MITSUBISHI POWER

GTCC

Gas Turbine Combined Cycle Power Plants

Mitsubishi Power is a power solutions brand of Mitsubishi Heavy Industries.

MOVE THE WORLD FORW>RD MITSUBISHI HEAVY INDUSTRIES GROUP

Mitsubishi Heavy Industries, Ltd.
Energy Systems
3-3-1, Minatomirai, Nishi-ku, Yokohama,
Kanagawa, 220-8401, Japan
power.mhi.com

METP-11GT01E1-B-0, (1.0)22-06, ZEG

HOW TO POWER THE WORLD

OUR PLANET IS CALLING FOR AFFORDABLE, SUSTAINABLE, HIGHLY RELIABLE AND CLEAN POWER. TOGETHER WE CAN ACHIEVE IT.

Power grows when we all work together.

There is a strong demand for energy decarbonization in the world today. One in ten people is forced to live without reliable access to electricity, while global demand for power continues to grow. Mitsubishi Power addresses such needs by providing stable, highly reliable, and clean energy solutions.

Mitsubishi Power, a power solutions brand of Mitsubishi Heavy Industries based on a long history of product development and supply for more than a century, has been dedicated to designing, manufacturing, verifying, engineering, installing and providing services for a wide range of proprietary power generation systems.

One of our products is gas turbine combined cycle (GTCC) power plants, which provides incredibly efficient electric power while reducing CO_2 emissions.
We also provide next-generation power systems, such as integrated coal gasification combined cycle (IGCC) power plants, steam power plants, geothermal power plants, air quality control systems (AQCS) and intelligent solutions TOMONI™.

Mitsubishi Power combines cutting-edge technology with deep experience to deliver innovative, integrated solutions that help to realize a carbon neutral world, improve the quality of life and ensure a safer world.

GTCC
Power Plants

Delivering high-efficiency energy
through combined cycle power generation

World-class Highest Efficiency
More than 64%
(LHV)

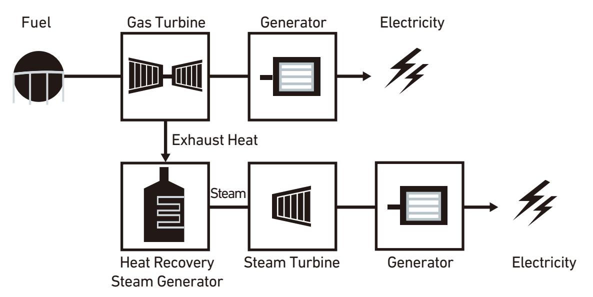
Wide Output Range
30-1,332 MW
(1 on 1 / 2 on 1 / 3 on 1)

Combined Cycle Power Plants
Verification Testing
Mitsubishi Power On-grid Facility

CO_2 Emission
About 50% Lower
Compared with those of Coal-fired thermal power generation

What makes GTCC the most suitable choice?

Power Generation Cycle



Clean, high-efficiency power
Gas turbine combined cycle (GTCC) power plants use natural gas to deliver one of the cleanest and most efficient forms of power. Plants employing Mitsubishi Power's cutting edge J-series gas turbines are 20% more efficient than conventional coal-fired power plants and have attained the world's highest level of efficiency of more than 64%.

What's more, the system's high efficiency reduces CO_2 emissions by about 50%. Mitsubishi Power installed the first combined cycle power plant for a Japanese power company in 1971. Since then, we have installed numerous units for various customers who depend on Mitsubishi Power not only for the supply and installation of power plants, but also a wide range of ongoing services including inspections, maintenance and intelligent solutions TOMONI™.

The key advantages of GTCC thermal power plants

High level of thermal efficiency

In comparison with steam power plants, which offer a thermal efficiency of about 40%, combined cycle power plants deliver a thermal efficiency of about 60% (both figures are based on lower heating values).

Less impact on the natural environment

- Less carbon dioxide (CO_2)
- Less Nitrogen oxides (NOx) and sulfur oxides (SOx)
- Less high-temperature wastewater
- Less water consumption compared to coal generators

CASE STUDY

How Mitsubishi Power helped deliver low-emission GTCC power to Oklahoma

Charles J. Barney
Executive Vice President
Grand River Dam Authority (GRDA)

In 2014, Mitsubishi Power signed a contract to supply a natural gas powered M501J Gas Turbine, Steam Turbine and associated electric generators to the Grand River Dam Authority (GRDA). The power generation equipment was designed for the GRDA's new Unit #3 power generation facility in Chouteau, Oklahoma, USA. Also, as part of the project, GRDA signed a 25-year long term service agreement with Mitsubishi Power.

Manufactured at Mitsubishi Power's main US production facility in Savannah, Georgia, this project was delivered on schedule as the first order for a state-of-the-art J-type gas turbine for the US market. Only two days after it achieved successful First Fire on March 14, 2017, it synchronized to the grid to deliver electricity for GRDA.

First 60 Hz plant to achieve 62% efficiency

The Oklahoma plant is the first 60 Hz plant in the world to achieve an efficiency of 62%. During the smooth startup process, the M501J turbine exceeded its performance guarantee and GRDA was selling power to the grid ahead of schedule.

First Fire was well ahead of schedule

"It has been my privilege to work with the technology team assembled to create Unit 3 at the Grand River Energy Center," said Charles J. Barney, Executive Vice President of GRDA.

"These partners all shared our vision to set a new standard for efficiency and reliability. Each partner contributed their best engineers and constructors, and I congratulate them on their exceptional accomplishment. This ultra-efficient electric generator is now integrated with our hydro and wind generation, and will help assure that GRDA customers have low-cost, clean and reliable electricity for many decades," said Mr. Barney.

Because Mitsubishi Power is focused on GTCC power solutions that reduce environmental burdens, this project is another example of how Mitsubishi Power GTCC technology is playing a key role in preserving the planet by lowering CO_2 emissions.

Project summary

Project	Grand River Energy Center Unit 3
Customer	GRDA (Grand River Dam Authority)
Output	505 MW
Net Efficiency	more than 62%
Product	M501J
Start of operation	2017

DELIVERY RESULTS

Grand River Energy Center Unit 3 (USA)

Customer	Grand River Dam Authority
Output	505 MW
Start of operation	2017
Model	M501J

Yulchon Power Plant (Korea)

Customer	MPC Yulchon Generation Co., Ltd.
Output	950 MW
Start of operation	2013
Model	M501J×2

Khanom Power Plant (Thailand)

Customer	Khanom Electricity Generating Company Limited
Output	930 MW
Start of operation	2016
Model	M701F×2

Nuon Magnum Power Plant (Netherlands)

Customer	Nuon N.V.
Output	1,300 MW
Start of operation	2011
Model	M701F×3

Datan Power Plant (Taiwan)

