Chapter 1

Current Situation of Cogeneration System Installation in Japan

November 2023

This chapter should be cited as

ERIA study team (2023), 'Current Situation of Cogeneration System Installation in Japan', in Kimura, S., S. Miyakoshi, L.S. Meng and L.C. Beng (eds.), *Cogeneration Potential in Indonesia's Industry Sector with Reference to Japan and Malaysian Experiences.* ERIA Research Project Report FY2023 No. 14, Jakarta: ERIA, pp.1-15.

Chapter 1

Current Situation of Cogeneration System Installation in Japan

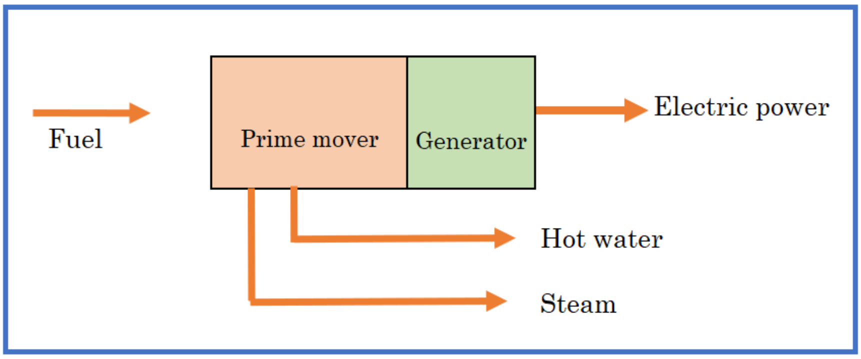
1.1. What is a Cogeneration System?

This section introduces the meaning and mechanism of cogeneration systems (CGSs). The introduction contains the following three points: CGS types, mechanisms, and effects. The source is a document from the Japan Gas Association.

1.1.1. Mechanisms and types of cogeneration

A CGS is a system that simultaneously produces multiple forms of energy from a single form. Cogeneration (combined heat and power generation) uses natural gas, oil, liquid petroleum gas (LPG), or other fuels to generate electricity with an engine or turbine and simultaneously recovers the waste heat generated during the process.

Figure 1.1. Image of a Cogeneration System



Source: Authors.

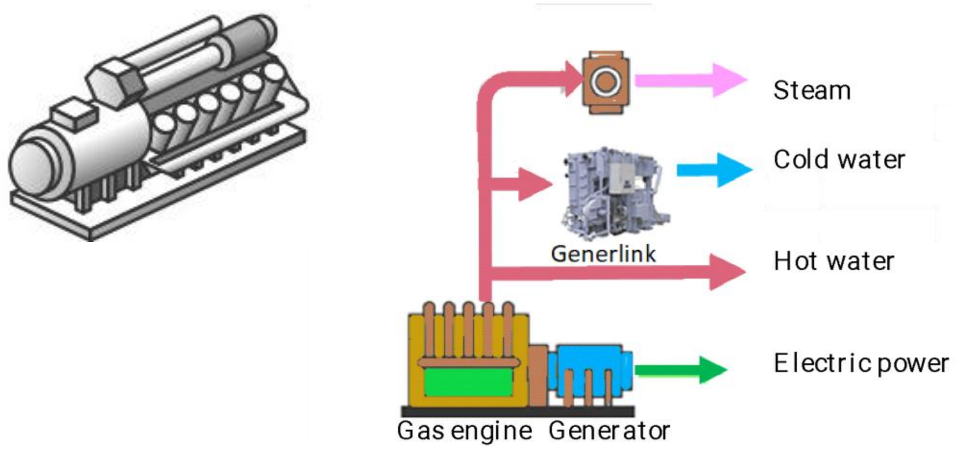
The recovered waste heat can be transformed into steam or hot water for factory heat sources, air conditioning, hot water supply, etc. If heat and electricity are used together, high overall energy efficiency can be achieved at 75%–80% of the original energy content of the fuel.

There are three types of generators depending on the power source.

1) Gas engine

Gas-fueled engines generate electricity by rotating a generator. It has high efficiency of power generation and stable output. The exhaust gas has a high combustion temperature and can be used as steam or hot water for various purposes. The output has a high ratio of electricity (40%–50%) and heat (23%–40%), and overall efficiency reaches 63%–90%.

Figure 1.2. Mechanism of CGS Applied to Gas Engines

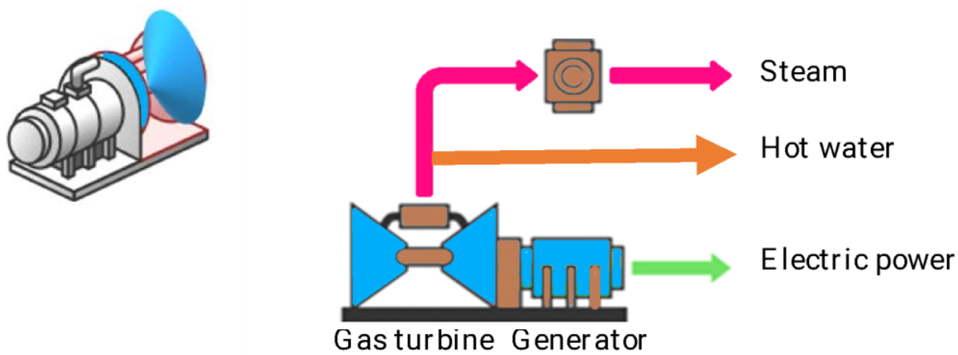


Source: Japan Gas Association, modified by the authors.

2) Gas turbine

High-temperature combusted gas produced in a combustor rotates a turbine to generate electricity. Due to its high heat recovery efficiency, it is mainly used by customers with large heat demand. The output has a high heat ratio (40%–60%) and electricity ratio is 24%–40%, so overall efficiency is 64%–100%.

