Eastern Interconnection Planning Collaborative

Phase 2 Report:

Interregional Transmission Development and Analysis for Three Stakeholder Selected Scenarios And Gas-Electric System Interface Study

DOE Award Project DE-OE0000343

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Volume 12 Appendices to Section 11

FINAL

Acknowledgement

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Disclaimers

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GE LM6000 Turbine Brochure

GE Power & Water
Distributed Power

More Power – Total Flexibility

GE's LM6000-PG* (SAC)

Adding technology advancements to deliver greater value.

In its quest to push the limits of gas power and performance, GE Power & Water continues to innovate available gas turbine offerings that improve power capability and enhance customer operations.

Offering a 25% simple cycle power increase and an 18% boost in exhaust energy for cogeneration applications, GE introduces one of the latest enhancements of its proven LM6000® aeroderivative gas turbine product line: the LM6000-PG with single annular combustor (SAC).

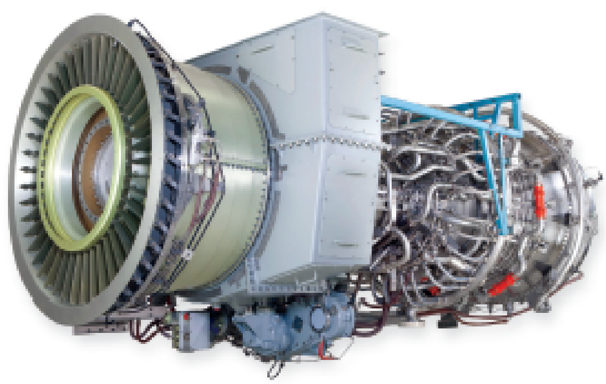
The LM6000-PG will provide combined cycle power in the range of 66 megawatts (MW) with efficiencies ranging from 50 to 52%, depending on selected emissions control methods. The power increase comes from the same 4.5 m X 21.5 m package footprint as existing 50 Hz LM6000 technology, yielding a power density improvement of nearly 20%.

GE's LM6000 has a product heritage of over 1,000 units shipped and +21 million operating hours with over 99% reliability. The improved combined cycle efficiency of the LM6000-PG can reduce fuel consumption by the equivalent of 33,000 barrels of oil per year, when compared to other similar aeroderivative solutions in its class. The LM6000 uprate also reduces carbon dioxide emissions by 6,500 tons over the course of a typical operating year—the same emissions reduction achieved by removing 2,500 cars from the road annually.

Material and technology upgrades previously demonstrated on the CF6-80E and GE90 aircraft engine, and the LMS100® were key to the improvements on the LM6000. The LM6000-PG has been designed with specific attention to commonalities between the 50 Hz and 60 Hz offerings, allowing operators to benefit from a global experience base. The 60 Hz packages will be assembled in GE's Houston, Texas facility, while the 50 Hz packages will be manufactured in GE's Hungary facility.

ISO Performance based on natural gas at ISO conditions, zero losses

NO_x Control Method/Sprint®	Unabated/-	Water/-	Water/Sprint®
Power Output (kWe)	52,784	55,617	58,036
Thermal Efficiency (%)	43.2%	41%	40.8%
Heat Rate LHV (Btu/kWe-Hr)	7,898	8,324	8,355
Exhaust Flow (lbs/sec)	310	320	324
Exhaust Temperature (°F)	878	858	867
NO_x Emissions (ppmvd)	—	25	25
Water Injection for NO_x (lbs/hr)	—	27,965	26,519
Power Turbine Speed (rpm)	3,930	3,930	3,930
No. of Compressor Stages	19	19	19
No. of Turbine Stages	7	7	7



The LM6000-PG provides more power and total flexibility. Built upon the heritage of an industry leader, the LM6000-PG is ready to meet your power needs.

STANDARD 60/50 Hz LM6000-PG (SAC)
Package Configuration

Gas Turbine

- Cold-end drive
- Single Annular Combustor (25 ppm NO_X, 50 mg/Nm³) combustor
- Horizontally split casing
- Variable inlet guide vanes
- Gas turbine familiarization training

Generator

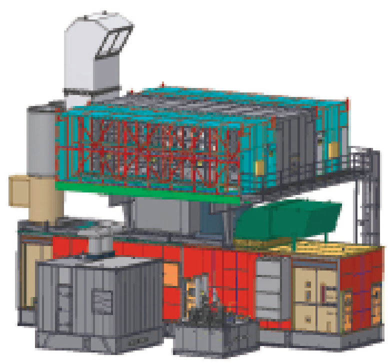
- 13.8 kV, 0.85 PF brushless 2-pole exciter (60 Hz)
- 11.5 kV, 0.8 PF brushless 2-pole exciter (50 Hz)
- WPII weather protected
- Voltage regulator/neutral side protection CTs
- NEMA Class F insulation and B temperature rise
- Integrated protective relay panel
- Vertical offset gearbox

Package

- Auxiliary module containing turbine lube oil, water wash, hydraulic start, and water injection systems
- Fully enclosed gas turbine and generator system meeting 85 dBA near field design
- Direct drive generator fans
- Guard inlet air filters
- Electro-hydraulic start/shutdown system
- Class I Div 2 Group D/Zone 2 class electrical system
- Digital control system with duplex key reliability sensors and instrumentation
- Simplex shell and tube coolers for the lube oil system
- Axial exhaust collector
- Fire protection system with gas detectors, and optical flame and thermal detectors

Options

- Dual igniter
- Integrated piping, cable trays, and wiring
- Enhanced walkway (60 Hz units only)
- Control Module
- Generator options
  - Voltages from 12.47 kV to 13.8 kV (60 Hz)
  - Voltages from 10.5 kV to 11.5 kV (50 Hz)
- Fuel systems
  - Gas with water or steam for NO_X control – 25 ppm, 50 mg/Nm³
  - Liquid with water for NO_X control – 42 ppm, 86 mg/Nm³
  - Dual fuel
- Control system
  - Black start for island operation
  - Continuous Emission Monitoring
  - Remote display to control or monitor the unit
  - Power & Control Module fully wired
  - Motor control center
- Lube oil system
  - Oil/water coolers
  - First fill lubricants
- Winterization interval packages down to -39°F, -39°C
- Pulse air filter for less maintenance
- 80 dBA capability
- Inlet conditioning for optimized efficiency
  - Evaporative cooling
  - Mechanical chilling
  - Heating



LM6000-PG/PH*
Enhanced Packaging

Key Characteristics

- Universal aux skid reduces footprint
- Minimizes field connections
- Main base has same footprint
- Mark VIe and Woodward Controls
- Same inlet air filter house
- Same chiller coils

For more information, contact your GE representative or visit www.ge-aero.com.

GEA17012D (05/2013)

Appendix 36

GE LMS100 Turbine Brochure

GE Power & Water
Distributed Power

LMS100 Gas Turbine (60 Hz)

fact sheet

Technology

The LMS100 is an intercooled gas turbine system, developed from GE frame and aeroderivative gas turbine technologies, with simple cycle thermal efficiencies of up to 44%.

- Peaking, mid-range and baseload power capabilities of up to 106 MW
- Unrestricted daily stops and starts
- Modular design for ease of maintenance and high availability
- Fast 10-minute start-up
- High part-power efficiency
- Load following and cycling capabilities

Experience

The LMS100 is a new gas turbine based on a combination of proven technologies, derived from the CF6-80E and CF6-80C2 aircraft engines, the predominant engines for the Boeing 747 and 767 wide-body aircraft, and from the frame 6FA gas turbine.

- GE CF6-80 engines have more than 100 million operating hours in airline service
- GE F technology units have more than eight million operating hours in power generation service
- End-Users: utilities, municipalities, independent power producers
- Configurations: simple cycle, cogeneration and combined cycle

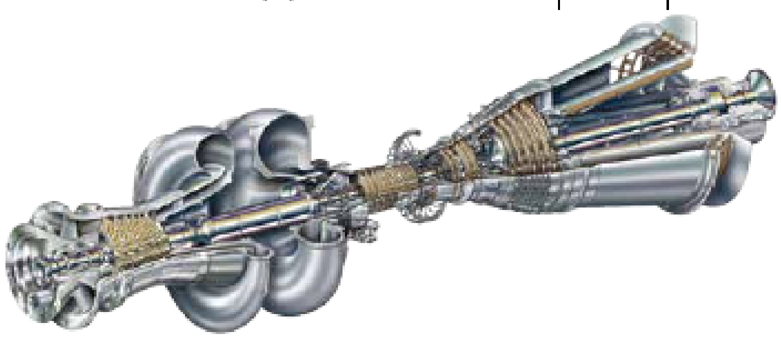
Innovation

GE Energy and GE Transportation collaborated—along with three companies from outside of GE—to develop the first modern intercooled gas turbine cycle.

