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Cogeneration Potential in Indonesia's Industry Sector with Reference to Japan and Malaysian Experiences

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Preface

Indonesia has announced achieving carbon neutrality in its energy sector by 2060. Thus, it will need zero-emission technologies such as hydrogen and carbon capture, utilisation, and storage. But first, Indonesia has to reduce energy consumption in its final sectors: industry, transport, and residential and commercial. The country's energy consumption, especially electricity, has been increasing rapidly in the past few decades, and the industry sector is the second-largest energy consumer. Thus, promoting energy efficiency and conservation is a priority energy policy in the industry sector. The sector consumes two types of energy: heat and electricity. Therefore, if factories need heat and electricity for their production activity, a cogeneration system (CGS) should be appropriate due to its high thermal efficiency. This is because CGS recovers heat, which is waste to air.

Due to this background, this project studies the CGS potential of Indonesia's industry sector, referring to the experience of Japan and Malaysia in terms of CGS installation in their industry sector.

Indonesia's industry sector is equipped with an auto-generation system called 'gen-sen' due to the unstable public utility service of the Perusahaan Listrik Negara, a state-owned company tasked with the country's energy needs. Thus, when factories want to shift from an auto-generation system to a cogeneration one, they will attach a heat recovery system by applying a heat exchange system. But they do not need the heat recovery system if they need only electricity. Consequently, a CGS works well for factories that demand electricity and heat. Then, information on sub-industry sectors, such as chemicals and machines, is useful for Indonesia to seek the CGS potential of its industry sector.

I hope this report will contribute to the increase of CGS in the industry sector and result in significant energy savings for Indonesia.

Shigeru Kimura

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Acknowledgement

This report was developed by the Economic Research Institute for ASEAN and East Asia (ERIA), Japanese and Malaysian experts in cogeneration systems (CGSs), and Indonesian energy experts. The Japanese CGS expert introduced 33 samples of the CGS system across Japan's sub-industry sectors. Malaysian CGS experts presented 24 samples of the CGS system across Malaysia's sub-industry sectors. We especially acknowledge Shigeru Kimura, Special Advisor on Energy Affairs to the ERIA President, who initiated and led this CGS project. In addition, special thanks to the ERIA publication team led by Stefan Wesiak for their great contribution to improving the quality of this report.

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List of Abbreviations and Acronyms

BCP	business continuity plan
BOS	blackout start
BTG	boiler turbine generator
CCGT	combined cycle gas turbine
CGS	cogeneration system
CHP	combined heat and power
CO_2	carbon dioxide
EMS	Energy Management System
EPC	energy performance contracting
EPCC	engineering, procurement, construction, and commissioning
ESCO	energy service company
EV	electric vehicle
GHG	greenhouse gas
GE	gas engine
GT `	gas turbine
GTG	gas turbine generator
HRSG	heat recovery steam generator
IEPRe	Institute of Energy Policy & Research
ITA	investment tax allowance
LNG	liquid natural gas
LPG	liquid petroleum gas
MGT	micro gas turbine
VOC	volatile organic compound
PEFC	polymer electrolyte fuel cell
SOFC	solid oxide fuel cell

Executive Summary

A cogeneration system (CGS) is one of the energy efficiency technologies in the industry and commercial sectors. It shows high energy efficiency, defined as energy output (electricity and heat) divided by fuel input, especially natural gas, which usually achieves more than 70%. But CGS cannot be applied if there is no demand for electricity and heat in factories and commercial buildings. This is one reason CGS is not popular worldwide.

This project shows which industrial subsectors have applied CGS so far. In the case of Japan, the food, chemical, and machinery sub-industries are the top three in CGS installation. On the other hand, in Malaysia, chemical, palm oil/ oleochemical, and sugar processing are the three major sub-industries in CGS installation. Thus, the food and chemical sub-industries of Indonesia's industry sector might have considerable CGS potential. In addition, CGS can be installed in the machinery, steel and metal, textiles, ceramic, and cement subsectors.

CGS installation depends on economic incentive activities because CGS saves energy and reduces factories' energy costs. Thus, CGS installation cases in Malaysia indicate a short payback period, mainly less than 5 years. Decisions on CGS installation in Japan are based on three factors: (i) economic factors (saving energy consumption and cost), (ii) climate change issues (reduction of carbon dioxide [CO_2] emissions), and (iii) business continuity plan (BCP). If factories do not have a CGS, energy like electricity and heating fuel is supplied through public infrastructures, such as transmission lines and roads. The East Japan Great Earthquake and strong typhoons damaged public infrastructure. As a result, factories had to stop producing goods due to supply disruption of electricity and heating fuel. Thus, factories installed a CGS or self-energy supply system to continue production. This is the concept of the BCP.

CGS installation needs experts familiar with engineering issues and basic economics. They are called energy managers or energy service companies (ESCOs) who can estimate energy savings brought by CGS installation. In addition to energy saving calculation, they can propose the appropriate size of gas turbine, gas engine, and heat exchanger. Japan and Malaysia have many energy managers and ESCOs. This is why both countries have installed more CGS units than Indonesia. In this regard, growing energy managers and ESCOs are indispensable for Indonesia to increase CGS installation, urging institutions to develop energy managers.

CGS installation depends on an economic incentive. But Japan and Malaysia prepared a financial support system for CGS – a subsidy for CGS costs in Japan and a tax incentive in Malaysia. Thus, a financial support system for CGS installation could be appropriate in Indonesia's industry.

Chapter 1

Current Situation of Cogeneration System Installation in Japan

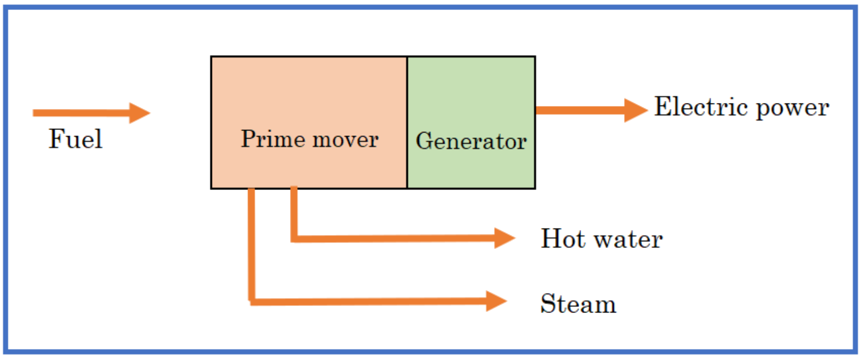
1.1. What is a Cogeneration System?

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.

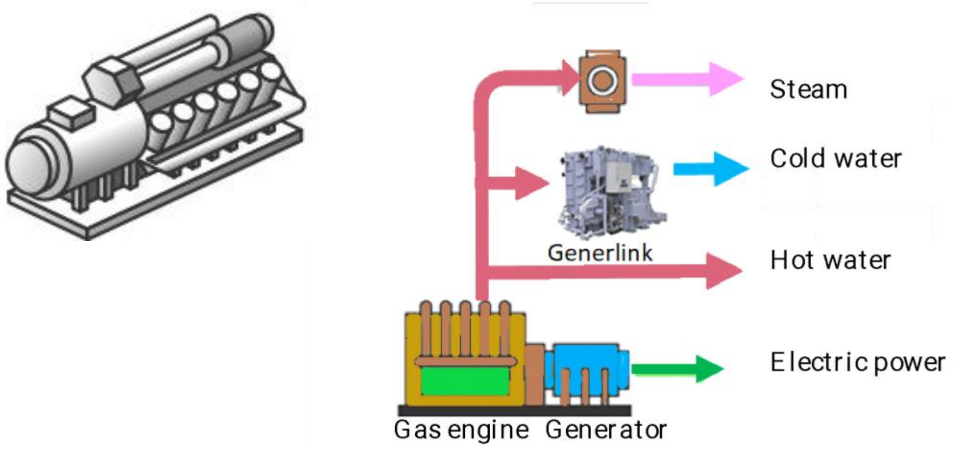
The recovered waste heat can be transformed into steam or hot water for factory heat sources, air conditioning, hot water supply, etc. If heat and electricity are used together, high overall energy efficiency can be achieved at 75%–80% of the original energy content of the fuel.

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

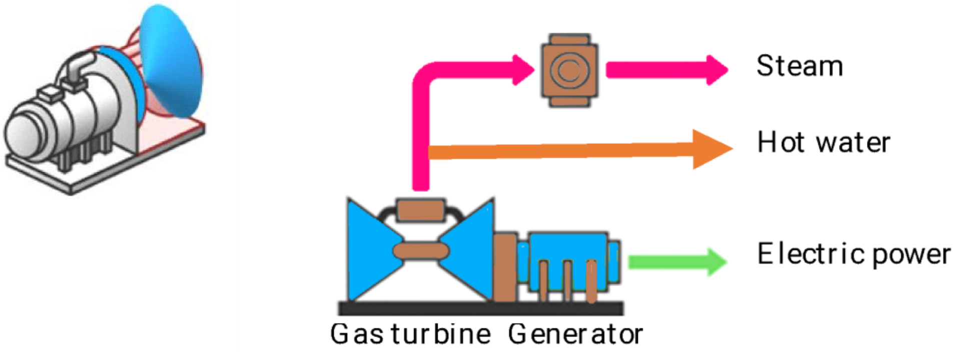


Source: Japan Gas Association, modified by the authors.

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

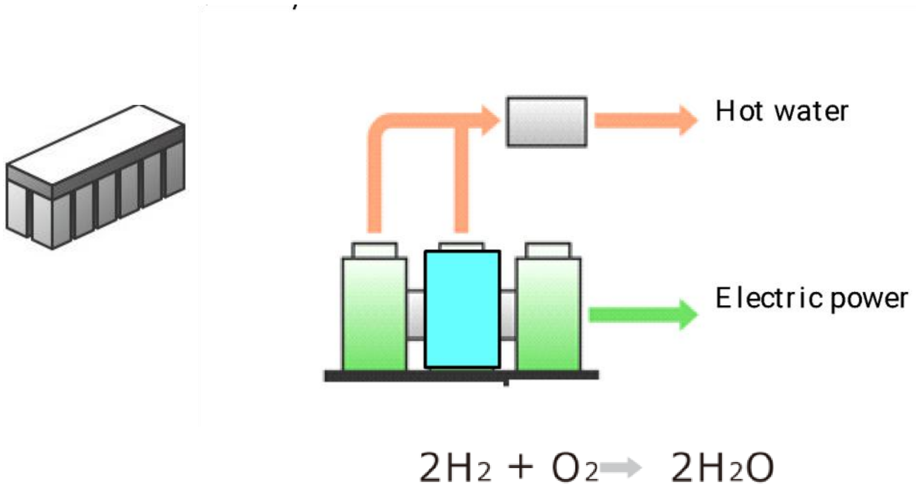


Source: Japan Gas Association, modified by the authors.

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



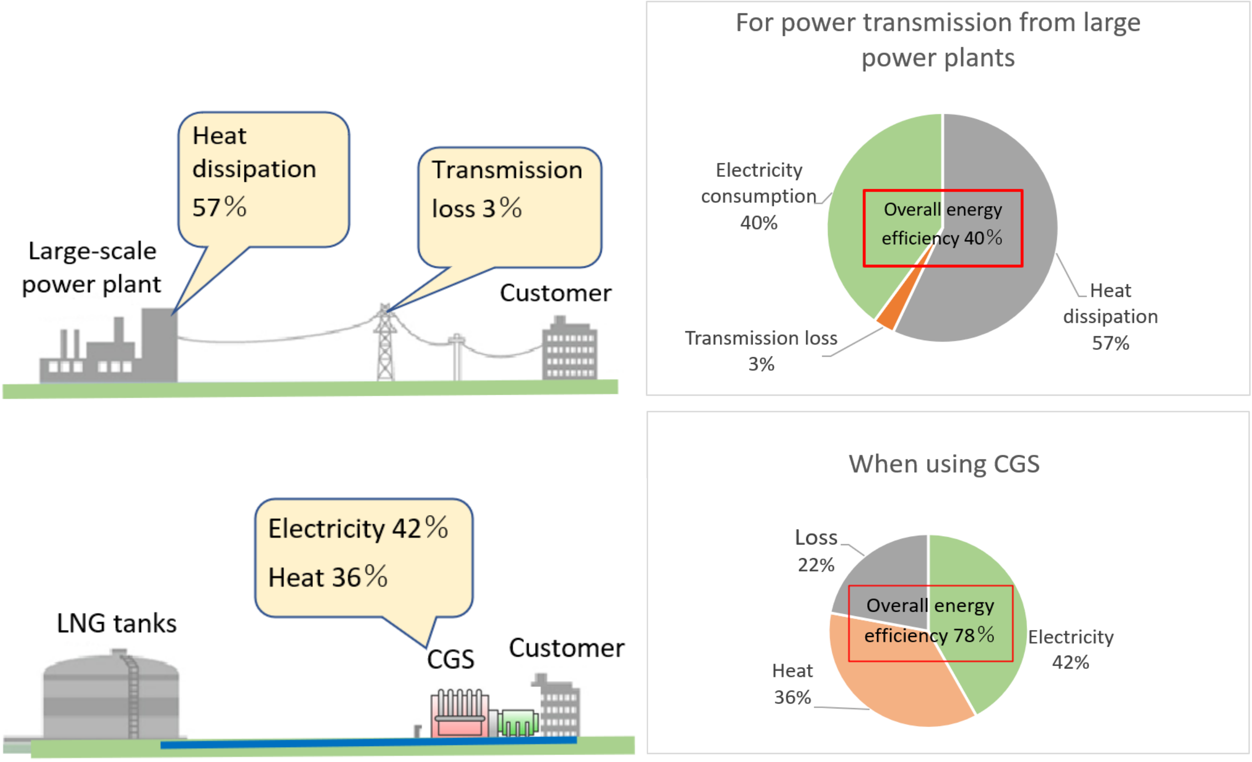
Source: Japan Gas Association, modified by the authors.

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

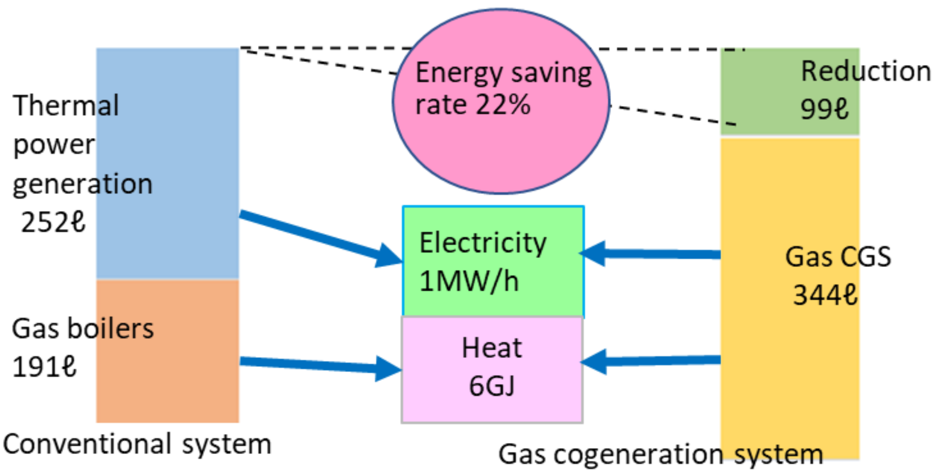


LNG = liquid natural gas.
Source: Japan Gas Association, modified by the authors.

(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

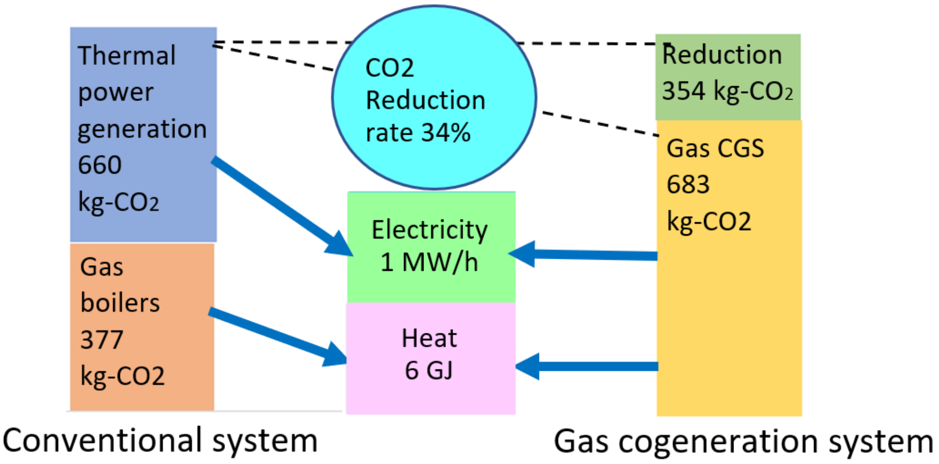


Note: All units are crude oil equivalent. Grid electricity is assumed as the average consumption of thermal power generation, and gas boiler is assumed at 40% efficiency. CGS power generation efficiency is assumed to be 85%, and CGS waste heat recovery is assumed to be 40%.
Source: Japan Gas Association,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

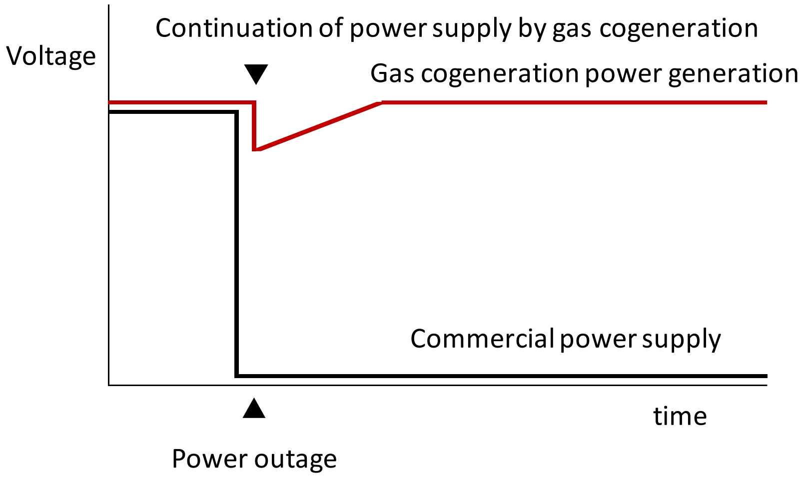
Normally, the power from the power company and that generated by CGS are interconnected. Thus, when the power supply from the electric power company is stopped due to natural disasters or accidents, the CGS can start supplying electricity to the site activities.

(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

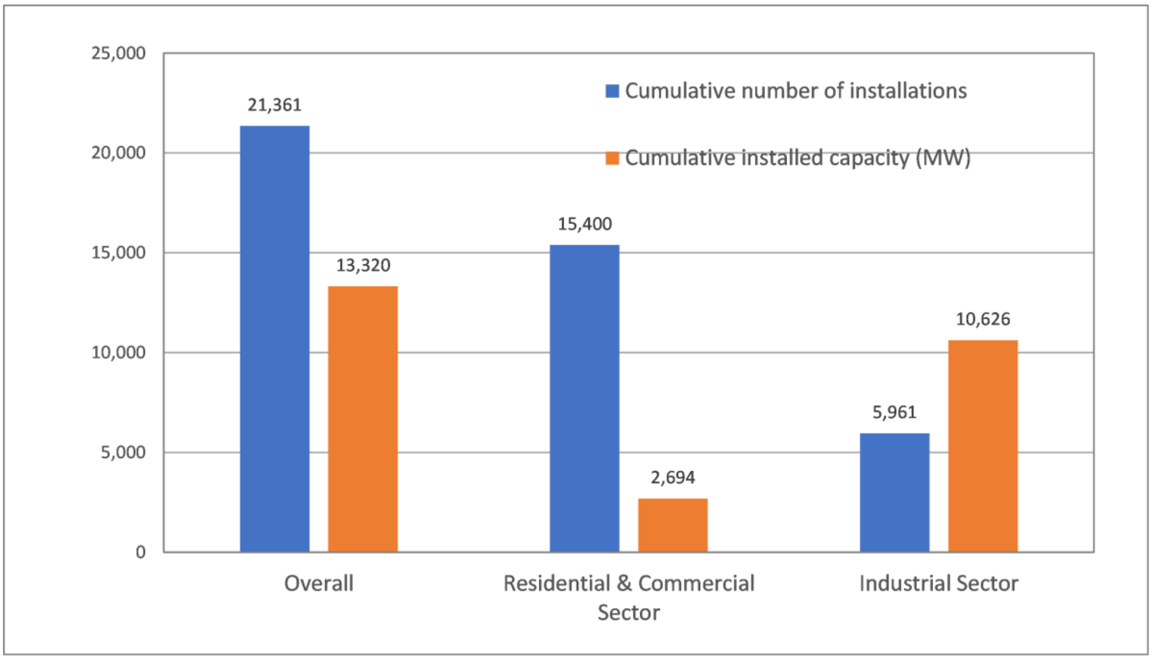
(1) Cumulative number of CGSs installed in Japan

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.

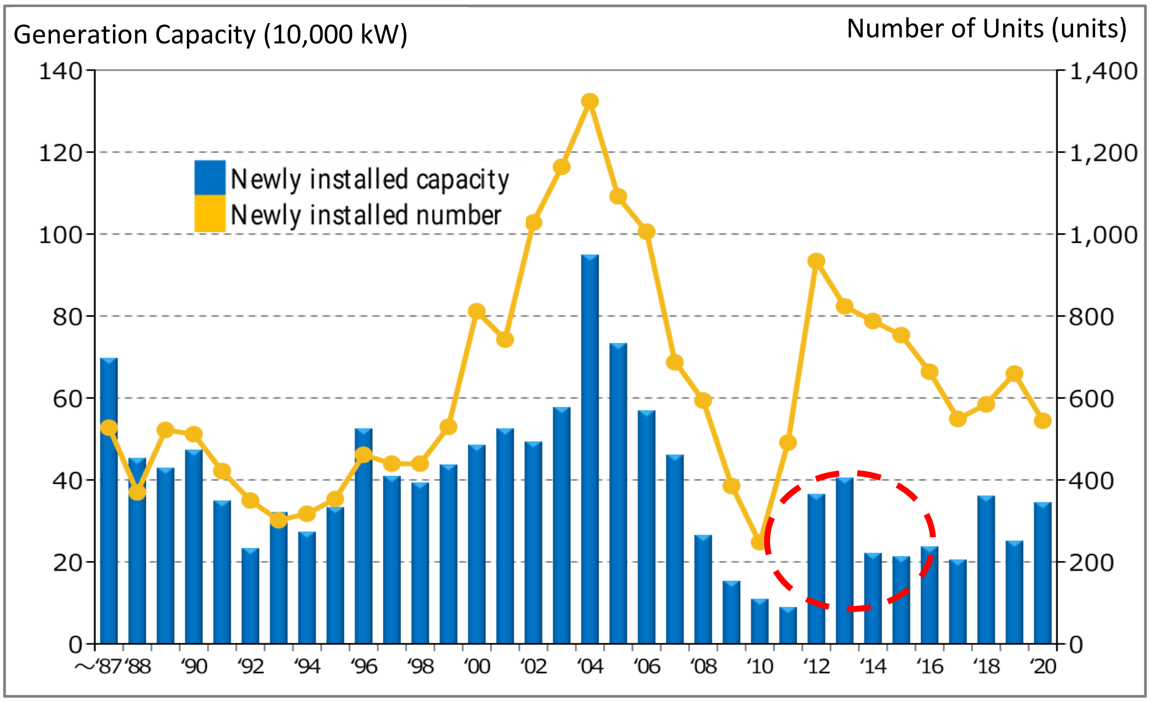


Source: Advanced Cogeneration and Energy Utilisation Center Japan, modified by the authors.

(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

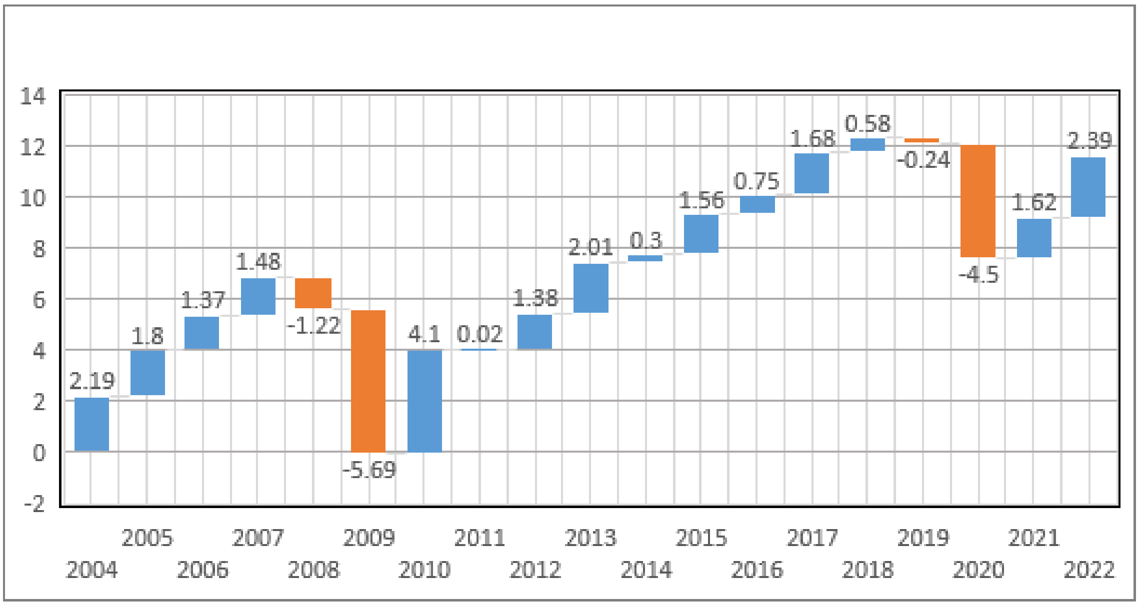
Figure 1.10 shows Japan's economic growth rates. The economic growth rate is defined below and represents the degree of GDP growth compared to the previous year.

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



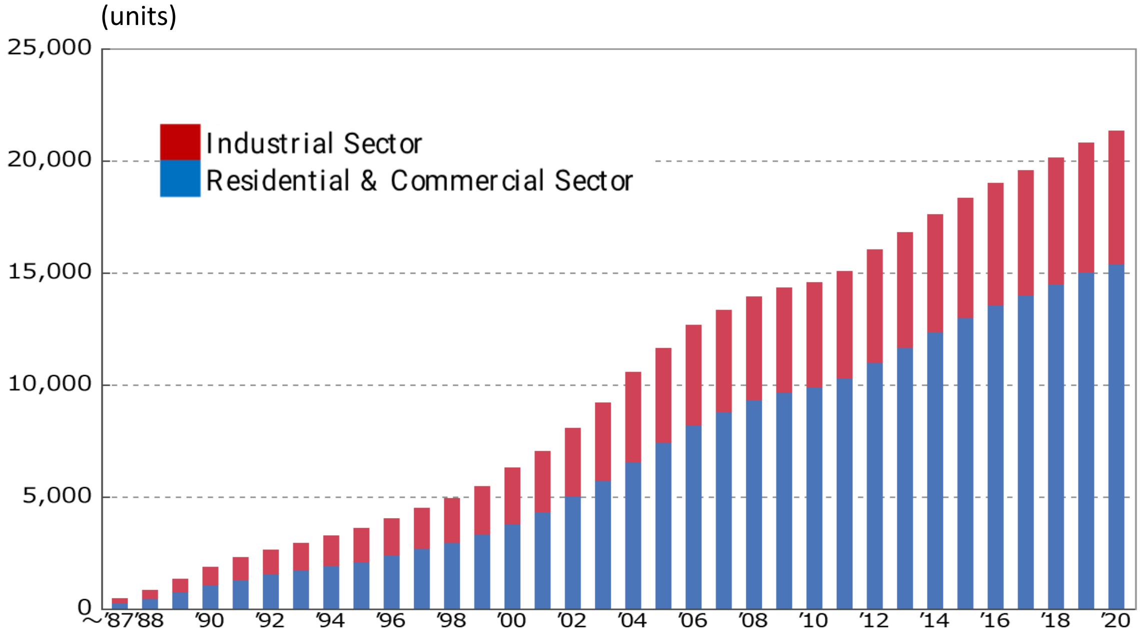
Source: Authors, based on IMF database (2022), https://www.imf.org/en/Publications/WEO/weo-database/2022/April/weoreport?c=158,&s=NGDP_R,NGDP_RPCH,NGDP,&sy=2020&ey=2027&ssm=0&scsm=1&scc=0&ssd=1&ssc=0&sic=0&sort=country&ds=.&br=1

(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

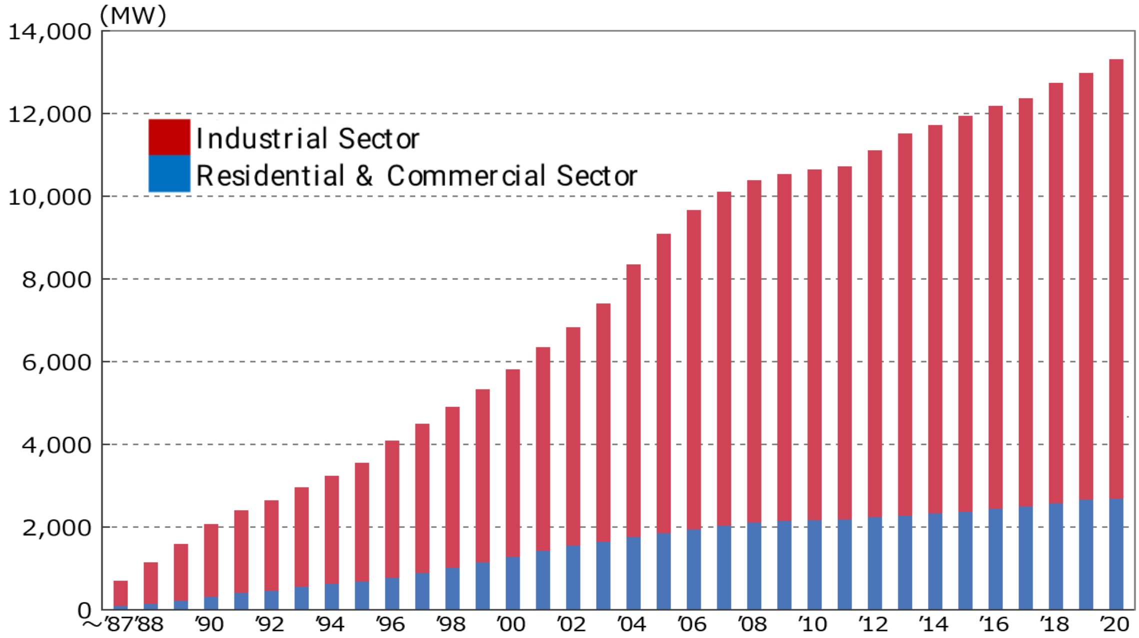


Source: Advanced Cogeneration and Energy Utilization Center Japan, modified by the authors; https://www.ace.or.jp/web/works/works_0020.html.

- 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)

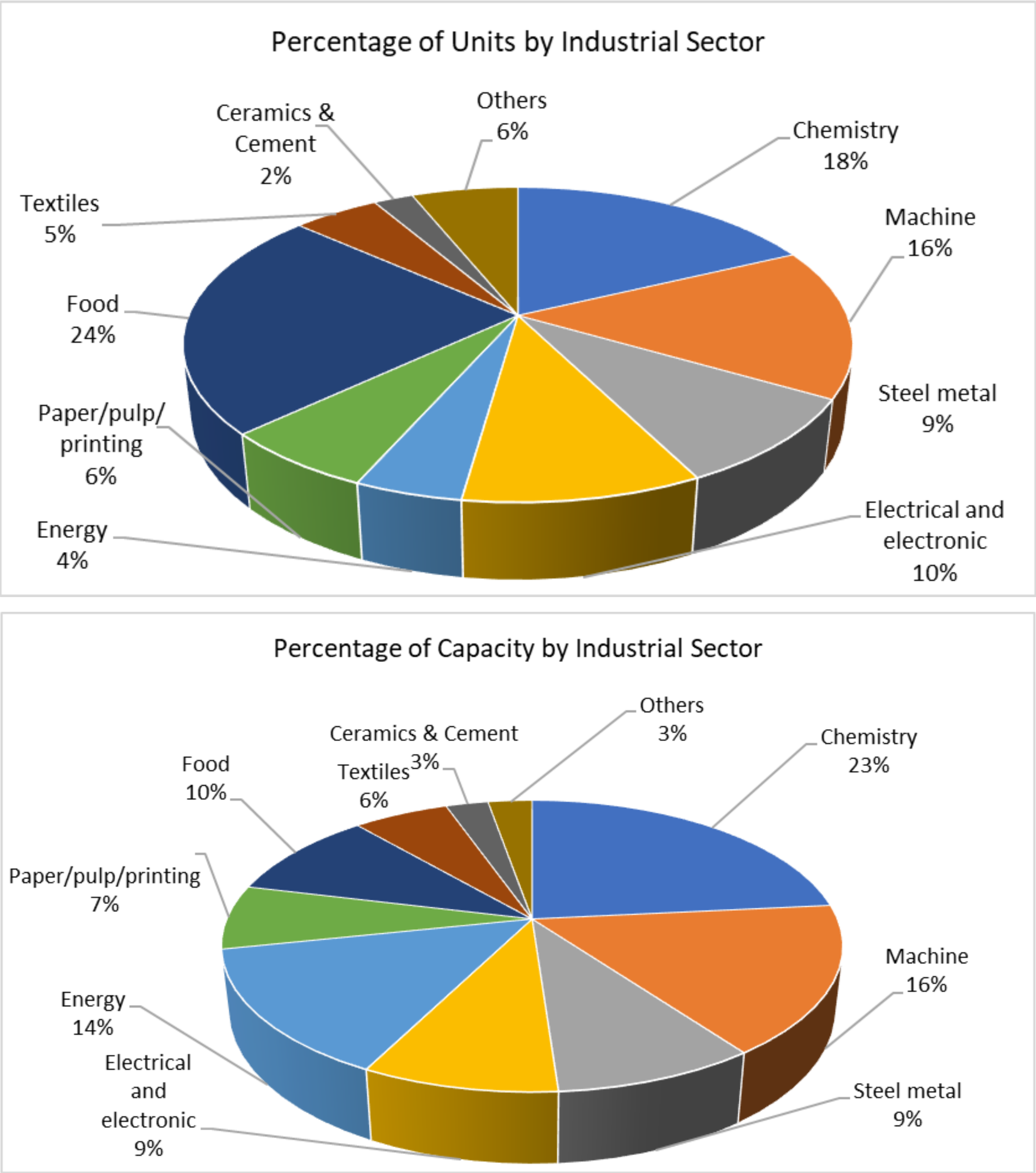
Since cogeneration produces electricity and heat simultaneously, it benefits sub-industries with high heat demand. In terms of the number of units, food, chemical, and machinery industries, which use a lot of electricity and heat, are the top three. Regarding capacity, energy supply, which includes large-scale 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

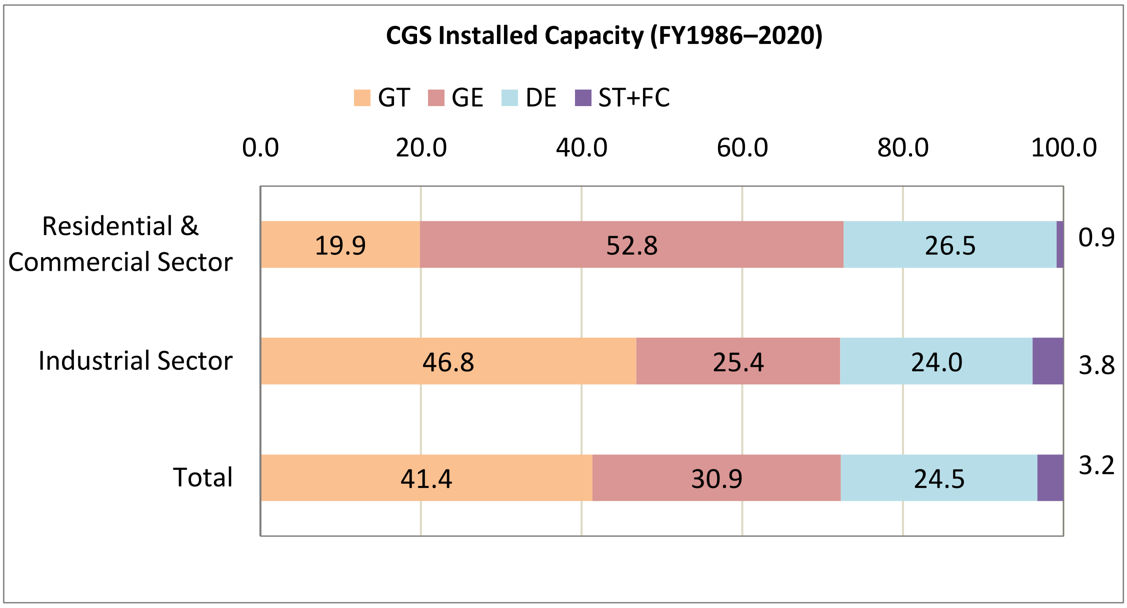
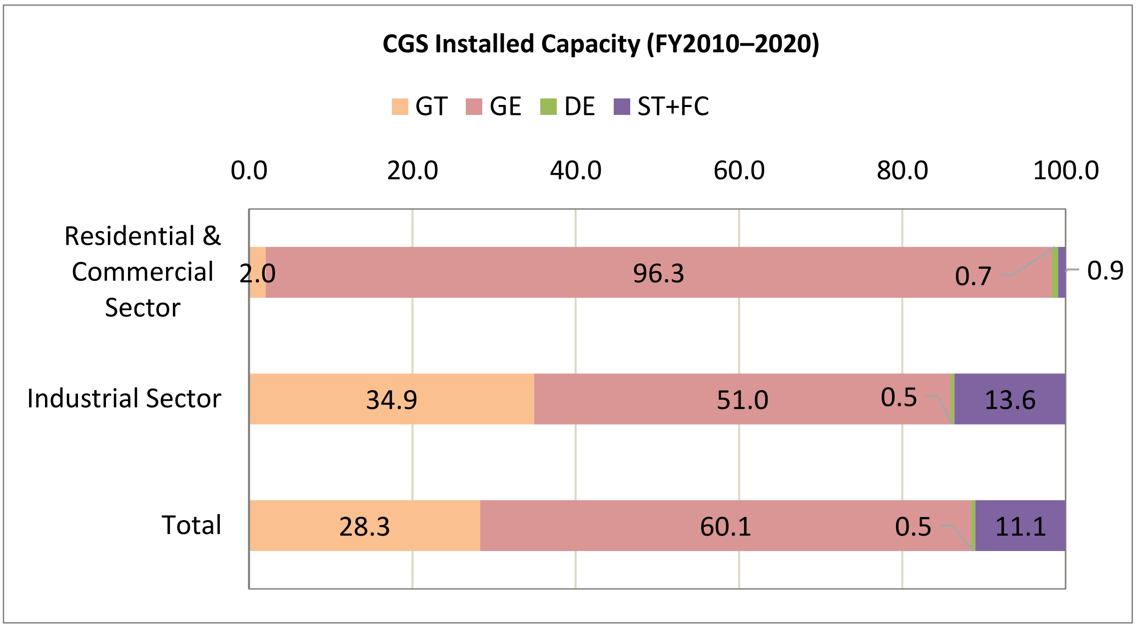


Figure 1.14. ***Continued***



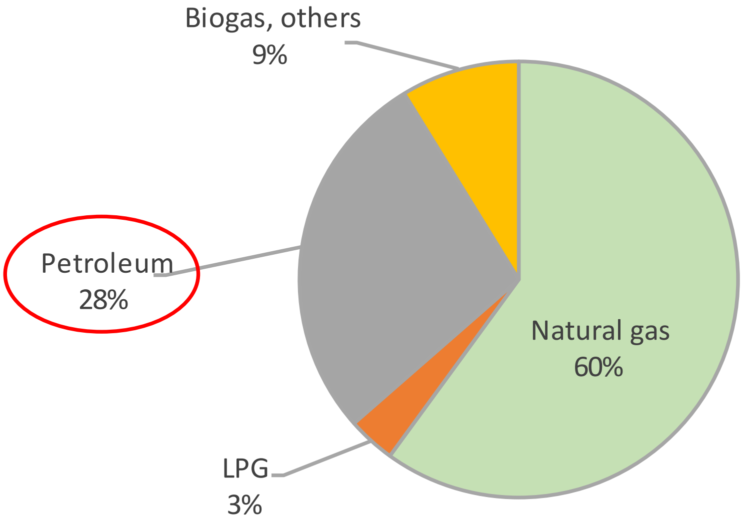
Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0060.html, modified by the authors.

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

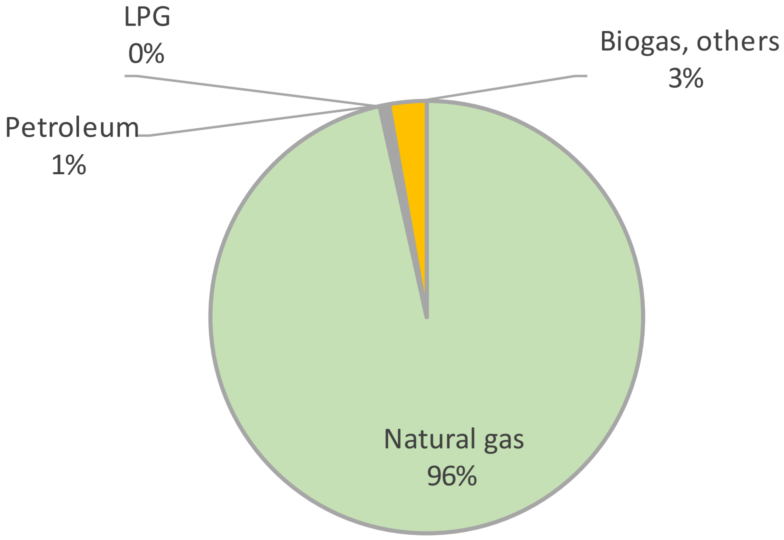


Source: Advanced Cogeneration and Energy Utilization Center Japan, https://www.ace.or.jp/web/works/works_0060.html, modified by the authors.

(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.

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.