Figure 1.3. Mechanism of CGS Applied to Gas Turbines

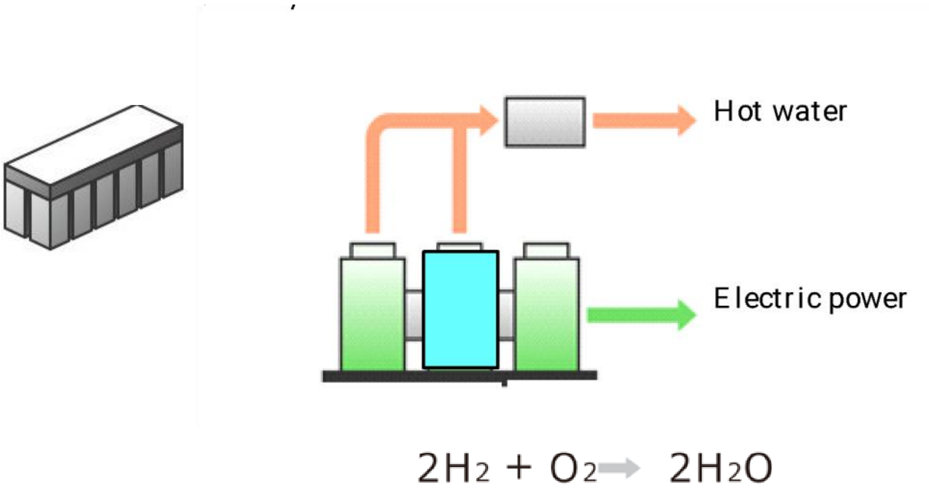


Source: Japan Gas Association, modified by the authors.

3) Fuel cell

Hydrogen is extracted from methane contained in city gas and LPG and used to generate electricity by applying electrolysis technology with oxygen in the air. Since the fuel cell directly uses fuel, such as city gas, without burning, a high efficiency of power generation of 60%–70% can be achieved.

Figure 1.4. Mechanism of CGS Applied to Fuel Cells



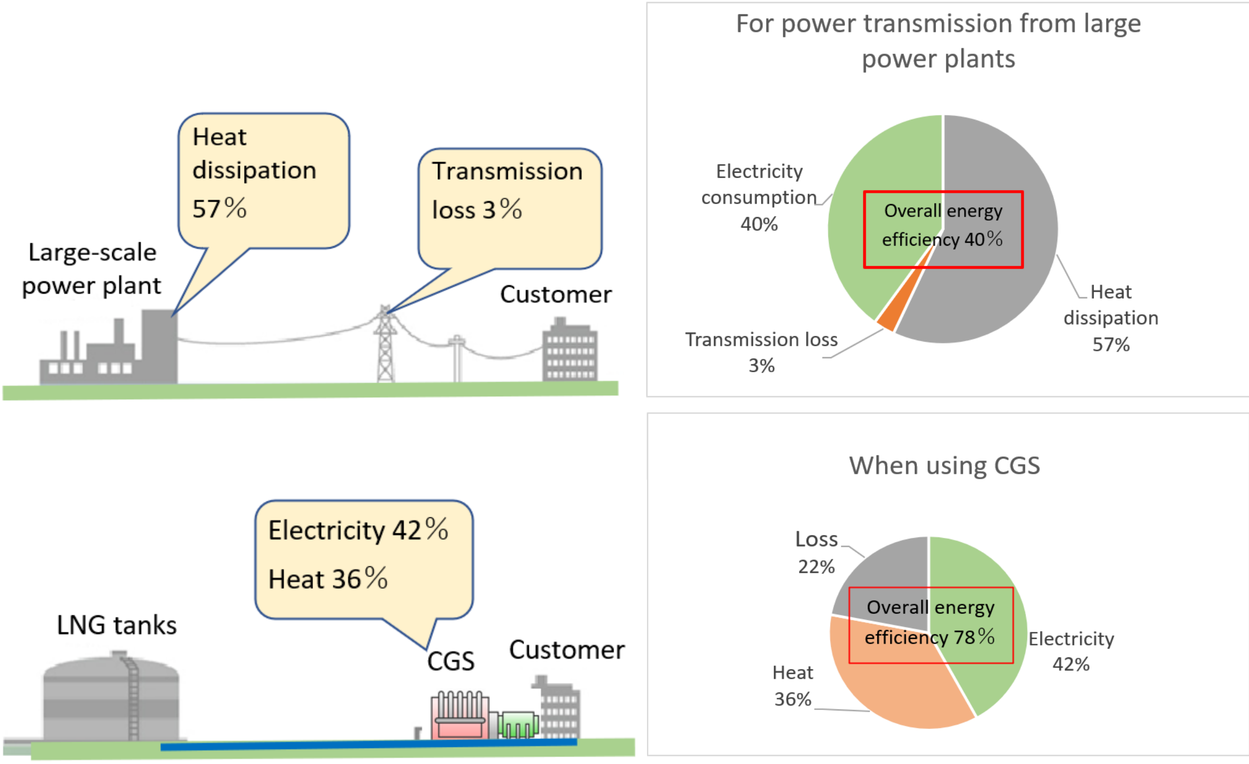
Source: Japan Gas Association, modified by the authors.

1.1.2. Advantages of introducing CGS

(1) Conserves energy and promotes business continuity

The CGS system, a 'distributed power generation system', generates power on-site. The main purpose of large-scale power plants is to generate electricity, but most of the heat is wasted, resulting in a 60% loss when combined with transmission losses. On the other hand, CGS on-site can achieve high energy efficiency because it can effectively utilise the heat generated simultaneously with power generation. In addition, on-site CGS can continue to supply electricity for its production activities during a power outage.

