Chapter 2

Introduction of Installed CGS in Japan's Industry Sector

November 2023

This chapter should be cited as

ERIA study team (2023), 'Introduction of Installed CGS in Japan's Industry Sector', 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.16-33.

Chapter 2

Introduction of Installed CGS in Japan's Industry Sector

This chapter introduces CGS case studies in Japan. It includes an overview of CGS, major energy equipment, and CGS features and benefits. The source of this report is the CGS Case Studies from 2014 to 2021[1], published by the Advanced Cogeneration and Energy Utilization Center of Japan on its website. This report introduces 35 carefully selected CGS case studies from said publication.

Since each case study is in a standardised format, detailed data other than published figures, drawings, and photographs are not available.

Therefore, in this report, the text and figures are presented in English to make the case study understandable and to explain the CGS system in a way that is easy to understand.

Each case study consists of the following items:

1) Industrial classification case number

2) System overview

3) Configuration and performance overview

4) System features

5) Investment (estimated value)

To correspond with the original publication, the selected CGS case studies are identified by applying the following numbering, AA-BB, where AA is the last two digits of the year and BB is a sequential number of CGS case studies in the publication. Table 2.1 shows these 35 selected CGS case studies. It includes the year of publication, industry, title, fuel type, and type and scale of the prime mover. Note that 1-33 are CGSs using engines and turbines, 34 is a small fuel cell for household, and 35 is a large fuel cell.

Appendix 1 presents detailed information on the 35 selected case studies.

[1] The title of the publication is *Cogeneration Grand Prize*.

Table 2.1. List of 35 Selected CGS Case Studies (1/2)

No	Year-No	Industry	Title of Case Study	Fuel	GE	GT	ST
1	15-1	Printing industry	State-of-the-art energy-saving system using CGS fueled by VOC and city gas	City gas			
2	15-2	Salt industry	Environment-friendly energy-saving and BCP system with natural gas cogeneration and woody biomass cogeneration	City gas Woody biomass			
3	15-3	Chemical industry	Improving productivity and business continuity centered on the power sales business by introducing cogeneration	City gas Recycled oil			
4	15-5	Chemical industry	ESCO business that utilises CGS low-temperature waste heat in the production process to improve overall efficiency	City gas			
5	16-1	Plant factory	Introduction of trigeneration to plant factories	natural gas			
6	16-2	Pharmaceutical industry	Efficiency of energy supply through the introduction of LNG satellites and CGS	LNG			
7	16-3	Automotive industry	Realisation of waste heat utilisation of large cogeneration through inter-company collaboration	City gas			
8	16-4	Power generation at gas relay station	Power generation using gas engine CGS at a gas relay station and unused energy at the time of city gas depressurisation	City gas (high-pressure)			
9	16-5	Paper industry	Reduction of primary energy by updating CGS and advanced utilisation of waste heat	City gas			
10	17-1	Beverage Industry	Realisation of thermal/electrical energy rebalancing by CGS to use self-consignation between multiple factories	City gas			
11	17-4	Plastic film industry	A factory's non-stop production thorough BCP and energy-saving measures	LNG			
12	17-5	Press machine production	Electric power and cold and heated water fusion system by integrating high-efficiency CGS and Genelink with existing facilities	City gas			
13	17-6	Automobile Industry (brake)	By systematisation of cogeneration increased efficiency and reduced greenhouse gas emissions	City gas			
14	18-1	Textile Industry	Introduced on-site energy supply type CGS to overseas factories	Natural gas			
15	18-2	Paper Industry	Reduction of primary energy by installing a total steam recovery gas engine CGS	City gas			
16	18-3	Water purification plants	Introduction of gas CGS in water treatment plants to utilise electricity and waste heat for sludge treatment	LNG			
17	18-4	Beverage Industry	Effects of introducing groundwater utilisation CGS in beverage factories	City gas			
18	18-5	Chemical factory	Realisation of BCP restructuring and CO2 reduction through integrated replacement of cogeneration facilities	City gas 13A			