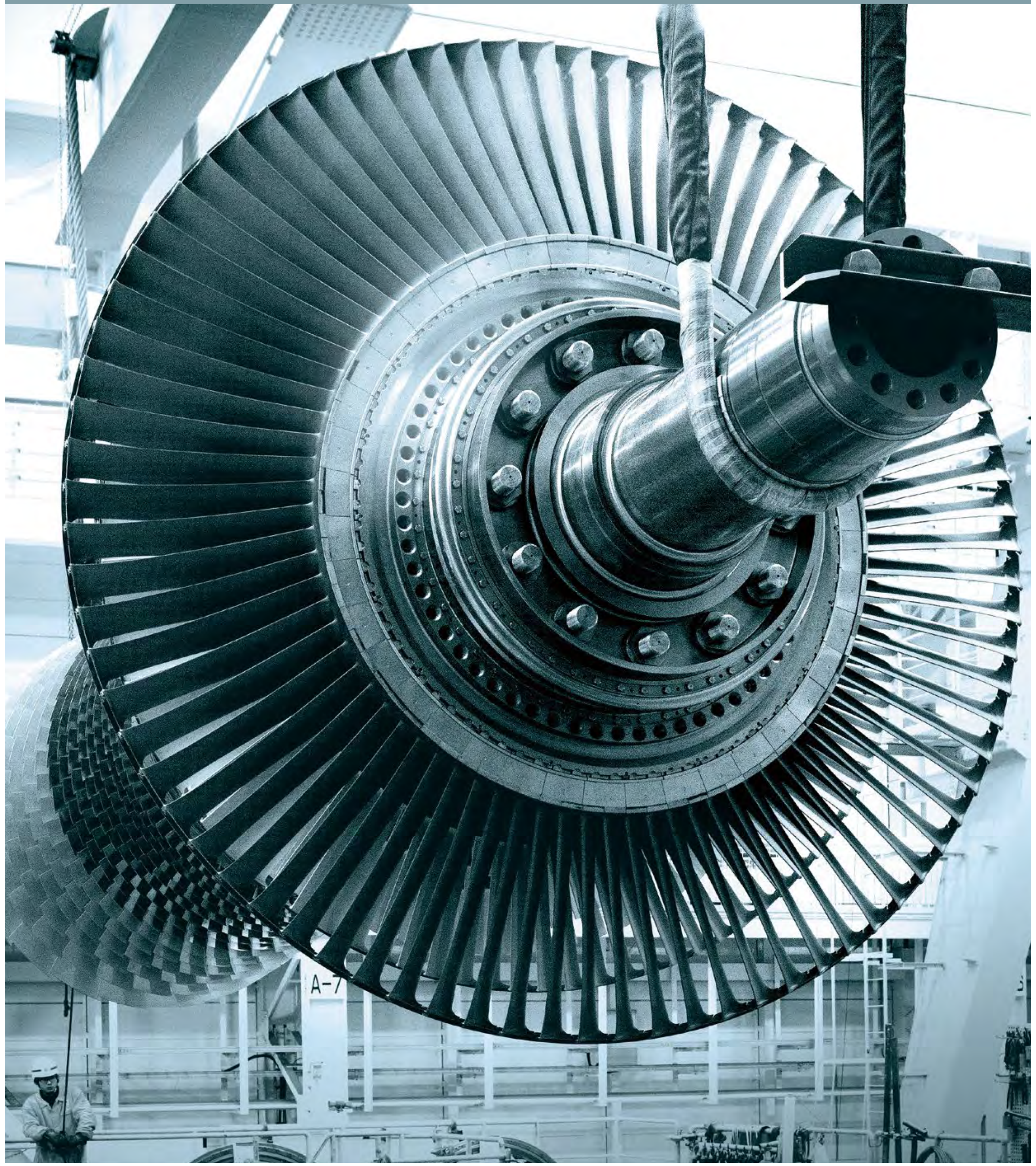
Customer	Taiwan Power Company
Output	1,400 MW/2,800 MW (Stage Ⅰ/Stage Ⅱ)
Start of operation	2006/2008
Model	M501G×8/M501F×6

Blue Hills Power Station (The Bahamas)

Customer	Bahamas Electricity Corporation
Output	31 MW
Start of operation	2013
Model	H-25

Gas Turbines

Raising the world's standards for capacity and efficiency



Mitsubishi Power gas turbines made with cutting-edge technology

Small and medium capacity gas turbines (41 MW to 116 MW)

H-25-series
H-100-series

Large capacity gas turbines (114 MW to 574 MW)

For 60 Hz

- M501J-series
- M501G-series
- M501F-series
- M501D-series

For 50 Hz

- M701J-series
- M701F-series
- M701G-series
- M701D-series

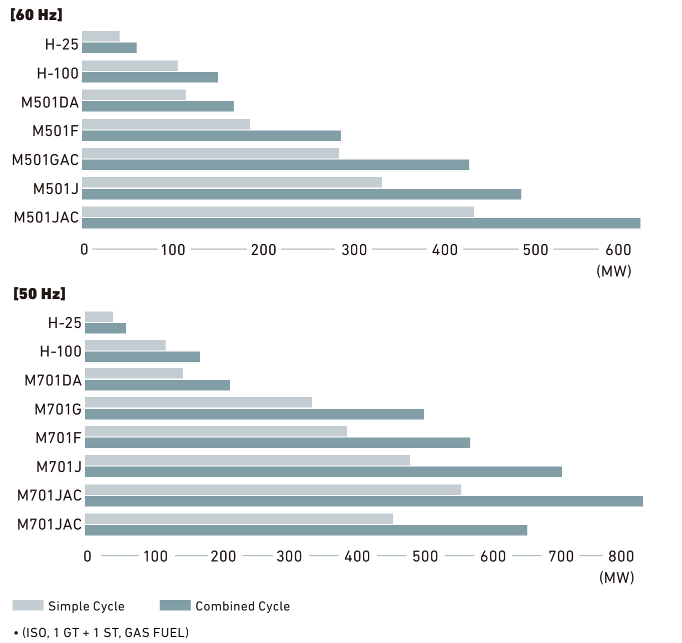
Aero-Derivative Gas Turbines (30 MW to 140 MW)

- FT8® MOBILEPAC®
- FT8® SWIFTPAC®
- FT4000® SWIFTPAC®

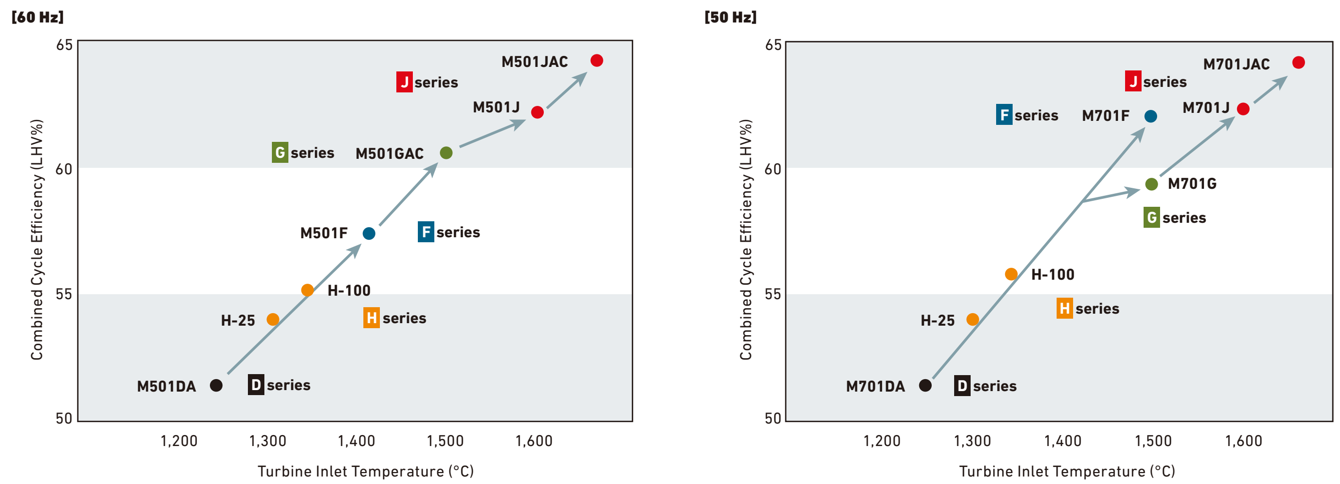
Powering the world with a full range of gas turbines

To meet the power demands of industries and societies around the world, Mitsubishi Power produces a wide range of gas turbines from the 30 MW to the 574 MW class for power generation and industrial use. These turbines drive the development and supply of highly-efficient, clean energy around the world. In fact, Mitsubishi Power has delivered more than 1,600 gas turbines to customers in more than 50 countries worldwide.

