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Energy Efficiency and Decarbonisation of Industrial Heat in Japan and Germany

Prepared as part of the bilateral energy partnership on behalf of the German Federal Ministry for Economic Affairs and Energy



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List of Abbreviations

AgNes	General grid charge system
BEHG	Fuel Emissions Trading Act
BfEE	Federal Office for Energy Efficiency
BNetzA	German Federal Network Agency
CBAM	Carbon Border Adjustment Mechanism
CfD	Contract for Difference
CCfD	Carbon Contracts for Difference
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Utilisation and Storage
CO_2	Carbon Dioxide
DAC	Direct Air Capture
EAF	Electric Arc Furnaces
EED	Energy Efficiency Directive
EDL-G	Energy Services Act
EEW	Federal Funding for Energy and Resource Efficiency in the Economy
EHB	European Hydrogen Bank
EIB	European Investment Bank
EnMs	Energy Management System
EnWG	Energy Industry Act
EGS	Enhanced Geothermal Systems
EU	European Union
EU ETS	EU Emissions Trading System
FIP	Feed-in Premium
FIT	Feed-in Tariff
FJ	Fiscal Year
GX	Green Transformation
GXA	GX Acceleration Agency
GJ	Gigajoule
GW	Gigawatt
IE3	International Efficiency 3
IEA	International Energy Agency
IPCEI	Important Projects of Common European Interest
ISO	International Organization for Standardization
JOGMEC	Japan Organization for Metals and Energy Security
KSG	Climate Protection Act
LCoH	Levelised Cost of Heat
METI	Ministry of Economy, Trade and Industry
MW	Megawatt
MSR	Measurement, Control, and Regulation
Mt	Million Tonnes
Mt/yr	Million Tonnes per Year
NEDO	New Energy and Industrial Technology Development Organization
PJ	Petajoule
PPA	Power Purchase Agreement
RED	Renewable Energy Directive
R&D	Research and Development
SME	Small and Medium-sized Enterprises
t	Tonnes
t/a	Tonnes per year
TES	Thermal Energy Storage
TRL	Technology Readiness Level
TWh	Terawatt Hour
UBA	Federal Environment Agency
WPG	Heat Planning Act

Executive Summary

Industrial energy efficiency and the decarbonisation of industrial heat are central to achieving climate-neutral industry. Energy efficiency measures reduce energy demand across industrial processes, while decarbonising of industrial heat can be reached through direct electrification, renewable heat sources, low-carbon energy carriers and carbon management for residual process-related emissions. Against this background, this study compares these approaches in Germany and Japan, examines their regulatory frameworks, funding instruments and deployment status, and identifies concrete recommendations for further cooperation under the bilateral Japan-Germany Energy Partnership.

The different approaches complement each other. Energy efficiency and waste heat recovery lower the total energy demand directly. Waste heat recovery also supports electrification, as industrial heat pumps can raise recovered heat to usable temperatures. Direct electrification complements these measures by substituting electricity for fuels. It is particularly relevant for applications below 200 °C, where industrial heat pumps can provide process heat, and for steam supply through electric boilers at temperatures of up to approximately 500 °C. For higher temperature processes, electric arc furnaces and induction heating already provide established options. Resistance, plasma, and shock wave heating, by contrast, remain at earlier stages of technological development. Renewable heat sources, renewable hydrogen and biomethane are relevant options, while carbon management addresses process-related emissions.

In Germany, industry accounts for 27 % of final energy consumption, approximately two-thirds of which is used for process heat. In 2024 industrial energy consumption was 3,343 petajoules (PJ). Natural gas was the largest energy source (29 %), followed by electricity (21 %), mineral oil and oil products (17 %) and coal (15 %). This energy use and the associated emissions are concentrated in energy intensive sectors, including chemicals, iron and steel, refining, paper, glass and food. Germany addresses industrial decarbonisation through a combination of European Union legislation and national measures. The framework includes the EU Emissions Trading System, the Carbon Border Adjustment Mechanism and the Energy Efficiency Directive, alongside the German Climate Protection Act, the Energy Efficiency Act. Funding programmes such as the Federal Funding for Energy and Resource Efficiency in the Economy, Carbon Contracts for Difference and European instruments, including the Innovation Fund and the European Hydrogen Bank, provide further support for industrial transformation.

This policy and funding framework has supported the deployment of energy efficiency measures and technologies for industrial heat decarbonisation. Energy efficiency measures in particular have for many years been supported through the Federal Funding for Energy and Resource Efficiency in the Economy, particularly for cross-cutting technologies such as motors and drive systems. This long-standing support is also reflected in the established role of energy management, with more than 10,000 ISO 50001 certificates. Even so, further savings remain possible in cross cutting technologies and industrial processes. Installed heat pump capacity for industry and district heating has risen above 180 MW, with a further 900 MW announced, with a large proportion being used to supply district heating networks. Electric arc furnaces are established in secondary steelmaking and account for roughly 30 % of German crude steel production. Induction heating is also used in selected metal-processing applications. Other technologies remain less deployed. Plasma heating has been deployed in small-scale applications, whereas resistance heating remains limited to pilot and demonstration projects. Thermal energy storage is used primarily through established steam storage systems. The use of renewable hydrogen remains marginal, with approximately 4 terawatt hours (TWh), equivalent to 14 petajoules (PJ)[1], of green hydrogen produced out of roughly 60 TWh (216 PJ) of total hydrogen production. Carbon management has not yet reached commercial scale deployment and remains concentrated in pilot, demonstration and project development activities.

Japan shows a comparable picture. Its industrial sector accounts for close to 30 % of final energy consumption and represents the country's largest energy-consuming sector. Electricity supplies 37 % of industrial energy use, while coal and oil each account for 22 %. Demand is concentrated in the iron and steel and chemical sectors. As a result, a relatively small number of energy intensive sites account for a substantial share of industrial

[1] 1 TWh = 3.6 PJ

consumption. Japan addresses industrial decarbonisation through its national Green Transformation framework. The GX Promotion Act combines a carbon-pricing approach with public financing, while the Energy Conservation Act requires large consumers to report their energy consumption, targets and measures for the transition to non-fossil energy. The Hydrogen Society Promotion Act and the CCS Business Act establish specific frameworks for low-carbon hydrogen and carbon storage.

These framework conditions are reflected in Japan's technology deployment. Energy efficiency is the most established among the decarbonisation approaches. The Top Runner Program has also supported improvements in product efficiency, including the efficiency of electric motors. Energy management remains less widespread than in Germany. Only 13 ISO 50001 certification cases were reported at the end of 2024. Heat pump deployment is more advanced, with installed capacity reaching almost 650 MW in 2024. Electric arc furnaces have long been used in scrap-based steelmaking and account for around a quarter of national crude steel production. Induction heating is commercially available, with documented applications in metal processing and manufacturing while plasma technology also has established industrial small-scale applications. The deployment of thermal energy storage differs by application. Heat storage, typically integrated with heat pumps, is well established, whereas storage for high-temperature and process heat remains largely at the demonstration stage. Solar thermal process heat remains a niche application. Geothermal energy has considerable potential, but industrial applications remain limited. Total hydrogen production amounted to approximately 2 million tonnes (Mt) in 2022, most of which was used in refining. Carbon management has not reached commercial scale. Japan has completed the Tomakomai full-chain CCS demonstration, while further CCS projects remain in planning or development, with most targeting demonstration by 2030.

The comparison of Germany and Japan highlights both differences and common ground. The two countries differ in their regulatory frameworks, funding instruments and levels of technology deployment. At the same time both countries share several challenges in the transformation of their industrial energy systems In both countries, industrial energy demand remains concentrated in a small number of energy-intensive sectors. Both countries have also adopted climate-neutrality targets and established a range of energy efficiency and decarbonisation measures. The study thus identifies three priority areas for cooperation:

- **Funding instruments for industrial decarbonisation;** including a comparison of the design, eligible sectors and technologies and results of support instruments in both countries, with carbon pricing and carbon leakage considered as context;

- **Energy management, efficiency standards and digitalisation**; including opportunities to strengthen industrial energy management in Japan and build on German experience;

- **Technology exchange on process heat,** differentiated by temperature level and technological maturity.

Introduction

The industrial sector represents nearly 40 % of total global final energy consumption and, since 2019, has contributed roughly two-thirds of the increase in global final energy demand (IEA 2025b). A large part of this demand occurs in the form of heat: industrial processes are responsible for around half of the final energy consumed for heat worldwide, and industrial heat alone constitutes close to one-fifth of global energy consumption. Because the vast majority of this heat still originates from the combustion of fossil fuels, it also accounts for most of the carbon dioxide (CO_2) emitted by industry each year (IEA 2018, 2022).

Against this background, a set of complementary decarbonisation pathways has emerged. These comprise energy efficiency; the direct electrification of process heat; the direct use of renewable energy sources such as solar thermal, bioenergy and geothermal energy; electrolytic and low-carbon liquid and gaseous energy carriers, in particular green hydrogen and biomethane; and, for residual and process-related emissions, industrial carbon management. Their relative suitability depends on the temperature level required, the process concerned, and the technical, infrastructural and economic conditions at a given site.

Germany and Japan share several structural similarities. Both are industrialised economies with energy-intensive manufacturing sectors, both depend on imported energy, and both have adopted long-term climate-neutrality targets that require reductions in industrial emissions. At the same time, the two countries differ in their regulatory frameworks, funding instruments and the deployment status of individual technologies. This study, prepared as part of the framework of the bilateral energy partnership between Japan and Germany, examines the current status of energy efficiency and the decarbonisation of industrial heat in both countries.