Table 2.1. *Continued*

No	Year-No	Industry	Title of Case Study	Fuel	GE	GT	ST
19	18-6	Energy supply plant	Effects of updating CGS at power plants that supply electricity and heat to industrial parks	City gas 13A			
20	19-1	Gas Production	Overhaul and high-efficiency modification of existing cogeneration system to improve power generation efficiency	City gas 13A			
21	19-2	Automotive industry	The construction of high-efficiency energy supply system thorough utilisation of CGS waste heat and unused heat	City gas			
22	19-3	Tire Industry	An environment-friendly CGS that is effective for BCP measures by using a natural gas high-pressure trunk line	City gas			
23	19-5	Electronic Components industry	Promotion of energy saving by introducing the latest cogeneration equipment suitable for factory loads	Natural gas City gas			
24	19-6	Iron Steel Secondary processing	Energy-saving measures using CGS and improvement of regional disaster prevention capabilities using EV	City gas 13A			
25	20-1	Industrial zone	Shared use of electricity and heat by constructing an energy centre in an industrial zone	City gas 13A			
26	20-3	Food industry	CCGT construction for BGT renewal (expansion of heat utilisation and energy reduction)	LNG vaporization gas			
27	20-4	Paper industry	Energy saving by exhaust heat recovery of gas turbine CGS	City gas			
28	20-5	Sewage treatment plant	CGS power generation using digestion gas at a sewage terminal treatment plant	Digestion gas			
29	20-6	Chemical industry	Expansion of heat utilisation and energy reduction by gas compressor with GT renewal	City gas			
30	21-1	Cooperative power plant	The improvement of overall plant efficiency by introducing high-efficiency gas turbine cogeneration	City gas 13A			
31	21-2	Automotive industry	Energy saving of production equipment by utilising low temperature waste heat of cogeneration	City gas			
32	21-4	Chemical industry	Gas turbine cogeneration system integrated with ethylene plant cracking furnace	Natural gas			
33	21-5	Foods industry	Realisation of energy saving and BCP measures by LPG cogeneration centered on EMS	LPG			
34	22-1	Product introduction	Introduction of Ene-Farm	Fuel cells			
35	22-2	Product introduction	Fuel cells (SOFC) for industrial use	Fuel cells			

Note: over10000kW 7000-10000kW 1000~7000kW less 1000kW
GE:gas engine GT: gas turbine ST: steam turbine

Source: Authors.

2.1. Introduction of Typical CGS Case Studies

Here, we introduce the five examples of small-scale CGSs, mentioned in Table 2.1, and those using LNG (see Appendix 1).

1) Efficiency of energy supply through the introduction of LNG satellites and CGS

Outline

✓ Industrial field: Pharmaceutical industry

Type and scale of prime mover: (Gas turbine) 1,615 kW × 2 units

The pharmaceutical process uses a lot of heat and electricity at various temperatures. The factory is in an area where city gas is unavailable. So a gas turbine CGS system was installed using an LNG satellite, utilising cold heat and exhaust gases after LNG vaporisation and CGS power generation.

(1) Industrial Field Case No. 16-2

Pharmaceutical industry

(2) System Overview

This core factory in Japan carries out integrated manufacturing from drug substances to pharmaceuticals and packaging. Since a reaction in a particular temperature range is required in the production process, a large amount of electric power and cold and heat sources is used. Therefore, CGS supplied the energy, effectively utilising LNG satellite equipment that could save much energy. In addition to introducing high-efficiency gas turbines, the recovery and utilisation of LNG vaporisation cold heat and the utilisation of exhaust heat from exhaust gas boilers resulted in a total cogeneration efficiency of 89%. By utilising CGS as a power source during a long-term power outage, such as a disaster, continuous production and shipment of pharmaceutical products have been realised.

(3) Configuration and Performance

Table 2.2 Configuration and Performance

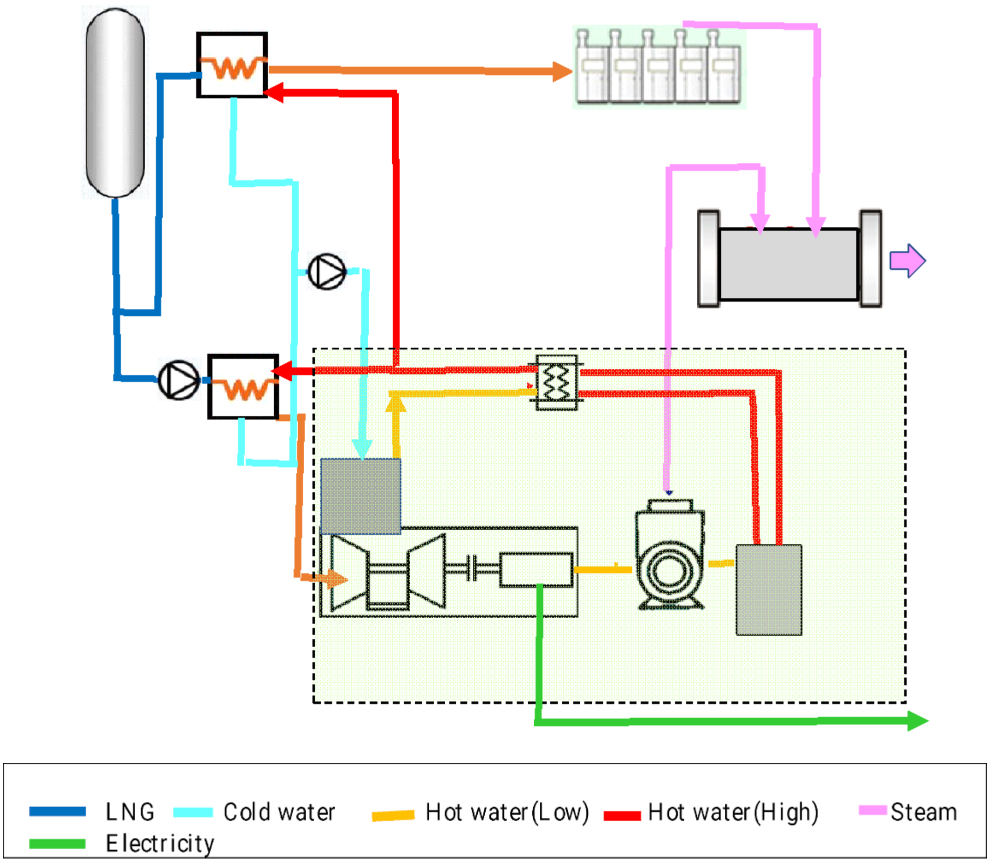
Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	1,615 kW x 2 units
Waste heat utilisation	Manufacturing process, LNG vaporisation
Fuel	LNG
Power peak cut rate	36.2%
Primary energy reduction rate	21.7%
Expected CO_2 saving amount	395 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 27.7%, 56.1%, 16.2%

Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors, https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130.

(4) System Features

- The fuel for cogeneration was natural gas, which had a small environmental load. The fuel for steam boilers was changed from heavy oil to natural gas. In addition, since there was no natural gas conduit in the vicinity, LNG satellite equipment was installed on the factory premises.
- The cold heat of LNG vaporisation was used to cool the intake air of the gas turbine to prevent a decrease in power generation output during the summer without additional energy input.
- As a heat source for the LNG vaporiser, a hot water boiler was installed after the cogeneration steam boiler to recover and use the low-temperature waste heat to recover the hot water. Thus, the thermal efficiency of the cogeneration improved from 85% to 89%.
- The system can be effectively used by balancing the LNG load fluctuation, the gas turbine intake cooling load fluctuation, and the gas turbine low-temperature exhaust heat recovery amount change.
- Energy utilisation flow

Figure 2.1 Energy Utilisation Flow of CGS Plants (Pharmaceutical Industry)



Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors, https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130.

(5) Investment (estimated value)

- Cost

  CGS (equipment cost); Approximately ¥420 million

- Estimated energy-saving amount

  Electricity equivalent 895 KW/h

  Note: The method for estimating energy saving is shown in section 2.2.

2) Power generation using gas engine CGS at a gas relay station and unused energy at the time of city gas depressurisation

Outline

✓ Industrial field: Power generation at a gas relay station

Type and scale of prime mover: GE 7800 kE × 2 units, GT990 kW, GT420 kW

The city gas production factory is located on the waterfront, and high-pressure gas is piped to the city centre. At the relay station, a CGS for power generation equipment has been installed to supply gas and electricity, and the waste heat is used to heat the high-pressure gas, which expands to depressurise it. The expanded gas is used to rotate a turbine to generate electricity in the first stage. Then the exhausted gas is further expanded by heating it a second time to generate electricity at the second stage.

(1) Industrial Field Case No. 16-4

Power generation at a gas relay station

(2) System Overview

This factory is a power plant where a gas company has introduced a gas engine CGS for the electric power business. In general, city gas companies supply gas at high pressure and supply it by dropping it to the required pressure through a pressure regulator near the demand destination. When the pressure is reduced, the gas adiabatically expands, and the temperature drops. So, the pressure regulator may freeze and malfunction, and an electric heater or the like may prevent freezing. The energy used for this boost is wasted. (In Japan, about 200 city gas companies constantly produce this waste). To eliminate this waste, the first is to utilise the waste heat from the gas engine for the preheat required for depressurising the gas in the city's gas supply. The second is to introduce two differential pressure turbine generators to use the expansion energy when depressurising the city gas and generate electricity using the expansion energy in two stages.

