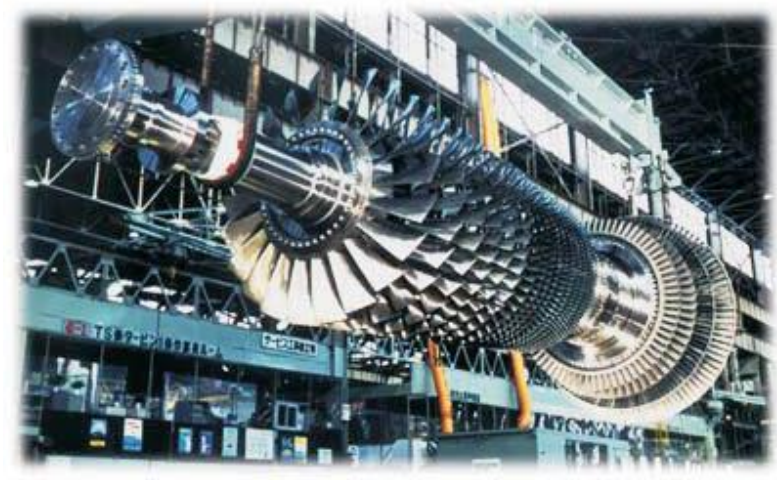
Mitsubishi Hitachi Power Systems M501/M701

Heavy Industrial Gas Turbines
November 2019



Quick Specs:

Power Class:	114 – 563 MW
Thermal Efficiency (simple cycle):	34.8% - 44.0%
Heat rate (@ISO):	8,182 – 10,350 kJ/kWh

Program Briefing

The Mitsubishi Hitachi Power Systems (MHPS) M501 and M701 are very large, heavy duty single-shaft, axial-flow industrial gas turbines based on the Westinghouse 501 (now Siemens SGT6; see report herein). The M501 series is for 60 Hz applications and the M701 series is for 50 Hz applications. Generally, the M701 engines produce more power than their corresponding M501 counterparts.

The letters following the model number generally refer to Turbine Inlet Temperature. The "D" refers to turbines between 1,200°C and 1,300°C; "F" is between 1,400°C and 1,500°C, "G" is around 1,500°C, and "J" is between 1,600°C and 1,700°C.

MHPS is well-positioned to take advantage of the faster growing Asia/Pacific region, especially China. During the next 10 years we forecast the production of 223 M501 and M701 gas turbines, mostly for combined cycle plants. We expect annual production levels to be slightly declining over the forecast period with older technology, less efficient machines giving way to newer technology and more efficient ones. Total value of the engines (not including associated plant gear) is expected to be $11.9 billion.

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Technical Description

Components

Layout

Single-shaft, axial-flow, heavy duty industrial gas turbine.

Compressor

M501DA/M701DA: Nineteen-stage axial compressor with stationary vanes at the back end and variable inlet guide vanes.

Summary Forecast

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
Units Produced	24	24	24	23	23	22	22	21	20	20	223
Value (2019 $Millions)	1,220	1,246	1,220	1,246	1,220	1,197	1,171	1,172	1,113	1,113	11,920

M501F: Sixteen-stage axial compressor with variable inlet guide vanes.

M501G/M701F: Seventeen-stage axial compressor with advanced airfoil design and variable inlet guide vanes.

M701G: Fourteen-stage axial compressor with advanced airfoil design, inlet guide vanes and variable stationary vanes at first three stages.

M501J/M701J: Fifteen-stage axial compressor with advanced 3-D airfoil design, inlet guide vanes and variable stationary blades at the first three stages.

Combustor

Can-annular dry low-NOx combustors comprised of one pilot burner and eight main burners. An air bypass mechanism enables fuel-air ratio regulation. Variations include:

M501DA: 19 cans, air cooled

M501F: 16 cans, air cooled

M501G1: 16 cans, steam cooled

M501GAC: 16 cans, air cooled

M501J: 16 cans, steam cooled

M501JAC: 16 cans, air cooled

M701DA: 18 cans, air cooled

M701F: 20 cans, air cooled

M701G: 20 cans, steam cooled

M701J: 22 cans, steam cooled

M701JAC: 22 cans, air cooled

Turbine

All M501 and M701 variants feature a four-stage turbine. Variations include:

M501DA/M701DA: First three stages of stationary vanes and first two stages of rotor blades are air cooled. Fourth stage rotor blades are housed in a Z-shaped shroud for enhanced vibration resistance.

M501F/M701F: First two rotating stages are free standing while the third and fourth stages are integral shroud blades.

M501G/M701G: 3-D aerodynamic blades and vanes; first three stages air cooled; first two stages use directionally solidified materials and thermal barrier coatings.

M501J/M701J: Unspecified high-performance cooling technologies and advanced thermal barrier coatings developed for 1,700°C class gas turbines (100°C higher than G).

Other Features:

Horizontally split casing; single-shaft rotor with two bearing support; bolt connected discs with torque pins in the compressor section and CURVIC couplings in the turbine section.