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[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

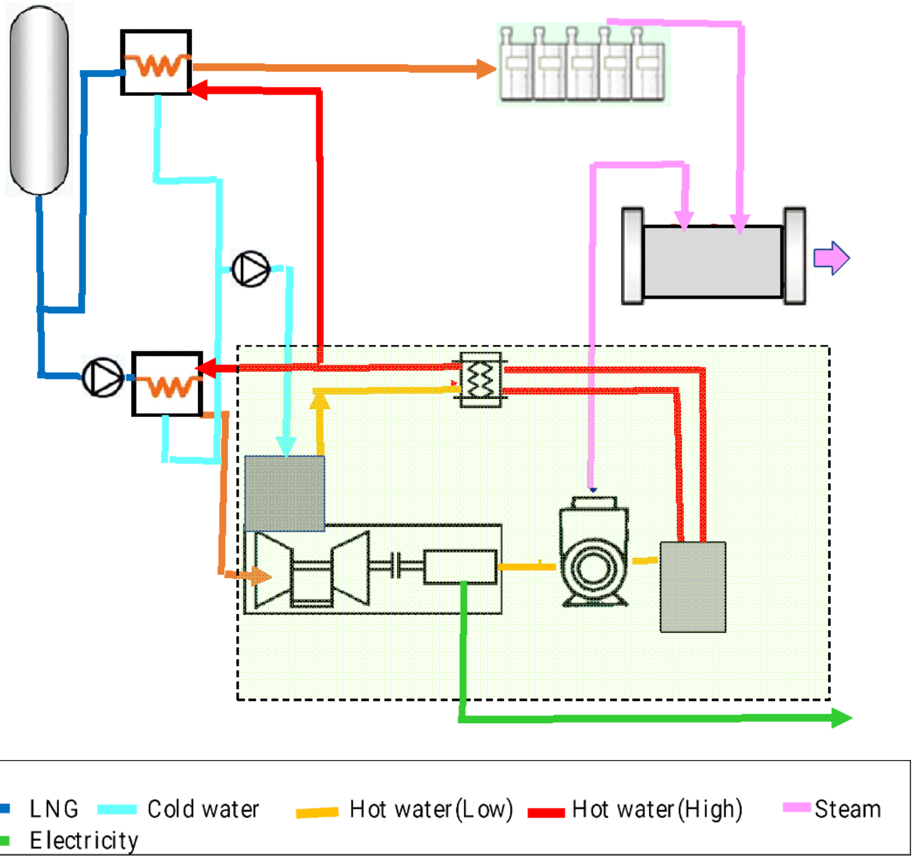
Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	1,615 kW x 2 units
Waste heat utilisation	Manufacturing process, LNG vaporisation
Fuel	LNG
Power peak cut rate	36.2％
Primary energy reduction rate	21.7%
Expected CO_2 saving amount	395 kg-CO_2/h
Electricity, heat,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

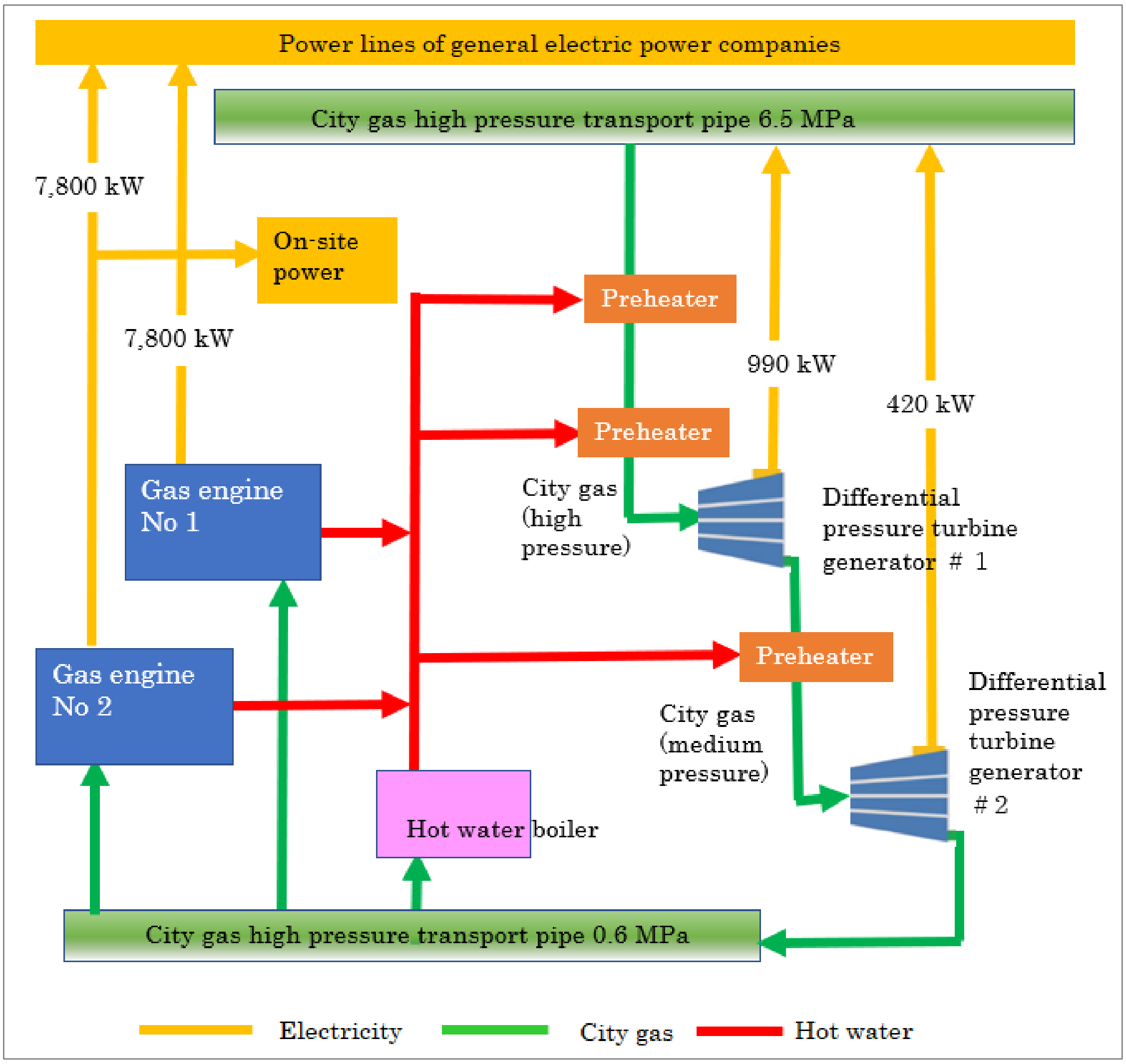
Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 7800 kW × 2 units (15,600 kW)
Waste heat utilisation	City gas preheat
Fuel	City gas
Power peak cut rate	—
Primary energy reduction rate	18.7%
Expected CO_2 savings amount	1,582 kg-CO_2
Electricity, heat, loss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

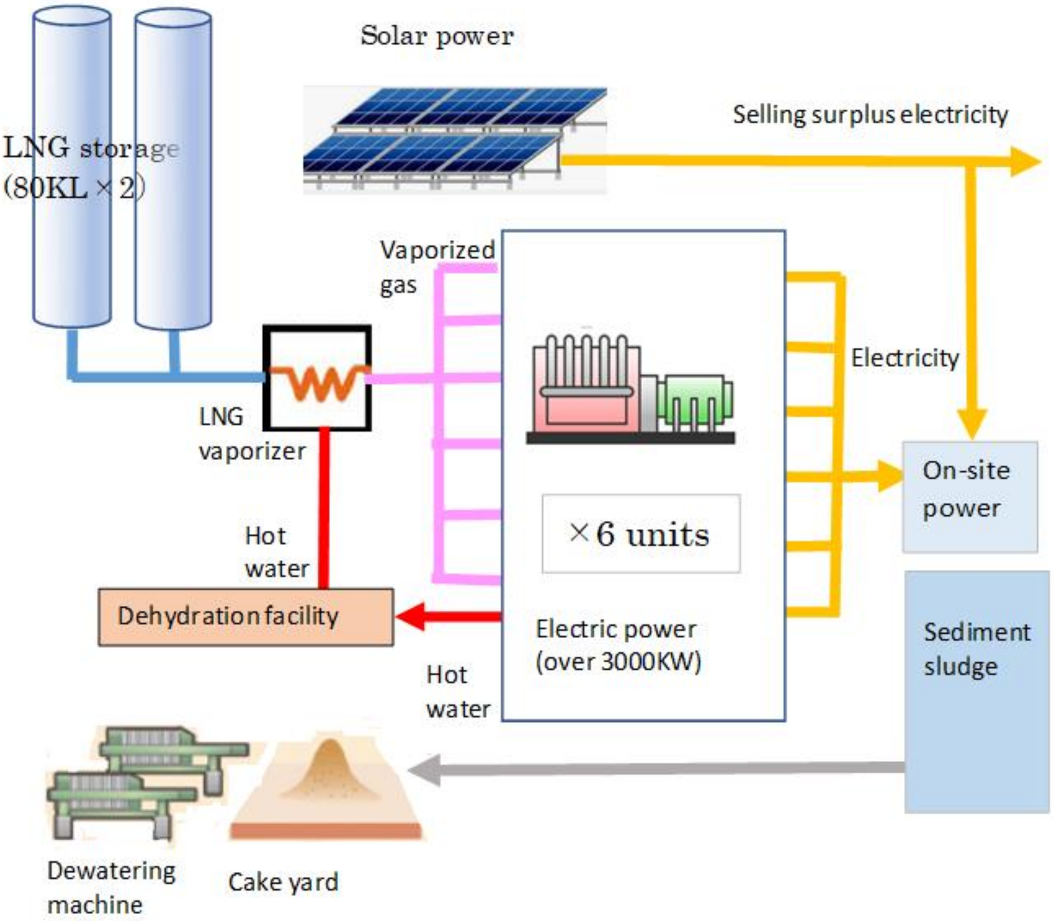
- Reuse of residual sludge

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

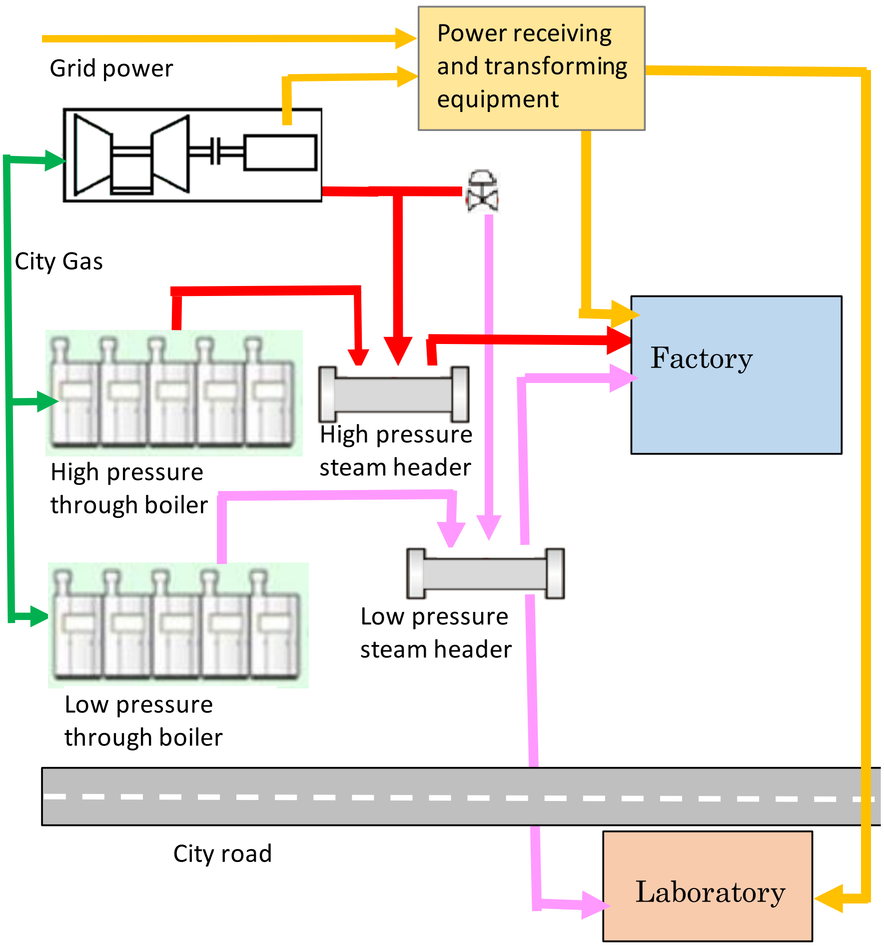
Load leveling was achieved by combining the different power load patterns of the factory and the laboratory. Introduction of a gas turbine with higher efficiency and generating capacity than the existing machine became possible. The steam was already being supplied between the two sites through a dedicated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

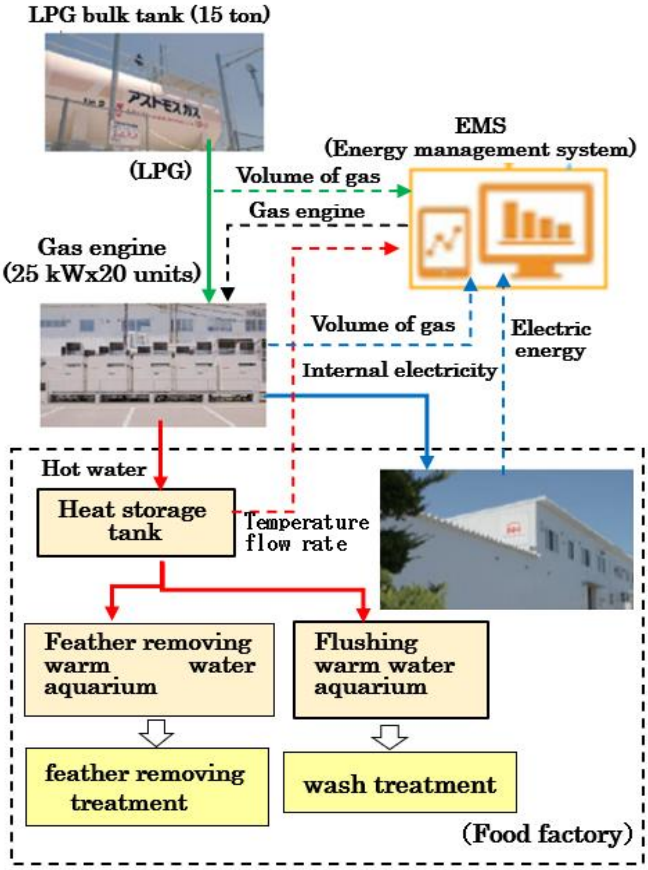
Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	(GE) 25 kW × 20 units
Waste heat utilisation	Production process
Fuel	LPG
Power peak cut rate	—
Primary energy reduction rate	25.5%
Expected CO_2 savings amount	75 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 33.5%，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

Chapter 3

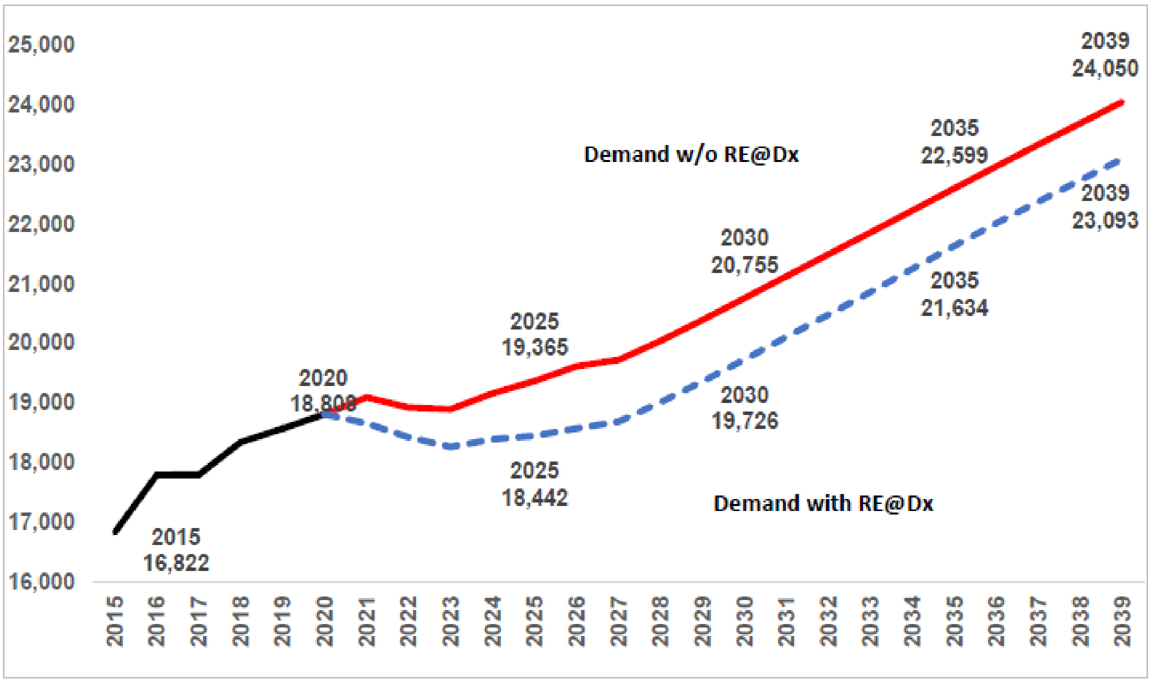
Cogeneration Systems Installed in Malaysia

3.1. Overview of Energy Demand in Malaysia

The total final energy consumption in Malaysia as of 2018 was 64,658 ktoe, out of which electricity consumption was 13,153 ktoe or 152,866 GWh as reported in the National Energy Balance Malaysia 2019. Based on the Energy Commission's report (2018), the installed CGS capacity is low at 3.3% of the total electricity generation of 133,447 GWh for Peninsular Malaysia, and 3.1% of the total electricity generation of 6,539 GWh for Sabah. There are CGS plants in the public and private sectors. The energy sources are natural gas, diesel, biomass, and waste heat from industrial processes.

Historically, the growth of demand from 2015 to 2020 was 16,822 MW to 18,808 MW, or an annual growth rate of 2.3%. The COVID-19 pandemic significantly reduced the overall demand in 2020. However, new peak demand was recorded on 10 March 2020, a week before the imposition of Movement Control Order due to COVID-19 on 18 March 2020. For 2021–2030 and 2030–2039, demand is projected to grow by 0.9% and 1.7% per annum, respectively (Figure 3.1). COVID-19 is expected to cause a temporary decline in demand. But from 2023 onwards, the growth is projected to normalise in line with economic recovery.

Figure 3.1. Peak Demand, Actual 2015–2020 and Projection 2021–2039



Source: Energy Commission Malaysia (2021a).

Cogeneration is recognised as an energy-efficient technology in Malaysia. It enables the simultaneous production of two different forms of useful energy – typically electricity and thermal energy – from a single primary energy source, also known as combined heat and power (CHP), merging the generation of usable heat and electricity into a single process, substantially reducing carbon emissions and energy costs. The electricity generated is normally for on-site use, and any excess may be exported to the local utility network. Thermal energy produced may be used for industry purposes or to produce steam, hot water, or hot air for drying or heating, or chilled water for cooling purposes. As a general observation, electricity generation alone from a simple CGS in Malaysia is not competitive compared to the electricity supply from the national grid. This is because the electricity tariff in Malaysia is relatively low due to government subsidies for electricity generation by power utilities and higher cycle efficiency from combined cycle generation plants. However, the viability of CGS installation improves with increasing heat energy demand in a process plant, for example.

3.2. Introduction: Installed CGS in Malaysia

This part of the study is research conducted on existing CGS installations in Malaysia's industry sector. It reviews the state and viability of CGSs through literature research, published information from Malaysian authorities and institutions, interviews with plant operators, and assistance from equipment manufacturers and system suppliers on a non-disclosure agreement basis. Despite the reported benefits of CGS installations with an improved energy efficiency of as much as 90%, the pace of cogeneration installation in Malaysia has remained sluggish. Moreover, before introducing the New Enhanced Dispatch Arrangement ((Energy Commission Malaysia, 2019a), the private sector experienced some barriers to implementing cogeneration projects, as listed below.

(1) A cogenerator could not export and sell the excess energy generated in the facility through the electricity supply grids unless a power purchase agreement exists with the electricity supply or utility company, which is the only electricity distributor. This was one reason affecting the wider use of cogeneration, as the sale of excess energy may be a factor in the investment consideration. The generation of electricity for sale requires a licence from the Energy Commission, which regulates the generation and supply of electricity in Malaysia. Furthermore, the cost of electricity generation from CGS installation is not as competitive as that of the utility company for the reasons stated above.

(2) The utility company imposes high standby charges on cogenerators that sell excess electricity.

Other challenges to cogeneration in Malaysia are as follows:

(1) Constraints in natural gas supply

(2) Subsidised electricity tariffs make cogeneration projects not as attractive

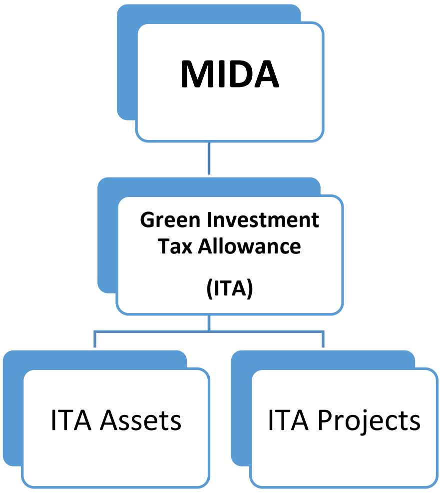
(3) High reserved margin in the grid system

(4) Lack of specific fiscal incentives and financing mechanisms to increase the viability of cogeneration projects

In 2015, the Ministry of Energy Malaysia implemented the National Energy Efficiency Action Plan. Under Key initiative 4, cogeneration for industries and buildings was promoted by addressing barriers such as standby and top-up charges, gas tariff pricing agreement, incentives, technical hurdles such as licensing requirements, and lack of awareness on benefits of cogeneration.

As a result, the Malaysian government offers some attractive incentives for investors in cogeneration plants. These include incentives for companies entering into energy performance contracting (EPC) schemes with ESCOs or investors in cogeneration plants serving their energy needs. Other incentives include import duty and sales tax exemptions, investment tax allowance (ITA), and pioneer status. The Energy Commission evaluates applications for import duty and sales tax exemptions for cogeneration equipment while the Malaysian Investment Development Authority (MIDA) processes ITA and pioneer status applications for energy-efficient investments.

Figure 3.2. ITA Application Flowchart



MIDA = Malaysian Industrial Development Authority.
Source: Authors.

The eligibility of companies applying for ITA is based on the following criteria:

(1) The company must be incorporated under the Companies Act, 2016.

(2) The company must achieve the following green results:

- Conserve the use of energy and/or other forms of natural resources, promote renewable energy, or recycle waste material resources.
- Minimise the degradation of the environment or reduce GHG emissions.
- Promote health and improve the environment.

Table 3.1. Example of ITA Benefits by Comparing Tax Computation based on 'With' and 'Without' Tax Incentives based on an Assumed Green Project Investment of RM10 Million

	Without Tax Incentive (RM)	With Tax Incentive (RM)
Profit before tax Add/less tax adjustment	15,000,000 2,000,000	15,000,000 2,000,000
Adjusted income Less capital allowance	17,000,000 (5,000,000)	17,000,000 (5,000,000)
Statutory income	12,000,000	12,000,000
ITA amount		10,000,000
Taxable income		2,000,000
Tax liability/saving @24%	2,880,000	480,000
Overall Tax Savings (Comparing with without tax incentive)		**2,400,000**

Source: Authors in consultation with Kawan Engineering Sdn Bhd in 2022.

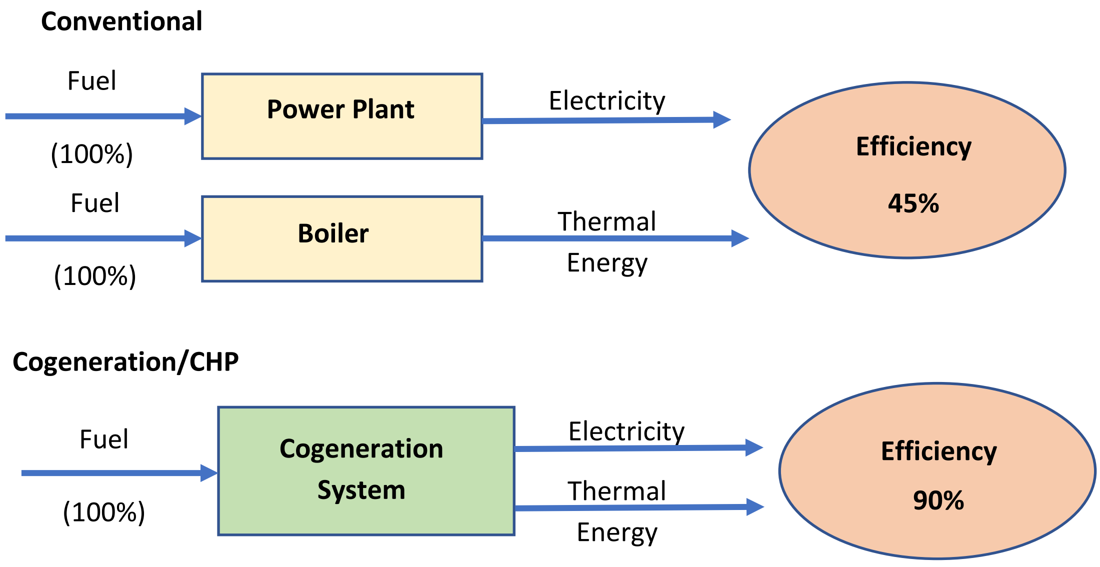
Table 3.1 shows an example of tax benefits under the ITA scheme. This example is based on an assumed green project investment of RM10 million that can be used to offset the statutory income under the ITA scheme. The overall tax saving works out to be RM2.4 million. Green projects include CGS installations.

3.3. Benefits of the Cogeneration System

Cogeneration is an energy-efficient technology (Figures 3.3 and 3.4). CGS benefits are briefly summarised as follows:

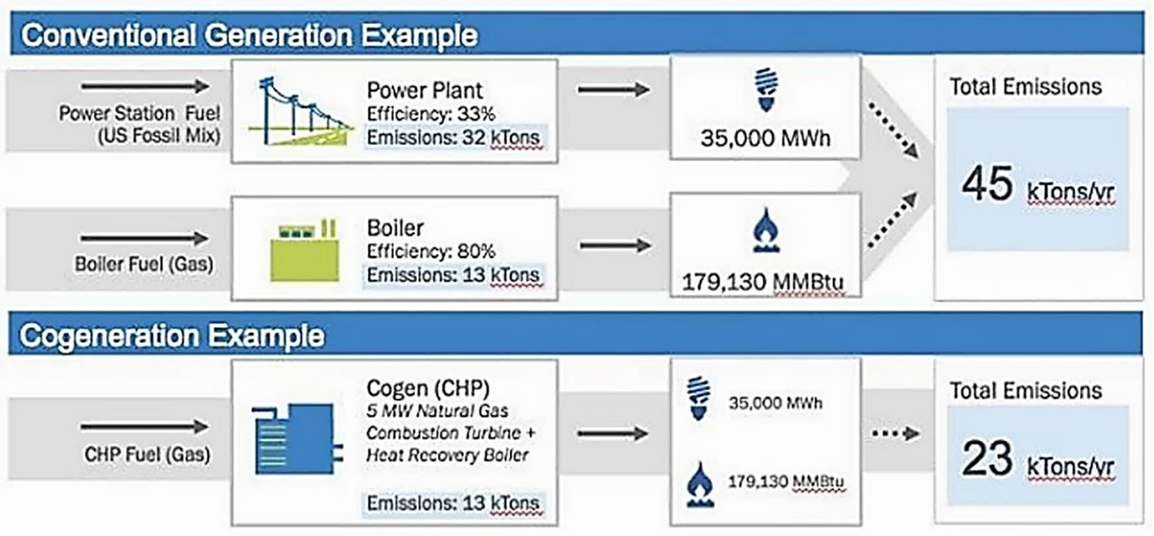
- Improve overall system efficiency in the use of energy resources
- Savings in energy consumption result in saving in running costs
- Improve profitability and competitiveness of the business operation
- Help manage limiting maximum demand and improve the operation of less efficient peaking plants
- Local generation will help reduce demand and energy losses in the transmission and distribution of electricity

Figure 3.3. Cogeneration/Combined Heat Power with Improved Plant Efficiency at 90% vis-à-vis Conventional Plant at 45% Plant Efficiency



Source: REEEP (2020).

Figure 3.4. Example Showing Significant Reduction of Carbon Emissions and Energy Costs



Source: https://blogs.constellation.com/sustainability/what-are-the-benefits-of-cogeneration.

Due to waste heat recovery, CGS can improve the overall plant efficiency (Figure 3.3) and significantly reduce CO_2 emissions (Figure 3.4). Figure 3.4 shows a conventional power plant with an efficiency of 33% and a boiler plant generating 35,000 MWh of electricity and 179,130 MMBtu steam with emission of 45 ktons/y. This example is compared with a CHP system generating the same output of 35,000 MWh electricity and 179,130 MMBtu steam but with a reduced emission of 23 ktons/y.

3.4. State of Cogeneration Installations in Malaysian Industries

Based on electricity generation capacity, three industrial sectors – oil refinery and gas processing, chemical and petrochemical, and iron and steel – take up the largest shares of CGS installation. However, regarding the number of installations, the three largest sectors are utilities, chemical and petrochemical, and palm oil and oleochemical industries. Other industrial sectors taking up significant shares of CGS installation are paper mills and sugar processing plants. CGS installations are also found in cement and rubber glove production plants but to a smaller extent. The Energy Commission Malaysia reports no CGS installation in the commercial sector.

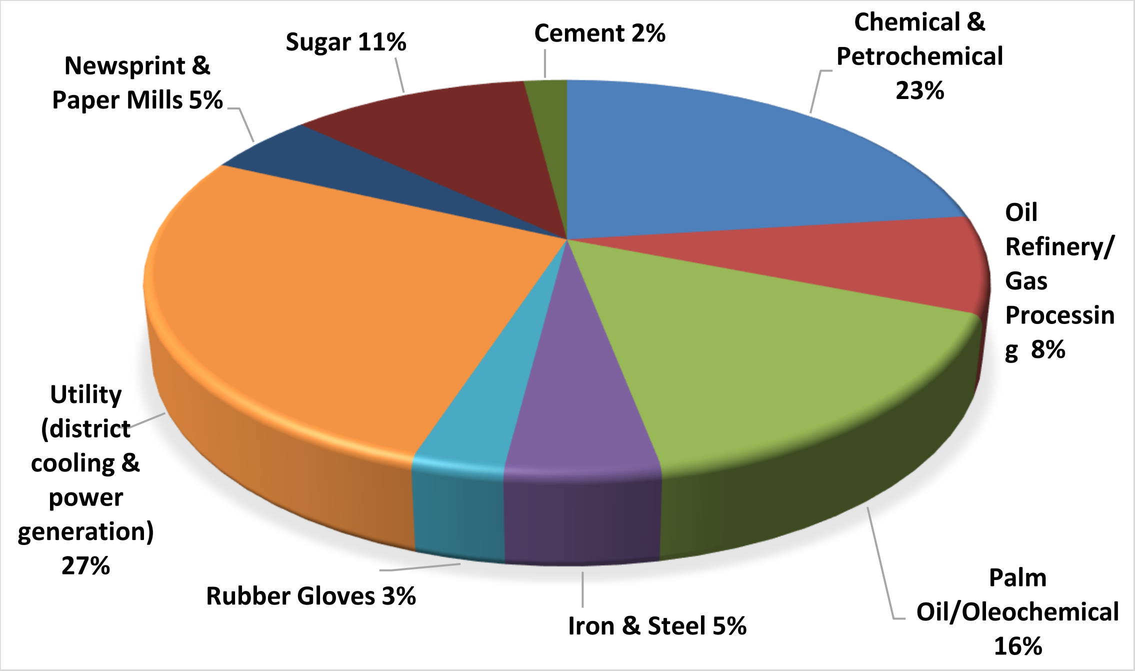
Table 3.2 shows the cogeneration-installed capacities and the number of installations based on the Energy Commission's 2021 publication. The percentage shares by the number of installations and installed capacities are shown in Figures 3.5 and 3.6, respectively.

Table 3.2. Overview of CGS Application and Installation in Malaysian Industries

Category of Industries	No. of CGS Installations	Cogen Installed Capacity (MW)	Share of CGS installed by Number of Installations (%)	Share of CGS Installed by Capacity (%)
Oil refinery/Gas processing	5	574.50	8	28
Iron & steel	3	282.50	5	14
Chemical & petrochemical	14	611.07	23	30
Newsprint & paper mills	3	126.60	5	6
Utility (district cooling & power generation)	17	270.69	27	13
Palm oil/Oleochemicals	10	69.43	16	3
Sugar processing	7	79.51	11	4
Rubber gloves	2	12.00	3	1
Cement	1	12.00	2	1
TOTAL	**62**	**2,050.30**	**100%**	**100%**

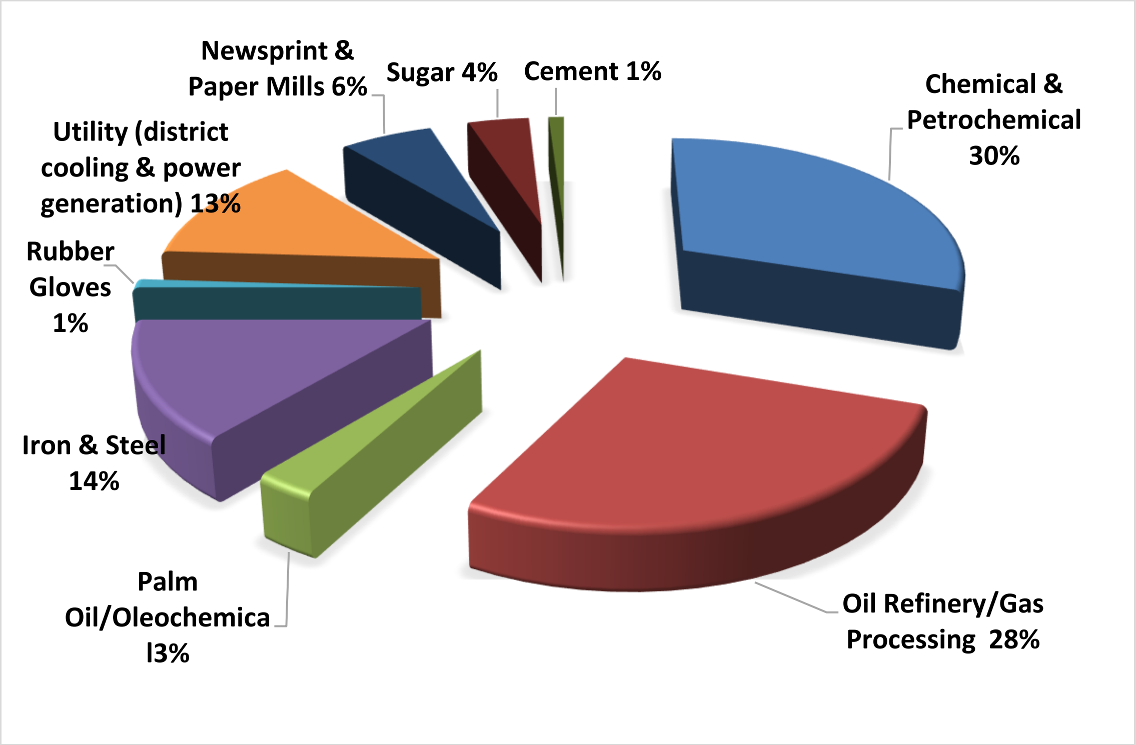
Source: Summarised from Energy Commission Malaysia (2021a).

Figure 3.5. Percentage Shares of CGS Installations in Various Industries, by Number of Installations



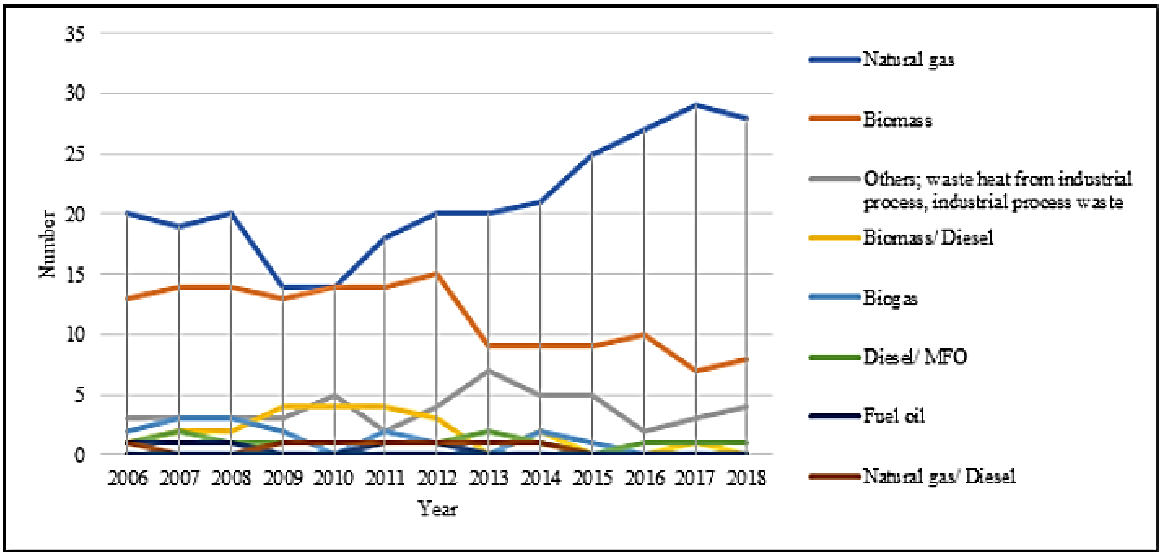
Source: Authors.

Figure 3.6. Percentage Shares of CGS Installations in Various Industries, by Installed Capacities



Source: Authors.

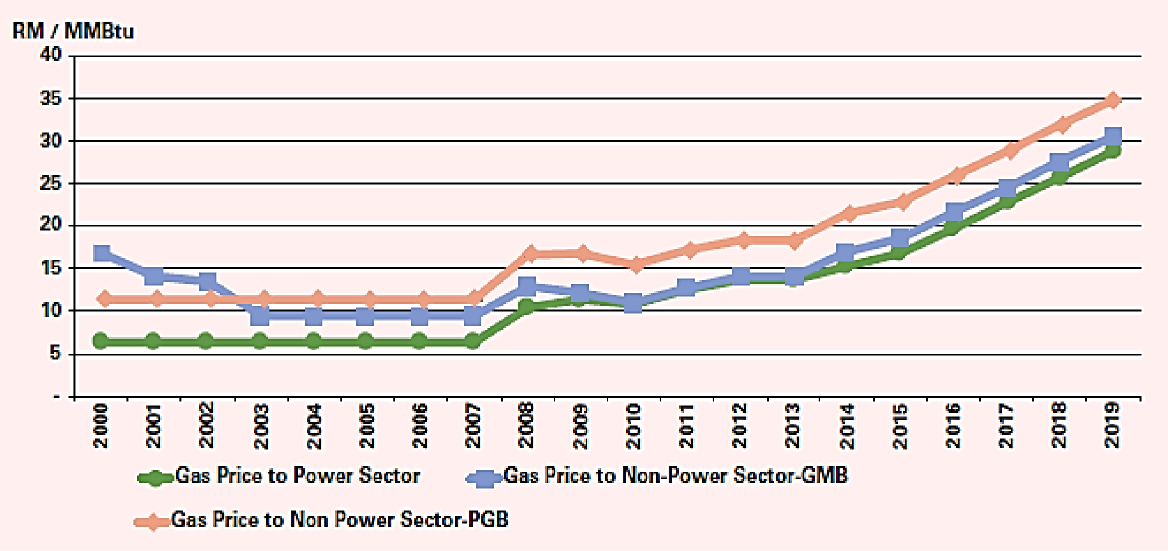
Figure 3.7. Energy Source of Cogeneration in Malaysia, 2006–2018



Source: IEPRe (2020).

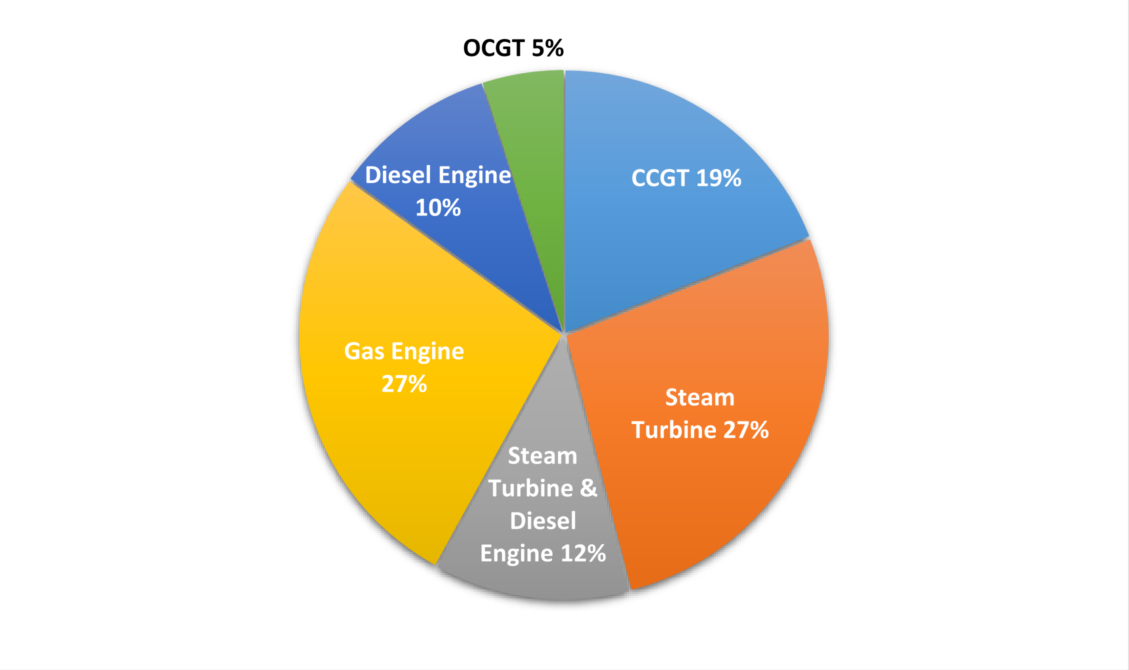
Figure 3.7 shows that most of Malaysia's CGS installations use natural gas, followed by biomass and others, such as waste heat from industrial processes. The availability and reliability of energy sources are essential in cogeneration development. Another vital element in CGSs is the type of prime mover that drives the system. Figure 3.8 shows the extent of rising natural gas prices in Malaysia. Figure 3.9 shows the type of cogeneration technologies deployed in Malaysia in 2018. Steam turbine and gas engines are the most used, representing 27% of all the installations, followed by combined cycle gas turbines (CCGTs) at 19% and diesel engines at 10%.

Figure 3.8. Natural Gas Prices in Malaysia



Source: Energy Commission Malaysia (2020).

Figure 3.9. Percentage of Technology Shares Used by CGS Installations, as of 2018



CCGT = combined cycle gas turbine, OCGT = open cycle gas turbine.
Source: The Institute of Energy Policy & Research (IEPRe) (2020).

3.5. Selected Cogeneration Installations in Malaysian Industries

Technical and operational data on CGS installations in Malaysia are not available in the public domain. The search for technical information on CGS installations had been confined to publications of the Energy Commission Malaysia, *Techno-economic Study on the High-efficiency Cogeneration in Malaysia in the Compendium of Energy Economic Research 2020* (IEPRe, 2020), and industrial sources from CGS plant operators and equipment manufacturers and system suppliers on non-disclosure agreement basis.