- 100 MW Blocks of power
- Cycling capability
- Sustained power capability on hot days
- Fuel flexibility
- Boiler feedwater heating
- Two waste heat sources (exhaust and intercooler)

ISO performance based on natural gas

LMS100 (60 Hz)	SAC	DLE
Power Output (MW)	105.8	101.2
Heat Rate LHV (Btu/kWh)	7,877	7,816
Exhaust Flow (lbs/sec)	497	488
Exhaust Temperature (°F)	771	789
Emissions, NO_x @ 15% O_2 (ppm)	25	25
Power Turbine Speed (rpm)	3,600	3,600
No. of Compressor Stages	20	20
No. of Turbine Stages		
Intermediate Pressure (IPT)	2	2
High Pressure (HPT)	2	2
Power (PT)	5	5



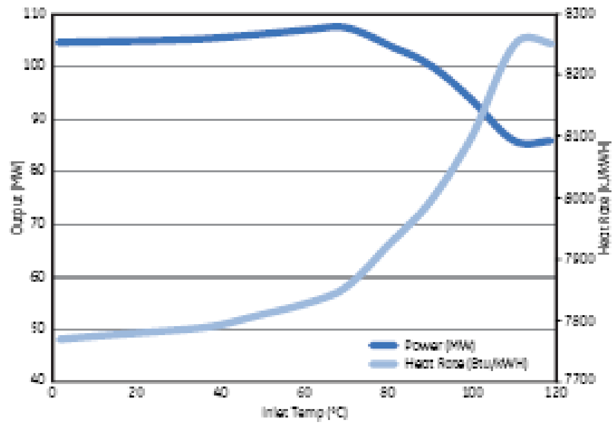
Service

GE Energy is the world's largest aeroderivative service provider, with a global network of field service offices and fully equipped service centers. A wide range of products and services are offered for the LMS100 utility and industrial operators, including:

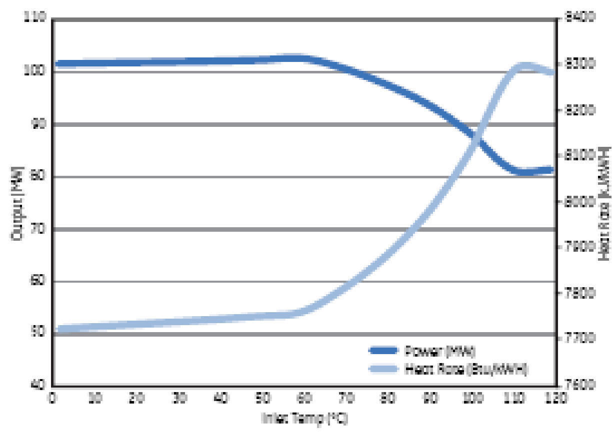
- Customer support 24/7/365
- Global field services capability
- Level IV Service Centers in Houston, Texas and Rheden, The Netherlands
- Comprehensive spare parts support
- Critical repairs available globally
- Spare or lease engine module options
- Rotatable module exchange programs
  - Gas Turbine Supercore
  - High Pressure Turbine
  - Intermediate Power Turbine
  - Combustor
  - Power Turbine
  - Low Pressure Turbine (Booster) Rotor
- CM&U – Upgrade programs
- Remote diagnostic services
- Customer training courses
- Wide variety of contractual or long-term service agreements

This comprehensive product offering, combined with our commitment to reduce service center and outage turn times, results in substantial life cycle cost savings for the plant owner/operator.

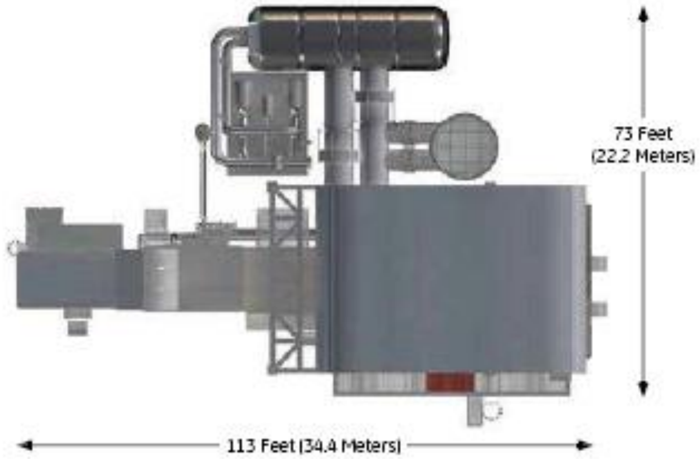
LMS100 SAC 60 Hz Output and Heat Rate



LMS100 DLE 60 Hz Output and Heat Rate



Package Layout



Standard 60 Hz LMS100 Generator Package

Gas Turbine

- 20-Stage Axial Compressor
  - 6 Low Pressure Stages and 14 High Pressure Stages
  - Off-Engine Air-to-Water Intercooler
  - Horizontal Split Casing
  - 42:1 Compression Ratio
  - 460 lb/s (209 kg/s) Nominal Inlet Mass Flow
- Annular Combustor
  - 30 Gas Fuel Nozzles, Water or Steam Injection for NO_x Control
  - 15 Gas Fuel Nozzles, Dry Low Emission Control
- 2-Stage High Pressure (HPT) and Intermediate Pressure Turbine (IPT)
- 5-Stage Aerodynamically Coupled Power Turbine (PT)

Generator

- 11.5 kV, 0.85 PF Continuous Duty
- 2 Pole, 3 Phase, Brushless Exciter
- WPII Weather Protected
- Voltage Regulator/Neutral Side Protection CTs
- NEMA Class F Insulation and B Temperature Rise
- Integrated Protection Relay Panel

Package

- Local Control System in Weatherproof Room
- 24 V and 125 V DC Batteries
- 85 dBA Near Field Design
- Static Inlet Air Filters
- Electro-Hydraulic Start/Shutdown System
- Class 1 Div 2 Group D Class Electrical System
- Mark* VIe Duplex Digital Control System with a Human Machine Interface (HMI)
- Lube Oil System with Duplex Shell and Tube Coolers
- Turbine Factory Tested (Static)
- On and Off Line Water Wash
- 1-Year Parts/Service Warranty and Remote Monitoring and Diagnostics
- Package Familiarization Training
- Electronically Transmitted Drawings
- Start-Up Technical Assistance

fact sheet

Optional Equipment (Packaging)

- Water Cooled Generator (TEWAC)
- High Inertia Generator
- Power System Stabilizer (PSS)
- Synchronous Condenser
- Distillate (Liquid) Fuel System (available only for SAC)
- Dual Fuel System (available only for SAC)
- Pulse Clean Inlet Air Filter
- Online Water Wash for LPC
- Water Injection for NO_X Control - Gas or Liquid Fuel (available only for SAC)
- Dry Low Emissions (DLE)
- Combustion Inlet Air Heating Anti-Icing Coil – External-Heated
- Combustion Inlet Air Heating Anti-Icing – Compressor Bleed (available only for SAC)
- Combustion Inlet Air Heating Anti-Icing – Exhaust Heat Recovery
- Combustion Inlet Air Cooling - Evaporative Cooling
- Combustion Inlet Air Cooling – Chilling Coil
- Winterization (for colder climates)
- Duplex Shell and Tube Lube Oil Coolers
- Secondary Discharge CO_2 System
- Duplex Integrated Generator Protection System (IGPS)
- Ni-Cad Battery System
- Remote Workstation
- Alternative Generator Lineside and Neutral Cubicle Locations
- Duplex Water Injection Pumps (for NO_X Control)
- Combined Lineside and Breaker Cubicle

Optional Equipment (Balance of Plant)

- Secondary Cooling – Water to Air (Cooling Tower)
- Secondary Cooling – (Finned Tube to Air Heat Exchanger)
- Secondary Cooling Motor Control Center
- Gas Fuel Filter/Coalescing Skid
- Liquid Fuel Forwarding Pump Skid
- Liquid Fuel Filter Skid
- Fuel Gas Compressor System
- Instrument Air Compressor Skid
- Demineralized Water Filter Skid
- Simple Cycle Exhaust Stack
- Exhaust Stack Expansion Joint
- SCR and COR Catalyst Emissions Control Systems
- Continuous Emissions Monitoring System (CEMS)
- CTG Package Anchor Bolts/Fixators
- CTG Package First Fill Lubricants
- Power Control Module (PCM)
- Combustion Turbine Generator (CTG) Motor Control Center
- Intercooler Water Pump Skid Motor Control Center
- Balance of Plant (BOP) Motor Control Center
- Generator Step-Up (GSU) Transformer
- 15 kV Rated Generator Breaker
- Supervisory Control System
- Black Start Diesel Generator Package
- Black Start Generator Control System
- 240 V DC Motor Starters

www.ge-energy.com/lms100

GEA19632B (10/2013)

Appendix 37

GE 7F.05 Turbine Brochure

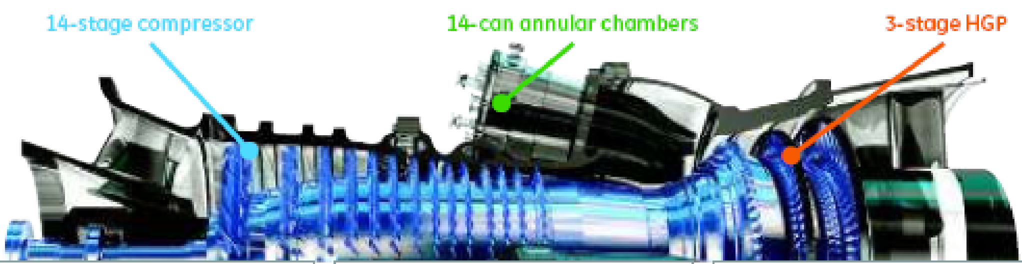
7F.05 Gas Turbine –
The Next Generation F-Class Workhorse

To meet the increasingly dynamic operating demands of today's global energy industry, power producers are looking for flexible, efficient and reliable technology to partner with renewables.

- Positioned to meet customer demands for flexible cyclic operation by delivering power with **advanced start-up** and **extended turndown** capability, **fast ramp rate**, and **low life-cycle costs** in peaking, cyclic, and continuous operation.
- Flexibility is enhanced by a **proven compressor** with **removable blades**. The 3D aerodynamic compressor with super-finish airfoils delivers **improved fuel efficiency** with **less long-term degradation**.
- The DLN 2.6 combustion system provides proven operating flexibility on a **wide range of natural gas or distillate fuel** compositions.
- The air-cooled turbine hot gas path has advanced cooling and sealing technologies to improve efficiency and provide the lowest lifecycle cost in its class.