Figure 1.5. Comparison of Thermal Efficiency between a Large-scale Power System and CGS

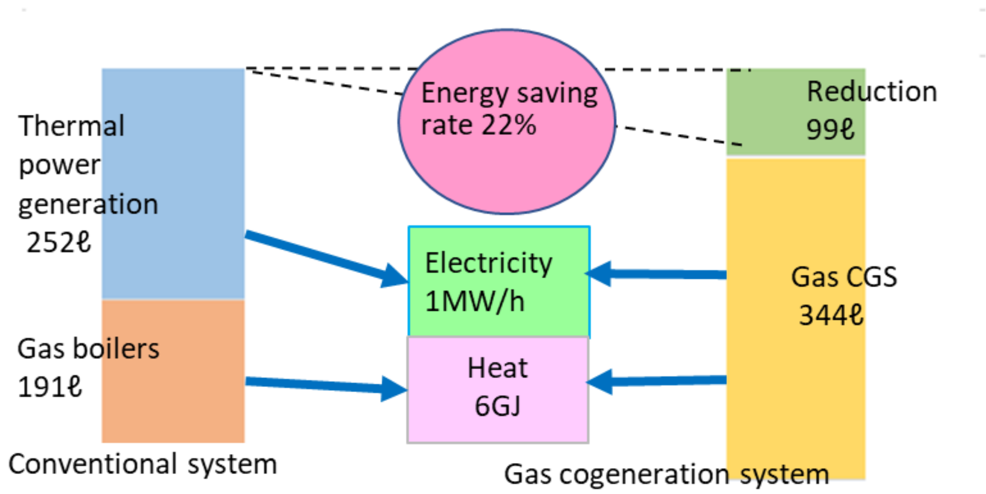


LNG = liquid natural gas.
Source: Japan Gas Association, modified by the authors.

(2) Reduces fuel consumption

Comparing fuel consumption to produce 1 MW/h of electricity and 6 GJ of heat between a conventional system and a gas CGS system, the energy-saving effect of CGS will be 22% due to waste heat.

Figure 1.6. Fuel-saving Effect of CGS

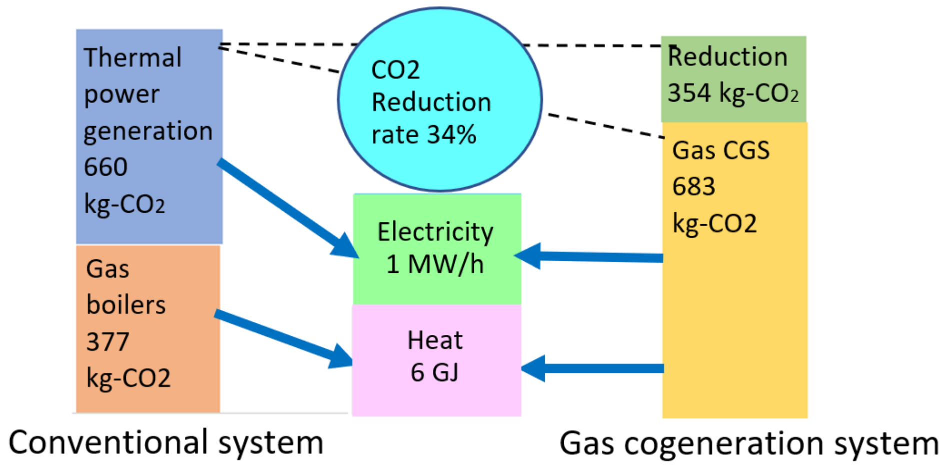


Note: All units are crude oil equivalent. Grid electricity is assumed as the average consumption of thermal power generation, and gas boiler is assumed at 40% efficiency. CGS power generation efficiency is assumed to be 85%, and CGS waste heat recovery is assumed to be 40%.
Source: Japan Gas Association, modified by the authors.

(3) Reduces CO_2 emissions and contributes to environmental preservation

Comparing CO_2 emissions when producing 1 MW/h of electricity and 6 GJ of heat with a conventional system and a gas CGS system, if we assume natural gas as $_{fuel}$ for CGS, CO_2 emission is expected to reduce by 34% compared to conventional power and fuel supply systems.

Figure 1.7. CO_2-saving Effect of CGS



Note: CO_2 emission coefficients are based on thermal power emission coefficients for grid electricity and city gas emission coefficients for boilers and CGS. Boiler efficiency and CGS waste heat recovery rates are the same as above.
Source: Authors.

(4) BCP measures by multiplexing power sources

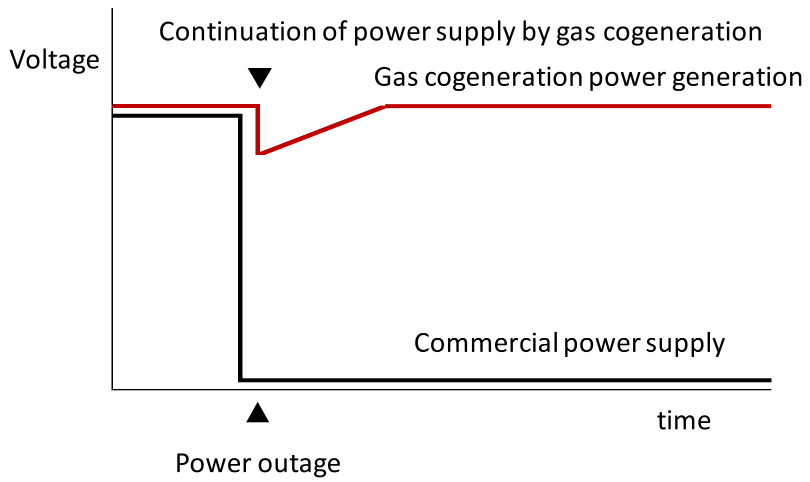
Normally, the power from the power company and that generated by CGS are interconnected. Thus, when the power supply from the electric power company is stopped due to natural disasters or accidents, the CGS can start supplying electricity to the site activities.

(5) Power Supply Continuity System

Suppresses instantaneous voltage drops

The power supply continuity system is effective for operations greatly affected by instantaneous voltage drops and power outages. During a power failure or momentary voltage drop, the CGS can be quickly disconnected from the grid to continue supplying power to critical loads without interruption.

Figure 1.8. Image of a Power Supply Continuity System



Source: Authors.

1.2. Current Situation of CGS Installation in Japan's Industry Sector

The cumulative number of CGSs installed is shown separately by the residential and commercial sectors and industrial use. Furthermore, the CGS is broken down into the installation year of the CGS. The industry is also broken down into each sub-industry sector. In addition, the type of prime mover and its fuel are historically compared in 1986–2020 vs 2021–2020. The source is the document from the Advanced Cogeneration and Energy Utilization Center Japan, which was edited and created based on this cogeneration report.

