

ARCHIVED REPORT

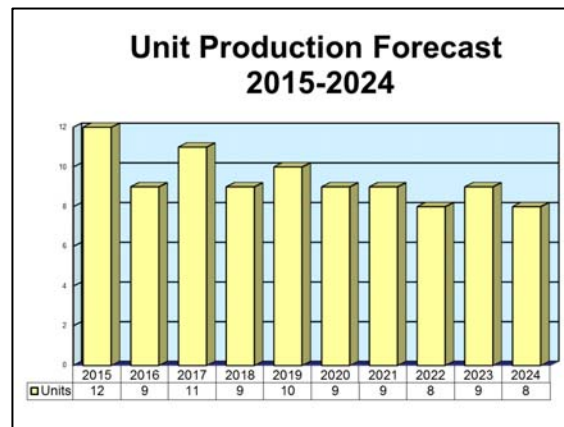
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GE Model 5000

Outlook

- Continued order pattern projected well into the decade, especially for mechanical drive duty
- GE Oil & Gas currently the main builder of the Frame 5; production by Bharat Heavy Electricals in India also projected
- 31- to 32-MW MS5002E available as a new-build machine or as a technology update in kit form for older Frame 5s; one 5E ordered for a project in the Netherlands



Orientation

Description. The GE Frame 5 is a single- and twin-shaft, simple-cycle, axial-flow, heavy-duty industrial design gas turbine in the 25- to 30-MW class. The Model 5000 is also referred to as the Frame 5; its GE designations are MS5001 (single-shaft) and MS5002 (twin-shaft). These designations can be used interchangeably.

Sponsor. The Model 5000 was privately developed by the prime contractor.

Power Class. The approximate power output of the Frame 5 machines is as follows:

Model	Power Output
MS5001	26.83 MWe for industrial and utility generator drive
MS5002C	38,005 hp for mechanical drive for use in process industries
MS5002D	43,690 hp for mechanical drive for use in process industries
MS5002E	42,913 shp (32.0 MW) for mechanical load drives; 31.1 MW for generator drive

Status. In production. The only current producers are GE Energy's GE Oil & Gas (the former Nuovo Pignone unit) and Bharat Heavy Electricals in India.

The entities A-C Compressor, Conneq, Gemini, GE Packaged Power-Odessa, Rotoflow, Thermodyn, and PII Pipeline Solutions, along with Nuovo Pignone, are now collectively referred to as GE Oil & Gas.

Total Produced. As of 2015, GE and its licensees and affiliates had built and installed more than 3,200 Frame 5 machines. At least 755 units are of the current production models.

Application. Current applications include utility and industrial power generation, including cogeneration and combined-cycle installations, in addition to process industry compressor-drive applications. A total of 19 machines have been installed for marine propulsion and transportation/rail power duty. Frame 5 machines are no longer offered for marine propulsion and transportation/rail power applications.

Price Range. Estimated prices in current U.S. dollars are as follows (in millions):

Model/Use	Price Range
PG5371(PA) (Generation)	\$9.4-\$9.6
MS5002E (Generation)	\$11.0-\$11.2
MS5392C (Mech. Drive)	\$9.0-\$9.2
MS5342D (Mech. Drive)	\$9.3-\$9.5
MS5002E (Mech. Drive)	\$9.4-\$9.6

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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 a conventional combustion system.

Competition. In the mechanical load drive arena, the MS5002 faces competition from Rolls-Royce's RB211 6562, 6761 and 6762. Other competition includes the GE LM2500+ at 41,500-42,500 shp and the Zorya-Mashproekt UGT-25000.

In the power-generation arena, the MS5001/MS5002 faces competition from the Rolls-Royce RB211-6762 DLE, Mitsubishi MF-221, Siemens SGT-700 (formerly the GT10C), and LM2500+ G4.