(3) Configuration and Performance

Table 2.3. Configuration and Performance

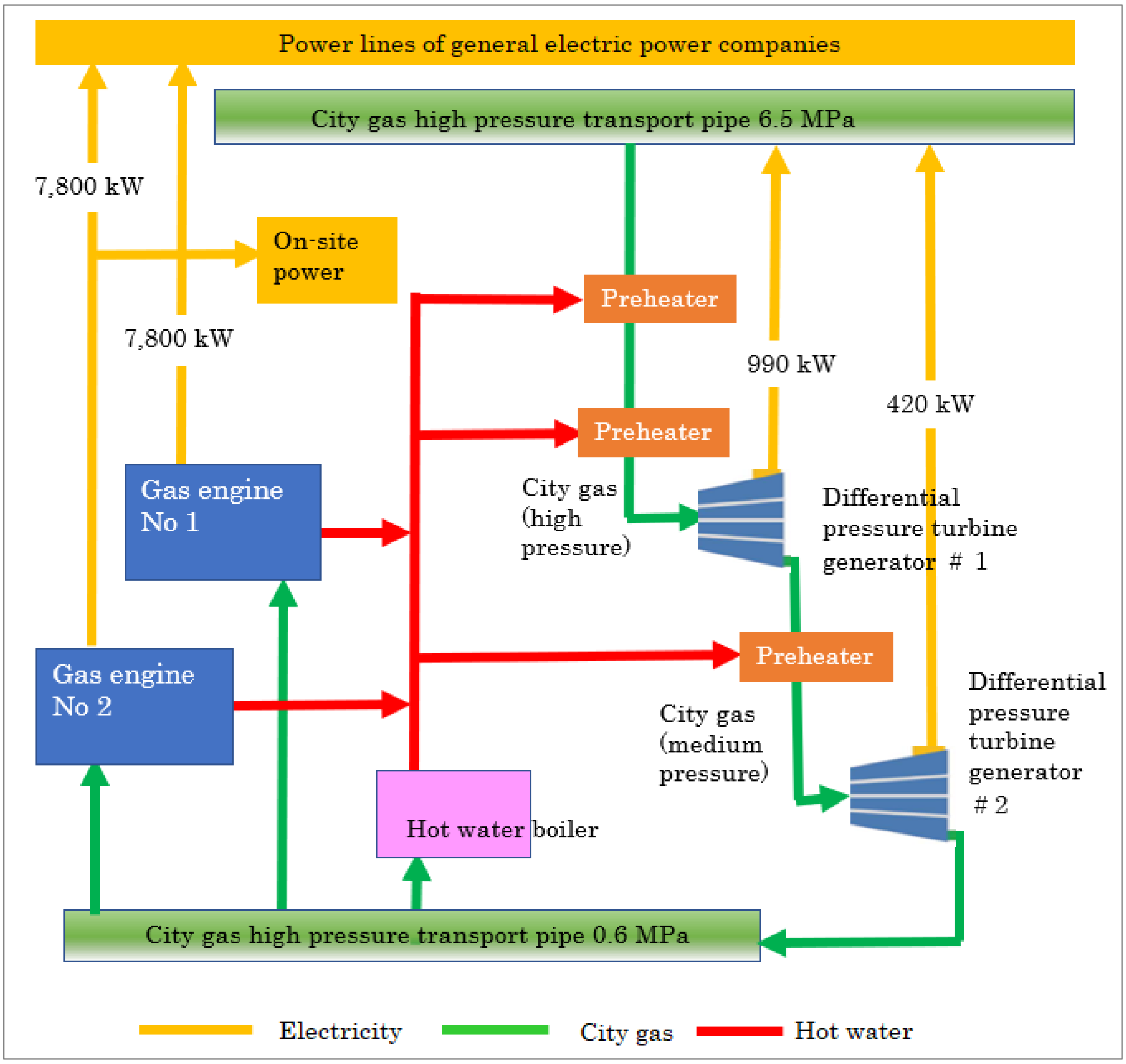
Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 7800 kW × 2 units (15,600 kW)
Waste heat utilisation	City gas preheat
Fuel	City gas
Power peak cut rate	—
Primary energy reduction rate	18.7%
Expected CO_2 savings amount	1,582 kg-CO_2
Electricity, heat, loss ratio	(GE) 49.0%, 23.7%, 27.3%

Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors, https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130.

(4) System Features

- This company purchases, distributes, and sells surplus electricity from local power CGSs. For sales, CGS was introduced as a power source capable of adjusting its output according to the demand curve. Specifically, the company has installed supply and demand monitoring equipment that monitors the operating status of the power CGS at the other site every 5 minutes and adjusts the amount of electricity generated at this site.
- A differential pressure generator utilising the energy of high-pressure gas during decompression (increased power generation output) is introduced.
- Even during a disaster, gas can be supplied to cogeneration by reducing the pressure to medium pressure on the premises from a high-pressure transport conduit with extremely high supply stability.
- Energy utilisation flow.

Figure 2.2. Energy Utilisation Flow of CGS Plants (Power Generation at Gas Relay Stations)



Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors, https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130.