Specifications

M501 Series

Simple Cycle Applications

	M501DA	*M501F*
Power Output:	113.95 MW	185.4 MW
Frequency:	60Hz	60 Hz
Efficiency	34.9%	37.0%
Pressure Ratio:	14:1	16:1
Heat Rate-LHV:	10,320 kJ/kWh	9,740 kJ/kWh
	9,780 Btu/kWh	9,230 Btu/kWh
Exhaust Flow:	354 kg/s (780 lb/s)	468 kg/s (1,032 lb/s)
Exhaust Temp.:	543°C/1,009°F	613°C/1,136°F
NOx Emissions*:	25 ppm	25 ppm
CO Emissions*:	30 ppm	10 ppm
Turndown Load:	75%	75%
Ramp Rate:	7 MW/min	12 MW/min
Starting Time:	30 min	30 min
Dimensions (L x W x H):	11.4 x 4.5 x 4.8 m	11.6 x 5.2 x 4.9 m
Weight:	190,000 kg	225,000 kg

	M501G1	*M501GAC*
Power Output:	267.5 MW	283 MW
Frequency:	60Hz	60 Hz
Efficiency	39.1%	40.0%
Pressure Ratio:	20:1	20:1
Heat Rate-LHV:	9,211 kJ/kWh	9,000 kJ/kWh
	8,730 Btu/kWh	8,531 Btu/kWh
Exhaust Flow:	612 kg/s (1,349 lb/s)	618 kg/s (1,364 lb/s)
Exhaust Temp.:	601°C/1,113°F	617°C/1,143°F

NOx Emissions*:	15 ppm	15 ppm
CO Emissions*:	9 ppm	9 ppm
Turndown Load:	50%	50%
Ramp Rate:	18 MW/min	18 MW/min
Starting Time:	30 min	30 min
Dimensions (L x W x H):	12.1 x 5.1 x 5.5 m	12.1 x 5.1 x 5.5 m
Weight:	295,000 kg	295,000 kg

	M501J	*M501JAC*
Power Output:	330 MW	425 MW
Frequency:	60Hz	60 Hz
Efficiency	42.1%	44.0%
Pressure Ratio:	23:1	25:1
Heat Rate-LHV:	8,552 kJ/kWh	8,182 kJ/kWh
	8,105 Btu/kWh	7,775 Btu/kWh
Exhaust Flow:	620 kg/s (1,367 lb/s)	738 kg/s (1,626 lb/s)
Exhaust Temp.:	635°C/1,176°F	649°C/1,201°F
NOx Emissions*:	25 ppm	25 ppm
CO Emissions*:	9 ppm	9 ppm
Turndown Load:	50%	50%
Ramp Rate:	40 MW/min	42 MW/min
Starting Time:	30 min	30 min
Dimensions (L x W x H):	14.4 x 5.4 x 5.7 m	15.0 x 5.6 x 5.6 m
Weight:	320,000 kg	347,000 kg

1 x 1 Combined Cycle

	M501DA	*M501F*
Power Output:	167.4 MW	265.1 MW
Efficiency (LHV):	51.4%	57.1%
Starting Time	70 min	70 min

	M501G1	*M701GAC*
Power Output:	398.9 MW	427 MW
Efficiency:	58.4%	60.5%

	M501J	*M71JAC*
Power Output:	484 MW	614 MW
Efficiency:	62.0%	64.0%

M501 Series

2 x 1 Combined Cycle

	M501DA	*M501F*
Power Output:	336.2 MW	285.1 MW
Efficiency (LHV):	51.6%	57.3%
Starting Time	70 min	70 min

	M501G1	*M501GAC*
Power Output:	800.5 MW	856 MW
Efficiency:	58.6	60.7%

	M501J	*M501JAC*
Power Output:	971 MW	1,231 MW
Efficiency:	62.2%	64.4%

701 Series

Simple Cycle Applications

	M701DA	*M701F*	*M701G*
Power Output:	144.09 MW	385 MW	334 MW
Frequency:	50 Hz	50 Hz	50 Hz
Efficiency:	34.8%	41.9%	39.5%
Pressure Ratio:	14:1	21:1	21:1
Heat Rate-LHV:	10,350 kJ/kWh	8,592 kJ/kWh	9,110 kJ/kWh
	9,810 Btu/kWh	8,144 Btu/kWh	8,630 Btu/kWh
Exhaust Flow:	453 kg/s (999 lb/s)	748 kg/s (1,650 lb/s)	755 kg/s (1,664 lb/s)
Exhaust Temp.:	542°C/1,008°F	630°C/1,167°F	587°C/1,089°F
NOx Emissions*:	25 ppm	25 ppm	25 ppm
CO Emissions*:	30 ppm	10 ppm	10 ppm
Turndown Load:	75%	45%	60%
Ramp Rate:	9 MW/min	38 MW/min	22 MW/min
Starting Time:	30 mins	30 min	30 min
Dimensions (L x W x H):	11.9 x 5.0 x 5.3 m	14.3 x 5.8 x 6.1 m	14.4 x 6.2 x 6.7 m
Weight:	240,000 kg	415,000 kg	490,000 kg