The report is structured as follows. Chapter 1 sets out the key technologies for the decarbonisation of industrial heat and for increasing energy efficiency in industry. Chapters 2 and 3 analyse the situation in Germany and Japan respectively, covering final energy consumption, legal requirements and framework conditions, funding schemes, deployment status, and the barriers and challenges encountered in each country. The report concludes in Chapter 4, drawing conclusions from this comparison and developing recommendations for Japanese-German cooperation.

1 Overview: Key technologies for energy efficiency and industrial heat decarbonisation

1.1 Energy efficiency

Energy efficiency is widely regarded as the first and most cost-effective building block of industrial decarbonisation, and is frequently described as the "first fuel" (UNECE 2022). Its relevance is systemic: by reducing absolute energy demand and operating costs, efficiency measures lower the required expansion of renewable generation and grid capacity, thereby supporting the systemic transformation of industrial energy systems (UNIDO 2026). For industry, the potential to reduce average energy-intensity is estimated at 25 to 30 %, particularly in the aluminium, paper and cement subsectors (IEA 2021b). Because efficiency reduces the scale of every other transformation task, its priority is largely uncontested.

Cross-cutting technologies

Cross-cutting technologies used across almost all branches of industry form the backbone of industrial energy efficiency. They include electric motor driven systems, compressed air systems, pumps, ventilation and lighting. As these account for a large share of industrial energy consumption and are typically characterised by low complexity and short payback periods, they offer high and rapidly realisable efficiency potentials. Industrial electric motor systems alone account for around 60 % of global industrial electricity demand and roughly 25 % of global electricity consumption (IEA 2025a).

Process optimisation

Process optimisation reduces energy use and emissions within existing production processes through improvements in process engineering, more efficient resource use, and the demand-oriented flexibilization of operations. Process-integrated measures include the optimisation of burner settings, improved thermal insulation, and the reduction of idle and standby times. An increasingly important dimension is the temporal flexibilization of consumption (demand response). Industrial firms can align energy-intensive processes with periods of high renewable supply and low electricity prices (Next Kraftwerke 2026). It should be noted that flexibilization may entail a modest loss of energy efficiency even as it reduces emissions and costs.

Energy management systems, energy audits and digital control

Without systematic recording, analysis and control of energy consumption, efficiency potentials frequently remain untapped. Energy management systems (EnMS), energy audits and digital control provide the organisational and technical foundation for embedding efficiency in industrial operations. The International Organization for Standardization (ISO) 50001 standard sets out requirements for an energy management system that supports continuous monitoring and the identification of potential savings (UNIDO 2026; Dekra 2026). Internet-of-things platforms, digital twins and AI-based optimisation increasingly enable real-time monitoring and the dynamic adaptation of consumption to production conditions and price signals (Fraunhofer ITWM 2023).

1.2 Heat recovery and the use of waste heat

Industrial processes generate substantial quantities of waste heat that are released unused in the absence of suitable recovery systems. Waste heat can be used internally within the same process, elsewhere within the same facility, or externally through district heating grids (Hirzel et al. 2013). Its relevance lies in displacing primary energy demand directly, which makes it one of the most immediate efficiency levers available. It is also closely linked to electrification: because industrial heat pumps can raise recovered waste heat to usable temperature levels, the two pathways are complementary rather than separate. This connection is a recurring theme in the assessment of low- and medium-temperature supply and is examined further in the country analyses.

1.3 Direct electrification of process heat

Process heat requirements span a wide temperature range, and the appropriate technological response differs markedly across this range. The direct use of renewable electricity to generate process heat is regarded as one of the central decarbonisation pathways in virtually all scenarios for climate-neutral industry (Luderer et al. 2021). Its relevance is greatest for low- and medium-temperature applications, where established technologies such as heat pumps and electric arc furnaces can

already cover more than 60 % of the industrial energy demand in Europe that has not yet been electrified. By 2035, this share is estimated to rise to as much as 90 % (Fraunhofer ISI 2024a, 2024b). The technologies are not mutually exclusive, and their relative suitability depends on the temperature level required, the process concerned, and the technical, infrastructural and economic conditions at a given site. Electrification only contributes to decarbonisation, however, to the extent that the electricity used originates from renewable sources (see Section 2.4).

Industrial heat pumps

Industrial heat pumps transfer heat from a lower-temperature source, such as ambient air, water, or industrial waste heat, to a higher temperature level supplying it as hot air, hot water or steam. They also function as an active heat recovery technology (SPH 2023; Jacobi 2023). They primarily address heat demand up to around 200 °C and can already be deployed in sectors such as paper, food, chemicals and petrochemicals (Fraunhofer ISI 2024b). Industrial heat pumps supplying heat below 140°C have also reached technology readiness level (TRL) 8 or higher. For supply temperatures between 140°C and 200°C, however, technology readiness varies considerably. It ranges from TRL 4 to TRL 9, depending on the specific temperature and capacity requirements. (European Commission 2024a). Given the large share of industrial heat demand falling within this temperature band, heat pumps are among the most consequential near-term electrification technologies.

Electric boilers

Electric boilers generate hot water or steam directly and are an established electrification technology, valued for comparatively simple integration into existing infrastructures and for strong flexibility, since they respond quickly to load and price changes (entelios 2024). They reach temperatures of up to around 500 °C, with typical applications in steam generation in the paper, food and chemical industries (Fraunhofer ISI 2024b).

Electric arc furnaces (EAF)

Electric arc furnaces use electric arcs to melt metals and have been commercially established in the steel industry for decades, reaching temperatures of up to around 1,800 °C. As a mature, high-temperature electrification technology, they are of particular strategic relevance to steel-sector transformation (Fraunhofer ISI 2024b; Leonhard 2026).

Induction, resistance, plasma and shockwave heating

A further group of electrothermal technologies addresses higher temperatures with differing degrees of maturity. Induction heating, based on electromagnetic induction, reaches up to around 3,000 °C and is a proven, commercially available solution already in use in metal processing applications (Rosenow et al. 2025). Resistance heating covers a broad range up to around 2,000 °C and can serve numerous medium- and high-temperature processes (Fraunhofer ISI 2024b). Plasma heating is considered a relevant potential option for high-temperature applications up to around 3,000 °C, but its industrial application remains largely at the demonstration stage. It is used only in niche applications. (Leicher et al., 2024). Shockwave heating, which transfers energy mechanically, operates between roughly 700 and 1,000 °C but remains at an early research stage (Rosenow et al. 2025). The relevance of these technologies depends strongly on their technological maturity: induction is deployable today, whereas resistance, plasma and shockwave heating remain prospective options for hard-to-electrify high-temperature processes. Under suitable framework conditions, broad deployment of resistance and plasma heating by 2035 appears feasible (Fraunhofer ISI 2024a, 2024b).

Thermal energy storage (TES)

Thermal energy storage systems absorb heat, store it, and release it when needed, thereby decoupling heat generation from use and enabling the flexible integration of fluctuating renewable electricity into industrial processes (Fraunhofer UMSICHT 2026). TES technologies are broadly classified into three categories according to their storage mechanism: sensible heat storage, latent heat storage using phase change materials, and thermochemical storage. Sensible heat storage is operating between 290 °C and 565 °C and is the most commercially mature, reaching TRL 9. Latent heat storage using PCMs is at TRL 6–8 and is currently being demonstrated at temperature ranges of 80–400 °C. Thermochemical storage, which can operate up to 1,200 °C, remains at TRL 3–5, that is, at the laboratory and pilot stage (Kwasi-Effaha and Okpako 2025).

1.4 Direct use of renewable energy sources

This decarbonisation pathway complements direct electrification rather than substituting for it, while also covering the supply side. It includes solar and wind power generation and solar thermal and geothermal energy. Bioenergy in solid, liquid or gaseous form provides renewable fuels as energy carriers and, in certain sectors, as a material feedstock.

Industrial companies can procure renewable electricity through several channels. The most common route remains supply from the wholesale markets via the public grid. Beyond these options, companies can also generate electricity themselves or contract directly with generation assets. In self-generation models, photovoltaic systems or wind turbines are operated on the company site or in its immediate vicinity, allowing part of the

electricity demand to be met on site. A further option is the long-term supply contract with a renewable energy installation, known as a power purchase agreement (PPA), under which a company procures renewable electricity directly from a wind or solar installation at pre-agreed, often stable prices over a period of, for example, ten years, without having to invest in generation assets itself.

Solar thermal process heat

Solar thermal systems use concentrated or direct solar radiation to generate process heat. Different collector technologies are used depending on the targeted temperature level. Non-concentrating systems provide process heat up to around 150 °C for applications such as cleaning, drying, washing, pasteurisation, cooking, and sterilisation (Solar Heat Europe 2026); the technology is mature and commercialised. Concentrating solar systems enable temperatures of up to 400 °C or more. Both temperature level and technology readiness level depend on the exact technology used. On an levelised cost of heat (LCoH) basis, the cost of non-concentrating solar thermal systems can compare favourably to heat generated via electricity from solar photovoltaic, especially at low-temperature differentials and high irradiation levels (Meyers 2018).

Bioenergy

Biomass encompasses a broad range of solid, liquid, and gaseous biogenic energy carriers, including wood pellets, wood chips, agricultural biogenic residues, biogas, and liquid biofuels. These energy carriers are combusted or thermochemically converted in industrial facilities to generate process heat or combined heat and power. Unlike many other renewable energy carriers, biomass can be used for baseload supply and independently of weather conditions. Biomass can provide both low- and high-temperature heat. In combination with CCS, biomass can also result in negative emissions. However, the use of biomass in industry is subject to significant limitations. Given the limited availability of sustainable biomass, it should be prioritised for applications for which few or no alternative decarbonisation options exist (IEA Bioenergy 2021).

