The Market for Gas Turbine Electrical Power Generation

Product Code #F646

A Special Focused Market Segment Analysis by:

FORECAST INTERNATIONAL

Analysis 1
The Market for Gas Turbine Electrical Power Generation 2010-2019

Table of Contents

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PROGRAMS

The following reports are included in this section: (**Note:** a single report may cover several programs.)

Heavy Gas Turbines (11,185 kW and Larger)
Alstom GT 8/11/13
Alstom GT24/GT26
GE LM1600
GE LM2500
GE LM6000
GE LMS100
GE Model 5000
GE Model 6000
GE Model 7000
GE Model 9000
General Electric GE-10
Hitachi H-25
Kawasaki L20A
Mitsubishi MF-111
Pratt & Whitney Power Systems FT8
Rolls-Royce Industrial RB211
Rolls-Royce Industrial Spey
Rolls-Royce Industrial Trent
Siemens SGT-400
Siemens SGT-500
Siemens SGT-600/700
Siemens SGT-800
Siemens SGT5-2000/3000/4000
Siemens Westinghouse SGT6-3000/5000/6000
Solar Titan
Heavy Industrial & Marine (I&M) Gas Turbines: Design and Development

Light Gas Turbines (Up to 11,185 kW)
Daihatsu DT Series
Dresser-Rand KG2
General Electric GE-5
Kawasaki M1A/M1T Series
Kawasaki M7A
Kawasaki S1/S2 Series
MAN TURBO THM 1200/1300
Mitsui SB5
Optimal Radial Turbine OP16
Pratt & Whitney Power Systems ST6
Pratt & Whitney Power Systems ST18/ST40
Rolls-Royce 501-K
Siemens SGT-100
Siemens SGT-200

Introduction

A review of the factors that drive the effectiveness of gas turbines as industrial workhorses will help explain why they remain the logical choice for a majority of new power plant projects, and will continue to do so for many years to come.

One of the benefits of gas turbine machines is their modularity and extreme flexibility. Schools, civic centers, and shopping malls are good applications for 200-kilowatt units; entire cities can be powered by 200-megawatt units. Heat recovery units add the ability to cooperate with industry and provide steam for power or processes, or even supply a municipality with district heating/cooling. This also highlights the fact that in combined cycle and CHP applications, efficiencies up to near 60 percent are realized. Simple cycle machines with ICR (intercooled recuperated) systems can see up to 35 percent efficiency.

Many lobbies and special interests proclaim dubious facts, incomplete pictures, and questionable statistics in an attempt to shape public policy. It is time to develop a comprehensive energy policy that strikes a balance, moving toward renewable and sustainable goals without hobbling the horsepower of economic and technological development.

No solitary source will meet all of the world's power requirements, but gas turbines are increasingly being adapted to many schemes to improve the efficiency and reliability of power projects. Renewable fuels show promise, as well as synthetic fuels from coal and biomass; careful consideration of the energy demand for energy investment is required. It makes no sense to process materials through so many steps that it costs more to make them than any value you will ever get out of them. With the energy demand projected in the next decade, there will be room for unprecedented development in all sectors and regions.

When the need becomes critical, new electrical power generation capacity can come from several sources: fossil-fuel-burning machines such as gas turbines (including microturbine machines of under 250 kW) and the new wave of gas engines and diesels; hydroelectric, nuclear, solar, and wind power; waste-to-energy plants (which burn paper/wood, scrap, food waste, and bagasse); and exotic alternatives such as geothermal energy, ocean currents, and fuel cells.

One source of electrical power, which many dismiss for initially appearing to be fiscally unproductive, is conservation. Though it may slow the demand for new machine installations, there is a positive side to concerted conservation efforts in established markets. First, showing concern for overall efficiency, and not simply immediate profit, helps build credibility with the customer. While many original equipment manufacturers (OEMs) are entering into long-term operations and maintenance contracts, they must be realizing that steady, baseloaded machines and unencumbered transmission and distribution lines are favorable in terms of maintenance costs and overall financial performance.

Fuel cells are still considered to be in the demonstration stage despite their immense appeal stemming from their "relocation" of harmful emissions, but we believe they will be abundant from about 2014. Wind power, while commercially available, is not available everywhere; its overall efficiency is about 50 percent, and it is expensive in the near term on a dollar-per-kilowatt-hour basis. Nuclear power and hydroelectric plants are very expensive and require a long period of hearings, followed by attempts to obtain financing and approvals, and finally, construction. Solar power is very appealing, but shares the drawbacks of wind power – it is not available everywhere, electrical power storage technology is immature and cannot handle the capacity, and it, too, is expensive on a dollar-per-kilowatt-hour basis.

The viable alternatives are few. Above the level of microturbines, whose efficiencies range from 20-28 percent, are what we consider to be true gas turbine machines that range in power output from 200-250 kW at the low end to the super-high-power machines of 350+ MW. Today, gas turbine machines have simple-cycle efficiencies of at least 35 percent, with some approaching 45 percent, while some are advertised as already having a 60 percent efficiency in combined-cycle mode.

What does past performance predict? While gas turbine machines continued to be ordered and fabricated for electrical generation for their usual end uses (continuous duty, standby duty, and peaking duty), the lower-powered gas turbine machines, those up to 3.5-4 MW, have traditionally been employed in standby duty. As we move up the power spectrum, the normal-use shift toward continuous duty becomes more noticeable at the power level of 20-30 MW. At 120-125 MW and larger, virtually all gas turbine machines have been/should be ordered for use in continuous generation duty.

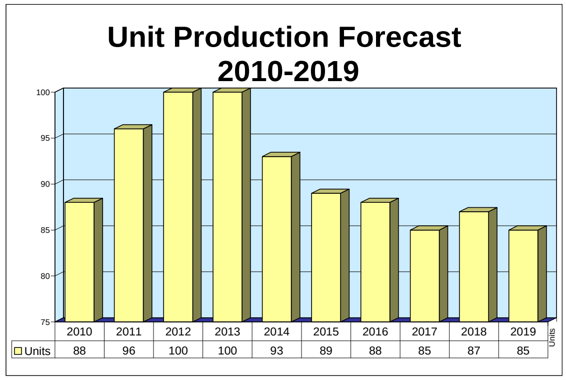
Given the current need for new baseload capacity, as well as for power plant capacity additions, Forecast International believes that the worldwide demand for the latest technology gas turbine-based power plants will result in modest production of the super-large gas

Continued…

GE LM2500

Outlook

- Healthy order pattern projected for the machine for all applications; higher-rated LM2500+ and LM2500+G4 models are available for refitting
- Medium/large commercial ships and LNG carriers remain a potential market for LM2500s of all marks and variants
- Military marine customers may look at higher-rated gas turbine packages, but the LM2500 will still win a majority of orders



Orientation

Description. The LM2500 is a twin-spool, axial-flow, aeroderivative industrial gas generator/gas turbine machine in the 25-35-MW class.

Sponsor. The LM2500 was privately developed by the prime contractor.

The U.S. Department of Defense, through the U.S. Navy, Naval Sea Systems Command, has sponsored work on the LM2500 marine engine variant.

Power Class. The approximate power output of the LM2500 machine is as follows (see **Technical Data** section, Performance subsection, for details):

Application	Power Output
LM2500/LM2500+	
Power Generation	23.29-36.33 MWe
Mechanical Load Drive	31,164-45,751 shp
Marine Propulsion	31,164-40,500 shp
LM2500+G4	
Power Generation	35.32 MWe
Marine Propulsion	47,370 shp

Status. In production for all applications.

Total Produced. As of 2010, over 1,789 LM2500 gas turbine machines, gas generators, and marine engines had been built and installed by GE and its affiliates.

Application. Utility and industrial electric power generation, including combined-cycle and cogeneration installations, various mechanical load drives, and marine propulsion. A two-trailer, fully mobile electrical generation unit, the TM2500, at 21-23 MW, was introduced in 1999.

Price Range. Prices of the LM2500 are estimated as follows (2010 U.S. calendar-year dollars): electrical generation, $9.9-$10.5 million; mechanical load drive, $8.3-$8.6 million; marine power, $7.8-$8.4 million. LM2500+G4 for electrical generation estimated at $11.75-$12.75 million.

For electrical generation (simple cycle), the genset price covers a single-fuel skid-mounted gas turbine, electric generator, air intake with basic filter and silencer, exhaust stack, basic starter and controls, and conventional combustion system.

For mechanical drive, the price covers a gas-fired gas turbine (without driven equipment) with gearbox, skid, enclosure, inlet and exhaust ducts and exhaust silencer; basic turbine controls; fire protection; starting systems; and conventional combustion system.

The combined-cycle price for a single LM2500-based package is estimated at $22.5-$26.5 million. This price range covers a basic gas-fired combined-cycle plant having a gas turbine (usually a DLN-equipped machine), unfired multi-pressure heat recovery steam generator (HRSG) without bypass stack, multi-pressure condensing steam turbine, electric generator, step-up transformer, water-cooled heat rejection equipment, standard controls, starting system, and plant auxiliaries.

Competition. In the electrical generation and mechanical load drive arenas, the gas turbines competing against the LM2500 include the Siemens SGT-600/700 (formerly GT10), UTC Pratt & Whitney Power Systems FT8, Rolls-Royce RB211-6556/ Coberra 6562, Hitachi H-25, and Zorya-Mashproekt UGT-15000.

In marine propulsion/marine power applications, the LM2500 series faces competition mainly from the Rolls-Royce/Northrop Grumman/DCN WR-21 and secondarily from the MAN TURBO FT8/FT8+, Mitsubishi Heavy Industries (MHI) MFT-8, and Zorya-Mashproekt UGT-25000.