The appendices present 24 case studies. Table 3.3 summarises the 24 case studies, listing key information such as energy sources, heat-to-power ratio, estimated payback period, and system configuration. Based on information gathered in this study exercise, a general trend of improved payback periods can be observed for industrial plants with higher heat demand than electricity demand, i.e. higher heat-to-power ratios will improve the viability of CGS installations, as illustrated in Figure 3.10.

Table 3.3. List of Cogeneration Plants in Malaysia's Industrial and Commercial Sectors

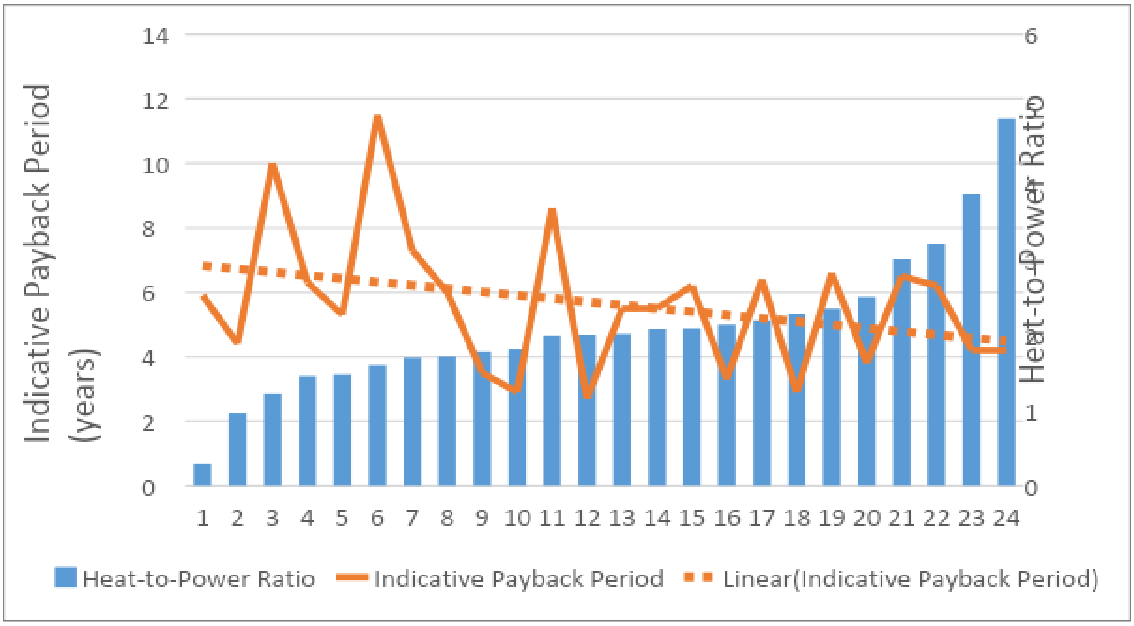
Sector	Energy Source	Heat-to-Power Ratio	Estimated Payback Period (years)	Plant Capacity Generator System Configuration with HRSG/WHRB
Paperboard & packaging	Natural gas	3.01	6.5	• 1 x 32 MWe gas turbine • 1 X 140 t/h @ 60 barg saturated steam
Chemical plant #1	Natural gas	2.20	6.4	• 3 x 25 MWe gas turbine • 3 x 80 t/h @ 65 barg saturated steam each
Paper mill #2	Natural gas	2.08	5.5	• 1 x 33 MWe gas turbine • 1 x 100 t/h @ 65 barg saturated steam
Gas district cooling	Natural gas	0.96	4.4	• 2 x 5.4 MWe gas turbine • 1 x 15 t/h @18 barg saturated steam
Edible oil	Natural gas	1.72	6	• 1 x 6.4 MWe gas turbine • 1 x 15 t/h from waste heat + 17 t/h through supplementary firing @ 45 barg saturated steam
Glove manufacturing	Natural gas	1.82	2.9	• 1 x 1.2 MWe + 1 x 2.0 Mwe gas engine • 2 x heat exchanger with total capacity 80–100 m3/h @ 60°C–80°C
Chemical plant #2	Natural gas	1.48	5.3	• 2 x 1.4 MWe gas turbine • 1 x 6 t/h @ 13 barg saturated steam • Exhaust gas for process drying
Chemical plant #3	Natural gas	1.46	6.3	• 2 x 22 MWe gas turbine • 2 x 40 t/h from waste heat + 39 t/h from supplementary firing at 385°C–400°C superheated steam each
Papermill #3	Natural gas	2.29	2.9	• 3 x 4.8 MWe gas turbine • 3 x 16 t/h from waste heat + 7 t/h from supplementary firing @ 11 barg saturated steam each
Oleochemical #1	Natural gas	1.60	11.5	• 1 x 6.5 MWe gas turbine • 1 x 15 t/h from waste heat + 7.6 t/h from supplementary firing @ 22 barg saturated steam
Oleochemical #2	Natural gas	1.78	3.5	• 1 x 6.5 MWe gas turbine • 1 x 16.7 t/h @ 16 barg saturated steam
Oleochemical #3	Natural gas	2.02	5.5	• 1 x 4 MWe gas turbine • 1 x 11.7 t/h from waste heat + 18.3 t/h from supplementary firing @ 10.5 barg saturated steam
Oleochemical #4	Natural gas	1.70	7.3	• 1 x 6.5 MWe gas turbine • 1 x 16 t/h from waste heat + 20 t/h @ 16 barg saturated steam
Fabric	Natural gas	0.29	5.9	• 1 x 5.2 MWe gas engine • 1 x 2.2 t/h @ 8 barg saturated steam

Sector	Energy Source	Heat-to-Power Ratio	Estimated Payback Period (years)	Plant Capacity Generator System Configuration with HRSG/WHRB
Third- party utility supply	Natural gas	1.22	10	• 1 x 16.28 MWe Gas Turbine • 1 x 28 t/h from waste heat + 60 t/h from supplementary firing @ 60.8 barg, 292^{o}C superheated steam
Textile factory	Natural gas	2.09	6.2	• 1 x 4.66 MWe gas turbine • 1 x 37.6 t/h @ 60^{o}C hot water
Oil refinery	Natural gas	4.88	4.2	• 1 x 4.62 MWe gas turbine • 1 x 17.6 t/h @ 80^{o}C hot water
Rubber gloves	Natural gas	3.87	4.2	• 1 x 13.94 MWe gas turbine • 1 x 27 t/h @ 120^{o}C hot water
Oleochemical #5	Natural gas	3.22	6.2	• 1 x 7.03 MWe gas turbine • 1 x 35 t/h @ 34 barg saturated steam
Biomass processing plant	Natural gas	2.35	6.6	• 1 x 5.5 MWe gas turbine • 1 x 20 t/h @ 35 barg saturated steam
Animal feed ingredient plant	Natural gas	2.51	3.8	• 1 x 33.55 MWe gas turbine • 1 x 130 t/h @ 11 barg saturated steam
Chemical plant #4	Natural gas	1.99	8.6	• 1 x 0.85 MWe micro turbine • 1 x 50.77 t/h @ 236^{o}C thermal oil heater from 227^{o}C • 1 x 5.8 t/h @ 80^{oi}C hot water from 30^{o}C • 1 x 70 t/h @ 90^{o}C hot water from 77^{o}C • 1 x 103.2 t/h chilled water at 8^{o}C
Papermill	Natural gas	2.14	3.3	• 1 x 14.4 MWe gas turbine • 1 x 40 t/h @ 11 barg saturated steam
Sugar mill	Natural gas	2.01	2.7	• 1 x 11.5 MWe gas turbine • 1 x 30 t/h @ 11 barg saturated steam

HRSG = heat recovery steam generator, WHTB = waste heat recovery boiler.

Source: Compilation from industries and original equipment manufacturers.

Figure 3.10. Trend of Improved Viability of CGS Installations with a Higher Heat-to-power Ratio



Source: Authors.

3.6. Introduction of Typical CGS Case Studies

This section describes and provides details of three CGS installations from these industrial sectors:

(1) Oleochemical plant #1

(2) Third-party utility (ESCO) operator and distributor of electricity and steam

(3) Paper mill

3.6.1. CGS case study no. 1: Oleochemical-produced fatty acids, methyl esters, and refined glycerine

1) Description of industry motivational factors leading to CGS installation and benefits

A large oleochemical company owns the gas turbine CGS and uses it for the internal electricity and steam supply. The oleochemical company produces fatty acids, methyl esters, and refined glycerine, which are exported.

Established in 1989, this oleochemical company, is committed to supporting its parent company to achieve sustainable goals. Among the targets were a 50% reduction in GHG emissions and a 35% increase in water efficiency compared to the 2010 baseline.

Electricity is supplied from two sources to meet the demand of the factory, 90.4% (31,200 MWh/year) from its CGS. In contrast, the balance of 9.6% (3,300 MWh/year) is imported from the grid, totalling 34,500 MWh/year of electricity demand for production and utility use. However, electricity supply can be obtained from the grid in case of tripping or partial loading of the cogeneration unit. However, some standby and topping-up charges apply.

The plant initially produced its own steam through two water tube boilers 15.8 t/h each at 10 barg saturated steam. With the cogeneration plant, the factory can produce the same amount of saturated steam with free energy recovered from the waste heat from the gas turbine exhaust.

The company set up the CGS to reduce the cost of energy (combined electricity and steam) required by the plant and reduce the GHG emissions from the higher thermal efficiency of the cogeneration plant by adopting heat recovery from the gas turbine generator exhaust. In addition, it can also take advantage of the Malaysian government's incentives through the Green Investment Tax Allowance.

2) System features and operational information

Atmospheric air enters the compressor and is then compressed to a higher pressure and mass ratio as combustion air and cooling air for turbine buckets. Next, fuel is injected into the combustion chamber and burned with the combustion air. The combustion product then flows to the gas turbine at about 1000°C where work is done in turning the gas turbine generator (GTG) shaft to produce electricity. Finally, the waste gas is exhausted at about 500°C to the heat recovery steam generator (HRSG). Table 3.4 describes the specification of the CGS, and Figure 3.11 shows the process flow diagram.

At the HRSG, steam is produced while the available mechanical energy drives the generator to produce electricity. The recovered heat from the gas turbine exhaust can raise 11.7 tons/hour of steam, and a further supplementary firing at the duct can raise another 18.3 tons/hour at the same 10.5 barg saturated steam. The exhaust temperature from the gas turbine exhaust is 500°C. The supplementary firing raises the flue gas temperature to 733°C and exhaust after the economiser is about 90°C. Hence, considerable heat is recovered in the HRSG.

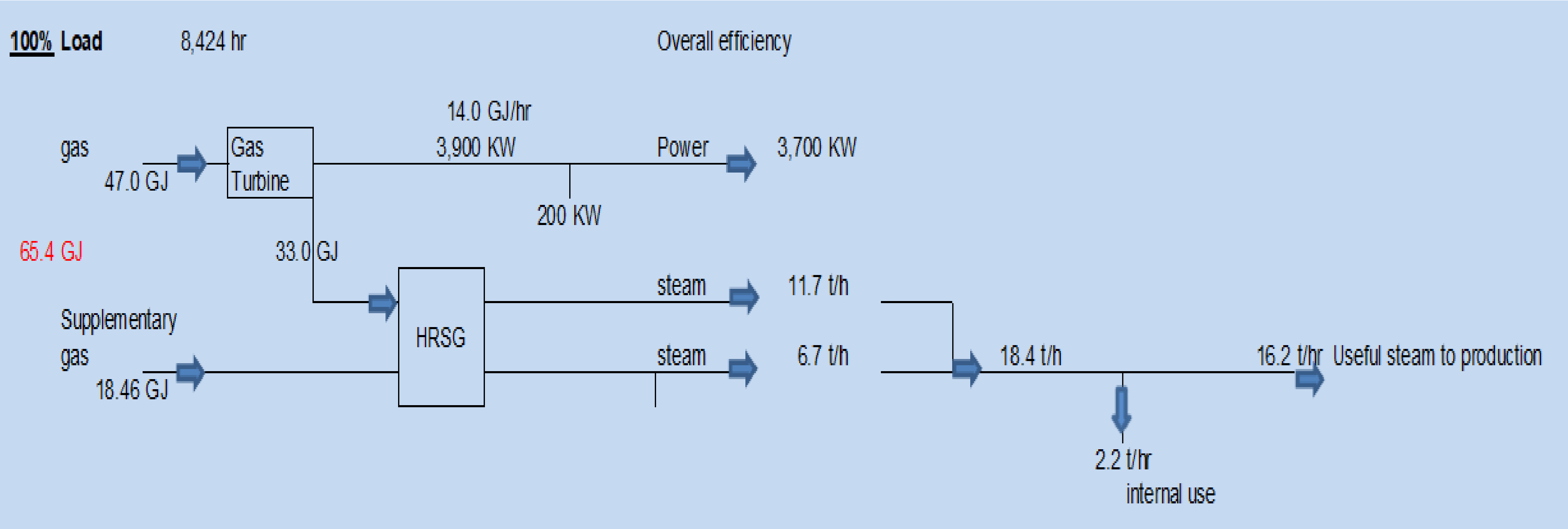
Power output and efficiency decrease quickly at partial load operation and load. Hence, understanding electricity and steam demand is important when selecting the capacity of the equipment during the design stage.

Table 3.4. System Specification of CGS Case Study No. 1

Description	Parameters
Type and rated power output of the prime mover	1 unit x 4 MWe gas turbine
Fuel	Natural gas
Capacity of heat recovery steam generator	1 unit X 30 t/h total saturated steam capacity with: • 11.7 t/h from waste heat recovery • 18.3 t/h from supplementary firing
Energy produced	Electricity and steam
Heat: Power ratio	2.02
Estimated fuel consumption/year	605,877 GJ/year
Estimated electricity demand/year	34,500 MWh/year (100%)
Estimated electricity from cogeneration/year	31,200 MWh/year (90.4%)
Estimated operating hours/year	8,424 hours

Source: Authors.

Figure 3.11. Process Flow Diagram of CGS Case Study No. 1



Source: Authors.

3) Investment and cost benefits: investment through self-financed or EPC through ESCO

The owner and loans funded the investment. Table 3.5 shows the investment and estimated savings. Investment cost includes engineering, procurement, construction, and commissioning (EPCC) costs (excluding land cost) of one unit gas turbine generator, one unit HRSG, and other supporting auxiliaries, pumps, and tanks. A simple payback period of 5.5 years can be achieved (Table 3.5).

Table 3.5. Investment and Return of CGS Case Study No. 1

Description	Cost
Cost of investment	RM30,500,000
Estimated savings	RM5.59 million/year
Simple Payback Period	5.5 years

Source: Authors in consultation with plant operator.

3.6.2. CGS case study no. 2: Third-party utility (ESCO) operator and distributor of electricity and steam

1) Description of industry motivational factors leading to CGS installation and benefits

A third party owned the gas turbine CGS that produces and sells electricity and steam mainly to a nearby large textile factory producing polyester fibre, polyester chips, and polyester film and fabric through a supply contract.

Established in 1973, the textile factory has grown from a simple factory into a sustainable and green company committed to ecological product safety and sustainable production conditions. It was awarded the Global Recycle Standard Certificate for its product.

The factory purchases electricity from two sources: 15 MWe (86%) from the ESCO cogeneration plant and 2.5 MWe (14%) from the national utility of Malaysia, making the total demand 17.5 MWe (100%) for production and utility use. The plant initially produced its own steam but now purchases the entire steam from the cogeneration plant. The existing boilers are on standby mode to support the production lines in case of any failure or abnormality with the cogeneration plant. Standby electricity is also available from the grid at standby and top-up charges.

The cycle efficiency of the cogeneration is typically between 80% to 90%, much higher than the combined cycle gas turbine cycle power plant between 50% to 60%. This is because a large portion of the waste heat is recovered in the HRSG compared to a combined cycle power plant, where some 30% of heat is lost through the heat sink in the condenser. Hence, cogeneration is much more efficient and emits fewer GHGs. Besides having steam at minimum cost, generating electricity at the source of use also eliminates other energy losses, such as transmission and distribution losses, thus lowering electricity and steam costs and making the business more attractive.

In summary, the identified objectives of the cogeneration plant are to:

- Reduce operating costs by generating power in-house and steam by HRSG, utilising the waste heat energy of GTG exhaust gas
- Improve power quality and provide reliable power generation to the existing manufacturing plant
- Meet the normal plant demand with minimum import power from the national grid under normal operating conditions
- Provide reliable steam to the existing manufacturing plants
- Be capable of operating in 'Island Mode' during national grid failure.

2) System features and operational information

Atmospheric air enters the compressor and is then compressed to a higher pressure and mass ratio as combustion air and cooling air for turbine buckets. Fuel is burned with the combustion air in the combustion chamber and enters the turbine at about 1000°C; exhaust gas is about 500°C. Table 3.6 describes the specification of the CGS, and Figure 3.12 shows the process flow diagram.

Exhaust from the gas turbine exit is then channelled to a heat recovery steam generator (HRSG) for steam production, while the available mechanical energy drives the generator to produce electricity. The recovered heat from the gas turbine exhaust can raise 28 tons/hour of steam at a superheated temperature of 292°C. A further supplementary firing at the duct burner can raise another 60 tons/hour of superheated steam. The exhaust after the economiser is about 200°C; hence, a heat recovery of 300°C is achieved in the HRSG.

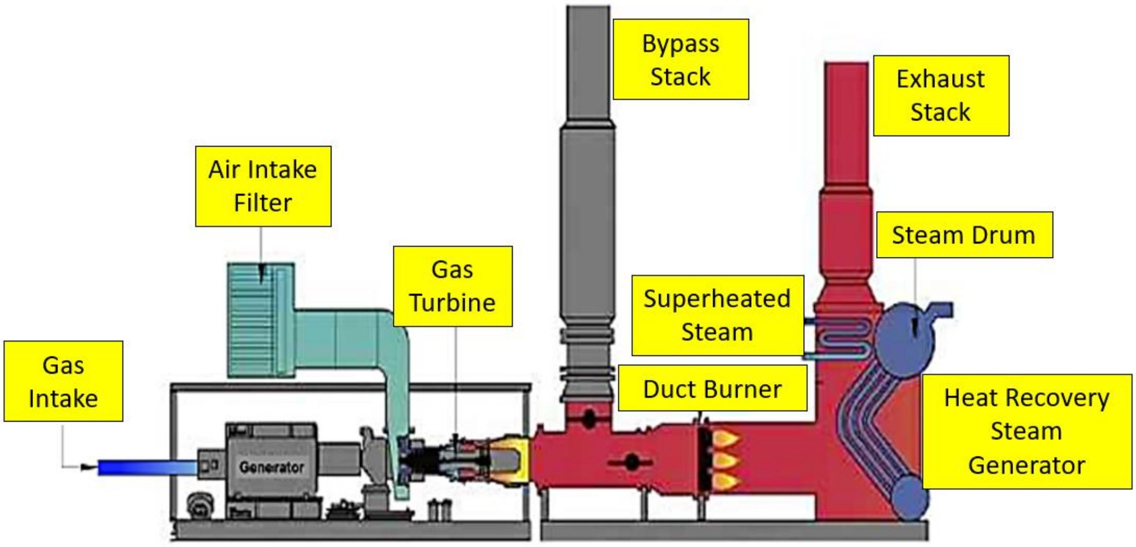
Power output at the partial load will cause the thermal efficiency to decrease quickly. Thus, the design and selection of the capacity of the GTG-HRSG are critical.

Table 3.6. System Specification of the CGS Case Study No. 2

Description	Parameters
Type and rated power output of the prime mover	1 x 16.28 MWe gas turbine
Fuel	Natural gas
Capacity of heat recovery steam generator	1 X 88 t/h total superheated steam capacity @ 292°C supplied through: ● 28 t/h from waste heat recovery and ● 60 t/h from supplementary firing
Energy produced	Electricity and steam
Heat: Power ratio	1.22
Estimated fuel consumption/year	40,508,781 S m3/year
Estimated electricity demand/year	133,900 MWh/year (100%)
Estimated cogeneration generation/year	115,288 MWh/year (86%)
Estimated operating hours/year	8,400 hours

Source: Authors in consultation with plant operator.

Figure 3.12. Process Flow Diagram of CGS Case Study No. 2



Source: Authors.

3) Investment and cost benefits; investment under EPC through ESCO

The investment was funded through an ESCO with a supply contract signed with the buyer. Table 3.7 shows the investment and estimated savings. Investment cost includes the EPCC cost (excluding land cost) of one unit gas turbine generator, one unit HP HRSG complete with duct burners, and other supporting auxiliaries, including auxiliary gas boiler, cooling towers, gas compressor unit, deaerator, screw compressor, water treatment unit, and various pumps and tanks. A simple payback period of 10 years is achievable (Table 3.7).

Table 3.7. Investment and Returns of CGS Case Study No. 2

Description	Cost
Cost of investment	RM110,000,000
Estimated savings	RM11 million/year
Simple payback period	10 years

Source: Authors in consultation with plant operator.

3.6.3. CGS case study no. 3: paper mill

1) Description of industry motivational factors leading to CGS installation and benefits

The case study focuses on a significant and leading industrial-grade paper producer in Malaysia, which started its paper mill business in the 1960s. The mill recycles wastepaper and converts it into a wide range of paper products – from test liners, corrugated medium, various categories of chipboard, wrapping paper, inserting paper, and multiple types of paper.

As a paper mill is an energy-intensive industry, the company has initiated installation of three units of 4.8 MWe CHP plant, thus, generating a total of 14.5 MWe (67%) for its power consumption while topping up with another 7 Mwe (33%) from the grid. At the same time, the waste heat generated is recovered through the HRSG to produce sufficient process steam for the paper mill's use. This has contributed substantially towards reducing carbon emissions while mitigating the escalating cost of energy expenditure.

2) System features and operational information

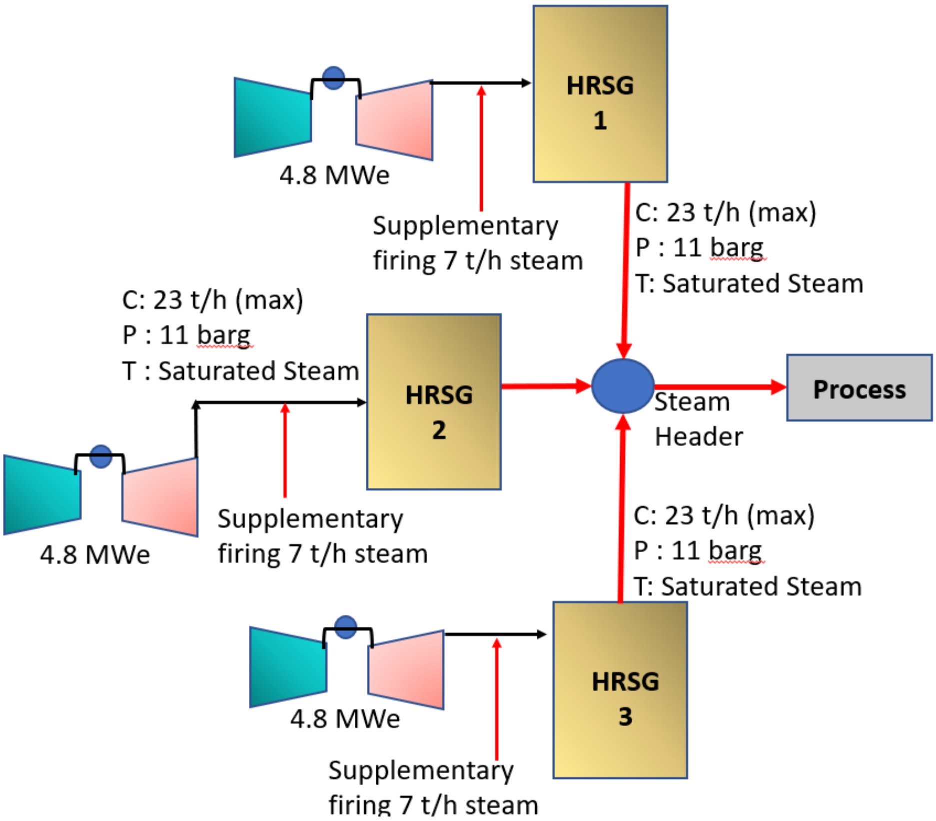
Three 4.8 MWe gas turbine generators operate in the same manner as cases 1 and 2. Exhaust gas from each gas turbine goes into their respective HRSG to produce 16 t/h of saturated steam, and an additional 7 t/h saturated steam from supplementary firing, making a total of 23 t/h saturated steam from each HRSG. The steam from each HRSG is channelled to a common steam header before distributing for process usage. The combined total steaming capacity from the three HRSGs is 69 t/h for the entire paper mill process usage. Table 3.8 describes the specification of the CGS, and Figure 3.13 shows the process flow diagram.

Table 3.8. System Specification of CGS Case Study No. 3

Description	Parameters
Type and rated power output of the prime mover	3 units x 4.8 MWe gas turbine
Fuel	Natural gas
Capacity of heat recovery Steam Generator	3 units X 23 t/h saturated steam supplied through • 16 t/h from waste heat recovery and • 7 t/h from supplementary firing
Energy produced	Electricity and steam
Heat: Power ratio	2.29
Estimated fuel consumption/year	Not available
Estimated electricity demand/year	184,900 MWh/year (100%)
Estimated electricity from cogeneration /year	124,700 MWh/year (67%)
Estimated operating hours/year	8,600 hours

Source: IEPRe (2020).

Figure 3.13. Process Flow Diagram for CGS Case Study No. 3



Source: Authors.

(3) Investment and cost benefits: investment through self-financed or EPC through ESCO

The owner and loans fund the investment. Table 3.9 shows the investment and estimated savings. Investment cost includes EPCC cost (excluding land cost) of three units of gas turbine generator, three units of HRSGs, and other supporting auxiliaries, pumps, and tanks. A simple payback period of 2.9 years can be achieved, as shown in Table 3.9.

Table 3.9. Investment and Returns of CGS Case Study No. 3

Description	Cost
Cost of investment	RM47 million
Estimated savings	RM16.83 million/year
Simple payback period	2.9 years

Source: IEPRe (2020).

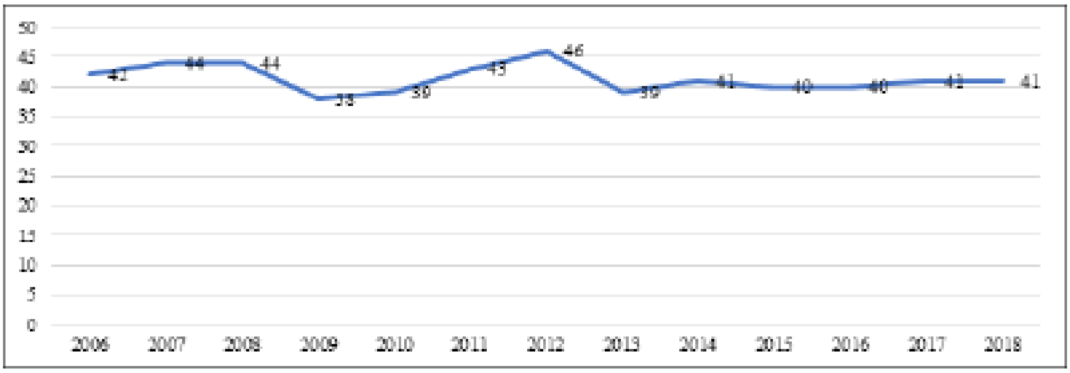
3.7. General Discussion

3.7.1 Overview of CGSs in Malaysia

The uptake of CGS installations in Malaysia has been slow despite the proven and successful cogeneration operation in the industrial sector. It is uncommon to find CGS installations in Malaysia's commercial sector, likely because of the subsidised electricity tariffs and the relatively low or lack of heat demand in the sector. Figure 3.14 shows the sluggish trend of CGS installations in Malaysia from 2006 until 2018, with almost stagnant growth. However, the Energy Commission reported that this number has increased to 62 (Table 3.2).

The increase in the number of CGS installations reported by the Energy Commission Malaysia may be due to the government's promotion following the implementation of the National Energy Efficiency Plan 2015, which includes Key Initiative 4, namely, the promotion of CGSs generating electricity and thermal energy. This action plan initiative focused on promoting cogeneration in industries and buildings by reducing barriers, including standby, top-up charges, and gas tariff pricing.

Figure 3.14. Trend of CGS Installations in Malaysia, 2006–2018



Source: IEPRe (2020).

3.7.2. Cogeneration experiences in Malaysia

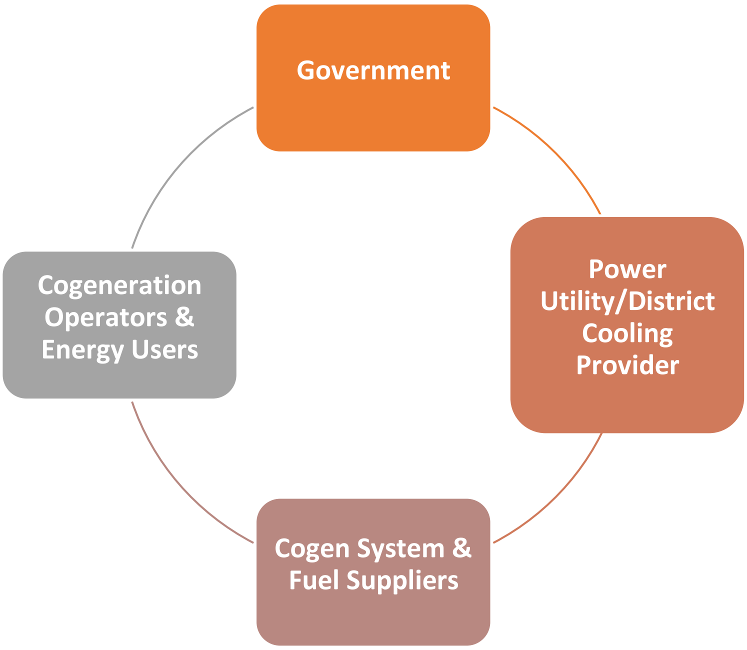
1) Malaysia's cogeneration ecosystem

In the Malaysian context, each of the four key stakeholders plays an essential role in making cogeneration viable (Figure 3.15). The government, the CGS owners cum energy users, CGS and fuel suppliers, and power utilities are the four major stakeholders in cogeneration development. Each has its goals and perspectives on the CGS with interrelated impacts to one another, as summarised below.

- The government intends to improve energy efficiency and reduce CO_2 emissions.
- Cogeneration owners' objectives are to reduce their facility operational costs and improve the reliability and continuity of energy supply.
- The power utility intends to reduce network losses, improve reliability, and improve network efficiency and performance.

- Cogeneration development will enhance the business activities of equipment manufacturers and fuel suppliers.

Figure 3.15. Key Stakeholders in Malaysia's Cogeneration



Source: IEPRe (2020).

2) Government policy and action plan

The National Energy Efficiency Plan 2015, which includes Key Initiative 4 on promoting cogeneration, seemed to have improved cogeneration development in Malaysia. The facilitation in addressing stakeholders' concerns about the barriers previously mentioned in Section 3.2 and the government's incentive scheme seemed to have yielded a positive outlook for CGS installations.

Despite the government's attractive incentives for cogeneration installations, the uptake of cogeneration in the industry remained far off the expectation. The sluggish cogeneration development may be improved by the following:

- Approval and implementation of the long-awaited Energy Efficiency and Conservation Act
- Continuous awareness campaigns on technical and financial benefits
- Reduced subsidies in electricity tariffs
- Capacity building to improve the skill levels for the operation of CGSs.

3) Lessons learned from Malaysia's cogeneration installations

The key findings on Malaysian cogeneration experiences are summarised as follows:

- There is a general lack of knowledge in the industry on detailed cogeneration and financial analysis for CGS planning and design.

- Most cogeneration installations are in medium to large industries. The risk of cogeneration failure may be too high for small-to-medium business operators. An EPC arrangement with ESCOs may address such risk.
- The decision-making process for cogeneration installation is complex. Business operators must consider technical challenges, such as reliability and quality of supply, system protection, metering, operating protocol for connection and disconnection, islanding, and reactive power management. In addition, business operators should consider system operation and performance; licensing requirements; coordination with utility, environmental, and safety characteristics; and reliability and infrastructure costs of fuel supply, such as natural gas. Other challenges include top-up and standby charges, connection/exit fees, planning/siting and/or ownership, and metering arrangement.
- There is a need to establish a business model that involves a utility provider as a strategic partner for large-scale cogeneration as a mini and distributed utility. Such a business model can address technical and financial issues and regulatory and administrative requirements for cogeneration implementation in Malaysia.
- The Malaysian CGS case studies show that most cogeneration installations' payback period is less than 10 years. Figure 3.10 shows that the payback period for CGS installations with a higher heat-to-power ratio seems to improve. This is attributed to the utility's subsidised electricity tariffs, higher power generation, and increased costs in steam generation due to rising fuel costs, especially of natural gas (Figure 3.8).

4) Favourable conditions for considering CGS installation

Generally, the ideal conditions for a CGS installation can be summarised as follows:

- Consistent consumption of a large amount of heat energy
- Wish to benefit from government incentives
- Accessibility to reliable and competitive fuel supply
- Long plant operation with consistent base loads
- Plan to expand, construct, retrofit, or upgrade central plant equipment and facilities.

5) Success factors for successful implementation and operation of CGS facilities

The success of operating a cogeneration facility depends on many factors (Energy Commission Malaysia, 2019b) such as:

a. Technology
b. Type of fuel used
c. Size of the plant
d. Optimised use of heat produced and electricity generated
e. Daily and annual load profiles
f. Annual full-load operating hours
g. Opportunity for sales of excess energy produced

h. Electricity and fuel prices

i. Electricity top-up and standby charges

j. Tax incentives

k. Energy policy and regulatory requirements

Chapter 4

Conclusion and Recommendations

4.1. Conclusions

Indonesia has a huge potential for energy conservation that can contribute significantly to meeting its nationally determined contribution target in 2030 and net-zero emission target in 2060. In the industrial sector alone, the energy saving potential is as high as 26%, or around 83 million barrels oil equivalent (BOE). In the power plant, the energy-saving potential may reach about 14 million BOE. As stipulated in Government Regulation No 79 of 2014 on the National Energy Policy, energy elasticity should be below 1 in 2025, and energy intensity should be reduced by 1% annually to 2025.

CGS is an available option to achieve energy conservation targets. CGS produces multiple forms of energy from a single form of energy simultaneously. CGS or CHP uses natural gas, oil, coal, geothermal, or other fuels to generate electricity with an engine or turbine and simultaneously recovers the waste heat generated during the process. CGS has several advantages. First, compared to the conventional electricity supply from the power grid and fuel consumption, using waste heat, CGS can save energy by around 22%. Secondly, natural gas–fueled CGS can reduce CO_2 emissions to 34% more than conventional power and fuel supply systems. Thirdly, CGS can conserve resources with less energy to produce the same value-added output.

CGS has been used in some industries in Indonesia. With all the advantages CGS can offer, its implementation needs to be enhanced. This effort can support Indonesia’s NDC and net-zero emission targets. However, some challenges face CGS implementation, among others: (i) considerable project cost; (ii) subsidised fuel, gas, and electricity prices affecting the potentially optimum energy conservation efforts; (iii) no or limited market to sell excess power; (iv) lack of awareness of the industrial sector to implement CGS; and (v) limited access to adequate financial sources.

The introduction of CGS in Japan (33 cases) and Malaysia (24 cases) is a good reference for Indonesia to increase CGS installation in its industry sector to achieve the national energy efficiency and conservation target. The CGS cases of Japan and Malaysia suggest to Indonesia the following points: (i) potential industrial subsectors to install CGS, (ii) appropriate size of gas turbine or gas engine and heat exchanger, (iii) expected payback period, (iv) energy saving and CO_2 emissions reductions potential.

4.2. Recommendations

The role of gas in Indonesia’s energy mix is still crucial, accounting for 22% in 2025 and 24% in 2050. With increased gas use, especially in power plants and the industrial sector, CGS implementation will be more significant given its advantages in increasing energy efficiency and reducing GHG emissions. The monitoring and evaluation of the target a 1% reduction in energy intensity in energy-producing and -consuming companies must be conducted in detail to gain recommendations on better policies and support that can be provided.

The availability of data for all potential users of cogeneration needs to be improved, especially for medium and small industries and other potential consumers like commercial buildings, so that they can be promoted to install cogeneration facilities.

Fiscal and nonfiscal Incentives are much needed for industries to accelerate CGS implementation as they can help reduce project costs. In addition to the incentives provided for import duty exemption for materials and machinery supporting renewable energy and energy conservation and other tax allowances, support for investment loans with low interest and longer tenors from banking or other funding sources is also needed. These incentives will compensate for GHG emission reduction contributed by CGS implementation. Nonfiscal incentives are also very much needed, including streamlined licensing and other related processes that may involve local governments. A clear and consistent policy on energy conservation will help ease the possible policy risk for investors or financial institutions.

The possibility and simplicity of selling excess power from cogeneration power plants to electricity business licensing holders or the community will also help increase the interest in deploying cogeneration in industrial or other energy-intensive activities.

Planning a human development system to include growing energy managers and ESCOs is indispensable in achieving the national energy efficiency and conservation target. The energy managers should (i) master energy engineering, both electricity and heat; (ii) have a basic understanding of economics; (iii) compare energy consumption with CGS and without CGS, etc.

References

Advanced Cogeneration and Energy Utilisation Center Japan (ACEJ). https://www.ace.or.jp/ (accessed 24 April 2022).

2015 : https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf

2016 : https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130

2017 : https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf

2018 : https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf

2019 : https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf

2020 : https://www.ace.or.jp/web/gp/pdf/2020/CGS-Award2020_Detail.pdf?v=2

2021 : https://www.ace.or.jp/web/gp/pdf/2021/CGS-Award2021_Detail.pdf?v=220128

2021: Licensed Co-generators in 2021 (Peninsular Malaysia) https://meih.st.gov.my/STOASPublicPortlet/energystatistic/downloadElcFile.oas?id=54&37E

Energy Commission Malaysia (2018a), Performance & Statistical Information on the Malaysian Electricity Supply Industry, https://meih.st.gov.my/.

Energy Commission Malaysia (2018b), Performance and Statistical Information on the Malaysian Electricity Supply Industry. Putrajaya.

Energy Commission Malaysia (2019a), Guidelines for New Enhanced Dispatch Arrangement (GP/ST/No.12/2017 [Pindaan No. 2/2019]).

Energy Commission Malaysia (2019b), Co-generation: An Energy Efficient Technology. Putrajaya.

Energy Commission Malaysia (2019c), National Energy Balance 2019. Putrajaya.

Energy Commission Malaysia (2020), Malaysia Energy Statistics Handbook 2020. Putrajaya.

Energy Commission Malaysia (2021a), Report on Peninsular Malaysia Generation Development Plan 2020 (2021 – 2039) by Planning, Implementation and Electricity Supply and Tariff Committee (Jawatankuasa Perancangan dan Pelaksanaan Pembekalan Elektrik dan Tarif [JPPPET]).

Energy Commission Malaysia (2021b), Licensed Co-generators in 2021 (Peninsular Malaysia), https://meih.st.gov.my>downloadElcFile

Japan Gas Association (JGA), https://www.gas.or.jp/gas-life/cogeneration/shikumi/;

https://www.gas.or.jp/user/comfortable-life/enefarm-partners/enefarm/

Kawan Engineering Sdn Bhd (consultations in 2022), engineered solutions provider, http://kawanengineering.com.my

The Institute of Energy Policy & Research (IEPRe) (2020), Universiti Tenaga Nasional (UNITEN), Compendium of Energy Economic Research, Energy Research Symposium 2020, jointly organised by IEPRe, Tenaga Nasional, and Energy Commission Malaysia Selangor, Malaysia.

REEEP Group (2020), Long-Term Energy Solution in Malaysia – Review on COGEN/ CHP, https://www.reeepgroup.com.

Appendix 1

Japan’s Cogeneration Systems: Case Studies

This appendix contains detailed information on 35 selected cogeneration system (CGS) case studies.

Case studies no. 1-33 are CGSs using engines and turbines, no. 34 is a small fuel cell (ENE-FARM), and 35 is a large fuel cell.

Table A1. 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		▨	

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

Table A1. *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.

A1.1. State-of-the-art Energy-saving System Using CGS fueled by Volatile Organic Compound (VOC) and City Gas

1. Industrial Subsectors Case No. 15-1

Printing industry

2. System Summary

This system fully uses the energy generated by the cogeneration facility to produce electricity, steam, and cold heat in the factory. Furthermore, using VOC generated in the production process as an alternative fuel for city gas in gas turbines and boilers can reduce primary energy and reduce environmental load. In addition, as a BCP measure, in the event of a power outage, the gas engine is operated independently to continue production at the factory. By combining high-efficiency equipment, waste heat is used more effectively, contributing to energy saving.

3. Configuration and the Performance

Item	Contents
Types of power engine	Gas turbine (GT） Gas engine (GE）
Rated power output & number of units	(GT) 2,400 kW × 1 unit (GE) 8,730 kW × 2 units
Waste heat utilisation	Steam, cold water generation for production process
Fuel	City gas
Power peak cut rate	80.9%
Primary energy reduction rate	25.5%
Expected CO_2 savings amount	2,998 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 49.0%, 23.9%, 27.1% (GT) 23.7%, 58.1%, 18.2%

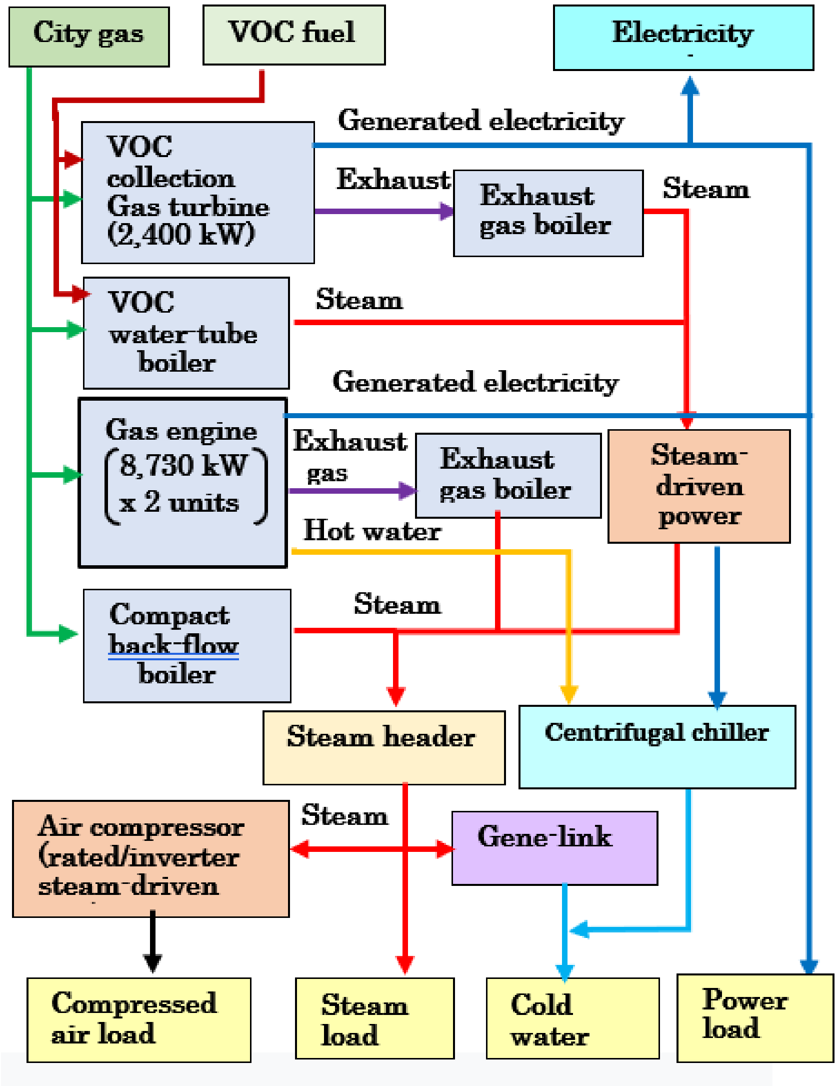
Source: Advanced Cogeneration and Energy Utilisation Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

4. System Features

- Effective use of unused energy (VOC) by combining a gas turbine and a gas engine
- Effective use of waste energy with high-efficiency equipment. Waste hot water and surplus steam are used as cold water by Genelink. The energy of steam decompression is effectively used for electric power and compressed air.
- Maintaining optimal operation and reducing operator load by patterning equipment operation through operation simulation
- Disaster prevention and power supply security: The system's ‘lightning mode’ allows it to be disconnected from the power grid when lightning occurs and reconnected to the grid when the lightning mode ends. The blackout start (BOS) specification enables autonomous operation even during an unforeseen situation during a disaster. BCP measures are being

strengthened for equipment. (Install equipment at a height that avoids flood damage, use medium-pressure gas, etc.).