Geothermal energy

Geothermal energy refers to the utilisation of thermal energy stored within the Earth's interior and can broadly be divided into two technological categories: shallow geothermal energy (depths up to 400 Meter (m)) and deep geothermal energy (depths exceeding 400 m, extending to several kilometres). Shallow geothermal systems access temperature levels of 10 to 20 °C via surface collectors, borehole heat exchangers, or groundwater heat pumps. Since these temperatures are generally insufficient for industrial process requirements, the use of a heat pump for temperature elevation is usually required. Deep geothermal energy, by contrast, extracts hot water or steam from geologically deep reservoirs, and can achieve temperatures of 100 °C to over 300 °C, depending on the geological setting. With regard to the extraction technologies employed, two approaches can be distinguished: the hydrothermal method, in which natural hot water reservoirs are developed via production and reinjection boreholes, and petrothermal systems, also known as Enhanced Geothermal Systems (EGS), in which an artificial reservoir is created in hot dry rock through hydraulic stimulation (Bracke and Huenges 2021). Geothermal energy's relevance is tempered by the considerable economic and geological risks of exploration and drilling, and by strong dependence on regional geological conditions, which limits spatial transferability.

1.5 Electrolytic and low-carbon liquid and gaseous energy carriers

Electrification offers a technically feasible and economically promising decarbonisation pathway for low- and medium-temperature applications. However, several hard-to-decarbonise sub-sectors structurally limit its applicability. On the one hand, some high-temperature processes, such as clinker and primary glass production, require thermal energy above 1,000 °C, remain difficult to electrify at commercial scale. On the other hand, in some key industries, alternative energy sources fulfill functions beyond the provision of heat: In the steel sector, hydrogen can be used as a chemical reducing agent and is an indispensable molecular feedstock in ammonia synthesis using the Haber-Bosch process. This chapter, therefore, examines green hydrogen and biomethane as complementary decarbonisation options.

Renewable hydrogen

Renewable hydrogen and its derivatives are a key pathway for decarbonisation of hard-to-electrify industrial processes. As a feedstock, renewable hydrogen can be swapped in for its fossil counterpart in ammonia production, for hydrotreating and desulphurisation processes in oil refineries, and for methanol synthesis. Hydrogen can also serve as a process gas in sectors such as steel manufacturing and as a substitute for natural gas in some high-temperature heat applications. A structural advantage of using hydrogen lies in its ability to bypass the electricity grid where grid capacity remains constrained. Hydrogen and especially its derivatives such as ammonia and methanol can also be used in energy storage applications. However, renewable hydrogen remains constrained by high costs and high capital expenditure needs, conversion and reconversion losses, available transport and storage infrastructure, and in some cases the need to adapt existing end-use applications. Hydrogen should therefore be prioritised for applications for which no economically viable electrification alternatives

exist (Mural et al. 2025; IRENA 2024; Fraunhofer ISI 2024b).

Biomethane

Biomethane is essentially chemically identical to natural gas and can therefore be used in existing gas infrastructure, in current industrial facilities, and with proven combustion technologies. Compatibility with existing gas infrastructure is a decisive advantage compared with hydrogen (BDEW 2025; FNR 2026). As with biomass, the availability of sustainable feedstocks is also the key bottleneck for biomethane. Priority uses of biomethane should therefore be weighed carefully from the systemic perspective.

1.6 Carbon management

Energy efficiency, direct electrification, the use of renewable energy, and alternative climate-neutral energy carriers constitute the primary decarbonisation pathways for the industrial sector. However, for certain energy-intensive processes, these approaches alone are not sufficient to achieve full climate-neutrality. The reason lies in process-related emissions which do not originate from the combustion of fossil energy carriers, but arise as a direct by-product of chemical reactions within the production process itself (UBA 2020; KEI 2026).

Industrial carbon management encompasses technologies to capture, transport, use and store CO_2 emissions from industrial and energy production facilities, as well as to remove CO_2 from the atmosphere. The first is carbon capture and storage (CCS), in which captured CO_2 is transported and permanently stored in suitable geological formations. The second is carbon capture and utilisation (CCU), in which captured CO_2 serves as a feedstock for products or industrial processes. The third is direct air capture (DAC), which extracts CO_2 directly from the atmosphere and can be combined with permanent storage. Several established and emerging capture processes can be distinguished (IEA 2021a; European Commission 2024b).

2 Germany

2.1 Energy consumption of German industry

Industry accounts for 27% of final energy consumption in Germany (AGEB 2025). Approximately two-thirds of final energy consumption is used in industry for process heat (UBA 2026a).

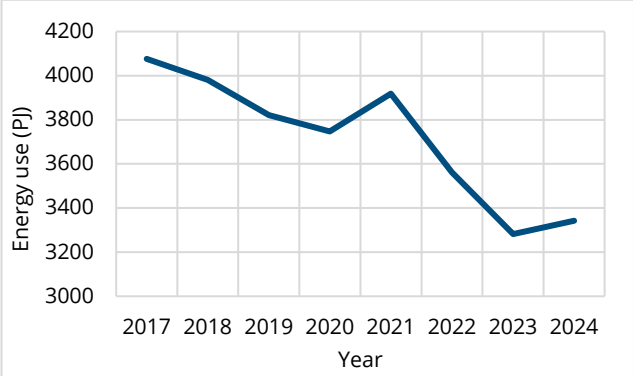


Figure 1 Annual energy use by German industry (2017-2024). Own illustration based on (Destatis 2026a).

German industry consumed a total of 3,343 petajoules (PJ) of energy in 2024. Recent demand has been volatile rather than steadily falling. The energy consumption (Figure 1) dropped sharply in 2022 and 2023 as energy prices rose and output contracted, then rebounded modestly in 2024 (Destatis 2025). Natural gas accounts for the largest share of industrial energy consumption, followed by electricity, mineral oils and coal (Figure 2). A substantial share of industrial consumption stays tied to fossil fuels (Destatis 2025).

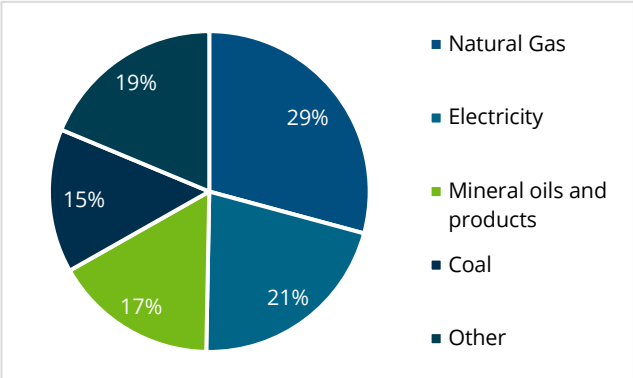


Figure 2 Energy use in German industry by energy source. Own illustration based on (Destatis 2025).

Consumption is also highly concentrated. A small group of energy-intensive branches like chemicals, metal production and processing, coke and mineral oil refining, paper, glass and ceramics, and food accounts for the large majority of industrial final energy demand (Destatis 2026b).

2.2 Legal requirements and framework conditions

Germany's regulatory framework for industrial decarbonisation is shaped at two levels: European Union (EU) legislation that sets the broader framework, and national legislation that implements and, in some areas, extends the requirements. The following is a non-exhaustive collection of the most central provisions.

The **Federal Climate Protection Act (*Klimaschutzgesetz*, KSG)** provides the overarching national target of greenhouse gas neutrality by 2045. The 2024 amendment removed binding sector-specific annual targets, introducing instead a cross-sectoral budget with a corrective mechanism triggered after two consecutive years of overshooting. The responsible federal ministries must propose corrective measures if they miss the targets. The federal government will then discuss and decide on these measures.

Carbon pricing is a key economic driver across all decarbonisation technologies and pathways. The 2023 revision of the **EU Emissions Trading System (EU ETS, Directive 2003/87/EC as amended)** tightens the emission cap for power generation and energy-intensive industry. Free allocation is conditioned on companies' own decarbonisation efforts and is being phased out between 2026 and 2034. Over the same period, the **Carbon Border Adjustment Mechanism (CBAM, Regulation 2023/956)** will be phased in. It extends the carbon price to imports of carbon-intensive goods, preventing carbon leakage from undermining domestic investment. From 2028 onward, **EU ETS II** will also cover the buildings and road transport sectors, which are currently covered by Germany's national **Fuel Emissions Trading Act (*Brennstoffemissionshandelsgesetz*; BEHG),** into a harmonised European carbon market. By doing so, it will replace the Effort Sharing Regulation's sector coverage for these emitters with a direct and rising CO_2 price signal.

Energy efficiency is anchored at EU level through the **Energy Efficiency Directive (EED III, Directive 2023/1791)**, which establishes the "efficiency first" principle and sets binding national energy consumption reduction targets. Germany's **Energy Efficiency Act (*Energieeffizienzgesetz*; EnEfG)** transposes these obligations, requiring companies exceeding the respective final energy consumption thresholds to operate energy management systems compliant with ISO 50001 or EMAS and to publish

implementation plans for all economically viable savings measures, thereby directly targeting cross-cutting technologies, process optimisation and waste heat utilisation. A revision expected in autumn 2026 will relax these thresholds while adding new requirements, including efficiency criteria for large infrastructure investments. The **Energy Services Act (*Energiedienstleistungsgesetz*; EDL-G)**, under revision since 2024, is set to base the energy audit obligation on absolute energy consumption rather than company size.