Gas Turbine and Combined Cycle Output



Thermal Efficiency of Combined Cycle Systems



J-series

M501J series

Simple Cycle Output	Combined Cycle Output	Combined Cycle Efficiency
330-453 MW	**484-664 MW / 971-1,332 MW** (1 on 1 / 2 on 1)	**More than 64%**

M701J series

Simple Cycle Output	Combined Cycle Output	Combined Cycle Efficiency
448-574 MW	**650-840 MW** (1 on 1)	**More than 64%**

Verified
High Reliability (J-series)

More than 1,700,000 AOH
(Actual Operating Hours)

Date as of Mar 2022

High-capacity gas turbines for power generation incorporating cutting-edge technologies

J-series gas turbines build on the proven G-series design with advanced technologies developed as part of a Japanese government's national project to develop a class of gas turbines that have a turbine inlet temperature (TiT) of 1,700°C.
The J-series, with a TiT of 1,600°C is well on its way to meeting the Project's goal.

Compressor
Advanced 3D design techniques were used to improve the performance and reduce the shockwave loss in the intermediate and final stages. This concept was evaluated using 3D computational fluid dynamics (CFD) software and verified using a full-scale, high-speed research compressor. In addition to variable inlet guide vanes used to modulate air flow, J-series gas turbines are equipped with three variable vanes at the front stages of the compressor. The four stages operate together to modulate the gas turbine air flow, in order to maintain a relatively high exhaust temperature (at part load) for improved bottoming cycle efficiency.

Combustor
The J-series combustor is based on the proven steam cooling system used in G-series gas turbines. The turbine inlet temperature of 1,600°C (2,912°F) is 100°C (180°F) higher than the G-series. We were also able to maintain emissions to levels equivalent to the G-series.

This was accomplished through the use of low-NOx technologies including optimization of the local flame temperature in the combustion zone, and by improving the combustion nozzle to produce a more homogeneous mixture of fuel and air. The advanced JAC-series with air-cooled combustors enhances operational flexibility by eliminating the need for steam cooling in the bottoming cycle.

Turbine
The blades of turbine rows 1 to 4 are cooled by compressor bleed air, which is cooled by an external air cooler. The vanes of turbine rows 1 to 4 are also air cooled, with row 1 vane cooled by compressor discharge air, and the remaining vane rows are cooled by compressor intermediate stage bleeds respectively. The cooling structure was improved for the G-series turbine, and again for the J-series.

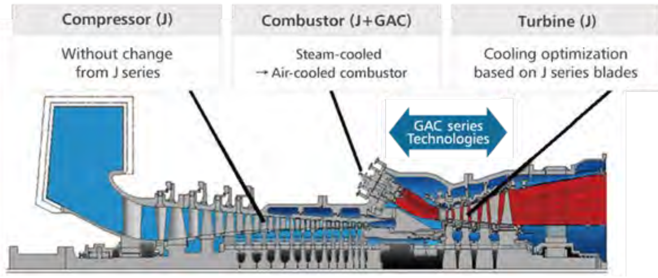
The application of high-performance film cooling, developed as part of the Japanese Government's National Project, further offsets the temperature increase.

The metal temperature is maintained at the same level as the J-series by utilizing the 1,700°C technology developed in the Japanese National Project. The 100°C (180°F) temperature increase from the G-series to the J-series is offset in part by an advanced thermal barrier coating (TBC).

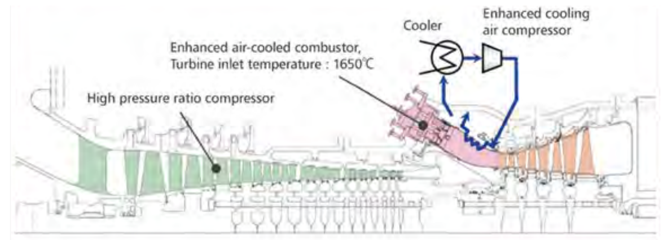
Development of the air-cooled JAC-series

The JAC-series gas turbines use air cooling for combustors instead of steam cooling. With performance equivalent to the J-series gas turbines, they produce a high level of flexibility including a shorter start-up time.

Advantages of the JAC-series
While the flow path of the compressor and the turbine has the same shape as that of the J-series, the JAC-series has a cooling structure for the blades and vanes of the turbine, which is optimized according to the air-cooled combustor. The combustor uses the air cooling system that has proven its effectiveness and reliability in the GAC-series. JAC-series turbines also feature the low-NOx technology used in the J-Series.



The latest models in the J-series and the JAC-series gas turbines. In combined cycle operation, the JAC-series achieves power generation efficiency of more than 64%.



Enhanced air cooling system (Joint research with Tohoku Electric Power Co., Inc.)
Air extracted from the combustor casing in the compressor outlet is cooled using an external cooler. It is then pressurized by an enhanced air compressor and returned to the combustor casing to cool the combustor.

The air cooling system, already verified at Mitsubishi Power's T-Point validation facility, has the following features:
- Exhaust heat from the external cooler is recovered in the bottoming cycle in a system that offers excellent efficiency.
- The combustor cooling mechanism is optimized to produce cooling performance equivalent to that of steam cooling.
- This system starts up faster than the steam cooling system.

Design Concept

JAC-series
- J-series compressor
- GAC-series combustor: same air-cooled combustor as GAC
- J-series turbine: Cooling optimization for JAC

GAC-series combustor — J-series combustor/turbine

G-series (1500°C)
- GAC: Air-cooled combustor
- G: Steam-cooled combustor

J-series (1600°C)
- H-series technology: Compressor technology (23:1)
- G-series technology: Steam-cooled combustor technology
- Japanese National Project turbine technology: TBC/High performance cooling & aerodynamic technologies

Japanese National Project (1700℃)
- Compressor: Waste gas recycling system
- High performance cooling technology
- Advanced thermal barrier coating (Advanced TBC)
- Turbine aerodynamic technology
- Compressor aerodynamic technology
- Material development (mainly single-crystal)

F-series

M501F series

Simple Cycle Output	Combined Cycle Output	Fuel Diversification
185 MW	**285-572 MW** (1 on 1 / 2 on 1)	**Compatible with blast furnace gas (BFG)**

M701F series

Simple Cycle Output	Combined Cycle Output	Combined Cycle Efficiency	Attaining High Performance and High Operability
385 MW	**566-1,135 MW** (1 on 1 / 2 on 1)	**62% or more**	**Utilizes J-series technologies**

Gas turbines for power generation to accommodate diverse fuels

In 1991, Mitsubishi Power developed the M501F-series gas turbines for 60 Hz power generation. The following year, it developed the M701F-series for 50 Hz power generation with similar design features.

Since then, Mitsubishi Power has continued to improve the design of F-series gas turbines. While introducing advanced elemental and material technologies, verified by the G-series' proven track record, the F-series attains continuous performance enhancement.

Compressor

Variable inlet guide vanes ensure operational stability at start-up and enhanced performance at partial load in combined cycle operation.

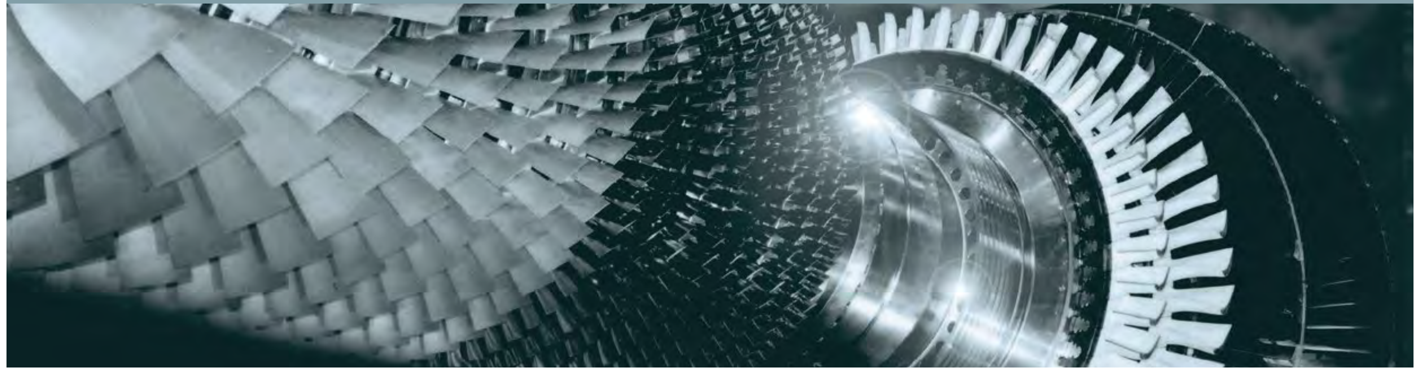
Combustor

A premixing low-NOx combustor is composed of one pilot burner surrounded by eight main burners. The compressor has an air bypass mechanism that enables regulation of the fuel-air ratio in the combustion region.