Contractors

Prime

Avio SpA	http://www.aviogroup.com, Via I Maggio, 99, Rivalta di Torino, 10040 Torino, Italy, Tel: + 39 011 00 82111, Fax: + 39 011 00 82000, Licensee
GE Energy	http://www.gepower.com, 4200 Wildwood Pkwy, Atlanta, GA 30339 United States, Tel: + 1 (770) 859-6000, Fax: + 1 (678) 844-6690, Prime
MTU Aero Engines GmbH	http://www.mtu.de, Dachauer Strasse 665, Munich, 80995 Germany, Tel: + 49 89 1489 0, Fax: + 49 89 1489 5500, Email: info@muc.mtu.de, Licensee

Subcontractor

Alcoa Fastening Systems, Aerospace Products, Fullerton Operations (Plant 1)	http://www.alcoa.com, 800 S State College Blvd, Fullerton, CA 92831 United States (Nuts)
Altair Filters International Ltd	http://www.altairfilter.com, Omega Park, Alton, GU34 2QE Hants, United Kingdom, Tel: + 44 1420 541188, Fax: + 44 1420 541298, Email: info@altairfilter.com (Air Filtration System)
Arkwin Industries Inc	http://www.arkwin.com, 686 Main St, Westbury, NY 11590-5018 United States, Tel: + 1 (516) 333-2640, Fax: + 1 (516) 334-6786, Email: rhultmark@arkwin.com (Variable Stator Vane Actuator; Variable Bypass Valve Actuator)
Arrow Gear Co	http://www.arrowgear.com, 2301 Curtiss St, Downers Grove, IL 60515-4055 United States, Tel: + 1 (630) 969-7640, Fax: + 1 (630) 969-0253 (Bevel Gear)
Chromalloy Los Angeles	http://www.chromalloy-cla.com, 2100 W 139th St, Gardena, CA 90249 United States, Tel: + 1 (310) 532-6100, Fax: + 1 (310) 329-2228 (Coating)
Cincinnati Gear Co	http://www.cintigear.com, 5657 Wooster Pike, Cincinnati, OH 45227-4120 United States, Tel: + 1 (513) 271-7700, Fax: + 1 (513) 271-0049 (High Power Density Reduction Gearing)
Dollinger Corp	http://www.dollinger-usa.com, 2499 S W 60th St, Ocala, FL 34474 United States, Tel: + 1 (352) 861-7873, Fax: + 1 (352) 873-5783 (Oil Mist Eliminator)
Hamilton Sundstrand	http://www.hamiltonsundstrand.com, 4747 Harrison Ave, PO Box 7002, Rockford, IL 61125-7002 United States, Tel: + 1 (815) 226-6000 (Fuel Pump)
Haynes International Inc	http://www/haynesintl.com, 1020 W Park Ave, PO Box 9013, Kokomo, IN 46904-9013 United States, Tel: + 1 (765) 456-6000, Fax: + 1 (765) 456-6905 (High Temperature Superalloy Mill Product)
Howmet Castings, Corporate Machining	http://www.alcoa.com, 145 Price Rd, Winsted Industrial Park, Winsted, CT 06098 United States, Tel: + 1 (860) 379-3314, Fax: + 1 (860) 379-4239 (Investment Cast Blade & Vane)
Industrial Acoustics Co Ltd	http://www.iacl.co.uk, IAC House, Moorside Rd, Winchester, SO23 7US Hants, United Kingdom, Tel: + 44 1962 873000, Fax: + 44 1962 873132 (Noise Control & Shock-Mounting System)
Meggitt Sensing Systems	http://www.endevco.com, 30700 Rancho Viejo Rd, San Juan Capistrano, CA 92675 United States, Tel: + 1 (888) 363-3826 (Accelerometer; Transducer)
Parker Aerospace Gas Turbine Fuel Systems Division	http://www.parker.com/ag, 9200 Tyler Blvd, Mentor, OH 44060 United States, Tel: + 1 (440) 954-8100, Fax: + 1 (440) 954-8199 (Fluid Management System)

Thales Australia	http://www.thalesgroup.com/australia, Locked Bag 3000, Potts Point, 2011 New South Wales, Australia, Tel: + 61 2 9562 3333, Email: communications@thalesgroup.com (Acoustic Enclosure; Base Structure; Exhaust Duct)
Westech Gear Corp	2600 E Imperial Hwy, Lynwood, CA 90262-4018 United States (Marine Propulsion Drive)

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Contractors are invited to submit updated information to Editor, International Contractors, Forecast International, 22 Commerce Road, Newtown, CT 06470, USA; rich.pettibone@forecast1.com

Technical Data

Note: *While the manufacturer of the LM2500 gas turbine is GE Infrastructure's Aircraft Engines segment in Cincinnati/Evendale, Ohio, the gas turbine is packaged by GE in Houston, Texas, in order for GE Energy to market the final product.*

Design Features. The GE Energy LM2500 gas generators and gas turbine machines have the following design features:

Inlet Section. Section consists of a bellmouth and bulletnose. The bellmouth contains a spray manifold for injecting liquid cleaning solutions into the compressor to remove fouling.

Compressor. Single-rotor, variable stator 16-stage axial flow with overall pressure ratio of 18-24:1. Rotor and stators are fabricated from titanium- and nickel-based alloys, the rotor being built up of three discs and three drums. Variable stators (Stages 1-6) are positioned by fuel pressure as a function of compressor-corrected speed and pressure ratio. Some of the compressed air is extracted for engine cooling; bleed air is available from the compressor discharge. Materials are as follows: Stages 1-14 blades and Stages 1-2 vanes are Ti-6Al-4V; Stages 15-16 blades and Stages 3-16 vanes are A286. Stages 11-13 spool of IN718. Compressor front frame of 17-4 PH; rear frame of IN718.

For the LM2500+, a zero stage (Stage 0) has been added to the compressor to increase compressor airflow by approximately 20 percent; it features wide-chord aeroengine-derived technology. Redesign of CF6-80C2/ LM6000 Stage 1 blades to wide-chord configuration will eliminate mid-span dampers. A CF6-80C2/ LM6000 rotor airfoil design is being added to Stages 2-3. Other changes include a new inlet guide vane assembly.

Combustor. The combustor is annular and consists of four major components riveted together (cowl assembly, dome, inner skirt and outer skirt). It is fitted with 30 fuel nozzles in individual swirl chambers, which may be removed externally. Walls are film-cooled by air introduced through small holes. Liners are Hastelloy X and Haynes 188 material; transition duct is IN718, Rene 41, and Hastelloy X. The ignition system consists of two ignition units which convert the 15-volt, 60-Hz power to high voltage, feeding two high-tension leads and two igniters; it is used only during starting and is turned off once the engine reaches idle speed.

High-Pressure Turbine. Two axial-flow stages drive the compressor spool. Both stages of the HP turbine blades are cooled by compressor discharge air, which flows through the dovetail and through blade shanks into the blades. Stage 1 blades are cooled by internal convection and impingement and external film cooling. Stage 2 blades are cooled by convection, with all of the cooling air discharged at the blade tips.

Both stages of the HP turbine nozzle assemblies are convection and impingement air-cooled, and are coated to improve erosion, corrosion and oxidation resistance. The Stage 1 nozzle is also film-cooled. Materials are as follows: Stages 1-2 blades and Stage 2 vanes are investment cast of Rene 80; Stage 1 vanes are X-40. Casing is a combination of IN718, Rene 41, Hastelloy X and Haynes 188. A major component of the high-pressure turbine is the turbine midframe. It supports the aft end of the high-pressure turbine rotor and the forward end of the power turbine rotor. This frame provides a smooth diffuser for the flow of HPT discharge air into the power turbine.

For the LM2500+, HPT rotor and stator components are being redesigned to reduce maintenance costs, and will include new materials for improved oxidation resistance. Stage 1-2 contours are being optimized for higher flows.

Power Turbine. The power turbine, offered by GE and several distributors, consists of six discs and integral spacers. The blades of all six stages contain interlocking tip shrouds for low vibration levels and are retained in the discs by dovetails. Replaceable rotating seals, secured between the disc spacers, mate with stationary seals to prevent excessive gas leakage between stages.

GE LM2500

The power turbine stator consists of two casing halves, Stages 2 through 6 turbine nozzles, and six stages of blade shrouds. The Stage 1 nozzle is part of the turbine midframe assembly. Stages 2-6 nozzles have segments of six vanes each. Materials are as follows: Stages 1-3 vanes are investment cast Rene 77; Stages 4-6 are Rene 41. Casing is IN718, blades are Rene 77, and discs are IN718. The turbine rear frame forms the power turbine exhaust flow path and supports the aft end of the GE power turbine and forward end of the flexible coupling. It also contains a bearing housing for the No. 7 ball and No. 7 roller bearings.

For the LM2500+, the power turbine was redesigned for the higher power output. Stages 1 and 6 blades are being optimized for aerodynamic efficiency. The rotor is being strengthened for the higher torque and potentially higher energy of the higher rated machine.

Accessory Drive Section. Consists of an inlet gearbox in the hub of the front frame, a radial drive shaft inside the six o'clock strut of the front frame, and a transfer gearbox bolted underneath the front frame. The starter, fuel pump and filter, main fuel control, lube and scavenge pumps, and air/oil separator are mounted on the transfer gearbox.