The **Renewable Energy Directive (RED III, Directive 2023/2413)** sets renewable targets for industry at the EU level, including a yearly 1.6% increase in renewables' share of final energy consumption and a sub-target for renewable electrolytic hydrogen. The **Electricity Market Reform (Regulation 2024/1747 and Directive 2024/1711)**, the **Affordable Energy Action Plan (COM/2025/79)** and the **Electrification Action Plan (COM/2026/595)** directly address the high costs of electricity. Between them, they promote long-term power purchase agreements (PPAs), mandate two-way contracts for difference for clean electricity, push member states to remove non-energy charges from industrial electricity bills, and set a target for electricity to account for 32 % of final energy consumption by 2030. In Germany, the **Bundesnetzagentur's AgNes process** (Allgemeine Netzentgeltsystematik Strom) is overhauling the power grid tariff scheme, with the explicit goal of making tariffs cost-reflective while dismantling barriers to flexibility; orientation points on industrial tariffs were published in April 2026, with a final determination pending. The **Heat Planning Act** (***Wärmeplanungsgesetz*; *WPG*)** obliges German municipalities to establish a municipal heat plan. It sets a strategic framework for a sustainable, renewable, and cost-efficient heat generation and supply of space heating, hot water and process heat to renewable energy, unavoidable waste heat by 2045 and sets binding share targets for heat networks.

The **EU Gas and Hydrogen Package (Directive 2024/1788 and Regulation 2024/1789),** which is being transposed through a pending amendment to Germany's **Energy Industry Act** (***Energiewirtschaftsgesetz*; EnWG)** and other laws, establishes the regulatory framework for hydrogen networks and decarbonised gases. The hydrogen core network spanning 9,000 km, approved by Bundesnetzagentur (BNetzA) in October 2024, provides the infrastructure backbone for connecting electrolysers, industrial off-takers, storage facilities, and neighbouring countries. The first 500 km are operational since 2025, and the core network is to be completed by 2037. The core grid forms the basis and is not the final stage of development for the hydrogen infrastructure in Germany. From 2025/2026 onwards, the core grid will be expanded on a scenario- and demand-driven basis through an ongoing, two-year grid development planning process (BMWE 2026b). Germany's **updated National Hydrogen Strategy (2023)** designates these industrial end uses as the priority for scarce hydrogen supply.

The amended **CO_2 Storage and Transport Act (*Kohlendioxid-Speicherung-und-Transportgesetz; KSpTG*)** reverses the previous ban on geological CO_2 storage and creates the legal foundation for industrial-scale carbon capture and storage in Germany , essential for decarbonising process-related emissions in cement, lime and chemicals, for which no other pathway alone suffices (UBA 2020). The EU **Industrial Carbon Management Strategy (COM/2024/62)** and **Carbon Removal Certification Framework (Regulation 2024/3012)** provide the overarching policy rationale and verification standards at EU level for industrial CCS.

2.3 Funding schemes

A central instrument within Germany's funding landscape for industrial enterprises is the Federal **Funding for Energy and Resource Efficiency in the Economy (*Bundesförderung für Energie- und Ressourceneffizienz in der Wirtschaft*; EEW)**, which is designed to support investment in energy and resource efficiency as well as the expansion of renewable energies for process heat. The EEW follows a modular structure and covers, among other areas: cross-sectional technologies; process heat from renewable energy sources; measurement, control, and regulation technology (MSR); sensor systems; and energy management software; energy and resource optimization of equipment and processes; electrification of small companies; and the funding of transformation plans.

Carbon Contracts for Difference (CCfD) constitute a funding instrument targeted specifically at particularly emissions-intensive industrial processes such as steel, chemicals, glass, paper and non-ferrous metals; the second round (2026) expanded the scope to CCU/S, industrial steam and cement and lime production. The aim of CCfDs is to offset the additional costs of low-carbon production methods relative to conventional processes; subsidies are awarded based on financial efficiency of avoided emissions. Funding recipients may be obliged to make surplus payments to the state where the low carbon process proves cheaper than the reference, subject to a cap and suspension rules (BMWE 2026a).

At EU level, the **Innovation Fund** financed from EU ETS auction revenues is the principal grant instrument for industrial decarbonisation. A dedicated **industrial process heat decarbonisation auction** (€1 billion, launched October 2025) was the first EU-wide competitive tender specifically targeting the substitution of fossil fuels in industrial process heat via electrification, renewable heat and hydrogen (European Commission 2025a). The **European Hydrogen Bank (EHB)**, operating within the Innovation Fund, provides fixed-premium competitive auctions to bridge the cost gap for renewable and low-carbon hydrogen production for industrial end uses; successive calls since 2023 have established it as a direct support instrument for the hydrogen ramp-up. **The**

European Investment Bank (EIB) PPA Counter-Guarantee Facility (€500 million pilot, 2025) reduces counterparty risk in long-term power purchase agreements between renewable energy developers and industrial consumers, directly lowering the cost barrier to procuring clean electricity for electrification (European Investment Bank 2025). **Industrial Decarbonisation Bank (IDB)**, proposed under the Clean Industrial Deal (COM/2025/85), is intended to aggregate approximately €100 billion from ETS revenues, the Innovation Fund, InvestEU and Member State co-financing, scaling these instruments significantly from 2026 onwards (European Commission 2025b; carbongap 2025).

Important Projects of Common European Interest (IPCEI) are a state aid instrument of the European Union that enables member states to co-finance strategically significant projects with public support. IPCEIs target projects that make a substantial contribution to key Union objectives – for example in the areas of research and innovation, climate protection, digitalisation, or industrial transformation. A prerequisite is that the project is transnational in scope, involves several member states, and generates a clearly demonstrable pan-European added value that extends beyond the economic benefit to the participating companies.

2.4 Deployment Status

2.4.1 Energy efficiency

Energy efficiency has long been a central pillar of Germany's decarbonisation agenda, supported by decades of regulatory frameworks and funding programmes.

Cross-cutting technologies are supported over many years by the EEW (Modul 1). Since its start, the support provided has led to accelerated market penetration of highly efficient cross-cutting technologies, particularly in motors and drive systems, as well as fans. A substantial efficiency saving potential nonetheless remains in German industry. These low-complexity, short-payback measures remain a priority despite decades of activity (Meyer et al. 2025).

German industry is broadly receptive to energy management systems and digital technologies. More than 10,000 ISO 50001 certificates are held in Germany, over 40 % of the global total (UBA 2026b).

Digital adoption is advancing on a parallel track, with AI emerging as a key tool: around 70 % of industrial and commercial enterprises either used AI or plan to introduce it within the next three years (DIHK 2025).

Cross-asset operational optimisation in the energy domain often goes beyond strategic procurement and includes process flexibilization, energy storage, and revenue stacking. Commercial providers offer digital and AI-supported management solutions and offer load flexibility on reserve and spot markets on behalf of their industrial clients (entelios 2026). Studies identify a flexibility potential of industrial processes of 460 Megawatt (MW) load increase and 870 MW load reduction at present (SynErgie 2026) and up to 7.5 Gigawatt (GW) by 2045 (FfE 2024).

2.4.2 Heat recovery and use of waste heat

The recovery and use of waste heat is a well-recognised but under-exploited lever. The Platform for Waste Heat of the Federal Office for Energy Efficiency (*Bundesstelle für Energieeffizienz*; BfEE) documents reported waste heat potentials amounting to around 205 TWh (738 PJ) per year (BfEE 2026). The literature estimates the technical and economic potential for waste heat avoidance and use at 20 to 30 % of energy used (Bayerische Staatsregierung 2026). As noted in Section 2.2, waste heat is also closely linked to electrification, since industrial heat pumps can raise recovered waste heat to usable temperature levels.

2.4.3 Direct electrification of process heat

Direct electrification is the central pathway for low- and medium-temperature heat, yet deployment lags well behind its technical potential.

Industrial heat pumps for process heat are comparatively little used in German industry. Installed capacity of large-scale heat pumps for industry and district heating has recently risen above 180 MW, with more than 70 projects in planning or construction (BWP 2025) and around 900 MW of further capacity announced (LEA Hessen 2025). A large proportion of the existing and planned large-scale heat pump capacity is used to supply district heating networks. Deployment at scale across the broader industrial sector remains limited.

Electric boilers, an established technology for steam generation in the paper, food and chemical industries, are commercially deployed in Germany. Recently, InfraLeuna installed a 35 MW electrode boiler at the Leuna chemical site (Leuna Echo 2025). Other examples include the 7 MW electrode steam boiler at CHEMPARK Leverkusen (Fraunhofer ISI 2024a) and an electrode boiler commissioned at Chempark Krefeld-Uerdingen. The latter generates up to 60 tonnes (t) of steam per hour to supply process heat (Chemieindustrie-online.de 2026). Reliable estimates regarding their total number or installed capacity have not been found, and they still appear to be rather niche than ubiquitous.

Electric Arc Furnaces (EAF) have long been established in secondary steel routes and today account for roughly 30 % of German crude steel production (Wasserstoff-Kompass 2024). Their strategic significance is growing through transformation projects in the primary steel sector projects. For example, the planned SALCOS project in Salzgitter combines hydrogen-based direct reduction

with an electric arc furnace (Home of Foundry 2022; thyssenkrupp 2026).

Induction heating is deployed in selected industrial process-heat applications in Germany, particularly in metal processing (Fraunhofer ISI 2024a). The UBA study reports that induction furnaces are already used in specific applications, such as in the foundry industry, metal forming, or aluminum melting. Further documented examples come from steel processing (UBA 2023b). Georgsmarienhütte commissioned its first fully automated inductive single-bar tempering plant in February 2024 and its second system in March 2026 (GMH 2026).