Contractors

Prime

GE Oil & Gas (formerly Nuovo Pignone)	http://www.ge-energy.com/about/oil_and_gas.jsp , Via Felice Matteucci, 2, Florence, 50127 Italy, Tel: + 39 55 423 211, Fax: + 39 55 423 2800, Prime
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Subcontractor

Camfil Farr Co	http://www.camfilfarr.com , 2201 Park Pl, El Segundo, CA 90245-4909 United States, Tel: + 1 (310) 727-6452, Fax: + 1 (310) 727-6425 (Self-Cleaning Air Intake System)
Industrial Acoustics Co Inc	http://www.industrialacoustics.com , 1160 Commerce Ave, New York, NY 10462-5599 United States, Tel: + 1 (718) 430-4523, Fax: + 1 (718) 863-1138 (Resonator Exhaust Silencer)
Mee Industries Inc	http://www.meefog.com , 204 W Pomona Ave, Monrovia, CA 91016 United States, Tel: + 1 (626) 359-4550, Fax: + 1 (626) 359-4660 (Gas Turbine Cooling Fog System)
Parker Aerospace Fuel Systems Division	http://www.parker.com , 8940 Tyler Blvd, Mentor, OH 44060 United States, Tel: + 1 (440) 266-2384, Email: gtfsmarketing@parker.com (Fluid Management System)
Petrotech Inc	http://www.petrotechinc.com , 108 Jarrell Dr, PO Box 503, Belle Chasse, LA 70037 United States, Tel: + 1 (504) 394-5500, Fax: + 1 (504) 394-6117 (Sequencing & Protection System)
Praxair Surface Technologies, formerly Sermatech	http://www.sermatech.com , 595 Honeybee Ln, New Castle, PA 16105-9030 United States, Tel: + 1 (724) 598-1300, Fax: + 1 (724) 658-1745, Email: info@sermatech.com (Sermaloy J Diffusion Coating)
Triconex Systems Inc	4916 Texas Ave, La Marque, TX 77568 United States, Tel: + 1 (409) 935-3555, Fax: + 1 (409) 935-3881 (Control System)
Unison Industries	http://www.unisonindustries.com , 7575 Baymeadows Way, Jacksonville, FL 32256 United States, Tel: + 1 (904) 739-4000, Fax: + 1 (904) 739-4093 (Exciter)

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Technical Data

Design Features

Intake. Air enters radially and is turned 90° for entry to the compressor. Various filtration and sound suppression systems are available.

Compressor. MS5001 single-shaft versions have a 17-stage compressor, with variable inlet guide vanes; MS5002C and MS5002D two-shaft versions have 16 stages (5002C) or 17 stages (5002D) and no variable stators. Compressor rotors are built up of forged

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wheels, each of which is balanced individually. Rabbet fits and through-bolts are used to join the wheels into a single rotor. Blading is of large chord, subsonic design. Current overall pressure ratios are in the range of 8.9:1 to 10.8:1. Inlet casing is A356 ductile cast iron, and the discharge casing is of A312 austenitic steel. Blades and vanes are of 12 percent Cr steel, and discs are of 4330 forged alloy steel.

The MS5002E has an 11-stage high-pressure-ratio, axial-flow compressor directly scaled up from the GE-10 gas turbine compressor.

Combustor. Single-shaft versions have 10 chambers, each with 10-inch-diameter cannular combustion, while two-shaft versions have a reverse-flow, multichamber (can-annular) combustion system with 12 chambers. Combustors are ringed around the outside of the compressor and are slightly offset. Spark igniters and ultraviolet flame detectors are located in two chambers; all combustors are interconnected by an atomizing spray manifold. Oil, gas, or dual-fuel nozzles are available. Liner is of RA 333 and transition duct is Hastelloy X.

Turbines. Single-shaft versions have two axial stages that drive the gas generator; Stage 1 nozzles are cooled. Two-shaft versions have a single-stage gas generator turbine and a single-stage power turbine (4,670 rpm) with variable-angle nozzles. Turbine casing is A395 ductile cast iron, discs are 12 percent Cr steel, and blades are IN738. Stator vanes are made of FSX414.

The MS5002E has an axial-flow, two-stage reaction HP turbine with air-cooled nozzles and buckets designed for high efficiency over a wide power range. It also has an LP turbine that is the same module used in the GE LM2500+.