Fuel/Control Systems. These consist of a combination of a centrifugal and positive displacement fuel pump, a high-pressure fuel filter, a fuel control, two fuel shut-off and drain valves, a fuel pressurizing valve, a fuel manifold, and 30 duplex fuel nozzles. The fuel control system is a hydromechanical type that uses fuel as the servo fluid. The control is the bypass type in which the excess fuel flow is bypassed back to the high-pressure pump. The bypass valve maintains a constant pressure differential across the fuel metering valve so that flow is directly proportional to the main valve opening. The control governs generator speed, compressor discharge pressure, and compressor inlet temperature, and schedules both the steady-state and transient fuel flow to maintain the set speed and prevent over-temperature or compressor stall during acceleration or deceleration. It does not control power turbine speed. Power turbine speed, for any setting of gas generator speed, will vary as a function of the load.

The fuel control also schedules the movement of the compressor variable stator vanes as a function of gas generator speed and compressor inlet air temperature to maintain compressor efficiency and stall margin at all operating speeds.

Dimensions. The LM2500/LM2500+ marine gas turbines have the following dimensions and weights:

APPLICATION = MARINE PROPULSION

	Metric Units	**U.S. Units**
Length (LM2500)	6.52 m	21.4 ft
Length (LM2500+; +G4)	6.7 m	22 ft
Height	2.04 m	6.7 ft
Weight (LM2500)	4,672 kg	10,300 lb
Weight (LM2500+; +G4)	5,237 kg	11,545 lb

The following are the dimensions and weight of the generator of the LM2500/LM2500+ gas turbines for 60-Hz and 50-Hz non-recuperated-mode generation duty:

APPLICATION = ELECTRICAL GENERATION

	Metric Units	**U.S. Units**
Length	17.37 m	57.0 ft
Weight	2.74 m	9.0 ft
Height	3.04 m	10.0 ft
Weight	113,340-117,936 kg	250,000-260,000 lb

The following are the dimensions and weight of the baseplate of the GE LM2500/LM2500+ gas turbine-based mechanical drive package:

APPLICATION = MECHANICAL DRIVE

	Metric Units	**U.S. Units**
Length	10.67 m	35 ft
Weight	2.4 m	8 ft
Height	3.04 m	10 ft
Weight	53,070 kg	117,000 lb

Performance. The simple-cycle LM2500 gas turbine for electrical generation has the following performance parameters (59°F/15°C, 60% RH, no inlet/exhaust losses, natural gas fuel for industrial machine, LHV = 18,400 Btu/lb; for LM2500 STIG™, 4"/10" H_2O inlet/exhaust losses). Tables below do *not* include the LM2500+G4:

APPLICATION = ELECTRICAL GENERATION (60 Hz)

	LM2500PH	LM2500PE	LM2500RD	LM2500RC
Power Output	27.76 MW	23.29 MW	33.16 MW	36.33 MW
Heat Rate (LHV)	8,391 Btu/kWh	9,315 Btu/kWh	8,774 Btu/kWh	9,184 Btu/kWh
Efficiency	40.7%	36.6%	38.9%	37.2%
Pressure Ratio	19.4:1	19.1:1	23.0:1	24.4:1
Exhaust Flow	75.7 kg/sec	69 kg/sec	91 kg/sec	97 kg/sec
EGT	494°C	533°C	525°C	507°C

APPLICATION = ELECTRICAL GENERATION (50 Hz)

	LM2500PE	LM2500PH	LM2500RD	LM2500RC
Power Output	22.34 MW	26.46 MW	32.69 MW	35.84 MW
Heat Rate (LHV)	9,630 Btu/kWh	8,673 Btu/kWh	8,901 Btu/kWh	9,313 Btu/kWh
Efficiency	35.4%	39.3%	38.3%	36.6%
Pressure Ratio	18.0:1	19.4:1	23.0:1	24.4:1
Exhaust Flow	70 kg/sec	76 kg/sec	91 kg/sec	97 kg/sec
EGT	538°C	497°C	525°C	507°C

The approximate performance parameters of the simple-cycle LM2500 as a mechanical load driver and for marine propulsion/drive are as follows (ISO; no losses; liquid fuel):

MECHANICAL DRIVE

	LM2500PE	LM2500RD	LM2500RC
Power Output	31,164 shp	45,439 shp	45,751 shp
Heat Rate	6,780 Btu/hp-hr	6,404 Btu/hp-hr	6,389 Btu/hp-hr
Efficiency	37.5%	39.7%	39.8%
Pressure Ratio	19.5.1	23.0:1	23.0:1
SFC (lb/shp-hr)	n/a	n/a	n/a
Exhaust Flow	68.9 kg/sec	91.2 kg/sec	91.6 kg/sec
EGT	524°C	497°C	524°C

n/a = not applicable

The approximate performance parameters of the simple-cycle LM2500 for marine propulsion/drive are as follows (power and SFC at ISO continuous):

MARINE PROPULSION

	LM2500	LM2500+	LM2500+G4
Power Output	33,600 shp	40,500 shp	47,370 shp
Power Output	*25,060 kW*	*30,200 kW*	*35,320 kW*
SFC	0.373 lb/shp-hr	0.354 lb/shp-hr	0.352 lb/shp-hr
Heat Rate	6,860 Btu/shp-hr	6,522 Btu/shp-hr	6,469 Btu/shp-hr
Pressure Ratio	19.3.1	22.2:1	24.0:1
Exhaust Flow	155 lb/sec	189 lb/sec	204.7 kg/sec
EGT	1,051°F	965°F	1,020°F

Variants/Upgrades

Since the inception of the program, an inordinately large number of designations have been applied to the GE LM2500 industrial and marine gas turbine machines.

It should be noted here that in the Web sites of GE Energy and GE Infrastructure-Marine, the designation LM2500+ is used conflictingly. While it is often used for all applications, the designation is now most often applied to the marine propulsion/power arena.

In the electrical generation arena, the currently offered models are the LM2500PH, LM2500PE, LM2500RD, and LM2500RC.

In the mechanical load drive arena, the currently offered models are the LM2500PE, LM2500RC, and LM2500RC.

In the marine power arena, the most often referred to models are the LM2500 (the normal, lower-rated model) and the LM2500+ (LM2500 Plus).

LM2500 STIG™. The LM2500 STIG is a steam injection version of the basic LM2500 gas turbine.

LM2500+G4. The LM2500+G4 is the latest update to the LM2500 family (see **Program Review** below).

Program Review

Background. The GE Energy LM2500 is an axial-flow, gas generator/gas turbine engine designed to power a wide variety of marine and industrial applications. Its development stems from a combination of the GE TF39 turbofan engine, which powers the Air Force C-5A/B, and the CF6-6, which powers a number of commercial aircraft.

GE recently began using advanced, cooled turbine blades in the high-pressure turbine section. This development originated with the CF6-50 commercial aviation program. The new single-shanked blade with a cast-in cooling system permitted an increase from 27,500 shp to 29,500 shp with improved fuel specifics. This power output was accomplished by allowing turbine inlet temperatures to increase, but material temperatures have actually been reduced, thus increasing the life of the engine core.

The single-shank turbine blade has been operating on the U.S. Navy's MSTS *Callaghan* for thousands of hours on its regular run between Bayonne, New Jersey, and Bremerhaven, Germany.

The largest and most active market for the LM2500 continues to be marine propulsion. While the CG-47 cruiser production program has been completed, the DDG-51 destroyer program will continue through the decade at a rate of three to five ships per year. Several navies continue to order LM2500s. Most notably, Thailand has ordered two sets for its planned new helicopter carrier, and Korea has orders for its KDX destroyer program. Ishikawajima-Harima continues to supply these engines to the Japanese Navy for the new destroyers it is funding (Murasame class). However, it is the international fast-ferry market that holds the most promise for sales as the popularity of this type grows.

Italy's *Aquastrada*, the first gas turbine-powered fast ferry, began operations in the summer of 1993 powered by MTU-built LM2500s (see MTU below). Kværner Energy ordered two LM2500s and two LM1600s in August 1993 from GE Marine & Industrial for Stena AB's Highspeed Sea Service ferry. This is a truly large craft, accommodating 1,500 passengers and 375 cars at speeds of up to 40 knots in service across the Irish Sea between Holyhead, Wales, and Dublin Bay, Ireland. The fast ferry offers the convenience of avoiding increasingly congested airports, and eliminates the need for a rental car.

In one of the largest contracts won by GE in recent years, the LM2500 was selected for the U.S. Navy's Sealift Program ships. In February 1994, GE received a $60 million order to power six U.S. Navy sealift vessels with the 33,600-shp LM2500. At the same time, GE has developed a recuperation scheme for the LM2500. The use of a recuperator enhances the power efficiency of the engine at the lower power levels (targeted below 10,000 bhp) that naval vessels operate in 90 percent of the time. A recuperated engine also eliminates the cost and time of developing a new aero-derived engine aimed at comparable fuel savings. Finally, this engine answers the challenge of the Westinghouse/Rolls-Royce RB211 family-derived ICR marine gas turbine engine.

Low-Btu Development. GE has modified LM2500 and LM5000 gas turbines to accommodate Steam Injection (STIG) for performance enhancement. (As used in this report, STIG is a registered trademark of GE.)

In the STIG system, steam generated from an exhaust heat recovery boiler is directed back into the engine by being injected into the fuel nozzles and compressor discharge ports. Mass flow and power are thus increased, and other benefits are derived: the temperature of the hot section cooling medium is lowered, allowing the turbine to operate at higher combustion firing temperatures; the steam reduces NOx formations, with emissions as low as 25 ppm attainable without catalysts; and, when used on a cogeneration site with varying steam demand, steam production is always put to good use.