Fraunhofer ISI reports that plasma heating is currently used for selected small capacity industrial applications (Fraunhofer ISI 2024b). Several suppliers have developed commercially available systems which are available in Germany. A small number of commissioned plasma heat projects have been identified in Germany during the research for this study, in applications such as metal melting, ladle pre-heating, cutting, and welding. The results of the 2025 Innovation Fund Heat Auction include no plasma heating projects across the EU (European Commission 2026). The use of resistive heating is currently also used for selected small capacity industrial applications (Fraunhofer ISI 2024b; UBA 2023a). A small number of pilot or demonstration projects for industrial heat have been identified. Among the projects submitted under the European Commission's 2025 Innovation Fund call, two German projects involving resistive heating have been identified: GS4P and ABIRHB (European Commission 2026). For shock wave heating, no documented commercial system for industrial process heat was identified in the sources reviewed.

Heat storage systems are already being used in industry for process-based applications (dena 2024b). Steam storage is the widely used industrial storage technology. Its widespread application is primarily because numerous industrial processes rely on the use of steam. Latent heat storage, on the other hand, is currently only used to a limited extent, although applications exist in sectors such as food and pharmaceutical production. There are currently only a few practical application examples for thermochemical storage systems (BMWE 2025). Publicly documented installations include the steam storage facility at the Essity plant in Mannheim, which was commissioned in September 2025, and a planned power-to-heat system with integrated thermal storage at tesa's Hamburg plant (Essity 2025; Tesa 2026).

2.4.4 Direct use of renewable energy sources

Photovoltaic deployment on industrial and commercial rooftops developed particularly rapidly in 2024. Newly installed photovoltaic capacity on these rooftops increased by 30 % compared with the previous year. It is estimated that more than 100,000 companies in Germany use electricity generated by their own photovoltaic systems. Based on data from the Federal Grid Agency, approximately 12,000 photovoltaic systems can be identified on industrial roofs (BSW 2025). Wind energy is also used by German industry through both contractual procurement and direct physical supply, albeit at a much smaller scale. One example of direct physical electricity supply is thyssenkrupp Hohenlimburg. Since June 2024, the plant has received locally generated wind power from four wind turbines via a direct line connecting the wind farm to the plant network. The project was presented as the first direct connection of a wind farm to an industrial plant in Germany (thyssenkrupp 2024).

Germany leads Europe in contracted PPA volume, with most of it being off-site while on-site PPAs remain rare. PPAs are particularly relevant for large industrial electricity consumers, including energy-intensive companies in the chemicals and other industrial sectors (dena 2025b; BWE 2025). SCHOTT provides an example of contractual electricity procurement. The company concluded two PPAs with ENGIE for solar and wind energy with a total volume of 200 GWh and a term of three years starting in 2023. By 2024, the PPAs were expected to cover around 25 percent of SCHOTT's German electricity demand (Schott 2024).

Solar thermal process heat in German industry has so far been deployed only in a limited number of individual projects. Various suppliers are active on the German market, including Industrial Solar GmbH and Solarlite. Solarlite develops and installs decentralised solar thermal parabolic trough systems for electricity generation and industrial process heat. The power stations have an electrical output ranging from 500 kW to more than 30 MW (Solarlite 2026). The existence of specialised suppliers and operating reference projects indicates that commercial solutions are available. However, the small number of installations to date suggest that the market is still at an early stage of deployment (DLR Institut für Solarforschung 2026).

Geothermal energy has so far played only a limited role in Germany's industrial process heat supply, despite its technical potential to meet up to a quarter of Germany's industrial useful heat demand (Fraunhofer IEG 2023; Bundesverband Geothermie 2024). The "Geothermal Paper Drying" project at Kabel Premium Pulp & Paper examined the feasibility of using deep geothermal energy to produce process steam for paper drying (Fraunhofer IEG 2022).

Bioenergy already supplies a meaningful share of renewable process heat (approximately 6 %) and dominates renewable heat overall, used across bakeries, feed mills, coating and greenhouse operations, mostly at low- to medium- temperatures (AEE 2023) (FNR 2025). The main source is solid biomass, especially firewood, wood pellets and wood chips (FNR 2025). In Germany, however, biomass use is constrained by competing demands for land and biomass, including food and feed

production, as well as by biodiversity and soil protection requirements.

2.4.5 Electrolytic and low-carbon energy carriers

Green hydrogen currently plays a marginal role in German industry. Of roughly 60 terawatt hour (TWh) (216 PJ) of hydrogen produced annually in Germany, only around 4 TWh (14 PJ) is currently green (KPMG 2025). Electrolysis capacity has grown to around 193 MW with some 1.2 GW under construction, but remains far behind the 10 GW target set by the National Hydrogen Strategy for 2030 (dena 2026a). Projected industrial demand rises steeply towards 2045 (Umweltdialog 2024).

Biomethane is an established renewable gas option in Germany. Around 10 TWh (36 PJ) was produced and fed into the grid in 2024. A further 3.5 (12.6) TWh was imported (dena 2024a, 2025a). Biomethane is currently used mainly for electricity generation in combined heat and power (CHP) plants, as a transport fuel and in the heat market, although the available sources do not provide a complete sectoral breakdown for 2024.

2.4.6 Carbon management

The deployment of carbon management technologies in German industry remains limited. To date, their actual use has been documented mainly through individual pilot and demonstration projects. The IEA's CCUS Projects Database shows that Germany's project pipeline is still concentrated in the planning and construction stages. Its 2026 data lists two German CCU projects as under construction, with operation scheduled to begin in 2026 or thereafter, while most projects are expected to become operational by 2030 (IEA 2026a). One notable CCU project is being developed at Heidelberg Materials' Lengfurt cement plant in Bavaria. Under the name Capture to Use (CAP2U), Heidelberg Materials and Linde established a joint venture to build and operate a carbon dioxide capture, purification and liquefaction facility (Heidelberg Materials 2024). Construction began in June 2024. The project was initially scheduled to begin operations in 2025, but more recent information indicates that operations may begin in 2026. CCS deployment in Germany currently consists of projects under development. Heidelberg Materials' GeZero project at its cement plant in Geseke is one prominent example. The project aims to establish a complete CCS value chain at an inland industrial site, including CO_2 capture, compression, temporary handling, transport by rail and permanent geological storage under the North Sea. GeZero is designed to capture approximately 700,000 t of CO_2 per year from 2029. Construction is scheduled to begin in 2026, with commissioning planned for 2029 (Heidelberg Materials 2026). An up-to-date overview of projects under development is available in the *CCS Facilities CO2RE* database maintained by the Global CCS Institute (Global CCS Institute 2026).

2.5 Barriers and challenges

This section focuses on energy efficiency, direct electrification and renewable hydrogen. Together, these represent the main near-term options for improving energy efficiency in German industry and decarbonising industrial heat. Solar thermal process heat, geothermal energy and bioenergy are not discussed separately because their principal constraints are resource- and- site specific. Carbon management is omitted because it primarily addresses process related emissions rather than heat supply.

For energy efficiency the main challenge is implementation within operating production systems. Germany's Energy Efficiency Act requires larger energy consumers to use energy management systems or conduct audits and implement economically viable measures. These requirements do not eliminate the informational, organizational, and financial barriers to implementing the identified measures. Missing measurement and process control can make it difficult to determine reliable baseline values, identify losses, and demonstrate savings. Implementing these measures may also require operational changes or temporary interruptions. Energy efficiency measures involve investment costs, and expectations of short amortization periods may exclude measures whose benefits only materialise over longer operating periods (PwC 2025). Existing tariff regulations can further disadvantage flexible operations: the individual grid charge under § 19(2) of the Electricity Grid Charges Ordinance (Stromnetzentgeltverordnung, StromNEV) rewards steady asset utilisation and high load hours; flexible operation can cause a consumer to fall below the qualifying thresholds so that the reduced tariff is lost. The Bundesnetzagentur has opened a determination procedure to replace it with a system that rewards system-serving flexibility. The AgNes process pursues the same objective, but a final determination is still pending (see Section 2.2).

For direct electrification, economic and infrastructural barriers remain more important than technology maturity for low- and medium- temperature applications (Rosenow et al. 2025). Electricity prices relative to gas directly affect operating costs (Fraunhofer ISI 2024b). The electricity-to-gas price ratio for industrial customers in Germany was estimated at around 2.5 for the first half of 2026 (European Climate Neutrality Observatory 2026). Switching from fossil fuels to direct electrification requires new equipment and its integration into existing production processes. This generally involves higher capital expenditure than replacing or modernising an existing fossil fuel-based installation. The local and surrounding infrastructure also usually requires adaptation. These investment requirements concern not only the heat generation technology itself, but also its integration into the production process and the associated infrastructure (Fraunhofer ISI 2024b). Above 1,000 °C,

technological maturity remains an additional constraint for several electrothermal options.

Hydrogen is limited mostly by high costs (dena 2026b, 2026a). Compression, transport, storage and site connections can increase the cost for industrial consumers. Domestic deployment depends on the hydrogen core grid, storage and site connections, which remain under development (BMWE 2026b).

3 Japan

3.1 Energy consumption of Japan industry

Industry is Japan's largest energy-consuming sector, accounting for close to 30 % of total final energy consumption, ahead of transport and the residential sector (IEA 2026c).

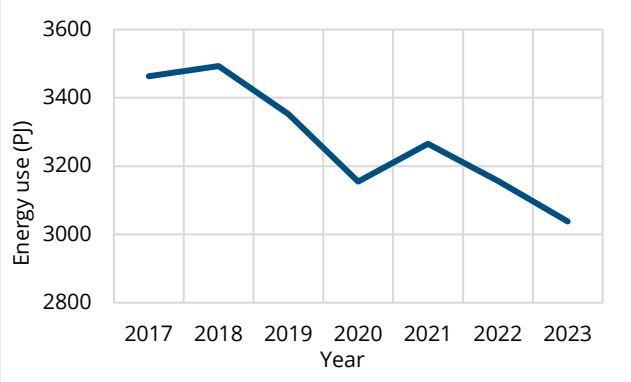


Figure 3 Annual energy use by Japan industry (2017-2023). Own illustration based on (IEA 2026c).