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration investment costs:

Approximately ¥2,383 million

- Estimated energy-saving amount

Electricity equivalent 6,798 KW/h

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

A1.2. Environment-friendly Energy-saving and BCP System with Natural Gas Cogeneration and Woody Biomass Cogeneration

1. Industrial Subsectors Case No. 15-2

Salt industry

2. System Summary

This system is a fusion plant of woody biomass power generation equipment (BTG) and natural gas cogeneration equipment (gas turbine). All the power generated by the gas turbine is consumed on the premises, and the steam is supplied to the adjacent factory in addition to the salt-making process and the intake cooling of the gas turbine. The system uses all the bleed steam from the bleed condensate turbine in salt production. It supplies power to important loads with a gas turbine in an emergency. In addition, when the woody biomass boiler is stopped (failed), the steam used in salt production is supplied by reheating the gas turbine, and the system is designed to continue production (BCP).

3. Configuration and the Performance

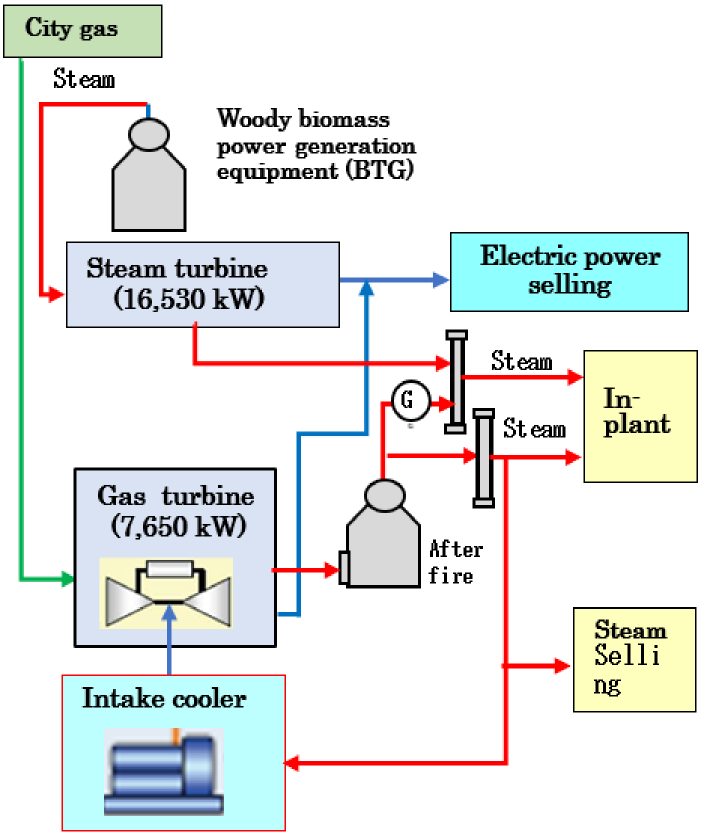
Item	Contents
Types of power engine	Gas turbine (GT） Steam turbine (ST）
Rated power output & number of units	(GT): 7,650 kW ×1 unit (ST): 16,530 kW × 1 unit
Waste heat utilisation	Steam for the production process
Fuel	City gas Woody biomass
Power peak cut rate	69.0%
Primary energy reduction rate	63.4% (Woody biomass is not counted as the primary energy)
Expected CO_2 savings amount	5,844 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 33.1%, 52.1%, 14.8% (ST) 33.5%, 51.9%, 14.6%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

4. System Features

- A system with energy savings and environmental resistance was constructed using woody biomass cogeneration and gas cogeneration.
- The cogeneration steam was used for the salt-making process and intake cooling of the gas turbine. Surplus steam was supplied to the adjacent factory to achieve high efficiency.
- All the electricity generated from the woody biomass power generation facility is sold, and the generated heat is used in the factory.

- As a BCP measure, measures were taken against instantaneous voltage drop using a high-speed circuit breaker, and the two pure water supply pumps were designed so that one of the two pumps will always operate by receiving power from the 77 kV and 33 kV commercial systems.
- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration investment costs:

Approximately ¥2,902 million

- Estimated energy-saving amount

Electricity equivalent 13,252 KW/h

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

A1.3. Improving Productivity and Business Continuity Centred on the Power Sales Business by Introducing Cogeneration

1. Industrial subsectors Case No. 15-3

Chemical industry

2. System Summary

Combining the newly introduced gas turbine and the existing steam turbine secures a power source that exceeds the demand for electricity on the premises and sells surplus electricity. As a countermeasure against a momentary power outage due to a lightning strike, it became a stable power source by disconnecting it from the commercial power system. By balancing the steam generated from the existing boiler and the steam generated from the exhaust gas boiler of the gas turbine, it became a system that can suppress the loss of released steam and save energy.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT） Steam turbine (ST）
Rated power output & number of units	(GT) 7,630 kW × 1 unit (ST) 3,000 kW × 1 unit (existing)
Waste heat utilisation	Manufacturing process steam
Fuel	City gas 13A Recycled oil Recycled gas
Power peak cut rate	99.9%
Primary energy reduction rate	44.5% Recycled oil and gas are not counted as primary energy）
Expected CO_2 savings amount	3,759 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 33.1%, 52.1%, 14.8% (ST) 23.7%, 58.1%, 18.2%

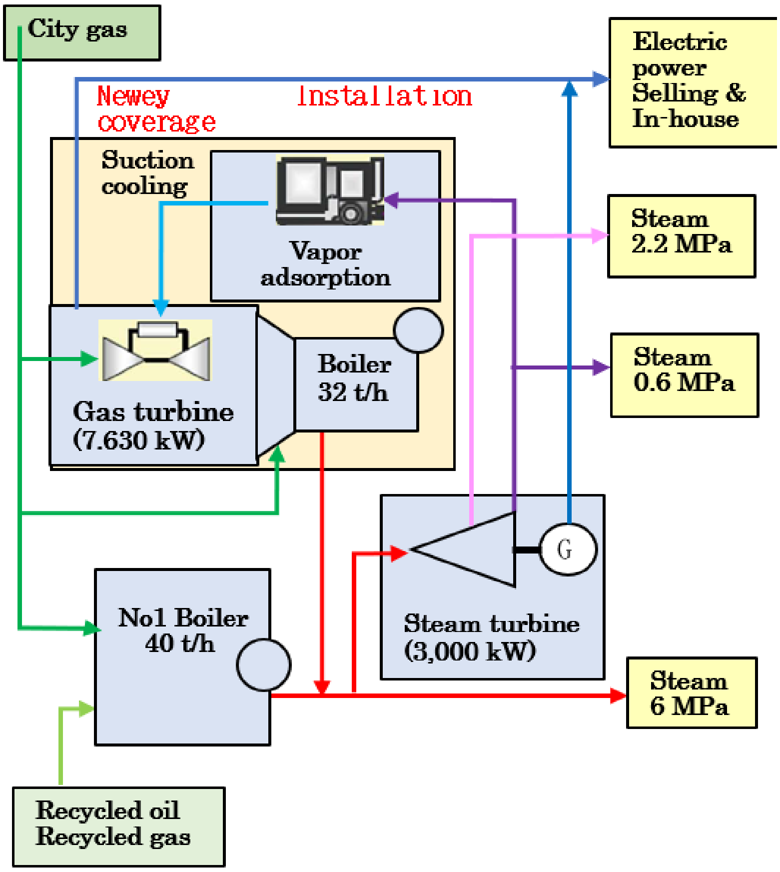
Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

4. System Features

- Improvement of disaster prevention and power supply security performance
- During a lightning alert, operational measures are taken to disconnect the system power supply from the commercial system as a countermeasure against an instantaneous voltage drop. In the load sharing between the gas and steam turbines, the gas turbine with a stable

fuel supply supplies power to the important load, and the steam turbine supplies power to the general load. Power can be supplied to all loads in the factory, even in an emergency.

- Improvement of waste heat utilisation rate of cogeneration by using steam absorption chiller for intake cooling of gas turbine and combined
- By-product oil (main component: toluene) and by-product gas (main component: hydrogen) are used.
- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

5. Investment (Estimated value)

- Cost

  Cogeneration investment costs:

  Approximately ¥916 million

- Estimated energy-saving amount

  Electricity equivalent 8,523 KW/h

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

A1.4. ESCO Business utilising CGS Low-temperature Waste Heat in the Production Process to Improve Overall Efficiency

1. Industrial Subsectors Case No. 15-5

Chemical industry (synthetic resin, high-performance fibre, starch saccharide)

2. System Summary

The annual demand for electricity and steam was analysed when introducing the cogeneration system. It was found that 40% of in-house power generation could be operated most efficiently. In addition, multiple 30 kW x 2 systems were selected for risk diversification.

The exhaust heat of the gas engine was taken out as steam and hot water. The steam was used as a substitute for the existing boiler, and the hot water was directly supplied to the production line and used for preheating. As a result, the high annual total efficiency was achieved by constructing an energy system that could effectively utilise waste heat throughout the year.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	(GE) 930 kW × 2 units
Waste heat utilisation	Production process
Fuel	City gas
Power peak cut rate	36.5%
Primary energy reduction rate	26.1%
Expected CO_2 savings amount	290 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 40.0%，33.2%，26.8%

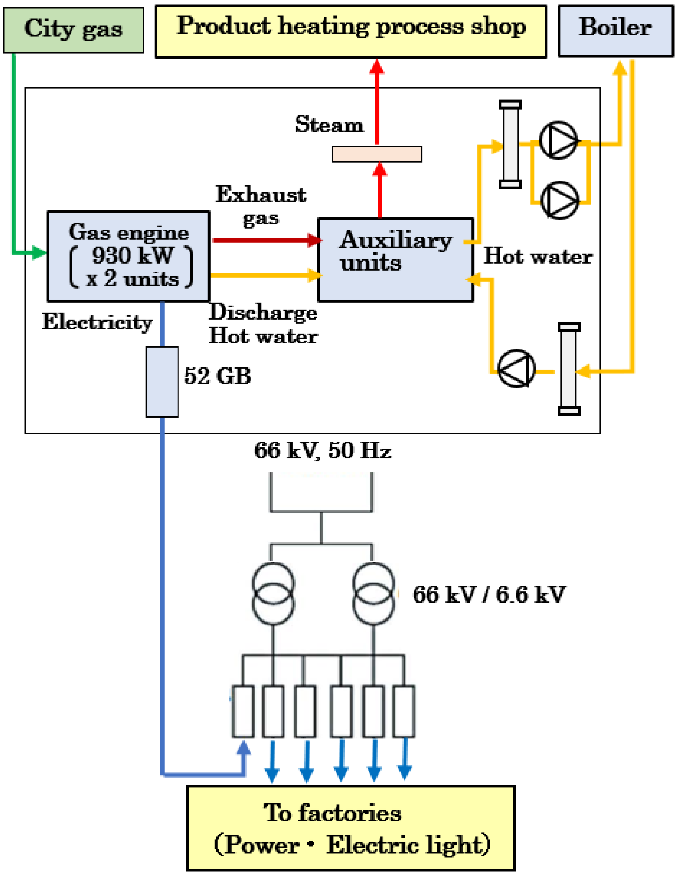
Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

4. System Features

- The shared ESCO was used to reduce the hurdles for introducing CGS equipment.
- Overall energy efficiency for the year was improved by preheating products and realising high-temperature water transportation (supplying hot water at 88°C to a factory 100 metres away and returning to 60°C).
- Fine adjustment of product heating is performed with cogeneration steam.
- The business operator and the designer check the energy-saving effect every month and strive to maintain a high-efficiency operation (results such as improvement when power generation efficiency decreases).
- The electric power generated from cogeneration is supplied to the factory in the premises and the head office and research building, etc. The waste heat (steam and hot water)

generated simultaneously is mainly used at the saccharification first factory.

- Considering resistance to earthquakes, a CGS was designed to be installed on a solid foundation surface after removing the large furnace tube smoke tube boiler.
- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/H27_Co-gene_Award_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration investment costs:

Approximately ¥242 million

- Estimated energy-saving amount

Electricity equivalent 657 KW/h

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

A1.5. Introduction of Trigeneration[2] to Plant Factories

1. Industrial field Case No. 16-1

Plant factory

2. System overview

This smart agri-plant combines a Dutch-style advanced cultivation control system with various energy utilisation technologies to cultivate high-yield, high-quality agricultural products. The plant creates the optimal greenhouse environment for plant growth according to local weather conditions. It utilises the best energy source for the region to grow various crops throughout the year efficiently. The smart agri-plant is equipped with a gas engine regenerative system, which provides electricity to the plant, recovers hot water to heat the greenhouse, and uses the CO_2 contained in the exhaust gas for plant cultivation.

3. System Configuration and Performance

Item	Contents
Types of prime movers	Gas engines (GE)
Rated power output &number of units	(GE) 230 kW x 1 unit
Use of waste heat Hot water	Greenhouse heating, snowmelt
Fuel	Natural gas
Power peak cut rate	58.60%
Primary energy reduction rate	19.60%
Expected CO_2 savings amount	25 kg-CO_2
Electricity, heat, loss ratio	(GE) 40.5%, 30.7%, 28.8%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

4. System Features

Vegetables hydroponically cultivated in a plant factory must be stably produced throughout the four seasons. For that purpose, controlling the light, CO_2, temperature, and nutrients required for plants is very important.

For that purpose, controlling the light, CO_2, temperature, and nutrients required for plants is very important.

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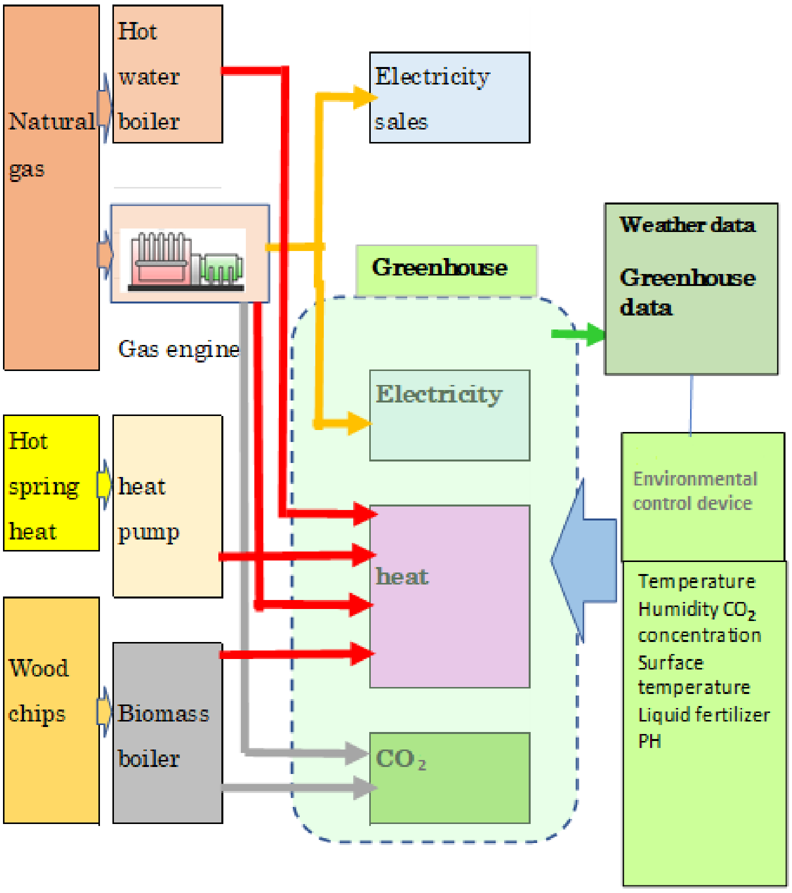
[2] Trigeneration is a coined word meaning triple generation. It is an energy supply system that effectively utilises CO_2 in addition to electricity and heat.

- A trigeneration system was introduced to operate the plant factory efficiently. A natural gas field is adjacent to the area, and natural gas can be used.
- Adopting stoichiometric combustion + three-way catalytic gas engine, CO_2 is supplied to the greenhouse without additional exhaust gas treatment equipment and effectively used for the photosynthesis of agricultural products.
- Introduce a heat pump using natural gas for cogeneration fuel, wood chips for biomass boiler fuel, and hot spring heat. (Selling surplus electricity in summer.)
- CGS has BOS specifications. During a power outage, the gas engine can supply power to the power load required for cultivation and maintain the cultivation environment.
- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

5. Investment (Estimated Value)

- Cost
  Cogeneration (equipment costs): Approximately ¥46 million
- Estimated energy-saving amount
  Electricity equivalent 56 KW/h
  Note: The method for estimating energy savings is shown in section 2.2.

A1.6. Efficiency of Energy Supply through the Introduction of LNG Satellites and CGS

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 or heat sources is used. Therefore, energy was supplied by a CGS that effectively utilised LNG satellite equipment that could save a lot of 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 using CGS as a power source in the event of a long-term power outage, such as a disaster, continuous production and shipment of pharmaceutical products have been realised.

3. Configuration and Performance

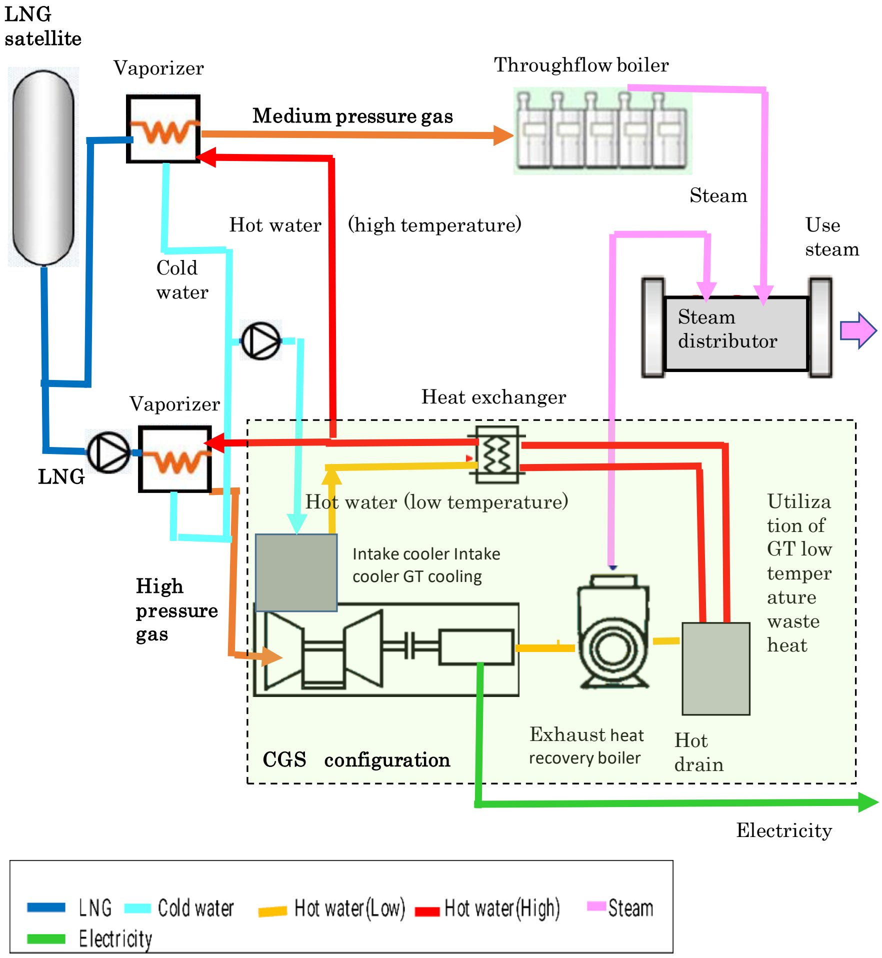
Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	1,615 kW x 2 units
Waste heat utilisation	Manufacturing process, LNG vaporisation
Fuel	LNG
Power peak cut rate	36.2％
Primary energy reduction rate	21.7%
Expected CO_2 savings amount	395 kg-CO_2/h
Electricity, heat,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

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

4. System features

- The fuel for cogeneration was natural gas, which has a small environmental load, and the fuel for steam boilers was changed from heavy oil to natural gas. In addition, since there is 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 in 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. The cogeneration's thermal efficiency 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



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration (equipment costs): Approximately ¥420 million

- Estimated energy-saving amount

Electricity equivalent 895 KW/h

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

A1.7. Realisation of Waste Heat Utilisation of Large Cogeneration through Inter-company Collaboration

1. Industrial Subsectors Case No. 16-3

Automobile manufacturing industry

2. System Summary

This factory manufactures automobiles but was considering renewing the existing CGS. However, the Great East Japan Earthquake and the tightening of electricity supply and demand reaffirmed the importance of private power generation. Since there is a lot of electricity demand and little heat demand in this factory, if a large CGS is introduced, the waste heat cannot be used up, and the CGS cannot be operated with high efficiency. On the other hand, since a large amount of steam is used in the refining process of edible oils and fats in the neighbouring food manufacturing factory, there is room to utilise the exhaust heat that cannot be consumed in the automobile manufacturing process. However, it seemed the city had permission to lay a heat pipe on the city road and supply steam. Therefore, the energy service provider, the two factories, and the city of Yokohama collaborated to realise a cross-sectional heat supply system that crosses a city road. The energy service provider is optimising the operation by renewing one large CGS and continuing to use one existing CGS.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 8,730 kW × 1 unit (GE) 8,730 kW × 1 unit (existing)
Waste heat utilisation	Process steam
Fuel	City gas
Power peak cut rate	44.6％
Primary energy reduction rate	17.7%
Expected CO_2 savings amount	1,489 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 49.0%, 23.7%, 27.3%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

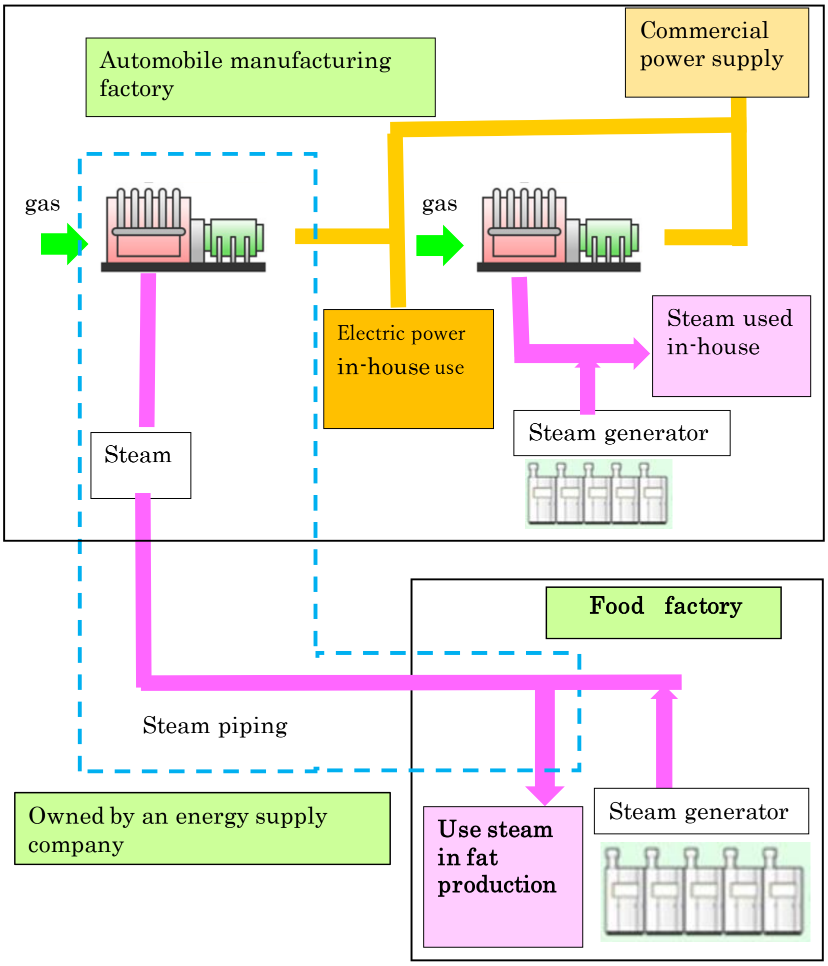
4. System Features

- Heat (steam) interchange between companies with different operating patterns

Reduce initial investment hurdles by owning assets such as operation management and heat pipes by energy service providers. The new CGS operates continuously for 24 hours. The existing CGS operates 24 hours a day on weekdays and is closed on holidays.

- Efforts to improve disaster prevention and power supply security

The new CGS, fueled by medium-pressure gas piping, is of BOS specification (auxiliary power is supplied from the diesel engine). During a commercial power outage, it can switch to a heavy-load uninterruptible power supply.



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration (equipment costs): Approximately ¥1,048 million

- Estimated energy-saving amount

Electricity equivalent 3,375 KW/h

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

A1.8. Power Generation Using Gas Engine CGS at a Gas Relay Station and Unused Energy at the Time of City Gas Depressurisation

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.

City gas companies generally supply gas at high pressure 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 that the pressure regulator may freeze and malfunction. An electric heater or the like may prevent freezing. The energy used for this boost is wasted. (About 200 city gas companies in Japan constantly produce this waste.)

To eliminate this waste, utilise first the waste heat (hot water) from the gas engine for the preheat required for depressurising the gas in the city gas supply. Then 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

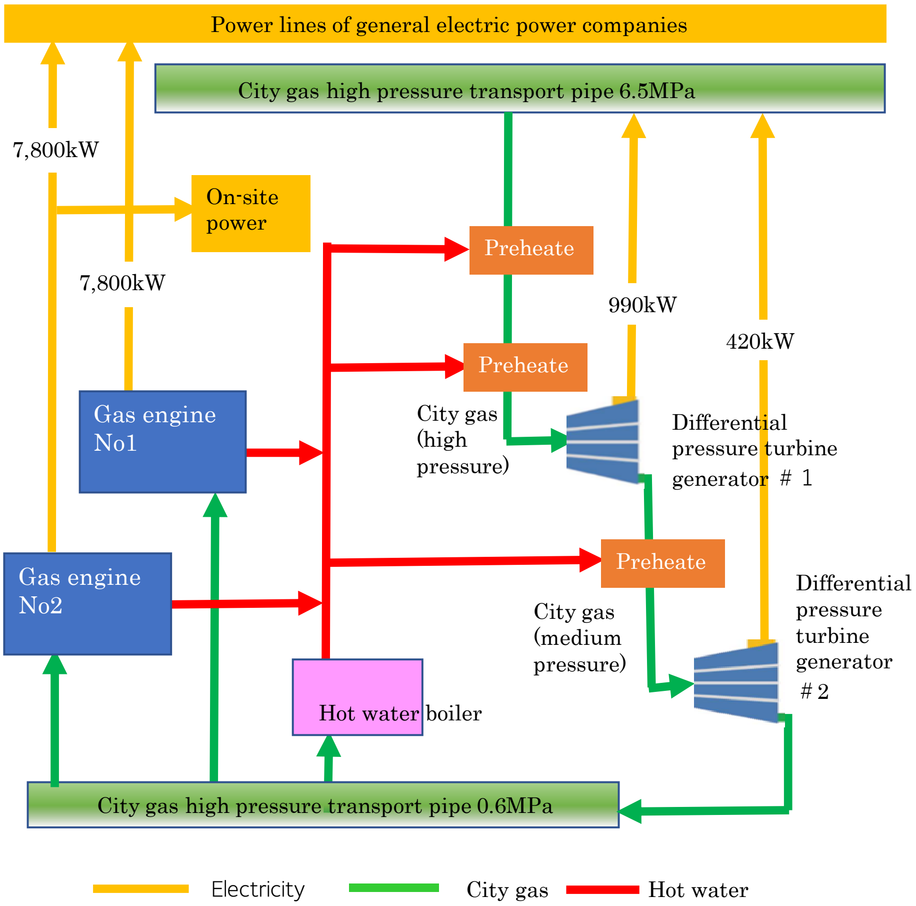
Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 7,800 KW × 2 units (15,600 kW)
Waste heat utilisation	City gas preheat
Fuel	City gas
Power peak cut rate	—
Primary energy reduction rate	18.7%
Expected CO_2 savings amount	1,582 kg-CO_2
Electricity, heat, loss ratio	(GE) 49.0%, 23.7%, 27.3%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

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 shape of demand. 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.
- Introduction of a differential pressure generator that utilises the energy of high-pressure gas during decompression (increased power generation output).

- Even during a disaster, gas can be supplied to cogeneration by reducing to medium pressure on the premises from a high-pressure transport conduit with extremely high supply stability.
- Energy utilisation flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration (equipment costs): 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.

A1.9. Reduction of Primary Energy by Updating CGS and Advanced Utilisation of Waste Heat

1. Industrial Field Case No. 16-5

Paper industry

2. System Overview

This factory produces paperboard, such as corrugated board, but it consumes much electricity and heat during production. Therefore, the ageing boiler and turbine power generation facility (BTG: 9,400 kW) and existing gas turbines are being upgraded with high-efficiency gas turbines with BTGs to increase capacity, thereby contributing to expanding power peak shaving (80% of the plant's electricity is generated in-house).

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT), Gas engine (GE)
Rated power output & Number of units	(GT) 7710 kW x 2 units (GE) 5500 kW x 1 unit
Waste heat utilisation	GT exhaust: steam (papermaking process) GE hot water: GT cold water for intake cooling
Fuel	City gas
Power peak cut rate	—
Primary energy reduction rate	18.7%
Expected CO_2 savings amount	4,106 kg-CO_2
Electricity, heat, loss ratio	(GT) 33.1%, 52.1%, 14.8% (GE) 45.8%, 33.2%, 21.0%

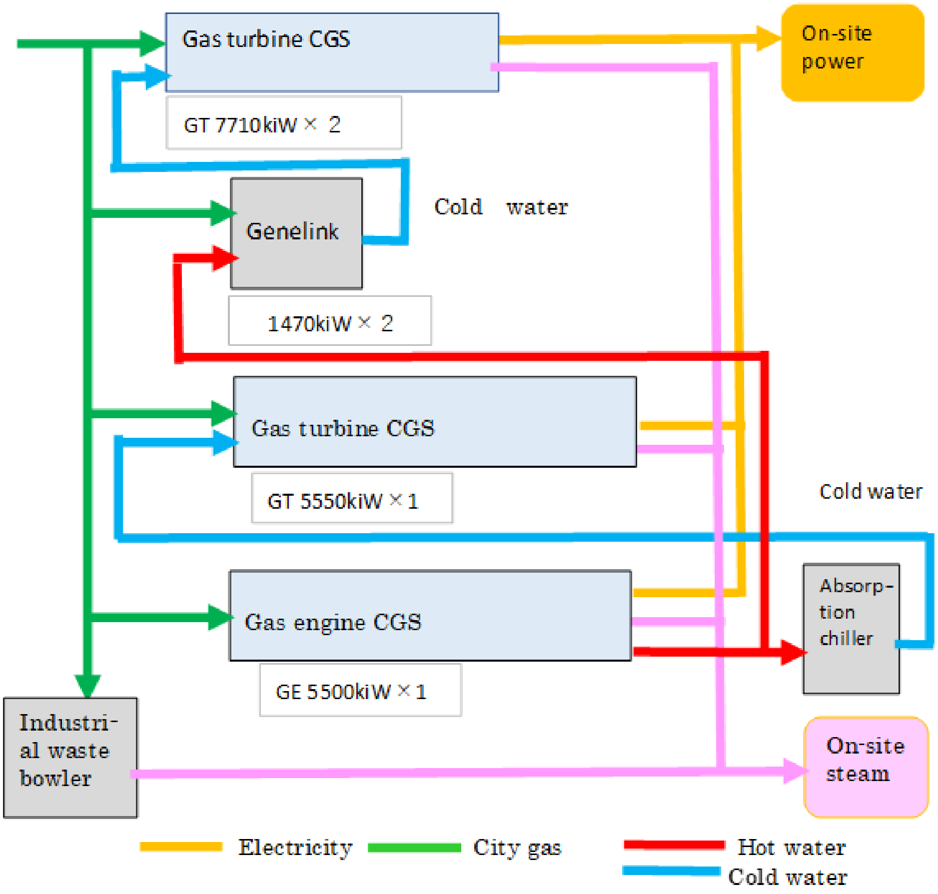
Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130,modified by the authors.

In addition, installing a reheating burner on the exhaust heat boiler of the renewed gas turbine made it possible to operate flexibly according to the fluctuation of the steam load on the production line, thus, saving energy. As a result, renewing the gas turbine reduced CO_2 by about 3,800 t-CO_2/year.

4. System Features

- The hot water of the gas engine is converted to cold water by Genelink and used for intake cooling of the gas turbine to generate stable power even during the daytime in summer.
- The exhaust heat boiler of the gas turbine is equipped with a reheating burner, which follows the fluctuation of steam load, reduces atmospheric steaming, and contributes to the reduction of primary energy (the amount of atmospheric steaming is one-third compared to before remodelling).

- System flow



Note: Genelink: Exhaust heat from CGS is fed into the chiller to produce chilled water.
Source: Advanced Cogeneration and Energy Utilization Center Japan (2021),
https://www.ace.or.jp/web/gp/pdf/h28/H28_Co-gene_Award_Detail.pdf?ver=170130,
modified by the authors.

5. Investment

- Cost

CGS (equipment cost): Approximately ¥2,510 million

- Estimated energy-saving amount

Electricity equivalent 9,311 kW/h

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

A1.10. Realisation of Thermal and Electrical Energy Rebalancing by CGS to Use Self-consignation among Multiple Factories

1. Industrial Subsectors Case No. 17-1

Beverage-making industry

2. System Summary

Due to fluctuations in product items and production volumes produced at each factory, the amount of electricity and steam used also changed. Reviewing the energy balance was one of the management issues. Therefore, a new large-scale cogeneration facility was installed in factory no. 1. Its surplus power was consigned to other factories by utilising the electric power self-consignment system to optimise the overall energy balance among factories.

3. Configuration and Performance

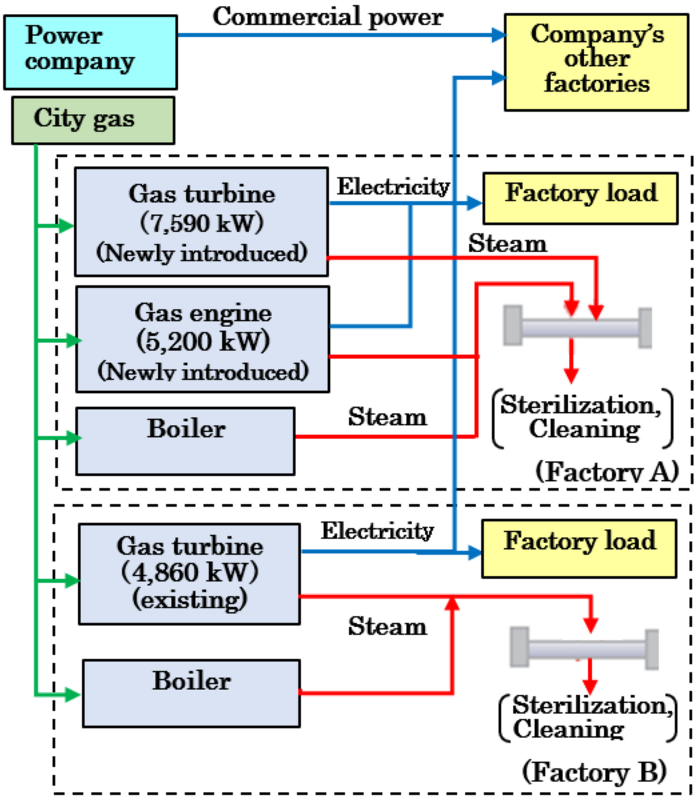
Item	Contents
Types of power engine	Gas turbine (GT） Gas engine (GE）
Rated power output & number of units	・Existing (GT) 4,860 kW × 1 unit ・Newly introduced (GT) 7,590 kW × 1 unit (GE) 5,200 kW × 1 unit
Waste heat utilisation	Sterilisation, washup
Fuel	City gas
Power peak cut rate	100%
Primary energy reduction rate	19.0%
Expected CO_2 savings amount	1,826 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 31.9%, 52.7%, 15.4% (GE) 45.8%, 33.2%, 21.0%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

4. System Features

- Optimising the energy balance of the four factories by accommodating electricity and heat among multiple factories. A steam pipe network and a self-employed power line network have been developed between the adjacent nos. 1, 2, and 3 factories (supply side) to exchange heat and electricity. Excess power is reverse-transferred to the grid and self-transmitted to distant factories (demand side).
- The EMS automates complicated self-consignation operations.
- Automatically collects heat and electricity performance data on supply and demand sides and incorporates them into production planning. Automatically controls the cogeneration output so that each frame’s plan and actual result match.

- Improvement of BCP measures in the production process line
- The scope of BCP measures has been greatly increased by expanding the cogeneration and networking of three nearby factories. When a system abnormality is detected, the line is disconnected by a high-speed circuit breaker, and the cogeneration equipment automatically switches to independent operation.
- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration investment (New introduction): Approximately ¥1,535 million

- Estimated energy-saving amount

Electricity equivalent 4,140 KW/h

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

A1.11. A Factory’s Non-stop Production through BCP and Energy-saving Measures

1. Industrial Subsectors Case No. 17-4

Plastic film manufacturing industry

2. System Summary

This plant had adverse conditions for gas engine generators, such as a large total power load and instantaneous power load fluctuations. Therefore, detailed data on load fluctuations and harmonics were measured. Load application tests were conducted repeatedly under simulated loads based on the data. Furthermore, by using the exhaust hot water from the gas engine for the chiller and LNG vaporisation, the overall efficiency is much higher than that of a conventional gas engine. Even in the unlikely event that the LNG supply is interrupted, compressed natural gas is used to supply fuel to ensure a minimum energy supply, thus providing a complete BCP.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	1,000 kW × 6 units
Waste heat utilisation	Steam, cold water LNG evaporation
Fuel	LNG
Power peak cut rate	82.4%
Primary energy reduction rate	15.6%
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 (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

4. System Features

- Efforts to improve disaster prevention and power supply security

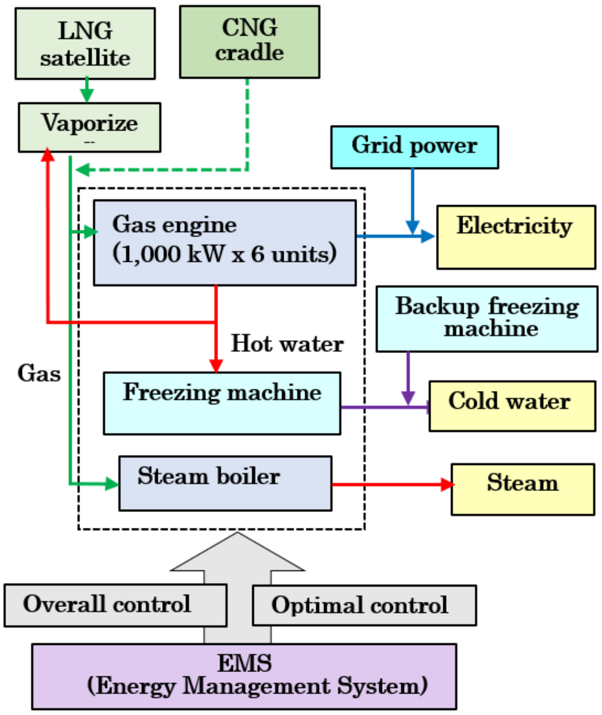
Continuation of production by dual operation of ‘manual’ and ‘automatic. Compressed natural gas allows gas engine cogeneration to operate with a BOS function even if the factory is completely out of power due to a disaster or accident.

Installing multiple units allows maintenance to stop CGS to be performed alternately, so high-quality power can be supplied at all times without stopping the gas engine CGS. By constructing a selective load cut-off, it is possible to avoid the shutdown of all equipment and realise continuous power supply to production equipment of high importance. Increasing the private power generation rate makes it possible to respond to power-saving requests from public institutions.

- Utilisation of EMS

Visualising the heat quantity of the cold water and the amount of air used, which cannot be grasped until now, and the amount of electric power and steam make it possible to respond to public power-saving requests.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

5. Investment (estimated value)

- Cost

Cogeneration investment costs: Approximately ¥900 million

- Estimated energy-saving amount

Electricity equivalent 1,109 KW/h

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

A1.12. Electric Power and Cold and Heated Water Fusion System by Integrating High-efficiency CGS and Genelink with Existing Facilities

1. Industrial Subsectors Case No. 17-5

Press machine production

2. System Summary

The power generated by the high-efficiency cogeneration installed this time was linked to the power grid and used in multiple buildings (offices, factories, etc.). Cold and hot water would be used for air conditioning in two buildings and three zones on the factory premises. Furthermore, by enabling the integrated operation of area-distributed energy equipment, it has become possible to operate the energy equipment dispersed over wide areas in an integrated manner, and comprehensive energy saving and peak cuts have been achieved.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	(GE) 390 kW × 2 units (GE) 300 kW × 3 units (existing)
Waste heat utilisation	Cooling, air warming
Fuel	City gas
Power peak cut rate	61.2%
Primary energy reduction rate	9.1%
Expected CO_2 savings amount	74 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 40.8%, 33.1%, 26.1%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

4. System features

- Introduction to industries with low cogeneration penetration

  The machinery manufacturing industry, including press machine manufacturers, has a large electricity demand. But there is little demand for heat that can use low-temperature waste heat of less than 200°C. This project is a leading example of using low-temperature waste heat and raising competitiveness.