(5) Investment (estimated value)

- Cost

  CGS (equipment cost): Approximately ¥1,872 million

- Estimated energy-saving amount

  Electricity equivalent 3,588 kW/h

  Note: The method for estimating energy savings is shown in section 2.2.

3) Introduction of gas CGS in water treatment (Plants to utilise electricity and waste heat for sludge treatment）

Outline

✓ Industrial field: Water purification plant operated by municipality

Type and capacity of prime mover: GE 1000 kW × 6 units

The water purification plant has been operating since the experience of the Great East Japan Earthquake. The plant uses LNG satellites for fuel storage, CGS for power generation, and waste heat for sludge treatment. The water purification plant also generates solar power and sells surplus electricity to nearby customers.

(1) Industrial Field Case No. 18-3

Water purification plants operated by the prefecture

(2) System Summary

The Aichi Prefectural Waterworks and Industrial Waterworks purification plants have been updating the dewatering facilities for sludge residue generated in the water treatment process and securing a place to take the sludge. This project utilises the Private Finance Initiative method to (i) upgrade the dewatering facilities of a water purification plant (dedicated for water supply); (ii) construct a new gas engine CGS with blackout start (BOS) specifications and a solar power generation system; and (iii) construct, operate, maintain, and manage these facilities for 20 years.

The waste heat from the CGS heats the sludge residue generated in the water treatment process at the water purification plant to about 40°C, reducing the sludge's viscosity and increasing the capacity of the dewatering facility by about 20% to 30%.

In addition to the risk of power outages in the power transmission line network, the Great East Japan Earthquake also revealed the risk of power outages related to power plant operations. Thus, the water purification plant decided to quickly develop its in-house power generation facilities in addition to receiving commercial power from the power company.

(3) Configuration and Performance

Table 2.4. Configuration and Performance

Item	Contents
Types of power engine	Gas engines (GE)
Rated power output and number of units	(GE) 1,000 kW × 6 units
Waste heat utilisation	Sludge heating LNG vaporisation
Fuel	LNG
Power peak cut rate	55.2%
Primary energy reduction rate	2.7%
Expected CO_2 savings amount	489 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 41.7%, 32.6%, 25.7%

Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors, https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130.

(4) System Features

- BCP at water purification plants

Improvement of water supply infrastructure security by combining commercial electric power, cogeneration, and solar power generation to create multiple power supply sources

Installed six generators (1,000 kW x 6 units, LNG supply, BOS specification) for normal and emergency uses. Four generators are operated for normal use, and six are operated synchronously during BOS.

LNG storage tanks are sufficient for 5 days.