The benefits of the LM2500 STIG gas turbine include direct-drive for power generation, a variable steam injection rate, at least 25 percent more power compared to the normal LM2500, ease of installation for cogeneration applications, and dual-fuel capability (distillate or natural gas). In addition, excess heat is absorbed when electric rates are high and maximum steam is injected when electric prices are low.

LM2500+. In June 1994, GE announced the LM2500+ (LM2500 Plus) gas turbine machine, based on the LM2500. The LM2500+ currently has a rating of 40,200 shp for mechanical drive duty and 33.2-33.4 MWe for 60-Hz power generation. Among the changes made to the LM2500 to create the LM2500+ are the addition of a Stage 0 to the compressor, redesign of the Stage 1 blades in the compressor, redesign of the HPT rotor and stators, and redesign of the power turbine. Other benefits of the new gas turbine include dual-fuel capability (distillate and gas), rapid startup and loading, variable speed operation, and excellent part-load efficiency.

The two-shaft machine is aimed at the industrial markets for mechanical drive and direct-drive power generation applications in the 50-Hz and 60-Hz markets – with potential for marine propulsion use, including fast-ferry service. Emission control is provided by water and steam injection using a standard combustor of the LM2500 Dry Low Emissions (DLE) combustion system. Operating on natural gas at the design point rating, the LM2500+'s expected hot section repair and overhaul intervals are 25,000 and 50,000 hours, respectively.

LM2500 Licensees/Packagers/Affiliates. The following firms have acted as licensees, OEMs, and/or packagers of the LM2500/LM2500+:

Dresser-Rand. Dresser-Rand had been a long-time packager of the LM2500: it has also packaged several other GE models.

Dresser-Rand has a long-standing OEM agreement with GE Aircraft engines and has sold more than 200 units.

Stewart & Stevenson. In June 1994, GE announced that Stewart & Stevenson Services (Houston, Texas) had placed a 25-unit launch order for the machine. Delivery of the new gas turbines began in 1996, to S&S's Houston facility. S&S packaged and tested each machine, and provided full-load package testing before shipment to customers.

In 1997, Stewart & Stevenson sold its Gas Turbine Division to GE.

Stewart & Stevenson was involved in the installation of 141 LM2500s.

GE Energy GE Oil & Gas (Nuovo Pignone Entity). In December 1994, GE announced that under a GE contract, a new high-speed power turbine (HSPT) was being designed and developed by Nuovo Pignone for the LM2500+ gas turbine. The LM2500+ gas turbines equipped with the HSPT are designed for applications requiring higher output shaft speeds than offered by currently available LM2500s. (The LM2500 units have an uprated derivative of the six-stage, aeroderivative power turbine rated at 3,600 rpm.)

The HSPT is aimed at the mechanical drive market for powering pipeline centrifugal compressors of 30 MW. In this application, the HSPT would turn at 6,100 rpm. The HSPT can also be used for 50/60-Hz generation applications. For applications in the 3,000-3,600-rpm-output shaft-speed range, the LM2500+ uses the uprated six-stage power turbine. Continuous operation is possible over the speed range 3,050-6,400 rpm, with a trip speed setting of 6,710 rpm. As with the LM2500+ equipped with the six-stage power turbine, the HSPT version is available with GE's DLE and standard combustion systems.

The HSPT design uses hydrodynamic bearings to support the cantilevered rotor. Separate lubricating oil systems will be required to handle synthetic oil for the generator, and mineral oil for the power turbine.

Nuovo Pignone is now 100 percent owned by GE. The entities A-C Compressor, Conmec, Gemini, GE Packaged Power-Odessa, Rotoflow, Thermodyn, PII Pipeline Solutions, and Nuovo Pignone are now collectively referred to as GE Oil & Gas.

Nuovo Pignone and GE Oil & Gas have installed at least 94 LM2500s.

China National Machinery & Equipment Import & Export Corp (CMEC). GE lists the China National Machinery & Equipment Import & Export Corp, located in Beijing, China, as a business associate and licensee of the LM2500. The nation could eventually manufacture a large percentage of the LM2500s, not only for marine use but for industrial use as well.

There have been no recent reports of LM2500 activity by CMEC.

Cooper Energy Services. Cooper Energy Services has mated the LM2500 gas turbine to its own compressor unit as the RT-200 packaged system, one of which was delivered in 1977 to the Great Lakes Gas Transmission Company for the Gas Transmission Pipeline's Shevlin (Minnesota) site.

Cooper Energy Services has been melded into Rolls-Royce plc.

Crawford Enterprises. This Texas-based firm has offered the LM2500 gas turbine in its line of packaged machinery, designating the unit TURBOMOD. It

GE LM2500

delivered six machines in 1980 to Petroleos Mexicanos for use on Pemex offshore platforms.

There have been no recent reports of LM2500 activity by Crawford Enterprises.

FiatAvio. FiatAvio (now Avio SpA) participated in the early stages of development of the LM2500 for marine applications, and was instrumental in getting the gas turbine aboard several Italian ships, including the Lupo, Maestrale, and Garibaldi classes of naval vessels. Other countries operating Lupo class frigates are Venezuela, Peru, and Iraq. The *Garibaldi* is one of two aircraft carriers propelled by the LM2500.

Fiat has delivered three LM2500 systems, the first in 1989 to the city of Genoa, Italy, for the Ansaldo facility.

Fiat Avio/Avio has delivered at least 99 LM2500s.

Hindustan Aeronautics Ltd (HAL). Hindustan Aeronautics Ltd signed an agreement with GE in November 1986 culminating a seven-year competition with Rolls-Royce. With LM2500s in use on India's ONGC Bombay High South Platform, HAL has become the service and supply source for the gas turbine. HAL also supplies the gas turbine machine for marine propulsion duty.

There have been no recent reports of LM2500 activity by HAL.

Ishikawajima-Harima (IHI). IHI packages GE's LM1600, LM2500, LM5000, and LM6000 aeroderivative gas generators with IHI power turbines. Its first LM2500-based system was delivered in 1982 to the Papua New Guinea Electric Company for use in the Moitaka Power Station. Two LM2500-based units were delivered in 1993 to the Kansai Electric Power Company for electric duty at the Kansai Airport in Japan.

IHI has packaged and delivered at least 40 LM2500s.

Kværner Eureka. The Oslo-based firm, formerly known as Kværner Brug A/S, is the first of GE's Manufacturing Associates to handle the LM2500, with all its work being directed to the North Sea, specifically for maintenance and logistics support of Statfjord platforms.

Kværner Energy ordered two LM2500s and two LM1600s from GE Marine & Industrial for Stena AB's high-speed sea service ferry in the British Isles. The LM2500s are rated at approximately 27,100 shp (20,208 kW) each, while the LM1600s are rated at approximately 17,500 shp (13,050 kW) each, for a maximum total output of 89,200 shp (66,516 kW). The powertrain arrangement is COGAG (combined gas turbine and gas turbine).

Kværner has delivered at least 65 LM2500 machines, including 32 gas turbines for generation and 33 units for mechanical drive duty aboard offshore platforms. Kværner Energy is now a part of GE Energy.

MTU. MTU Motoren-und Turbinen-Union Friedrichshafen GmbH signed an OEM (original equipment manufacturer) agreement in September 1992 with GE for the stationary application of LM1600 and LM2500 gas turbines. MTU Friedrichshafen's development and production share includes the module with all peripheral systems, the electronic systems for monitoring and control, and the turbine monitoring system. Power outputs are in the range of 22 to 28 MW for the LM2500 modules. MTU Maintenance in Hanover, Germany, a subsidiary of MTU Munich, maintains the LM2500 modules. MTU began acquiring orders at the close of 1992.

MTU provided the CODAG (combined diesel and gas turbine) propulsion package for Italy's *Aquastrada* monohull passenger ferry, the first gas turbine-powered fast ferry to enter commercial service (July 1993). The ferry is powered by one 28,000-shp (20,880-kW) LM2500 and two MTU diesels with a total output of 9,600 shp (7,158 kW). The 102-meter vessel, which began operations between Italy and Sardinia, attained a maximum speed of 43 knots at 90 percent power during sea trials. It can carry 150 automobiles.

MTU has delivered at least 12 LM2500s.

Thomassen. Thomassen has offered the aeroderivative LM2500 gas turbine in its line of power engineering services and products. It has installed about 10 machines for generating duty, all for use in the Netherlands, including two machines for N. V. Ilsselmij for the Utility/District Heating facility in Enschede and one for PNEM for its Warmtekracht Station, District Heating, in Helmond.

Thomassen International (now Thomassen Turbine Services BV, a part of Calpine Corp) is no longer involved with the LM2500., Thomassen installed nine LM2500s.

Other Associates. Other packagers and firms have delivered LM2500 machines, but are now inactive or have ceased operations. These include the following:

- Curtiss Wright: eight machines, including six in 1978 for Statoil's Statfjord Platforms in the North Sea.
- Penske Power Systems: two gas turbine machines delivered in 1981 to the Saudi Consolidated Electricity Corp for electric power generation at the Qaisumah Power Station.

- Alstom and European Gas Turbines Ltd: EGTL/Alstom discontinued its association with GE in 1999. It had installed 20 LM2500s, including four machines in the U.S. Of the 20 machines, 17 were for electrical generation.

The LM2500+G4. In September 2005, GE Energy's aeroderivative division launched the fourth significant increase in the rating of the LM2500. Referred to as the LM2500+G4, the model is an uprated version of the LM2500+, designed with greater power capabilities. The improvements come from an infusion of proven technologies derived from GE's flight engines and its LM6000. At the time this model was announced, GE said that the LM2500+G4 would be available in the fourth quarter of 2005.