Control System. All functions from start through loading, including automatic shutdown in the event of malfunction, are controlled by GE's SpeedTronic solid-state control system.

Accessories. All starting and auxiliary drives are mounted on the front shaft, which extends forward from the intake section. Starting is normally by diesel with a torque converter, but induction motor, steam turbine, or expansion turbine systems are available.

Dimensions. The approximate dimensions and weights of the GE MS5001 and MS5002C/D in a standard configuration (excluding the inlet and exhaust ducts) are as follows:

	MS5001		MS5002C/D	
	Metric Units	U.S. Units	Metric Units	U.S. Units
Length	11.6 m	38.06 ft	15.0 m	49.21 ft
Width	3.2 m	10.5 ft	3.2 m	10.5 ft
Height	3.7 m	12.14 ft	3.8 m (a)	12.47 ft
Weight	87.43 tonnes	96.37 tons	110 tonnes (a)	121.5 tons

(a) Including auxiliary skid.

The approximate dimensions and weight of the GE MS5002E in a packaged configuration are as follows:

	MS5002E	
	Metric Units	U.S. Units
Length	17.0 m	55.77 ft
Width	3.4 m	11.15 ft
Height	4.0 m	13.12 ft
Weight	117 tonnes	128.9 tons

Performance. The MS5001 and MS5002 have the following performance parameters (ISO conditions, natural gas fuel):

APPLICATION = GENERATOR DRIVE							
Model	ISO Rated	Heat Rate	Efficiency	Pressure	Exhaust Flow	Turbine	EGT
	Power			Ratio		Speed	
MS5001	26,830 kW	12,687 kJ/kWh	28.4%	10.5:1	125.2 kg/sec	5,094 rpm	483°C
MS5002E	31,100 kW	10,285 kJ/kWh	35.0%	17.0:1	102.0 kg/sec	5,714 rpm	511°C
APPLICATION = MECHANICAL LOAD DRIVE							
MS5002C	38,005 shp 28,340 kW	8,816 Btu/shp-hr 12,470 kJ/kWh	28.8%	8.8:1	274.1 lb/sec 123.4 kg/sec	4,670 rpm	963°F 517°C
MS5002D	43,690 shp 32,580 kW	8,653 Btu/shp-hr 12,239 kJ/kWh	29.4%	10.8:1	311.7 lb/sec 141.4 kg/sec	4,670 rpm	948°F 509°C
MS5002E	42,913 shp 32,000 kW	7,070 Btu/shp-hr 10,000 kJ/kWh	36.0%	17.0:1	225.0 lb/sec 102.0 kg/sec	5,714 rpm	901°F 483°C

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Variants/Upgrades

MS5001. The MS5001 is the single-shaft model in the Frame 5 series. The latest subvariant is the MS5001P, which has a 17-stage compressor and variable inlet guide vanes. It has a can-annular combustion system with 10 chambers and a two-stage turbine (with Stage 1 nozzles being cooled).

This model offers steam or water injection systems for NOx abatement.

MS5001R/RN. The designations MS5001R and MS5001RN indicate a regenerative cycle operation for the Frame 5 machine; they have 16-stage compressors. The models have been used for mechanical drive.

MS5002. The MS5002 is the twin-shaft model in the Frame 5 series. The MS5002A uses the compressor of the mid-1960s single-shaft MS5001M series, less the 16th stage; the MS5002B model uses the MS5001N series compressor, less the 17th stage.

MS5002C. The MS5002C, introduced in 1987, has a nominal ISO baseload rating of 38,005 hp (on natural gas fuel). This model has a 16-stage axial compressor.

This model offers steam or water injection systems for NOx abatement.

MS5002D. The MS5002D is an uprated version of the Frame 5 machine; it has a nominal ISO baseload rating

of 43,690 hp (on natural gas fuel). This model has a 17-stage axial compressor. The machine model has a combustion system that has 12 cans, plus one HPT and one LPT stage. It has a simple-cycle efficiency of 30.3 percent. This model offers steam or water injection systems for NOx abatement.