Turbine

The rotating blades on the first two stages are free-standing, while the third and fourth stages are integral shroud blades. Stationary vanes are supported by blade rings that are independent at individual stages to prevent turbine casings from being affected by thermal expansion.

G-series



M501G series

Simple Cycle Output	Combined Cycle Output	Combined Cycle Efficiency
283 MW	**427 MW / 856 MW / 1,285 MW** (1 on 1 / 2 on 1 / 3 on 1)	**More than 60%**

M701G series

Simple Cycle Output	Combined Cycle Output	Combined Cycle Efficiency
334 MW	**498-999 MW** (1 on 1 / 2 on 1)	**More than 59%**

High capacity to high output gas turbines for power generation

In February 1997, the first M501G gas turbine with a TiT of 1,500°C entered commercial operation. This series features the use of steam for cooling combustors. The GAC-series, which is the current mainstay model, uses the latest air-cooled combustor technology in place of conventional steam-cooled combustors, using compressor discharge air for cooling combustors to add operational flexibility by eliminating the need for steam for cooling from the bottoming cycle.

Compressor

The GAC uses the existing proven G-series compressor. The advanced airfoil designs were incorporated to support a large volume, high efficiency and higher pressure ratio. Variable inlet guide vanes operate to modulate the gas turbine air flow to maintain relatively high exhaust temperatures (at part load) for improved bottoming cycle efficiency.

Combustor

The M501GAC has 16 annular combustor cans. The combustor is an ultra-low-NOx design with a single pilot nozzle for diffusion firing surrounded by eight nozzles for premixing firing. Innovations such as an air-cooled, dry-low-NOx combustor and the latest blade technology have been incorporated into the GAC following stringent element and operational model tests.

Similar to the proven steam-cooled G-series, the advanced GAC adds operating flexibility by eliminating steam cooling needs from the bottoming cycle.

Turbine

The G-series employs a 3D aerodynamic design in a four-stage axial-reaction turbine. Directionally solidified (DS) materials with thermal barrier coating (TBC) are applied to the first two stages and the first three stages are air-cooled. The turbine blade rows to 3 are cooled by the compressor bleed air, which is cooled by the external air cooler. The vanes of turbine rows 1 to 3 are also air cooled, with the vanes of row 1 cooled by compressor discharge air. The remaining rows of vanes are cooled by intermediate-stage compressor bleeds respectively. The first and second stages on the turbine rotor are free-standing. The third and fourth stages use integral shrouds. Each row of vane segments is supported in a separate blade ring, which is keyed and supported to permit radial and axial thermal response independent of possible external cylinder distortions.

Shared Features of the J-, F-, and G-series

Designs backed with 40 years of experience

The J, F and G-series incorporate basic design features and concepts developed over 40 years of experience, such as cold-end generator drive, single shaft rotor construction and axial exhaust.

Gas turbines that are easy on the natural environment

- Most efficient use of fossil fuel resources
- Low NOx, CO, UHC and VOC emissions

Overall design

First deployed in the early 1970s, these gas turbines are based on over 40 years of proven experience.
The main features are:

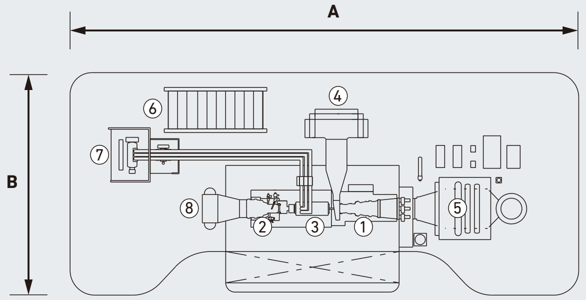
- The compressor shaft end drive reduces the effect of thermal expansion on alignment and eliminates the need for a flexible coupling (cold-end generator drive).
- The rotor has a two-bearing structure to support the compressor and turbine ends.
- An axial flow exhaust structure is used to optimize the combined-cycle plant layout.
- Horizontally split casings facilitate field removal of the blades with the rotor in place.

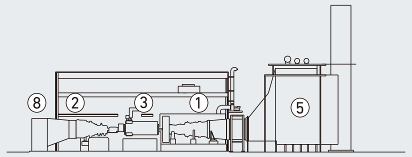
Flexible configurations

Based on our sophisticated combined cycle plant technology and diverse product applications, we not only offer our customers multi-shaft arrangements such as a 2 on 1 configuration, but also a 1 on 1 configuration with the gas turbine, steam turbine and generator connected on the same shaft.

Typical Plant Layout

Single-shaft 1 on 1 configuration



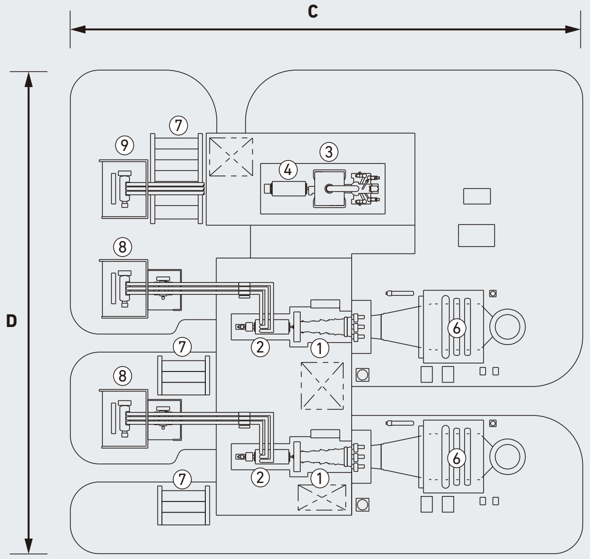


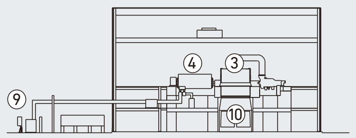
① Gas Turbine
② Steam Turbine
③ Generator
④ Inlet Air Filter
⑤ Heat Recovery Steam Generator
⑥ Electrical/Control Package
⑦ Main Transformer
⑧ Condenser

A M701J/180 m, M701F/160 m, M701G/160 m
M501J/160 m, M501F/140 m, M501G/140 m

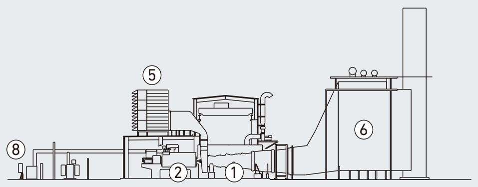
B M701J/90 m, M701F/80 m, M701G/80 m
M501J/80 m, M501F/70 m, M501G/80 m