The 47,379-shp/35.32-MW LM2500+G4 is intended to deliver up to 12 percent more power, compared to its predecessor, over a wide range of conditions. The latest upgrade gives customers additional horsepower in the same engine envelope. This model operates in both simple-cycle and combined-cycle modes, with plans for availability in standard and DLE combustion models capable of burning natural gas, fuel oil, or both in a dual-fuel capacity. The LM2500+G4, in combined-cycle mode relative to the LM2500+, is to have an 8.5 percent power and 0.75 percent heat rate advantage.

LM2500 U.S. Navy Applications. The LM2500 gas turbine machine has been actively applied in military marine propulsion. Marine applications of the LM2500, solely for the U.S. Navy, include:

Class	Engines
8 Watson Class Ro-Ro Sealift Vessels	2
4 Supply Class Fast Combat Support Ships	4
22 Ticonderoga Class GM Destroyers	4
56 Arleigh Burke Class (Flight I, II, IIA) GM Destroyers	4
30 Oliver H. Perry Class GM Frigates	2
1 Surface Craft-Experimental (FSF-1)	2

Oliver Hazard Perry Class Frigates. The second major application of the LM2500 marine gas turbine module is the 3,638-4,100-ton Oliver Hazard Perry class guided missile frigate (FFG-7), with each frigate using two LM2500s driving a single screw in a COGAG mode. The original procurement plan called for up to 60 ships; the current inventory total is 30. Australia has taken delivery of five Oliver Hazard Perry class vessels (Adelaide class in Australia), all built in the U.S.

Spain has taken delivery of six 3,696-ton FFG-7 class ships (Santa Maria class in Spain).

Ticonderoga Class Cruisers. The 9,407-9,516-ton CG-47 Ticonderoga class guided missile cruisers use the proven hull and propulsion machinery of the Spruance class vessels; the superstructure was modified to accommodate the AEGIS Weapon System. In addition, AEGIS can assume control of the weapons systems of accompanying ships in order to concentrate fleet defense.

A total of 27 vessels of this class had been commissioned by January 1996; the current inventory is 22. As with the Spruance class vessels, the Ticonderoga class ships use four GE LM2500 marine gas turbines on two shafts, generating 86,000+ horsepower in a COGAG mode.

Arleigh Burke Class Destroyers. Originally designated DDGX, the 9,238-ton (maximum) class of guided missile destroyers is now called the Arleigh Burke class. A total of 56 vessels have been built, with six to nine more IIAs to be commissioned. All vessels employ four LM2500 engines in a COGAG mode.

International Military Naval Applications. Beyond use by the U.S. Navy, LM2500s power the surface vessels of more than 25 other nations, as follows (for ships laid down as of 2008). As used in the listing below, GM = Guided Missile; FAC = Fast Attack Craft. Several countries have both guided missile-firing frigates and non-guided missile-firing frigates in their inventories.

Country	Military Vessel
Australia	5 GM Frigates; 8 Frigates
Bahrain	1 GM Frigate
Brazil	5 Frigates/Corvettes
Canada	3 Destroyers; 12 Frigates
China	2 GM Destroyers
Denmark	3 Frigates/Corvettes
Egypt	4 GM Frigates
France	2 GM Destroyers
Germany	11 GM Frigates; 4 Frigates
Greece	4 Frigates
India	3 GM Frigates
Indonesia	4 FAC/GM Patrol Boats
Israel	3 GM Corvettes
Italy	13 GM Destroyers
	8 GM Frigates; 4 Frigates
	1 Aircraft Carrier
	1 Amphibious Vessel
Japan	15 GM Destroyers
	4 AEGIS Destroyers
Korea	3 Destroyers
	6 GM Frigates
	24 Corvettes
	13 Frigates
	1 Maritime Police Ship

GE LM2500

Country	Military Vessel
New Zealand	2 Frigates
Norway	5 Frigates
Peru	8 GM Frigates
Poland	2 GM Frigates
Portugal	5 GM Frigates
Saudi Arabia	4 GM Corvettes
	9 FAC/GM Patrol Boats
South Africa	4 Corvettes
Spain	1 Aircraft Carrier
	1 Strategic Projection Vessel
	10 GM Frigates
Taiwan	4 GM Destroyers; 8 Frigates
Thailand	1 Helicopter Carrier
	2 GM Frigates
Turkey	12 GM Frigates
Venezuela	6 GM Frigates

Commercial Marine Applications. LM2500s have been installed on or ordered for the following commercial vessels:

Country	Commercial Vessel
Denmark	4 High-Speed Ferries
France	1 High-Speed Ferry
Greece	1 High-Speed Ferry NEL *Corsaire*
Italy	3 Fast Frigates (including *Aquastrada*)
	2 High-Speed Ferries (MDV-3000)
Sweden	4 Frigates
	2 High-Speed Ferries
U.S.	4 Royal Caribbean Cruise Ships
	4 Celebrity Cruises Cruise Ships
	4 Princess Cruises Cruise Ships
	1 Cunard Line Cruise Ship
	4 Holland America Line Cruise Ships

Funding

U.S. Navy RDT&E Funding. There are no current U.S. Navy R-1 program elements or projects involving the LM2500. Navy funding, however, has been provided for an Intercooled Regenerative Cycle (IRC) gas turbine machine, with all of the effort focused on the Rolls-Royce/Northrop Grumman/DCN WR-21 machine.

USN IRC-related work has been carried out under PE#0603573N, Advanced Surface Machinery, Project S1314-IRC-Gas Turbine Engines. No funding for this project has been requested for FY06 and beyond.

U.S. Navy Procurement Funding. U.S. Navy funding for the GE Energy LM2500 gas turbine machine is identified in the U.S. Department of the Navy FY09 Budget Estimates under "Other Procurement, Navy." Specifically, it is in BA1, "Ships Support Equipment." Line Item details for accounts below were not available at the time of publication.

Descriptive material in the P-1 Item "LM2500 Gas Turbine (81GA) (0110)" follows:

> The LM2500 marine gas turbine and its associated engineering control systems provide main propulsion for the Navy's newest surface combatants, including the FFG 7 Oliver Hazard Perry class, DD 963 Spruance class, CG 47 Ticonderoga class, DDG 51 Arleigh Burke class, and AOE 6 Supply class. The LM2500 is composed of two major subassemblies, the gas generator and power turbine sections. It is coupled to the ship driver train by a high-speed coupling shaft. The control system provides for both local and remote engine operations. The budget funds the following:
>
> Modification Kit Program (GA009). A metrics program has been established for the LM2500 engine to track service history for individual engine components and compile data regarding failure rates. The data are compiled for various ship classes and engine configurations. The metrics program clearly identifies where engineering efforts should be focused to improve component reliability and also indicates which modification kits should be procured. The modifications kits can either be installed at the depot level during engine overhauls or at the intermediate level aboard ship via IMA support teams.
>
> Failure to procure modification kits will prevent improvement to mean time between removal (MTBR) and will significantly increase life-cycle costs, including increasing the requirement for additional spare engine assets, increasing the cost to overhaul engines at the depot and negatively impacting the reliability of engines and fleet readiness. It should be noted that although some gas turbine ships are decommissioning, the total engine population in the fleet remains stable until FY05 and then decreases only by six engines per year. The effects of decommissioning are being offset by an aggressive DDG 51 construction program.
>
> Gas Generator in Container (GA010). The attainment of LM2500 spare single shank gas generator inventory level of 26 is considered the program's minimum requirement based upon the current total population of 348 engines, along with the requirement to forward deploy some inventory assets to support the fleet overseas. This inventory level is based upon 25 years of experience with the LM2500 Engine and ensures 90 percent probability for spare asset availability. A total of 18 complete gas generator units have been procured through FY05. In FY02, several one-time components were procured to start an available pool of high failure items. One complete gas generator unit will be procured each year from FY06- FY11 (seven units).

Control System Modifications (GA012). The engine control system consists of sensors, data acquisition units, processors, and operator consoles. Peripheral devices include bell and data loggers, printers, tape readers, mass storage devices, and tape recorders. These end items consist of printer circuit boards, meters, CRTs, switches, and power supplies. Inventory objectives not required. Unit costs vary per modification kit. Obsolescence is increasingly an item that needs to be managed.

Special Support Equipment, SSE (GA014). Procurement of Special Support Equipment allows for increased depot repair capability, thereby stabilizing or reducing the cost to overhaul engines at the depot. This tooling is generally associated with depot modifications being made to the engine to increase engine reliability. This increased capability reduces engine overhaul costs.

Full Authority Digital Electronic Control (FADEC) (GA015). Funding will procure five DDG 51/CG-47 shipsets each year to replace existing on-engine fuel controls with off engine digital fuel controls, starting in FY06. This addresses an obsolescence, maintainability, and reliability issue. Four shipsets will be procured in FY07 and FY08 (8 shipsets). Five shipsets will be procured in FY09 thru FY11 (15 shipsets).

Production Engineering (GA830). The review and approval of any production contract technical documentation, or the separate development of this documentation to include Technical Manuals, Signal Flow Diagrams, PMS, Level III production drawings, provisioning technical documentation (PTD), program support data (PSD), allowance parts lists (APLs) and engineering in support of final design reviews.

The Program Element totals and individual Elements of Cost for the LM2500 as contained in the Department of Navy FY09 budget estimates are as follows:

U.S. FUNDING

	FY07 AMT Expended	FY08 AMT Budgeted	FY09 AMT Budgeted	FY10 AMT Proposed	FY11 AMT Proposed
Other Procurement, Navy:					
BA1 Ships Support Equipment					
LM2500 Gas Turbine (all)	7.4	8.1	8.0	9.2	9.5

All figures are in millions of FY10 U.S. dollars.