MS5002E. In September 2002, GEPS unveiled the MS5002E, a 42,913-shp (32.58-MW) machine designed initially for mechanical load drive applications in the oil and gas industry, but also available for power generation. The machine has an 11-stage high-pressure-ratio, axial-flow compressor directly scaled up from the GE-10 gas turbine compressor, a two-stage reaction-type HPT, and a two-stage LPT. It has a simple-cycle efficiency of between 35 and 36 percent.

This machine, manufactured by GE Oil & Gas in Florence, Italy, became available in 2004.

This model has, as standard equipment, a dry low NOx (DLN) combustion system.

MS5002R. The designation MS5002R indicates a regenerative cycle operation of the Frame 5 machine for mechanical drive duty.

Program Review

Background. GE MS5000 (Frame 5) series gas turbines have been marketed since 1957. They are offered in both single- and dual-shaft versions (MS5001 and MS5002, respectively) and in a broad range of configurations and power ratings, largely tailored to individual customer specifications. The Frame 5 machines have great versatility and have been applied in virtually all forms of industrial power activity, including transportation duty and marine propulsion.

Frame 5 machines are normally sold as complete packaged power plants together with all necessary control and support gear. Individual components are skid-mounted, and the systems are installed on-site, housed in appropriate metal structures. With the series generally ordered to customer specifications, the designations vary widely.

Model 5000 Improvements. Since the introduction of the Model 5000, GE has been uprating and upgrading its various Frame machines on an ongoing basis. For the Model 5000, a Performance Improvement

Package was designed for Frame 5 Models A through P, including such items as floating seal transition pieces, combustion liners, splash plate crossfire tubes, improved Stage 2 nozzles, shrouded tip Stage 2 buckets, GTD 111 Stage 1 buckets, and outer combustion casings. Such additions and improvements have resulted in incremental percentage gains, from 31.1 percent in power output and 9.1 percent in heat rate for the MS5001L generator of the late 1960s to 5.1 percent in power output and 2.9 percent in heat rate for the most recent MS5001P generator.

In addition, GE has on offer its Simplex SpeedTronic control system for retrofit of previously supplied GE gas turbines with pre-SpeedTronic and Mark I or Mark II control systems. The Simplex is a microprocessor-based, dual-processor derivative of the Mark IV control system. The system, which is the same size as the older controls it can replace, employs the same microelectronics technology as the Mark IV, less that system's triple-redundant microcomputer feature. It is

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offered by GE as a generally less costly alternative where the Mark IV's triple-redundant feature is not considered essential.

Emissions Controls. For emissions control, the GE Oil & Gas MS5001 and MS5002 are available with steam or water injection for NOx abatement. A DLN combustion system is available.

Applications. Frame 5 machines have been used in the following applications:

Power Generation. About 73 percent of Model 5000 production has been for power/electrical generation, usually for peaking installations with packaged power plants and power block configurations. Similar installations have been made in the petroleum sector and at industrial sites. Generation packages made up the bulk of Model 5000 applications.

Of late, GE Oil & Gas (Nuovo Pignone entity) has produced almost all single-shaft Frame 5 machines for power generation (generator drive) applications; some production has also been done by Bharat Heavy Electricals in India.

An estimated 2,285 Frame 5s have been installed for power-generation duty.

Mechanical Drive. Mechanical drive applications have historically been a lesser market for the Model 5000, although the number produced has been noteworthy. The former USSR's Yamal natural gas pipeline system was the first major application for the MS5002; 120 mechanical drives were procured by the then-Soviet import agency.

The Soviet Union negotiated a massive loan and equipment purchase agreement with Western nations for construction of the Yamal natural gas pipeline. The 3,600-mile (5,792-km) pipeline extends from the Yamal Peninsula in Siberia to the Western European frontier near the Czech Republic and Slovakia. The equipment purchased included 120 Model 5000 pipeline drivers and five Model 3000 compressor sets for the head station. John Brown Engineering, Nuovo Pignone, and then-AEG Kanis completed production and deliveries of the gas turbines to the Soviet Union in 1984. The original contracts called for the delivery of 21, 57, and 42 machines, respectively. GE was originally contracted to supply certain rotor components to its European licensees.