Double-shaft 2 on 1 configuration





ST Section



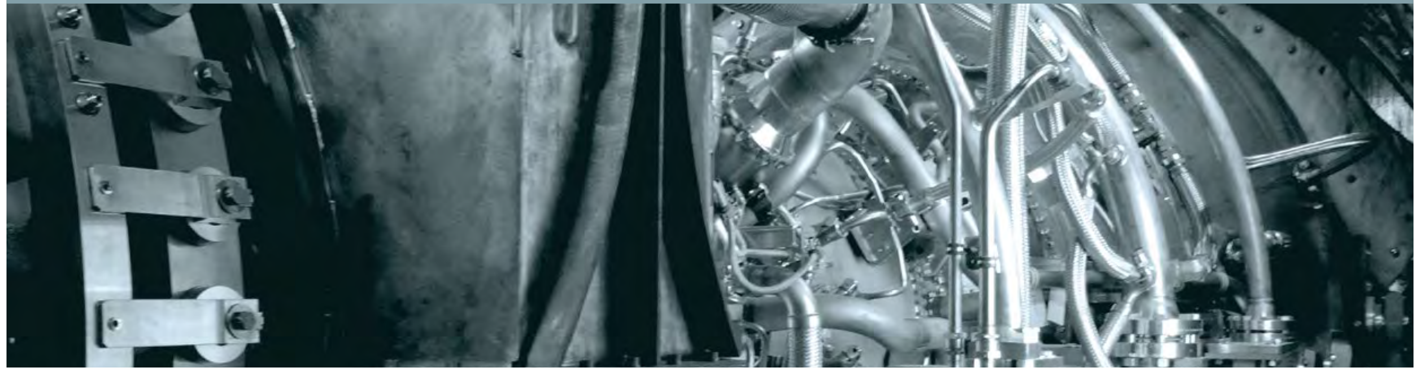
GT Section

① Gas Turbine
② GT Generator
③ Steam Turbine
④ ST Generator
⑤ Inlet Air Filter
⑥ Heat Recovery Steam Generator
⑦ Electrical/Control Package
⑧ GT Main Transformer
⑨ ST Main Transformer
⑩ Condenser

C M701J/160 m, M701F/140 m, M701G/140 m
M501J/140 m, M501F/120 m, M501G/130 m

D M701J/150 m, M701F/140 m, M701G/140 m
M501J/140 m, M501F/130 m, M501G/140 m

Aero-Derivative Gas Turbines



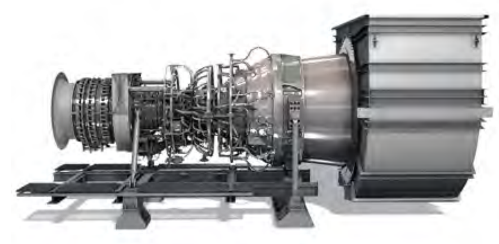
Aero-Derivative

Simple Cycle Efficiency **More than 41%** (FT4000)	**Quick start-up in 5 minutes**	**Cooling water not required. Compact layout**	**Mobile package available for quick delivery**

Aero-Derivative Gas Turbine Package

Mitsubishi Power supplies aero-derivative and industrial gas turbines. Having installed more than 550* industrial gas turbines in over 50 countries worldwide, we pride ourselves in our expertise in gas turbine repairs and overhauls. Our portfolio offers competitive, efficient and flexible products generating from 30 to 140 MW of power.

- FT8®, FT4000®



FT4000® Gas Turbine

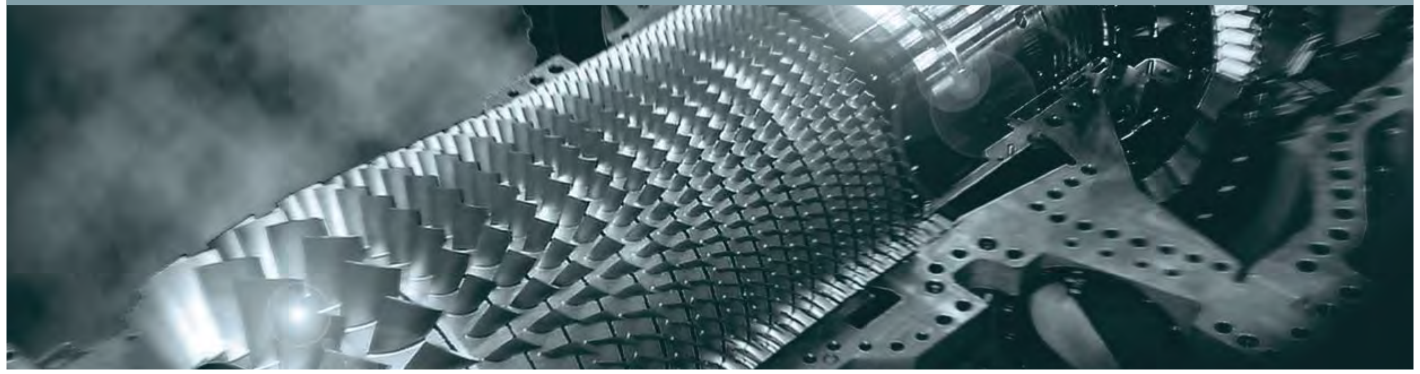
70/140 MW SWIFTPAC®

FT8® Gas Turbine

30/60 MW SWIFTPAC®

30 MW MOBILEPAC®

H-25 series



H-25 series

Simple Cycle Output	Combined Cycle Output	Co-generation Efficiency	High Reliability
41 MW	**60-121 MW** (1 on 1 / 2 on 1)	**More than 80%**	**Cumulative total operating time exceeds 6.3 million hours**

Highly-reliable gas turbines for industrial applications

The H-25-series of highly-reliable gas turbines for industrial applications were developed for utility and industrial customers in both 50 Hz and 60 Hz markets. The first unit came into commercial operation in 1988.

Mitsubishi Power has continued efforts to improve the design of the H-25-series gas turbines, while incorporating advanced elemental and material technologies verified for H-series gas turbines.

Key features of the H-25-series

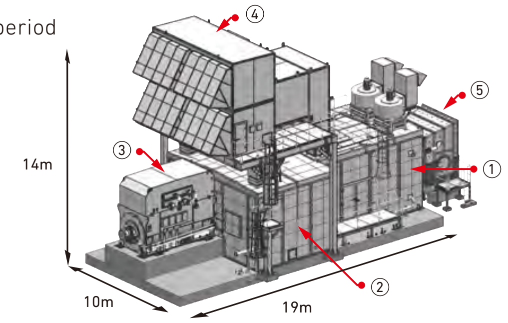
The H-25-series of heavy-duty gas turbines reach high efficiency among heat recovery steam generators, as co-generation systems or combined cycle power plants. The H-25-series features a simple cycle gas turbine output of 41 MW and a combined cycle output of 60 MW in a 1 on 1 configuration, and 121 MW in a 2 on 1 configuration.

Advantages of the H-25-series

- Heavy duty structure: A highly reliable design with a focus on ease of maintenance and long continuous operation
- High efficiency: High performance in various power generation cycles (simple, combined and co-generation)
- Fuel flexibility: Natural gas, off gas, syngas, light oil, kerosene, and bio-ethanol
- Package: Easy to transport and install

Package design advantages

- Minimizes on-site installation work and time
- Flexible layout
- Short delivery period



	Weight
① Gas Turbine	55 ton
② Lube Oil Tank, Reduction Gear and Auxiliaries	63 ton
③ Generator	83 ton
④ Air Intake System	36 ton
⑤ Exhaust System (excluding silencer duct, stack)	8 ton

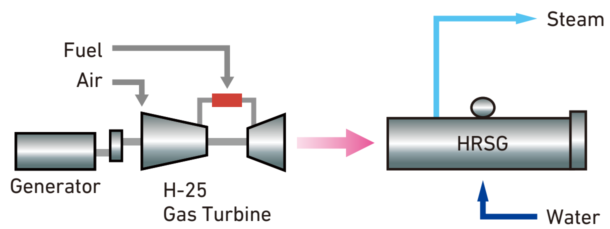
For co-generation plants

A co-generation plant with the H-25 series gas turbine produces the highest steam supply volume in the turbine class and high thermal efficiency. Mitsubishi Power offers system engineering on requests for a combination of electric power and steam.