Contracts/Orders & Options

Contractor	Award (in millions)	Date/Description
GE Infrastructure-Marine	N/A	Dec 2006 – Contract to provide OAO Territorial Generating Company No 4 (TGK-4) with two LM2500+ DLE aeroderivative gas turbine generator sets for its Belgorod TEC power station in Russia. This was a follow-on order; two units were shipped in 2006 and are currently in commercial operation. The power station generates both heat and electrical power to reduce the cost of operation for the local power and district-heating grid.
GE Infrastructure-Marine	N/A	Nov 2004 – Two LM2500+ generator sets for Looch Power Station in Belgorod, Russian Federation. IR-Leasing will lease the two LM2500+ generator sets to BelgorodEnergo for a four-year period.
GE Infrastructure-Marine	N/A	Nov 2004 – Three TM2500 mobile gas turbine generators. The customer is TERNA SA, Greece.
GE Infrastructure-Marine	N/A	Nov 2004 – Twelve LM2500 gas turbines for Korea's next-generation KDX -3 destroyers. The customer is the Republic of Korea.
GE Infrastructure-Marine	N/A	Nov 2004 – One LM2500 gas turbine for the service's multimission cutter under the Integrated Deepwater System (IDS) program. The customer is the U.S. Coast Guard.

GE LM2500

Contractor	Award (in millions)	Date/Description
GE Infrastructure-Marine	N/A	Nov 2004 – Two LM2500+ gas turbines with six-stage power turbines to repower existing Rolls-Royce Olympus packages at the Leiden Power Station. The customer is E.ON Benelux Generation of the Netherlands.

Timetable

Month	Year	Major Development
	1967-9	Design/development of LM2500
1Q	1969	U.S. Navy contract awarded for LM2500 test units
Dec	1969	Marine engine installed in MSTS *Callaghan*
Jan	1971	GE awarded DD-963 propulsion contract
Jul	1975	DD-963 delivered to U.S. Navy
	1979	First industrial units become operational in Lake Charles, North Sea
	1981	First Nuovo Pignone-installed machines become operational
	1983	First units become operational in Saudi Arabia
	1983	Uprated LM2500 becomes available
	1983	First Kanis Energie, Thomassen-installed units become operational
Mid-	1987	First STIG plant becomes operational
	1989	Fiat awarded contract for combined-cycle cogeneration plant in Genoa
Early	1988	IPSA Phase II contract awarded
	1990	Fiat unit in Genoa becomes fully operational
May	1993	IMO, Stewart & Stevenson, Thomassen form turbine-powered compressor package production/sales alliance
Jul	1993	First turbine-powered fast ferry, *Aquastrada,* becomes operational
Jun	1994	GE M&IE announces S&S launch order for LM2500+
Dec	1994	GE Nuovo Pignone LM2500+ power turbine announced
1Q	1996	Second LM2500+ engine test using the power turbine
Early	1996	Start of shipment of LM2500+ machines to S&S
Jun	1996	First LM2500+ for power generation ordered
	1997	First LM2500+ machines for all applications delivered
	1998	GE acquires 91 percent of equity shares of Nuovo Pignone
May	1998	First-ever cruise ship contract signed for gas turbines involving up to 12 LM2500+s
	1999	First marine CODAG installation of LM2500, for Germany's F-124 class frigates
	1999	Alstom dropped as a packager
Late	1999	GE Energy Rentals introduces TM2500 at 21-23 MW
	2000	Nuovo Pignone becomes an integral part of GE Oil & Gas
Dec	2000	*Radiance of the Seas* sea trials begin
2Q/3Q	2001	LM2500s chosen for *Queen Mary 2* transatlantic liner
Oct	2001	LM2500s chosen for Norway's F310 class frigates
Dec	2002	USN orders LM2500+ machines for eighth LHD Wasp ship
Jan	2003	GE announces sale of the 100th LM2500+ gas turbine machine
Aug	2003	LM2500 chosen to power U.S. Navy's X-Craft vessel (along with MTU diesel engines)
	2004	Volvo Aero signs two contracts with GE on LM2500 work/cooperation
Jan	2004	LM2500-powered *Queen Mary 2* makes maiden voyage
Sep	2004	GE announces LM2500+G4
Oct	2005	Volvo increases its role in LM2500 program
4Q	2005	LM2500+G4 becomes available
Thru	2019	Continued production/aftermarket support of LM2500 by GE and affiliates

Worldwide Distribution/Inventories

As of 2010, over 712 current-model LM2500s for all applications were installed in more than 30 countries and territories worldwide, including the North Sea region.

Note: *According to Forecast International's Industrial & Marine Gas Turbine Installations database, 1,789 LM2500 machines were installed worldwide by the start of 2010.*

The following are major customer nations: ***Canada*** *(62 machines),* ***German****y (44),* ***Ital****y (89),* ***Korea*** *[ROK] (59),* ***Japan*** *(71),* ***Mexic****o (34),* ***Norway*** *(137),* ***U.S.*** *(612), and* ***Venezuela*** *(42).*

Forecast Rationale

The GE LM2500 has defied the test of time. It's a machine that's been available for a long time, but continues to sell well. From 2002-2003 alone, GE sold about 180 machines, and in 2004, the company sold about 75 machines. It's expected that the machine will continue to be produced for the utility and industrial power generation arena, especially for cogeneration projects. While the STIG™ configuration is a strong selling point for the LM2500, overall sales during the upcoming decade may not reach the high levels of past years.

The market for LM2500/LM2500+-sized gas turbines as mechanical load drivers continues to hold its own worldwide. With increasing activity in natural gas and other pipeline construction throughout the world, the GE machine is well-positioned to obtain a share of the total orders as they emerge. The chief supplier of LM2500-powered drivers should continue to be GE Oil & Gas (here referring in particular to the former Nuovo Pignone). It should be noted that GE and GE Oil & Gas can offer variants of the LM2500 in the output range of 31,000-46,000 shp.

The 46,000-shp/34.3-MW LM2500+G4 offers more than a 12 percent increase in power compared with its predecessor, over a wide range of conditions. This latest upgrade gives customers additional horsepower in virtually the same engine envelope. The newest model can operate in both simple-cycle and combined-cycle modes, and will quickly be available in both standard and DLE combustion models, capable of burning natural gas, fuel oil, or both in a dual-fuel capacity. The LM2500+G4, in combined-cycle mode relative to the LM2500+, will have more power plus a 0.8 percent heat rate advantage.

Without any doubt, the LM2500+/LM2500+G4 has evolved in response to the Rolls-Royce RB211-based WR-21 – not only in the marine arena, but also in the pipeline and process industries market. The WR-21, now under the sponsorship of Rolls-Royce/Northrop Grumman/DCN, has been selected for the U.K.'s Type 45 destroyers and Alternative Landing Ships Logistic (ALSL) – a selection based more on the need of the U.K. to protect U.K.-based jobs than on the merits of one engine versus another. Again, to no one's surprise, the choice of the WR-21 was undoubtedly based on the fact that Rolls-Royce has long been the preferred gas turbine supplier to the U.K. Royal Navy. (GE-Marine has had the same relationship with the U.S. Navy.)

Furthermore, the large fast-ferry market is expected to grow worldwide, with strong sales projected in Asia/Pacific Rim nations. Moreover, a potentially strong market for LM2500/LM2500+-sized gas turbines are large luxury cruise ships operated by Princess Cruises, Royal Caribbean International, and Celebrity Cruises, in addition to Cunard Line's *Queen Mary 2* transatlantic liner. While the gas turbine does indeed have much to offer the large commercial vessels – smaller footprint, lessened vibration, we do not expect to see a serious effort to refit large, in place, low-speed diesel engines with the lighter LM2500s of any variant. Virtually all of the marine LM2500/LM2500+/ LM2500+G4 gas turbines, we believe, will be ordered for new-build vessels. Any refitting will largely be confined to military vessels.

Based on our recent review of the LM2500 – and an assessment of recent known orders – we are projecting that 911 engines/machines will be built during the forecast period, a total that includes production by GE's affiliates.

With uprating and upgrading efforts moving ahead with almost lightening speed, the LM2500 – in the guise of the LM2500+ and LM2500+G4 – is on its way to becoming one of the most well-known gas turbine engines of all time.

GE LM2500

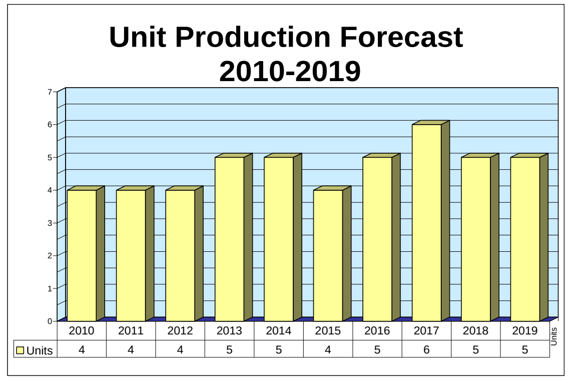
Ten-Year Outlook

ESTIMATED CALENDAR YEAR UNIT PRODUCTION												
Designation or Program		**High Confidence**				**Good Confidence**			**Speculative**			
	Thru 2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Total**
GE Energy												
LM2500/+ <> MW 20.0 to <50.0 <> Industrial Power Generation												
	336	40	44	46	44	42	42	40	38	38	38	412
LM2500/+ <> SHP =>20,000 <> Marine Propulsion												
	166	28	30	32	34	30	26	28	26	28	26	288
LM2500/+ <> SHP =>20,000 <> Mechanical Drive (Pumps & Compressors)												
	210	20	22	22	22	21	21	20	21	21	21	211
Subtotal	712	88	96	100	100	93	89	88	85	87	85	911
Total	712	88	96	100	100	93	89	88	85	87	85	911

Kawasaki M7A

Outlook

- Machine's target market is the electrical generation arena, especially cogeneration and combined-cycle installations; high heat output and availability of steam injection are sales assets
- No sales yet of the machine series for mechanical load drive duty, despite the machine being well sized for pump and compressor duty
- Newly announced M7A-03 offers increased load and higher efficiency



Orientation

Description. The M7A is a single-shaft, simple-cycle, axial-flow, high-efficiency gas turbine machine in the 5.5- to 7.4-MW class.