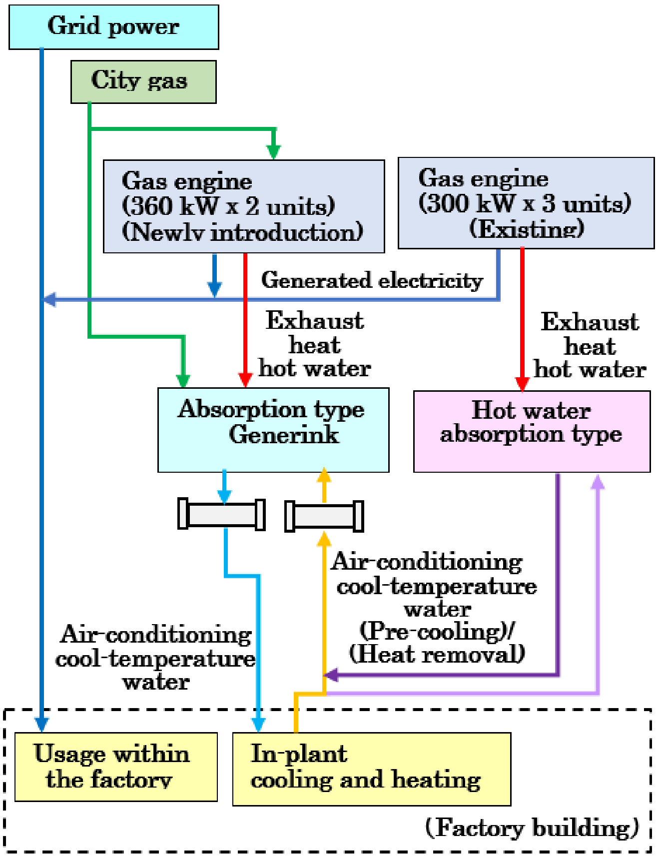
- Areal utilisation of electricity generated and chilled/heated water for air conditioning

  By combining the air-conditioning piping for the three zones into the hot/cold water supply piping system, the previously independent air-conditioning loads are now integrated. As a result, the air-conditioning load has been leveled, enabling optimal operation of the air-conditioning heat source equipment.

- Introduction of EMS

  During peak cooling and heating periods, the existing CGS is operated in addition to the new high-efficiency CGS. The hot water from the CGS can be used as a heat source for the hot and cold water generation equipment to the maximum extent.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

  Cogeneration investment (newly installed equipment): Approximately ¥117 million

- Estimated energy-saving amount

  Electricity equivalent 168 KW/h

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

A1.13. Systematising Cogeneration Increased Efficiency and Reduced Greenhouse Gas Emissions

1. Industrial Subsectors Case No. 17-6

Automobile parts production

2. System Summary

The introduction of cogeneration has improved overall efficiency and contributed to peak shaving by supplying power externally.

In addition, this company has contributed to the electric power business by introducing advanced equipment using waste heat and combining it with renewable energy. Consistently, gas engine systems have been built to reduce CO_2 emissions by improving power generation efficiency and waste heat utilization efficiency.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	(GE) 5,750 kW × 1 unit
Waste heat utilisation	Hot water, steam, power generation
Fuel	City gas
Power peak cut rate	71.4%
Primary energy reduction rate	10.5%
Expected CO_2 savings amount	297 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 45.8%， 33.2%, 21.0%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

4. System Features

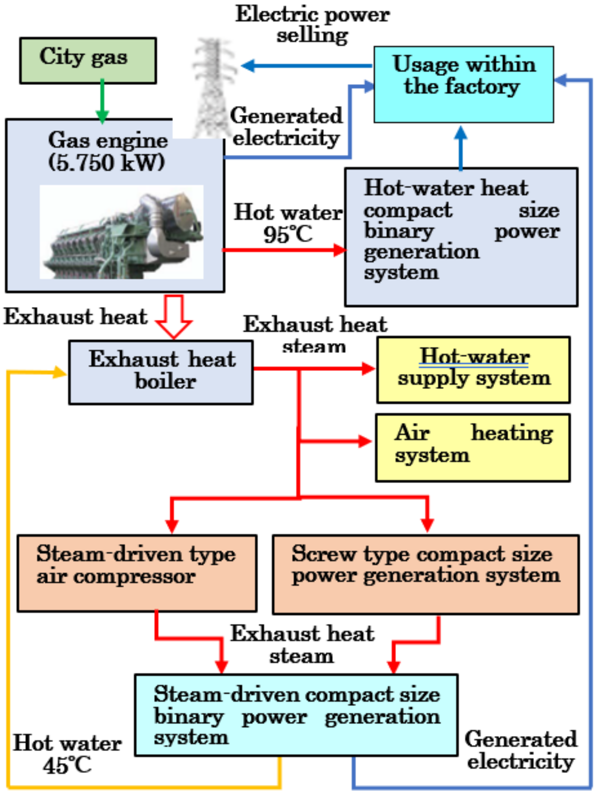
- Efficient use of insatiable energy

To effectively use waste heat, the factory successively introduced a steam-driven air compressor, a screw-type compact steam power generation system, a steam heat-source compact binary power generation system, and a hot water heat-source compact binary power generation system using hot water. It has now achieved an overall power generation efficiency of 49% and maximum energy use efficiency of 74%. An annual CO_2 emissions reduction effect of 460 tons was achieved.

- Improvement of disaster prevention and power supply security

The CGS has a BOS function. During a power outage, the auxiliary power required to operate the cogeneration equipment can be supplied from the separately installed emergency power generation device, and 100% of the power supply can be covered by the independent operation of the cogeneration.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2017/CGS-Award2017_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration investment costs: Approximately ¥690 million

- Estimated energy-saving amount

Electricity equivalent 675 KW/h

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

A1.14. Introduce On-site Energy Supply Type CGS to Overseas Factories

1. Industry subsectors Case No. 18-1

Textile manufacturing Industry

2. System Summary

Because of the large investment and long payback period of CGSs, stable and highly efficient operation over a long period is essential. Because of these characteristics, it has been difficult to achieve a payback on investment in emerging countries such as Thailand, where few cogeneration plants operate. Also, CGSs have not been widely used. In response, NS-OG Energy Solutions Thailand Ltd (or NSET) offers a one-stop on-site energy supply service that includes facility planning, installation and ownership, operation, maintenance, and gas procurement and supply. The Thai factory, which manufactures woven fabrics, consumes large amounts of heat. However, the nearby power system is extremely fragile, with power outages and instantaneous voltage drops occurring approximately 30 times a year.

3. Configuration and Performance

Item	Contents
Types of prime movers	Gas turbine (GT)
Rated power output &number of units	(GT) 6,690 kW x 1 unit
Use of waste heat Hot water	Manufacturing process steam
Fuel	Natural gas
Power peak cut rate	100%
Primary energy reduction rate	24.7
Expected CO_2 savings amount	570 kg-CO_2/ｈ
Ratio of electricity and heat and loss	30.0%、52.5%，17.5％

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

In Thailand, where turnover is high, it is not easy to secure and train excellent staff in the utility sector and ensure stable operations over the long term. There are many cases where stable operations have not been achieved despite the introduction of complex facilities such as CGSs. Therefore, the initial investment burden was reduced by outsourcing to an on-site energy supply company that handles all aspects of the CGS, including design, construction, equipment ownership, operation, and maintenance.

Considering the plant's large heat demand, a 7 MW-class gas turbine CGS, larger than the plant's electricity demand, and a waste heat recovery boiler were the system’s main components, with a total efficiency of over 90%.

4. System Features

- Use of on-site energy supplier

  This company recruits and trains new operators and transfers operation management technology to build an on-site operation and maintenance infrastructure.

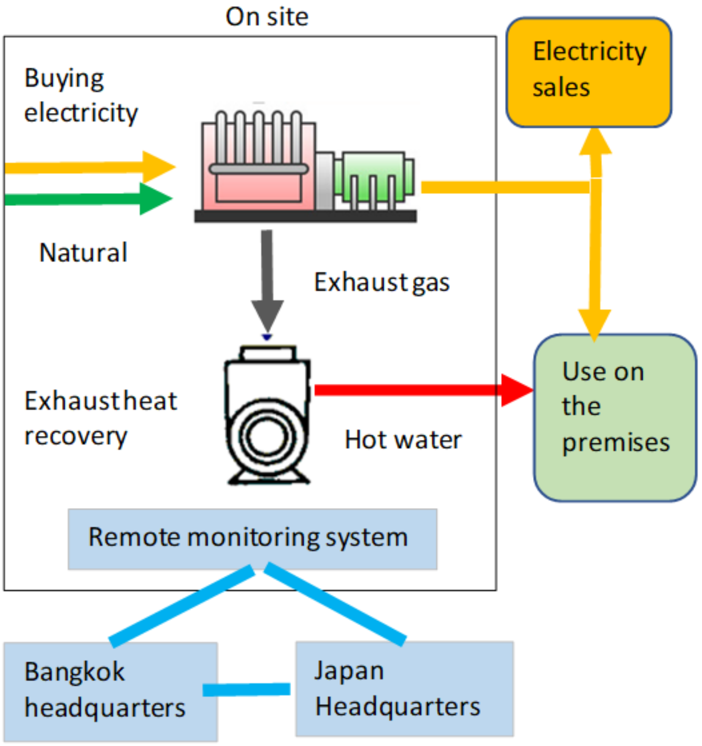
- Realisation of stable operation

  This company utilises a remote monitoring system to support stable operation by professional staff from the company's Bangkok headquarters and Japan.

- Responding to frequent power outages

  The system can shift to stand-alone operation with the entire plant load during a system failure to avoid any impact on production.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

  Cogeneration (equipment costs): Approximately ¥803 million

- Estimated energy-saving amount

  Electricity equivalent 1,293 KW/h

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

A1.15. Reduction of Primary Energy by Installing a Total Steam Recovery Gas Engine CGS

1. Industrial subsectors Case No. 18-2

Paper manufacturing industry

2. System summary

The mill manufactures paper and adhesive films. Due to changes in production items, the balance of heat and power within the mill has shifted towards electricity. The mill has been shifting its heat and power balance towards electricity due to changes in production items. Thus, the mill upgraded to a gas engine CGS (5,770 kW x 1 unit), which has a higher power output and power generation efficiency than the existing gas turbine CGS. By adopting a total steam recovery system that efficiently converts waste hot water generated from the gas engine into steam, high steam recovery efficiency was achieved, and energy-saving effects were enhanced. Typically, the system is operated as a highly energy-efficient total steam recovery gas engine CGS. However, during peak power demand, the system is switched to an operation that maximises power generation output by stopping the total steam recovery system.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 5,770 kW × 1 unit
Waste heat utilisation	Process steam
Fuel	City gas
Power peak cut rate	50.7%
Primary energy reduction rate	24.4%
Expected CO_2 savings amount	470 kg-CO_2/h
Electricity, heat, loss ratio	(GE)45.8%, 33.2%, 21.0%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

4. System Features

- System improvement using a total steam recovery system

In the first case of introducing a total steam recovery gas engine, the engine’s cooling water is heated to 120°C and fed to the steam generator to produce saturated steam of approximately 0.05 MPaG. A steam compressor boosts this low-pressure steam to increase the amount of steam recovery.

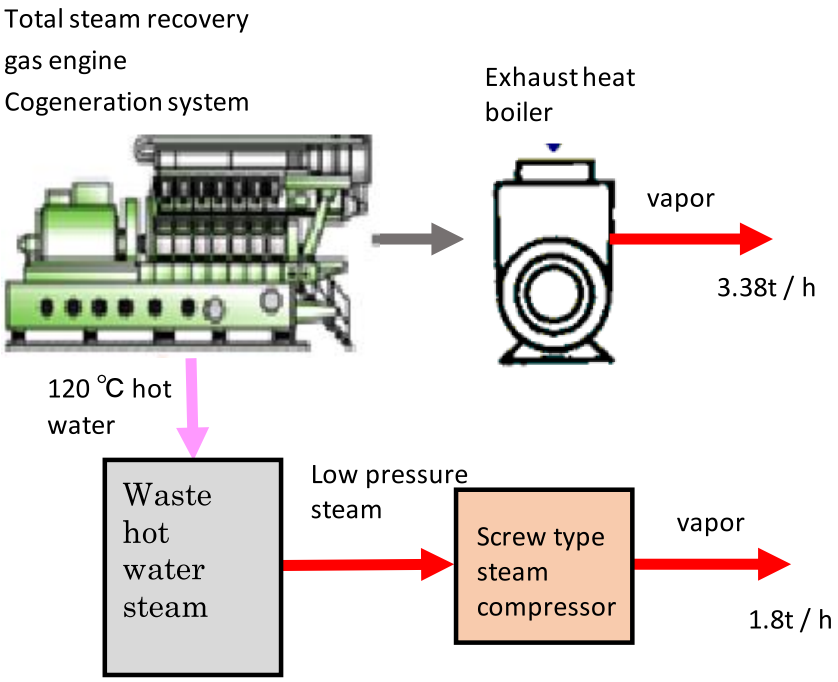
- Energy efficiency

The overall efficiency (power generation + steam efficiency) of 71.5%, the highest in the world, is achieved by combining the power generated, excluding hot water, and the amount of steam generated.

- Improved disaster prevention and power security

The system is capable of self-supporting operation. During a grid power failure, the gas engine (5,770 kW x 1-unit, medium-pressure feed) can be disconnected from the grid to continue supplying power to important loads on the premises.

- System flow



Note: Normally, there is no place to use hot water at 90°C.
Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

CGS (equipment cost): Approximately ¥692 million

- Estimated energy-saving amount

Electricity equivalent 1,066 KW/h

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

A.16. Introduction of Gas CGS in Water Treatment Plants to Utilise Electricity and Waste Heat for Sludge Treatment

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 facing the issues of updating the dewatering facilities for sludge residue generated in the water treatment process and securing a place to take the sludge.

This project uses the Private Finance Initiative method[3] to upgrade the dewatering facilities of a water purification plant (dedicated for water supply); construct a new gas engine CGS with BOS specifications and a solar power generation system; and 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 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. As a result, 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

Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 1,000 kW × 6 unit
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 (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

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[3] The Private Finance Initiative (PFI) method is a method of public works that utilises private funds, management ability, and technical capabilities (know-how) to design, construct, repair, update, maintain, manage, and operate public facilities. The local public body will be the ordering party and will be carried out as a public project.

4. System Features

- BCP at water purification plants

  Water supply infrastructure security is improved by combining commercial electric power, cogeneration, and solar power generation to create multiple power supply sources.

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

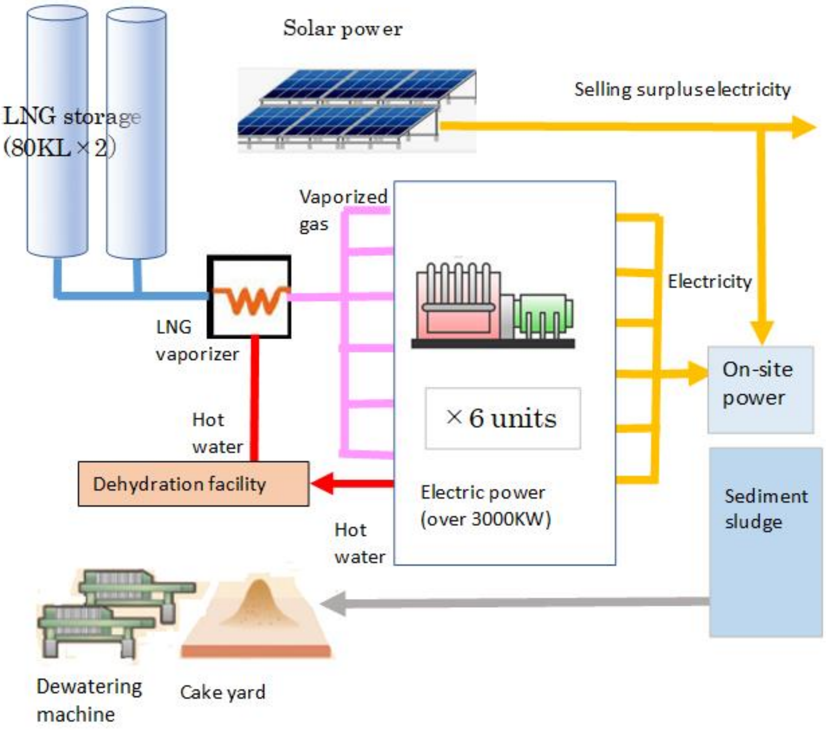
  LNG storage tanks are sufficient for 5 days.

- 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 as gardening soil and ground soil.

- Operation control using renewable energy

  The CGS is operated continuously during the daytime to sell solar power, and the generator power covers part of the load power in the premises.



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

5. 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 saving is shown in section 2.2.

A1.17. Effects of Introducing Groundwater Utilisation CGS in Beverage Factories

1. Industrial Field Case No. 1 8-4

Beverage production

2. System Overview

This factory performs integrated contract manufacturing of various beverages of other companies' brands, from mixing to filling and packaging. The groundwater used for beverage production is also utilised as an intake air cooling source (unused energy) for a gas turbine CGS (2,000 kW x 1 unit). In addition to enabling an increase in power output of approximately 180 kW during the summer, introducing a variable output exhaust gas-fired steam boiler has enabled the plant to achieve an overall efficiency of 90.1%, the highest in its class.

In terms of energy conservation and CO_2 emissions reduction, the factory expects to save 11.2% of energy and reduce CO_2 emissions by 8.0% compared to the level before the introduction of the CGS. In addition, the power and heat from the CGS are used for multiple buildings and processes within the plant. The BOS specifications enable the CGS to supply power even during a disaster (power outage).

5. Configuration and performance

Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	(GT) 2,000 kW × 1 unit
Waste heat utilisation	Process steam
Fuel	City gas
Power peak cut rate	43.6%
Primary energy reduction rate	11.2%
Expected CO_2 savings amount	111 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 24.1%, 57.8%, 18.1%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

6. System Features

- This plant improved the efficiency of waste heat utilisation of the CGS and improved the plant's ability to cope with fluctuations in steam output. In addition, while the high capital investment in constructing new buildings and other facilities continued, the company avoided a large initial investment by using an ESCO.
- Promotion of efficient energy use

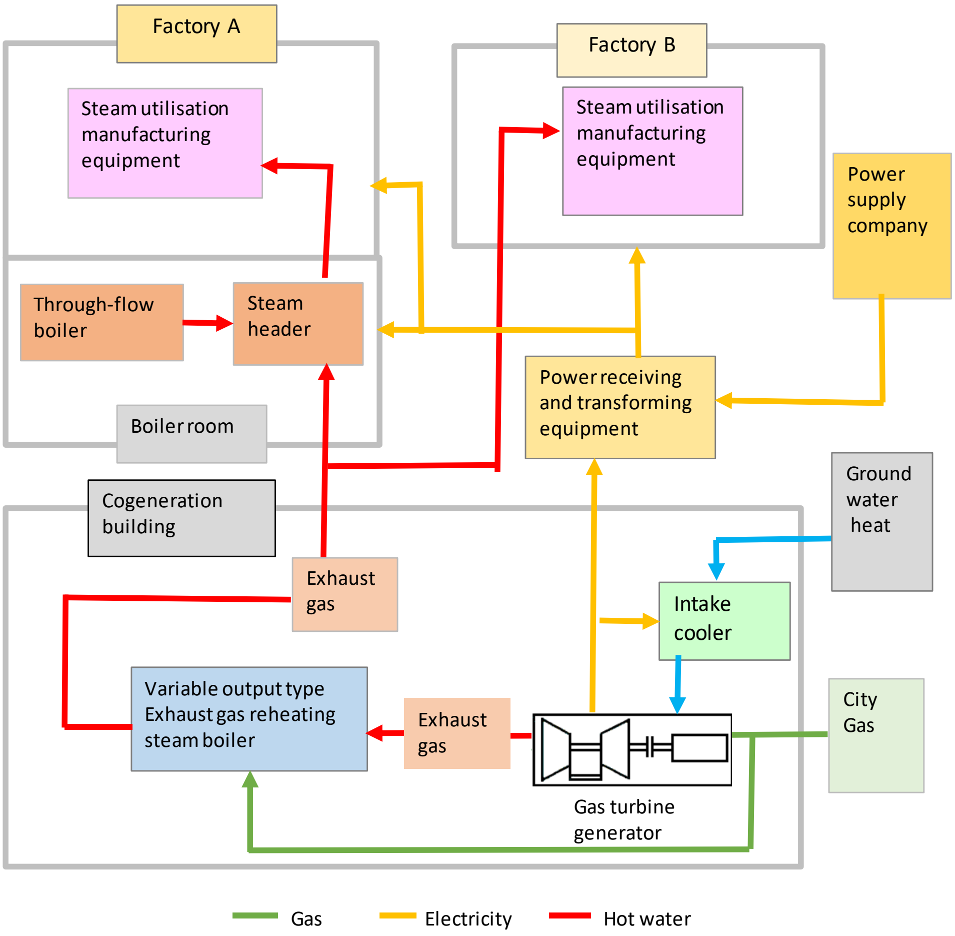
In summer, when the intake air temperature rises, the power generation efficiency of the gas turbine declines. (When the intake air temperature is 30°C, the rated output of 2,000 kW drops to 1,670 kW, but the intake air cooling system restores output to 1,850 kW.)

An evaporator is placed in front of the burner to lower the temperature of exhaust gas entering the burner, and a variable output system is introduced to allow more fuel gas to be injected. The overall efficiency achieved is 90.1%.

- Inter-building distribution of electricity and heat

Electricity and steam are supplied to and from multiple plant buildings within the main plant.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

7. Investment (Estimated Value)

- Cost

  CGS (equipment cost): approximately ¥240 million

- Estimated energy-saving amount

  Electricity equivalent 252 kW/h

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

A1.18. Realisation of BCP Restructuring and CO_2 Reduction through Integrated Replacement of Cogeneration Facilities

1. Industrial Field Case No. 18-5

Chemical factory

2. System Overview

This plant is a complex of a production factory and a research institute. The plant must have a business continuity plan (BCP) to continue supplying electricity to the production factory, laboratory, and other important loads in case of emergency.

As several existing gas CGSs are approaching the age of renewal, we examined the optimal future state of the entire plant from the viewpoints of BCP, CO_2 emission reduction, cost-effectiveness, and so on.

3. System Configuration and Performance

Item	Contents
Types of prime movers	Gas turbines （GT）
Rated power generation output	(GT) 8,000 kW × 1 unit
Waste heat utilisation	Processed steam, air conditioning
Fuel	City gas 13A
Power peak cut rate	57.3％
Primary energy reduction rate	30.9％
Expected CO_2 savings amount	1,578 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 34.3%, 38.1%, 27.6%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

Initially, the study started with a single machine’s ageing renewal. But as a result of studying from a multifaceted perspective, such as optimal electricity, heat, BCP, etc., for the entire business site, integrated replacement with a gas turbine with the optimum capacity was selected. The existing cogeneration unit no. 3 is being used after being modified for BOS, transferred to a critical load system, and overhauled to be used for the next 15 years.

4. System features

- Integration: effect of update

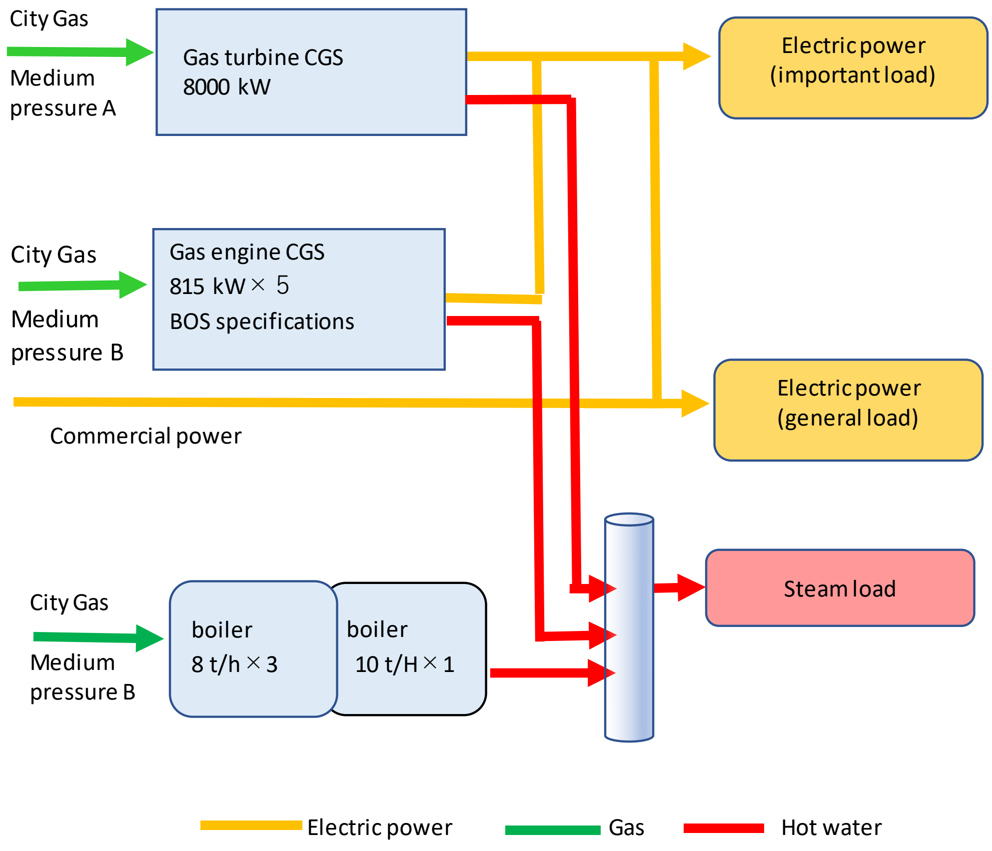
  High efficiency and energy reduction by increasing the size

  Since the number of two CGSs became one and the empty space increased, the first floor was made hollow to prevent tsunamis.

- Build a new BCP system

  The existing gas engine CGS (815 kW x 5) was left behind, and a new BCP system was built.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

5. Investment

- Cost

  CGS (equipment cost): Approximately ¥960 million

- Estimated energy-saving amount

  Electricity equivalent 3,577 kW/h

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

A1.19. Effects of Updating CGS at Power Plants that Supply Electricity and Heat to Industrial Parks

1. Industrial Area Case No. 18-6

Energy supply plant

2. System Summary

The plant was established in 1975 to supply steam, electricity, etc., to companies in the industrial park.

The plant has six cogeneration facilities (two gas turbines and four gas engines), two oil-fired water tube boilers, and five gas-fired once-through boilers.

The plant supplies electricity and steam to 19 companies in the industrial park with 6 cogeneration units (2 gas turbines and 4 gas engines), 2 oil-fired water tube boilers, and 5 gas-fired once-through boilers. The system is more efficient than the existing units. It has double the steam supply capacity partly due to the use of waste heat boilers with burners and partly due to the ability to use hot water from the existing gas engines. As a result, the primary energy reduction rate for the entire system improved by 4.4%. In addition, the existing gas-fired once-through boiler became a spare unit, enabling the steam supply to continue while minimising the steam pressure drop even if another boiler unexpectedly breaks down, enhancing energy security.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GE)
Rated power output & number of units	(GT) 8,400 kW × 2 units (GE) 5,750 kW × 4 units (existing)
Waste heat utilisation	Production process (Heating, distillation, sterilisation)
Fuel	City gas 13A
Power peak cut rate	81.4%
Primary energy reduction rate	27.1%
Expected CO_2 savings amount	6,525 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 45.8%, 33.2%, 21.0%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

4. System Features

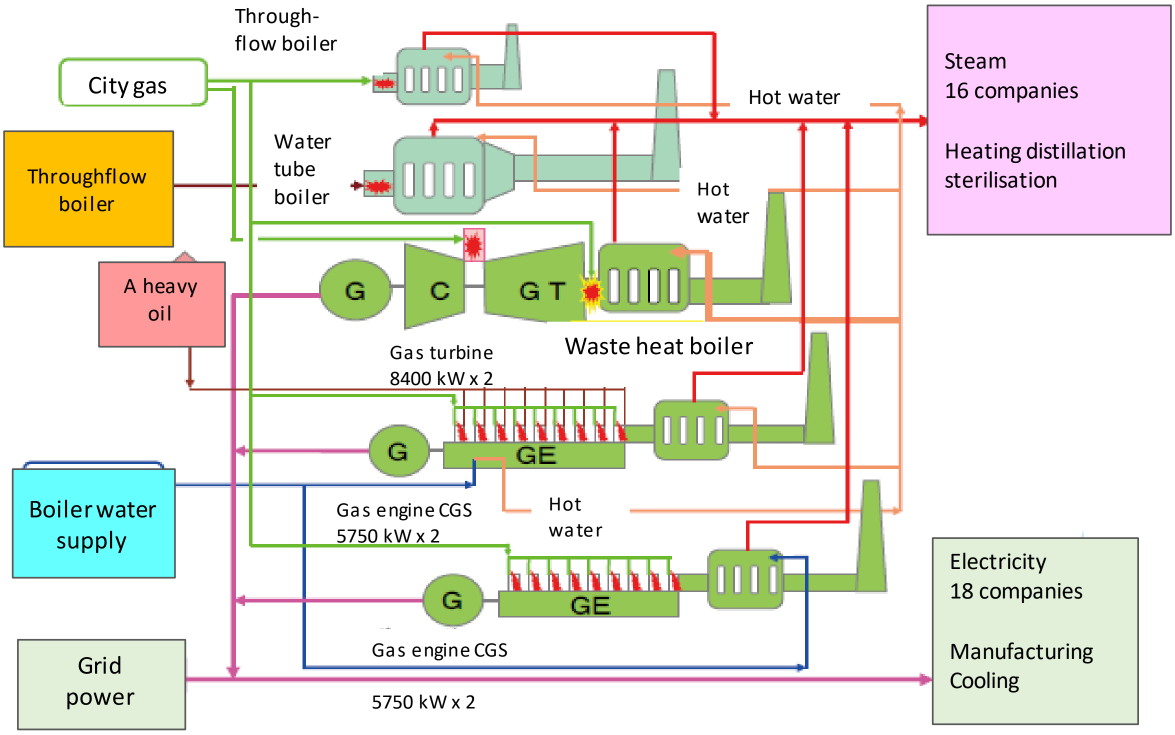
- Efficient and planned operation

The gas turbine is used as the base load machine, and the gas engine is used as the peak cut-off machine. The system is operated in a planned manner to minimise the amount of electricity purchased. Each CGS is connected to the load of each consumer. In the event of a grid failure, each grid interconnecting a circuit breaker is disengaged, and the system is switched to stand-alone operation to protect each customer's load.

- Increased efficiency and enhanced steam backup function through the introduction of a burner

The existing gas-fired boiler will be turned into a backup unit to enhance resources in case of trouble and to meet BCP requirements.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2018/CGS-Award2018_Detail02.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

CGS (equipment cost): Approximately ¥2,016 million

- Estimated energy-saving amount

Electricity equivalent 14,795 kW/h

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

A1.20. Overhaul and High-efficiency Modification of Existing CGSs to Improve Power Generation Efficiency

1. Industrial Subsectors Case No. 19-1

Gas manufacturing industry

2. System Summary

In 2004, a gas engine-based cogeneration facility (5,500 kW x 2 units) was installed, and the waste heat is used to vaporise LNG. The running costs had been rising due to increased the maintenance scope and the number of parts to be replaced due to age-related deterioration, which had become an operational issue. Therefore, power generation efficiency improved by implementing a high-efficiency gas engine installation applying the technology of the latest machines.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	(GE) 5,500 kW × 2 units
Waste heat utilisation	LNG vaporisation
Fuel	City gas 13A
Power peak cut rate	88.5%
Primary energy reduction rate	23.9%
Expected CO_2 savings amount	1,524 kw-CO_2/h
Electricity, heat, loss ratio	(GE) 45.8%， 33.2%， 21.0%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

4. System Features

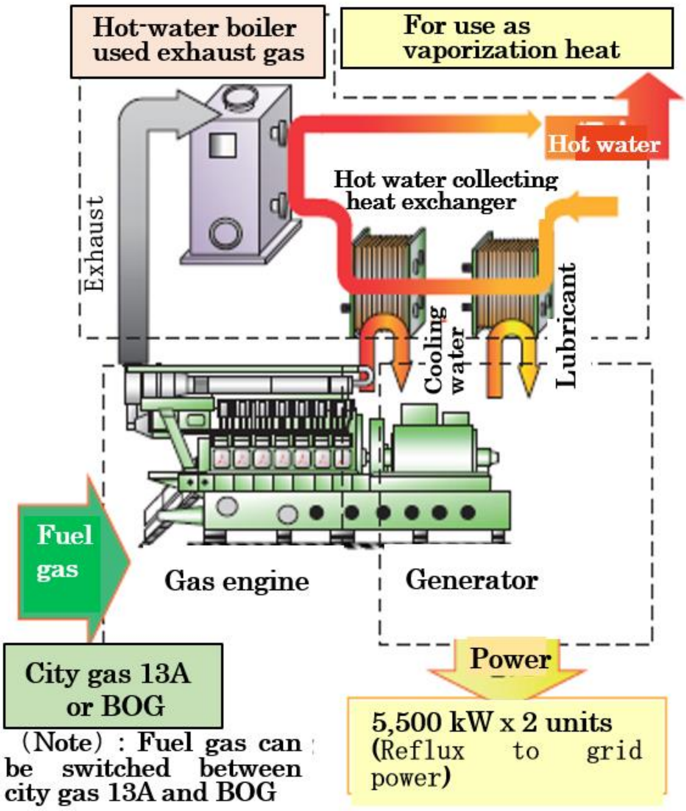
- Improvement of plant efficiency and operational performance

By improving cycle and combustion efficiency, adopting a high-efficiency turbocharger, etc., the power generation efficiency has improved while maintaining nitrogen oxide in the exhaust gas. Furthermore, by changing to a spark ignition system that does not require ignition fuel, fuel costs are reduced, and operability is improved. The air–fuel ratio adjustment device has been changed, and the latest combustion technology has been used to minimise the decrease in steam generation and maintain overall efficiency. The maintenance cycle of pistons and bearings has been doubled by replacing them with the latest model parts. The spark ignition method and the latest combustion technology have improved the load follow-up speed by 30% and shortened the start-up time to one third.

- Renewal of aged machines that suppressed initial investment

The spark ignition method and the latest combustion technology have improved the load follow-up speed by 30% and shortened the start-up time by one third. By replacing parts that may be replaced in the medium to long term at the time of remodeling, the risk of trouble due to deterioration and ageing has been reduced.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration investment costs: Approximately ¥1,320 million

- Estimated energy-saving amount

Electricity equivalent 3,455 kW/h

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

A.21. Construction of a High-efficiency Energy Supply System through the Use of CGS Waste Heat and Unused Heat

1. Industrial Subsectors Case No. 19-2

Automobile manufacturing industry

2. System Summary

The gas engine CGS, which has a high ratio of electricity and is highly efficient, was introduced to optimise the use of waste heat. The maximum effective use of energy has been realised, in line with the highly efficient gas engine CGS introduced, by introducing groundwater heat, using waste heat from compressors, and monitoring and controlling integrated EMS. In addition, as a measure against instantaneous voltage drop, a one-cycle circuit breaker was installed, and the CGS was equipped with a BOS function to enable early recovery of the power supply. Efforts were made to strengthen the disaster prevention function in the event of a disaster.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine (GE)
Power output & number of units	(GE) 7,800 kW × 1 unit
Waste heat utilisation	Air conditioning, hot-water supply
Fuel	City gas
Power peak cut rate	32.5%
Primary energy reduction rate	29.3%
Expected CO_2 savings amount	1,425 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 49.0%, 23.9%, 27.1%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

4. System Features

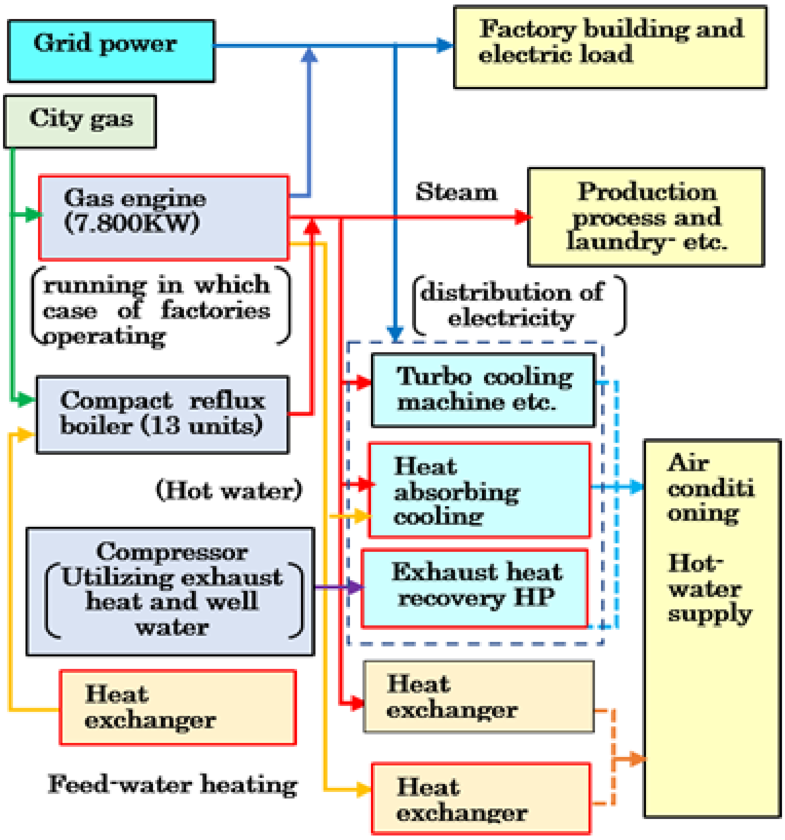
- Configuration and operation system that efficiently uses heat

Waste heat from the air compressor and unused heat of well water (15°C–20°C) used for production are recovered and used by the waste heat recovery heat pump. In summer, high-temperature water becomes a heat source for absorption chillers and is then used as a heat source for hot and boiler water supply. In winter, most of the available waste heat is used to execute in a cascade that the exhaust hot water of CGS is first used for air heating. The exhaust hot water is then used as the heat source water of the exhaust heat recovery heat pump.

- Integration control of factory operation and energy system

We have built a system that enables centralised management of the entire system by adopting EMS, such as linking CGS with the demand of factory production equipment, controlling the number of heat source equipment based on the measurement of secondary air-conditioning load, linking CGS and heat source equipment, and visualising energy use.

- System flowchart



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

Cogeneration investment costs: Approximately ¥936 million

- Estimated energy-saving amount

Electricity equivalent 3,233 kW/h

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

A1.22. An Environment-friendly CGS that is Effective for BCP Measures by Using a High-Pressure Natural-gas Trunk Line

1. Industrial subsectors Case No. 19-3

Tire manufacturing industry

2. System summary

Until now, it has been difficult to use natural gas due to the factory's location. However, due to the construction of a high-pressure main line nearby, it was possible to replace the coal boiler turbine generator (BTG) with a gas turbine CGS (7,630 kW x 2 units) that uses natural gas as fuel and a backup steam once-through boiler. As a result, CO_2 was significantly reduced. At the same time, BCP measures could also be realised using a high-pressure natural-gas conduit with high disaster prevention properties.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	(GT) 7,630 kW × 2 units
Waste heat utilisation	Production process Air conditioning
Fuel	City gas
Power peak cut rate	69.8%
Primary energy reduction rate	24.1%
Expected CO_2 savings amount	2,137 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 33.1%, 52.1%, 14.8%

Source: Advanced Cogeneration and Energy Utilisation Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

4. System Features

- Energy and CO_2 saving by improving the efficiency of CGS

By adopting a high-efficiency gas turbine CGS, environmental performance is greatly improved. The exhaust gas boiler is equipped with a reheating burner to improve overall efficiency, and 1.9 MPa steam is used for vulcanising and heating products.

- Adopted an intake cooling system using a gas-fired absorption chiller

Seasonal fluctuation of power generation output is suppressed by intake air cooling.

- Gas supply by highly reliable high-pressure trunk line

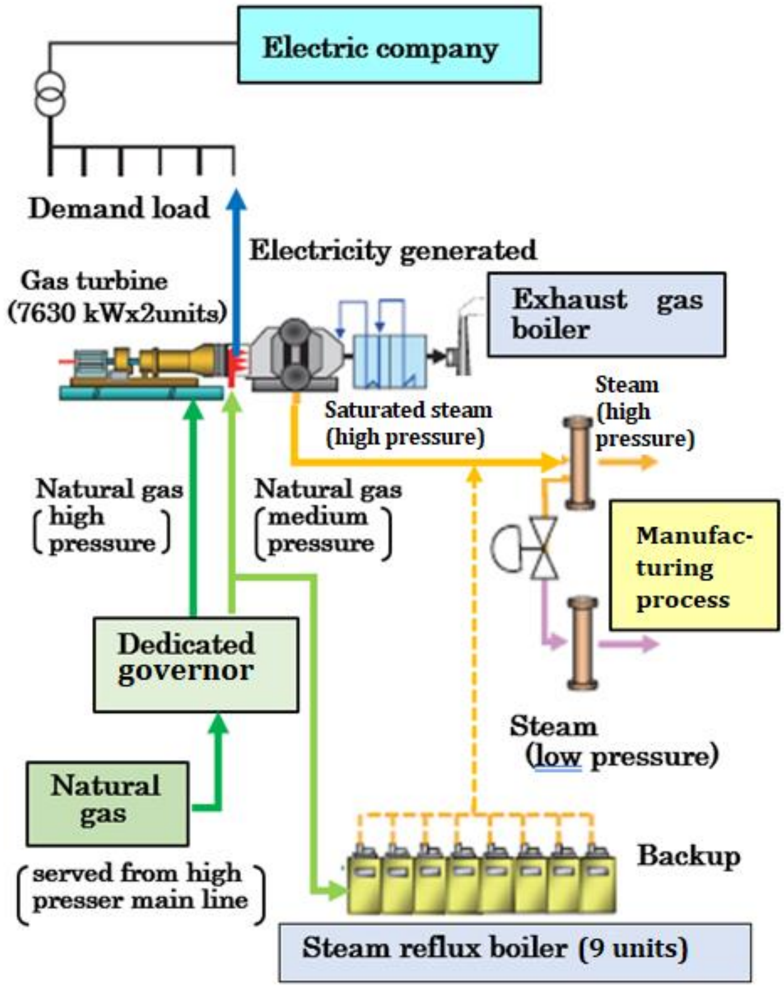
Natural gas is supplied by a high-pressure conduit of 3.0 MPa, which has high earthquake resistance. In addition, the gas compressor for the gas turbine is no longer required; it also reduces costs.

- Improving disaster prevention and reliability of CGS for BCP compliance

Multiple CGSs are installed to make the system redundant.