Technical Data

Model	GT output	1x1 CC output	2x1 CC output	3x1 CC output	CC efficiency
GE GT-7F.05	227 MW	343 MW	688 MW	1033 MW	> 59%



Compressor

- Variable IGVs plus three rows of Variable Stator Vanes (VSV)
- 18.2:1 pressure ratio
- 3D aero airfoils with super-finish for improved efficiency and reduced deterioration
- Field-replaceable blades for improved maintainability

Combustor

- DLN 2.6 combustor
- 9 ppm NO_x and CO emissions
- Emission Compliant Turndown: 36% baseload
- Auto-tune capability accommodates wider fuel variation
- Low fuel pressure reduces need for on-site fuel compression

Turbine

- 3-stage turbine
- 3D aero air-cooled hot gas path
- Single crystal and directionally solidified (DS) blades
- Reduced oxidation and creep
- Improved cooling and sealing

Appendix 38

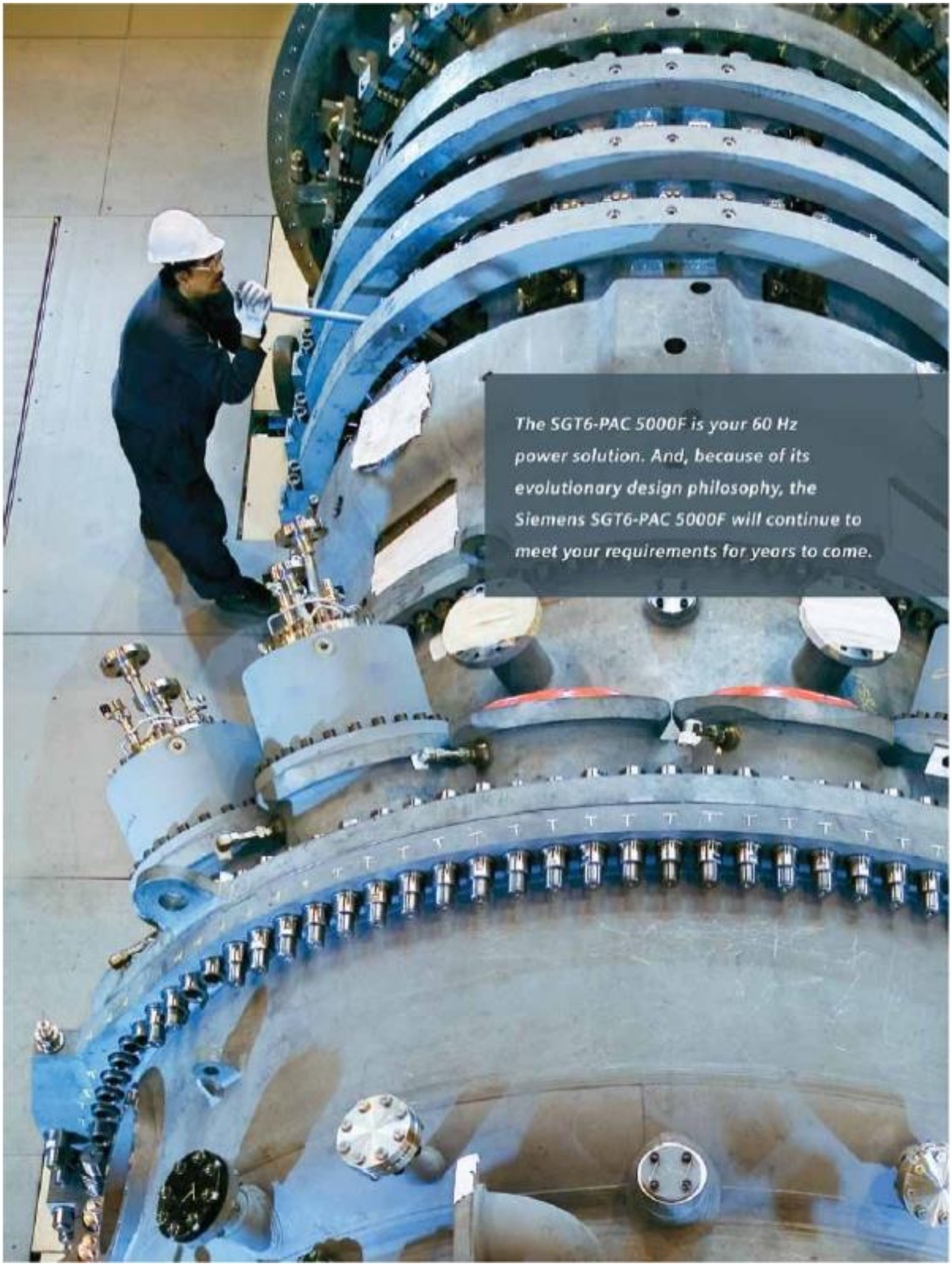
Siemens SGT6-5000F Turbine Brochure

Siemens Gas Turbine SGT6-5000F

Reliability with Flexibility

Answers for energy.

SIEMENS


The SGT6-PAC 5000F is your 60 Hz power solution. And, because of its evolutionary design philosophy, the Siemens SGT6-PAC 5000F will continue to meet your requirements for years to come.

Revolutionary performance through evolutionary design

At the forefront of the gas turbine industry, the uncompromising Siemens Gas Turbines (SGT™) continue to set reliability and continuous operation records. Packaged with the generator and other auxiliary modules the SGT6-5000F is the muscle within the stand-alone power generation package (SGT-PAC™) known as the SGT6-PAC 5000F. The 60 Hz SGT6-5000F gas turbine has more than 5.3 million hours of fleet operation and net combined cycle efficiencies of over 57.5%. These achievements are the result of successfully implementing increments of performance improvements into a proven technology platform.

The SGT6-PAC 5000F power generation system provides economical power for peaking duty, operational flexibility and load following capabilities for intermediate duty, while maintaining high efficiencies for continuous service.

Key system benefits include:

- Most powerful 60 Hz F-class engine – capable of over 230 MW
- High simple and combined cycle efficiencies
- Single digit ppm NO_x and CO capability
- Operational flexibility
  - 10 minute start-up capability
  - Cyclic capacity including daily start/stop
- Hot re-start capability – without time delay
- Foremost maintainability – easily removable blading and combustion components
- High reliability – 99% average
- Advanced service and maintenance technologies for increased availability

The SGT6-5000F gas turbine is ideally suited for simple cycle and heat recovery applications including Integrated Gasification Combined Cycle (IGCC), cogeneration, combined cycle and repowering. Flexible fuel capabilities include natural gas, LNG, distillate oil and other fuels, such as low- or medium-Btu gas.

The SGT6-PAC 5000F is your 60 Hz power solution. And, because of its evolutionary design philosophy, the Siemens SGT6-PAC 5000F will continue to meet your requirements for years to come.

Siemens Gas Turbine SGT6-5000F

As the heart of the SGT6-PAC 5000F, the SGT6-5000F gas turbine consists of three basic elements: axial-flow compressor, combustion system and turbine section. Incorporated into the advancements of this proven gas turbine design are features such as horizontally split casings, two-bearing rotor support, external rotor air cooler, and axial-flow exhaust.

Compressor

The compressor is a 13-stage axial-flow design, which achieves a 17 to 1 pressure ratio. The compressor is equipped with four stages of variable guide vanes to improve the low speed surge characteristics and part-load performance in combined cycle applications. The blade path design is based on an advanced three-dimensional flow field analysis computer model. Compressor vanes rows four through eight consist of mechanically assembled 60° segments while rows nine through 13 are individually removable from a T-root section of the vane carrier. One row of exit guide vanes is used to direct the flow leaving the compressor. Stationary airfoils utilize corrosion and heat resistant stainless steel throughout. All compressor rotating and stationary airfoils are coated to improve aerodynamic performance and corrosion protection. The compressor rotor is comprised of multiple discs equipped with Hirth Serrations on the single tie-bolt rotor.

Combustion system

The combustion system consists of 16 can-annular combustors. Each combustor has an air-cooled transition piece, which directs the combustion gases to the turbine blade path.

Turbine

The turbine section is comprised of four-stages, each containing a stationary and rotating row of blading. The turbine rotor, which contains the rotating blades, is constructed of four interlocking discs using Hirth Serrations on the single tie-bolt rotor.

Rotor

The rotor is a single tie-bolt comprised of multiple discs equipped with Hirth serrations for torque transmission and is supported by two tilting-pad bearings. Design features include advanced materials, coatings and cooling schemes that are implemented throughout the turbine section to yield high turbine efficiencies and maintain long turbine component life.

Rotor air cooler

A comprehensive cooling system is provided to supply cooling air to the high temperature areas of the turbine section. Rotor cooling air is extracted from the combustor shell. The air is externally cooled and introduced into the turbine section to be used for sealing purposes and to cool the appropriate rotating discs and rotating blades. This provides a blanket of protection from hot blade path gases.

In combined cycle applications, the "waste" energy removed from the cooling air is used to produce intermediate- and low-pressure steam which is introduced into the steam circuit to increase steam turbine output and cycle efficiency. Alternatively, this energy can be reclaimed for fuel heating or boiler feed water heating.

Inlet air system

A side- or top-mounted inlet duct directs airflow into the compressor inlet manifold, which is designed to provide an efficient flow pattern of air into the axial-flow compressor. A parallel-baffle silencing configuration is located in the inlet system for sound attenuation. Air filtration is provided by a two-stage pad filter as the standard arrangement. Other filter systems are also available.

Generator

The SGT6-5000F gas turbine is coupled to an open air-cooled (OAC) Siemens generator (SGen™) which is equipped with cooling air filtration, silencers, inlet and exhaust ducting, collector ring assembly, acoustical enclosure and necessary instrumentation. The isolated phase bus interfaces are near the non-drive end of the generator and the top of the enclosure. There are three main (line side) leads and three neutral leads. Internal cooling is provided via shaft-mounted blowers, which direct filtered ambient air through the generator's major internal components. Totally enclosed water-to-air-cooled (TEWAC) is available as an option.