Most of the dual-shaft Frame 5 machines currently being produced by GE Oil & Gas are for mechanical drive applications.

About 870 Frame 5 machines have been installed for various mechanical load drives.

Marine Propulsion. GE's business associates/licensees have produced five Model 5000s for marine propulsion: Thomassen built two (one each in 1974 and 1976) for Union Steamship, and European Gas Turbines built three machines in 1996.

No further Model 5000 marine propulsion activity is expected, especially given the LM2500/LM2500+ produced by GE.

Transportation Applications. GE built 16 Model 5000 machines for transportation applications: 12 for the Union Pacific Railroad Company, one for Exxon USA, one for Ferromex (for use in Mexico), and two for Broken Hill Proprietary (for use in Australia). No applications for Frame 5 machines in this market segment have emerged since 1973.

The Newest on the Street: the MS5002E

The new MS5002E, also referred to as the Frame 5E, is designed for simple-cycle efficiency (shaft) of 35-36 percent and combined-cycle efficiency of 85.1 percent. Its combined-cycle output is 46.1 MW. The Frame 5E's LPT shaft speed is 6,100 rpm. The machine can run in 50-Hz/60-Hz applications.

The Frame 5E offers NOx emissions of 25 ppm or less through use of a dry emissions combustion system derived from GE DLN2 combustion technology.

Historical Activity. The following firms are or have been affiliated with GE on the Frame 5 program:

- Bharat Heavy Electricals Ltd; Tiruchirappalli, Tamil Nadu, India.
- Hitachi Ltd; Tokyo, Japan.
- Kanis Energie GmbH; Essen, Germany.
- Kvaerner Energy Ltd; Clydebank, Dunbartonshire, Scotland, U.K. (the former John Brown Engineering Ltd).
- Kvaerner Energie a.s. (now a part of GE Energy); Oslo, Norway.
- MAN TURBO AG; Oberhausen, Germany.
- Marubeni Corporation; Tokyo, Japan.
- Mitsui Engineering and Shipbuilding Company Ltd; Tokyo, Japan.
- Nanjing Turbine Works; Beijing, China.
- Thomassen International BV; Rheden, the Netherlands.
- Toshiba Corporation; Tokyo, Japan.

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Funding

No military funding for the Frame 5 series of machines has been identified.

Contracts/Orders & Options

<u>Contractor</u>	<u>Award (in millions)</u>	<u>Date/Description</u>
GE Oil & Gas	N/A	Jun 2011 – GE Oil & Gas to provide two new MS5002D units to Pluspetrol Energy for the Malvinas Lima project in Peru.
GE Oil & Gas	N/A	Feb 2008 – The second MS5002E (Frame 5-2E) gas turbine produced by GE Oil & Gas entered commercial service at the Yara Sluiskil BV fertilizer plant in Sluiskil, the Netherlands. The gas turbine, equipped with the latest GE dry low NOx technology (DLN2), achieved 12 ppm of NOx emissions during testing, compared to the contractual guarantee of 18 ppm.

N/A = Not Available

Timetable

<u>Month</u>	<u>Year</u>	<u>Major Development</u>
	1952	Frame 5 series development begins
	1957	First installation
	1967	First order placed, with GE Associates
	1971	Initial order placed for MS5002
	1972	Initial order placed for marine propulsion machines
	1981	Up-rated Frame 5 gensets introduced
1Q-4Q	1982	Trade sanctions imposed against USSR, then lifted
	1986	First Frame 5 machine enters service in PRC
	1987	MS5002C model introduced
Mid-Late	1991	GE, Kirov Works agreement signed
	1995-97	Nuovo Pignone ships 30 MS5002s to Tragaz/Gazprom
	1998	Uprate kits offered; new MS5002D model sold
Mid-	1999	Williams/Schlumberger orders eight MS5002Cs for reinjection duty
Dec	1999	Atlantic LNG orders MS5002Ds for Point Fortin plant, Trinidad and Tobago
Mid-	2001	GEPS reported to be developing MS5002E
Oct	2001	Frame 5C gas turbines ordered for duty in Venezuela
Sep	2002	40,230-shp/30-MW Frame 5E introduced
Mar	2003	GE Oil & Gas awarded contract to upgrade six MS5002C gas turbines to MS5002D configuration for Atlantic LNG in Trinidad and Tobago
1Q-2Q	2004	Frame 5E becomes available
	2005-2012	Older Frame 5 machines being up-rated to Frame 5E configuration
Mar	2006	Frame 5E ordered for project in the Netherlands
Jan	2012	GE institutes modular replacement strategy for Frame 5 machines with Qatargas
Sep	2012	MS5002E reaches 16 million operating hours worldwide
Thru	2023	Continued aftermarket support of older Frame 5 machines

