead market changes in the industry and turn customer input into proprietary materials. IHI has developed the "Heat Innovator," a 100-kW class ORC power generation system that consists of an ORC module, a boiler for recovering heat from the exhaust gas of an engine, heat input and rejection cycles, and an overall control system. Gas turbine power plant systems consume fossil fuels as energy resources and generate electricity and high temperature exhaust gas. The Heat Recovery Steam Generator (HRSG) generates steam by recovering the gas turbine exhaust gas energy, and supplies steam to the customer facility as process steam for heat utilization. The company has a strong market position and an efficient operational network with locations around the world.

Ormat Technologies is another major U.S. multinational, with a large sales network globally. The company engages in new product development, increasing its global presence by exporting to customers in other regions. As a vertically integrated company, Ormat offers a full suite of products, from equipment sales to project development and operation. The Ormat Recovered Energy Generation (REG®) unit is based on Organic Rankine Cycle (ORC) technology to take waste heat from industrial processes and convert it to power that can be consumed on-site or sold to the grid.

Waste heat recovery systems manufacturing represents significant value creation. Consumers and suppliers to the industry are constantly trying to vertically integrate into the market. The advantages of such integration include a captive source of raw materials, quality assurance, and shorter supply chains with greater profit realization. These elements of integration have been evident in the industry over the past few years.

Recent Key Developments

Table 19
Global Waste Heat Recovery Systems Market, Recent Key Developments, 2017–2022

Company	Description
Siemens AG	In February 2021, Siemens Energy and Canada's TC Energy have signed an agreement to build a first-of-its-kind waste heat to power facility in Alberta. The plant will have the capacity to capture waste heat from a gas-fired turbine at a pipeline compression station and convert it into emissions-free power. The energy generated by the facility will feed the grid. This will power more than 10,000 homes, offsetting 44,000 tons of greenhouse gases annually. The process is based on advancing Rankine Cycle and uses superficial carbon dioxide as the working fluid to convert the waste heat into power. Because of its properties, sCO_2 can interact more directly with the heat source than water/steam, eliminating the need for a secondary thermal loop, typically required in traditional waste heat recovery systems. In May 2019, Siemens AG and Turboden S.p.A, a subsidiary of Mitsubishi Heavy Industries, jointly launched Heat ReCycle solution. The combination of a gas turbine power plant with ORC technology to convert waste heat into electricity without using water is a response to the market challenges. Heat ReCycle allows remote areas to be provided with highly efficient and reliable power generation. Unmanned operation in isolated regions enables deployment in desolate areas, supporting economic growth in these parts of the world.
Climeon AB	In August 2022, Climeon AB launched its new waste heat recovery product, HeatPower 300 Marine, at SMM Hamburg. Optimized for the maritime industry, Climeon's HeatPower 300 Marine system increases energy efficiency by generating clean, onboard energy from low temperature waste heat.
Dürr AG	In October 2021, Dürr and Uniper jointly offered integrated solutions for waste heat recovery with ORC systems. Both partners see enormous potential for reducing energy consumption in various industrial settings, thus, making a significant contribution to decarbonization
John Wood Group	In October 2017, Wood Group announced that it has completed the acquisition of Amec Foster Wheeler. This transformational acquisition creates a global leader in the delivery of project, engineering, and technical services to energy and industrial markets.

Source: Company websites

Chapter 9

Company Profiles

Chapter 9: Company Profiles

ABB LTD.

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Switzerland
Tel: +41-43-317-71-11
Website: www.global.abb/group/en

Founded in 1883
Headquarters: Zurich, Switzerland.
Full Time Employees: 106,380.

Overview
ABB Ltd. engages in the manufacture and sale of electrification, automation, robotics, and motion products for customers in utilities, industry and transport, and infrastructure in Switzerland and internationally. Its Electrification segment provides electric vehicle charging infrastructure, renewable power solutions, modular substation packages, distribution automation products, switchboard and panelboards, switchgear, UPS solutions, circuit breakers, measuring and sensing devices, control products, wiring accessories, enclosures and cabling systems, and intelligent home and building solutions. It serves aluminum, automotive, buildings and infrastructure, cement, channel partners, chemical, data centers, food and beverage, process automation, life sciences, marine and ports, metals, mining, oil and gas, ports, power generation, printing, pulp and paper, railway, smart cities, water, and wind power industries.

ABB's Waste Heat Recovery System (WHRS) is designed to recover much of the standard heat and friction energy losses. For large vessels with a main propulsion machinery with a mechanical output of over 20MW, it is possible to get more than the standard 50% efficiency from fuel. Recovery of waste heat begins in the exhaust boiler. WHRS' dual pressure exhaust gas boiler efficiently generates steam suitable for electricity generation. For optimum efficiency, it generates steam at high and low pressure. Both the high- and low-pressure steam flows are led through the ship's steam piping system to a condensing steam turbine, which is connected to a generator. The turbine converts the thermal steam energy into mechanical energy to run the generator connected to the propeller shaft.

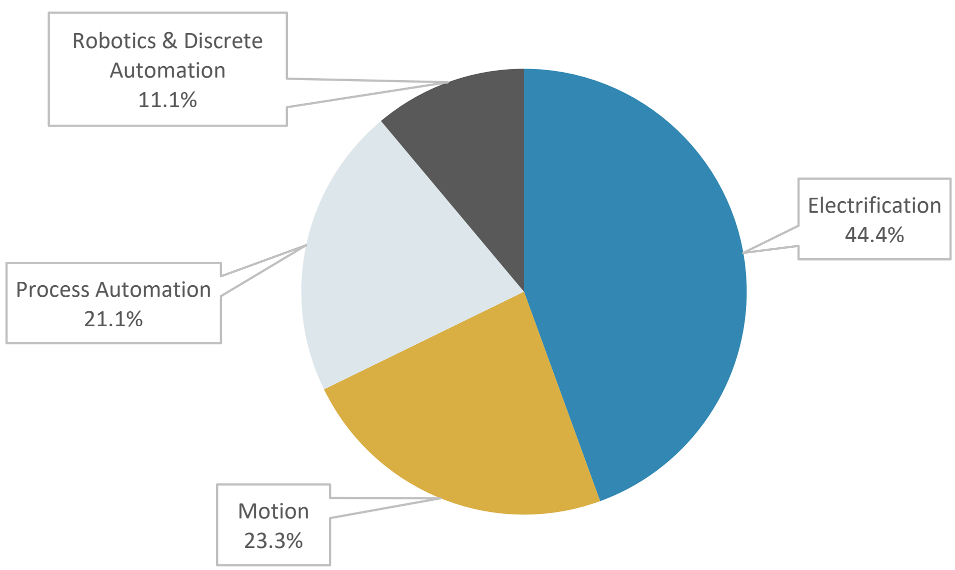
Financial Outlook

Table 20
ABB Ltd.: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$27,978.0 million	$26,134.0 million	$28,945.0 million
EBIT	$2,077.0 million	$1,081.0 million	$5,935.0 million
Gross profit	$8,906.0 million	$7,878.0 million	$9,467.0 million

Source: Company annual report, BCC Research

Figure 11
ABB Ltd.: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

AURA GMBH & CO. KG

Siebeinstrasse 3 (Zone 2)
76726 Germersheim
Germany
Tel: +49-7274-7006-0
Website: www.auragmbh.com

Overview

AURA GmbH & Co. KG is a medium-sized family business founded in 1982. The company has been serving the growing demand for industrial process heat at various locations of the world. The AURA waste heat recovery system for turbines can make the heat contained in turbine flue gases usable for other processes in a temperature range of up to 350°. Lower temperature flue gases can also be utilized with this system by installing an additional afterburner. The system can generate an output of up to 12,000 kW.

BOSCH INDUSTRIEKESSEL GMBH

Nürnberger Straße 73
91710 Gunzenhausen
Germany
Tel: +49-9831-56-0
Website: www.bosch-thermotechnology.com/global/en/commercial-industrial/home/

Overview

For over 150 years Bosch Industriekessel has been engaged in developing customer-specific system solutions for thermal and process heat. To date, more than 120,000 steam, hot water, and heating boiler systems have been commissioned in over 140 countries. The company manufacturing plants in Germany and Austria serve the global market, while it also manufactures in Russia and Czech Republic for regional markets. Its innovative heat recovery systems utilize existing waste heat sources in order to provide, for example, thermal heat or process heat. These hot water and steam boilers are conventionally fired boilers based on a 3-pass design, with an additional separate integrated smoke tube pass for waste heat utilization. They are primarily used in combination with CHP units or gas turbines. The waste heat system uses hot flue gases from upstream combustion processes to assist in the generation of thermal or process heat.