Starting system

The Static Frequency Converter (SFC) is used for starting the gas turbine. The SFC generates a rotating magnetic field in the generator stator that interacts with the magnetic field generated by the static excitation equipment (SEE) in the generator rotor to provide the torque required to rotate the turbine. Brushless excitation is available as an option.

Exhaust system

After passing through the combustor and turbine section, combustion gas discharges axially through a transition section which is an interface on the exhaust system. For heat recovery applications, the exhaust stack is deleted and the gases are directed to the heat recovery steam generator.

Electrical and control package

The electrical and control package contains equipment necessary for sequencing, control and monitoring of the turbine and generator. This includes the Siemens Power Plant Automation (SPPA™) system known as the SPPA-T3000 Web-based distributed control system, motor control centers, generator protective relay panel, fire protection system for the electrical package, battery and battery charger. The batteries are in an isolated section of the package and are readily accessible for maintenance.

Lubricating oil package

The lubricating oil package houses the common lube oil system for the gas turbine and generator.

Gas fuel system

The principal components of the gas fuel system are located within the gas turbine enclosure. Monitoring instrumentation is mounted on a fuel control panel located inside the turbine enclosure. Pressure gauges to locally monitor the fuel pressure are typically located on this panel.

Net performance for the SGT6-PAC 5000F

Combustor type	ULN dry	DLN dry	DLN* steam augmentation
Fuel	Natural gas	Natural gas	Natural gas
Net power output (kW)	199,600	205,900	224,700
Net heat rate (Btu/kWh) LHV	9,102	9,081	8,802
Net heat rate (kJ/kWh) LHV	9,604	9,582	9,287
Exhaust temperature (°F/°C)	1088/587	1113/601	1114/601
Exhaust flow (lb/hr)	3,995,800	3,997,900	4,130,300
Exhaust flow (kg/hr)	1,812,400	1,814,400	1,873,400
Fuel flow (lb/hr)	84,500	86,900	91,971
Fuel flow (kg/hr)	38,340	39,400	41,717
Fuel	Liquid	Liquid	Liquid**
Net power output (kW)	190,700	191,100	-
Net heat rate (Btu/kWh) LHV	9,377	9,301	-
Net heat rate (kJ/kWh) LHV	9,893	9,813	-
Exhaust temperature (°F/°C)	1052/567	1045/563	-
Exhaust flow (lb/hr)	4,048,400	4,048,200	-
Exhaust flow (kg/hr)	1,836,300	1,836,200	-
Fuel flow (lb/hr)	96,946	96,741	-
Fuel flow (kg/hr)	43,974	43,881	-

Conditions: Natural gas or liquid fuel meeting Siemens' fuel specifications. Elevation: sea level; 14.696 psia barometric pressure, 60% relative humidity, 59°F (15°C) inlet air temperature, 3.4 in. water (87 mm water) inlet loss, 5 in. water (127 mm water) exhaust loss, air-cooled generator and .90 power factor (pf).

* Steam injected through the combustor section casing into the compressor discharge air to increase output.

** Steam augmentation with liquid fuel available on a case-by-case basis.

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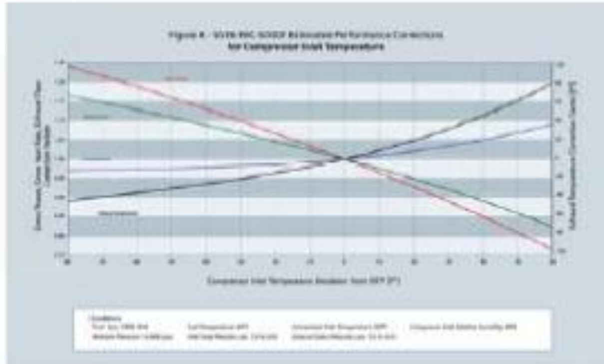
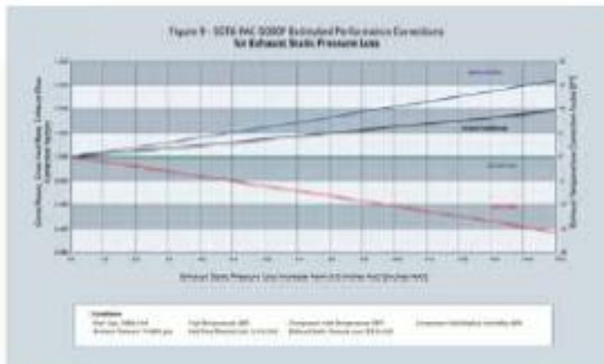
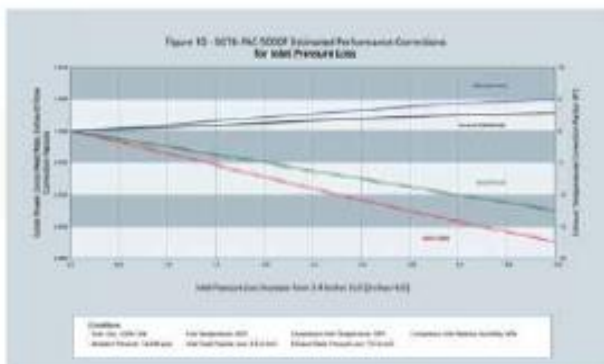
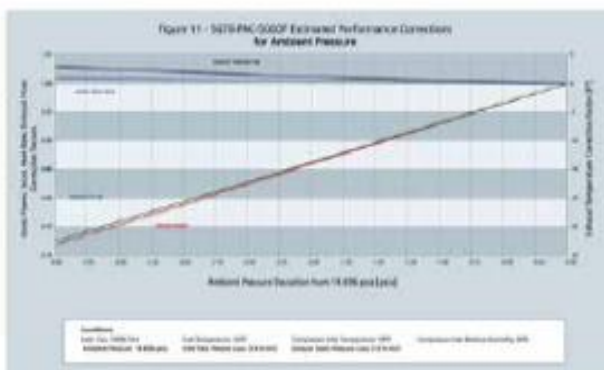




Correction curves

To estimate thermal performance of the SGT6-PAC 5000F at conditions other than those noted, the following correction curves may be used.





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Compressor water wash skid

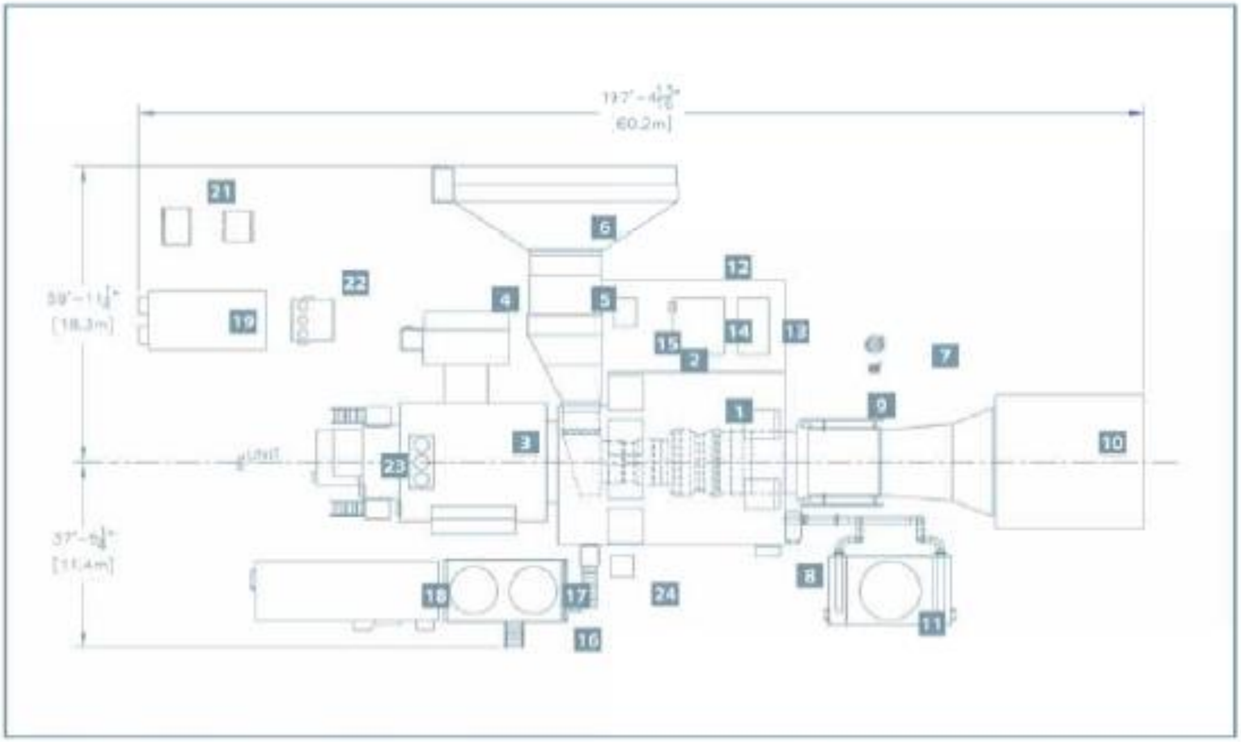
The compressor water wash skid is provided for both on-line and off-line compressor cleaning. This skid incorporates an AC motor-driven pump, piping, valves, strainer junction box, cabling, flowmeter and a detergent storage tank. These are assembled on a portable skid trailer with steel wheels attachable to a trailer hitch or clevis.

Cooler assemblies

An air-to-oil fin-fan lube oil cooler (water-to-oil cooler is optional) is located above the lubricating oil package. An air-to-air cooler for turbine rotor cooling is placed adjacent to the exhaust stack. Other cooler options are available for combined cycle applications.

Pipe rack assemblies

Piping for the SGT6-5000F power plant is designed and manufactured to minimize field work. Each of the major pipe assemblies is factory fabricated, requiring only a few field connections. The turbine pipe rack, located adjacent to the gas turbine in the turbine enclosure, contains piping and valves for the cooling air and lube oil supply and return.