Worldwide Distribution/Inventories

At the start of 2015, an estimated 3,200 GE-designed Frame 5 machines had been installed in 70 countries and/or territories worldwide since 1958, when the first unit began commercial service. Over 755 units are of current production models. The machine is primarily installed in the following nations: **Algeria** (157 machines), **Indonesia** (121), **Iran** (110), **Russia** (168), **Saudi Arabia** (155), **United Arab Emirates** (112), the **United States** (882), and **Venezuela** (162).

Forecast Rationale

The Model 5000 series of machines remain in production despite the availability of newer gas turbine models, including GE's own LM2500 and LM6000 and such European designs as the Siemens SGT 600/700.

Beyond the new-build machines listed in the forecast chart, we are confident that because the Frame 5 has such a large installed customer base geographically, many old Frame 5 machines will be uprated to the D or E standard, giving GE and GE Oil & Gas considerable work in the future.

New-build Frame 5 machines will be produced by GE Oil & Gas (the former Nuovo Pignone) in Italy and by Bharat Heavy Electricals in India. The orders are expected to be placed by customers in the Middle East/Asia, North Africa, and the Caribbean.

At this point, we are not issuing a specific forecast for the MS5002E because initial models might be sold as uprate packages for older Frame 5s.

New strategies for modular replacement to minimize downtime, pioneered with Qatargas, may help extend the production lifetime of these machines and increase the viability of the product line, especially in applications where reliability and minimal downtime are paramount.

With so many strongly performing aged machines in service, it is wise to note that GE's Technical Information Letter (TIL) 1576, issued in 2007, requires rotors with 200,000 equivalent operating hours or 5,000 equivalent starts (whichever comes first) to undergo a comprehensive inspection. Hours-limited rotors that pass inspection, with or without rehabilitation or replacement of critical parts, can be certified for extended service (50,000 or more hours). The OEM's current position reportedly is that rotors that have accumulated 5,000 starts are at end of their lifespan no matter how good they might look.

Cycling units at utilities and IPPs are most likely to be retired due to this starts limitation. Otherwise this unit is a workhorse, with the only Achilles heel being a tendency of the compressor tenth-stage extraction slot to develop cracks in the gray cast iron, allowing the vane to work free and the possibility of airfoils impinging downstream. Thus several third-party services have developed a patch ring protocol to avoid this eventuality.

While MAN TURBO AG and Hitachi could become affiliates of GE on the GE Model 5000, the machines are not likely to be produced by them during the forecast period.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR UNIT PRODUCTION												
Designation or Program	High Confidence					Good Confidence			Speculative			Total
	Thru 2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
Bharat Heavy Electricals Ltd												
Model 5000 (Frame 5)/MS5001 <= MW 20.0 to <50.0 <= Industrial Power Generation												
	45	3	2	3	3	2	3	2	2	3	3	26
GE Oil & Gas												
Model 5000 (Frame 5)/MS5001 <= MW 20.0 to <50.0 <= Industrial Power Generation												
	176	2	1	1	0	0	0	0	0	0	0	4
Model 5000 (Frame 5)/MS5002 <= SHP =>20,000 <= Mechanical Drive (Pumps & Compressors)												
	534	7	6	7	6	8	6	7	6	6	5	64
Subtotal	710	9	7	8	6	8	6	7	6	6	5	68
Total	755	12	9	11	9	10	9	9	8	9	8	94