Sponsor. The M7A was privately developed by the prime contractor.

Note: *Some Japanese government funding for the M7A-01 and M7A-02 was granted to Kawasaki through the Japanese Ministry of Trade and Industry (now the Ministry of Economy, Trade and Industry). The funding is considered non-military in scope and application.*

Power Class. The M7A machine's ISO baseload power rating (electrical generation duty) is 5.5 to 7.4 MW.

Status. In production.

Total Produced. At the start of 2010, at least 61 KHI M7A-01 (29) and M7A-02 (32) gas turbine machines/ generator sets had been built and installed worldwide for electrical generation/cogeneration.

Application. The main application at present is electrical generation, including cogeneration and combined-cycle installations. No M7A-01s or M7A-02s have been ordered for mechanical load drive duty.

Price Range. Prices are as follows for electrical generation (2009 U.S. dollars):

Model	Price Estimate
M7A-01D	$2.1-$2.3 Million
M7A-02D	$2.7-$2.9 Million
M7A-03D	$3.0-$3.2 Million

For electrical generation (simple-cycle), the genset price covers a single-fuel skid-mounted gas turbine, electric generator, air intake with basic filter and silencer, exhaust stack, basic starter and controls, and conventional combustion system.

Competition. In the electrical generation arena, the M7A-01/-02's greatest competition comes from the Solar Taurus 60, Zorya-Mashproekt UGT-6000, Siemens SGT-200 (nee Tornado), Rolls-Royce 501-KH5, and GE Energy PGT5B.

Kawasaki M7A

Kawasaki M7A-02 in an IESL 7000B Package

Source: International Energy Systems (1983) Ltd

Contractors

Prime

International Energy Systems Ltd	http://www.iesl.com, 15-1520 Cliveden Ave, Delta, V3M 6J8 British Columbia, Canada, Tel: + 1 (604) 540-5080, Fax: + 1 (604) 540-5090, Email: ies@iesl.com/rds@iesl.com, Co-producer
Kawasaki Heavy Industries - Gas Turbine Division, Akashi Works	http://www.khi.co.jp/gasturbine, 1-1 Kawasaki-cho, Akashi, Hyogo, 673-8666 Japan, Tel: + 81 78 921 1842, Fax: + 81 78 923 6541, Prime

Subcontractor

Allen Gears	http://www.allengears.com, Atlas Works, Station Rd, Pershore, WR10 2BZ Worcestershire, United Kingdom, Tel: + 44 44 1386 552211, Fax: + 44 1386 554491, Email: sales@allengears.com (Epicyclic Gearbox)
Goodrich Engine Components	http://www.goodrich.com, 811 Fourth St, PO Box 65100, West Des Moines, IA 50265-0100 United States, Tel: + 1 (515) 274-1561, Fax: + 1 (515) 271-7201 (Dual Fuel Nozzle)

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Contractors are invited to submit updated information to Editor, International Contractors, Forecast International, 22 Commerce Road, Newtown, CT 06470, USA; rich.pettibone@forecast1.com

Technical Data

Design Features

Casing. The machine has a horizontally split, light casing. Each casing is split vertically to allow certain parts to be detached for inspection and maintenance.

Compressor. The M7A-01 has an advanced high-efficiency axial-flow compressor that has 12 stages and a compression ratio of about 12.7:1, while the M7A-02 has an advanced transonic axial-flow compressor of 11 stages and a maximum compression ratio of about 15.9:1. For the M7A-02, Stages 1-6 are made of Ti-6Al-4V; Stages 7-11 rotor blades and all stages of vanes are stainless steel. Stages 1-2 rotor blades are of a multi-circular arc airfoil type. Wide chord airfoils are used in the front stages.

Combustor. The machine has six can-type combustors with double-wall structure, and thermal barrier coating at the inner wall. Spark plug ignition is standard. Two igniters are employed. Six fuel nozzles. Combustors are detachable.

Turbine. A four-stage axial design is employed, with cooling in Stage 1-2 blades and vanes. Design/rated speed is 14,000 rpm. The M7A-02 features a transonic turbine. Turbine blades are made of Ni-based alloy; vanes are made of cobalt-based heat-resistant alloy. Blades and vanes are produced by precision casting.

Bearings. Compressor front dual bearings are hydrodynamic tilting pad journal bearings, while turbine rear dual bearings are basic tilting pad type.

Accessories. An electrohydraulic control system is standard. An electric motor with a torque converter is used for starting; hydraulic starting is optional.

Gearbox. Allen Gears has provided an epicyclic gearbox for the M7A-01. The gearbox is rated at 6,620 kW, reducing the gas turbine's operating speed of 13,894 rpm to 1,500-1,800 rpm.

Control Unit. Both the -01 and -02 gas turbines adopt a high-speed digital control unit governed by a 32-bit CPU capable of speed governing, temperature monitoring, starting and stopping sequence control, and shutdown control. For the -02, a separately installed monitoring system enables data logging and remote monitoring via telecommunications lines.

Dimensions. The approximate dimensions and weights of the Kawasaki M7A machines are as follows:

	Metric Units	English Units
Length (-01/02)	3.7 m	12.14 ft
Width (-01/02)	1.5 m	4.92 ft
Height (01/02)	1.7 m	5.57 ft
Weight (-01/01ST/02)	4,500/4,700/5,000 kg	9,921/10,362/11,023 lb

Performance. The Kawasaki M7A machine in simple-cycle electrical generation duty has the following performance parameters:

APPLICATION = ELECTRICAL GENERATION

Parameter	M7A-01	M7A-01D	M7A-02	M7A-02D	M7A-03D
ISO Base Rating	5,512 kW	5,381 kW	6,912 kW	6,721 kW	7,380 kW
Heat Rate (LHV)	11,530 Btu/kWh	11,648 Btu/kWh	11,190 Btu/kWh	11,264 Btu/kWh	10,367 Btu/kWh
	12,165 kJ/kWh	12,289 kJ/kWh	11,806 kJ/kWh	11,884 kJ/kWh	10,990 kJ/kWh
Pressure Ratio	12.7:1	12.7:1	15.9:1	15.9:1	15.9:1
Exhaust Flow	21.17 kg/sec	21.17 kg/sec	26.99 kg/sec	26.99 kg/sec	26.99 kg/sec
EGT	545°C	542°C	522°C	522°C	542°C

The M7A machine for cogeneration duty has the following performance parameters:

APPLICATION = COGENERATION

Model	Gas Turbine	Output	75-100% Load Steam Generated
GPC60	M7A-01	5,841 kW	11.9-14.8 tons/hr
GPC60 DLE	M7A-01D	5,684 kW	13.2-13.7 tons/hr
GPC70	M7A-02	6,958 kW	13.2-14.7 tons/hr
GPC70 DLE	M7A-02D	6,712 kW	14.4-15.5 tons/hr
GPC80 DLE	M7A-03D	7,230 kW	15.7-16.5 tons/hr

The M7A machine for combined-cycle duty (GPCS series) has the following performance parameters (S/T = steam turbine):

APPLICATION = COMBINED-CYCLE

Item	Physical Plant Make-up	Electrical Output	Overall Heat Rate	Total Combined Electric Efficiency
GPCS80	1x M7A-01 + 1x S/T	7,900 kW	8,902 kJ/kWh	40.4%
GPCS100	1x M7A-02 + 1x S/T	9,000 kW	8,720 kJ/kWh	41.3%
GPCS160	2x M7A-01 + 1x S/T	16,400 kW	8,576 kJ/kWh	42.0%
GPCS200	2x M7A-02 + 1x S/T	18,700 kW	8,336 kJ/kWh	43.2%

Note: *No M7A-01s or M7A-02s have been ordered for mechanical load drive duty.*

Kawasaki M7A

Variants/Upgrades

M7A-01. This designation applies to the basic gas turbine model that has been available since 1993.

M7A-01ST. Announced in June 1996, the M7A-01 was made available with steam injection to provide a large increase in power output.

M7A-02. This model is a power-up version of the M7A-01. Compared with the M7A-01, it has a 20 percent-uprated compressor.

M7A-03. This newest model (2006) is, at approximately 7.4 MW, the highest rated unit in the M7A line (see technical specifications above.)

Note: *Kawasaki offers the M7A-01 and M7A-02 in a dry low emissions (DLE) configuration.*

Program Review

Background. The Kawasaki M7A gas turbine machine series, which was introduced in the early 1990s, is considered a logical extension of the gas turbine experience Kawasaki had accumulated since 1987. The initial M7A-01, with its high simple-cycle efficiency, was touted as being particularly well suited for use in cogeneration applications. The first prototype M7A-01 was completed in May 1991. At that time, KHI indicated that the machine would be ready for initial deliveries in 1994. It also said that the M7A's entire structure was built to operate for more than 30,000 hours, and, with proper maintenance, could provide in excess of 100,000 hours of use.