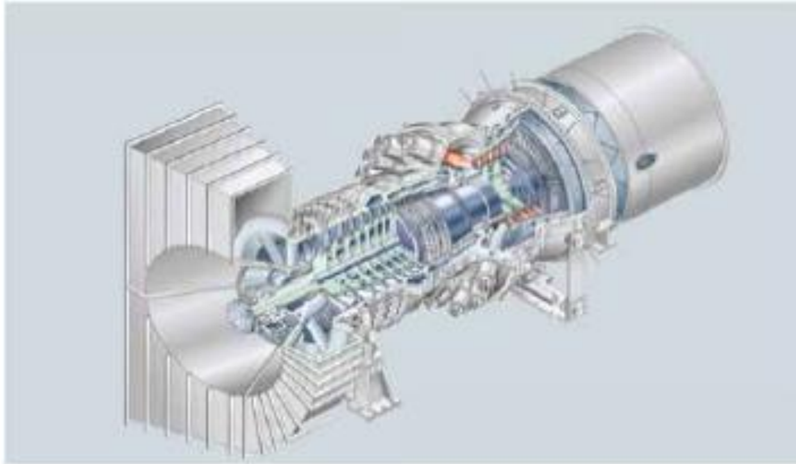
	Key:				
1.	Gas Turbine (GT)	9.	Exhaust Transition	18.	Electrical Package
2.	GT Enclosure	10.	Exhaust Stack	19.	SEE/SFC
3.	Generator (OAC)	11.	Rotor Air Cooler (Fin-Fan)	20.	SFC Transformer
4.	Generator Air Inlet Filter	12.	FOWI Acoustic Wall	21.	SEE Transformer
5.	Turbine Air Inlet Duct and Silencer	13.	NO_x Control Injection Skid	22.	VT Surge Protection and SFC Switch Cubicle
6.	Turbine Air Inlet Filter	14.	Fuel Oil Skid	23.	Turning Gear
7.	Fuel Gas Main and Pilot Filter/Separators	15.	Control Oil Skid	24.	Instrument Air Compressor
8.	FM-200® Fire Protection	16.	Lube Oil Package		
		17.	Lube Oil Cooler (Fin-Fan)		

SSC6- 5000F plant arrangement technical data

SGT6-5000F Gas Turbine				
Gas turbine		**Generator**		
Rotor Speed	3600 rpm	Type	- Standard	Open air-cooled
Compressor			- Option	Totally enclosed water-to-air cooled
Number of stages	13	Frequency		60 Hz
Pressure ratio	17:1	Voltage		16.5 kV
Combustors		Insulation		Class F
Number	16			
Type	Can-annular	**Major weights**		
Turbine		Generator/without enclosure	530,000 lbs	240,400 kg
Number of stages	4	Gas turbine	462,700 lbs	209,900 kg
		Lubricating oil package	48,700 lbs	22,090 kg
		Electrical Package	50,000 lbs	22,680 kg
		Turbine rotor/lifting beam*	205,800 lbs	93,350 kg

*Heaviest piece to be lifted after installation

10



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Appendix 39

Fuel Storage Tank Cost Estimation

Introduction

While storage tanks for liquid fuel are one of the most obvious requirements for power plant dual-fuel capability, their capital cost is a significant, but not overwhelming portion of the total incremental capital cost. Distillate fuels such as ULSD are generally stored in above-ground, field-fabricated tanks made from welded steel plate. They are surrounded by a concrete containment dike sized to handle the full capacity of the tank in the event of leak or rupture. The tank capacity is determined by the hourly burn rate of the power plant and the number of hours of inventory deemed necessary to maintain operation during a natural gas curtailment or price spike. The cost of the tank and its spill containment components is seldom reported as a breakout for new power plants, so LAI has relied on other public sources for estimates of tank cost as a function of capacity and location. A primary source is the "Petroleum Infrastructure Study Final Report' prepared for the New York State Energy Research and Development Authority by ICF Consulting LLC and Applied Statistical Associates in September 2006 ("the ICF Study"). The tabulated costs in the ICF Study are supplemented or confirmed with scattered reports of tank costs for new plants and modifications in the public record and a few data points from confidential documents available to LAI.

Fuel Tank Capacity

As indicated in the research conducted under Task 1 of Target 4, the capacities of on-site liquid fuel storage tanks for existing dual-fuel power plants, relative to full load burn rates, varies over a wide range. LAI has determined that a reasonable rule-of-thumb is to provide storage for 72 hours of full load fuel requirements, although this guideline is subject to variation based on application-specific variables such as the availability of near-by off-site storage and delivery capacity from fuel dealers and the expected operating profile of the plant. For a 2x1 7FA CC unit, the winter condition fuel burn rate is 4,540 MMBtu/hr (HHV) on ULSD, or 30,600 gallons per hour. A 72-hour supply would therefore be 2.2 million gallons. Roughly the same math would hold for a 2-unit 7F.05 SC station. For a 2-unit LMS100 SC station, the 72-hour requirement would amount to 0.9 million gallons.

Fuel Tank Cost Data

Cost data points for the tanks identified in the ICF Study and for several examples identified by LAI are shown in Figure A39-1. Costs from the ICF analysis are provided in 2004 dollars for the New York City area and for the Lower Hudson Valley. Dates for the other points are indicated in the labels.

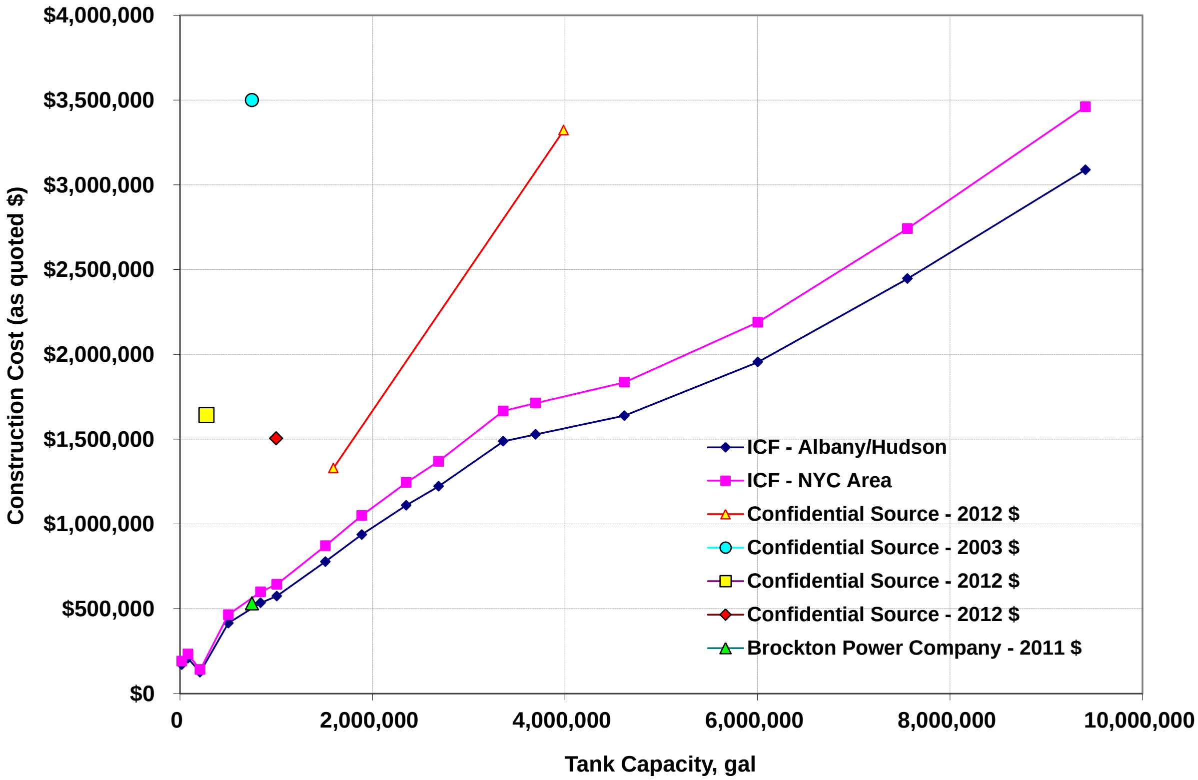

Figure A39-1. As-Quoted Tank Costs v. Capacity

LAI used the ICF Study data point for capacities from 500,000 gallons to 4,000,000 gallons to derive linear best-fit equations for New York City and Lower Hudson Valley tank costs, as shown in Figure A39-2.