1.2.1. Number of CGS units and capacity

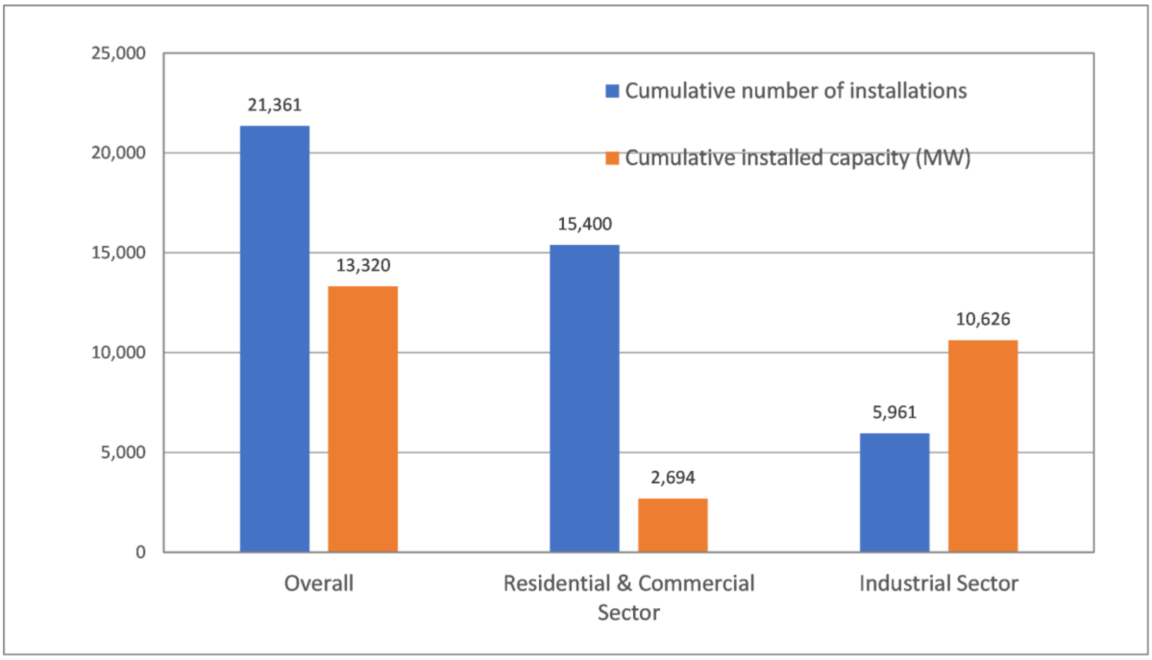
(1) Cumulative number of CGSs installed in Japan

The total number of CGS units is 21,361 units, of which 15,400 (72%) are for residential and commercial use, and 10,626 MW (80% of total capacity) are for industrial use. (refer to Table 1.1)

Table 1.1. Cumulative Number of Units and Installed Capacity
(Actual number as of 31 March 2021)

Category	Overall	Residential & Consumer Sectors	Industrial Sector
Cumulative installed (units)	21,361	15,400	5,961
Cumulative installed capacity (MW)	13,320	2,694	10,626

Note: The figures for residential and commercial use do not include residential fuel cells, called ENE-FARM.

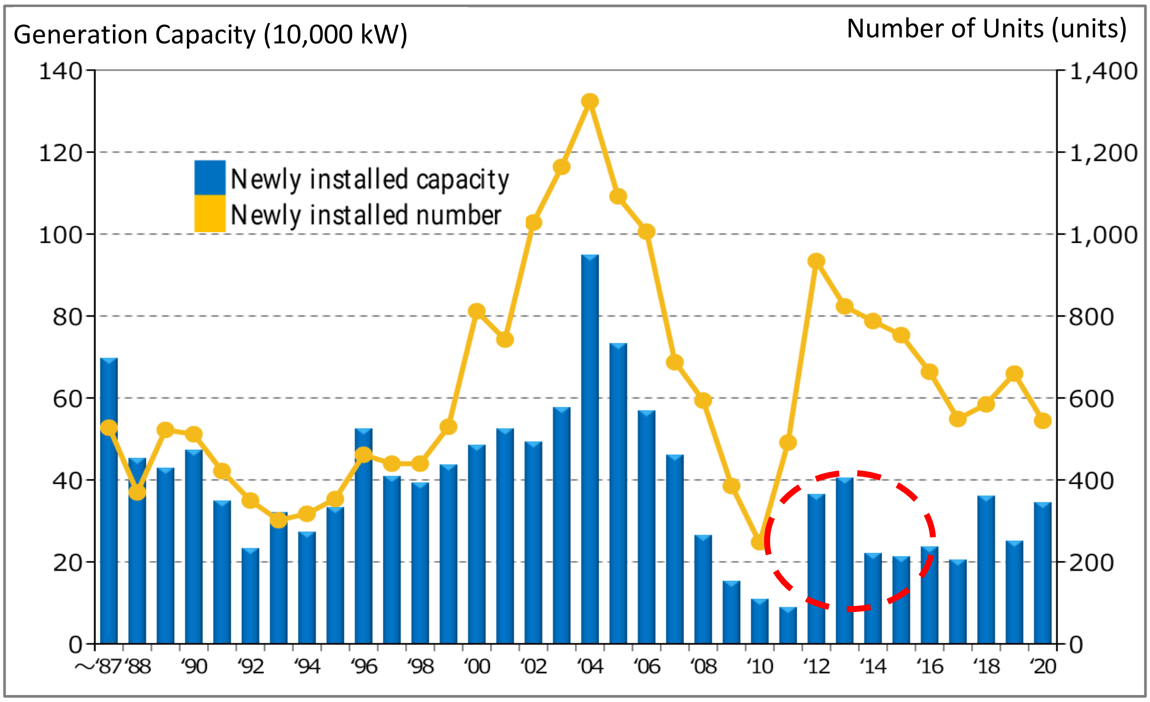


Source: Advanced Cogeneration and Energy Utilisation Center Japan, modified by the authors.