BOUSTEAD INTERNATIONAL HEATERS LTD.

Europa House, Woodlands Court
Albert Drive, Burgess Hill
West Sussex, RH15 9TN
United Kingdom
Tel: +44-1444-237-500
Website: www.bihl.com

Overview

Boustead International Heaters Ltd. (BIHL) was established in 1997. It is a leading designer and supplier of Direct Fired Heaters, Waste Heat Recovery Units (WHRUs), Heat Recovery Steam Generators (HRSGs), Once Through Steam Generators (OTSGs) and Reformers, complete with all support services. The company designs its equipment to international standards such as API 560 or ISO13705 in association with the client specifications and is certified to ISO 9001, 14001, 29001 and 45001 as well as PED and EN1090.

BIH specializes in the design and supply of Waste Heat Recovery Units (WHRUs), offering both onshore and offshore solutions across a wide range of gas turbines. BIH has supplied over 200 WHRUs including over 80 units offshore. BIH in-house experts provide efficient solutions for thermal recovery working within space and weight constraints.

COCHRAN LTD.

Newbie Works, Annan
Dumfries & Galloway, DG12 5QU
Scotland
United Kingdom
Tel: +44-1461-20-2111
Website: www.cochran.co.uk

Overview
Cochran is engaged in manufacturing and supplying industrial steam and hot water boilers. Cochran heat recovery systems harvest waste heat from a broad spectrum of industrial processes to generate 'free' steam or hot water that can be used elsewhere in a facility or sold to third parties, such as a housing developments or nearby businesses. ISO 45001 is applicable to all areas of the Cochran business, from design and manufacture to installation and commissioning of boiler islands, packaged boilers, combustion equipment and heat recovery systems, as well as supporting ancillary equipment and pressure vessels, together with aftermarket service, repairs, training, and operational support.

CLIMEON AB

Torshamnsgatan 44
164 40 Stockholm
Sweden
Tel: +46-101-60-44-33
Website: www.climeon.com

Founded in 2011
Headquarters: Kista, Sweden
Full Time Employees: 50

Overview
Climeon AB provides heat power systems in Sweden, rest of Europe, and Asia. The company's Heat Power System technology harnesses low temperature geothermal energy and energy in waste heat emitted from engines and industrial processes to generate electricity. It also offers Climeon Live software, which is a cloud-based monitoring and control system that allows multiple power plants to be monitored and controlled remotely, and consulting and support services for the Heat Power System. The company serves geothermal, industrial processes, oil and gas, and maritime industries.

Using the principles of an Organic Rankine Cycle, the Climeon Heat Power system exploits the temperature difference between hot and cold water to generate clean electricity.

In August 2022, Climeon AB officially launched its new waste heat recovery product, HeatPower 300 Marine, at SMM Hamburg. Optimized for the maritime industry, Climeon's HeatPower 300 Marine system increases energy efficiency by generating clean, onboard energy from low temperature waste heat.

Financial Outlook

Table 21
Climeon AB: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$111.1 million	$4.1 million	$2.7 million
EBIT	$(10.5) million	$(13.1) million	$(9.7) million
Gross profit	$3.2 million	$1.7 million	$0.38 million

Note: $1 = 10.49 SEK

Source: Company annual report, BCC Research

DÜRR AKTIENGESELLSCHAFT

Carl-Benz-Str. 34
74321 Bietigheim-Bissingen
Germany
Tel: +49-7142-78-0
Website: www.durr-group.com/en/

Founded in 1895
Headquarters: Bietigheim-Bissingen, Germany
Full Time Employees: 18,387

Overview
Dürr Aktiengesellschaft, together with its subsidiaries, operates as a mechanical and plant engineering company worldwide. The company's Clean Technology Systems segment offers exhaust-air purification systems, battery electrode coating systems, and noise abatement systems, as well as ORC technology and services.

The Cyplan® ORC modules developed by Dürr are the most flexible and technologically sophisticated systems on the market in the < 500 kWel power range. Dürr's Cyplan® ORC technology covers a wide temperature range from 90°C to over 500°C. The high-temperature ORC modules work like electricity-generating heat exchangers, by using waste heat to generate additional electricity and providing useful heat. The process is similar to the water/vapor circuit of a conventional power plant. Unlike the open circuit in a steam turbine, however, the circuits in an ORC system are closed and vaporize an organic working fluid with a low boiling point instead of water. The Cyplan® ORC technology is used in geothermal systems, furnaces, solar heat, industrial manufacturing, gas turbines etc.

In October 2021, Dürr and Uniper jointly offered integrated solutions for waste heat recovery with ORC systems. Both partners see enormous potential for reducing energy consumption in various industrial settings, thus, making a significant contribution to decarbonization.

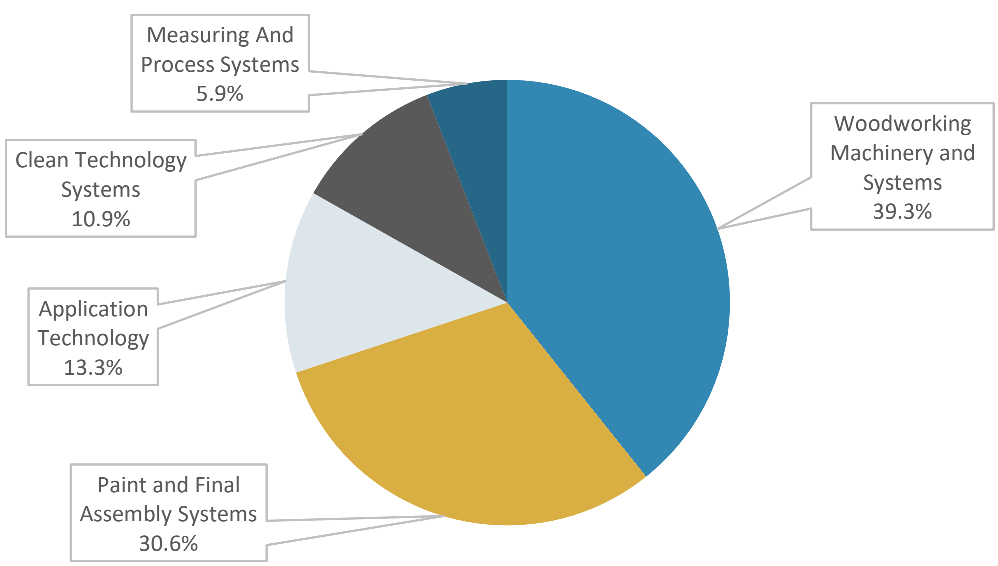
Financial Outlook

Table 22
Dürr Aktiengesellschaft.: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$4,073.2 million	$3,453.4 million	$3,673.5 million
EBIT	$203.5 million	$11.5 million	$182.5 million
Gross profit	$870.6 million	$619.3 million	$851.2 million

Source: Company annual report, BCC Research

Figure 12
Dürr Aktiengesellschaft.: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

ECHOGEN POWER SYSTEMS, LLC

365 Water Street
Akron, OH 44308
United States
Tel: 234/542-4379
Website: www.echogen.com

Overview

Founded in 2007, Echogen is a producer of scalable heat to power systems. Echogen waste heat recovery units capture heat energy which would normally be lost and converts it into higher value, usable power. The company offers a cost-effective solution to monetize customers' otherwise wasted heat. It serves companies that generate significant levels of heat as a byproduct of their processes.

Echogen's heat recovery system is an advanced power generation cycle for usable waste heat recovery. The company achieves this by harnessing CO_2 in a closed loop, which allows it to deliver a more compact, flexible, and low-cost thermal engine. Its heat engine is able to deliver a wide range of power outputs, currently from 1 to 9 MW of net power but feasible up to 500+ MW. Echogen improves the efficiency of industrial processes while increasing financial returns.

ECONOTHERM LTD.

Unit F1, Waterton Road
Bridgend, CF31 3YY
United Kingdom
Tel: +44-1656-658-640
Website: www.econotherm.co.uk

Overview

Since 2007, Econotherm has been engaged in designing and manufacturing heat pipes and heat pipe exchangers for use in diverse areas of industrial waste heat recovery. Econotherm is an associate company of Spirax Sarco Engineering Plc. Econotherm is currently involved in four Horizon 2020 EU funded development projects and has completed two Innovate UK funded projects. Additionally, Econotherm is active on two privately funded development projects in the silicon and marine sectors.