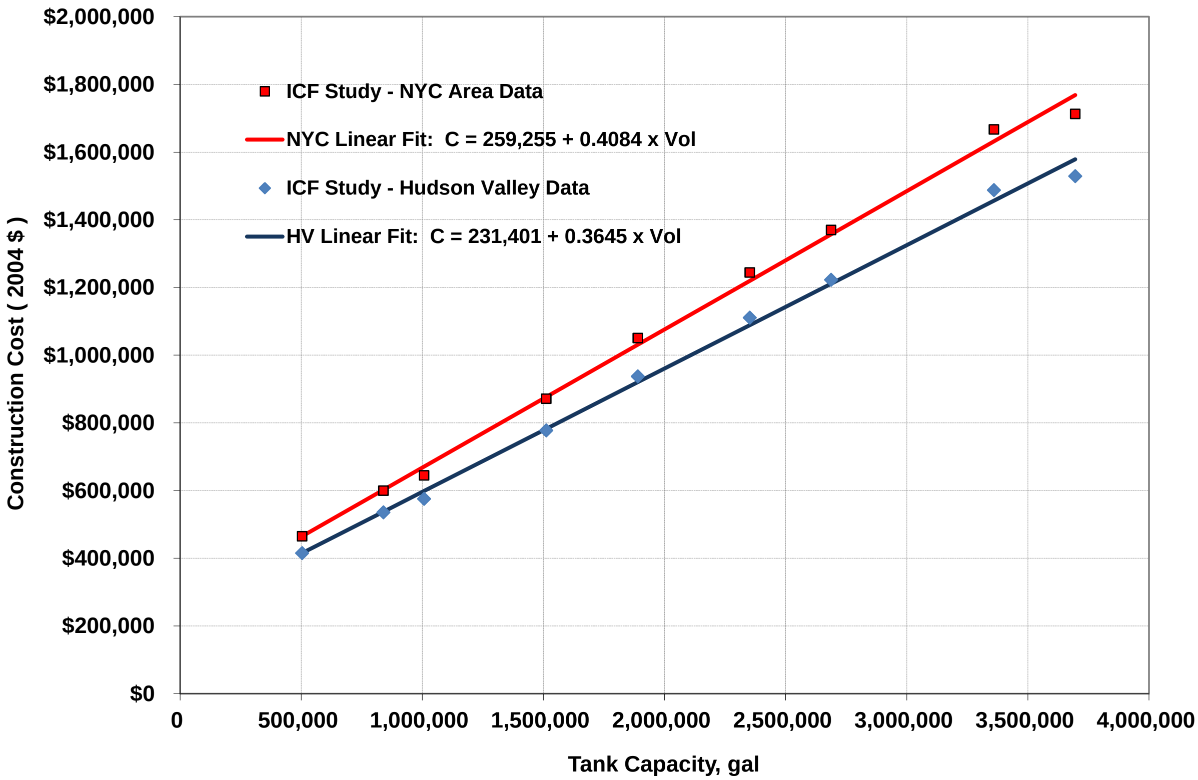

Figure A39-2. Regression Analysis on ICF Study Cost Data

The regression equations were then adjusted from 2004 dollars to 2018 dollars to obtain the cost functions used in this study:

For New York City:	C = 371,829 + 0.5857 x Vol (gallons)
For Lower Hudson Valley:	C = 331,881 + 0.5228 x Vol (gallons)

Land Requirements for Tanks

Land requirements for fuel storage tanks are estimated based on the following assumptions:

- Tank effective height (excluding dome top) is 40 ft for volumes from 500,000 gallons to 4,000,000 gallons
- Containment dike is square, and wall height is 8 ft.

Tank diameter (ft), square area containing tank (acres), and square area of dike (acres) are plotted in Figure A39-3.

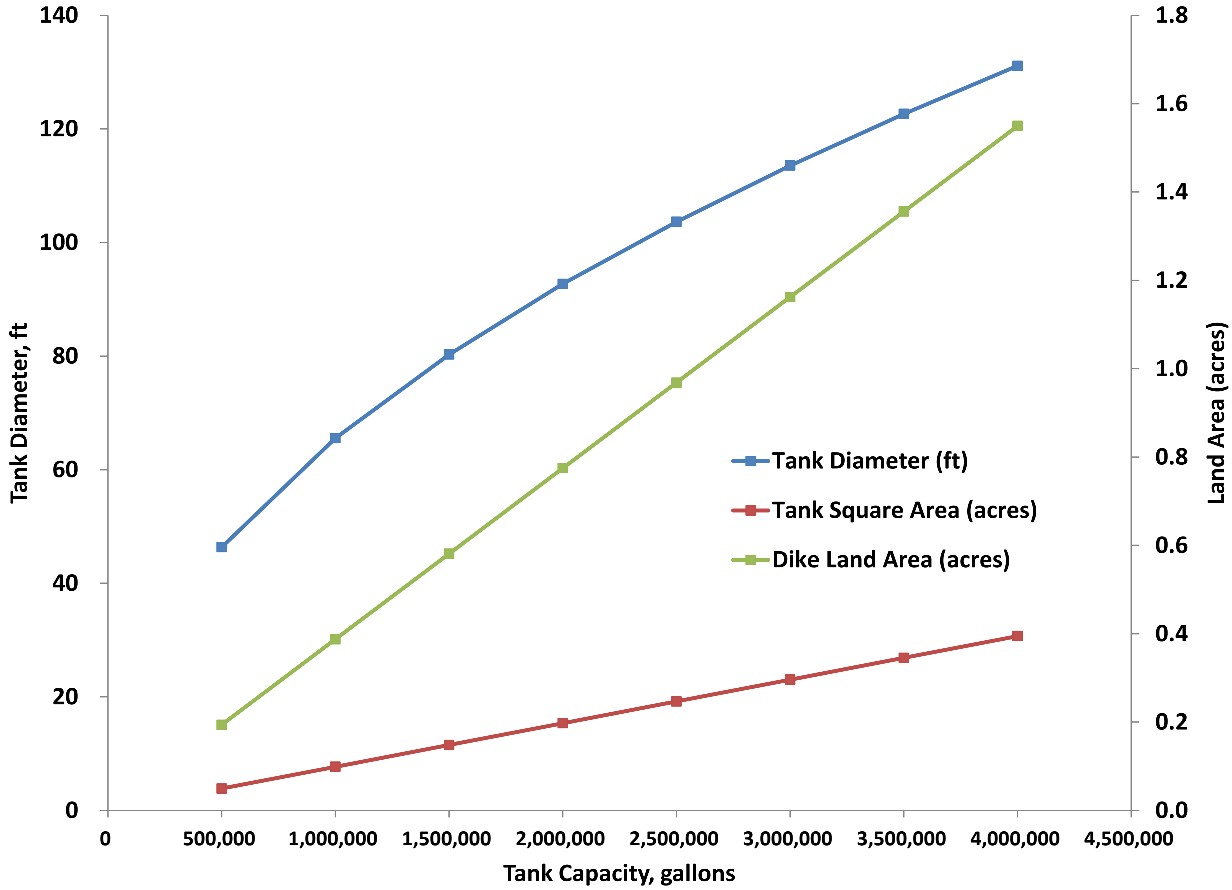

Figure A39-3. Tank Diameter and Land Requirements v. Capacity

Appendix 40

Mobile Demineralized Water Capacity

Introduction

Demineralized water supply is an issue for dual-fuel capability at CT-based generation plants because most current model heavy-frame CTs use dry low-NO_x burner systems to control NO_x emissions under current emission rules when firing natural gas, but must use water (or in some cases, steam) injection when firing a liquid fuel such as ULSD. The CT scope of supply for dual-fuel capability includes manifolds and burners, as well as forwarding pumps and filtering systems to accommodate water injection, but the balance-of-plant scope must provide for adequate supply and storage of demineralized water for CT injection purposes. CC plants require demineralized water for boiler make-up purposes on a continuous basis whenever the plant operates, but the flow rates for this use are an order of magnitude less than the rates required for NO_x control injection.

This appendix provides background for estimating the capital and operating costs associated with providing the demineralized water supply required for NO_x control for a typical F-technology plant with 2 CT units in either SC or CC configuration. The information on mobile demineralizer capacity is based primarily on communications with GE Water & Process Technologies.[1]

Water Requirements for NO_x Control Injection

Each GE 7FA CT requires approximately 350 gpm of demineralized water for injection when operating on ULSD, so the requirement for a 2x1 CC installation is approximately 700 gpm. The CC unit, with a net output of about 651 MW (winter conditions) also requires about 38 gpm for boiler makeup. The water quality specifications for boiler makeup are sometimes more stringent than those for CT water injection.

A 2-unit LMS100 SC installation would require about 135 gpm for water injection firing ULSD under winter conditions, but would require 127 gpm firing natural gas, since most such installations use water injection for both fuels. Hence, demineralized water does not constitute a major incremental cost of dual-fuel capability for LMS100 peaking stations.

Mobile Demineralizer Technology

Several companies maintain large fleets of mobile demineralizer trailers which can be transported to and put in service at a power plant site on an emergency basis or a longer term scheduled basis. GE maintains a 24/7 logistics center to dispatch trailers to where they are needed. Customers usually set up a contract that provides pricing and terms for emergency service.

Each 43-foot trailer contains a string of demineralizer tanks, each with its own specialized anion, cation, or mixed bed media to achieve the required reduction in dissolved solids. Depending on the source water quality and final product specifications, a trailer might include a reverse

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[1] Discussions and communications with Mr. Scott Gorry of GE Water & Process Technologies, July 23, 2014 and July 31, 2014. Websites for suppliers of similar services, such as Evoqua Water Technologies (Siemens) and PureTec Industrial Water were reviewed, as well.

osmosis unit as well. Trailers are equipped with propane heating systems to avoid freezing, and include filter units and standardized connection flanges for inlet and outlet hoses. The trailers are designed to be hooked up to a 120 volt, 20 amp power supply for lighting and controls.

Throughput rate for a typical application using good quality city water as raw water input is up to 800 gpm per trailer, so one trailer is typically sufficient to supply a 2-unit 7F.05 installation. The trailer is limited by raw water quality to a cumulative throughput of from 360,000 gallons at 235 ppm total dissolved solids (TDS) to 1,425,000 gallons at 225 ppm TDS. Once the cumulative throughput has been reached, the demineralizer units must be recharged and the accumulated solids disposed of. The service provider would set up another trailer and haul the spent trailer to its regeneration center.

Mobile Demineralizer Cost Structure

Mobile demineralizer service providers typically charge a flat fee per trailer that includes the cost of recharging and a set number of days of on-site availability. There is a daily demurrage charge for additional days on-site and a round-trip transportation charge based on the distance from the provider's service center to the power plant site. Some generators rely on an inventory of stored demineralized water to cover one to three days of liquid fuel operation and arrange for emergency delivery of a trailer as soon as they begin to draw down that inventory. Other generators may arrange to have a trailer on-site for the entire 3-month winter period. The optimum supply arrangement would depend on the expected frequency and duration of liquid fuel operation events, as well as the proximity of service provider regeneration centers.