(2) Installed capacity and installed capacity by year (as of 31 March 2021)

Figure 1.9 shows the installed capacity each year from FY1987 to FY2020. The Lehman Shock in 2008 and the Great Earthquake in East Japan significantly impacted the CGSs' installed capacity in the industry sector.

Figure 1.9 Historical Installed Capacity of CGS



Source: Advanced Cogeneration and Energy Utilisation Center Japan, modified by the authors.

Reference materials: Why CGS adoption declined from 2008 to 2011

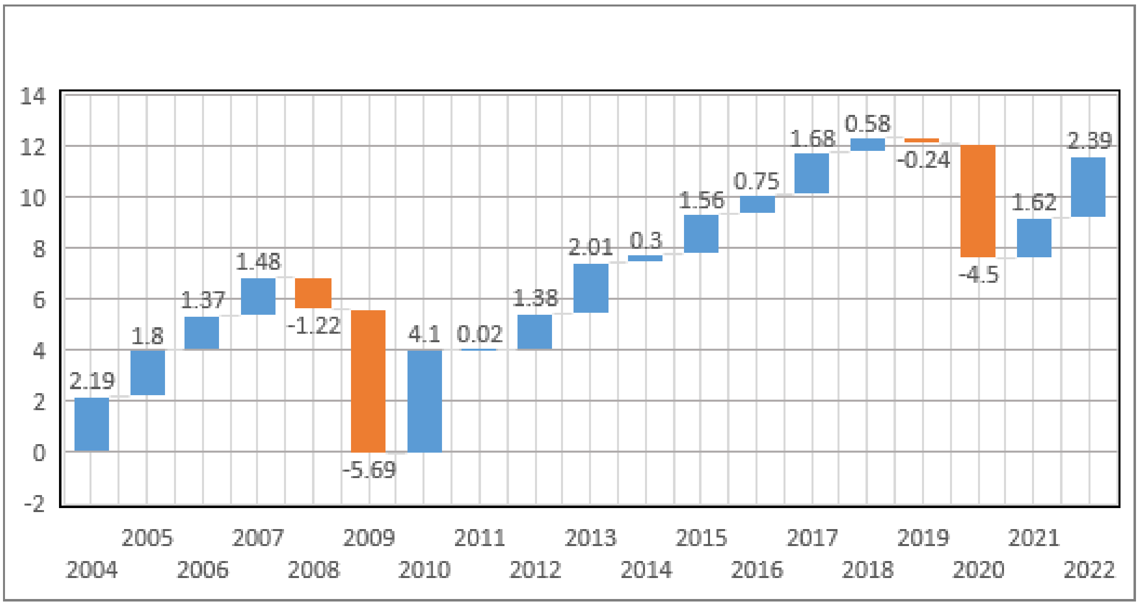
Figure 1.10 shows Japan's economic growth rates. The economic growth rate is defined below and represents the degree of GDP growth compared to the previous year.

Economic growth rate = (GDP of the current year – GDP of the previous year) ÷ GDP of the previous year × 100

The growth rate was positive from 2004 to 2007. However, after 2008, due to the Lehman Shock, it became negative in 2008 and 2009. The growth rate rebounded to +4.1% in 2010, but the earthquake in 2011 brought down the growth rate to 0.02%. After that, positive but lower growth continued until 2018. The dotted box in the graph shows the period of economic stagnation from 2008 to 2011.

Comparing this period of economic stagnation with the number of CGS installations from 2008 to 2011 shown in Figure 1.9, the result is consistent, indicating that CGS introduction is closely related to economic activity.

Figure 1.10. Economic Growth Rate, 2004–2022



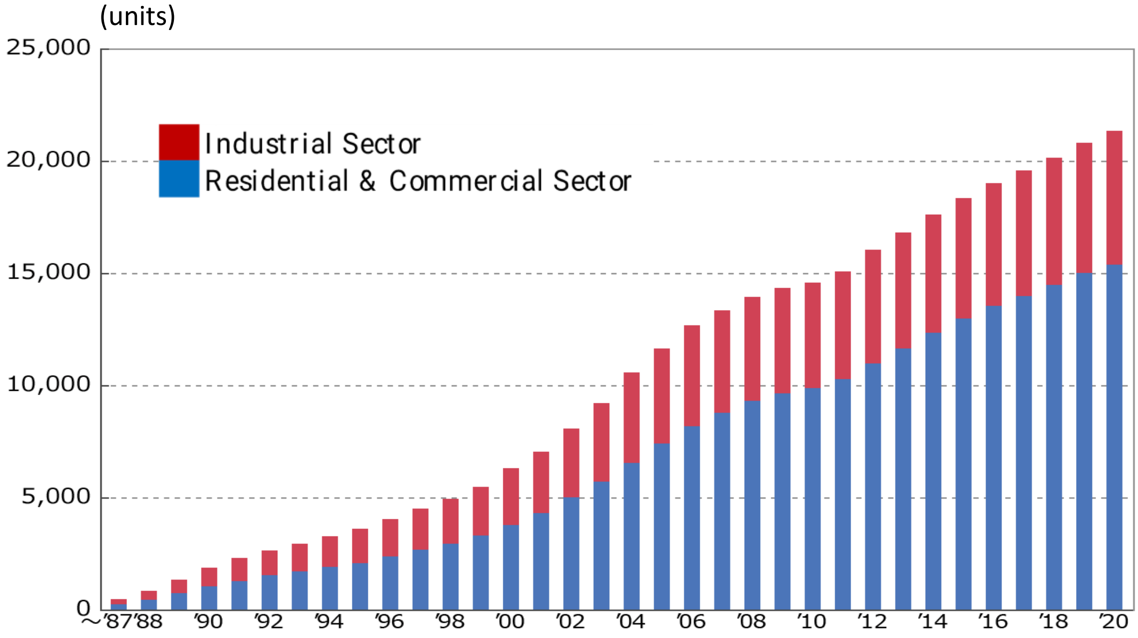
Source: Authors, based on IMF database (2022), https://www.imf.org/en/Publications/WEO/weo-database/2022/April/weoreport?c=158,&s=NGDP_R,NGDP_RPCH,NGDP,&sy=2020&ey=2027&ssm=0&scsm=1&scc=0&ssd=1&ssc=0&sic=0&sort=country&ds=.&br=1

(3) Historical CGS units (new establishment + renewal)

- Cumulative number of units installed (end of March 2021)

Regarding cumulative units, residential and commercial use accounts for 70% of the total. Both commercial and industrial use showed an increasing trend. However, as mentioned earlier, the increase from 2008 to 2011 was small due to ’the economic recession in Japan.