Econotherm provides solutions to complex waste heat recovery applications for industrial users. Its heat pipe exchangers offer many distinct advantages over more common technologies. It has received green technology awards from Shell Oil and UK Carbon Trust. All heat recovery products are made using its patented manufacturing process at production facilities in Wales, United Kingdom.

ENERTIME SA

1, rue du Moulin des BruyEres
Courbevoie 92400
France
Tel: +33-1-75-43-15-40
Website: www.enertime.com

Founded in 2008
Headquarters: Courbevoie, France
Full Time Employees: 30

Overview

Enertime SA designs, develops, and implements Organic Rankine Cycle modules to produce renewable or CO_2-free electricity from heat. The company also develops high temperature, heat pumps, gas expanders, and turbomachinery. It serves waste heat recovery, geothermal, waste-to-energy, district heating, and oil and gas industries.

Many industrial processes generate the hot flue gases that can be cooled before being released into the atmosphere. This heat can be recovered to be used to generate electricity, mechanical energy, and thermal energy at low cost and without CO_2 emissions.

Financial Outlook

Table 23
Enertime SA: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$1.9 million	$2.6 million	$2.3 million
EBIT	$(1.4) million	$(2.3) million	$(2.4) million
Gross profit	$1.6 million	$1.6 million	$1.9 million

Source: Company annual report, BCC Research

EXERGY INTERNATIONAL SRL

Street Santa Rita, 14
21057 Olgiate Olona (VA)
Italy
Tel: +39-0331-1817-711
Website: www.exergy-orc.com

Overview

Exergy International SRL is a leading provider of clean energy technologies. Exergy is engaged in designing, engineering, manufacturing, and maintenance of Organic Rankine Cycle (ORC) systems for electricity production from renewable energy (geothermal, biomass, solar) and waste heat resources from industrial processes, gas turbines, and engines. Exergy provides renewable energy equipment. The company offers biomass, geothermal, solar, and heat recovery equipment. In 2009, the company launched the innovative Radial Outflow Turbine technology and set new standards for the development of the 21st century ORC industry. After its founding in 2009, Exergy became a subsidiary of the Italian Maccaferri Industrial Group in 2011. In 2019, Exergy acquired Nanjing TICA Thermal Technology Co., Ltd. Through this new strategic alliance, Exergy can offer the global market a vast and competitive range of clean technologies and green power generation solutions. Exergy exports and implements its technology worldwide with a particular focus on high growth potential markets.

For decades, the traditional choice of expander for ORC cycles worldwide has been to employ axial or radial inflow turbines. Exergy introduced the innovative patented Radial Outflow Turbine (ROT) and is unique in applying this extremely efficient technology at a vast range of ORC power plants with additional advantages. By converting thermal energy to electricity from low to medium-high temperatures, ORCs are suitable for a wide range of applications, given a plant size between 100 kW ad 50 MWe.

Recovering exhaust heat from gas turbines and internal combustion engines is an easy way to optimize efficiency and performance while reducing the environmental impact of power generation plants widely employed for processing and refining in the oil & gas sector and at electricity production stations. In November 2022, Exergy International announced the launch of a new corporate rebrand, to reflect the transformation undergone by the company in a decade from an innovative start-up to a leading ORC provider worldwide with almost 500 MWe in portfolio.

FORBES MARSHALL

A-34/35, MIDC Industrial Area
H Block, Pimpri
Pune, Maharashtra, 411 018
India
Tel: +91-20-2744-2020
Website: www.forbesmarshall.com

Overview
Forbes Marshall is a multinational engineering company specializing in steam engineering and control instrumentation. Forbes Marshall Exhaust Gas/Waste Heat Recovery Boilers (WHRB) or Exhaust Gas Boilers are fully packaged smoke tube industrial boilers equipped with advanced instrumentation to deliver maximum possible heat recovery. These boilers are ideal to recover heat from gen sets, incinerators, blast furnace exhausts etc. They enhance system efficiency and help save fuel and money.

GENERAL ELECTRIC CO. (GE)

5 Necco Street
Boston, MA 02210
United States
Tel: 617/443-3000
Website: www.ge.com

Founded in 1892
Headquarters: Boston, Massachusetts.
Full Time Employees: 168,000.

Overview

General Electric Co. operates as a high-tech industrial company in Europe, China, Asia, the Americas, the Middle East, and Africa. It operates through four segments: Power, Renewable Energy, Aviation, and Healthcare. The Power segment offers gas and steam turbines, full balance of plant, upgrade, and service solutions, as well as data-leveraging software for power generation, industrial, government, and other customers. The Renewables segment provides various solutions for its customers through combining onshore and offshore wind, blade manufacturing, grid solutions, hydro, storage, hybrid renewables, and digital services offerings. The Aviation segment designs and produces commercial and military aircraft engines, integrated engine components, electric power, and mechanical aircraft systems, and provides aftermarket services. The Healthcare segment provides healthcare technologies to developed and emerging markets in medical imaging, digital solutions, patient monitoring and diagnostics, and drug discovery and performance improvement solutions that are the building blocks of precision health to hospitals and medical facilities.

With over 100 years of boiler experience and more than 1,300 Heat Recovery Steam Generators (HRSG) installed worldwide, GE is a leading HRSG OEM. Its product portfolio includes various configurations, including GE's Once Through technology, as well as several modular construction options that deliver the degree of prefabrication that best fits specific project requirements.

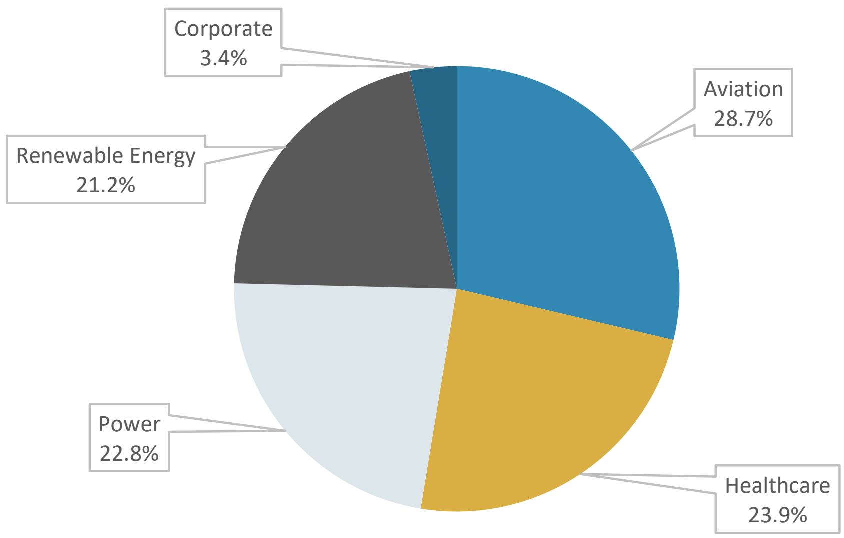
Financial Outlook

Table 24
General Electric Co.: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$95,215.0 million	$79,619.0 million	$74,196.0 million
EBIT	$5,376.0 million	$10,016.0 million	$(1,807.0) million
Gross profit	$25,187.0 million	$19,198.0 million	$20,300.0 million

Source: Company annual report, BCC Research

Figure 13
General Electric Co.: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

IHI CORP.

Toyosu IHI Building
1-1, Toyosu 3-chome, Koto-ku
Tokyo 135-8710
Japan
Tel: +81-03-6204-7800
Website: www.ihi.co.jp

Founded in 1853
Headquarters: Tokyo, Japan
Full Time Employees: 28,801

Overview

IHI Corp. operates in resources, energy, and environment; social infrastructure and offshore facilities; industrial systems and general-purpose machinery; aero engine, space, and defense; and other business areas in Japan and internationally. It provides carbon reduction solutions; gas turbines and engines, and diesel engines for land use, and high-speed ships and other marine vessels; LNG receiving terminals and storage tanks; and equipment for various plants. The company also constructs natural gas liquefaction, oil refining, petrochemicals, LPG, and other process plants; develops and constructs nuclear fuel cycle systems; provides components for boiling and pressurized water reactors; and constructs bridges and steel structures. It offers factory, heat treatment and surface engineering solutions; aero engines; air traffic control systems; and rocket systems and space exploration solutions. The company was formerly known as Ishikawajima-Harima Heavy Industries Co., Ltd and changed its name to IHI Corp. in 2007.