GE provided some pricing parameters that it claims are typical of providers in a competitive market. The base charge per trailer was given as $6,000, which includes 10 days "free" of demurrage charges. After that, demurrage would be $600 per day. Freight was estimated at $55 per mile, charged in each direction with credit for consecutive exchanges.[2]

Plant-Provided Infrastructure

The generation plant would provide a pad for the trailer with connections from the raw water supply source and to the demineralized water storage tank. Both raw water and demineralized water systems would presumably be heat traced as necessary for expected winter design conditions. Hoses for the trailer connections should also be heat traced where appropriate. GE Water recommended a demineralized water storage capacity of 1,000,000 gallons, or about 24 hours of full load operating requirements for a 650 MW CC unit. The amount of raw water storage required would depend on the source of raw water. A dependable full-flow connection to city water might make raw water storage unnecessary.

Cost Examples

Based on information provided by GE Water, LAI developed a simplified model for estimating the cost of mobile demineralizer capacity for a 2x1 7FA CC unit and a 2x7FA SC station at a

[2] For a full season, the freight charge would be ($55/mile) x (distance in miles) x (No. of trailers used + 2).

range of locations. It is assumed that the boiler make-up requirements for the combined cycle examples are provided with a separate system. The Newburgh, NY location has good quality raw water at 60 ppm TDS, and it is located 10 miles from a regeneration center. The Cleveland, OH location has poor quality raw water at 235 ppm TDS, and it is located 55 miles from a regeneration center. Petersburg, VA, is an intermediate location with moderate quality raw water (85 ppm TDS) and located about 14.5 miles from a regeneration center. It should be noted that other service providers would have regeneration centers at different distances from the locations. The examples developed in Table A40-1 below show a range in average costs from $7.73 per 1,000 gallons to $26.27 per 1,000 gallons.

Table A40-1. Mobile Demineralized Water Cases

Case	**1**	**2**	**3**	**4**	**5**	**6**
Assumptions:						
Plant Type	2x1 7FA CC	2x1 7FA CC	2x1 7FA CC	2x7FA SC	2x7FA SC	2x7FA SC
Nominal Capacity, MW	650	650	650	385	385	385
Demin water use (gpm)						
Firing gas	38	38	38	0	0	0
Incremental for injection firing oil	700	700	700	700	700	700
Plant Utilization on ULSD (hrs)						
Maximum annual hours on oil	720	720	720	720	720	720
Expected annual hours on oil (all in winter season)	240	240	240	120	120	120
Max consecutive hours on oil	72	72	72	24	24	24
Site Assumptions:						
General location						
State	NY	OH	VA	NY	OH	VA
City or County	Newburgh	Cleveland	Petersburg	Newburgh	Cleveland	Petersburg
Distance from Regeneration Center *(miles estimated by GE Water)*	10.0	55.0	14.5	10.0	55.0	14.5
Raw water source	City water	City water	City water	City water	City water	City water
TDS (ppm) *(estimated by GE Water)*	60	235	85	60	235	85

Table A40-1. Mobile Demineralized Water Cases

Case	**1**	**2**	**3**	**4**	**5**	**6**
LAI Calculations:						
Cost at projected operating level						
Expected seasonal usage for water injection (gal)	10,080,000	10,080,000	10,080,000	5,040,000	5,040,000	5,040,000
Throughput per trailer, gal (85,500,000/TDS per GE data)	1,430,000	360,000	1,010,000	1,430,000	360,000	1,010,000
Trailers required per season	7.05	28.00	9.98	3.52	14.00	4.99
Days in winter peak season	121	121	121	121	121	121
Total free days, at 10 per trailer	70	280	100	40	140	50
Demurrage days = greater of 0 or (121 -free days)	51	0	21	81	0	71
Cost components:						
Base unit charges at $6,000	$42,300	$168,000	$59,900	$21,100	$84,000	$29,900
Freight charges at $55/mile x Distance x (No of Trailers + 2)	$5,000	$90,800	$9,600	$3,000	$48,400	$5,600
Demurrage at $600 per day	$30,600	$0	$12,600	$48,600	$0	$42,600
Total Cost per Winter	$77,900	$258,800	$82,100	$72,700	$132,400	$78,100
Effective cost per 1,000 gallons	$7.73	$25.67	$8.14	$14.42	$26.27	$15.50
Trailers per day at peak usage	0.70	2.80	1.00	0.70	2.80	1.00
Seasonal stand-by cost (no usage)	$73,700	$78,700	$74,200	$73,700	$78,700	$74,200

Appendix 41

Gas Turbine Performance Parameters

The tables which follow show key performance characteristics for the GE 7FA CT in a 2x1 CC configuration, the GE 7FA CT in SC configuration, the GE LMS100 CT in SC configuration, the Siemens SGT6-5000F CT in a 2x1 CC configuration, and the Siemens SGT6-5000F in a SC configuration. Performance data were provided by manufacturer's representatives, and generally represent the most current version of the model, which may be slightly different than the performance data used by the Brattle Group in the 2014 PJM CONE Study or by NERA Economic Consulting in the 2013 NYISO Demand Curve Reset Study. In particular, the 7FA data provided by GE are for the 7F.05 version, while the 2014 PJM CONE Study was based on the 7F.04 version.

Table A41-1. General Electric 7FA.05 Combined Cycle

Manufacturer: General Electric						
Model: 7FA .05			Cooling (CC Only): Evaporative Tower			
Configuration: 2x1 Combined Cycle			Short Name: GE 7FA CC			
Conditions	**ISO 59 F, 60% RH, Sea Level**		**Winter Peak Day 20 F, 50% RH, Sea Level**		**Summer Peak Day 90 F, 60% RH, Sea Level**	
Fuel	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**
Combined Cycle Operation						
GT NO_x Control Type	DLN	Water Inj'n	DLN	Water Inj'n	DLN	Water Inj'n
Post combustion NO_x Control	SCR	SCR	SCR	SCR	SCR	SCR
CC Output (MW)	642	652	668	652	620	650
CC Heat Rate (Btu/kWh LHV)	5,880	6,505	5,935	6,515	5,965	6,535
CC Heat Rate (Btu/kWh HHV)	6,514	6,957	6,575	6,968	6,608	6,989
CO_2 Emissions (lb/h)	498,945	733,197	524,082	734,254	488,729	733,788
CO_2 Emissions (lb/MWh)	778	1,125	785	1,127	789	1,130
NO_x Emissions at GT Exhaust (ppmvd)	9	42	9	42	9	42
NO_x Emissions at HRSG Stack (ppmvd)	2	6				
NO_x Emissions at HRSG Stack (lb/MWh)	0.049	0.162				
Water Injection Rate (gal/min)	0	700				
Boiler makeup Rate (gal/min)	38	38				
AGC Ramp Rate (MW/min)	80	80				
Turndown Ratio (Maintaining emissions)	28%	30%				
Minimum Fuel Gas Pressure (psig)						
Full Load Operation	425		425		375	
Maximum Load for Fuel Switching (%)	80%					
Time to Complete Switch (Min)	2					
Major Maintenance Accrual:						
Equivalent natural gas hours	1.0	1.5				
Equivalent natural gas starts	1.0	1.5				

Table A41-2. General Electric 7FA.05 Simple Cycle

Manufacturer: General Electric	
Model: 7FA .05	Cooling (CC Only): na
Configuration: Simple Cycle	Short Name: GE 7FA SC

Conditions	**ISO 59 F, 60% RH, Sea Level**		**Winter Peak Day 20 F, 50% RH, Sea Level**		**Summer Peak Day 90 F, 60% RH, Sea Level**	
Fuel	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**
Gas Turbine Operation						
NO_x Control Type	DLN	Water Inj'n	DLN	Water Inj'n	DLN	Water Inj'n
NO_x Control Level at GT Exhaust (ppmvd)	9	42	9	42	9	42
GT Output (MW/GT)	216	222	229	224	207	220
GT Heat Rate (Btu/kWh LHV)	8,745	9,540	8,670	9,450	8,900	9,630
GT Heat Rate (Btu/kWh HHV)	9,688	10,203	9,605	10,107	9,860	10,299
Water Injection Rate (gal/min)	0	350				
CO_2 Emissions (lb/h)	249,858	366,123	262,456	366,182	243,656	366,264
CO_2 Emissions (lb/MWh)	1,157	1,649	1,146	1,635	1,177	1,665
Without SCR						
NO_x Emissions at Stack (lb/MWh)	0.329	1.659				
With air dilution SCR						
NO_x Emissions at Stack (ppmvd)	2	6				
NO_x Emissions at Stack (lb/MWh)	0.073	0.238				
AGC Ramp Rate (MW/min)	40	40				
Turndown Ratio (Maintaining emissions)	46%	50%				
Minimum Fuel Gas Pressure (psig)						
Full Load Operation	425		425		375	
Maximum Load for Fuel Switching (%)	85%					
Time to Complete Switch (Min)	2					
Major Maintenance Accrual:						
Equivalent natural gas hours	1.0	1.5				
Equivalent natural gas starts	1.0	1.5				

Table A41-3. General Electric LMS100 Simple Cycle

Manufacturer: General Electric	
Model: LMS100 PA+	Cooling (CC Only): na
Configuration: Simple Cycle	Short Name: LMS100 SC