The M7A (in a GPC60 cogeneration system, and later in a GPB/GPC70 and GPB70D system) was first installed in Japan by Settsu Corp at its Amagasaki paper and paperboard processing plant.

In June 1996, KHI announced the development of a steam-injected version of the M7A to provide a substantial increase in electrical output. While the then-standard M7A-01 developed about 5,960 kW at the gearbox shaft at a thermal efficiency of 30.5 percent, the newer steam-injected M7A-01ST had 1,100 kW greater shaft output at that time and offered a 3.5-point increase in thermal efficiency.

About mid-1997, KHI unveiled development of a 7-MW KHI gas turbine: the M7A-02. The M7A-02 is designed for a thermal efficiency of 32 percent. More than 80 percent of the parts used in the M7A-02 are common with the M7A-01.

The M7A-01 and M7A-02 can be employed in cogeneration systems and combined-cycle GPCS systems (for output parameters, see the Performance section above).

Hybrid Gas Turbine (HGT)/M7A-02. In 1999, the (then) Japanese Ministry of Trade and Industry (now the Ministry of Economy, Trade and Industry) launched the project "Research and Development to Practical Industrial Cogeneration Technology." The objective of the project was to promote industrial applications of cogeneration technology that employed hybrid gas turbines (HGTs), which are gas turbine machines that employ metal and ceramic materials in high-temperature parts. The final goal of the project was to contribute to the reduction of CO_2 by increasing the thermal efficiency of gas turbine engines. Under the project, the design, construction, and operation of the HGT engine was assigned to KHI. Development and evaluation of ceramic materials and the manufacture of ceramic parts was assigned to Kyocera. System application research was assigned to Tokyo Gas, Osaka Gas, and Toho Gas.

The HGT machine was designed by applying ceramic parts to an existing 7,000-kW-class industrial gas turbine. As the base machine, an M7A-02 was selected. To increase the turbine inlet temperature (TIT) to attain a higher thermal efficiency, stationary hot parts were replaced with ceramic parts. Also, new metallic parts were developed to match the increase in gas temperatures.

International Energy Systems Ltd (IESL) manufactures a comprehensive range of industrial gas turbine generator sets at its facilities in Vancouver, BC, Canada. Its primary products include:

- Its own industrial gas turbine generator set packages, from 200 kWe to 7,000 kWe
- Heat recovery steam generators and ancillary equipment for cogeneration applications
- Steam turbine generator sets

With its head office in Delta/Vancouver, BC, Canada, IESL has sales offices in Quebec, Taiwan, India, Australia, Egypt, and Venezuela and other South American nations. IESL's clients range from oil companies, utilities, and governments to industrial plants, hospitals, and universities.

The New M7A-03

In October 2006, Kawasaki Heavy Industries announced that it would begin selling its GPC80D co-generation system powered by Kawasaki's M7A-03, 7,000-kW-class gas turbine.

The M7A-03 gas turbine has been developed for co-generation system application based on Kawasaki's M7A gas turbine series that combines Kawasaki's experience and technologies in the field of small and mid-size industrial gas turbines with its technologies in the field of aircraft jet engines. The M7A-03 gas turbine incorporates the various state-of-the-art technologies demonstrated in the development of the 20-MW-class L20A high-performance gas turbine. In addition to its high thermal efficiency of 35 percent, other features of the M7A-03 include:

- DLE system employing a lean premix combustion method that reduces NOx to meet the strict Japanese regulatory standard of 80 ppm (0_2 = 0%), without the use of any denitrification equipment
- Improved durability through the use of the latest materials and cooling technology

The GPC80D is a co-generation system that harnesses the power of this enhanced M7A-03 gas turbine. It is used not only for power generation efficiency, but also for total thermal efficiency.

Funding

Kawasaki received some funding for its M7A-01 and M7A-02 machines from the Japanese Ministry of Trade and Industry (MITI), now the Ministry of Economy, Trade and Industry (METI). The funding is considered non-military in scope and application.

Contracts/Orders & Options

No military contracts for the KHI M7A-01 and M7A-02 gas turbine machines have recently been awarded. Recent commercial sales of the gas turbine include the following:

Contractor	Award (Amount)	Date/Description
Kawasaki Heavy Industries	N/A	Feb 2006 – Two M7A-02 gas turbines ordered for NYC-DEP in conjunction with Cummins. First recorded order in North America.
Kawasaki Heavy Industries	N/A	2H 2004 – One M7A-02 gas turbine generator set for PT Centex in Jakarta.

Timetable

Month	Year	Major Development
	1987	Development of M7A
Early	1991	First prototype M7A-01 completed
Feb	1993	M7A-01 formally announced
Apr	1994	First M7A begins commercial operation at Settsu Corp's Amagasaki plant
Jun	1996	M7A-01 development announced
Mid-	1997	M7A-02 development announced
	1998	First M7A machines installed in Austria and Malaysia
Aug	2003	First M7A machine delivered to a customer in Turkey
2H	2004	M7A-02 ordered by PT Centex in Indonesia
Feb	2006	First order for M7A-02 recorded in North America
2H	2006	M7A-03 boosts power output to 7.4 MW
Thru	2019	Continued production/aftermarket support of Kawasaki M7A series

Worldwide Distribution/Inventories

According to Forecast International's Industrial & Marine Gas Turbine Installations database, at least 54 Kawasaki M7A machines have been built and installed in six countries worldwide. The leading customer nation is **Japan** (42 machines). These machines are also installed in **Austria** (1 machine), **Germany** (3), **Indonesia** (1), **Malaysia** (4), **Turkey** (1), and the **United States** (2).

Of the 61 machines, 29 are M7A-01s and 32 are M7A-02s.

Forecast Rationale

In the electrical generation arena, the Kawasaki M7A 01 and M7A 02 are projected to continue to garner orders for cogeneration and combined heat and power applications from utilities, IPPs, and other commercial concerns – with or without steam injection. Orders will come mainly from the Pacific Rim area, including Japan. Cogeneration sets should continue to be ordered for duty in paper mills, chemical plants, ceramics plants, breweries, and other small industrial facilities.

While KHI's corporate offices have made no official announcement regarding the machine's possible use for various mechanical load drives, the M7A's size and output lend themselves to that arena. In the current worldwide search for oil, construction of pipelines of all diameters will continue, and KHI is in an excellent position to offer its M7A for pumps and compressor drives, especially in the countries of the former Soviet Union, around the Caspian Sea, and even in Central/South America.

For the forecast period from 2010-2019, production of 47 M7A machines, all for electrical generation, is expected. At this time, we are not projecting production of the M7A for mechanical load drive duty. Also, it is highly unlikely that the M7A series will be offered for marine propulsion duty.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR UNIT PRODUCTION												
Designation or Program		High Confidence				Good Confidence			Speculative			
	Thru 2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Kawasaki Heavy Industries - Gas Turbine Division												
M7 A -02 <> MW 3.0 to <10.0 <> Industrial Power Generation												
	32	4	4	4	5	5	4	5	6	5	5	47
Total	32	4	4	4	5	5	4	5	6	5	5	47

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E-Mail ______________________

Cardholder Name ______________________

Card# ______________________ Exp. ____________ csc# ________

Billing Address (if different from above) ______________________

____

- ☐ Check Enclosed
- ☐ Bill Company (Purchase Order # and Signature Required)
- ☐ Quotation Requested
- ☐ VISA ☐ MasterCard
- ☐ American Express

Name of Product/Service	Code	E-Mail Address	Qty.	Price

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Grand Total ________

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DVD	$50	$95
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DVD	$50	$95
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Aerospace		
Binder	$360	$680
DVD	$50	$95
Electronics		
Binder	$360	$680
DVD	$50	$95

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Binder	$540	$1,020
DVD	$50	$95
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Binder	$270	$510
DVD	$50	$95
Naval		
Binder	$90	$170
DVD	$50	$95
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Binder	$90	$170
DVD	$50	$95
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Binder	$180	$340
DVD	$50	$95

NOTE: No charge for Real-Time format.

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HEADQUARTERS EUROPE

(INCLUDING RUSSIA)
HAWK ASSOCIATES LTD.
UNITED KINGDOM
Templehurst House
New Street, Chipping Norton
Oxon, OX7 5LJ, U.K.
Phone: (44) 1608 643281
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Website: www.hawkinformation.com
Contact: Mr. Michael Hobbs

HAWK ASSOCIATES LTD.
FRANCE
6 Rue de Levis, Paris 75017 FRANCE
Phone: (33) 1 4294 0693 Fax: (33) 1 4294 0433
E-Mail: france@hawkinformation.com
Contact: Mr. Edward Hobbs

CHINA AND SOUTHEAST ASIA

CHINA NATIONAL PUBLICATIONS
I & E GROUP CORPORATION
PO Box 88
16 Gongti East Road
Chaoyang Beijing 100020 CHINA
Phone: (86) 10 6506 6688 ext. 8307
Fax: (86) 10 6586 6970
E-Mail: xiaoxiao0640@hotmail.com
Contact: Mr. Xiaoxiao Zhang

JAPAN

AVIATION RESEARCH INSTITUTE
1-427-2 Takano
Misato City Saitama Pref
Tokyo 341-0035 JAPAN
Phone: (81) 489 71 5040
Fax: (81) 489 55 7151
E-Mail: max@arijapan.com
Website: www.arijapan.com/forecast
Contact: Mr. Kenichi Oyama

REPUBLIC OF KOREA

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