IHI has developed the “Heat Innovator,” a 100-kW class ORC power generation system that consists of an ORC module, a boiler for recovering heat from the exhaust gas of an engine, heat input and rejection cycles, and an overall control system. The gas turbine power plant system consumes fossil fuels as energy resources and generates electricity and high temperature exhaust gas. The HRSG generates steam by recovering the gas turbine exhaust gas energy, and supplies steam to the customer facility as process steam for heat utilization.

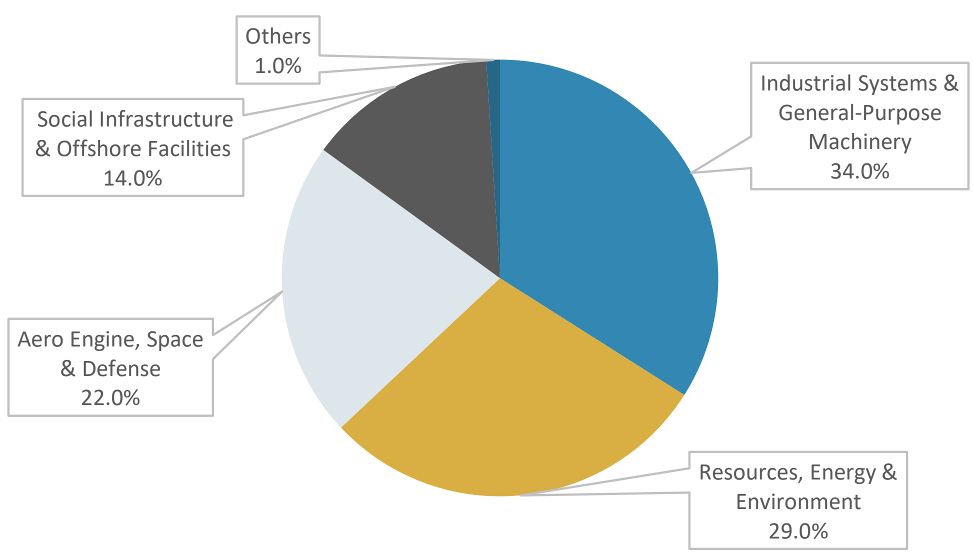
Financial Outlook

Table 25
IHI Corp.: Company Financial Highlights, 2020–2022
($ Millions)

Particulars	2020	2021	2022
Sales	$9,981.4 million	$8,011.8 million	$8,443.7 million
EBIT	$307.6 million	$235.5 million	$664.1 million
Gross profit	$1,833.7 million	$1,295.6 million	$1,507.5 million

Source: Company annual report, BCC Research

Figure 14
IHI Corp.: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

JOHN WOOD GROUP PLC

15 Justice Mill Lane
Aberdeen, AB11 6EQ
United Kingdom
Tel: +44-12-2485-1000
Website: www.woodplc.com

Founded in 1961
Headquarters: Aberdeen, the United Kingdom.
Full Time Employees: 33,100.

Overview
John Wood Group Plc, together with its subsidiaries, provides consulting, project management, and engineering solutions worldwide. This British multinational energy services company operates through four segments: Projects, Operations, Consulting, and Investment. The company offers engineering solutions, including decarbonization and optimization in energy and industry, and renewable energy, future fuels, and low carbon solutions. It also provides environment and infrastructure solutions comprising environmental studies and compliance, environmental remediation, public infrastructure, and geotechnical and materials services; clean energy solutions; mine planning and design, mineral processing and metallurgy, mineral resources, and project assessment services; and automation and control solutions, such as asset protection and facility and process automation solutions, as well as simulation, learning, and virtual systems. It serves oil and gas, infrastructure, industrial and manufacturing, mining, power, and government sectors.

Wood Group has worldwide experience in this specialized field, primarily with developing systems which cool hot gases and where the heat removed is used as additional energy. Significant cost savings can be made by recovering heat that would otherwise be lost during operations. Recovery of process heat for further use achieves the objectives of fuel economy and improved environmental emissions.

In October 2017, Wood Group announced that it had completed the acquisition of Amec Foster Wheeler. This transformational acquisition creates a global leader in the delivery of project, engineering, and technical services to energy and industrial markets.

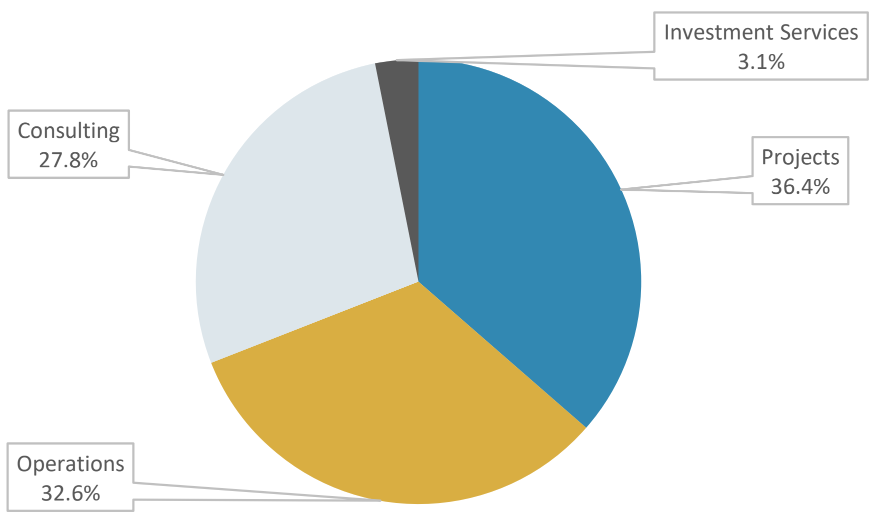
Financial Outlook

Table 26
John Wood Group Plc: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$9,890.4 million	$7,564.3 million	$6,400.6 million
EBIT	$309.1 million	$(23.4) million	$28.2 million
Gross profit	$1,121.9 million	$727.7 million	$684.8 million

Source: Company annual report, BCC Research

Figure 15
John Wood Group Plc: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

MITSUBISHI HEAVY INDUSTRIES, LTD.

2-3, Marunouchi 3-chome
Chiyoda-ku, Tokyo 100-8332
Japan
Tel: +81-03-6275-6200
Website: www.mhi.com

Founded in 1884
Headquarters: Tokyo, Japan.
Full Time Employees: 77,991.

Overview

Mitsubishi Heavy Industries, Ltd. manufactures and sells heavy machinery worldwide. The company operates through Energy Systems; Plants & Infrastructure Systems; Logistics, Thermal & Drive Systems; and Aircraft, Defense & Space segments. It offers thermal, renewable energy, nuclear, engine, nuclear power generation, and chemical power plants, lithium-ion battery products, and oil and gas production plants, as well as fuel cells; civil aircrafts and engines, aviation equipment, and maintenance, repair, and overhaul of aircrafts; and launch vehicles and services, rocket engines, reaction control systems, space stations, rocket launchers, rocket engine combustion test facilities, and electronic parts. Further, the company provides gas holders, vibration control systems, water pipes, tunnel excavation machinery, and cybersecurity solutions for industrial control systems; special vehicles, naval ship & maritime systems, defense aircrafts, helicopters, defense aeroengines, and guided weapon systems; and CO2 capture plants, as well as providing after-sales services.

Mitsubishi Heavy Industries Marine Machinery & Equipment Co., Ltd. has developed the state-of-the-art binary power generation system based on Organic Rankine Cycle technology (WHR-ORC system) mainly for waste heat recovery from sulfur free fuel burning engines, which are becoming mainstream in the transition to a low-carbon and decarbonized society. It consists of a lineup of three models that cover rated outputs of between 200kW and 700kW and is capable of being used on a wide range of vessel types. The WHR-ORC system is the most advanced waste heat recovery system with high thermal efficiency characterized by being oil-free, fully sealed, and maintenance-free. It was developed by combining MHI-MME's marine waste heat recovery system – which includes waste gas economizer, steam turbine, and power turbine (gas turbine) that have accumulated many achievements to date – with the superior centrifugal chilling technology possessed by MHI Group company Mitsubishi Heavy Industries Thermal Systems, Ltd.

Mitsubishi Power has manufactured and delivered HRSG with high reliability to accommodate the demand for higher gas turbine capacities as well as for higher temperatures and pressures in steam, associated with the higher efficiency and output of power plants. Mitsubishi Power offers two types of HRSG, a vertical gas flow type (Vertical HRSG) and a horizontal gas flow type (Horizontal HRSG). In addition, by combining a vast array of established construction methods for assembly and installation, Mitsubishi Power can develop proposals with specifications optimized to the transportation and site requirements.