	50Hz/60Hz
Power Output	39.6 MW
Heat Output (6 MPa/300 deg C)	79 ton/h
Overall Efficiency (LHV)	More than 80%

The figures specified above represent gross performance figures for gas fuel under ISO conditions (atmospheric pressure of 1,013 hPa atmospheric temperature of 15°C and relative humidity of 60%)

System Configuration



H-100 series

H-100 series

Simple Cycle Output	Combined Cycle Output	Standalone Gas Turbine	
106-116 MW	**150-171 MW / 306-346 MW** (1 on 1 / 2 on 1)	**Quick start-up in 10 minutes**	**Suited to power generation and mechanical drive applications**

The world's largest high-efficiency two-shaft gas turbines

Developed as the world's largest high efficiency two-shaft gas turbines, the H-100-series was designed for utility and industrial customers in both 50 Hz and 60 Hz markets. The first unit went into commercial operation in 2010. Mitsubishi Power is always seeking to improve the design of the H-100-series gas turbines by incorporating advanced elemental and material technologies proven by H-series' performance.

Advantages of the H-100 series

- Heavy duty design: A heavy and highly reliable structure focused on ease of maintenance and long-term continuous operation
- High efficiency: Exceptional performance in various power generation cycles (simple, combined and co-generation)
- Packaging: Easy to transport and install
- The series is applicable not only for power generation but also for mechanical drives.

For co-generation plants

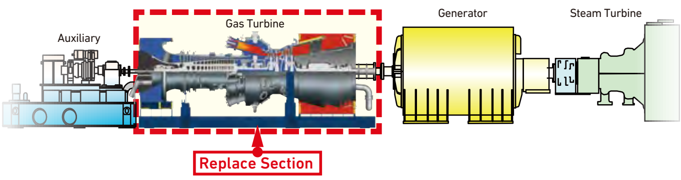
	50Hz	60Hz
Power Output	112.7 MW	102.5 MW
Heat Output (6 MPa/300 deg C)	213 ton/h	173 ton/h
Overall Efficiency (LHV)	More than 80%	More than 80%

The figures specified above represent gross performance figures for gas fuel under ISO conditions (atmospheric pressure of 1,013 hPa atmospheric temperature of 15°C and relative humidity of 60%)

Drop in replacement

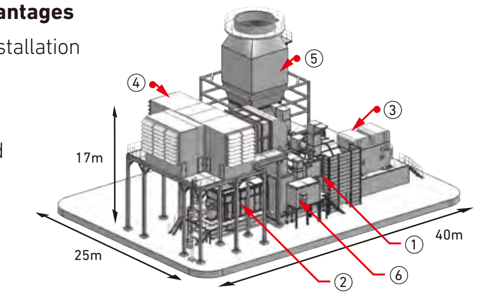
Replacing worn gas turbines with H-100-series units will result in reduced NOx and CO_2 emissions as well as lower fuel consumption after improvement of plant efficiency.

Replacing gas turbines paves the way for making the most of existing plant equipment, including both simple and combined cycle plants.



Package design advantages

- Minimizes on-site installation work and time
- Flexible layout
- Short delivery period



	Weight
① Gas Turbine	216 ton / 50Hz 175 ton / 60Hz
② Lube Oil Tank, Starting Means and Auxiliaries	89 ton
③ Generator	152 ton
④ Air Intake System	140 ton
⑤ Exhaust System	139 ton
⑥ Gas Valve Compartment	6 ton

Mechanical drive applications

H-100-series gas turbines are suitable for mechanical drive applications, especially for driving compressors in LNG plants.

Features

- H-100-series models are suitable for 4 to 6 million tons per annum (MTPA) class LNG plants.
- Variable speed operation.
- Start-up with a fully loaded compressor.
- No helper motor or variable frequency driver (VFD) required.
- High nitrogen (N_2 fuel) applicability.
- Over 99% reliability.
- Integrated into a gas turbine and compressor package in collaboration with Mitsubishi Heavy Industries Compressor Corporation.

Item	H-100	
Output	144,350 hp	160,780 hp
Rotating Speed	3,600 rpm (2,520 rpm～3,780rpm)	3,000 rpm (2,100 rpm～3,150rpm)
Efficiency	38.9% LHV	38.9% LHV
Heat Rate	6,542 Btu/hp-hr	6,549 Btu/hp-hr

without inlet and exhaust losses

Services

Proposing services tailored to meet diverse customer needs

Services Utilizing Advanced Technologies

The latest gas turbine models developed by Mitsubishi Power are equipped with a variety of advanced technologies, including component technologies developed in a Japanese national project to develop next-generation gas turbines. By applying these technologies to existing machines, we provide an upgrade service to improve performance, maintainability, reliability, and operability of existing plants. Since it is essential as a gas turbine manufacturer to be able to utilize the knowledge gained from our extensive operational experience with actual machines, we continue to work on technological developments that meet customer needs.

Solutions for Improving Thermal Efficiency

The latest J-series gas turbine technology is utilized in upgrades for F- and G-series gas turbines to improve thermal efficiency and increase power output of existing plants by replacing turbine and compressor components.
We also offer upgrades for the H-25 series of small/medium gas turbines for thermal efficiency improvement with the latest components.

Solutions for Power Augmentation

Mitsubishi Power provides solutions for increasing output for existing GTCC units. We offer a wide lineup of services for increasing power including water/steam injection, fogging, inlet air cooling systems such as chillers, changing the maximum IGV opening degree to increase working air, and compressor upgrades. We analyze economic and climatic conditions of each power plant and provide the best solution to meet the diverse needs of the market.

Solutions for Improving Availability

Services to improve power plant availability include:

- Shortening outage duration with maintenance-friendly product design
- Highly reliable products by applying the latest technology
- Maintenance optimization such as extended outage intervals by diagnostic analysis of operating conditions
- Early detection of signs of trouble by using intelligent solutions TOMONI™ to reduce forced outages

Solutions for Improving Plant Operability

With the increase in renewable energy, further flexibility is required in gas turbine operation for power generation. Mitsubishi Power provides services that meet market needs, such as reducing start-up time, improving load change rate, optimizing shutdown and restart times, and enabling turndown to operate at lower loads while improving emissions.
We are also developing options that meet diverse market needs such as thermal efficiency improvements during low load operation to meet power demand and reduce power generation costs. We provide solutions that further improve operability such as a twin-shaft gas turbine that achieves a load change rate of 25% per minute.

Solutions for Decarbonization

Mitsubishi Power is creating a future that works for people and the planet by developing innovative power generation technology and solutions to enable the decarbonization of energy and deliver reliable power everywhere.
To help achieve decarbonization, we will provide conversion of existing units to hydrogen or ammonia fired gas turbines with minimal modifications.

For hydrogen power generation technology, please refer to the "Hydrogen Power Generation Handbook".
https://power.mhi.com/catalogue/pdf/hydrogen_en.pdf

Image of a hydrogen-fired gas turbine

TOMONI HUB

Analytics and Performance Center

Our operation and maintenance experts work around the clock to monitor and support the operational status of plants around the world in real time, 365 days a year, 24 hours a day. By detecting signs of anomalies and diagnosing performance degradation based on ever-changing operation data as well as constant collaboration with customers, we provide optimal advice according to various situations to prevent problems and maximize availability.