	M701J	*M701JAC (2015)*	*M701JAC (2018)*
Power Output:	478 MW	563 MW	448 MW
Frequency:	50 Hz	50 Hz	50 Hz
Efficiency	42.3%	43.6%	44.0%
Pressure Ratio:	23:1	25:1	25:1
Heat Rate-LHV:	8,511 kJ/kWh	8,257 kJ/kWh	8,182 kJ/kWh
	8,067 Btu/kWh	7,826 Btu/kWh	7,755 Btu/kWh
Exhaust Flow:	620 kg/s (1,367 lb/s)	738 kg/s (1,626 lb/s)	765 kg/s (1,687 kg/s)
Exhaust Temp.:	635°C/1,176°F	649°C/1,201°F	663°C/1,226°F
NOx Emissions*:	25 ppm	25 ppm	25 ppm
CO Emissions*:	9 ppm	9 ppm	9 ppm
Turndown Load:	50%	50%	50%
Ramp Rate:	58 MW/min	66 MW/min	53 MW/min
Starting Time:	30 min	30 min	30 min
Dimensions (L x W x H):	16.7 x 6.5 x 6.9 m	16.7 x 6.5 x 6.9 m	16.7 x 6.5 x 6.9 m
Weight:	550,000 kg	550,000 kg	550,000 kg

1 x 1 Combined Cycle

	M701DA	*M701F*	*M701G*
Power Output:	212.5 MW	566 MW	498 MW
Efficiency (LHV):	51.4%	62.0%	59.3
Starting Time	70 minutes	45 minutes	n/a

	M701J	*M701JAC (2015)*	*M701JAC (2015)*
Power Output:	701 MW	818 MW	650 MW
Efficiency:	62.3%	64.0%	64.0

2 x 1 Combined Cycle

	M701DA	*M701F*	*M701G*
Power Output:	426.6 MW	1,135 MW	999.4
Efficiency (LHV):	51.6%	62.2%	59.5
Starting Time	70 min	45 min	n/a

**@15% O_2*

Marketing Data

Costs

Our estimated value for the MHPS M501D is $24.9 million, the M501F is $32.9 million, the M501G is $49.0 million, M501J is $67.1 million, the M701D is $25.6 million, the 701F is $68.5 million, the M701G is $59.4 million and the M701J is $83.2 million.

Recent Orders

June 2008—MHI received consecutive orders for blast-furnace-gas (BFG) fired gas turbine combined-cycle (GTCC) power generation plants from China and Korea. The equipment for a 150-MW BFG-GTCC power plant for Qian'an Iron and Steel Works, part of the Shougang Group, a major Chinese steelmaker, is slated for delivery in May 2009.

The equipment for two 142 MW plants of the same kind, 284 MW in total, are for POSCO Power Corporation, the largest IPP (independent power producer) in Korea and are scheduled for delivery in 2009 and 2010, respectively. POSCO Power is building the power plants at Gwangyang Works of POSCO, the Korea's largest steel company headquartered in Pohang. Mitsubishi Corporation will handle the trade particulars for both orders.

July 2008—MHI boosted its cumulative orders for gas turbines from the Middle East to 80 units with the receipt of two new orders: one for eight units for a large-scale power generation and desalination project by the Ras Laffan C independent water and power producer (IWPP) in Ras Laffan Industrial City, Qatar, and the other for one unit for a electricity and steam cogeneration project at the Karan Gas Facilities of Saudi Arabian Oil Company (Saudi Aramco), the state-owned national oil company of Saudi Arabia.

November 2008—MHI signed a contract with Dongfang Turbine for supply of major components for gas turbine combined cycle power generating facility. MHI is to supply some of the gas turbine high temperature parts, control modules, and steam turbine blades to Dongfang Turbine, and Dongfang will manufacture and assemble the gas turbine and steam turbine and deliver them to Belarus-Minsk-Power Plant 5 (the final customer).

This is a 40-MW gas turbine combined cycle power plant with one gas turbine (701F type) and one steam turbine. Start of operations is planned for the end of October 2011 and is expected to contribute to stable power supply in the Minsk region.

This project is the first time that Dongfang Turbine has used MHI licensed equipment in another country and is expected to deepen cooperative relations between the companies.

November 2008—MHI received an order from Técnicas Reunidas, SA, and a Spanish engineering company, for two sets of its natural gas-fired 150-MW M501F generators for a large-scale oil and gas production/processing project of Saudi Arabian Oil Company (Saudi Aramco), Saudi Arabia's state-owned oil firm. The latest order brings the cumulative number of gas turbines ordered for Saudi Aramco to seven units.

January 2009—MHI received an order for an 800-MW natural gas-fired GTCC power generation system from ENMAX Green Power Inc., a subsidiary of ENMAX Corporation, a Canadian electricity provider. The system is destined for the Shepard Energy Centre to be newly built near Calgary, Alberta, and slated to be online to serve the winter load of 2012.