Turboden, a Mitsubishi Heavy Industries group company, is an Italian firm and a global leader in the design, manufacture, and maintenance of Organic Rankine Cycle (ORC) systems, highly suitable for distributed generation. ORC systems can generate electric and thermal power exploiting multiple sources, such as renewables (biomass, geothermal energy, solar energy), traditional fuels and waste heat from industrial processes, waste incinerators, engines, or gas turbines.

Financial Outlook

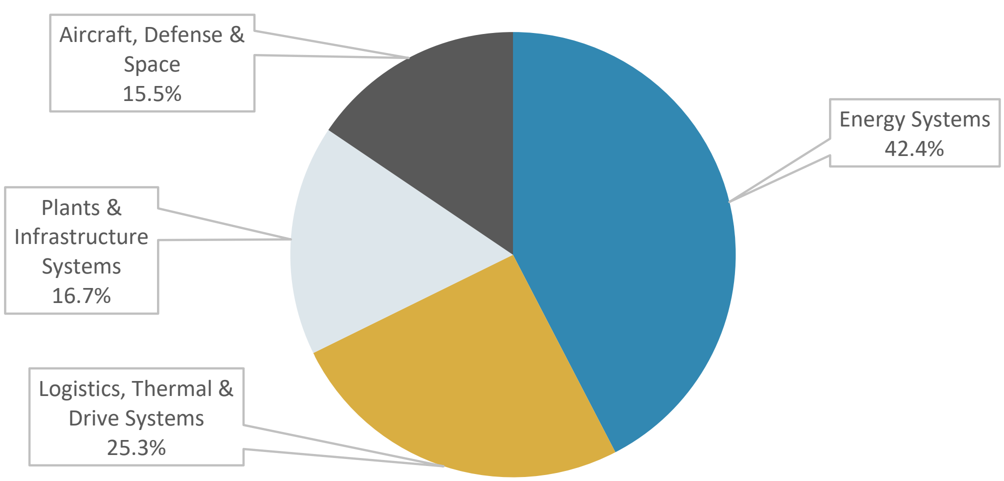
Table 27
Mitsubishi Heavy Industries, Ltd.: Company Financial Highlights, 2020–2022
($ Millions)

Particulars	2020	2021	2022
Sales	$29,286.0 million	$26,811.8 million	$27,973.7 million
EBIT	$(129.9) million	$476.5 million	$1,392.4 million
Gross profit	$5,145.3 million	$4,228.2 million	$4,753.1 million

Note: 1$ = 138 JPY

Source: Company annual report, BCC Research

Figure 16
Mitsubishi Heavy Industries Ltd.: Revenue Share, by Business Segment, 2022
(%)



Source: Company annual report, BCC Research

ORMAT TECHNOLOGIES, INC.

6140 Plumas Street
Reno, NV 89519-6075
United States
Tel: 775/356-9029
Website: www.ormat.com

Founded in 1965
Headquarters: Reno, Nevada
Full Time Employees: 1,385

Overview

Ormat Technologies, Inc. engages in the geothermal and recovered energy power business in the United States, Indonesia, Kenya, Turkey, Chile, Guadeloupe, Guatemala, Ethiopia, New Zealand, Honduras, and internationally. It operates through three segments: Electricity, Product, and Energy Storage. The Electricity segment develops, builds, owns, and operates geothermal, solar photovoltaic, and recovered energy-based power plants, and sells electricity. The Product segment designs, manufactures, and sells equipment for geothermal, recovered energy-based electricity generation, and remote power units, such as fossil fuel powered turbogenerators and heavy duty direct-current generators. It also provides services relating to the engineering, procurement, construction, operation, and maintenance of geothermal and recovered energy-based power plants. The Product segment serves contractors, developers, owners, and operators of geothermal power plants, and also serves owners and operators of interstate natural gas pipelines, gas processing plants, and cement plants, as well as companies in other energy-intensive industrial processes. The Energy Storage segment offers energy storage and related services, as well as services relating to the engineering, procurement, construction, operation, and maintenance of energy storage units.

As a vertically integrated company, Ormat offers a full suite of products, from equipment sales to project development and operation. It provides custom solutions across industries that are designed to help companies reduce emissions and generate carbon credits without interfering with the original plant operation. Ormat's OEC is based on the Organic Rankine Cycle – a thermodynamic process that transfers heat to an organic motive fluid that is vaporized. The expansion pressure inside a vapor turbine drives a generator or additional compressor coupled to the unit. The company has more than 71 U.S. patents to protect its OEC power plant systems and equipment designs.

The Ormat Recovered Energy Generation (REG®) unit is based on Organic Rankine Cycle technology to take waste heat from industrial processes and convert it to power that can be consumed on-site or sold to the grid. Its REG® is simple and proven based on OEC (Ormat Energy Conversion) technology. Ormat has developed and implemented waste heat recovery projects worldwide and owns a variety of its own plants in the U.S.

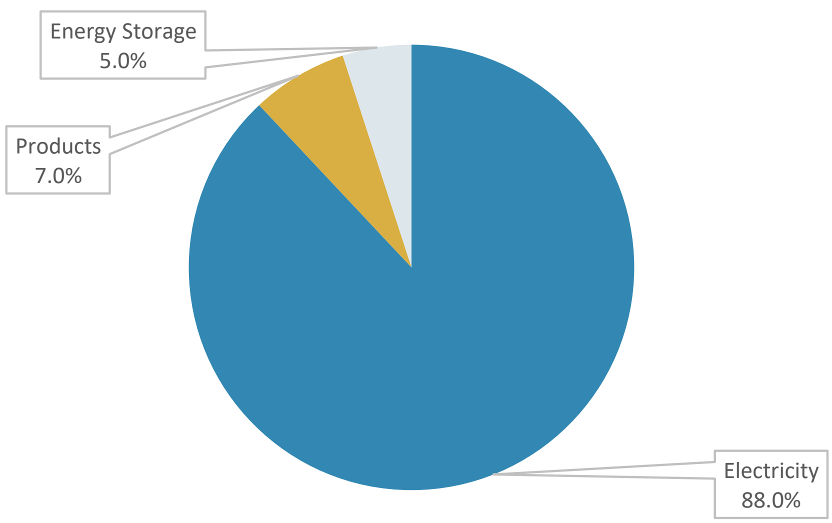
Financial Outlook

Table 28
Ormat Technologies, Inc.: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$746.0 million	$705.3 million	$663.1 million
EBIT	$217.7 million	$246.7 million	$186.2 million
Gross profit	$269.3 million	$276.3 million	$264.3 million

Source: Company annual report, BCC Research

Figure 17
Ormat Technologies, Inc.: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

RENTECH BOILER SYSTEMS, INC.

5025 East Business 20
Abilene, TX 79601
United States
Tel: 325/672-3400
Website: www.rentechboilers.com

Overview

Rentech was founded in 1996. Rentech designs, manufactures, and with its services group repairs boilers for a variety of industries across the U.S. and in global markets. It manufactures industrial package water tube boilers, heat recovery steam generators (HRSG), and waste heat boilers of water tube and fire tube type. Rentech custom designs all its boilers to fit the application and meet customer specifications. Rentech's expansive manufacturing facility located in Abilene, Texas is one of the most complete and highly integrated boiler facilities. It builds boilers to comply with ASME Section I, ASME Section VIII, Pressure Equipment Directives (PED/CE), CRN, Australian Work Safe, DOSH, and many other international codes and standards.

RENTECH Boiler Systems offers a full range of custom designed waste heat recovery boiler systems to meet most demanding project requirements. Its fire tube single shell, single pass boiler is a simple, low cost solution for sub-critical waste heat boiler applications.

SIEMENS AKTIENGESELLSCHAFT

Werner-von-Siemens-Strasse 1
Munich 80333
Germany
Tel: +49-89-636-00
Website: www.siemens.com

Founded in 1847
Headquarters: Munich, Germany
Full Time Employees: 311,000

Overview

Siemens Aktiengesellschaft, a technology company, focuses on the areas of automation and digitalization in Europe, Commonwealth of Independent States, Africa, the Middle East, the Americas, Asia, and Australia. It operates through Digital Industries, Smart Infrastructure, Mobility, Siemens Healthineers, and Siemens Financial Services segments. The Smart Infrastructure segment offers products, systems, solutions, services, and software to support sustainable transition in energy generation from fossil and renewable sources; sustainable buildings and communities; and buildings, electrification, and electrical products.