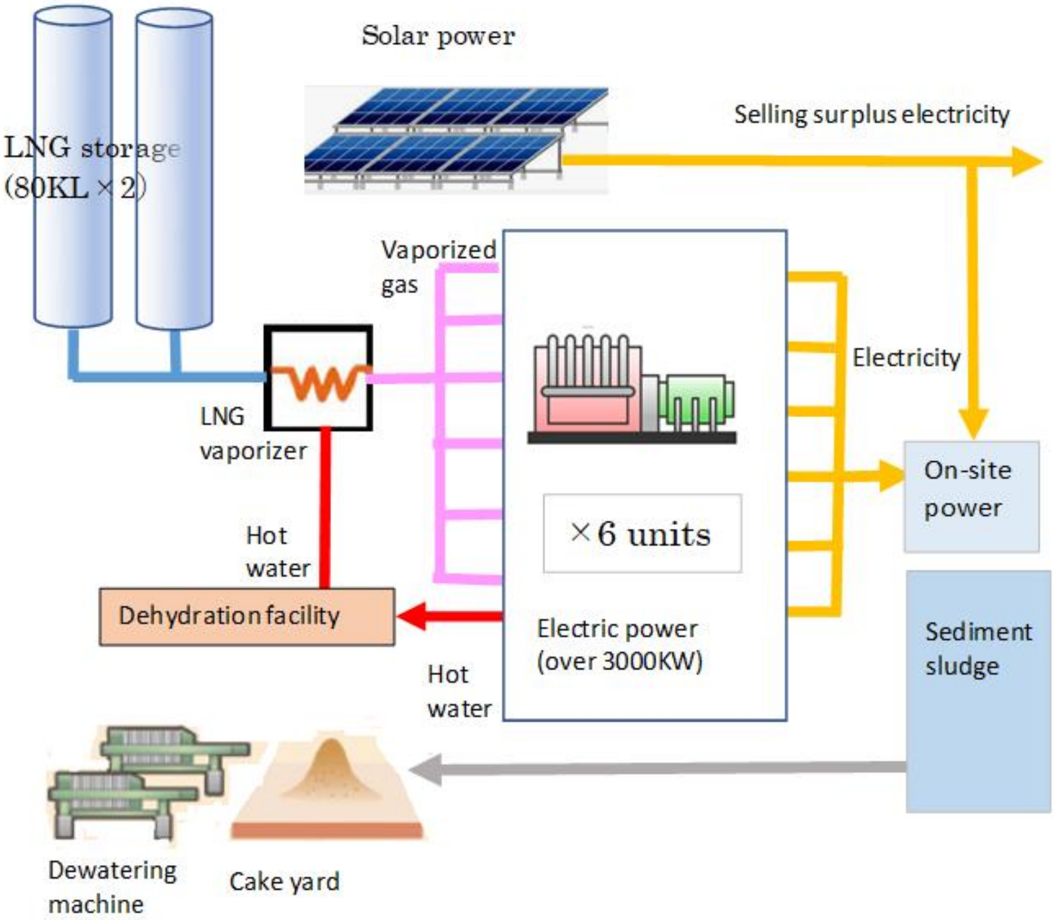
- Reuse of residual sludge

To improve treatment efficiency, residual sludge generated in the water treatment process is heated by waste heat from the CGS. The system can flexibly respond to changes in the amount and properties of sludge generated, and all the sludge is effectively used for gardening and ground soil.

- Operation control using renewable energy

The CGS is operated continuously during the day to sell solar power. Generator power covers part of the load power in the premises.

Figure 2.3. Energy Utilisation Flow of CGS Plants (Water Purification Plants Operated by Prefecture)



Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors, https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf.

(4) Investment (estimated value)

- Cost

  CGS (equipment cost): Approximately ¥720 million

- Estimated energy-saving amount

  Electricity equivalent 166 kW/h

Note: The method for estimating energy savings is shown in section 2.2.

4) *Expansion of heat utilisation and energy reduction by renewing gas compressors and gas turbines*

Outline

- ✓ Industrial field: Chemical industry

Type and capacity of prime mover: GT 1,660 ｋW × 1 unit

Due to ageing CGS equipment, a new gas turbine CGS with a capacity 1.4 times bigger than the old one was installed on the premises, including the factory and the laboratory, which is separated by a city road from the factory site. The laboratory is supplied with heat through an underground tunnel under a city street; electricity is supplied through a self-owned line across a city street. The factory and the laboratory have different heat usage patterns, which matrix converters control.

(1) Industrial Field Case No. 20-6

Chemical industry

(2) System Overview

This factory manufactures high-performance chemical products and products related to the electronics and information industries. The plant uses large amounts of high- and low-pressure steam in its manufacturing processes. Since 2000, it has been using a 1,200 kW-class gas turbine CGS to save energy. However, it has become obsolete, so the system was replaced.

(3) Configuration and Performance

Table 2.5 Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output& number of units	(GT) 1,660 kW × 1 unit
Waste heat utilisation	Manufacturing process
Fuel	City gas
Power peak cut rate	—
Primary energy reduction rate	8.2%
Expected CO_2 savings amount	65 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 27.7%, 56.1%, 16.2%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2020), modified by the Authors. https://www.ace.or.jp/web/gp/pdf/2020/CGS-Award2020_Detail.pdf?v=2.

In considering the renewal of facilities, an energy network, including the adjacent research institute, was constructed to level the load, increase energy savings, and strengthen the BCP. The laboratory is adjacent to the factory across a city road, and heat pipes are connected to the factory through an underground tunnel.

The company built a joint energy network with the factory for electric power to increase the power load on the premises. Since it is possible to introduce a larger CGS and strengthen energy conservation and the BCP, the company built a model of energy interconnection by combining its business sites.

In addition, the gas compressor, which boosts the pressure required for gas turbine operation, employs a matrix converter to control the rotation speed to reduce the driving power in accordance with the city gas supply pressure to achieve further energy savings.