January 2009—MHI received a full-turnkey order for a 750-MW natural gas-fired GTCC power plant from PT. PLN (Persero), Indonesia's state-owned electricity company. The project is to construct a new GTCC power plant on the premises of existing Tanjung Priok Power Plant, located approximately 10 km northeast of the central part of Jakarta. The plant is slated to go on-stream in November 2011.

June 2010—MHI received an order for major components of natural gas-fired GTCC power generation systems with heat supply capability, to be installed in a cogeneration facility built by Huaneng Power International, Inc., one of the major electricity providers in China. The order was placed through Dongfang Turbine Co., Ltd., a major power generation equipment manufacturer in China to which MHI has licensed its gas turbine technology. MHI is to provide two M701F gas turbines as well as major components of a steam turbine. Delivery of the gas turbines in February and March of 2011.

March 2012—MHI received orders for ten M501J gas turbines for installation at four large-scale combined cycle power plants in Korea with generation capacities ranging from near 950 to 1,900 MW. The ten gas turbines on order consist of two units each for the Yulchon 2, 2nd-Pyeongtaek and Ulsan 4 power plants and four units for the Dongducheon power plant which will have a collective power generation capacity near 4,750 MW and will be newly constructed.

April 2012—TransAlta Generation Partnership of Canada ordered two M501GAC gas turbines for installation at the Sundance 7 Power Generation a new natural gas-fired 800-MW gas turbine combined cycle (GTCC) power generation plant under construction in Alberta.

June 2013—Portland General Electric (PGE) selected Abengoa of

Spain to develop a 440-MW combined cycle power plant which will include the M501GAC gas turbine, SRT-50 reheat steam turbine and heat recovery steam generator.

September 2013—Uzbekenergo of Uzbekistan selected the M701F4 gas turbine for two GTCC powerplants it is constructing at the existing Talimarjan thermal power plant (TPP) in Qashqadaryo Province, Uzbekistan.

September 2013—Taiwan Power Company of Taiwan ordered six M501J gas turbines for a 2,600-MW natural gas-fired combined cycle power generation plant located in Tunghsiao Township, Miaoli County, Taiwan.

December 2013—KEPCO Engineering & Construction Company, Inc. (KEPCO E&C) selected MHPS for the core equipment of a combined heat and power (CHP) natural gas-fired generation plant, including an M501J gas turbine. The CHP plant is to be developed by DS Power Co., Ltd. in Osan City, Gyeonggi-do, approximately 50 kilometers south of Seoul and can produce 436 MW of electricity. It is scheduled to go on stream in March 2016.

May 2015—Virginia Electric and Power Company (VEPCO) ordered three M501J gas turbines for VEPCO's Greensville County Power Station. The new gas turbine combined cycle (GTCC) power plant will utilize low-cost natural gas and produce approximately 1,600-MW of power. The plant will be completed in 2018.

September 2015—Old Dominion Electric Cooperative (ODEC) is developing a 1,000-MW Wildcat Point generation facility in Cecil County, Maryland, US. The $675m combined-cycle plant is likely to be completed by early 2017 and will be equipped with two Mitsubishi M501 GAC combustion turbine generators (CTs), two heat recovery steam generators (HRSGs) and one steam turbine generator (STG). The M501 GAC gas turbines are being manufactured at MPSA's gas turbine facility in Savannah, Georgia.

October 2015—NTE Energy (NTE) M501GAC Gas Turbine for the Middletown Energy Center that will be built in Middletown, Ohio. Planned completion of the 525 MW facility is scheduled for April 2018.

November 2015—Spain-based Iberdrola SA ordered two M501J gas turbines and one steam turbine for the (Comisión Federal de Electricidad) CFE Noreste combined cycle power plant, located in Escobedo, Nuevo León, Mexico. CFE awarded Iberdrola a contract for an 850 MW combined cycle power plant to supply electricity to help meet the growing demand in northeastern Mexico. This project is likely to be completed in July 2018.

February 2016—TAS Energy has selected one M501J for a Turbine Inlet Chilling solution for the new Grand River Energy Center Unit 3 project, a combined cycle plant owned by the Grand River Dam Authority, located in Chouteau, Oklahoma. The project is expected to be delivered in the first quarter of 2016.

May 2016—Gemma Power Systems (GPS) will construct a 475 MW CCPP in Kings Mountain, NC. A second 475 MW project, like Kings Mountain, is being built in Middletown, OH. The Kings Mountain project is likely to be completed in the second half of 2018, while Middletown is scheduled for the second quarter of 2018. Both projects feature a M501GAC GT, a Vogt Power supplementary-fired HRSG and a Toshiba steam turbine (ST).

August 2016—Anshan Iron and Steel Group Corporation (Ansteel Group) of China ordered one M701S(DA)X for a blast-furnace-gas (BFG) fired gas turbine combined cycle (GTCC) power plant with a 180-MW class output. Operations are scheduled to commence in the first half of 2019.

February 2017—Entergy Louisiana, LLC has selected two M501GAC air-cooled gas turbines for its combined-cycle 980-MW St. Charles Power Station.