Figure 1.11. Accumulated CGS Installation Units

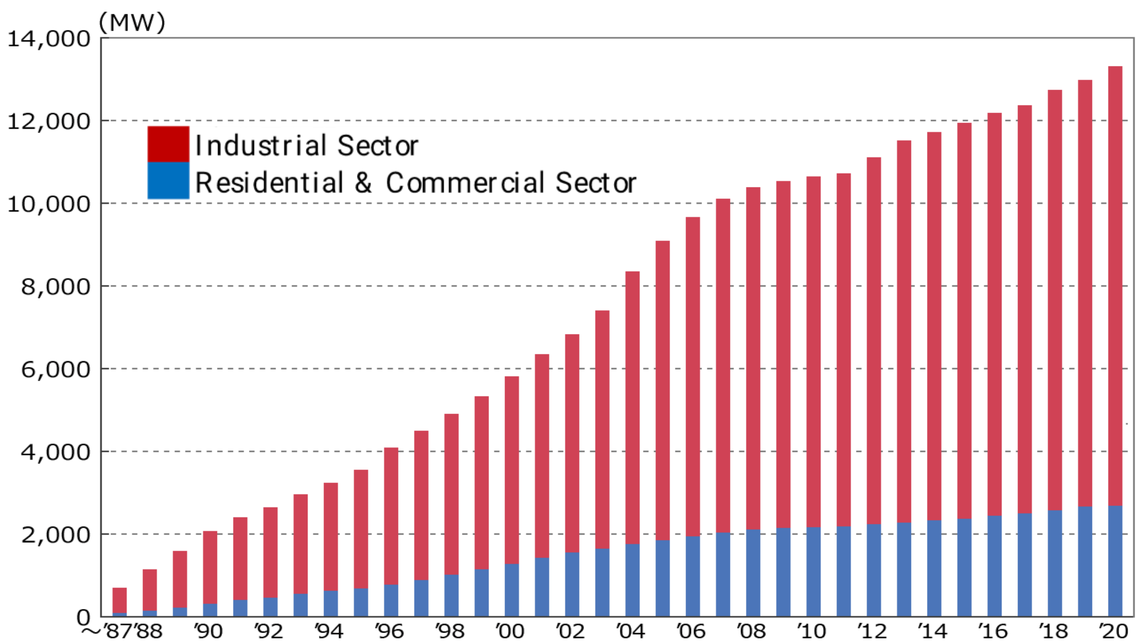


Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors; https://www.ace.or.jp/web/works/works_0020.html.

- Cumulative installed generation capacity (end of March 2021)

In terms of cumulative capacity, industry accounts for 80%. Commercial and industrial use slowed down from 2008 to 2011, but industrial use has shown a renewed upward trend since 2013.

Figure 1.12 Accumulated CGS Installation Capacity



Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors; https://www.ace.or.jp/web/works/works_0020.html.

1.2.2. Cumulative cogeneration installed in each sub-industrial sector (end of March 2021)

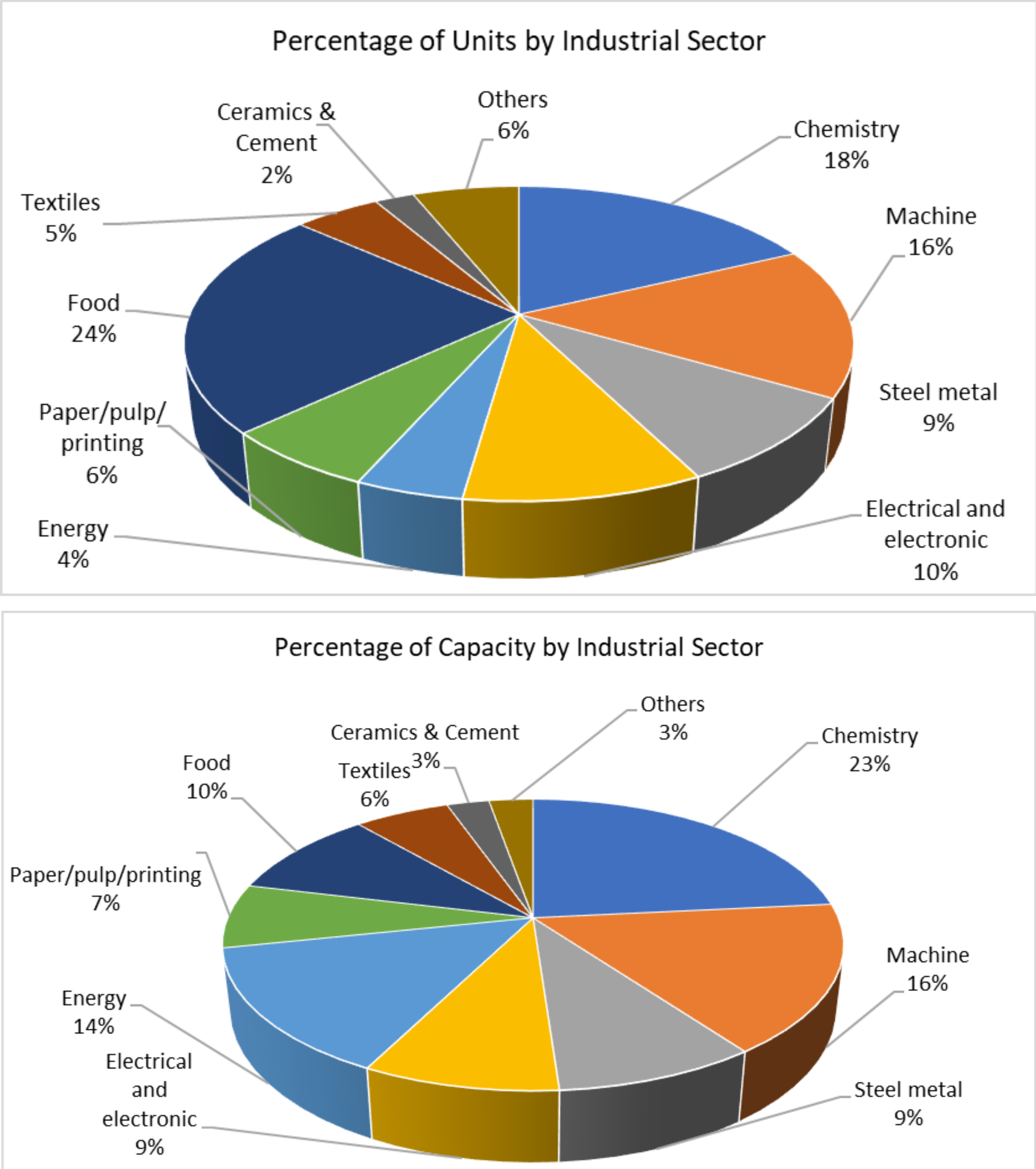
Since cogeneration produces electricity and heat simultaneously, it benefits sub-industries with high heat demand. In terms of the number of units, food, chemical, and machinery industries, which use a lot of electricity and heat, are the top three. Regarding capacity, energy supply, which includes large-scale power plants and city gas production factories using LNG as feedstock, ranks second. Since 2011, nuclear power plants have been shut down, and thermal power generation has increased. However, there has been a shift to LNG power generation in recent years.