(4) System Features

- Expansion of energy flexibility

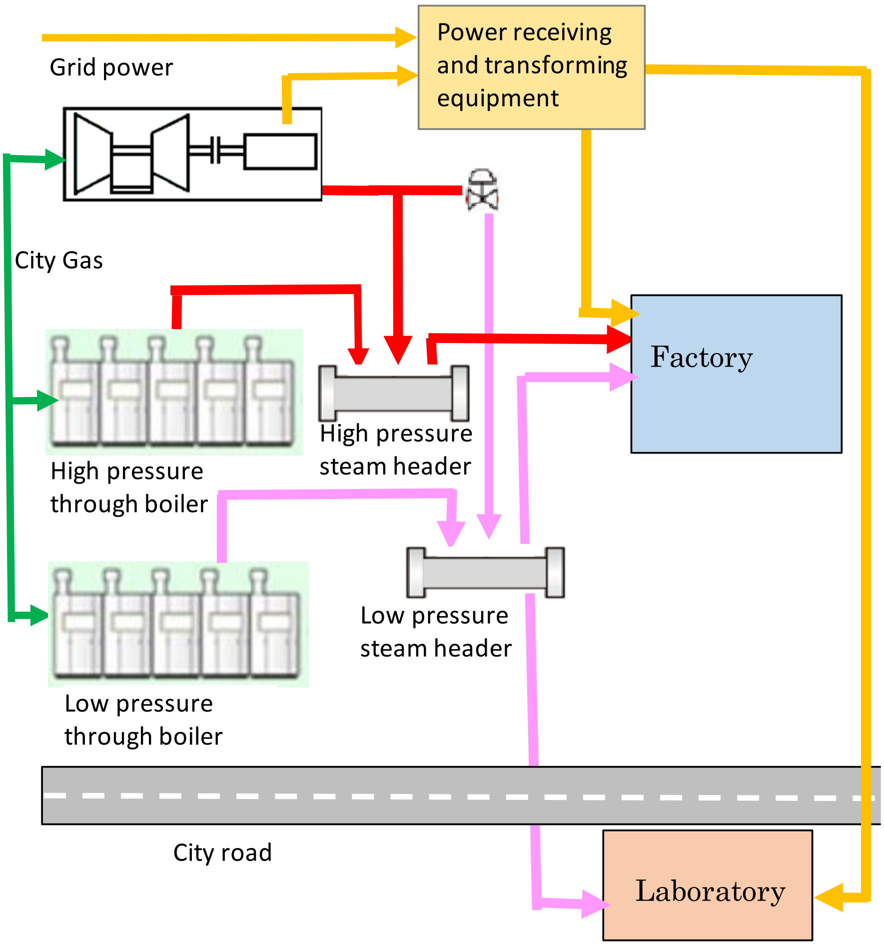
Load leveling was achieved by combining the different power load patterns of the factory and the laboratory. Introduction of a gas turbine with higher efficiency and generating capacity than the existing machine became possible. The steam was already being supplied between the two sites through a dedicated tunnel connected underground by a city road. Electric power was also supplied between the sites by installing a private line.

- Introduction of BOS (no-load standby function)

The existing gas turbine could not cope with power outages. But the new gas turbine has a BOS, which enables the restoration of power supply to important loads, even during a power outage. This enabled business continuity and improved the BCP of the plant.

- Energy saving was realised by introducing speed-controlled gas compressors.

Figure 2.4. Energy Utilisation Flow of CGS Plants (Chemical Industry)



Source: Advanced Cogeneration and Energy Utilization Center Japan (2020), https://www.ace.or.jp/web/gp/pdf/2020/CGS-Award2020_Detail.pdf?v=2, modified by the authors.

(5) Investment (Estimated Value)

- Cost

  CGS (equipment cost: Approximately ¥216 million

- Estimated energy-saving amount

  Electricity equivalent 148 kW/h

  Note: The method for estimating energy savings is shown in section 2.2.

5) Realisation of energy savings and BCP measures by LPG cogeneration centred on energy management system (EMS)

Outline

✓ Industrial subsectors: Food industry

Type and capacity of prime mover: GE 25 kW × 20 units

An LPG-type CGS was installed at a meat-processing factory because it uses a large amount of electricity and heat. In the past, the plant experienced a 2-day power outage due to a large earthquake in Hokkaido, destroying products since refrigerators did not operate. Therefore, as a blackout countermeasure. the CGS was installed to secure electricity supply from private power utilities. Multiple micro CGS units were installed because the number of units can be controlled according to load fluctuations. Since maintenance can be performed on each unit, a high operating rate can be achieved without having the entire power generation missing. In addition, multiple CGSs are operated to meet complex heat demand through the EMS.

(1) Industrial Subsectors Case No. 21-5

Food industry

(2) System Summary

A system that can make the best energy use has been constructed by converting the main heat source to LPG, which is more environment-friendly than heavy oil. Since this plant uses a large amount of hot water in the production process, an LPG micro CGS capable of supplying hot water was installed to utilise waste heat effectively. At the same time, introducing an EMS has realised optimal control of cogeneration and reduced energy management person-hours.