In addition, nine through-flow boilers are installed for backup, which are disconnected from the grid in the event of a power outage and operate independently according to their respective critical loads.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

  Cogeneration investment costs: Approximately ¥1,831.2 million

- Estimated energy-saving amount

  Electricity equivalent 4,845 kW/h

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

A1.23. Promotion of Energy Savings by Introducing the Latest Cogeneration Equipment Suitable for Factory Loads

1. Industrial Subsectors Case No. 19-5

Electronic components industry

2. System summary

At plant A, excess steam generated from the existing CGS was reducing efficiency. Therefore, the plant was upgraded to a state-of-the-art high-efficiency gas turbine CGS (5,000 kW x 1 unit) to match the amount of steam required, improving power generation efficiency and saving energy. On the other hand, plant B has adopted the world's most efficient gas engine CGS (7,500 kW x 1 unit) to meet the required steam volume. This realised improvements in operational benefits and energy savings. In addition, a system that can be operated independently was constructed to respond to emergencies and strengthen BCP measures.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT) Gas engine (GE)
Rated power output & number of units	(GT) 5,000 kW × 1 unit (GE) 7,500 kW × 1 unit
Waste heat utilisation	Production process Air conditioning
Fuel	(GT) Natural gas (GE) City gas
Power peak cut rate	39.7%
Primary energy reduction rate	16.2%
Expected CO_2 savings amount	1,066 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 49.0%, 23.9%, 27.1% (GT) 31.9%, 52.7%, 15.4%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

4. System features

- Renewal of gas turbines and introduction of gas engines to meet heat demand

Due to the decrease in steam load at Plant A (average 22.6 t/h → 10.2 t/h), the gas turbine CGS was replaced with a 5,000 kW system.

Both power generation efficiency (28%→32%) and waste heat recovery efficiency (47%→55%) were improved.

The gas engine (power generation efficiency: 49.5%) was installed at Plant B, where steam demand is low. Surplus power is transmitted to other plants through the company's transmission lines.

Both plants have increased efficiency and reduced energy costs.

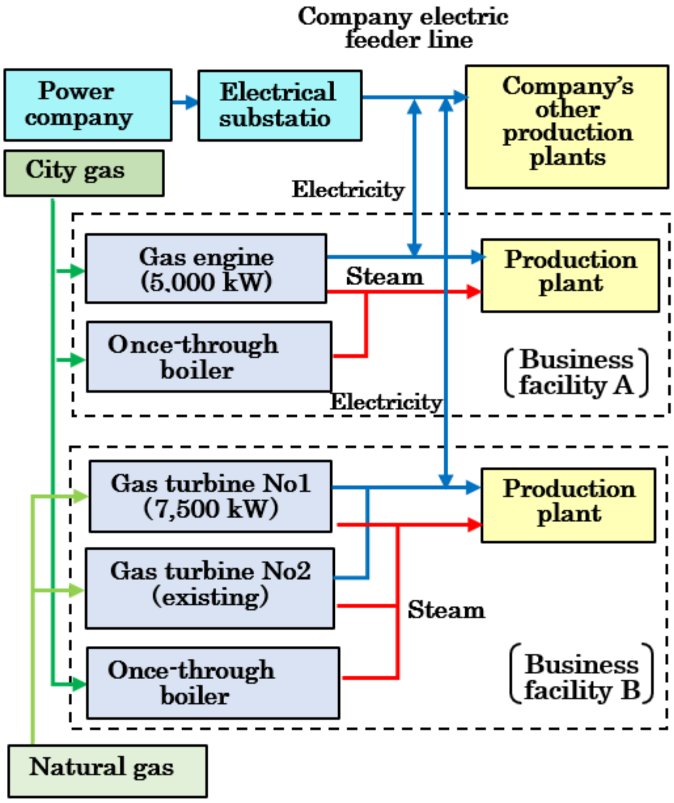
- Minimisation of investment cost and shortening of renewal work period

At the number one business site, by diverting the foundations, auxiliary equipment, and electrical equipment of the existing gas turbine as much as possible, the renewal cost was reduced. and the construction period was shortened.

- Power leveling and emergency response through centralised energy management of multiple factories connected by self-employed lines

Centralised management of five CGSs is implemented at the company's substation.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

5. Investment (estimated value)

- Cost

  Cogeneration investment costs:

  Approximately ¥1,500 million

- Estimated energy-saving amount

  Electricity equivalent 2,416 kW/h

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

A1.24. Energy-saving Measures Using CGS and Improvement of Regional Disaster Prevention Capabilities Using Electric Vehicles

1. Industrial Subsectors Case No. 19-6

Iron and steel secondary processing industry

2. System Summary

A gas engine CGS was installed on the factory premises to reduce the environmental load and save energy. The power generated by CGS is connected to the power grid and supplied to multiple production areas in the factory. In the production process, the materials are acid pickled, and CGS exhaust heat vapor and waste heat hot water are used to heat the treatment solution used in the acid pickling coat treatment tank.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine (GE)
Rated power output & number of units	(GE) 390 kW × 1 unit
Waste heat utilisation	Production process
Fuel	City gas 13A
Power peak cut rate	22.5%
Primary energy reduction rate	16.2%
Expected CO_2 savings amount	33 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 42.0%, 38.5%, 19.5%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

4. System Features

- Contribute to regional disaster prevention by charging electric vehicles (EVs) to use CGS during a disaster.

The city of A, which wants to improve its disaster-prevention capabilities, and the local automaker, which intends to promote the use and widespread adoption of EVs, have agreed to EV operation in times of disaster.

In a disaster, the manufacturer will supply power from the CGS to the EVs and use them as mobile storage batteries. In addition, a system will be established to provide electricity to city facilities and evacuation centres. EVs used for test drives at affiliated dealers (seven dealers) will be utilised in times of disaster.

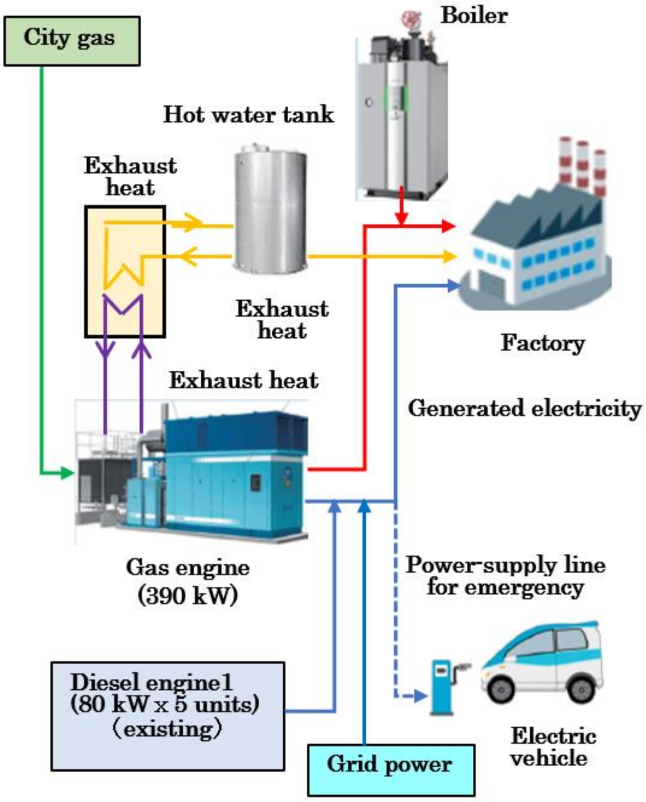
The BOS function enables CGS startup even during power outages. Power can be supplied to lighting and some production facilities through parallel operation with emergency generators.

It is possible to supply power to lighting and some production facilities by operating an emergency generator in parallel.

- Improvement of energy savings and production efficiency by using waste heat

CGS waste hot water is used to generate the treatment solution (dilute sulfuric acid, etc.) utilised in the factory process. As a result, the heating time can be shortened, the amount of steam used can be reduced, and the production efficiency is improved.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf, modified by the authors.

5. Investment (Estimated Value)

- Cost

  Cogeneration investment costs: Approximately ¥58.5 million

- Estimated energy-saving amount

  Electricity equivalent 75 kW/h

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

A1.25. Shared Use of Electricity and Heat by Constructing an Energy Centre in an Industrial Zone

1. Industrial Field Case No. 20-1

Shared use of industrial zone

2. System Overview

Currently, 35 companies are in this industrial zone, and the total area is 388 hectares. The background is the increased risk of natural disasters associated with the great earthquake and climate change. There was a desire to share electricity and heat in cooperation with neighbouring factories of different industries in this industrial zone. Therefore, the gas company assumed the coordinator role and built a unique network system consisting of an EMS centred on a highly efficient large-scale CGS, a self-employed electric power line, a district heating conduit, and a communication line. With this system, it has become possible to save about 20% of energy and CO_2, which is difficult to realise in a single office, and to continue to supply power and heat even during a long-term power outage due to a large-scale disaster.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 5,770 kW x 6 units （34,620 kW）
Waste heat utilisation	Manufacturing process, air conditioning, hot water supply
Fuel	City gas 13A
Power peak cut rate	-
Primary energy reduction rate	20.6%
Expected CO_2 savings amount	39,611 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 49.0%, 23.7%, 27.3%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2020/CGS-Award2020_Detail.pdf?v=2, modified by the authors.

4. System Features

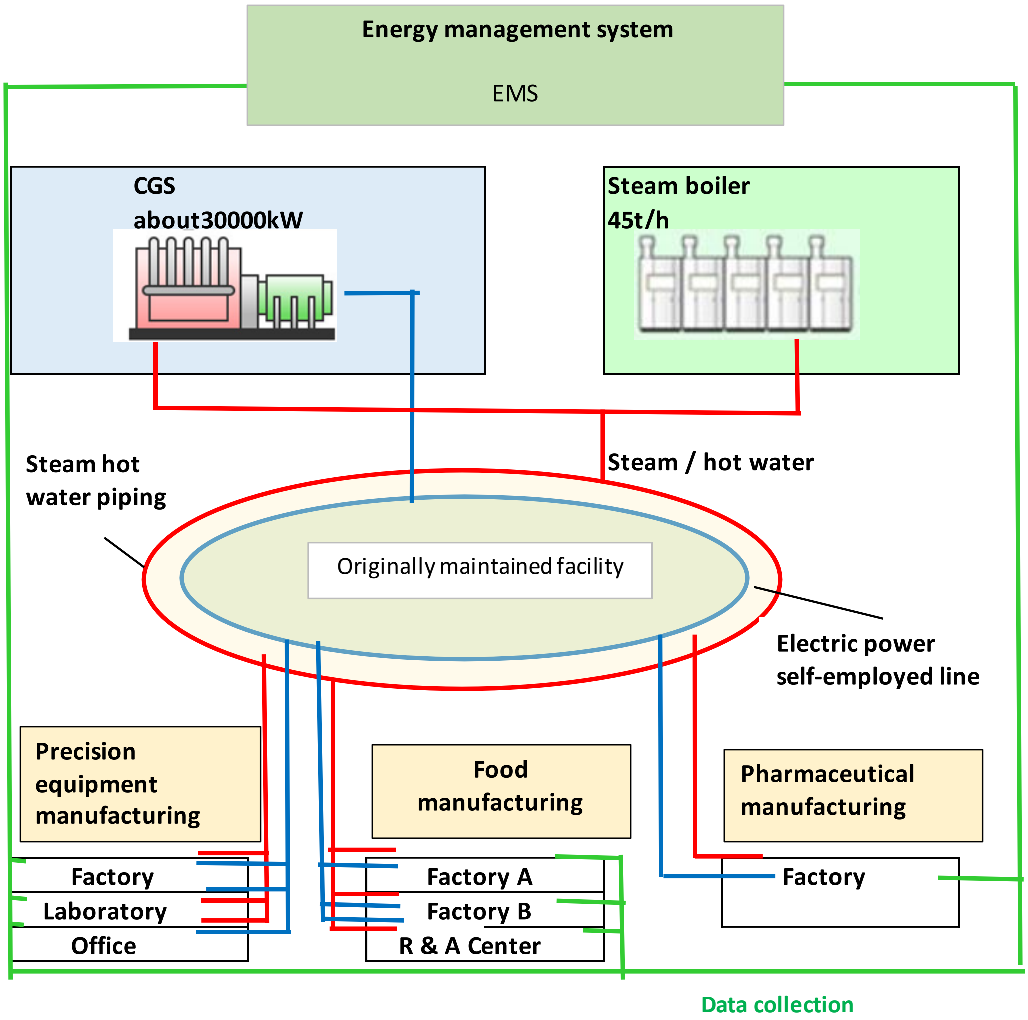
- Establishment of energy centre

EMS utilising the latest ICT enables the efficient operation of optimal energy in response to fluctuations in demand. It can supply power and heat to seven factories even during a long-term power outage by installing its self-employed power line, heat piping network, large-capacity cogeneration, and 24-hour resident operation management system.

- Introduction of renewable energy

A solar power generation system is installed next to cogeneration. Fluctuations in power generation output are adjusted by cogeneration.

- A radiator system that cools the CGS with air was adopted to prepare for a water supply interruption during a long-term power outage.
- Energy utilisation flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), 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 ¥4,154 million
- Estimated energy-saving amount

  Electricity equivalent 8,982 kW/h

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

A1.26. CCGT Construction for BGT Renewal (Expansion of Heat Utilisation and Energy Reduction)

1. Industrial Subsectors Case No. 20-3

Food industry

2. System Summary

This factory produces natural seasonings and other products using fermentation-related technologies. To cope with the increased environmental impact caused by increased production, the plant has sought to reduce energy consumption by introducing natural gas via an LNG satellite. The newly introduced gas turbine CGS was combined with the existing steam turbine to create a gas turbine combined cycle system. This system has increased power generation, a best-in-class overall efficiency of over 90%, a significant reduction in CO_2 emissions, and a contribution to the power system. The new system is also equipped with a backup gas boiler and countermeasures against instantaneous power loss, so the factory can continue its production activities even during a disaster or power grid accident.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	(GT) 7,550 kW × 1 unit (ST) 3,020 kW × 1 unit (existing)
Waste heat utilisation	Production process
Fuel	LNG vaporisation gas
Power peak cut rate	—
Primary energy reduction rate	—
Expected CO_2 savings amount	1.588 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 33.1%, 52.1%, 14.8%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2020/CGS-Award2020_Detail.pdf?v=2, modified by the authors.

4. System Features

- Renewal from BTG to CCGT (combined cycle gas turbine)

The CCGT system was constructed by effectively utilising the gas turbine CGS (8 MW class) and the existing steam turbine to increase the power generation output by about 3 MW. The heat recovery boiler of the CGS is a unique boiler system that supplies steam according to the fluctuating power and steam load according to the factory's production line. The system is also expected to be deployed as a new method for updating ageing BTGs. The factory is supplied with electricity from the new gas turbine and the existing steam turbine, and any surplus is sold to the power grid.

- High efficiency (ultimate use of cascade heat)

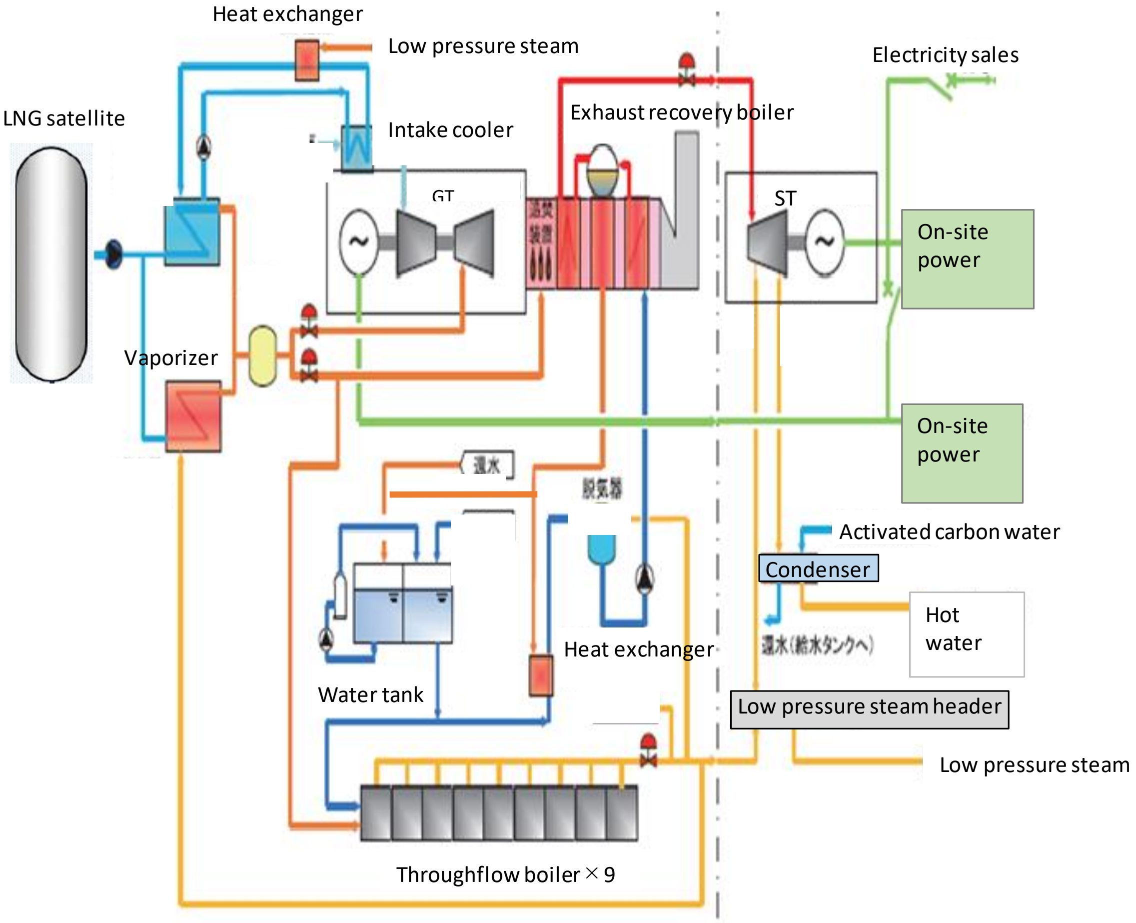
The steam turbine is an extraction back-pressure type, and the input high-pressure and high-temperature superheated steam is used for power generation in the latter stage. The use of a cascade of heat, total efficiency rate of 91% and annual total efficiency of 89% (highest efficiency in 8 MW class combined cycle industrial gas turbine) were achieved.

A total efficiency rate of 91% and annual total efficiency of 89% (highest efficiency in 8 MW class combined cycle industrial gas turbine) were achieved.

- Use of LNG vaporisation heat

A cold-water circulation system has been constructed to utilise the warm water from the gas turbine intake cooling as heat from LNG vaporisation, thus, making full use of the heat.

- System flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), 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 ¥900 million

- Estimated energy-saving amount

Electricity equivalent — kW/ h

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

A1.27. Energy Savings by Exhaust Heat Recovery of Gas Turbine CGS

1. Industrial subsectors Case No. 20-4

Paper manufacturing industry

2. System Summary

This factory manufactures and sells containerboard base paper. The raw material is 100% recovered paper, contributing to paper recycling. The existing BTG system (power generation boiler + steam turbine) was combined with a gas turbine CGS to form a gas turbine combined cycle (GTCC) system, which was renewed due to ageing. The newly installed gas turbine CGS (7,490 kW ×1 unit) has achieved high energy efficiency (overall efficiency of 98.5%) by optimising the system and capacity, and thoroughly recovering exhaust heat by installing a hot water heat exchanger in the rear stage of the exhaust gas boiler.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	(GT) 7,490 kW × 1 unit
Waste heat utilisation	Manufacturing process
Fuel	City gas
Power peak cut rate	—
Primary energy reduction rate	30.0%
Expected CO_2 savings amount	1,416 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 33.1%, 52.1%, 14.8%

Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), https://www.ace.or.jp/web/gp/pdf/2020/CGS-Award2020_Detail.pdf?v=2, modified by the authors.

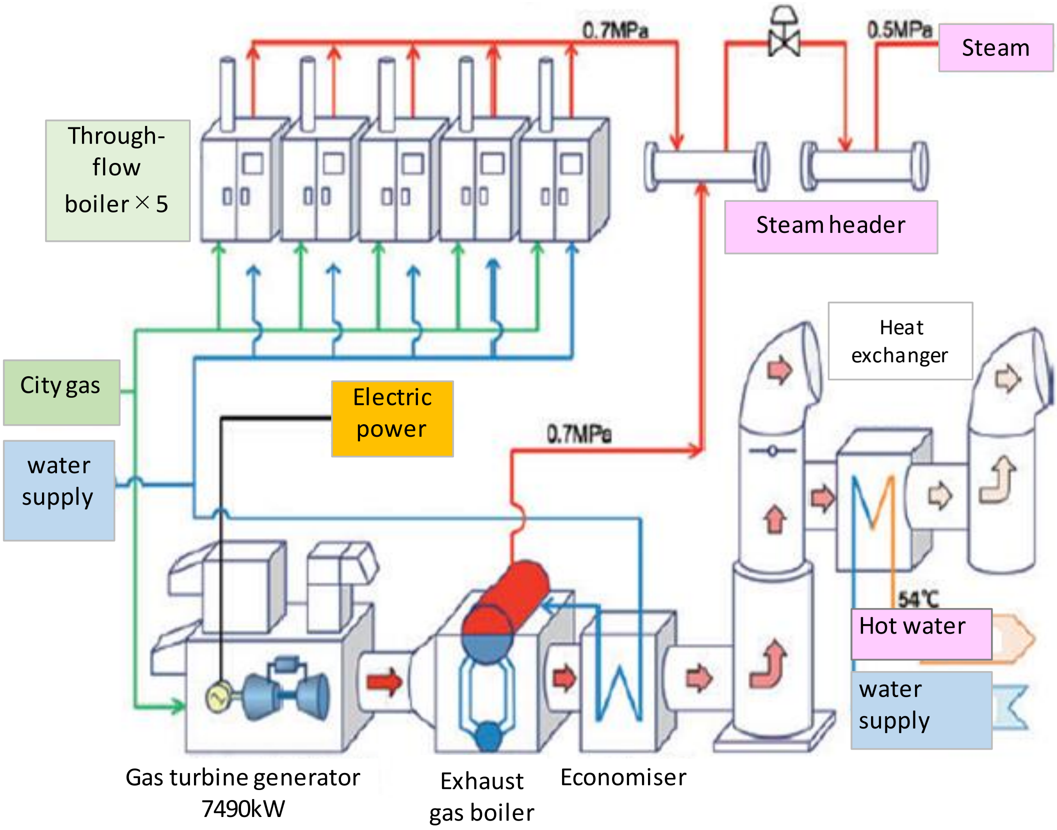
4. System Features

- Overall optimisation and simplification of operation and management through renewal Maintenance and operation management have been simplified through equipment renewal.
- High energy efficiency achieved through thorough exhaust heat recovery

By installing a hot water heat exchanger at the rear of the exhaust gas boiler of the gas turbine CGS, exhaust heat is thoroughly recovered; the feed water at 10°C is heated to 54°C; and the recovered hot water is supplied to the production facilities of the factory, contributing to further energy conservation in the entire factory.

- Total efficiency after renewal: 98.5%, an 11.6% improvement over the previous system

- Energy utilisation flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), 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 ¥899 million

- Estimated energy-saving amount

  Electricity equivalent 3,210 kW/h

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

A1.28. CGS Power Generation Using Digestion Gas at a Sewage Terminal Treatment Plant

1. Industrial Subsectors Case No. 20-5

Power generation at a sewage treatment plant

2. System Summary

Cogeneration is operated to carry out a power generation business using digestion gas generated during sewage treatment in the sewage terminal treatment plant. The digestion gas from sludge and human waste is resupplied to local consumers as electrical energy. It is a mechanism that can generate electricity stably for 24 hours. The citizen's electric power company becomes a power generation company and supplies digestion gas to high-pressure consumers and general households in the city. The digestion gas used is about 850,000 Nm3 per year, which leads to a power supply of about 1,400 thousand kWh (for about 390 ordinary households). In addition, the waste heat of cogeneration is collected as hot water and used for heating the digestive tank to generate digestion gas.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engines (GE)
Rated power output & number of units	(GE) 25 kW × 8 units
Waste heat utilisation	Heating of digester tank
Fuel	Digestion gas
Power peak cut rate	—
Primary energy reduction rate	97.3%
Expected CO_2 savings amount	6,357 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/2020/CGS-Award2020_Detail.pdf?v=2, modified by the authors.

4. System Features

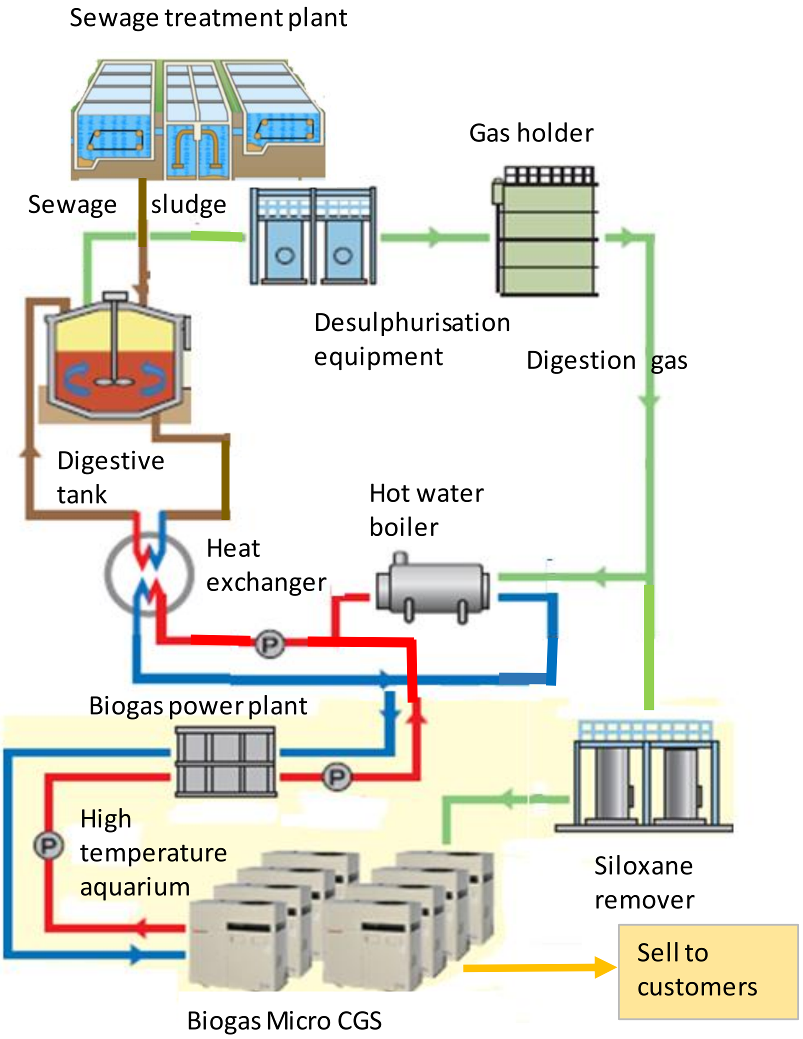
- Utilisation of digestion gas as a renewable energy source

Digester gas power generation can be used stably throughout the year. The use of waste heat achieves high overall energy efficiency throughout the year. Electricity is used for the digestion gas supply system and hot water circulation pumps on the premises. The remainder is sold to a citizen's electric power company via the power system line.

- Effective use of waste heat

The sludge generated in the sewage treatment process is decomposed and reduced in volume by the action of bacteria. However, the digester tank must be heated for the bacteria to be active. For this reason, the waste heat from the CGS is effectively used to maintain the digester tank at an appropriate temperature by exchanging heat between the sludge and hot water in the sludge heat exchanger.

- Energy utilisation flow



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), 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 ¥80 million

- Estimated energy-saving amount

Electricity equivalent 14,415 kW/h

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

A1.29. Expansion of Heat Utilisation and Energy Reduction by Gas Compressor with GT Renewal

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-pressure 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. But it has become obsolete, so the system was replaced.

3. 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 (2021), https://www.ace.or.jp/web/gp/pdf/2020/CGS-Award2020_Detail.pdf?v=2, modified by the authors.

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 BCP, it 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

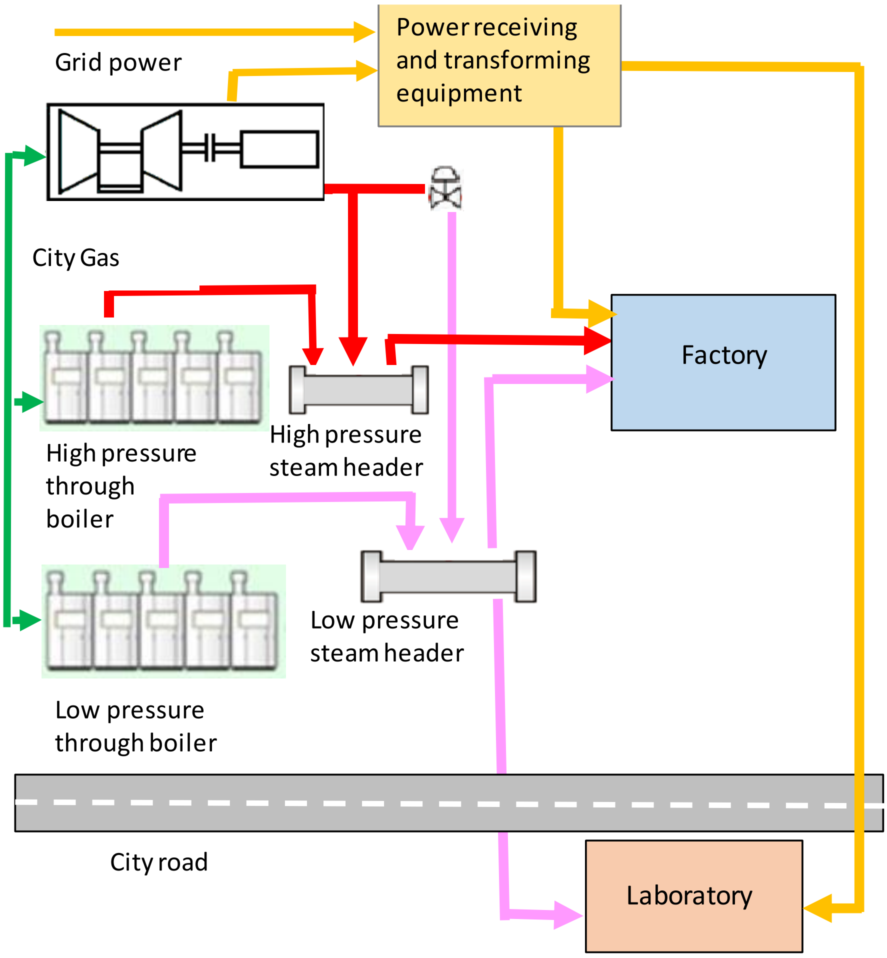
- Expansion of energy flexibility

Load leveling was achieved by combining the different power load patterns of the factory and the laboratory. Introducing 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 GT could not cope with power outages. But the new GT has a BOS, which enables restoration of power supply, mainly 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.



Source: Advanced Cogeneration and Energy Utilization Center Japan (2021), 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 1,498 kW/h

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

A1.30. Improvement of Overall Plant Efficiency by Introducing High-efficiency Gas Turbine Cogeneration

1. Industrial Subsectors Case No. 21-1

Cooperative power plant

2. System Summary

Joint power generation is a joint power plant of a complex supplying electricity, steam, and pure water to 15 neighbouring companies. In a cogeneration that combines a gas turbine cogeneration and the bleed back pressure steam turbine, the exhaust heat from the cogeneration is supplied to the steam turbine and the user's manufacturing process. The exhaust heat from the steam turbine is also supplied to the manufacturing process. With this equipment, the overall efficiency of the plant has been greatly improved and CO_2 has been reduced.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT) Steam turbine (ST)
Rated power output & number of units	(GT) 32,300 kW × 3 units (ST) 10,500 kW × 1 unit
Waste heat utilisation	(GT) Steam for ST & manufacturing process (ST) Manufacturing process (Bleed air, exhaust)
Fuel	City gas 13A
Power peak cut rate	—
Primary energy reduction rate	22.7%
Expected CO_2 savings amount	13,909 kg-CO_2/h
Electricity, heat, loss ratio	(GT) 39.1%, 46.0%, 14.9% (ST) 34.3%, 38.1%, 27.6%

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

- Responding to changes in thermoelectric demand and improving overall efficiency

By selecting combined cogeneration equipment that uses the world's highest level of improved high-efficiency gas turbines in its class, the overall plant efficiency of the entire business facility has improved by approximately 28%.

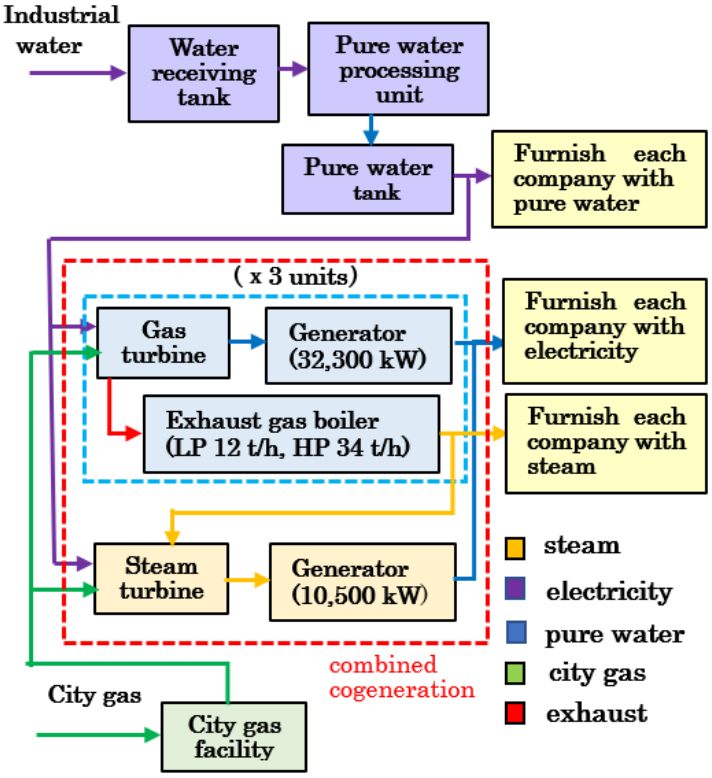
- Complete emergency response by making equipment redundant

By installing three gas turbines, flexible operation was realised in response to fluctuations in demand. In the unlikely event of a gas turbine equipment malfunction, inspection, and maintenance can be performed for each CGS even while the plant is in operation.

- Construction of a power system that can meet demand

A system was built to meet the demand for electricity in collaboration with neighbouring factories.

- System flow



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 ¥12,888 million

- Estimated energy-saving amount

Electricity equivalent 31,539 kW/h

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

A1.31. Energy Saving of Production Equipment by Utilising Low-temperature Waste Heat of Cogeneration

1. Industrial Subsectors Case No. 21-2

Automobile manufacturing industry

2. System Summary

The energy balance at the plant has changed, including a reduction in steam consumption due to energy conservation. The gas engine CGS has been upgraded to meet these plant demands. Of particular note is the utilisation of waste heat, which has created a new destination for waste heat in the existing vehicle painting process and promoted the use of hot water from the gas engine exhaust gas. In addition, a high-density adsorbent thermal storage system was used to recover heat from low-temperature exhaust gas and hot exhaust water after passing through the exhaust gas boiler.

In addition, heat is supplied to the painting factory and swimming centre by off-line heat transport. An energy-saving CGS was also constructed to enable the use of waste heat to fill the gap between supply and demand in terms of time and space.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas engine （GE）
Rated power output & number of units	(GE) 7,800 kW × 1 unit (GE) 5,750 kW × 1 unit
Waste heat utilisation	Production process Air conditioning
Fuel	City gas
Power peak cut rate	—
Primary energy reduction rate	22.7%
Expected CO_2 savings amount	1,755 kg-CO_2/h
Electricity, heat, loss ratio	(GE) 49.0% ,23.9%, 27.1%

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

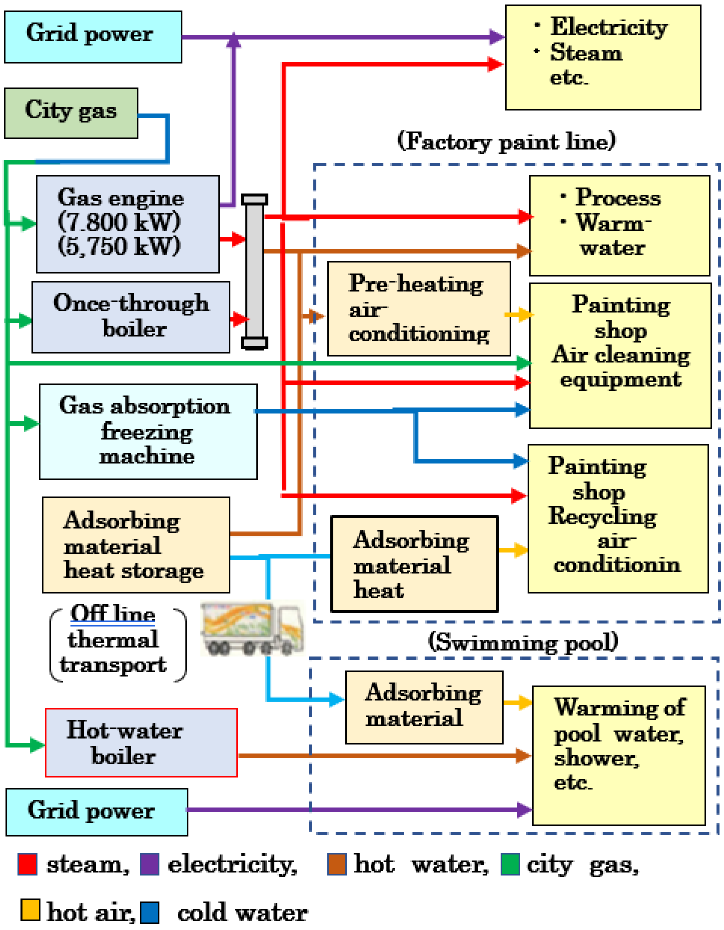
- By using exhaust hot water for heating, the process hot water tank (pre-treatment process) of the automobile painting line, and the preheat air conditioner installed for the painting booth air conditioner, the amount of steam and city gas used is reduced.
- High-density heat storage system uses adsorbent and offline heat transport

Cogeneration waste heat recovery has been realised locally by storing the low-temperature waste heat of cogeneration, which is difficult to utilise, in a newly developed high-density heat storage material. It is then transported to the heat utilisation destination by truck.

This contributes to reducing the energy load of facilities in the area.

Since the heat storage material uses the moisture absorption and desorption reaction, 90% or more of the heat storage amount can be used even if it is stored for a long time only by maintaining the seal. Maintaining the temperature during storage is not needed.

- System flow



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 ¥1,626 million

- Estimated energy-saving amount

Electricity equivalent 3,979 kW/h

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

A1.32. Gas Turbine CGS Integrated with Ethylene Plant Cracking Furnace

1. Industrial Subsectors Case No. 21-4

Chemical industry

2. System Summary

From the viewpoint of further promoting energy conservation at the plant and increasing the ratio of on-site power generation, one 30 MW gas turbine CGS integrated with the ethylene plant cracking furnace, the core plant was installed. The gas turbine generates electricity using natural gas supplied by a dedicated high-pressure pipeline as fuel. And the high-temperature combustion exhaust gas generated from the gas turbine is used as combustion air for the ethylene plant cracking furnace in the subsequent stage, reducing the fuel consumption of the cracking furnace and achieving high energy-saving performance.

3. Configuration and Performance

Item	Contents
Types of power engine	Gas turbine (GT)
Rated power output & number of units	(GT) 30,000 kW × 1 unit
Waste heat utilisation	Combustion air of the ethylene decomposition furnace
Fuel	Natural gas
Power peak cut rate	—
Primary energy reduction rate	26.3%
Expected CO_2 savings amount	4,721 kg-CO_2/h

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

- Energy savings by using combustion exhaust gas directly in an ethylene decomposition furnace

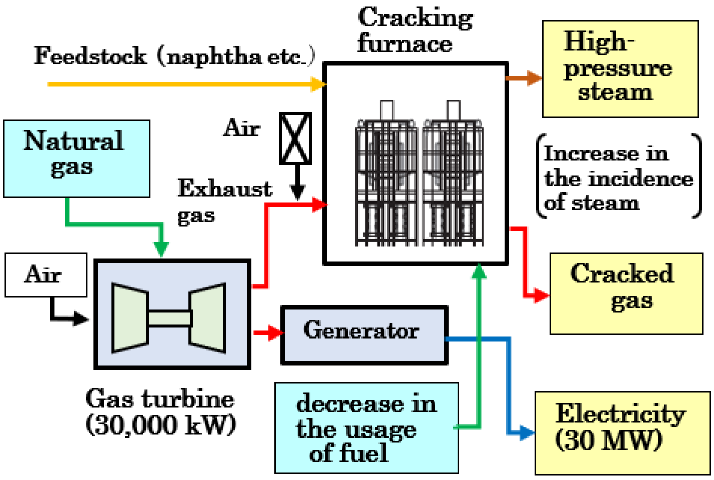
  To maximise use of the exhaust gas from the gas turbine instead of recovering heat by the exhaust heat boiler, etc., the high-temperature combustion exhaust gas after power generation by the gas turbine is used as combustion air for the decomposition furnace burner of the ethylene plant. As a result, the amount of fuel used in the decomposition furnace has been reduced, and the amount of high-pressure steam generated in the decomposition furnace has increased. By installing a gas turbine in the area adjacent to the decomposition furnace and shortening the duct distance for utilising waste heat as much as possible, the equipment cost and energy loss are minimised.

  To best use energy, all the exhaust gas generated from the gas turbine should be directly used in the decomposition furnace. The exhaust gas is evenly distributed to each furnace so that the back pressure of the gas turbine becomes constant.

- Resilience is strengthened, and incidental equipment is reduced by supplying fuel through dedicated piping of the gas company.

Since natural gas is supplied at high pressure, there is no need for a gas compressor dedicated to gas turbines, reducing initial costs. In addition, the absence of a gas compressor leads to energy savings for the compressor operating power during normal times. System reliability has also improved because gas compressor failures did not cause unexpected problems.

- System flow



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 ¥3,600 million

- Estimated energy-saving amount

Electricity equivalent 10,706 kW/h

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

A1.33. Realisation of Energy Savings and BCP Measures by LPG Cogeneration Centred on EMS

1. Industrial Subsectors Case No. 21-5

Food industry

1. System summary

A system that can make the best use of energy 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 production, an LPG micro-CGS capable of supplying hot water was installed to use waste heat effectively. At the same time, introducing an EMS has realised optimal control of cogeneration and reduction of energy management person-hours.