Siemens Energy Heat Transfer Technology is the leading OEM HRSG supplier, previously operating under the NEM brand name. The company is engaged in providing the boilers behind many gas turbines, varying in size from 10 MW up to the largest machines, and for all kinds of fuels and applications. It offers a wide variety of boiler designs in order to be able to meet specific requirements, focusing on the lowest total installed and/or operational costs. The Waste Heat Recovery Unit (WHRU) offers an efficient recovery method of thermal energy from gas turbine exhaust gases. The recovered thermal energy can be used for district heating, process steam heating, or for the generation of electrical power.

Heat Recycle is a gas turbine-based power plant with an Organic Rankine Cycle (ORC) as bottoming cycle. These power plants are designed specifically to reduce both CAPEX and OPEX compared to a water/steam cycle, while maintaining a relatively high level of efficiency.

Strategic Outlook

- In February 2021, Siemens Energy and Canada's TC Energy signed an agreement to build a first-of-its-kind waste heat to power facility in Alberta. The plant will have the capacity to capture waste heat from a gas-fired turbine at a pipeline compression station and convert it into emissions-free power. The energy generated by the facility will feed the grid. This will power more than 10,000 homes, offsetting 44,000t of greenhouse gases annually. The process is based on advancing Rankine cycle and uses superficial carbon dioxide as the working fluid to convert the waste heat into power. Because of its properties, sCO_2 can interact more directly with the heat source than water/steam, eliminating the need for a secondary thermal loop, typically required in traditional waste heat recovery systems.

- In May 2019, Siemens AG and Turboden S.p.A, a subsidiary of Mitsubishi Heavy Industries, jointly launched Heat ReCycle solution. The combination of a gas turbine power plant with ORC technology to convert waste heat into electricity without using water is a response to the market challenges. Heat ReCycle allows remote areas to be provided with highly efficient and reliable power generation. Unmanned operation in isolated regions enables deployment in desolate areas, supporting economic growth in these parts of the world.

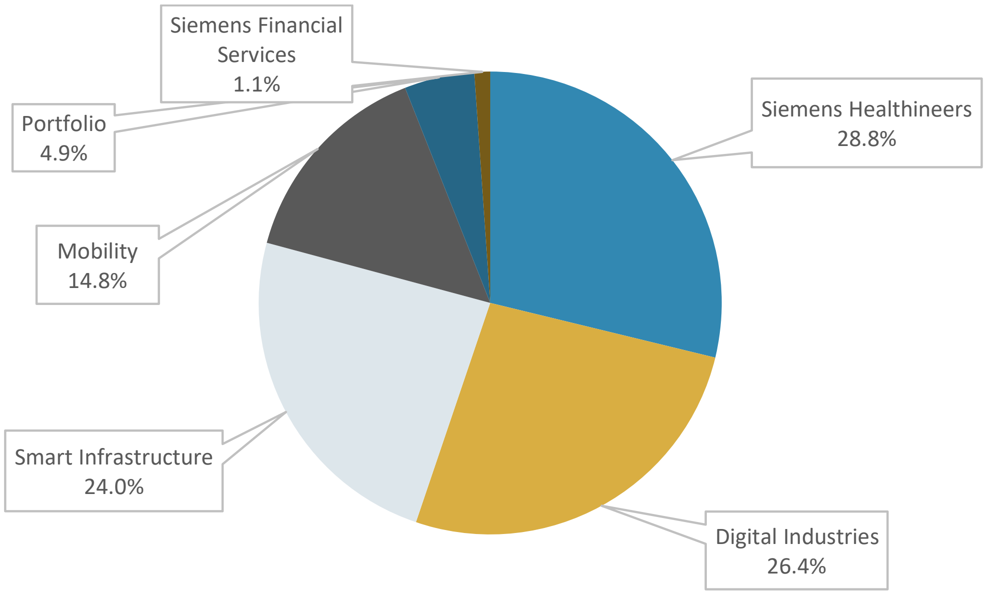
Financial Outlook

Table 29
Siemens AG: Company Financial Highlights, 2019–2021
($ Millions)

Particulars	2019	2020	2021
Sales	$90,202.6 million	$59,345.4 million	$64,669.3 million
EBIT	$8,980.9 million	$6,737.4 million	$8,454.3 million
Gross profit	$26,928.1 million	$20,965.4 million	$23,616.0 million

Source: Company annual report, BCC Research

Figure 18
Siemens AG: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

THERMAX LTD.

Thermax House
14, Mumbai-Pune Road
Wakdewadi, Pune 411 003
Maharashtra
India
Tel: +91-20-6605-1200
Website: www.thermaxglobal.com

Founded in 1966
Headquarters: Pune, India
Full Time Employees: 4,634

Overview

Thermax Ltd. provides energy, environment, and chemical solutions in India and internationally. It operates through three segments: Energy, Environment, and Chemical. The company offers vapor absorption and hybrid chillers, heat pumps, chiller-heaters, and heat transformers; evaporative condensers, closed loop cooling towers, adiabatic and dry coolers, radiators, and air-cooled heat exchangers and condensers; EPC solutions, such as cogen or trigen power plants, air cooled condensers, bio-CNG plants, waste heat recovery power plants, and refinery process units; and renewable energy solutions. It serves agriculture, automobiles, and auto components, aviation, biotechnology, cement, commercial/construction, engineering, and capital goods, as well as food and beverages, fast moving consumer goods, healthcare, hospitality, infrastructure, IT and datacenter, manufacturing, medical devices, metals, oil and gas, paper and pulp, pharmaceuticals, power, renewable energy, rubber, telecommunications, textiles, and wood industries. Thermax Ltd. is a subsidiary of RDA Holdings Pvt. Ltd.

Thermax has been at the forefront of commissioning Waste Heat Recovery (WHR) power plants for more than a decade. WHR power plants use waste heat from various sources like cement kilns, blast furnaces, sponge iron kilns, gas turbines etc. and convert these to power, thereby reducing consumption of fossil fuels. The HRSGs incorporate latest advances in thermal technology, offering benefits such as multiple pressure levels and unprecedented reliability. The steam generated by the HRSG can be used for process heating or generating electricity in a steam turbine. Such units are installed on gas turbines ranging from below 1 MW up to 320 MW.

WHRUs are engineered to recover waste heat from the exhaust of gas turbines or reciprocating engines. The heating media could be water, glycol mixture, thermal oil, or water, depending on the application. The company has built a number of heat recovery units downstream of gas turbines, gas engines/oil fired engines. The heat recovery units have been configured on engine size ranging up to 160 MW. These units are installed on offshore platforms, floating LNG, floating production storage and offloading vessels (FPSO), and onshore gas processing plants. The company provides energy solutions to utilize waste heat from various processes and applications to improve overall energy balance in ferrous metals, non-ferrous metals, cement, refinery, chemical, oil & gas, glass, and other sectors. These offerings include a variety of customized, turnkey solutions to generate steam and power.

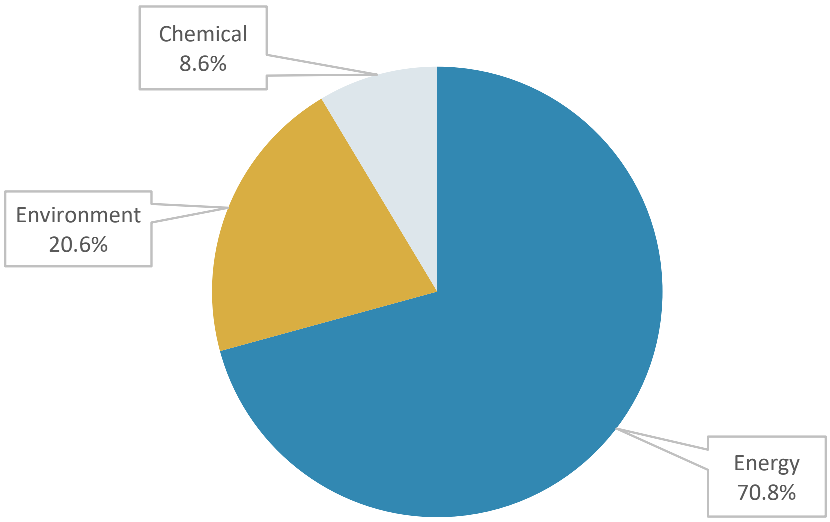
Financial Outlook

Table 30
Thermax Ltd.: Company Financial Highlights, 2020–2022
($ Millions)

Particulars	2020	2021	2022
Sales	$692.4 million	$576.6 million	$742.4 million
EBIT	$47.6 million	$36.2 million	$53.3 million
Gross profit	$216.8 million	$182.1 million	$211.8 million

Source: Company annual report, BCC Research

Figure 19
Thermax Ltd.: Revenue Share, by Business Segment, 2021
(%)



Source: Company annual report, BCC Research

Chapter 10

Project Scope and Methodology

Chapter 10: Project Scope and Methodology

Overview

The process of "heat integration," or utilizing heat energy that would otherwise be wasted or just released into the atmosphere, is known as waste heat recovery. Industrial plants can increase energy efficiency while lowering energy costs and CO_2 emissions by collecting waste heat. Energy-intensive operations like those carried out in steel mills, glass furnaces, cement kilns, and refineries all produce waste streams and hot exhaust gases that can be used to produce electricity. The main benefit of waste heat recovery systems is that they use waste heat from existing thermal operations to generate electricity or mechanical power instead of using extra fuel directly for this purpose.