March 2017—Iberdrola SA will take two M501J gas turbines, a steam turbine, a spare gas turbine rotor and a long-term service agreement for the 850 MW El Carmen combined cycle power plant, located in Nuevo León, Mexico. Commercial operation is expected to commence in September 2019.

December 2017—Gaz Et L'Energie (GEL) selected one M501JAC gas turbine for the Humay Power Station project in Peru. The project includes a heat recovery steam generator, and steam turbine to produce 500 MW of power. The plant will be built near Pisco, Peru, with a projected completion in 2020.

2017—In 2017, Entergy Louisiana selected MHPS to provide two M501GAC gas turbines for its 980-MW St. Charles Power Station. St. Charles is scheduled to open this year.

February 2018—A joint venture between Gulf Energy Development Public Company Limited and Mitsui & Co., Ltd. will construct two 2,650-MW combined cycle (GTCC) power plants incorporating eight M701JAC gas turbines The new power plants will be constructed in Chonburi and Rayong provinces, both approximately 130 km southeast of Bangkok, with commercial operations due to begin in 2021 and 2023, respectively.

February 2018—The M501 JAC Gas Turbine was selected for the Vale Azul II Project. The plant, which will have a contracted output of 466MW in combined cycle, was selected in the A-6 Brazilian Electricity Auction held on December 20, 2017. The new plant will be MHPS-TOMONI enabled.

August 2018—PT PLN (Persero), of Indonesia ordered one M701F which will serve as the core of a 500-MW natural-gas-fired gas turbine combined cycle (GTCC) power generation system at the Muara Karang Power Plant in western Java. Completion and inauguration of the new system are scheduled for October 2020.

January 2019—Danskammer Energy, LLC, ordered the M501JAC gas turbine for the repowering of the Danskammer Energy Facility, located in Newburgh, NY. The new natural gas–fired combined-cycle electric generation facility will replace an existing gas fired boiler plant and is expected to generate approximately 535 MW of baseload generating capacity.

January 2019—Entergy Texas has selected MHPS to power its 993 MW Montgomery County Power Station (MCPS) near Willis, Texas incorporating two M501GAC gas turbines. The plant is expected to be operational in 2021.

July 2019—J-Power USA Development Co. Ltd. (J-Power) has ordered two 1 on 1 M501JAC power trains for the 1,298 MW Jackson Generation Project in Elwood, Illinois. The plant is scheduled to start commercial operations in 2022.

September 2019—The Hongkong Electric Co., Ltd. (HK Electric), ordered one M701F gas turbine for the GTCC Lamma Power Station's Unit 12 to be built in Hong Kong. This follows previous orders for Unit 10 received in November 2015 and Unit 11 in November 2016.

October 2019—Suncor Energy ordered two M501JAC gas turbines and two heat recovery steam generators (HRSG) from MHPS for a future cogeneration facility at the company's Oil Sands Base Plant facility near Fort McMurray, Alberta. Along with steam generation needed for production processes, the new turbines will produce up to 800 megawatts (MW) of baseload power for Alberta's electrical grid.

November 2019—PowerSouth has ordered an M501JAC gas turbine power train to power the Lowman Energy Center located in Leroy, Alabama. This new 640 MW combined cycle power plant will replace three aging coal-fired units with a combined output of 556 MW. The award also includes a long-term service agreement.

Installations (not comprehensive)

Location	***Equipment***	***Total Power***	***Start-up***	***Note***
Tohoku Electric Higashi Niigata No. 3 unit	6xM701D	1,090 MW	1984	combined cycle
Turkish Electricity Generation & Transmission Co., Bursa, Turkey	4xM701F	1,400 MW	12/1999 bined cycle	2 x 2-on-1 com-
Altamira-II Combined Cycle Power Plant, Mexico	2xM501F	495 MW	5/1/2001	combined cycle
CFE, Chihauhua Combined Cycle Plant, Mexico	2xM501F	434.65 MW	5/8/2001	2-on-1 combined cycle
Electricidad Aguila de Tuxpan S de RL de CV, Tuxpan-II Combined Cycle Power Plant, Mexico	2xM501D	495 MW	12/12/2001	combined cycle; dual fuel
Gas & Power Co., Ltd., Japan	1xM501DA	149.9 MW	4/1/2002	combined cycle
AES Parana, Costanera Power Plant, Argentina	2xM701F	830 MW	5/2002	combined cycle
KEPCO Ilijan Corp., Ilijan, Batangas, Philippines	4xM501G	1,251 MW	5/31/2002	combined cycle
Syria Electric Power Authority, Jandaar Combined Cycle Plant	4xM701D	n/a	2003	combined cycle
Tuxpan #3 & #4, Mexico	4xM510F	1,000 MW	May 27, 2003	combined cycle
Covert Generating Project, Covert, MI	3xM501G	1,082 MW	Summer 2003	combined cycle
Mystic power plant, Boston MA	4xM501G	1,688 MW	June 2003	2 x 2-on-1 combined cycle