Table 1.2 Installed CGS by Each Sub-industry Sector

Industry Sector	Number of Units (units)	Generation Capacity (MW)	Average Capacity (kw/unit)
Chemistry	1,067	2,490	2,334
Machine	922	1,757	1,906
Steel metal	544	947	1,741
Electrical and electronic	581	915	1,575
Energy	262	1,509	5,759
Paper/pulp/printing	381	758	1,991
Food	1,404	1,049	747
Textiles	298	631	2,116
Ceramics & Cement	136	280	2,058
Others	366	291	794
Total	**5,961**	**10,626**	—

Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0040.html.

Figure 1.13. Units and Capacity by Industrial Sector



Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0040.html, modified by the authors.

1.2.3. Cumulative number/capacity of CGS by prime mover type in the industry sector (end of March 2021)

Gas engines are used primarily to generate power, and gas turbines to generate heat (steam). Gas engines rank first in terms of the number of gas turbines installed in all industries, while gas turbines rank first in terms of capacity. The small number of gas turbines is because each gas turbine has a large capacity.

Table 1.3. Number and Capacity of Installed CGS, FY1986–2020 and FY2021–2020

Items	Type of Prime Mover	FY1986–2020			FY2021–2020		
		Residential & Commercial Sector	Industrial Sector	Total	Residential & Commercial Sector	Industrial Sector	Total
Number of units (units)	GT	594	1,024	1,618	13	125	138
	GE	12,482	2,433	14,915	5,385	1,098	6,483
	DE	2,117	2,405	4,522	8	7	15
	ST+FC	207	99	306	84	45	129
	Subtotal	15,400	5,961	21,361	5,490	1,275	6,765
Generation capacity (MW)	GT	535	4,974	5,509	11	749	760
	GE	1,422	2,697	4,119	519	1,094	1,613
	DE	714	2,547	3,261	4	10	14
	ST+FC	23	408	431	5	291	297
	Subtotal	2,694	10,626	13,320	539	2,145	2,684

Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0060.html, modified by the authors.

A comparison was made with the last 10 years to see recent trends in motors. The biggest change is the replacement of diesel engines with gas engines, with the number of diesel engines sharply declining to prevent global warming.