Electricity is the dominant energy source in Japan's industry sector, followed by coal, oil, and natural gas, while biofuels and waste account for smaller shares.

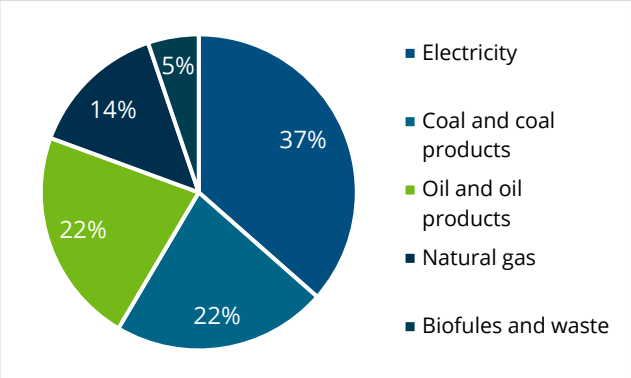


Figure 4 Energy use in Japan industry by energy source. Own illustration based on (IEA 2026c).

Consumption is even more concentrated than in Germany. Iron and steel, and chemicals together account for the large majority of industrial final energy consumption, with petroleum products and pulp and paper accounting for substantially smaller shares. Emissions are therefore concentrated at a relatively small number of energy-intensive sites.

3.2 Legal requirements and framework conditions

Japan's regulatory framework for industrial decarbonisation is organised under the Green Transformation (GX) umbrella. Unlike Germany, where EU legislation sets the broader frame and national law implements and possibly extends it, Japan's provisions are set entirely at national level.

The **Act on Promotion of Global Warming Countermeasures** establishes the framework for climate policy by assigning responsibilities, requiring national and local action plans, and providing for emissions monitoring and disclosure (Japanese Law Translation 2022). The associated Plan for Global Warming Countermeasures sets the concrete national targets of a 46% reduction in greenhouse gas emissions by fiscal year 2030 relative to fiscal year 2013, and climate-neutrality by 2050 (Cabinet of Japan 2025). It shapes ambition but imposes no plant-level obligations.

The **GX Promotion Act** provides the legal basis for implementing Japan's Green Transformation strategy. The Act establishes a policy package built around two mutually reinforcing elements. First, it introduces a growth-oriented carbon pricing concept, which combines an emissions trading system with a fossil fuel surcharge. More than 700 companies participated in voluntary phase 1, accounting for over half of national emissions. The mandatory phase 2 started on 1 April 2026 and runs to FY2032. It covers companies with average annual direct CO_2 emissions of at least 100,000 t setting emission limits and reporting obligations for these large emitters. The system-wide cap is not yet fixed, as baselines are expected only in autumn 2026 or later. As regards prices, the mandatory GX-ETS operates within a government-defined price corridor. For FY2027, the reference adjustment price was set at JPY 1,700 per t CO_2 (EUR 9.20)[2], while the reference upper trading price was set at JPY 4,300 per t CO_2 (EUR 23.2). A third phase from FY2033 introduces auctioning for high-emitting power sector companies (Mavandad and Friedmann 2025; ICAP 2026). The second element is the GX Economy Transition Bonds, through which the Japanese government plans to provide approximately JPY 20 trillion (around EUR 108 billion) in upfront support over ten years for decarbonisation investments. The GX Promotion Act authorises their issuance and links their

[2] 1 JPY = 0.0054 EUR

repayment to future revenues from the fossil fuel surcharge and the auctioning of emissions allowances. The bonds are intended to reduce investment risks and mobilise more than JPY 150 trillion (around EUR 808.5 billion) in total public and private GX investment over ten years (Climate Laws 2023).

The foundation of energy efficiency policy is **the Act on Rationalizing Energy Use**, revised in 2022 and renamed to the **Act on Rationalizing Energy Use and Shifting to Non-fossil Energy (Energy Conservation Act)** (IEA 2017). Where the Act previously obliged large consumers only to rationalise fossil energy use, it now requires the rationalisation of all energy and an active shift to non-fossil sources, through mandatory mid- to long-term transition plans and regular reporting (EnelX 2023). Companies whose total domestic energy consumption is at least 1,500 kl crude oil equivalent (64 TJ) per year must submit a regular annual report on their energy consumption and targets and measures for the transition to non-fossil fuels.

The **Renewable Energy Act** (the Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities) governs the feed-in tariff (FIT), under which electricity utility companies must purchase power generated from renewable sources at a government-determined fixed price for a defined period. Under the feed-in premium (FIP) scheme, generators receive a market-linked premium in addition to wholesale electricity revenues (Climate Laws 2018). Electricity-intensive businesses can obtain a reduction of the renewable energy surcharge of up to 80%. To qualify, they must improve their electricity intensity and, since FY2025, publicly disclose these efforts. The **Electricity Business Act** establishes the regulatory framework for Japan's electricity sector. It sets the requirements for electricity generation, retail supply, transmission and distribution, including the licensing of general transmission and distribution businesses, the registration of electricity retailers and the provision of wheeling services through the electricity grid. On this basis, self-wheeling allows companies to transmit electricity from their own generation facilities, including renewable ones, via the grid to their own sites elsewhere, such as factories (e-Gov 2023).

The Act on Promotion of Supply and Utilization of Low-Carbon Hydrogen and its Derivatives (Hydrogen Society Promotion Act, 2024) establishes the legal framework for scaling low-carbon hydrogen and its derivatives, addressing decarbonisation pathways beyond the reach of direct electrification and energy efficiency. It aims to accelerate the production, import and use of low-carbon hydrogen and its derivatives, such as ammonia and e-methane, to support Japan's transition to a decarbonised economy by 2050. The Act introduces a plan certification system and provides two core support instruments: a price differential subsidy mechanism, modelled on a contracts-for-difference approach, designed to close the cost gap between low-carbon hydrogen and fossil fuels, and infrastructure support for the development of supply clusters. Eligibility is contingent on compliance with defined carbon-intensity thresholds, aligned in part with EU standards, with a particular focus on hard-to-abate sectors such as steel and chemicals (IEA 2025c).

The CCS Business Act (Act No. 38/2024) creates a licensing, safety and monitoring regime for CO_2 storage. Together with the quantified storage targets set out in METI's CCS Long Term Roadmap, it supports the use of carbon management as a potential measure of last resort for addressing residual process emissions in sectors such as cement, chemicals and steel (METI 2024b; Climate & Capital 2025; Clifford Chance 2025).

3.3 Funding schemes

The anchor is Japan's **GX Economy Transition Bond** programme, under which the government plans to issue approximately JPY 20 trillion (around EUR 108 billion) over ten years. The first securities, issued in February 2024 as Japan Climate Transition Bonds, were presented as the world's first sovereign transition bonds. The programme provides upfront support through subsidies, tax incentives and research and development (R&D) funding, and is intended to be redeemed through future carbon pricing revenues, including proceeds from the GX-ETS and the fossil fuel levy(METI 2025b). It underwrites most instruments below rather than targeting a single sector or technology, structurally coupling financing to carbon pricing. Implementation is coordinated by the GX Acceleration Agency (GXA), established in 2024 as the delivery hub for the GX financial mechanisms, ETS operations and levy collection.

The JPY 2 trillion (around EUR 11 billion) **Green Innovation Fund**, operated by the New Energy and Industrial Technology Development Organization (NEDO), provides up to ten years of support for R&D, demonstration and deployment in priority fields such as industrial heat, hydrogen and fuel ammonia and renewable energy (METI 2025b). Flagship projects like the **"Decarbonisation of Thermal Processes in Manufacturing"** target CO_2-neutral industrial furnaces, staged ammonia and hydrogen combustion in metal processing, and hybrid electric furnaces with direct electrification and low-carbon carriers for high-temperature processes (NEDO 2026).

The **Energy Conservation Subsidies** (revised for FY2026 to include non-fossil conversion), support upfront investment in efficient plant, equipment replacement and energy management systems (Sustainable open Innovation Initiative 2026). They address energy efficiency and cross-cutting technologies directly through mature, short-payback measures, and are among the most consequential near-term financing levers for industrial efficiency. The **SHIFT Program** is the flagship line

promoting pioneering decarbonisation measures in factories and facilities, combining efficiency gains with fuel switching, and is the principal channel for firms pursuing deeper, plant-level abatement.

The Project for the Installation of Renewable Energy and Other Heat Utilization Equipment is eligible renewable heat utilisation equipment, self-consumption renewable electricity generation other than solar photovoltaic generation, and industrial waste heat utilisation, subject to cost and CO_2 reduction requirements.

Under the **Hydrogen Society Promotion Act**, the **Contract-for-Difference scheme (CfD)** (from October 2024) covers the gap between the cost of producing low-carbon hydrogen and its derivatives and a fossil-fuel reference price for up to 15 years. For imported hydrogen, the supported cost may also include overseas production and maritime transport. Complementary, **hydrogen-hub subsidies,** support the development shared of transport and storage infrastructure that multiple firms need to access low-carbon hydrogen and its derivatives (METI 2024c). The scheme is the most direct instrument for closing the cost gap on hydrogen and ammonia in hard-to-abate applications.