3. 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%s， 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

- Realisation of high-efficiency operation and high operating rate in normal times by installing multiple micro-cogeneration units and optimising control using EMS

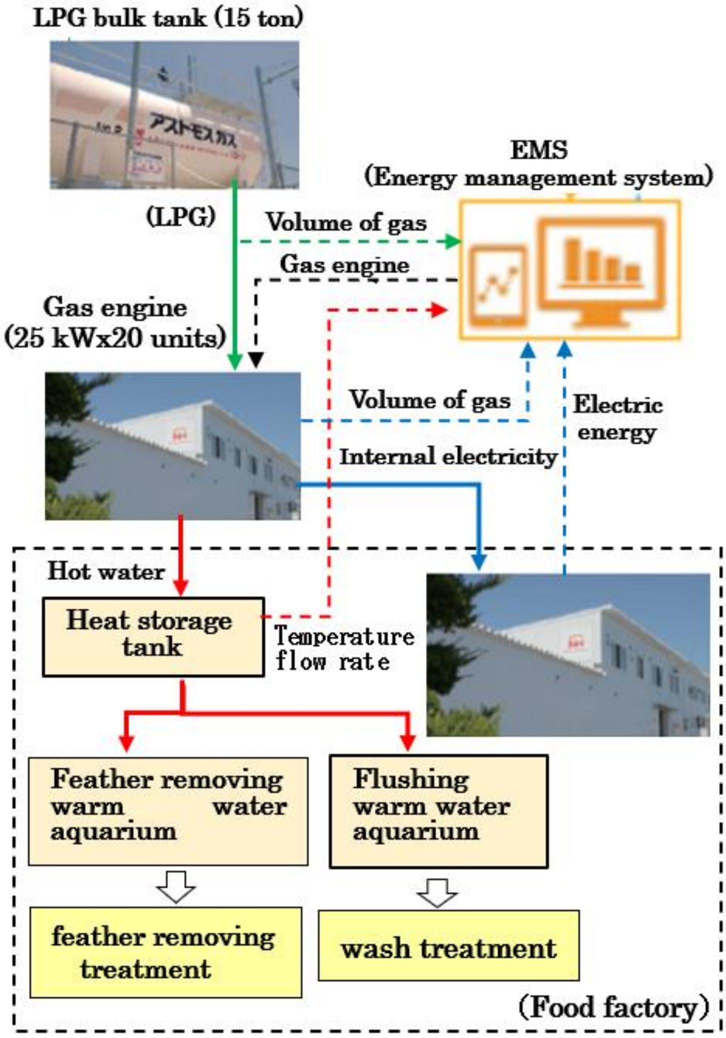
  Installing multiple micro-cogeneration units makes it possible to adjust the number of operating units even in a small load range and operate the equipment with high efficiency at the rated output. Optimal control that responds to fluctuations in electrical and heat loads has become possible by utilising the EMS. Since maintenance can be performed for each micro-cogeneration unit, a high operating rate can be achieved without completely stopping power generation.

- By newly installing the hot water storage tank (heat storage tank), cogeneration hot water can be used effectively.

  The hot water tank for the treatment to remove feathers and the cleaning hot water tank have different required temperature ranges.

Well water from a newly installed hot water storage tank can be heated to the temperature of each tank using waste heat from the CGS, enabling heat cascade use.

- Primary energy consumption and CO_2 emissions were reduced through fuel conversion from heavy oil to LPG.
- System flow



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

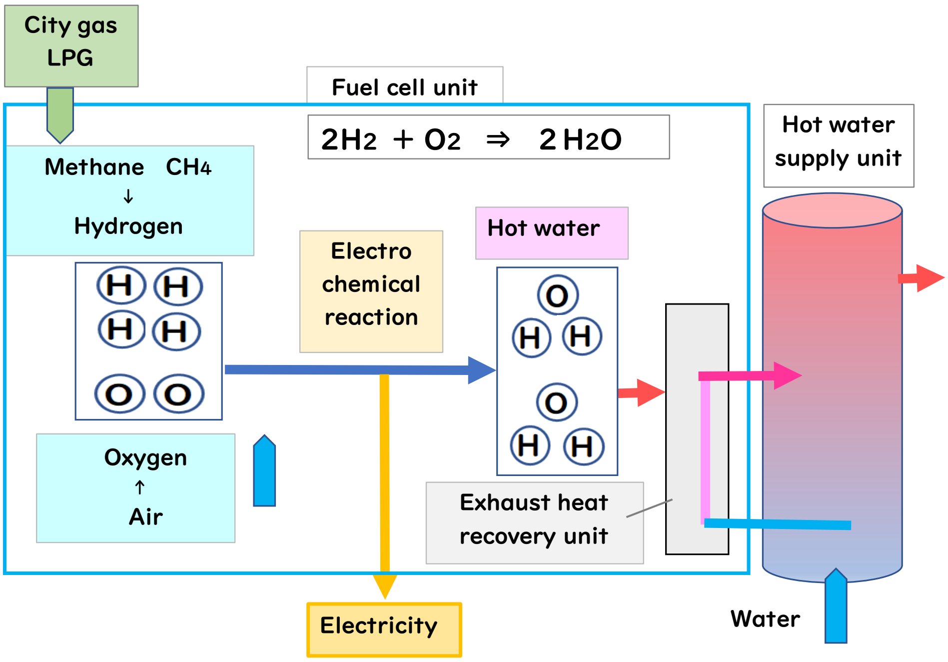
Electricity equivalent 171 kW/h

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

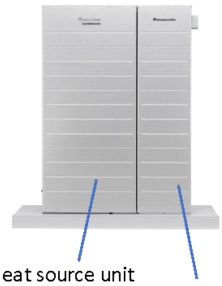
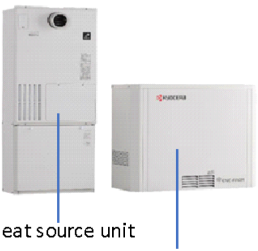
A1.34. Introduction of ENE-FARM

1. Overview

ENE-FARM generates electricity through an electrochemical reaction between hydrogen produced from methane, the main component of city gas and LP gas, and oxygen in the air. Since the energy contained in the fuel is directly utilised without burning it, high power generation efficiency is achieved. ENE-FARM is a household fuel cell CGS that produces electricity at home.



Source: https://www.gas.or.jp/user/comfortable-life/enefarm-partners/enefarm/, modified by the authors.

Manufacturers	P Company  	A Company  	K Company 
Fuel cell method	PEFC	SOFC	SOFC
Electrical output	700 W	700 W	400 W
Overall efficiency	97%	87%	80%
Electricity efficiency	40%	55%	47%
Size (H×W×D) (mm) Fuel cell unit Heat source unit	 1650×40×75 1650×51×75	 1274×66×33 750×480×240	 700×800×350 750×480×250

PEFC = polymer electrolyte fuel cell, SOFC = solid oxide fuel cell.
Source: https://www.gas.or.jp/user/comfortable-life/enefarm-partners/enefarm/ , modified by the authors.

2. Background

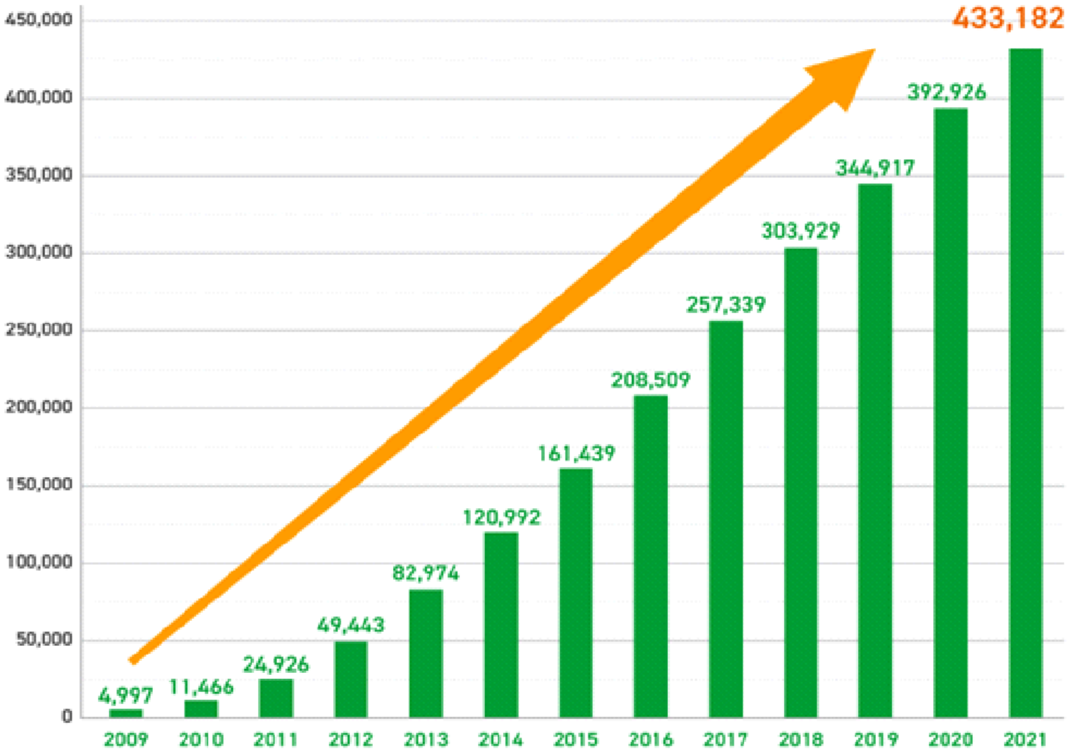
On 1 May 2009, the polymer electrolyte fuel cell (PEFC) type was launched as the world's first residential-use fuel cell. Since then, gas companies have taken the lead with several manufacturers' participation. The SOFC type was launched in 2011, followed by the expansion of models such as the condominium and miniaturised types.

The national government has positioned ’ENE-FARM’ as a front-runner for realising a hydrogen society. Expectations are high for its widespread use, including establishing support programmes for its introduction by the national and local governments.

Different manufacturers use different types. PEFCs have a power generation efficiency of 30%–40%, while SOFCs are more expensive but have a power generation efficiency of over 50%. A model with higher electrical output is currently being developed for industrial applications.

3. Introduction Results

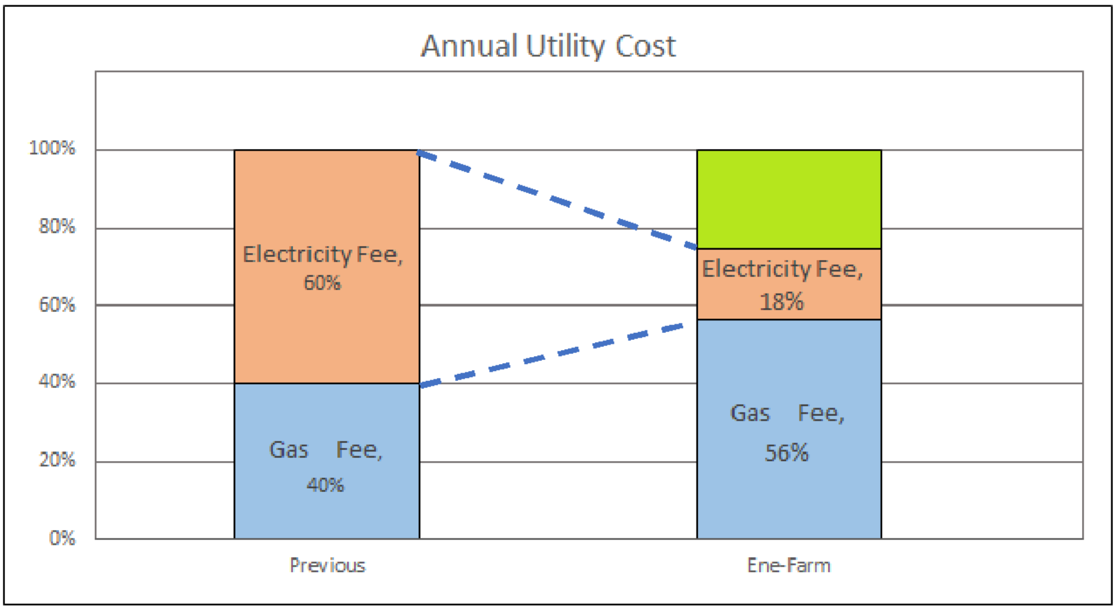
By the end of FY2021, the number of units installed totaled 423,000. (The number of industrial CGS units installed totaled 21,000 in the same year.) The average price is ¥1 million to ¥2 million, including installation costs.



Source: https://www.gas.or.jp/user/comfortable-life/enefarm-partners/enefarm/, modified by the authors.

4. Economic Efficiency

The introduction of ENE-FARM will lower the cost of electricity and increase the cost of gas, but many gas companies offer discounts for gas with ENE-FARM. For example, if the annual cost is ¥400 thousand, the reduction would be ¥104 thousand. If the installation cost of the ENE-FARM is ¥1,500 thousand, the simple payback period would be 14 years, making it difficult to recover the investment within 10 years. However, since it can generate its own electricity, it is effective in the event of power outages and contributes to CO_2 reduction.

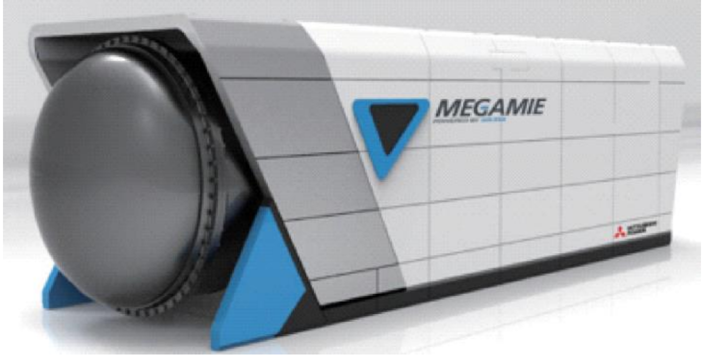


Source: https://www.gas.or.jp/user/comfortable-life/enefarm-partners/enefarm/, modified by the authors.

A1.35. Experimental Market Introduction of Fuel Cells (SOFC) for Commercial and Industrial Use

1. Overview

Towards a future low-carbon society, we have developed an SOFC system that combines as SOFC with a micro gas turbine (MGT), capable of highly efficient power generation. The development of the system began in 1983. Since FY2015, four demonstration units have been installed at four locations in Japan under a government-subsidised project for 250 kW-class units. Verification of durability, start-up, and shutdown tests under actual load, and load change tests were conducted in preparation for market launch, and stable operation was confirmed. The 250 kW-class machines were launched to the market in 2017.



Source: https://www.ace.or.jp/web/gp/pdf/2019/CGS Award2019 Detail.pdf.

2. System Configuration and Performance

Item	Contents
Type	Commercial/Industrial fuel cell
Types of prime movers	SOFC + MGT
Rated power output	200～220 kW
Fuel	City gas
Exhaust Heat Utilisation	Steam or hot water
Power generation efficiency	53%
Exhaust heat recovery efficiency	Steam 14％ Hot water 22％

Source: Advanced Cogeneration and Energy Utilization Center Japan (2019), modified by the authors. https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf'.

3. Features

- Hybrid system of SOFC and MGT

  The system comprises two power generation systems: an upstream SOFC and downstream MGT. Exhaust heat is recovered by installing a heat recovery unit in the exhaust gas section of the MGT. The regenerative heat exchanger raises the temperature of the air supplied to the SOFC.

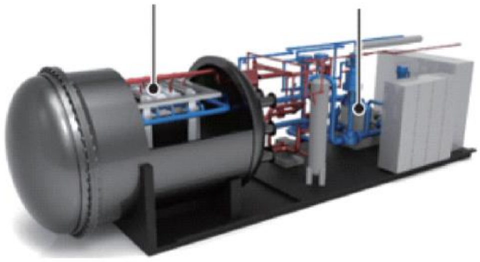
- High power generation efficiency

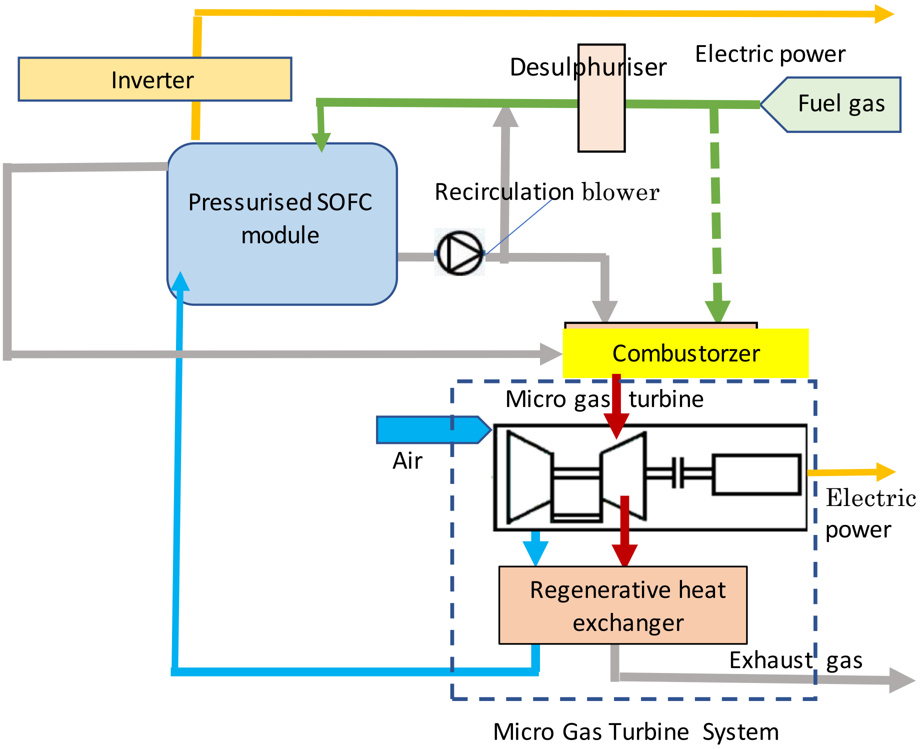
  The combination of SOFC and MGT achieves a power generation efficiency of 53%.

- Improvement of performance

  The pressurised air from the MGT compressor is used to generate power in the pressurised environment of the SOFC to improve the power generation performance.

- System configuration





Source: Advanced Cogeneration and Energy Utilization Center Japan (2019), modified by the authors. https://www.ace.or.jp/web/gp/pdf/2019/CGS-Award2019_Detail.pdf

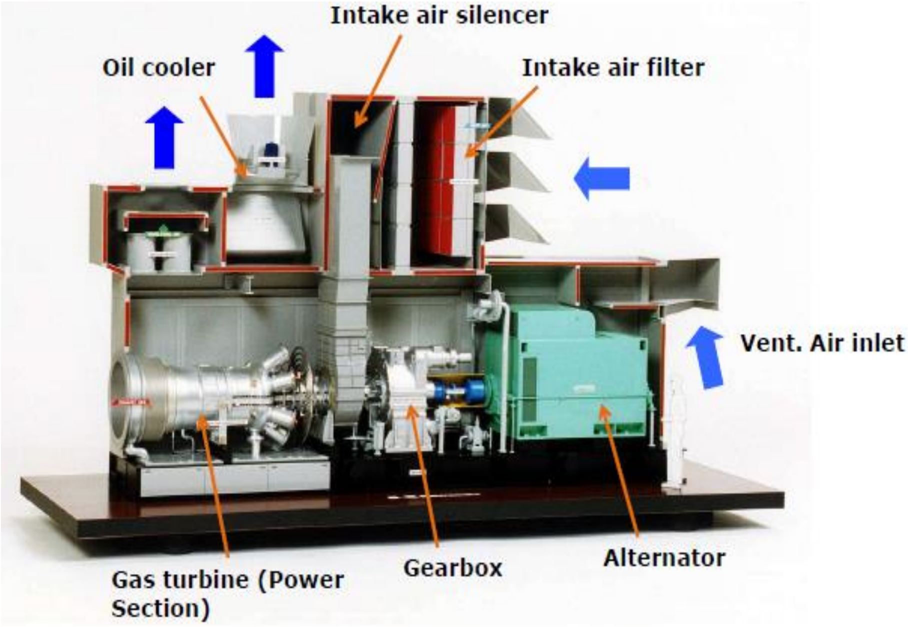
4. Expected effects

- SOFCs can generate electricity from various fuel gases such as digested sewage gas, biomass methane from food and beverage factories, and hydrogen.
- The development of a 1 MW-class system is underway. It is expected to be widely used as a power generation system for large-scale factories and local communities in the future.

Appendix 2

Malaysia's Cogeneration Systems: Case Studies

A2.1. Case Study No. 1: Paper Mill No. 1 – Paperboard & Packaging



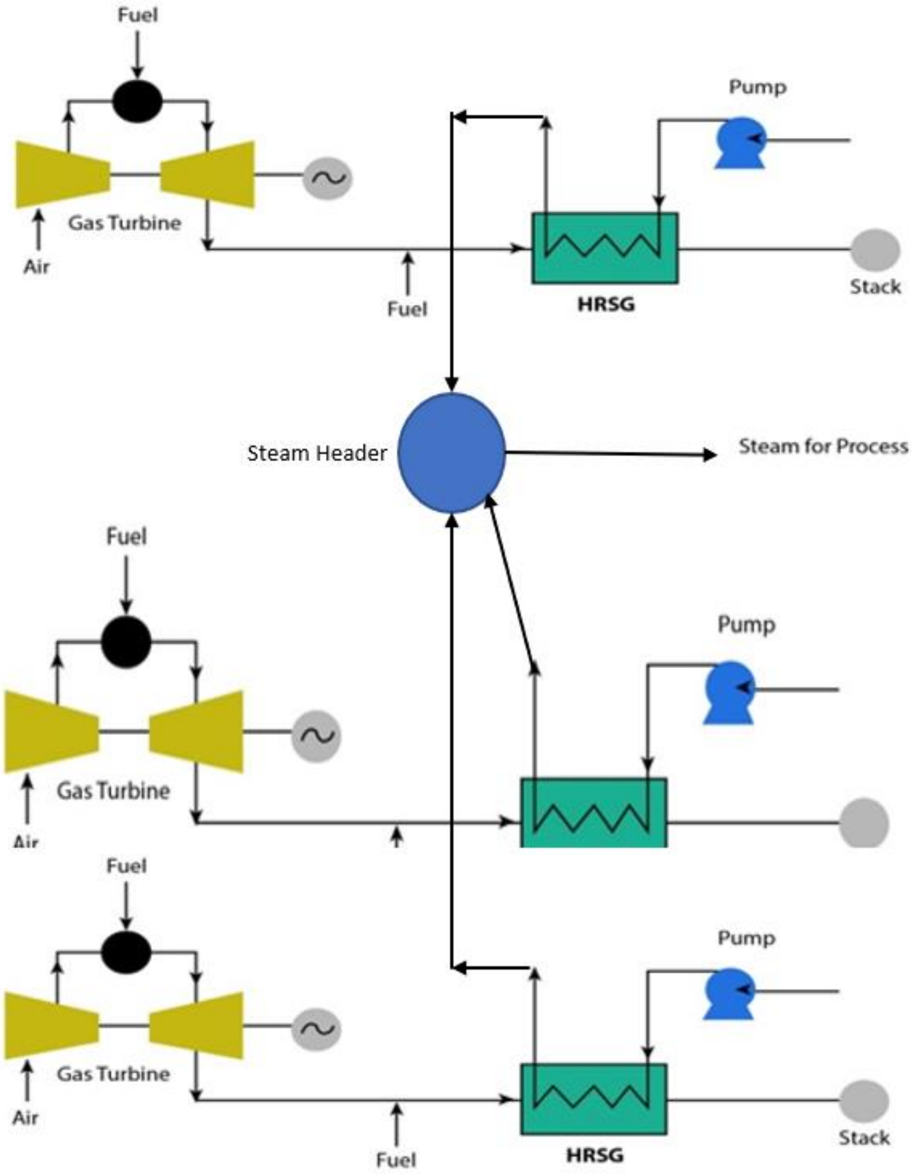
Source: Authors.

Item	Contents
Type of power engine (e.g. gas turbine. gas engine, diesel engine, steam turbine)	Gas turbine
Rated power output (kW)	1 x 32 Mwe
No. HRSG/HRSG pressure (barg) Steam temperature (°C) HRSG capacity from exhaust heat (ton/hr)	1 unit @ 60 barg HRSG Saturated (277°C) 140 t/hr
Fuel	Natural gas
Heat: power ratio	3.01
Estimated electricity demand/year	383,400 MWh/y
Estimated electricity by cogeneration/year	255,600 MWh/y
GT gas consumption/ year	2,840,000.00 MMBtu/y
Estimated operating hours/year	8520 h/y
Approximate cost of investment (RM)	GT: RM55 million HRSG & EPCC: RM20 million

Item	Contents
	Total: RM75 million
Approximate savings (RM/y)	RM11.4 million/y
Simple payback period	years

Source: Authors in consultation with plant operator.

A2.2. Case Study No. 2: Chemical No. 1

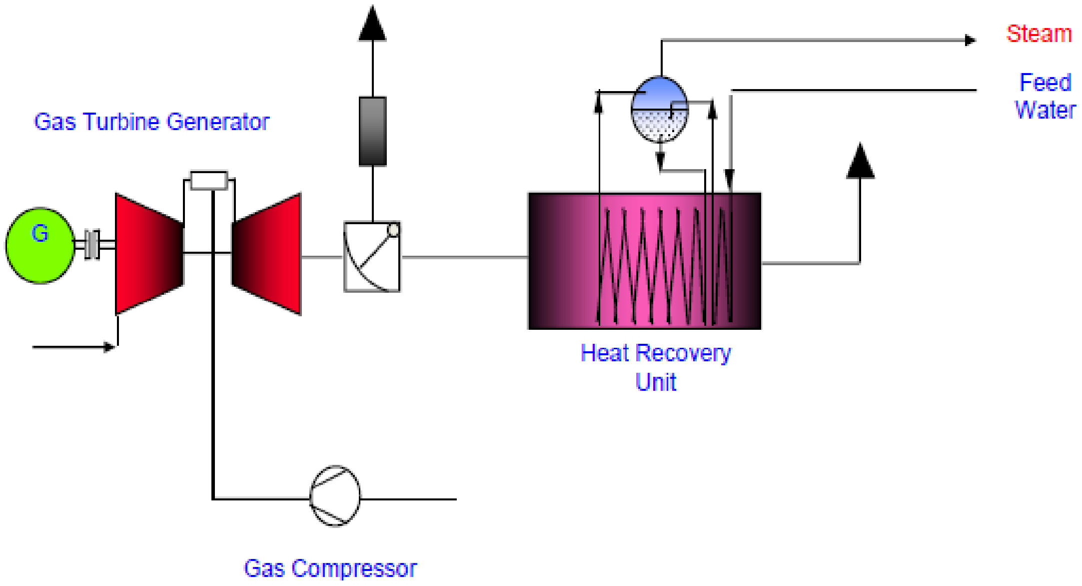


Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output (kW)	3 x 25 MW
HRSG pressure (barg) Steam temperature (°C) HRSG capacity from exhaust heat (ton/hr)	65 barg Saturated (282°C) 3 X 80 t/hr
Fuel	Natural gas
Heat: power ratio	2.2
Estimated electricity demand/year (MWh/y)	783,840
Estimated electricity by cogeneration/year (MWh/y)	613,440
GT gas consumption/year	2,307,500 MMBtu
Estimated operating hours/year (h/y)	8,520 hours/year
Approximate cost of investment (RM)	GT: RM174 million HRSG: RM36 million. Total: RM210 million
Approximate savings (RM/y)	RM33 million/yr
Simple payback period	6.36 years

Source: Authors in consultation with plant operator.

A2.3. Case Study No. 3: Paper Mill No. 2

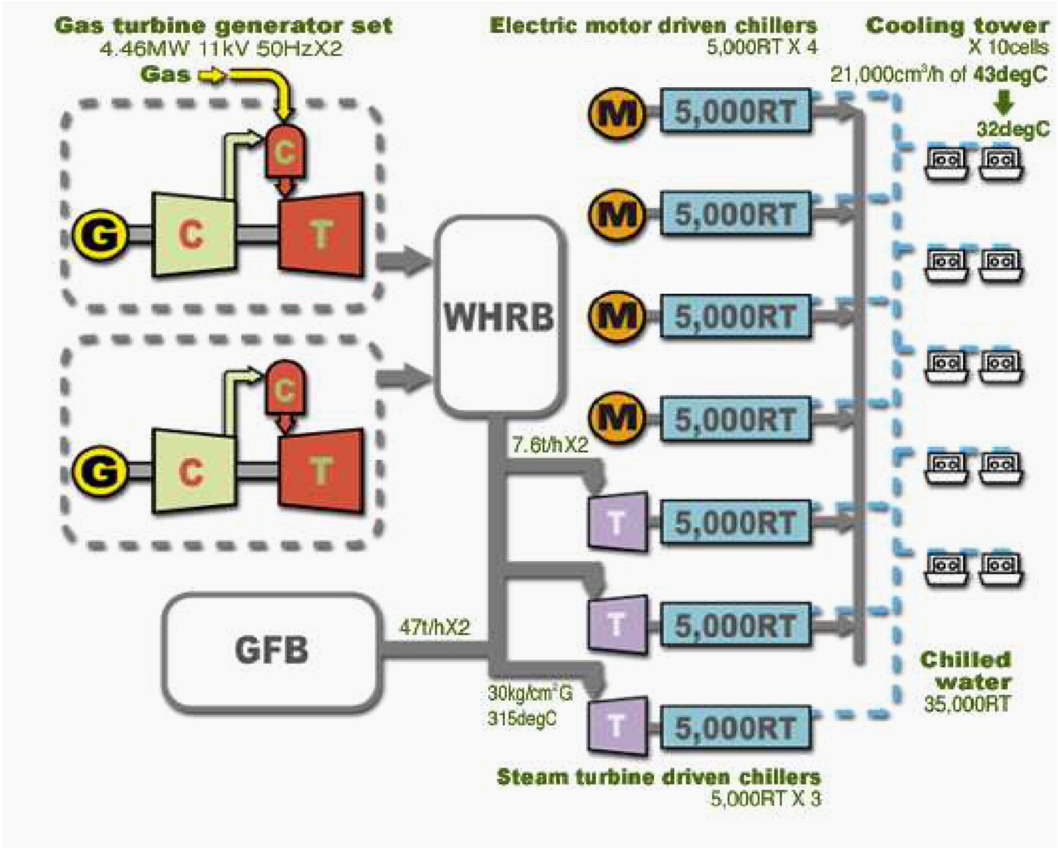


Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output (kW)	1 x 33MW
HRSG pressure (barg) Steam temperature (°C) HRSG capacity from exhaust heat (ton/hr)	65 barg Saturated (282°C) 1 x 100 t/hr
Fuel	Natural Gas
Heat: power ratio	2.08
Estimated electricity demand/year	391,920 MWh/y
Estimated electricity by cogeneration/year	264,120 MWh/y
GT gas consumption/year	3,017,500 MMBtu
Estimated operating hours/year	8,520 h/y
Approximate cost of investment (RM)	GT: RM48 million HRSG & EPCC: RM20 million Total: RM68 million
Approximate savings (RM/y)	RM12.4 million/y
Simple payback period	5.48 years

Source: Authors in consultation with plant operator.

A2.4. Case Study No. 4: Gas District Cooling



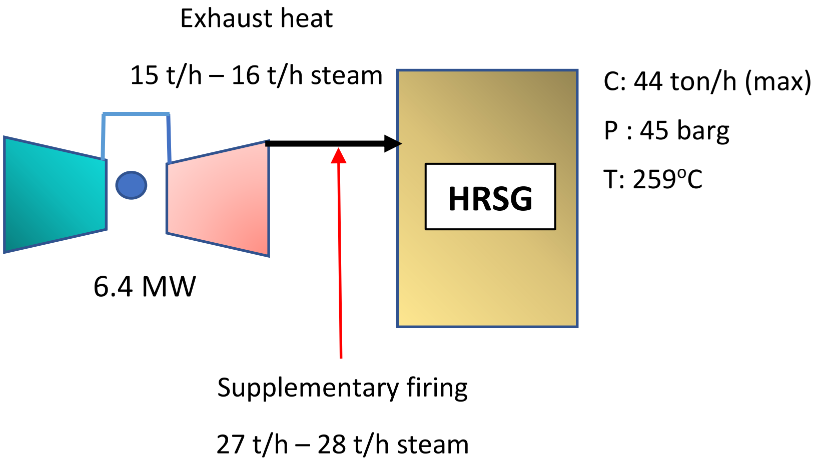
Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output (kW)	2 x 5.4 MW
HRSG pressure (barg) Steam temperature (°C) HRSG capacity from exhaust heat (ton/hr)	18 barg Saturated (210°C) 1 x 15 t/hr
Fuel	Natural gas
Heat: power ratio	0.96
Estimated electricity demand/year	53,700 MWh/y
Est. electricity by Cogen/year	42,960 MWh/y
GT gas consumption/year	1,008,000 MMBtu/yr
Estimated operating hours/year	8640 h/y

Item	Contents
Approximate cost of investment (RM)	GT: RM45 million WHRB & EPCC: RM30 million
Approximate savings (RM/y)	RM17 million/y
Simple payback period	4.4 years

Source: Authors in consultation with plant operator.

A2.5. Case Study No. 5: Edible Oil



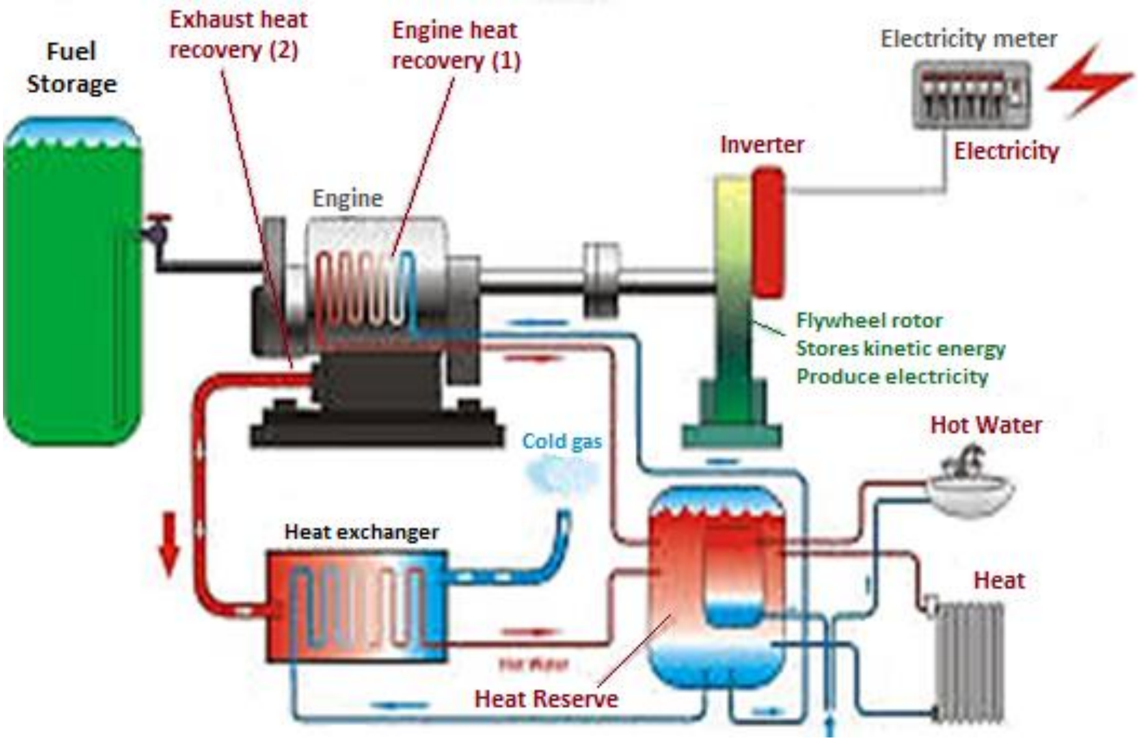
Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output (kW)	1 x 6.4 MW
HRSG pressure (barg) Steam temperature (°C) HRSG capacity from exhaust heat (ton/hr) HRSG capacity from duct burner (ton/hr)	1 no @ 45 barg Saturated (259°C) 15 t/hr–16 t/hr 27 t/hr–28 t/hr
Fuel	Natural gas
Heat : Power ratio	1.72
Estimated electricity demand/year	68,700 MWh/y
Estimated electricity by cogeneration/year	54,000 MWh/y
GT gas consumption/year	648,000 MMBtu/y
Estimated operating hours/year	8,640 h/y

Item	Contents
Approximate cost of investment (RM)	GT: RM28 million HRSG & EPCC: RM21 million Total: RM49 million
Approximate savings (RM/y)	RM8.1 million/yr
Simple payback period	6 years

Source: Authors in consultation with plant operator.

A2.6. Case No. 6: Glove Manufacturing



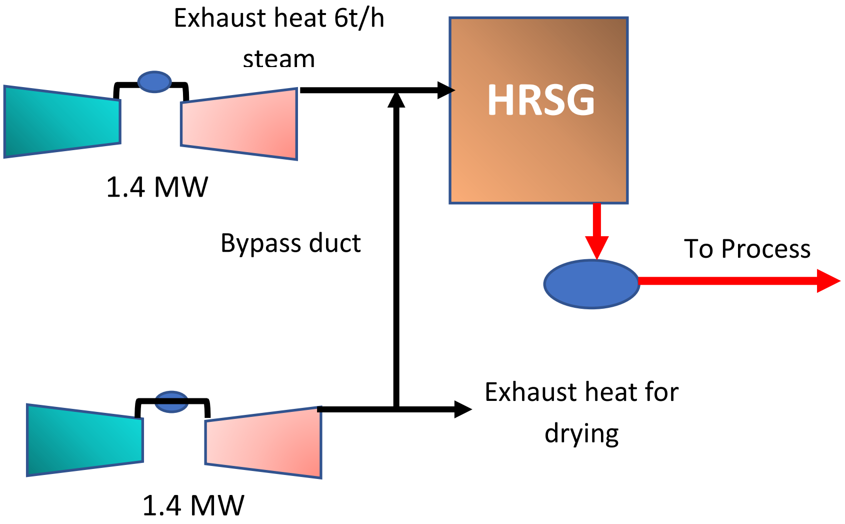
Source: Authors.

Item	Contents
Type of power engine	Gas engine
Rated power output (kW)	1 x 1.2 MW 1 x 2.0 MW
Total HRSG hot water flow (m^3/h) Steam temperature (°C) No. hot water HRSG utilising exhaust heat	60–100 m^3/h 60–80°C 2 nos.
Fuel	Natural gas
Heat: power ratio	1.82
Estimated electricity demand/year	30,240 MWh/y

Item	Contents
Estimated electricity by cogeneration/year	25,920 MWh/y
GT gas consumption/year	555,000 MMBtu/yr.
Estimated operating hours/year	8,640 h y
Approximate cost of investment (RM)	Gas engine: RM6 million
Approximate savings (RM/y)	RM2.1 million/yr
Simple payback period	2.85 years

Source: Authors in consultation with plant operator.

A2.7. Case Study No. 7: Chemical Plant No. 2



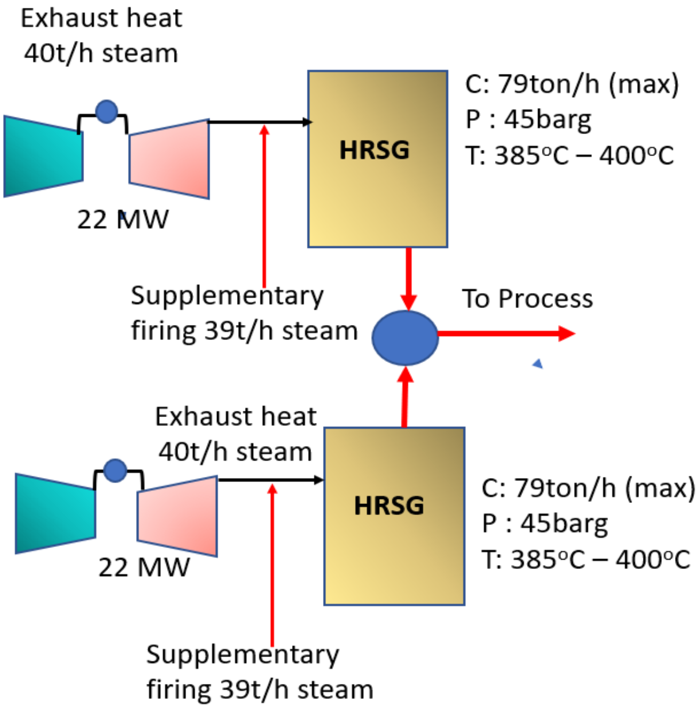
Source: Authors.

Item	Contents
Type of power engine	Gas turbine (GT)
Rated power output	2 x 1,400 kW
HRSG pressure (barg) Steam temperature (°C) Steam capacity from cogeneration (t/h)	13 barg Saturated (195°C) 6 t/h (run at 4 t/h)
Fuel	Natural gas
Heat: power ratio (actual total heat used: steam + drying)	1.48
Estimated electricity demand/year	1,049 MWh/y
Estimated electricity from cogeneration/year	877 MWh/y

Item	Contents
GT gas consumption/year	330,389 GJ/y
Estimated operating hours/year	8,424 h/y
Approximate cost of investment	RM 25 million
Estimated approximate savings (RM/y)	RM4.76 million/y
Simple payback period: longer payback due heat generated not being fully utilised.	5.25 years

Source: Authors in consultation with plant operator.

A2.8. Case Study No. 8: Chemical Plant No. 3



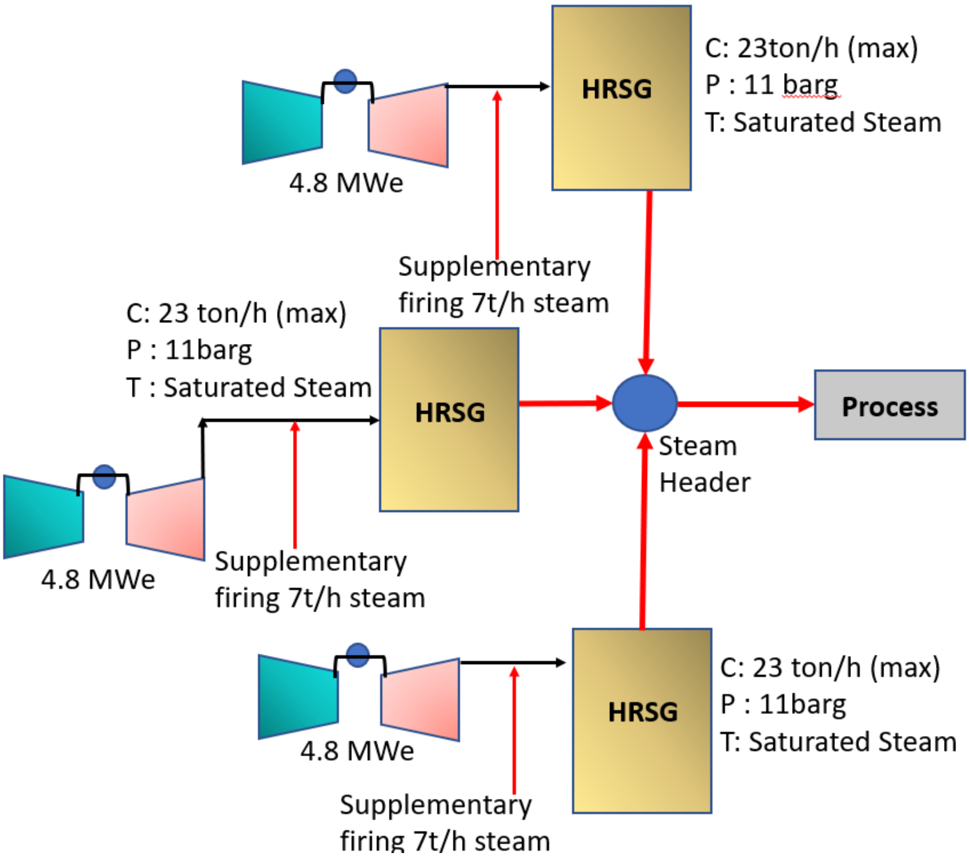
Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output	2 x 22 Mwe
HRSG pressure Steam temperature HRSG capacity (cogeneration/supplementary firing)	45 barg 385°C–400°C 2 X (40 t/h/39 t/h) Total output: 79 t/h (max)
Fuel	Natural gas
Heat: power ratio	1.46

Item	Contents
Estimated electricity demand/year	Not available
Estimated electricity from cogeneration/year	378,400 MWh/y
GT Gas consumption/year	Not available
Estimated operating hours/year (h/y)	8,600 h/y
Approximate cost of investment	RM203.4 million
Approximate savings (RM/y)	RM32.17 million/y
Simple payback period	6.32 years

Source: IEPRe (2020).