Nanpu No.4, Kaohsiung, Taiwan	1xM501F	248 MW	June 30, 2003	1-on-1 combined cycle
Tenaga National, Kuala Lumpur, Indonesia	2xM701D	750 MW	2004	combined cycle
Star Energy Power Corp., Chang Bin Power Station, Taiwan	2xM501F	490 MW	September 2004	2-on-1 combined cycle
Sun Ba Power Corp., Fong Der Power Station, Taiwan	4xM501F	980 MW	September 2004	2 x 2-on-1 combined cycle
Tenga Nasional Berhad, Port Dickson, Malaysia	2xM701F	714.6 MW	June 13, 2005	2-on-1 combined cycle

Milestones

Date	***Milestone***
1989	Full-load shop test of M501F
1992	Commercial operation of M701F/M501F
1997	Commercial operation of M501G
1999	Original M701G enters service
2002	Mitsubishi completes the M701G2 gas turbine shop load test
2004	Mexico orders two M501F gas turbines, two heat recovery steam generators, and one steam turbine for a 495 MW gas turbine combined cycle power plant.
2004	MHI completed delivery of three M501G gas turbines and three steam turbines for the Covert Generating Project located in Covert, Michigan.
2004	New Zealand orders one MHI M701F gas turbine for power plant
Jul. 13, 2009	MHI ships its 500th industrial turbine
Mar. 31, 2010	First M701F4 begins trial operation in Sendai No.4, Japan
2016	M701J begins commercial operations

Program Overview

Background

Early Development

Takasago Machinery Works was established in 1962 as a dedicated turbine manufacturing plant of MHI's Kobe Machinery Works; it became independent in 1964. Manufacture of industrial-use gas turbines was launched in 1963, and its first unit, an MW171 gas turbine with inlet temperature of 732 degrees Celsius (about 1,350 degrees Fahrenheit), was delivered to the Chiba Plant of Asahi Glass Co., Ltd.

MHI continued to focus on increasing turbine inlet temperatures to improve overall efficiency. In 1989, the company commercialized the 1,350 degrees C-class M701F and in 1996 developed the 1,500 degrees C-class G-Series.

G Series Development

On April 7, 1997, the first 501G gas turbine achieved full-load operation at MHI’s Takasago Combined Cycle Power Plant. The plant features a multi-shaft design with a rated 330 MW base load operating on LNG fuel. A natural circulation heat recovery steam generator operates at triple pressure without reheating, supplying steam to a steam turbine featuring a fully air-cooled steam condenser and dry cooling tower.

DLE Combustion System Developed

Beginning in 1980, MHI embarked on development of a dry low emission combustion system at the behest of the Japanese utility Tohoku Electric Higashi Niigata. To lower NOx emissions without the need for water- or steam-injection, MHI tried various schemes finally settling on the installation of a pilot burner and the application of an air bypass system. The DLE method initially lowered NOx emissions to 75ppm, but subsequent developments have lowered that number to 25ppm.

The first DLE system went into operation in 1984 when MHI delivered six M701Ds to Tohoku Electric Higashi Niigata No. 3 unit.

M501H

In March 2001, Mitsubishi successfully finished the load test, including closed-loop steam cooling in the combined cycle system of the new steam-cooled M501H.

M701G2

The M701G2 gas turbine melds the proven performance of the M701G and an advanced compressor from MHI's M501H gas turbine activity. The original M701G went into commercial operation in 1999.

The M701G2 is presently the most advanced commercial offering from MHI for the 50Hz power generation market, having a 1x1 combined cycle efficiency of 58.7% with output of 489MW, respectively. The primary objective of the M701G2 gas turbine was to marginally introduce H technology without upsetting the proven reliability track record of the original M701G gas turbine. The M701G2 shop load test was successfully completed in May of 2002 at MHI's Takasago factory. The test was up to approximately 40% load due to the factory load absorbing facility limitation.

The M701G2 gas turbine's unit rotor is of bolted construction with a positive torque incorporating such features as radial pins and curvic couplings, respectively. The rotor is supported by two-element tilting pad bearings and an upper-half fixed bearing. The thrust bearing is a double-acting type that uses the leading-edge groove lubrication system. The air inlet system, which contains a silencer, delivers air to the compressor via a plenum bell mouth and houses the inlet, main journal and thrust bearings. There are four stages in the turbine to maintain moderate aerodynamic loadings even at the increased firing temperature and pressure ratio, as in the case of all Mitsubishi large frame industrial gas turbines. The combustion system consists of a 20-can annular combustor with almost the same diameter and length as the M501G (the 60 Hz version), which has 16 such combustors. The low NOx hybrid combustor design is an improvement over the current highly successful design that has been in commercial operation in the M501F/M701F fleet for natural gas and liquid fuel firing. The transition piece is cooled by steam through a double-wall structure for more uniform cooling effectiveness. The presence or absence of flame and the uniformity of fuel flow distribution across the combustors are monitored by thermocouples located downstream of the last stage turbine blades. These can also detect combustor malfunctions when at load, while the ultraviolet detectors are used to sense ignition during the initial starting phase.