The **"Advanced CCS Projects"** programme, led by METI and implemented by the Japan Organization for Metals and Energy Security (JOGMEC), supports the development of integrated CCS value chains. In fiscal year 2024, JOGMEC selected nine projects for priority support, covering the electric power, oil refining, steel, chemicals, pulp and paper, and cement sectors. The programme provides priority support for designing the entire CCS value chain and assessing potential CO_2 storage capacity. The selected projects are expected to reach final investment decisions on their respective CCS projects by fiscal year 2026, with the broader aim of commencing commercial CCS operations by 2030. Accordingly, JOGMEC does not, in principle, plan to launch further calls for proposals for Advanced CCS Projects from fiscal year 2025 onwards. It may nevertheless launch an additional call if existing projects encounter difficulties in meeting the 2030 storage target or face exceptional circumstances, such as significant changes in domestic or international conditions (METI 2024a).

3.4 Deployment Status

3.4.1 Energy efficiency

The Top Runner Programme establishes product-specific efficiency standards for a total of 31 product categories, including electric motors (IEA 2024). Electric motors are an important category within the Top Runner programme. With around 100 million motors in operation accounting for roughly 55 % of industrial electricity consumption, improvements in motor efficiency offer high leverage for industrial decarbonisation. Since 2015, three-phase induction motors have had to meet premium-efficiency (International Efficiency 3; IE3) standards, and only compliant units are placed on the market (Jema 2015). The effect is visible: whereas almost all motors met only the lowest efficiency class until 2015, well over 70 % of units now shipped are IE3-compliant (Fuji Keizai 2025). A survey of the Japanese industry reveals that energy efficiency has the highest level of implementation among the decarbonisation measures considered: 90 % of the production sites that had already implemented or were considering concrete measures reported implementing energy efficiency measures (Central Research Institute of Electric Power Industry 2023).

Statistics published by the Japan Accreditation Board (JAB) report 13 ISO 50001 certification cases in Japan at the end of 2024 (JAB 2024). In a nationwide online survey of 383 employees in the Japanese food manufacturing sector, 53.9 % of respondents reported that their workplace was undertaking EMS related activities (Fuji Electric 2022).

Survey data on the state of digitalisation in Japanese manufacturing suggest that deployment remains at an early stage across the sector. According to data from 2024, only about 24–39% of companies, depending on their size, have already implemented digitalization measures or extended digitalization to other plants, while 61–76% have not yet taken any such measures. Larger companies are further along, but even in their case, digitalization is not yet comprehensive (ABeam 2024). In March 2026, METI published a guidance structuring digital and AI-based efficiency around real-time monitoring, automated analysis and control automation, with reported plant-level cases such as an AI control system at ENEOS Materials that cut steam consumption substantially while removing manual operation (朝日新聞 2026).

Process optimisation through the temporal flexibilisation of consumption (demand response) has moved from demonstration to market operation. Following reform of the Electricity Business Act, a megawatt trading market opened in 2017. In 2022, successful demand-response bids reached 2.3 GW (METI 2023; IEA 2023).

3.4.2 Heat recovery and use of waste heat

In the Japanese energy system around 60 % of primary energy is ultimately released as heat, making its recovery a key prerequisite for economy-wide efficiency gains (NEDO 2023). According to a NEDO estimate, the remaining unused waste heat in Japan amounts to around 743 PJ per year. 76 % of this is exhaust heat with temperatures below 200 °C (NEDO 2019). At the same time, there are several providers and implemented cases in Japan. These include JFE Steel's West Japan Works in Fukuyama, where waste heat from a coke dry quenching (CDQ) plant is utilised (JFE Engineering 2026).

3.4.3 Direct electrification of process heat

Japan, alongside Europe, is considered as one of the world's most developed heat pump markets, supported by strong domestic manufacturers such as Mitsubishi Heavy Industries and Fuji Electric (enegaeru 2025). In 2024, installed industrial heat pump capacity in Japan reached nearly 650 MW (IEA 2026b).

Electric boilers are gaining a foothold, with annual installations rising gradually from around 380 units in 2021 to a projected 600 by 2030. The electric boiler market has historically been driven by commercial users such as laundries and hospitality rather than by manufacturing industry, which still accounts for only around a quarter of the installed stock (Matsuda and Chiho 2025). Uptake is concentrated in machinery, food and beverages, automotive, electronics and chemicals. On the supply side, domestic manufacturers such as Miura, Takao Iron Works, and Nippon Electric Heating are active in the segment. Miura in particular has expanded into electric once-through steam boilers (Miura 2023).

EAFs have long been used in Japan's scrap-based steelmaking sector and account for around a quarter of national crude steel production (ISIJ International 2026). Integrated steel producers Nippon Steel and JFE Steel are now planning large, high efficiency "innovative EAFs" as part of the transformation of their steelmaking operations. JFE Steel plans an approximately 2 million tonne per year EAF at its Kurashiki site, while Nippon Steel has announced three EAF-related projects in Japan with a combined annual capacity of approximately 2.9 Mt (Luca 2026; CAJ 2025).

Induction heating is an established technology in several industrial applications. The Japan Electro Heat Center lists examples for metal processing and manufacturing (JEHC 2026a). Fuji Electric, for example, offers induction furnaces with a power output of up to 20 MW (Fuji Electric 2026; Inductotherm 2023).

The use of plasma heating in Japan appears to remain concentrated in specific applications rather than being deployed at scale as a decarbonisation option for industrial process heat (Tanabe 2026; Nozaki et al. 2024). A documented industrial application in Japan is Nippon Steel Engineering's NS Tundish Plasma Heater (NS TPH), which is used to maintain the temperature of molten steel in the tundish of a continuous casting machine (Nippon Steel). Resistance heating is a commercially available technology with documented industrial applications in Japan. The Japan Electro Heat Center lists applications in metal processing and manufacturing (JEHC 2026b).

Thermal energy storage in Japan is unevenly mature across applications. At the lower end of the temperature range, cold- and heat-storage systems integrated with heat pumps are well established and have seen broad deployment across commercial, industrial, and residential settings. Documented cases in production plants include both stationary and mobile storage configurations alongside conventional cold storage. High-temperature and process-heat applications present a different picture. Deployment here remains at an early, largely pre-commercial stage, with activity concentrated in publicly co-funded R&D programmes. Advanced sorption systems, thermochemical storage, and mobile high-temperature stores are in many cases still at the demonstration stage (Market Screener 2025).

3.4.4 Direct use of renewable energy sources

A survey of Japanese industry found that increasing the use of renewable energy within companies, particularly through the installation of their own on-site photovoltaic systems, was the second most commonly reported decarbonisation measure among the surveyed production sites, cited by 40% of respondents (Central Research Institute of Electric Power Industry 2023). Japan's corporate PPA market has grown rapidly, surpassing 700 cumulative deals representing more than 3.5 GW installed and planned capacity since 2021 (Japan Energy Hub 2026). One example is the industrial company Panasonic Automotive Systems, which has been supplying 10 % of the electricity consumption of its Yokohama Building with renewable solar power via a PPA since 2024 (Panasonic 2024).

Solar thermal process heat plays only a minor role. Japanese solar thermal has traditionally focused on domestic hot water, and industrial applications remain niche, further constrained by lower irradiation and snow in the north (REN21 2026; SHC 2026). Documented industrial cases exist but are mostly older and limited to low-temperature uses such as cleaning, washing and sterilisation.

Solid biomass is an important non-fossil source of industrial process heat, with use concentrated in the pulp and wood processing industries (IEA Bioenergy 2024). Since April 2023, METI has required operators of biomass power plants to calculate lifecycle greenhouse gas emissions, and it has published default values for the greenhouse gas emissions of those biomass feedstocks eligible for support under the FIT and FIP programmes. Reflecting the binding feedstock constraint, the Biomass Industry Society Network recommends a material cascade and a shift from power generation towards heat, directing biomass specifically to applications other renewables can supply only with difficulty – notably industrial heat and liquid fuels (Omondi et al. 2026; BIN 2026).

Geothermal energy has a large theoretical potential over 23 GW (Yasukawa 2021), while Japan's geothermal power generation capacity stands at only 0.6 GW (0.3 % of the electricity mix) (ThinkGeoEnergy 2025). Geothermal power is expected to account for approximately 1–2 % of electricity generation in fiscal year 2040. For industry, the best-documented applications use directly available

thermal water and steam at roughly 50–110 °C in food production, salt-making and timber drying.

3.4.5 Electrolytic and low-carbon energy carriers

Japan positions hydrogen and ammonia as central elements of its strategy to reach net-zero emissions, with a distinctive focus on importing both fuels and on co-firing them in existing thermal power plants as a transition technology. Total hydrogen production in Japan amounted to approximately 2 Mt in 2022, most of which was used on site in the refining industry (Osaki and Hughes 2025). This hydrogen is still produced predominantly from fossil fuels. In industry, hydrogen is currently at the demonstration stage for high-temperature process heat. One example is Kobe Steel, which has commissioned a large hydrogen fired metal heating furnace at its Takasago plant and is conducting initial demonstrations of hydrogen use (Kobelco 2026).

Biomethane deployment in Japan remains limited and is currently documented mainly through pilot and demonstration projects. Examples include the planned use of city gas linked to imported biomethane at part of Fujifilm's Ashigara manufacturing site, described as a preliminary pilot initiative, and a demonstration project in which liquefied biomethane was supplied as an LNG substitute to Yotsuba Milk's Tokachi plant (Fujifilm 2026). Japan's total biogas production is estimated at a marginal 0.17 PJ (47 GWh) (IEA Bioenergy 2024).