A2.9. Case Study No. 9: Paper Mill No. 3



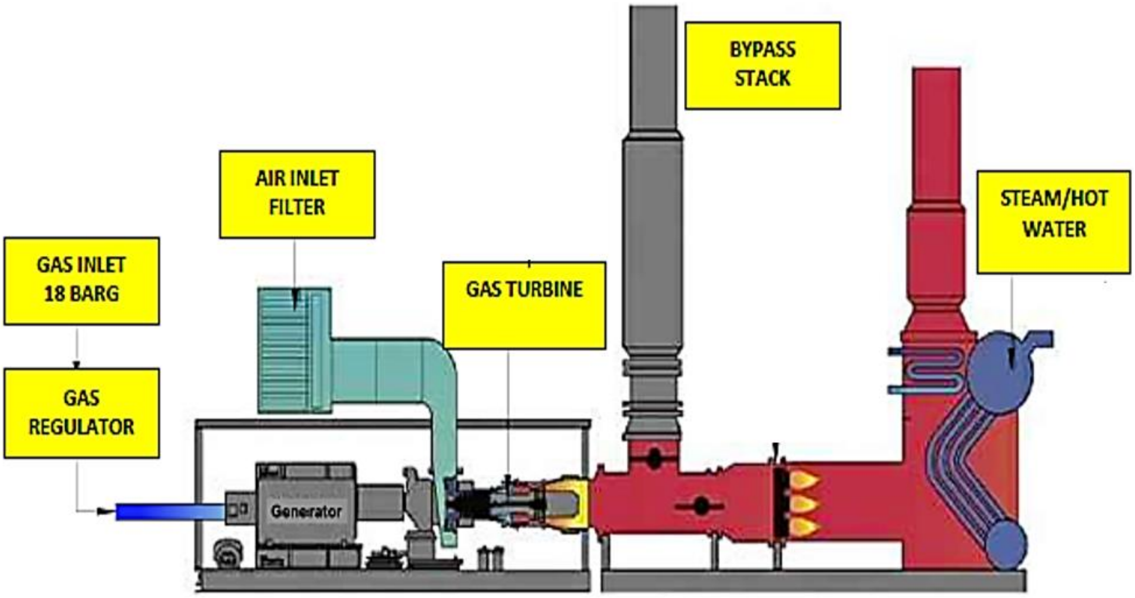
Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output (generating 14.5 MW and 7 MW import from TNB)	3 X 4.8 MW

Item	Contents
HRSG pressure Steam temperature Steam capacity (cogeneration/supplementary firing)	11 barg Saturated (188°C) 3 units HRSG: 16/h (Cogen)/7 t/h (S/F)
Fuel	Natural gas
Heat: power ratio	2.29
Estimated electricity demand/year	184,900 MWh/y
Estimated electricity from cogeneration/year	124,700 MWh/y
GT gas consumption/year	Not available
Estimated operating hours/year	8,600 h/y
Approximate cost of investment	RM47 million
Approximate savings (RM/y)	RM16.83 million / y
Simple payback period	2.92 years

Source: IEPRe (2020).

A2.10. Case Study No. 10: Oleochemical Plant No. 1



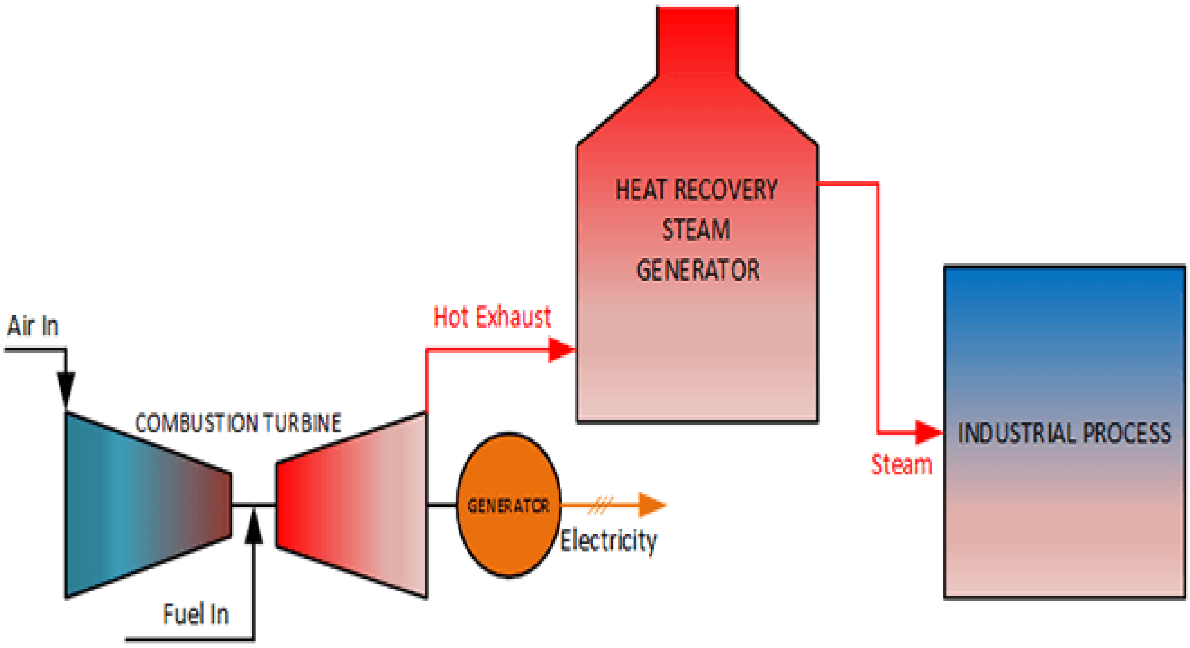
Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output (generation is 5.23 MW)	1 x 6500 kW

Item	Contents
HRSG pressure Steam temperature Steam capacity (cogeneration/supplementary firing)	22 barg Saturated 15 t/h /7.6 t/h
Fuel	Natural gas
Heat: power ratio	1.6
Estimated electricity demand/year (MWh/y)	48,400 MWh/y
Estimated electricity from cogeneration/year (MWh/y)	45,000 MWh/y
GT gas consumption/year	538,076 GJ/y
Estimated operating hours/year (h/y)	8,600 h
Approximate cost of investment (inclusive of all electrical & water treatment auxiliaries, etc.)	RM50 million
Approximate savings (RM/y)	RM995,291/y
Simple payback period (higher payback period due to higher investment on additional equipment as above)	11.51 years

Source: IEPRe (2020).

A2.11. Case Study No. 11: Oleochemical Plant No. 2

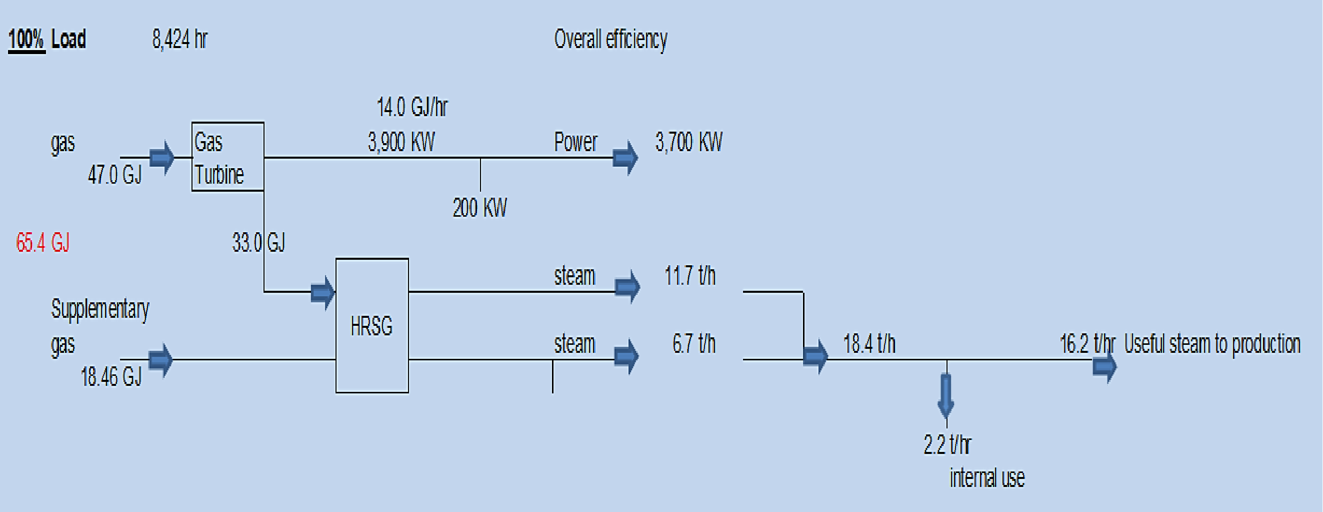


Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output	1 x 6500 kW
HRSG pressure (barg) Steam temperature (°C) Boiler capacity (ton/hr)	16 barg Saturated (204°C) 16.7 t/h
Fuel	Natural gas
Heat: power ratio	1.78
Estimated electricity demand/year	57,850 MWh/y
Estimated electricity cogeneration/year	56,693 MWh/y
GT gas consumption/year	657,000 MMBtu/y
Estimated operating hours/year (h/y)	8,600 h/y
Approximate cost of investment (huge discount - company bought few cogeneration)	RM19.1 million
Approximate savings (RM/y)	RM6 million/year
Simple payback period	3.54 years

Source: Authors in consultation with plant operator.

A2.12. Case Study No. 12: Oleochemical Plant No. 3

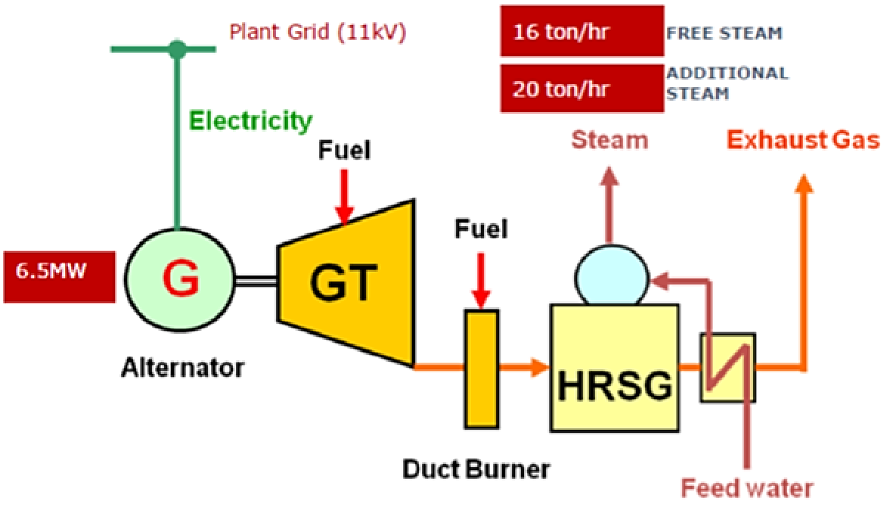


Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output	1 x 4.0 MW
HRSG pressure (barg) Steam Temperature (°C) HRSG capacity from exhaust heat (ton/hr) HRSG capacity from duct burner (ton/hr)	1 @ 10.5 barg Saturated (186°C) 11.7 t/h 18.3 t/h
Fuel	Natural gas
Heat: power ratio	2.02
Estimated electricity demand/year	34,500 MWh/y
Estimated electricity cogeneration/year	31,200 MWh/y
GT gas consumption/year	605,877 GJ/y
Estimated operating hours/year (h/y)	8,424 h/y
Approximate cost of investment	RM30.5 million
Approximate savings (RM/y)	RM5.59 million/y
Simple payback period	5.5 years

Source: Authors in consultation with plant operator.

A2.13. Case Study No. 13: Oleochemical Plant No. 4



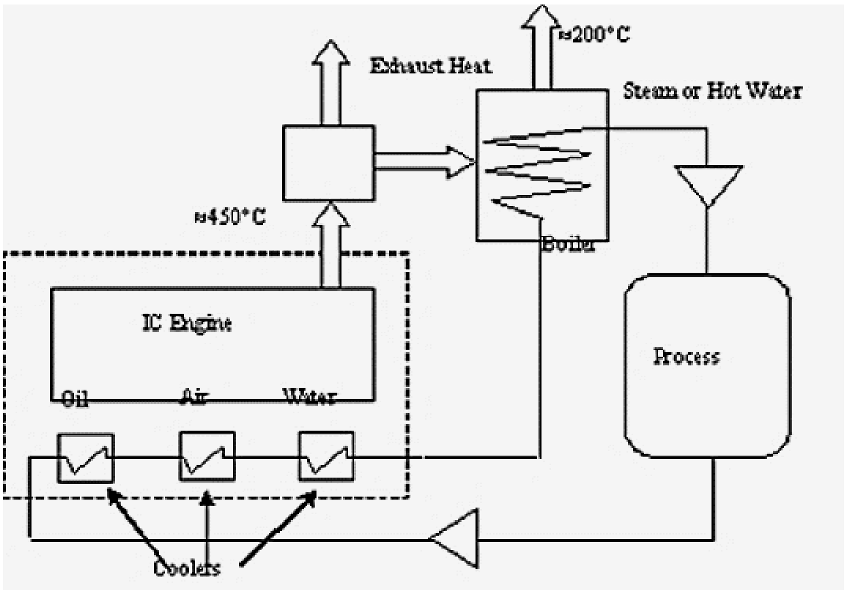
1 x GTG Output @ ISO Rating	7800	kW
1 x GTG Output @ 32° C (Gross)	6540	kW
1 x HRSG Unfired Steam Output (Gross)	16.9	tph

Source: Authors.

Item	Contents
Type of power engine	Gas turbine
Rated power output	1 x 6.5 MW
HRSG pressure (barg) Steam temperature (°C) HRSG capacity from exhaust heat (ton/hr) HRSG capacity from duct burner (ton/hr)	16 barg Saturated (204°C) 16 t/h 20 t/h
Fuel	Natural gas
Heat: power ratio	1.7
Estimated electricity demand/year	59,000 MWh/y
Estimated electricity cogeneration/year	52,500 MWh/y
GT gas consumption/year	655,000 MMBtu/y
Estimated operating hours/year (h/y)	8,520 hr
Approximate cost of investment	RM33 million
Approximate savings (RM/y)	RM4.5 million/y
Simple payback period	7.3 y

Source: Authors in consultation with plant operator.

A2.14. Case Study No. 14: Textile Factory No. 1

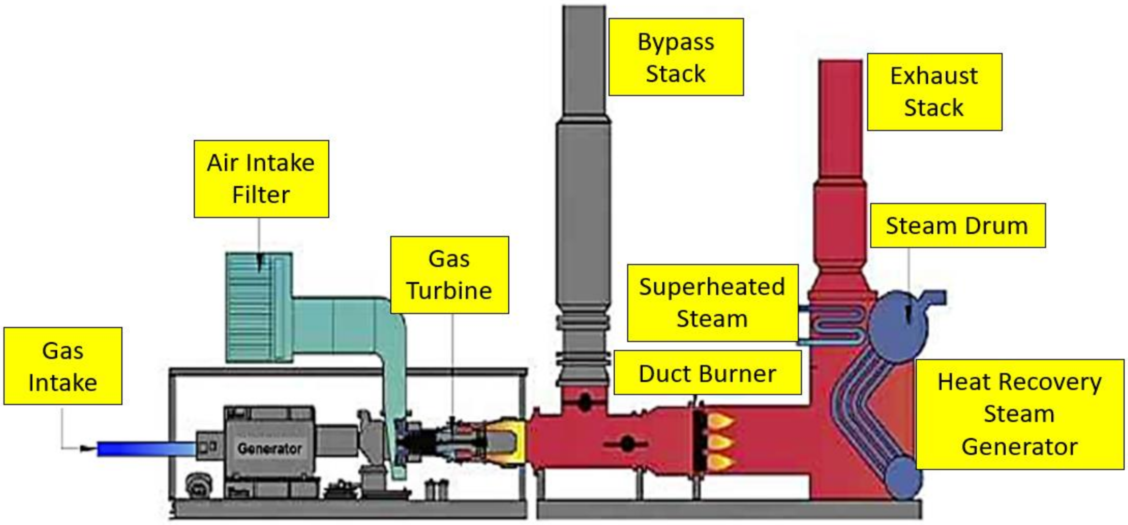


Source: Authors.

Item	Contents
Type of power engine	Gas engine
Rated power output	1 x 5.2 MW
HRSG pressure (barg) Steam temperature (°C) HRSG capacity from exhaust heat (ton/hr)	8 barg Saturated (175°C) 2.2 t/h
Fuel	Natural gas
Heat: power ratio	0.29
Estimated electricity demand/year	44,370 MWh/y
Estimated electricity cogeneration/year	41,600 MWh/y
Gas consumption/hour	1,083 Nm^3/h
Estimated operating hours/year	8,322 h/y
Approximate cost of investment	RM27.2 million
Approximate savings (RM/y)	RM5.64 million /y
Simple payback period	5.86 years

Source: Authors in consultation with plant operator.

A2.15. Case Study No. 15: Third-Party Utility (ESCO)

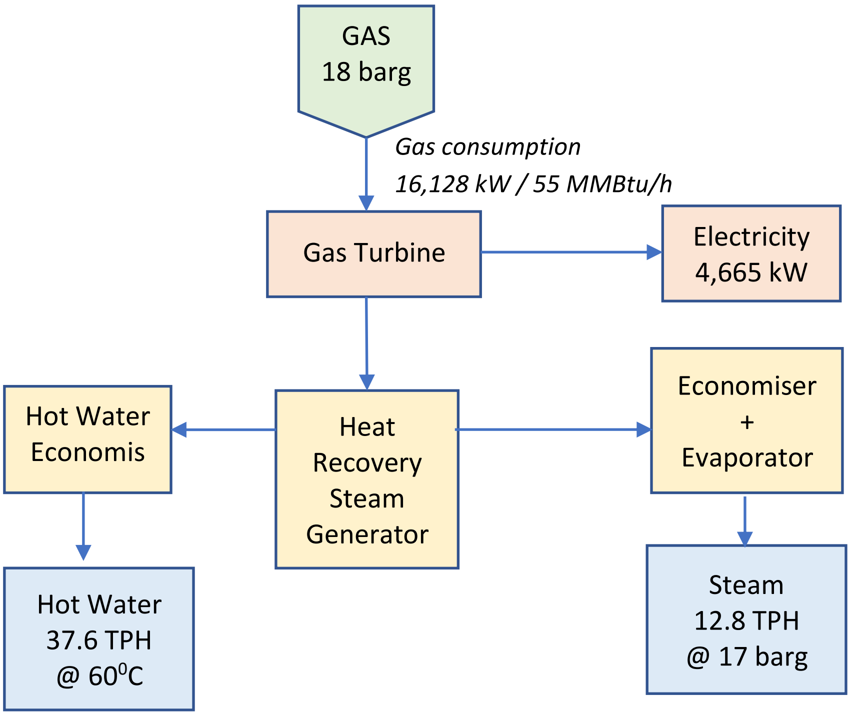


Source: Authors.

Item	Contents
Type of power engine	Gas turbine (GT)
Rated power output	1 x 16.28 MWe
HRSG pressure Steam temperature HRSG capacity from exhaust heat (ton/hr) HRSG capacity from supplementary firing (ton/hr)	60.8 barg 292°C) 28 t/h 60 t/h
Fuel	Natural gas
Heat: power ratio	1.22
Estimated electricity demand/year	133,900 MWh/y
Estimated electricity from cogeneration/year	115,288 MWh/y
GT gas consumption/year	40,508,781 S m^3 /y
Estimated operating hours/year	8,400 h/y
Approximate cost of investment	RM110 million
Approximate savings (RM/y)	RM11 million/y
Simple payback period	10 years

Source: Authors in consultation with plant operator.

A2.16. Case Study No. 16: Textile Factory No. 2

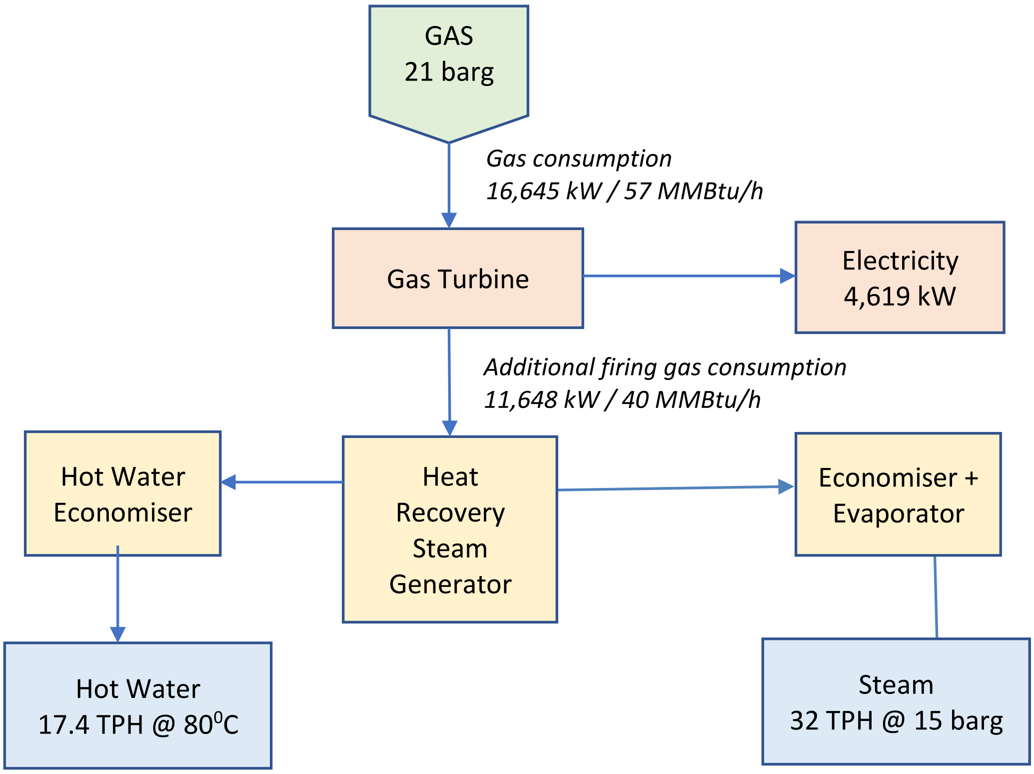


Source: Authors.

Specification	Description
System configuration	• 4,665 kW Gas turbine • HRSG • Steam/hot water generator
Operating hours	8,000
GT gas consumption	16,128 kW / 55 MMBtu/h
HRSG capacity	12.8 TPH steam @17 barg
Thermal energy for steam/y	66,560 MWh/y
HRSG capacity for hot water	37.6 TPH 60^{0}C hot water (from 27^{0}C)
Thermal energy for hot water/y	11,584 MWh/y
Heat: power ratio	2.094
Investment cost	RM35 million (US$8.33 million)
Savings	RM5.68 million/y
Simple payback period	6.16 years

Source: Authors.

A2.17. Case Study No. 17: Oil Refinery

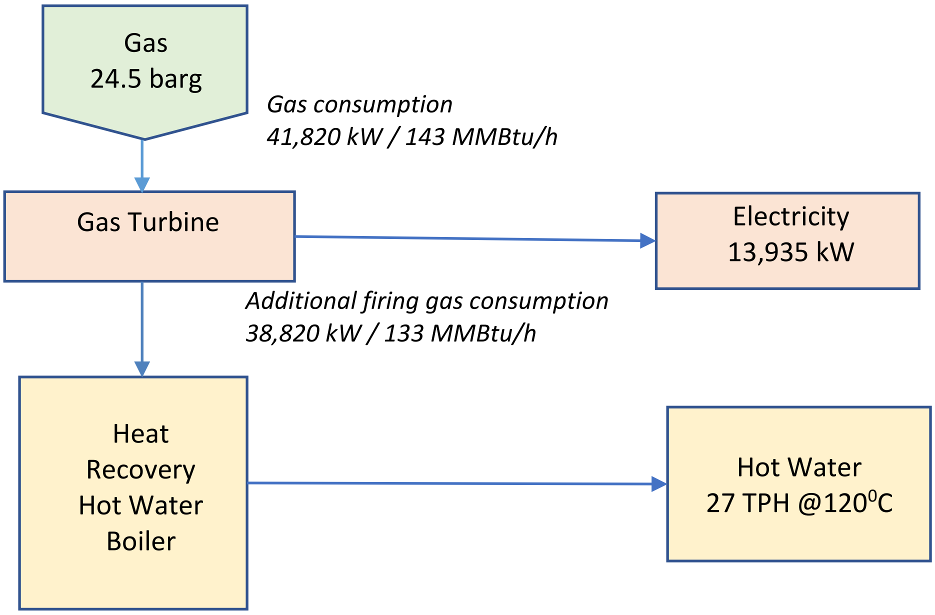


Source: Authors in consultation with Kawan Engineering Sdn Bhd. (2022).

Specification	Description
System configuration	- 4,619 kW gas turbine - HRSG - Steam/hot water generator
Operating hours	8,000
GT gas Consumption	16,645 kW 57 MMBtu/h
Gas consumption for additional firing	11,648 kW/40 MMBtu/h
HRSG capacity	32 TPH steam @15 barg
Thermal energy for steam/y	171,800 MWh/y
HRSG capacity for hot water	17.4 TPH 80^{0}C hot water (from 27^{0}C)
Thermal energy for hot water/year	8,640 MWh/y
Heat: power ratio	4.882
Investment cost	RM33 million
Savings	RM7.886 million/y
Simple payback period	4.18 years

Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

A2.18. Case Study 18: Rubber Glove Factory

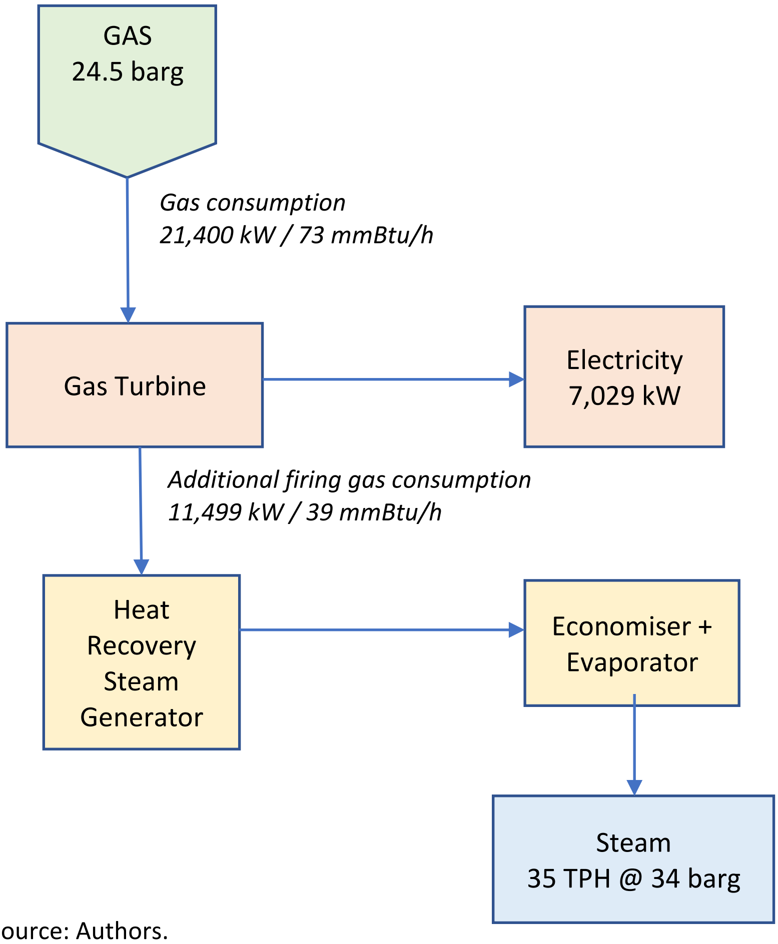


Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

Specification	Description
System configuration	- 13,935 kW gas turbine - HRSG - Hot water generator
Operating hours	8,000
GT Gas Consumption	41,820 kW/143 MMBtu/h
Gas consumption for additional firing	38,820 kW/133 MMBtu/h
HRSG capacity for hot water	27 TPH @120^{0}C from 90^{0}C
Thermal energy for hot water/year	432,000 MWh/y
Heat: power ratio	3.87
Investment cost	RM46 million
Savings	RM11.03 million/y
Simple payback period	4.17 years

Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

A2.19. Case Study No. 19: Oleochemical Plant No. 5

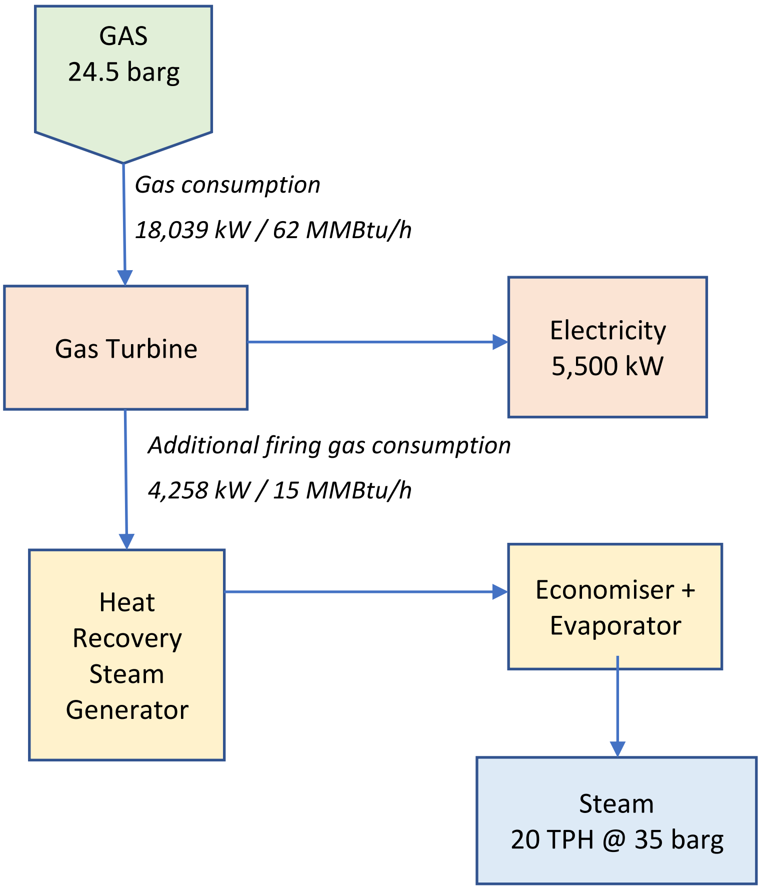


Source: Authors.

Specification	Description
System configuration	• 7,029 kW gas turbine • HRSG
Operating hours	8,000
GT gas consumption	21,400 kW/73 MMBtu/h
Gas consumption for additional firing	11,499 kW/39 MMBtu/h
HRSG capacity	35 TPH steam @34 barg
Thermal energy for steam/y	181,086 MWh/y
Heat: power ratio	3.22
Investment cost	RM37 million
Savings	RM5.974 million/y
Simple payback period	6.2 years

Source: Authors.

A2.20. Case Study No. 20: Biomass Processing Plant

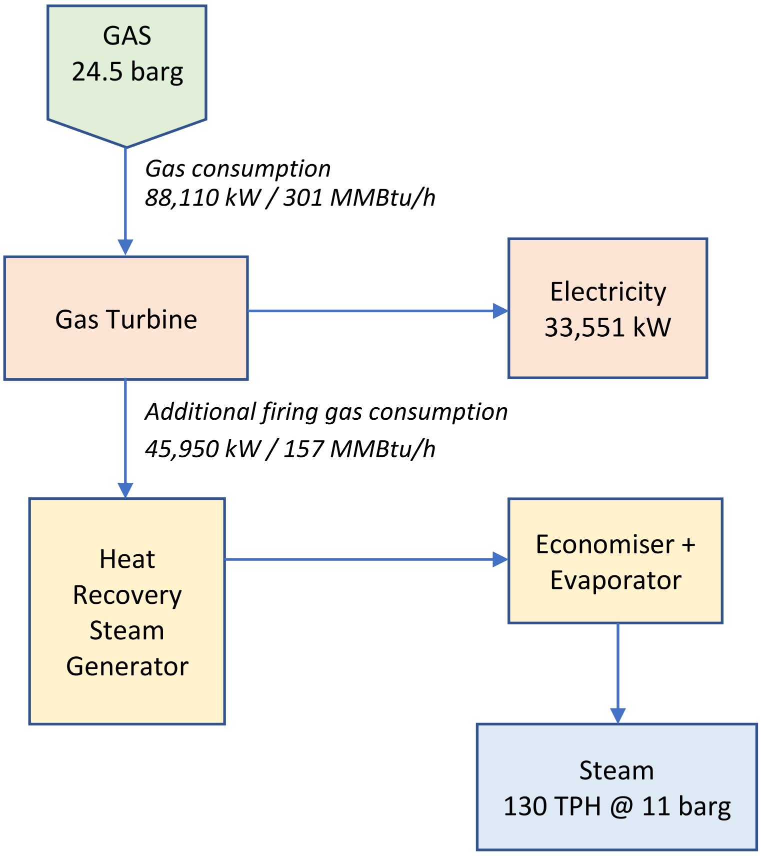


Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

Specification	Description
System configuration	5,500 kW gas turbine HRSG
Operating hours	8,000
GT gas Consumption	18,039 kW/62 MMBtu/h
Gas consumption for additional firing	4,258 kW/15 MMBtu/h
HRSG capacity	20 TPH steam @35 barg
Thermal energy for steam/y	103,784 MWh/y
Heat: power ratio	2.35
Investment cost	RM35 million
Savings	RM5.336 million/y
Simple payback period	6.56 years

Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

A2.21. Case Study No. 21: Animal Feed Ingredient Plant

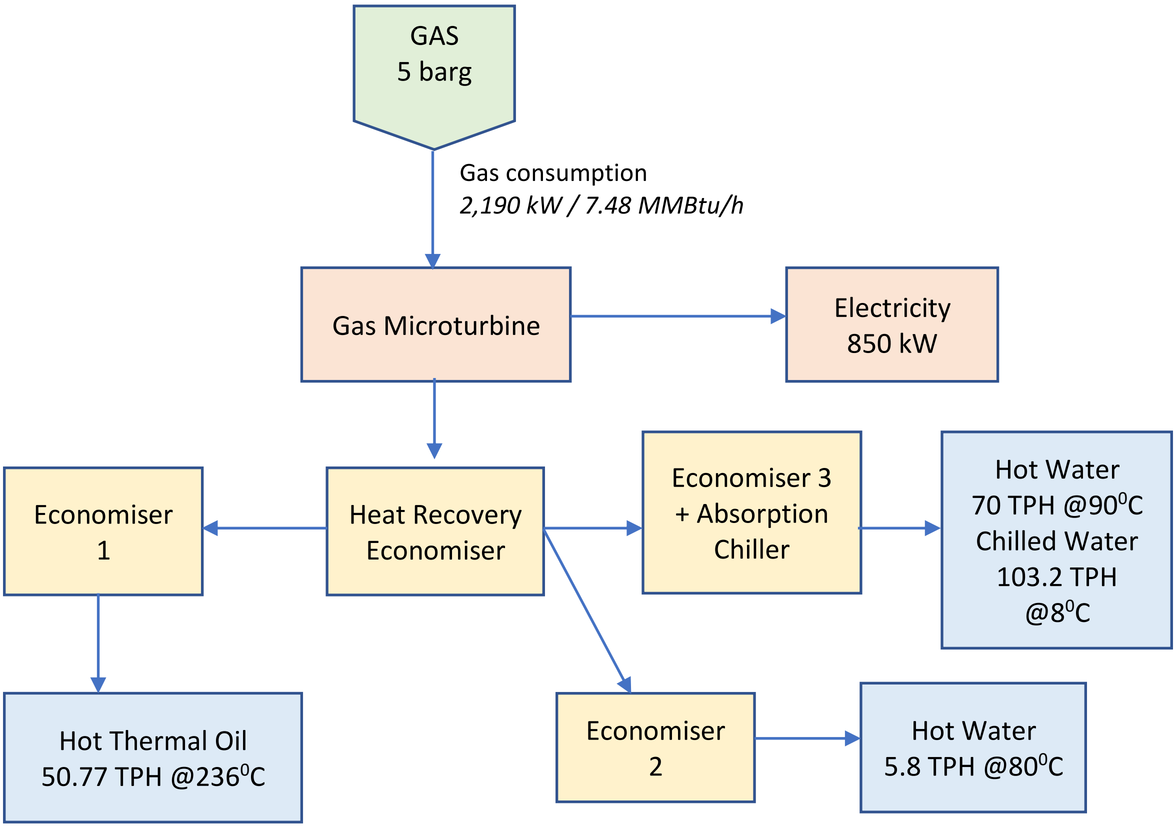


Source: Authors in consultation with Kwan Engineering Sdn Bhd (2022).

Specification	Description
System configuration	- 33,551 kW gas turbine - HRSG
Operating hours	8,000
GT gas consumption	88,110 kW/301 MMBtu/h
Gas consumption for additional firing	45,950 kW/157 MMBtu/h
HRSG capacity	130 TPH steam @11 barg
Thermal energy for steam/y	674,195 MWh/y
Heat: power ratio	2.51
Investment cost	RM144 million
Savings	RM37.83 million/y
Simple payback period	3.8 years

Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

A2.22. Case Study No. 22: Chemical Plant No. 3



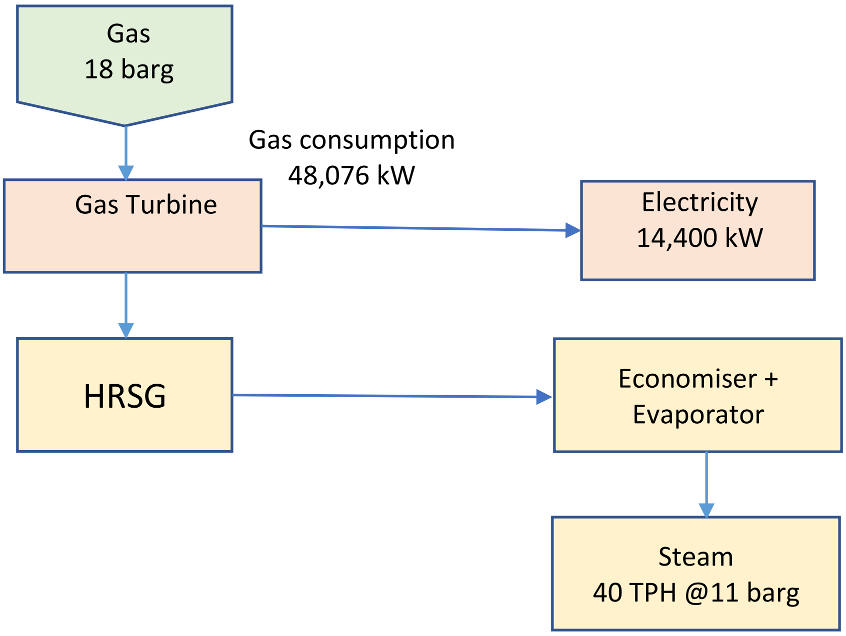
Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

Specification	Description

System configuration	- 850 kW microturbine - Economiser - Absorption chiller
Operating hours	8,000
Gas consumption	2,190 kW/7.48 MMBtu/h
Economiser capacity	- 50.77 TPH @236^{0}C thermal oil from 227^{0}C - 5.8 TPH 80^{0}C HW from 30^{0}C - 70 TPH 90^{0}C HW from 77^{0}C - 103.2 TPH chilled water @8^{0}C
Thermal energy for thermal oil & hot water	13,535 MWh/y
Electricity: heat ratio	1.99
Investment cost	RM18 million
Savings	RM2.087 million
Simple payback period	8.62 years

Source: Authors in consultation with Kawan Engineering Sdn Bhd (2022).

A2.23. Case Study No. 23: Paper Mill No. 4



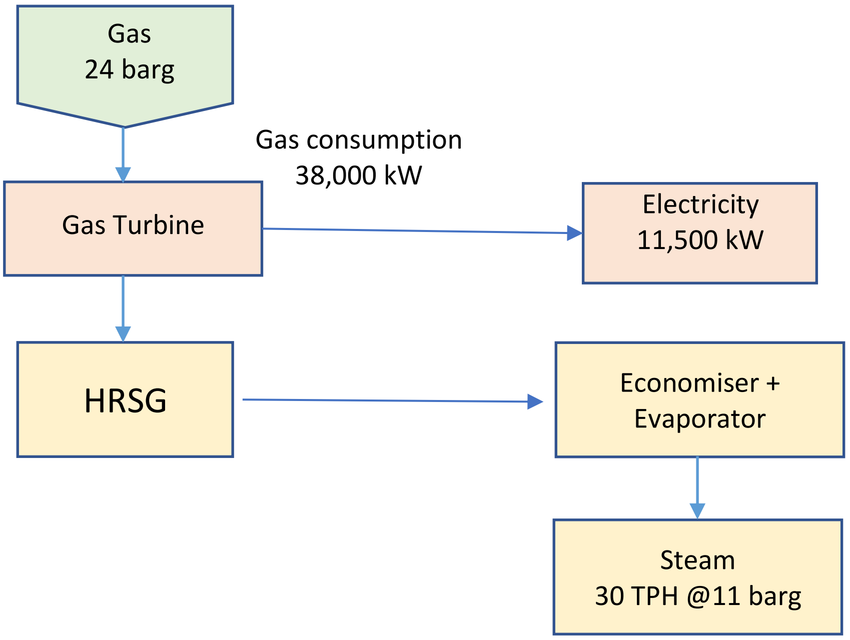
Source: Authors.

Specification	Description

System configuration	14.4 MW gas turbine (GT) HRSG Steam/hot water generator
Operating hours	8,000
GT gas consumption	48,076 kW/164 MMBtu/h
HRSG capacity	40 TPH @11 barg steam
Thermal energy for steam/y	246,889 MWh/y
Heat: power ratio	2.14
Investment cost	RM86.4 million
Savings	RM25.94 million/y
Simple payback period	3.3 years

Source: Authors.

A2.24. Case Study No. 24: Sugar Mill



Source: Authors.

Specification	Description

System configuration	• 11.5 MW gas turbine • HRSG
Operating hours	8,000
GT gas consumption	38,000 kW/130 MMBtu/h
Gas consumption for additional firing	Nil
HRSG capacity	30 TPH @11 barg steam
Thermal energy for steam/y	185,300 MWh/y
Heat: power ratio	2.01
Investment cost	RM68.9 million
Savings	RM25.2 million/y
Simple payback period	2.7 years

Source: Authors