Long Term Service Agreements (LTSA) for Gas Turbines

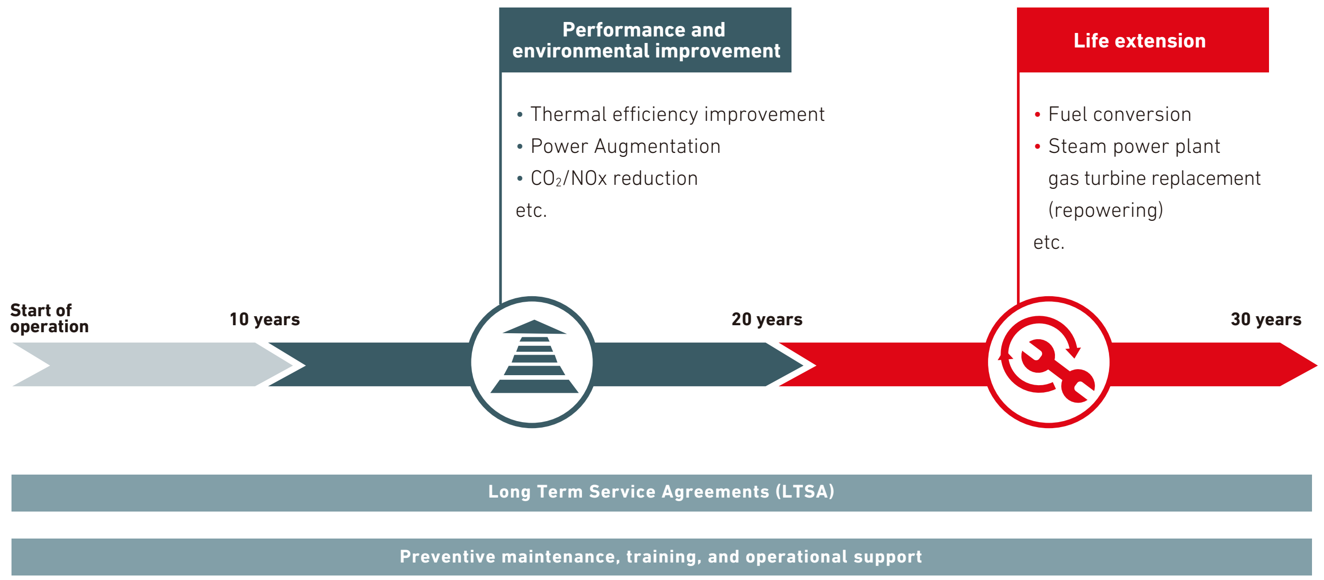
Mitsubishi Power provides comprehensive solutions to meet diverse customer needs to ensure high availability and reliability of gas turbines. Our LTSA-based solutions focus on efficient operation of power plants while minimizing maintenance costs, planning of maintenance programs and outages, supply and repair of parts, dispatch of technical advisors, TOMONI HUBs, and more.

Key Support Areas of Mitsubishi Power LTSA

- Short-term and long-term maintenance planning support for maximizing plant utilization and optimizing operation and maintenance costs
- Packaging of maintenance items to spread maintenance costs over time for customer budget optimization
- Reliable parts supply and technical support from expert engineers
- Utilizing remote monitoring services and data diagnosis using intelligent solutions TOMONI to optimize plant operations including fuel conversion, load changes, maintenance interval extensions, and more
- Solutions for business risks such as decreased demand, unexpected plant outages, and exchange rate fluctuations

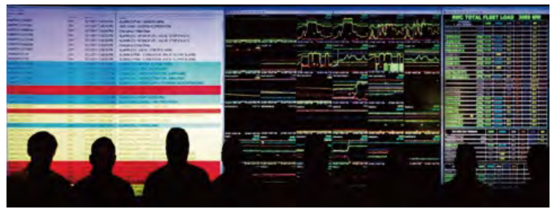
Providing Services Throughout the Plant Life Cycle

Mitsubishi Power provides optimal services to meet the changing needs of customers throughout the plant life cycle.



TOMONI™, a suite of intelligent solutions use advanced analytics and are driven by customer collaboration to deliver powerful financial and environmental advantages including decarbonization.

TOMONI, a Japanese word meaning "together with," reflects the emphasis Mitsubishi Power places on collaborating with customers to solve their unique challenges. Mitsubishi Power works together with customers, partners and society to deploy solutions that support the decarbonization of energy and deliver reliable power everywhere.



Features of TOMONI

- TOMONI is composed of three solution categories: O&M Optimization, Performance Improvement, and Flexible Operation. The combination of these categories allows us to deliver optimal solutions.
- From utility to industry power plant, TOMONI is applicable to a wide variety of power plants.
- TOMONI is able to customize for a variety systems such as cloud and edge computing as well as customer's existing platforms.
- Combining with AI technology and Mitsubishi Power's knowledges secured over the long history has enabled to develop solutions to optimize the operation of the power plant to meet customer' demands.

TOMONI™

Roadmap for TOMONI

Autonomous Operation of Power Plants.

Autonomous Operation — **Optimize operations in response to changes in environment**

Respond to diverse KPIs of power plant, automatic optimization with simulation technologies using high precision AI application (Digital Twin)

Advanced operation and maintenance — **Minimize maintenance costs, improvement reliability**

Combine AI technologies and our continuous accumulated knowledge to assist O&M

- AI identifies problems instantaneously and provides guidance
- Assist operations optimizing performance and environmental impact mapped to equipment status and plant's operational plan

Remote monitoring / status visualization — **Provide high performance solutions through digitalization of information**

Leverage IoT for remote monitoring, diagnostic applications

- Remote monitoring
- Detect abnormalities, offer solutions
- Visualize equipment abnormalities, performance degradation, changes in status

Notes: TOMONI is a trademark of Mitsubishi Heavy Industries, Ltd. in the United States and other countries. (Trademark registration has been applied for)

Validation facility

T-point at Mitsubishi Power's Takasago Works

Front side:T-Point 2 Back side:T-Point

Comprehensive capabilities from Development to Manufacturing

Mitsubishi Power is the only solution provider in Japan that handles the entire production process from development, design, manufacturing, construction and commissioning to after-sales services for large capacity power plants and their core equipment using its own technologies. For thermal power plants requiring advanced technology and reliability, we capitalize on our comprehensive approach to play a major role.

Offering research, development and design
Technological development and design based on the world's leading-edge technologies
- Development of the latest design and analysis tools
- New product development
- Design of independent technologies

Manufacturing high-quality products
Manufacturing of principal components in Mitsubishi Power facilities
- Blades and vanes of turbines
- Combustors
- Rotors
- Casings and more

Providing real-time testing and validation
Overall validation, before application, of real facilities
- One of the world's largest turbine testing facilities
- A combined cycle power plant is installed at Mitsubishi Power's own plant, offering practical operation validation

Purpose

- To validate gas turbine technologies newly applied to achieve higher efficiency, allow operations at elevated temperatures, and reduce NOx.
- To validate the reliability through long-term commercial operations of the highly efficient and environmentally friendly combined-cycle power generation.

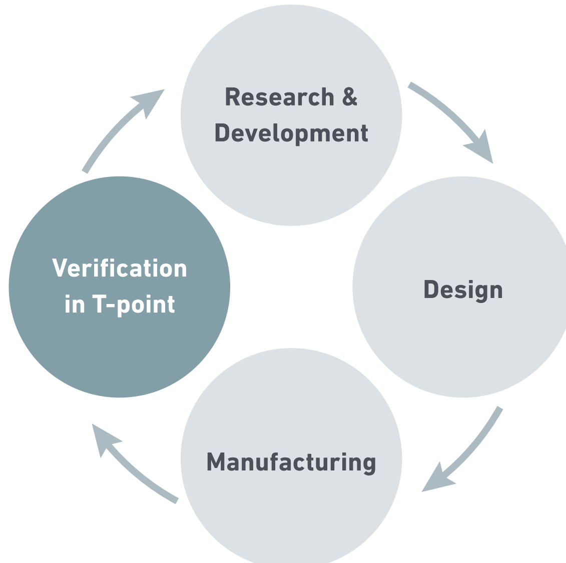
History

The unit 1 power plant (T-point) equipped with the M501G-series gas turbine and performance and reliability tests were conducted since 1997, and long-term validation tests had been successfully completed.
Then, in February 2011, the gas turbine was replaced with the M501J-series and the commissioning was completed safely in the same year.
In 2015, the unit was upgraded to forced air-cooling system.
The unit 2 power plant (T-Point 2) upgraded and replaced T-point, started commercial operation in July 2020 with its cutting edge M501JAC-series gas turbine.