Scope of Report

In this report, the market has been segmented based on application, end-use industry, and geography. The report provides an overview of the global waste heat recovery systems market and analyses market trends. Using 2021 as the base year, the report provides estimated market data for the forecast period, 2022-2027. Market values have been estimated based on the economic benefits realized in $ millions of waste heat recovery systems providers.

The report covers the market for the user base, across different regions. It also highlights major trends and challenges that affect the market and the vendor landscape. The report estimates the global market for waste heat recovery systems in 2021 and provides projections for the expected market size through 2027. The scope of the study includes entire waste heat recovery landscape including associated services and technologies like Steam Rankine Cycle (SRC), Organic Rankine Cycle (ORC), Kalina Cycle etc.

This report considers the impact of COVID-19. In 2020, the growth rate of manufacturing industries around the world was severely affected by the pandemic. The COVID-19 pandemic halted progress in every regional economy. Various governments around the world are taking measures to contain the economic slowdown.

Study Goals and Objectives

The goal of this report is to provide an up-to-date analysis of current and future markets for waste heat recovery systems. The study provides a comprehensive accounting of global waste heat recovery systems markets in a multi-client format. It presents a thorough and up-to-date global assessment of the market and the business of waste heat recovery. This will help industry participants, suppliers, government bodies, associations, and customers make the informed decisions needed to compete and succeed in the marketplace. In addition, the report studies in detail new developments in the waste heat recovery industry regarding continuous improvements in environmental performance.

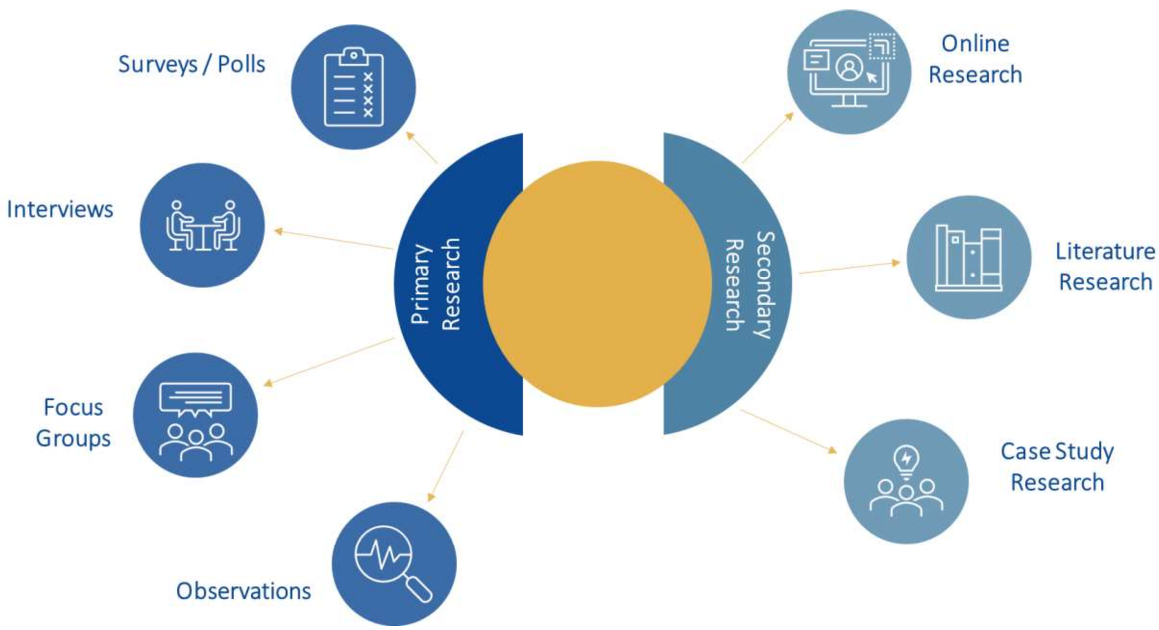
The goals and objectives of this study are to:

- Identify trends that will affect the waste heat recovery systems and its major end-use applications.
- Review, analyze, and forecast specific end markets and quantify the market for waste heat recovery systems.
- Analyze and forecast market developments that will affect high-volume applications.
- Calculate the current global market size and project growth over the next five years, based on the previous year's market trends.
- Examine region-specific developments in the industry.
- Assess the long-term outlook for the waste heat recovery industry.
- Profile prominent product manufacturers and suppliers.

Methodology

This report is a descriptive study with a trend analysis of the global market for waste heat recovery systems that uses quantitative and qualitative approaches. BCC Research conducted a comprehensive literature search that included technical newsletters, journals, open-access academic literature, and many other sources. Primary and secondary sources, including interviews with industry vendors, white papers, business journals, public financial proceedings, and historical market data from the internet, were also taken into consideration. To understand the market, major sources (the International Monetary Fund, The International Energy Agency, U.S. Energy Information Administration, and companies across the waste heat recovery market) were also considered. The impact of COVID-19 on global economies was assessed using data gathered from the World Health Organization (WHO).

Figure 20
Research Methodology Applied in the Analysis of the Global Market for Waste Heat Recovery Systems