(3) Configuration and Performance

Table 2.6. Configuration and Performance

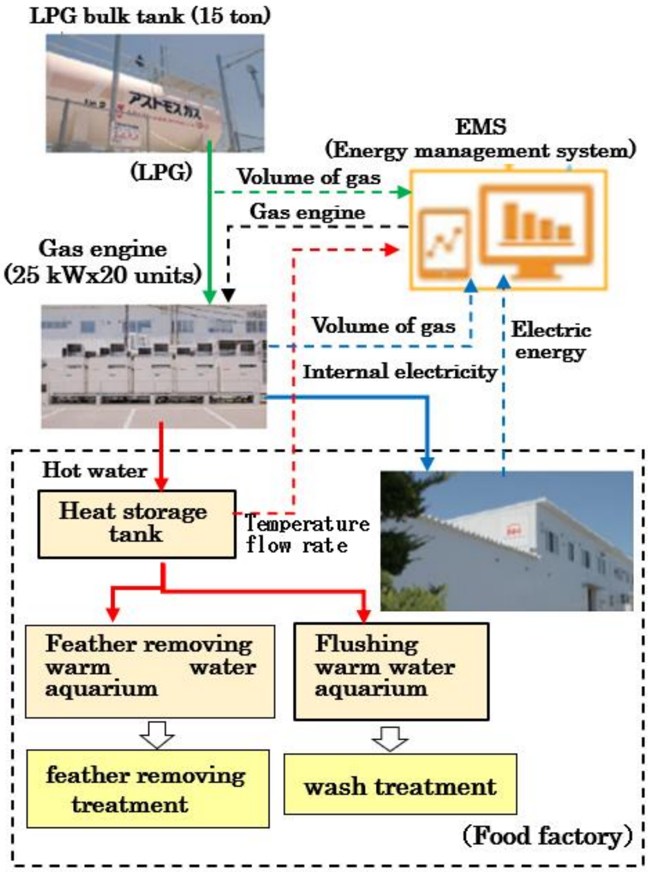
Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	(GE) 25 kW × 20 units
Waste heat utilisation	Production process
Fuel	LPG
Power peak cut rate	—
Primary energy reduction rate	25.5%
Expected CO_2 savings amount	75 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 33.5%, 52.0%, 14.5%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2021/CGS-Award2021_Detail.pdf?v=220128, modified by the authors.

(4) System Features

- Highly efficient operation and high operating rate in normal times were realised by installing multiple micro-cogeneration units and optimising control using the EMS. By installing multiple micro-cogeneration units, it is possible to adjust the number of operating units even in a small load range and to operate the equipment with high efficiency at the rated output. Optimal control that responds to fluctuations in electrical and heat loads has become possible by utilising the EMS. Since maintenance can be performed for each micro-cogeneration unit, a high operating rate is achievable without completely stopping power generation.
- Cogeneration hot water can be used effectively by installing a hot water storage tank (heat storage tank). The hot water tank for removing feathers and for cleaning has different required temperature ranges. The well water in the newly installed hot water storage tank can be heated to the temperature of each tank using the waste heat of cogeneration. As a result, heat cascade utilisation has become possible.
- Primary energy consumption and CO_2 emissions were reduced through fuel conversion from heavy oil to LPG.
- System flow

Figure 2.5 Energy Utilisation Flow of CGS Plants (Food Industry)



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2021/CGS-Award2021_Detail.pdf?v=220128, modified by the authors.

(5) Investment (estimated value)

- Cost

  Cogeneration investment costs: Approximately ¥100 million

- Estimated energy-saving amount

  Electricity equivalent 171 KW/h

Note: The method for estimating energy savings is shown in section 2.2.

2.2. Estimation Methodologies on CGS case studies

- **Primary energy saving**

Primary energy saving is estimated as electricity consumption from utilities plus fuel consumption for heating demand minus fuel consumption of CGS.

- **Investment**

The cost of CGS equipment (excluding piping and incidental work) is calculated by multiplying the rated output value by the unit price per kW from the table below.

Table 2.7 The Cost of CGS Equipment (excluding Piping and Incidental Work)

	Capacity	Assumed Unit Price	Remarks
1	6,500 kW or more	¥0.12 million/kW[a]	Assumed unit price come from examples of CGS equipment in Japan
2	500 to 6,500 kW	¥0.15 million to 0.12 million/kW	
3	300 to 500 kW	¥0.20 million to ¥0.15 million/kW	
4	5 to 300 kW	¥0.30 million to ¥0.20 million/kW	

Sources:
[a] Agency for Natural Resources and Energy, https://www.enecho.meti.go.jp › mitoshi › pdf (accessed 26 May 2022), modified by the authors.

- **Estimating CO_2 reduction**

The CO_2 reduction amount (CW) is estimated from the above energy reduction amount using the CO_2 emission factor of the Tokyo Electric Power Company (TEPCO).

$$CO_2 \text{ reduction amount (CW)} = \text{Reduction amount EKP(kW/h)} \times 0.441 \text{ kg-}CO_2$$

Source: TEPCO CO_2 emission factor (2021 value): 0.441 kg-CO_2/kWh, https://www.tepco.co.jp/ep/notice/news/2021/1628675_8909.html (accessed 26 May 2022).