Validation of Next Generation Combined Cycle Power Generation

With its combination of gas turbine and steam turbine, T-Point 2 is cutting edge combined cycle power plant validation facility.
By developing next-generation technologies and validating them in T-Point 2 GTCC facilities, Mitsubishi Power helps its customers world-wide attain a stable electricity supply.
Long term demonstration of off-site plant control at T-Point 2 is conducted from the Mitsubishi Power Takasago TOMONI HUB (Analytics and Performance Center). Validation operations are run to increase the reliability of the entire plant including the main equipment such as turbines as well as auxiliary equipment such as pumps and fans. In addition, various applications of a suite of intelligent solutions TOMONI™ that serve to shorten start-up time and automatically optimize operation parameters are installed in T-Point 2. Mitsubishi Power will also be training its AI applications, allowing T-Point 2 to eventually become the world's first autonomous combined cycle power plant.

Item	T Point		T Point 2
Output(5°C air temperature)	330MW	389MW	566MW
Gas Turbine Type	M501G	M501J	M501JAC
Turbine Inlet Temperature	1,500°C	1,600°C	1,650°C
Year Operation Started	1997	2011 (replacement date)	2020



Performance

Simple Cycle Specs

	ISO Base Rating (kW)	LHV Heat Rate		Efficiency (%-LHV)	Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (kg/s)	Exhaust Temp (°C)
		(kJ/kWh)	(Btu/kWh)					
50Hz / 60Hz								
H-25*	41,030	9,949	9,432	36.2	17.9	7,280	114	569
50Hz								
H-100*	116,450	9,400	8,909	38.3	18	3,000	296	586
M701DA	144,090	10,350	9,810	34.8	14	3,000	453	542
M701G	334,000	9,110	8,630	39.5	21	3,000	755	587
M701F	385,000	8,592	8,144	41.9	21	3,000	748	630
M701J	478,000	8,511	8,067	42.3	23	3,000	896	630
M701JAC	448,000	8,182	7,755	44.0	25	3,000	765	663
M701JAC	574,000	8,295	7,826	43.4	25	3,000	1,024	646
60Hz								
H-100*	105,780	9,421	8,930	38.2	18.4	3,600	293	534
M501DA	113,950	10,320	9,780	34.9	14	3,600	354	543
M501F	185,400	9,740	9,230	37.0	16	3,600	468	613
M501G	267,500	9,211	8,730	39.1	20	3,600	612	601
M501GAC	283,000	9,000	8,531	40.0	20	3,600	618	617
M501J	330,000	8,552	8,105	42.1	23	3,600	620	635
M501JAC	453,000	8,182	7,755	44.0	25	3,600	815	649

Mechanical Drive Specs

	ISO Base Rating		LHV Heat Rate		Efficiency (%-LHV)	Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (kg/s)	Exhaust Temp (°C)
	(hp)	(kW)	(kJ/kWh)	(Btu/hp-hr)					
H-100*	144,350	107,650	9,256	6,542	38.9	18.4	3,600	293	534
H-100*	160,780	119,900	9,266	6,549	38.9	20.1	3,000	315	552

Aero-Derivative Gas Turbine Specs

	ISO Base Rating (kW)	LHV Heat Rate		Efficiency (%-LHV)	Turbine Speed (rpm)	Exhaust Flow (kg/s)	Exhaust Temp (°C)
		(kJ/kWh)	(Btu/kWh)				
50Hz							
FT8®	28,528	10,376	9,834	34.7	3,000	92	496
FT4000®	70,154	8,908	8,443	40.4	3,000	183	431
FT4000®	140,500	8,896	8,431	40.5	3,000	367	431
60Hz							
FT8®	30,941	9,825	9,312	36.7	3,600	92	491
FT4000®	71,928	8,686	8,232	41.5	3,600	183	422
FT4000®	144,243	8,661	8,209	41.6	3,600	367	422

Notes: (1) All ratings are defined at ISO standard reference conditions: 101.3kPa, 15°C and 60% RH.
(2) All ratings are at generator terminals and are based on the use of natural gas fuel.
** without inlet and exhaust losses*

Combined Cycle Specs

	Plant Output (kW)	LHV Heat Rate		Plant Efficiency (%)	Gas Turbine Power (kW)	Steam Turbine Power (kW)	Number & Type Gas Turbine
		(kJ/kWh)	(Btu/kWh)				
50Hz / 60Hz							
MPCP1(H-25)	60,100	6,667	6,319	54.0	39,600	20,500	1×H-25
MPCP2(H-25)	121,400	6,606	6,261	54.5	79,200	42,200	2×H-25
50Hz							
MPCP1(H-100)	171,000	6,272	5,945	57.4	112,700	58,300	1×H-100
MPCP2(H-100)	346,000	6,207	5,884	58.0	225,400	120,600	2×H-100
MPCP1(M701DA)	212,500	7,000	6,635	51.4	142,100	70,400	1×M701DA
MPCP2(M701DA)	426,600	6,974	6,610	51.6	284,200	142,400	2×M701DA
MPCP3(M701DA)	645,000	6,947	6,585	51.8	426,300	218,700	3×M701DA
MPCP1(M701F)	566,000	5,807	5,504	62.0	379,300	186,700	1×M701F
MPCP2(M701F)	1,135,000	5,788	5,486	62.2	758,600	376,400	2×M701F
MPCP1(M701G)	498,000	6,071	5,755	59.3	325,700	172,300	1×M701G
MPCP2(M701G)	999,400	6,051	5,735	59.5	651,400	348,000	2×M701G
MPCP1(M701J)	701,000	5,779	5,477	62.3	472,300	228,700	1×M701J
MPCP1(M701JAC)	650,000	<5,625	<5,332	>64.0	441,700	208,300	1×M701JAC
MPCP1(M701JAC)	840,000	<5,625	<5,332	>64.0	570,900	269,100	1×M701JAC
60Hz							
MPCP1(H-100)	150,000	6,534	6,193	55.1	102,500	47,500	1×H-100
MPCP2(H-100)	305,700	6,418	6,083	56.1	205,000	100,700	2×H-100
MPCP1(M501DA)	167,400	7,000	6,635	51.4	112,100	55,300	1×M501DA
MPCP2(M501DA)	336,200	6,974	6,610	51.6	224,200	112,000	2×M501DA
MPCP3(M501DA)	506,200	6,947	6,585	51.8	336,300	169,900	3×M501DA
MPCP1(M501F)	285,100	6,305	5,976	57.1	182,700	102,400	1×M501F
MPCP2(M501F)	572,200	6,283	5,955	57.3	365,400	206,800	2×M501F
MPCP1(M501G)	398,900	6,165	5,843	58.4	264,400	134,500	1×M501G
MPCP2(M501G)	800,500	6,144	5,823	58.6	528,800	271,700	2×M501G
MPCP1(M501GAC)	427,000	5,951	5,640	60.5	280,800	146,200	1×M501GAC
MPCP2(M501GAC)	856,000	5,931	5,622	60.7	561,600	294,400	2×M501GAC
MPCP3(M501GAC)	1,285,000	5,931	5,622	60.7	842,400	442,600	3×M501GAC
MPCP1(M501J)	484,000	5,807	5,504	62.0	326,200	157,800	1×M501J
MPCP2(M501J)	971,000	5,788	5,486	62.2	652,400	318,600	2×M501J
MPCP1(M501JAC)	664,000	<5,625	<5,332	>64.0	450,300	213,700	1×M501JAC
MPCP2(M501JAC)	1,332,000	<5,608	<5,315	>64.2	900,600	431,400	2×M501JAC