MRO

MHI Offers LTSAs

MHI offers long-term service agreements (LTSAs) for any of its manufactured gas turbines, as well as for any associated equipment, such as steam turbines, DCS, and generators. Terms of the LSTAs normally are six to 12 years and cover provision of necessary manpower, replacement parts, and maintenance engineering support. The main services provided include planning of scheduled inspection and hot parts management; maintenance engineering service; trouble shooting; and Remote Monitoring Service.

MHI also offers long-term parts supply (LTPS) contracts in lieu of an LSTA. Terms are four to six years, during which supply of replacement parts is guaranteed.

November 2001—San Ishidro SA, a Chilean company, and MHI signed an LTSA on November 14, 2001. The LTSA covers four years of maintenance on one M701F Gas Turbine. The LTSA stipulates that MHI will supply new parts, repair parts, and consumables, and will dispatch supervisory and engineering service staff members to conduct inspections and maintenance work.

October 2002—ENDESA Chile signed a contract for the agreement on the LTSA (M701F gas turbine: 1 unit for four years) for the San Isidro power plant in Chile, and LTSA (M701F gas turbine: two units for six years) for Costanera power plant in Argentina.

July 2008—MHI signed a long-term parts management (LTPM) contract for Maanshan GTCC plant (150 MW) with Maanshan Iron & Steel Co. in China. The contract was received via Mitsubishi Heavy Industries BFG Gas Turbine Service (Nanjing) Co., Ltd., MHI's blast furnace gas fired gas turbine after service subsidiary in China. This plant is a GTCC power plant consisting of one-on-one-shaft configuration using the M701S(DA) gas turbine. This is a unit price contract over four years (2008-2012) for supply of high temperature parts and spares, dispatch of technical adviser, and maintenance.

October 2009—MHI concluded five new LTSAs in Egypt, Turkey, Australia and Argentina. Under the new agreements MHI will provide supply, maintenance and repair services for components that are exposed to very high temperatures as well as expendable parts, and dispatch engineers to the sites.

The five facilities subject to the newly concluded LTSAs are power generation plants at the Sidi Krir and El Atf Power Stations in Egypt, the Bandirma Power Station in Turkey, the Tamar Valley Power Station in Australia and the Costanera Power Station in Argentina. The plants are either new constructions going on-stream in 2009 or 2010, or existing plants subject to LTSA renewal.

August 2017—Cairo Electricity Production Company (CEPC) of Egypt contracted with MHPS to upgrade the 750-MW Cairo North Combined Cycle Power Station Module I which uses two M701F gas turbines and is located 20 km north of Cairo.

November 2018—MHPS was awarded a second Long-Term Service Agreement (LTSA) for the Ras Laffan C Independent water and Power Project (IWPP) in Ras Laffan Industrial City, Qatar, covering eight M701F gas turbines currently in operation at the gas turbine combined cycle (GTCC) power generation facility. The contract period will be for 15 years, starting from 2019.

November 2018—Taiwan Power Company (Taipower) awarded MHPS a contract for refurbishment of equipment at two thermal power plants: the Nanpu Power Plant in Kaohsiung and Datan Power Plant in Taoyuan. The order calls for low-NOx (nitrogen oxides) combustor and performance enhancement of seven M501F gas turbines previously delivered by MHPS to Taipower, as well as supply of spare components. Support will also be provided through introduction of "MHPS-TOMONI," MHPS' digital solutions service. The refurbishment is scheduled for completion in August 2019.

June 2019—MHPS will supply new components to upgrade M701F gas turbines and other generator parts at the 750-MW Siki Krir and El Atf power plants near Alexandria, Egypt.

Current Developments

MHI Begins Chinese Production

In 2005, Mitsubishi launched local production in China of gas turbine core components under a new joint venture. In July 2004, the Chinese government granted approval for the venture, Mitsubishi Heavy Industries Dongfang Gas Turbine (Guangzhou) Co. Ltd. MHI owns 51% of the company with local Dongfang Steam Turbine Works owning the remainder. MHI is furnishing the required technologies, starting with coating processes for M701F and D-type gas turbines. Eventually, production will expand to rotor blades and stator vanes.

New GE/MHI Steam Turbine

In June 2009, GE Energy and Mitsubishi Heavy Industries announced that they had signed final agreements regarding the co-development of a "next generation" steam turbine (original MoU signed in January 2009). The new unit will be used in cogeneration plants featuring GE's FA series and MHI's G series of gas turbines.

Under terms of the agreement the two companies will jointly develop the steam turbine and then separately market and build the unit for use in their proprietary 50-Hz systems.

New Plant in Savannah

In September 2009, MHI announced a plan to build a gas turbine manufacturing plant in the US, and as the plan's initial phase the company will construct a plant near Savannah, GA, to produce combustors, targeting production launch by the end of 2010. The plan also calls for MHI to develop this initiative further, taking subsequent market conditions into account, toward the establishment of a base in the US to both manufacture and service gas turbines. With the establishment of this base in North America, where significant increase in demand for gas turbine combined cycle power generation systems is expected, MHI aims to enhance its worldwide gas turbine production capacity to 50 units per year.