3.4.6 Carbon management

Japan has treated CCUS as a key component of its decarbonisation strategy for several years, with the aim of commercial application by 2020. However, this target was not achieved. For CCS one completed demonstration project is documented: the landmark full-chain Tomakomai project injected around 300,000 t of CO_2 captured from a Hokkaido refinery between 2016 and 2019, before concluding as planned (IEA 2021c). The government now aims to move the technology from pilot to commercial scale. Further initiatives remain in the planning phase, with most targeting demonstration by 2030 (METI 2024b). CCU has several concrete pilot and demonstration plants with actual use of CO_2. This includes the demonstration project by Mitsubishi Heavy Industries, Tokyo Gas and the city of Yokohama for the capture of CO_2 from the exhaust gas of a waste incineration plant, which is used to produce synthetic methane (Mitsubishi 2023). A distinctive feature for Japan is heavy reliance on cross-border CO_2 transport and overseas storage, given limited domestic geological capacity, supported by bilateral agreements and the METI-led Asia CCUS Network (Climate & Capital 2025). In February 2024, a demonstration project for the maritime transport of liquefied CO_2 was launched in Japan. The project transports CO_2 from a coal fired power plant in Maizuru, Kyoto Prefecture, to a storage site in Tomakomai, Hokkaido, located approximately 1,500 km away. The project represents the first global demonstration of maritime CO_2 transport using liquefaction at low-temperature and low-pressure (Japan News 2024).

3.5 Barriers and challenges

This section examines the main barriers for energy efficiency and decarbonising industrial heat in Japan, focusing on energy efficiency, direct electrification and renewable hydrogen. Solar thermal process heat, geothermal energy and bioenergy are not considered separately. Carbon management also falls outside the scope of this section, for the reasons set out in Section 2.5.

For energy efficiency, the main challenge in Japan is implementing measures within operating production systems. Japan's Energy Conservation Act requires designated large energy consumers to monitor and report their energy consumption, set targets for energy use and prepare medium to long term plans for energy conservation measures. These requirements do not remove the practical barriers of implementation. In a 2021 survey on industrial decarbonisation, high equipment costs represented the most cited barrier, followed by missing of in-house engineering staff, concerns about modifying existing production facilities, long payback periods and high electricity costs (Central Research Institute of Electric Power Industry 2023). By contrast, relatively few respondents identified immature technology, limited energy savings or limited carbon dioxide reductions as major obstacles. This suggests that, as in Germany, the principal barriers lie in investment conditions, organisational capacity and the integration of measures into operating production systems rather than in the basic availability or expected effectiveness of energy efficiency technologies.

In Japan, as in Germany, economic barriers remain more than technology maturity for low- and medium- temperature applications. The ratio of electricity prices to fuel prices is relatively high, which affects operating costs directly. The ratio remained slightly above 2 until 2014, increased from 2015 and fluctuated around 3 thereafter, exceeding 3 in 2020. The increase followed the long-term shutdown of nuclear power plants after the Great East Japan Earthquake and the introduction of the renewable energy surcharge, which is levied only on electricity (Journal of Life Cycle Assessment 2026). Above 1,000 °C, technological maturity remains an additional barrier for several application.

For renewable hydrogen high costs, limited domestic availability and uncertainty about the development of infrastructure and supply chains remain important barriers to its use in Japanese industrial applications. Japan has limited availability of domestic renewable energy. Japan's approach therefore places considerable emphasis on imports and on the development of storage and

transport infrastructure, which the Hydrogen Society Promotion Act addresses through price gap support covering overseas production and maritime transport for eligible (METI 2025a; Konovalov et al. 2025).

4 Conclusions and Recommendations for Japanese-German Cooperation

4.1 Conclusions

The comparison of Germany and Japan reveals substantial similarities in their industrial energy profiles and decarbonisation challenges. Industry represents the largest energy-consuming sector in both countries, accounting for approximately 27 % of total final energy consumption in Germany and 30 % in Japan. A limited number of energy-intensive branches concentrate industrial energy demand. In Germany, these include chemicals, iron and steel, refining, paper, glass and food. In Japan, iron and steel and chemicals account for the largest shares, followed by petroleum products and pulp and paper. Fossil fuels also remain an important component of industrial final energy consumption in both countries. Natural gas accounts for 29 % of industrial final energy consumption in Germany, while coal and oil each account for 22 % in Japan.

Germany and Japan have established climate-neutrality targets for 2045 and 2050, respectively, and both have developed comprehensive legal and regulatory frameworks for industrial energy efficiency and decarbonisation. Germany operates within a framework that combines EU legislation with national law, whereas Japan's framework is established at the national level under its GX policy framework.

Energy efficiency has become an established policy area in both countries, although the two systems rely on different instruments. Germany reports more than 10,000 ISO 50001 certificates, compared with 13 reported certification cases in Japan. Germany also uses mandatory energy audits for companies other than small and medium-sized enterprises to strengthen energy management. Under Japan's Law Concerning the Rational Use of Energy, companies must report information related to energy efficiency and submit medium- and long-term energy efficiency plans.

Several process heat technologies are commercially available in both countries, including industrial heat pumps and electric boilers. Both countries also have substantial supplier bases for these technologies. Deployment nevertheless remains well below the available technical potential. Germany has reached just over 180 MW of installed heat pump capacity for industry and district heating, with a further 900 MW announced, with a large proportion of capacity being used to supply district heating networks, while Japan had reached almost 650 MW of installed capacity for industry by 2024.

The technology landscape shows further similarities, alongside differences in the maturity and scale of deployment. Electric arc furnaces and induction heating are established in both countries, whereas plasma heating remains limited to specific applications. Resistance heating has reached the pilot stage in Germany and is commercially available, with documented industrial applications, in Japan. Thermal energy storage is already used for process-related applications in German industry. In Japan, low-temperature storage integrated with heat pumps is established, while high-temperature applications remain at the demonstration stage. Power purchase agreements are present in both countries, whereas solar thermal process heat and geothermal energy play only a minor role. Bioenergy provides relevant amounts of process heat in both countries. Green hydrogen and biomethane remain marginal in industrial applications, and industrial carbon management has not yet reached commercial scale deployment in either country.

Economic and infrastructural barriers continue to limit the uptake of low-carbon process heat technologies. Both countries report an unfavourable ratio between electricity and fuel prices - in Japan, it fluctuates around three, while in Germany it is around 2.5. Further barriers include high capital costs, short payback expectations and constraints related to grids and other infrastructure.

4.2 Potential areas of cooperation

Taken together, the findings of this study indicate that Germany and Japan face comparable challenges but address them through differently. This creates a strong basis for cooperation. Both countries could benefit from exchanging experience on energy management, comparing funding instruments for industrial decarbonisation, examining the conditions for competitive electrification and jointly assessing the deployment of process heat technologies across different temperature levels.

Thus, the findings presented above point to three potential areas for cooperation between Japan and Germany:

1. Funding instruments for industrial decarbonisation

Germany and Japan address the investment and operating cost barriers to industrial decarbonisation through different combinations of carbon pricing and public finance. The EU ETS has operated in Germany for several years as an established framework. Japan is transitioning

from the voluntary GX League pilot launched in 2023 to a mandatory emissions trading system in the fiscal year 2026, beginning on 1 April 2026. With regard to funding, Germany relies on national instruments such as the EEW and CCfDs, complemented by European instruments such as the Innovation Fund and the European Hydrogen Bank. Japan channels its support largely through the GX Economy Transition Bond programme, which underwrites instruments such as the Green Innovation Fund, the Energy Conservation Subsidies, and the Contract-for-Difference scheme for low-carbon hydrogen.

A comparative study of funding instruments for industrial decarbonisation could provide a basis for mutual learning and identify opportunities to improve the design of these instruments in both countries. The study could compare the instruments' objectives, eligible sectors and technologies, funding mechanisms, award criteria and results to date. The interaction of these instruments with carbon pricing under the EU ETS and Japan's GX ETS, including carbon leakage, could be considered as context.

2. Energy management, efficiency standards and digitalisation

Energy management and efficiency standards represent a further area of mutual interest. Both countries recognise the importance of reducing industrial energy consumption, and both have introduced various policy instruments to improve their energy performance over time.

- A bilateral exchange could compare Germany's experience with mandatory energy audits and Japan's approach of requiring large energy consumers to prepare mandatory mid to long-term transition plans and submit regular reports, identifying respective key strengths of these two very different approaches. The exchange could examine how these instruments support companies in reducing energy consumption, as well as the conditions required for their effective implementation.
- Germany's experience with Efficiency Networks offers an additional opportunity for cooperation. This horizontal, cooperative approach has supported companies in identifying and implementing energy efficiency measures. Establishing a similar scheme in Japan could therefore be explored, particularly because it would fit with the Japanese emphasis on cooperation and continuous improvement.
- Digitalisation could complement these approaches to energy management. Possible topics for exchange include artificial intelligence-based process optimisation, digital twins and cross-asset optimisation combining demand response, storage, own production and procurement. Cooperation could focus on how these applications improve energy management, optimise industrial processes and increase the flexibility of electricity consumption while reducing costs.

3. Technology exchange on process heat across different temperature levels

The maturity of process heat technologies varies considerably according to the required temperature level. Below approximately 200 °C, solutions such as industrial heat pumps and electric boiler storage are commercially available. High-temperature applications, by contrast, range from established industrial technologies to solutions that remain at an early research stage.

This variation in technology maturity provides a useful basis for a structured expert exchange under the Energy Partnership. Such an exchange could clarify the state of technology deployment in Germany and Japan and identify areas in which the two countries could learn from each other.

One possible format would be a targeted joint workshop involving research institutions, technology suppliers, industrial companies and public agencies from both countries. To ensure concrete results, the workshop should focus on a single sector or temperature level. For the selected focus, it could examine commercially available solutions, operating experience, process integration and barriers to wider deployment, and distinguish between technologies already in industrial use, those demonstrated at pilot scale and those that remain at the research stage. This approach would help identify opportunities for joint learning, technology cooperation and policy support. It would also distinguish between solutions that are ready for wider deployment, technologies that require further demonstration and areas in which continued research and development remain necessary.

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