Figure 1.14. CGS Installation Capacity (MW), FY1986–2020 and FY2010–2020

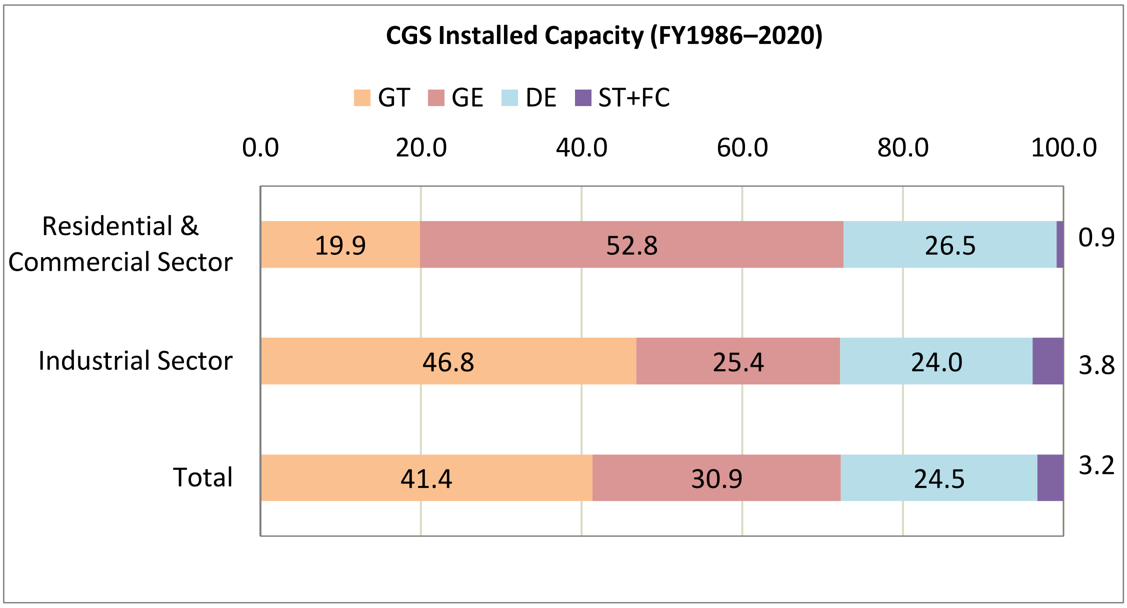
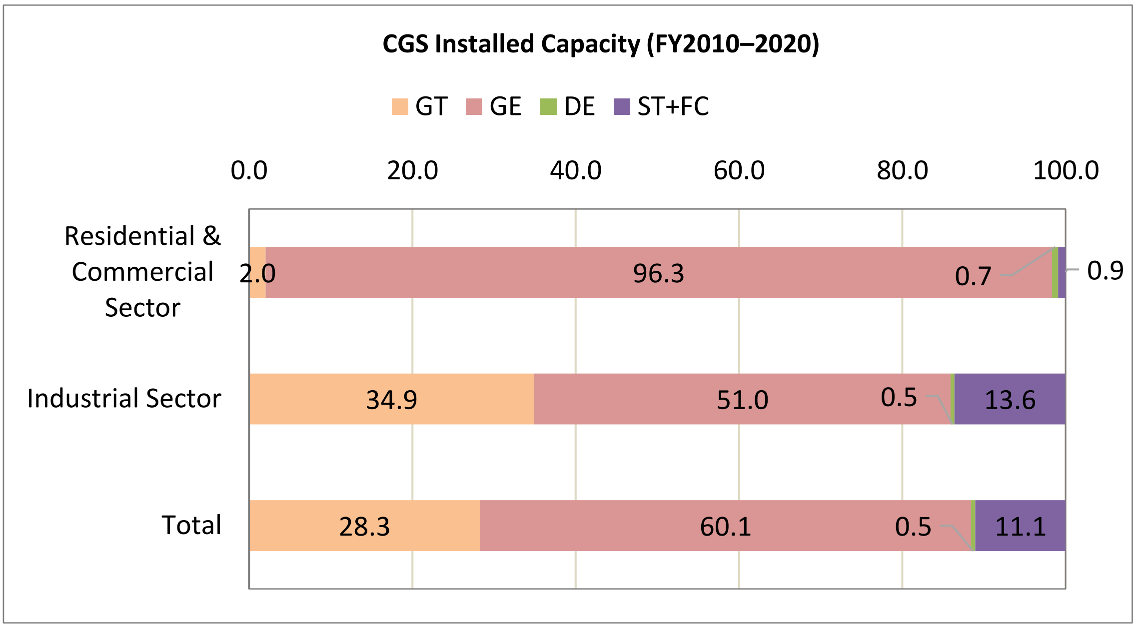


Figure 1.14. *Continued*



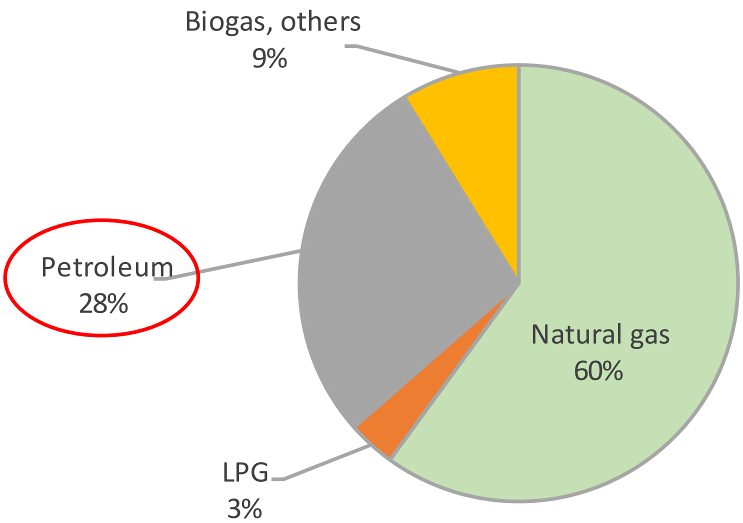
Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0060.html, modified by the authors.

1.2.4. CGS percentage by fuel

(1) Cumulative capacity by fuel through March 2021

Since 1986, petroleum-based engines have accounted for 28% of the total.

Figure 1.15. CGS Cumulative Capacity (MW), FY1986–2020

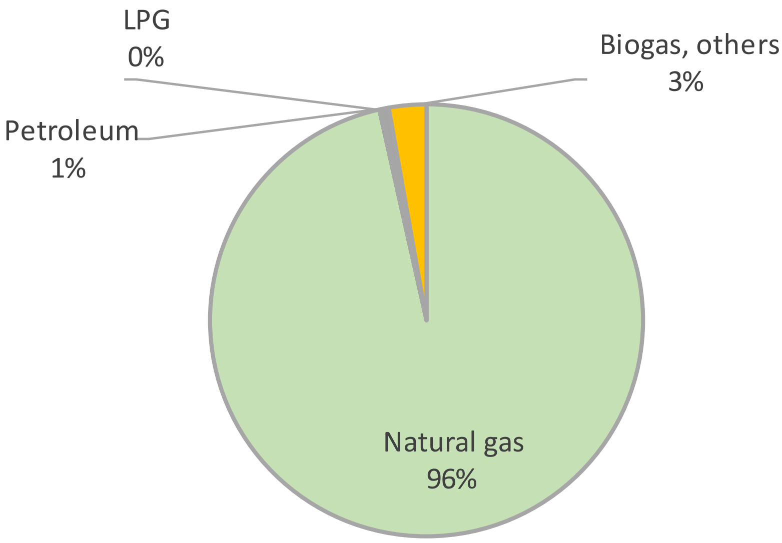


Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0060.html, modified by the authors.

(2) Cumulative capacity by fuel for the last 10 years

In the last 9 years, petroleum-based power generation has decreased and almost disappeared. The share of natural gas has increased from 60% to 96%.

Figure 1.16 CGS Cumulative Capacity (MW), FY2011–2020



Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0060.html, modified by the authors.