New J Series

MHI completed development of the J series gas turbine, incorporating in the spring of 2009 and has subsequently worked on its commercialization. The new turbine is able to withstand 100 degrees higher temperature than the 1,500°C-class G-Series gas turbine, the top-of-the-line until now. The 60-Hz W501J gas turbine achieves a rated power output of about 320 MW simple-cycle and 460 MW in combined-cycle applications. MHI says it has achieved over 60% gross thermal efficiency.

MHI says that it plans to commence delivery of the new variant to customers in 2011.

Air Cooled J Announced

In late 2016, MHPS released details of an enhanced air-cooled J-Series gas turbine. To convert the J-series from steam cooling to air cooling, modifications were made to the combustor and thermal barrier coatings were enhanced in the turbine section to allow for a higher firing temperature. This new system extracts and cools of a small fraction of the GT compressed air using an external cooler. A single stage radial boost-up compressor is then used to provide the required cooling air mass flow to the combustion liners.

The cooled air is circulated through a jacketed transition piece arrangement, like the steam cooled counterpart, and is mixed with the combustion air after removing heat from the combustion hardware, in a semi-closed configuration.

The supply of cooling air to the combustor in the Enhanced Air-Cooling system is also used to optimize the Turbine Row 1 and 2 tip clearances. The air supply line is provided with a three-way valve that allows diverting the cooling air through the blade rings prior to entering the transition piece and combustor.

The original steam cooled J started commercial operation at the T-Point validation power plant in July 2011. This unit was successfully converted to air cooling in 2014, following the same approach applied to the G to GAC conversion.

The Enhanced Air Cooling M501JAC has demonstrated solid reliability reaching 1,650 ºC TiT while temporary instrumentation data confirmed all operating parameters within the company's expectations.

The M501JAC operates with a combined cycle output of 540 MW and efficiency exceeding 63%.

SmartER GAC

With an order from a leading Midwest US utility, MHPS launched the M501GAC Enhanced Response program. The SmartER GAC is an integration of MHPS's G-Series turbine technology and MHPS-TOMONI analytics and artificial intelligence. Enhanced Response technology uses AI and data analytics to enable fast start, ramp rate and turn down features that make the SmartER M501GAC the new flexibility standard to complement intermittent renewables. Ten-minute fast start, 50 MW/ min ramp rate, 9 PPM NOx emissions, 275 MW output are some product features.

Program Status

As of October 2018, MHPS shows a total of 554 orders for M501/M701 gas turbines. The J series has accumulated more than 630,000 hours of operation.

Teal Group Evaluation

MHPS does well against its competitors GE and Siemens and has benefitted from Japan's pivot away from nuclear power. The 60 Hz 501J variant has done well in the US and is poised to continue to do well. Most of M701 interest appears to come from the F series with upgraded J series technology. Still market pressure on the gas turbine sector are undeniable and we see overall production declining modestly over the next ten years as older technology engines drop out in favor of more efficient newer technology units. During the next 10 years we forecast the production of 223 M501 and M701 gas turbines, mostly for combined cycle plants. Total value of the engines (not including associated plant gear) to be $10.7 billion.

Production Forecast

Units	Thru 2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
Power Generation												
earlier models	85	—	—	—	—	—	—	—	—	—	—	85
M501D	25	—	1	—	1	—	1	—	—	—	—	28
M501F	80	1	—	1	—	1	—	1	—	—	—	84
M501G	88	3	3	3	3	3	2	2	2	2	2	113
M501J	46	9	9	9	9	9	9	9	9	9	9	136
M701D	102	1	—	1	—	1	—	1	—	—	—	106
M701F	192	6	6	6	6	6	6	6	6	6	6	252
M701G	11	—	1	—	1	—	1	—	1	—	—	15
M701J	10	4	4	4	3	3	3	3	3	3	3	43
Total	**544**	**24**	**24**	**24**	**23**	**23**	**22**	**22**	**21**	**20**	**20**	**691**

Value (2019 $Millions)	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
Power Generation											
M501D	—	24.9	—	24.9	—	24.9	—	—	—	—	74.7
M501F	32.9	—	32.9	—	32.9	—	32.9	—	—	—	131.6
M501G	147.0	147.0	147.0	147.0	147.0	98.0	98.0	98.0	98.0	98.0	1,225.0
M501J	603.9	603.9	603.9	603.9	603.9	603.9	603.9	603.9	603.9	603.9	6,039.0
M701D	25.6	—	25.6	—	25.6	—	25.6	—	—	—	102.4
M701F	411.0	411.0	411.0	411.0	411.0	411.0	411.0	411.0	411.0	411.0	4,110.0
M701G	—	59.4	—	59.4	—	59.4	—	59.4	—	—	237.6
M701J	332.8	332.8	332.8	249.6	249.6	249.6	249.6	249.6	249.6	249.6	2,745.6
Total	**1,220**	**1,246**	**1,220**	**1,246**	**1,220**	**1,197**	**1,171**	**1,172**	**1,113**	**1,113**	**11,920**