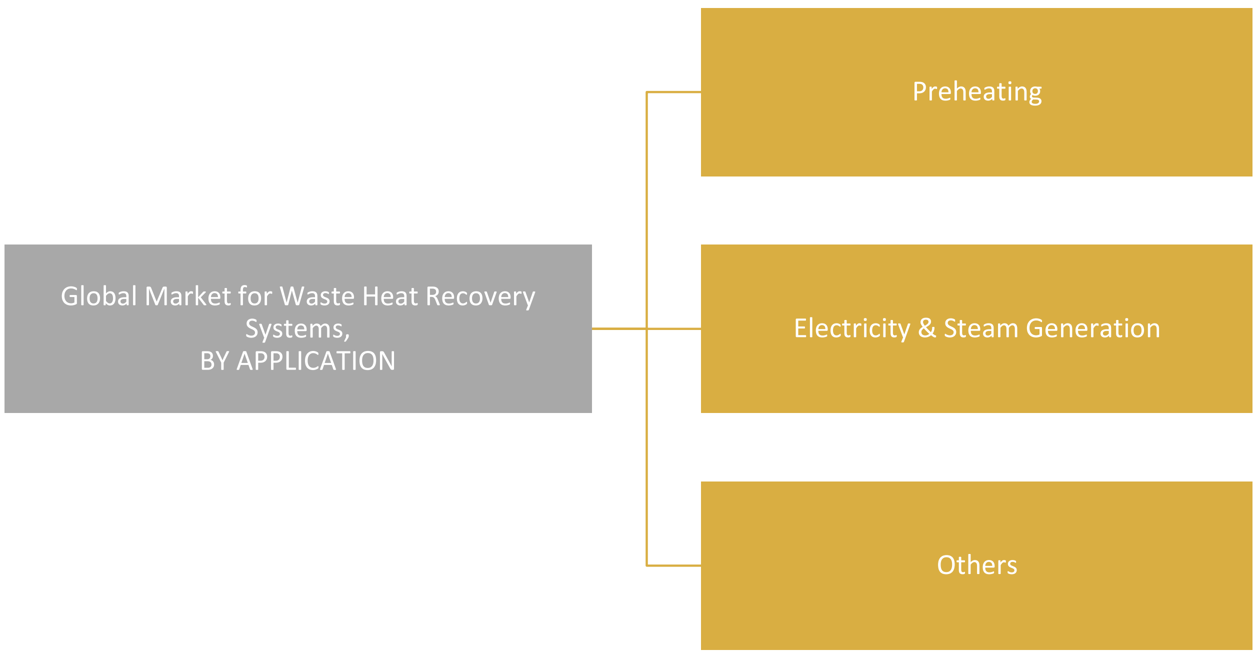
Source: BCC Research

Geographic Breakdown

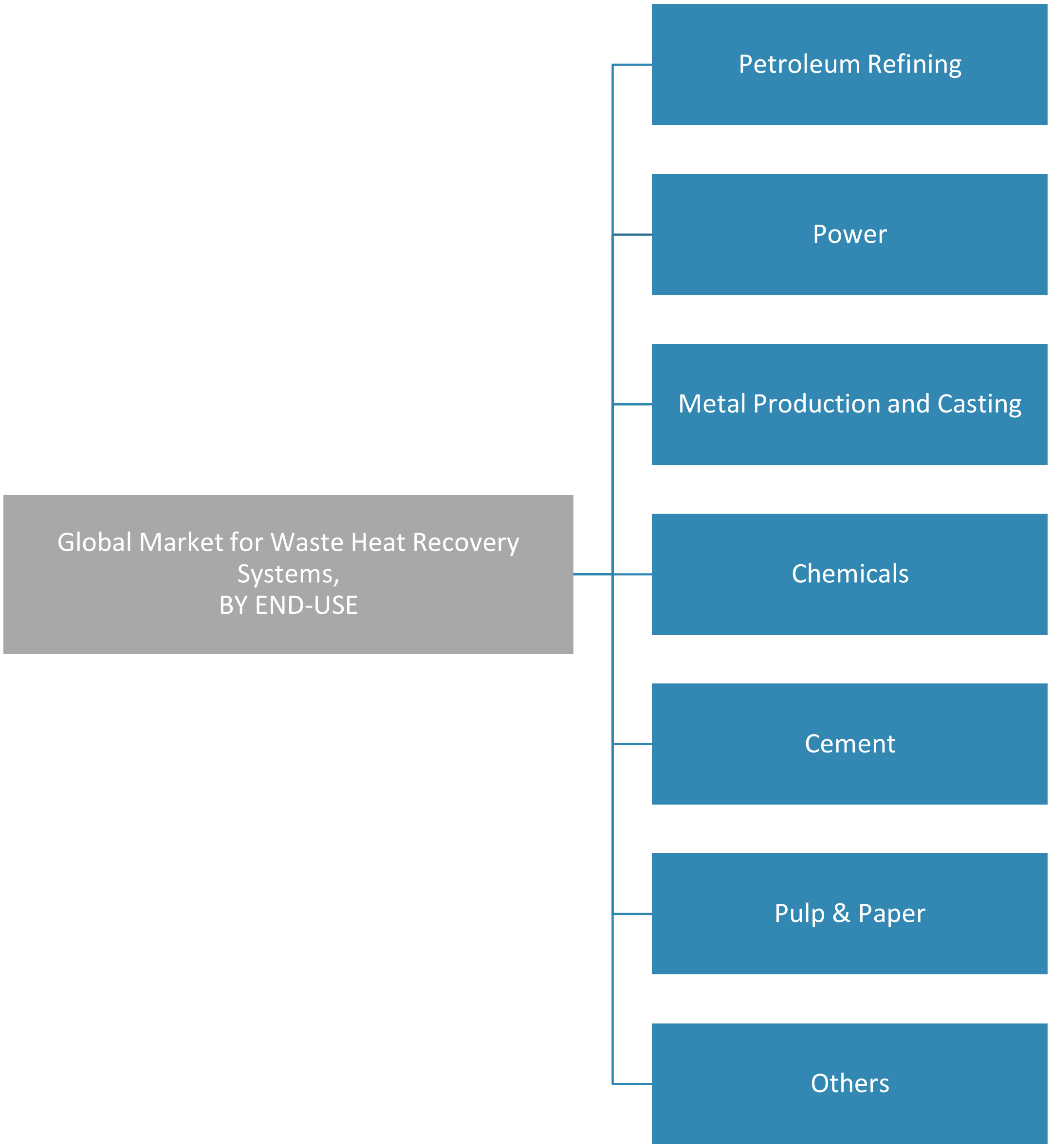
In this report, the geographic regions considered for market analysis include and only include the following:

- North America.
- Europe.
- Asia-Pacific.
- Rest of the World (RoW).

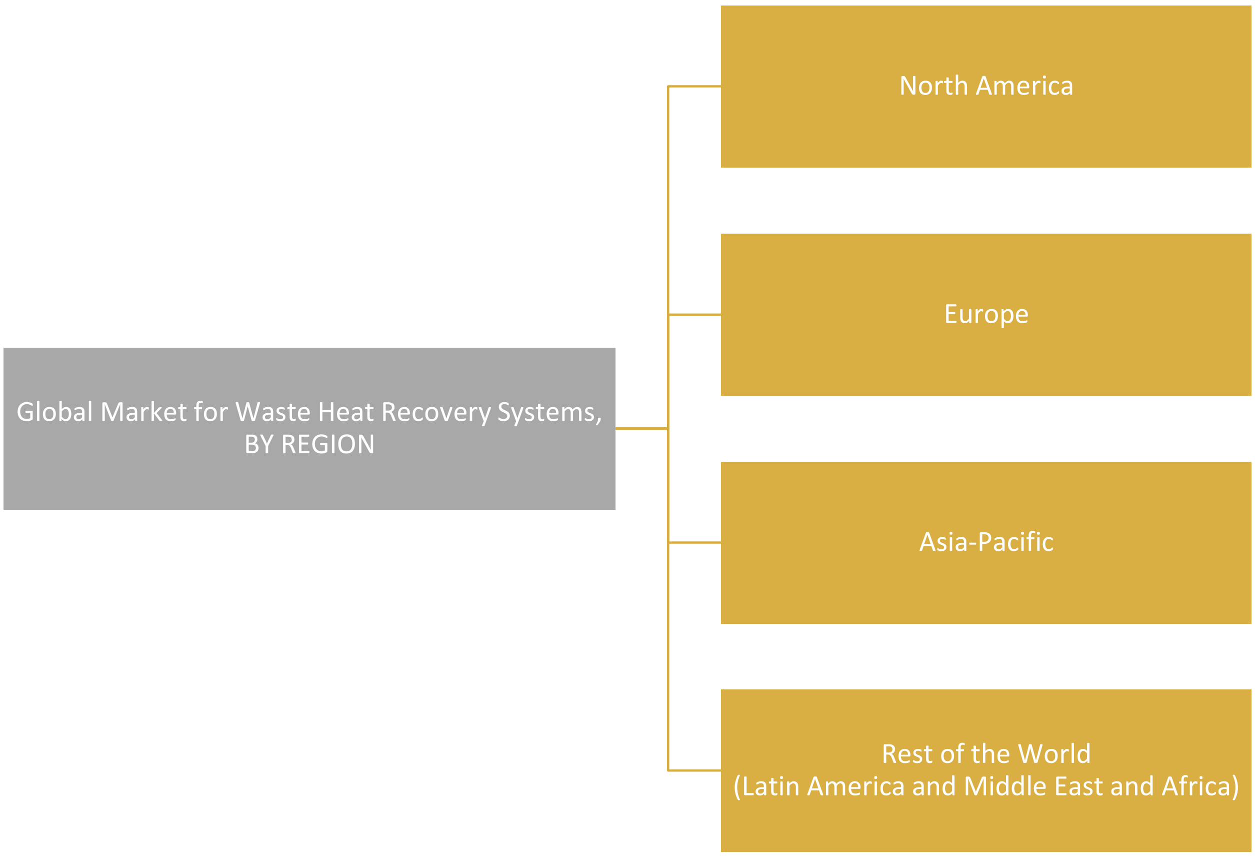
Global Market for Waste Heat Recovery Systems, by Application



Global Market for Waste Heat Recovery Systems, by End-Use



Global Market for Waste Heat Recovery Systems, by Region



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The BCC Publishing Staff comprises expert analysts who are skilled in conducting primary research, secondary research and data analysis and have decades of combined experience covering a wide range of industries, including healthcare, advanced materials and emerging technologies. Collectively, the team represents a diverse set of educational achievements with individual graduate work completed in fields such as microbiology, electrical engineering, business administration and surgery, among others.

Related BCC Research Reports

- MST078B *Smart Waste Management Systems: Global Markets*.
- EGY141A *Commercial Combined Heat and Power (CHP): Global Markets to 2022*.
- EGY063B *Thermal and Biological Waste-to-Energy Markets*.
- EGY130A *Energy-Efficient Technologies for Global Industrial Markets*.

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About BCC Research

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March 2023