Conditions	**ISO 59 F, 60% RH, Sea Level**		**Winter Peak Day 20 F, 50% RH, Sea Level**		**Summer Peak Day 90 F, 60% RH, Sea Level**	
Fuel	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**
Gas Turbine Operation						
NO_x Control Type	Water inj'n	Water inj'n	Water inj'n	Water inj'n	Water inj'n	Water inj'n
NO_x Control Level at GT Exhaust (ppmvd)	25	42	25	42	25	42
GT Output (MW/GT)	112.1	109.2	112.0	111.1	100.6	96.1
GT Heat Rate (Btu/kWh LHV)	7,945	8,067	7,922	8,000	8,169	8,329
GT Heat Rate (Btu/kWh HHV)	8,802	8,628	8,776	8,556	9,050	8,908
Water Injection Rate (gal/min)	58.2	61.9	63.7	68.3	48.5	52.2
CO_2 Emissions (lb/h)	117,809	152,283	117,325	153,777	108,674	138,438
CO_2 Emissions (lb/MWh)	1,051	1,395	1,047	1,384	1,080	1,440
Without SCR						
NO_x Emissions at Stack (lb/h)	93	152	92	153	85	138
NO_x Emissions at Stack (lb/MWh)	0.830	1.392	0.821	1.377	0.845	1.435
With air dilution SCR						
NO_x Emissions at Stack (ppmvd)	2.5	6.0				
NO_x Emissions at Stack (lb/MWh)	0.083	0.199				
AGC Ramp Rate (MW/min)	60	60				
Turndown Ratio (Maintaining emissions)	25%	25%				
Minimum Fuel Gas Pressure (psig)						
Full Load Operation	910		910		910	
Trip Point	250					
Maximum Load for Fuel Switching (%)	85%					
Time to Complete Switch (Min)	2					
Major Maintenance Accrual:						
Equivalent natural gas hours	1.0	1.5				
Equivalent natural gas starts	1.0	1.5				

Table A41-4. Siemens SGT6 Combined Cycle

Manufacturer: Siemens

Model: SGT6-5000F   Cooling (CC Only): Evaporative Tower

Configuration: 2x1 Combined Cycle   Short Name: SGT6 CC

Conditions	**ISO 59 F, 60% RH, Sea Level**		**Winter Peak Day 20 F, 50% RH, Sea Level**		**Summer Peak Day 90 F, 60% RH, Sea Level**	
Fuel	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**
Combined Cycle Operation						
GT NO_x Control Type	DLN	Water Inj'n	DLN	Water Inj'n	DLN	Water Inj'n
Post combustion NO_x Control	SCR	SCR	SCR	SCR	SCR	SCR
CC Output (MW)	688.5	659.7	678.4	653.2	661.6	608.4
CC Heat Rate (Btu/kWh LHV)	5,894	6,431	5,946	6,370	5,909	6,437
CC Heat Rate (Btu/kWh HHV)	6,530	6,878	6,587	6,813	6,546	6,885
NO_x Emissions at GT Exhaust (ppmvd)	9	42	9	42	9	42
NO_x Emissions at HRSG Stack (ppmvd)	2	6				
NO_x Emissions at HRSG Stack (lb/MWh)	0.049	0.162				
Water Injection Rate (gal/min)	0	252	0	188	0	276
Boiler makeup Rate (gal/min)						
AGC Ramp Rate (MW/min)	27	27				
Turndown Ratio (Maintaining emissions)	30%	30%				
Minimum Fuel Gas Pressure (psig)						
Full Load Operation	525		525		<525	
Maximum Load for Fuel Switching (%)	90%					
Time to Complete Switch (Min)	10					
Major Maintenance Accrual:						
Equivalent natural gas hours	1.0	1.5				
Equivalent natural gas starts	1.0	1.5				

Table A41-5. Siemens SGT6 Simple Cycle

Manufacturer: Siemens	
Model: SGT6-5000F	Cooling (CC Only): na
Configuration: Simple Cycle	Short Name: SGT6 SC

Conditions	**ISO 59 F, 60% RH, Sea Level**		**Winter Peak Day 20 F, 50% RH, Sea Level**		**Summer Peak Day 90 F, 60% RH, Sea Level**	
Fuel	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**	**Natural Gas**	**ULSD**
Gas Turbine Operation						
NO_x Control Type	DLN	Water Inj'n	DLN	Water Inj'n	DLN	Water Inj'n
NO_x Control Level at GT Exhaust (ppmvd)	9	42	9	42	9	42
GT Output (MW/GT)	231.6	226.8	231.6	231.1	217.0	205.3
GT Heat Rate (Btu/kWh LHV)	8,844	9,233	8,819	9,017	9,124	9,557
GT Heat Rate (Btu/kWh HHV)	9,798	9,875	9,770	9,644	10,108	10,221
Water Injection Rate (gal/min)	0	124	0	94	0	138
Without SCR						
NO_x Emissions at Stack (lb/MWh)	0.319	1.659				
With air dilution SCR						
NO_x Emissions at Stack (ppmvd)	2	6				
NO_x Emissions at Stack (lb/MWh)	0.073	0.238				
AGC Ramp Rate (MW/min)	13	13				
Turndown Ratio (Maintaining emissions)	30%	30%				
Minimum Fuel Gas Pressure (psig)						
Full Load Operation	525		525		<525	
Maximum Load for Fuel Switching (%)	90%					
Time to Complete Switch (Min)	10					
Major Maintenance Accrual:						
Equivalent natural gas hours	1.0	1.5				
Equivalent natural gas starts	1.0	1.5				

Appendix 42

Determination of Liquid Fuel Inventory Levels

General

In LAI's view there is no "right" amount of backup fuel inventory or storage tank capacity for a dual-fuel capable power plant. Optimizing tank size and fuel inventory requires multi-faceted mathematical analysis of PPA specific reliability goals, weather conditions, plant-specific criteria and transportation replenishment logistics that are beyond the overall scope of the Target 4 research goals and objectives. LAI formulated the tank "bogie" for distillate liquid fuel, usually ULSD, which would be utilized by combustion turbines in SC or CC applications as an alternate or back-up fuel.[1] In developing the "bogie" for constrained locations for PPA review, LAI has relied on the results of the Target 2 analysis, but then considered other factors affecting the PPAs'ability to realize the benefits of fuel assurance through dual-fuel capability in lieu of incremental firm transportation. Decisions regarding tank capacity and inventory management are influenced by a wide range of factors, including grid reliability. Reliability is the principal driver for traditional regulated cost-of-service utilities such as TVA and IESO, and for competitive markets developing market rules and penalties to promote generator availability when called on by PPAs in the day-ahead or real-time energy market. Owners' decisions are also driven by expected return on investment, tempered by the impacts of low-probability, high-impact events. In performing this analysis, LAI did not address specific financial risk factors attributable to PJM's Capacity Performance proposal or ISO-NE's two-part settlement mechanism designed to induce generator performance.

For the purposes of this analysis, LAI set a tank capacity/target inventory level for each power plant location selected by the PPAs based on a consideration of the pipeline constraint frequency-duration characteristics defined in Target 2 applicable to the location, along with an assumed winter peak period operation profile (5 days/week x 16 hours/day for CC, 5x8 for SC) and identifiable characteristics of the local ULSD delivery infrastructure.[2]

Plant Owner Considerations

The objective of a plant owner is to optimize cash flows consistent with system reliability and fuel assurance goals. In establishing tank size and/or target inventory level for backup fuel, owners are likely to consider the following list of factors:

---

[1] An alternative fuel assurance strategy for generators in NEMA / Boston and SEMA would be a seasonal peak arrangement for the purchase and storage of one or more cargoes of LNG at the Suez Distrigas terminal in Everett. This strategy would surely necessitate the participation of multiple generators to overcome diseconomy of scale problems. This analysis is limited to ULSD as a back-up fuel for new SC or CC generators, and does not include LNG alternatives. Logistics for existing dual-fuel capable plants, including steam plants using residual oil as backup/alternative fuel, are addressed in Section 2 of the report.

[2] The operation profile of the CC is based on the typical dispatch regime of a new CC observed in AURORAxmp, as well as a simplifying assumption for the SC. The 5 x 8 operation profile of the SC accounts for the real option value of an efficient, quick-start SC in the DA and RT markets. The profile determines the potential daily ULSD consumption during severe winter conditions, relative to the maximum daily quantity. That these profiles match the profiles used to quantify annual average natural gas consumption to calculate a credit for avoided IT service is purely coincidental.

1. Frequency and duration of pipeline limitations on the scheduling of natural gas during the peak heating season, January, February and December. To the extent non-firm shippers are exposed to curtailments or interruptions, nominations in accord with the existing or anticipated changes to NAESB scheduling protocols may still limit a generator's ability to obtain all or a portion of the daily fuel requirements to meet the expected dispatch regime in the day-ahead or real-time market. Curtailment can be characterized by both frequency and duration of curtailment events. Even without actual curtailment, pipeline constraints can make it difficult to schedule gas delivery to match ISO/RTO required dispatch profiles. Under usual wintertime operating conditions, there are no restrictions on the scheduling of natural gas if the generator holds a firm entitlement equal to or approximately equal to the MDQ. However, to the extent the pipeline posts an Operational Flow Order during a critical event, the generator's ability to schedule natural gas during such an event may be limited due to enforcement of the ratable take tariff provisions.

2. Economics of operation on back-up fuel. Owners would consider what fraction of the winter days is operation on backup fuel likely to be "in-the-money" relative to prevailing market energy prices? To what extent are such days likely to be consecutive? How many hours of equivalent full load operation per day can be expected when dispatched on backup fuel?

3. Delivery lag time for backup fuel delivery. How many hours are likely to pass between ordering replenishment service from a supplier and the arrival of first deliveries? Depending on the location and size of available transportation fleets (truck or barge), this lag could vary between one day or less and several days or more. Under normal road conditions, the lag time for initiation of delivery by truck is typically about one day. Barge deliveries typically have longer lead times but are aided somewhat by the much larger volume of deliveries (600,000 to 1 million gallons) as compared with truck (typically around 10,000 gallons).

4. Impact of severe weather events on backup fuel delivery capacity. To what extent can severe winter weather events, particularly snow (for truck delivery) or severe cold (for barge delivery) slow down or stop a contracted delivery stream to the plant? During and in the aftermath of a severe storm, truck drivers may not be able to reach oil terminals due to lags in plowing and sanding secondary and tertiary roads for 3 or more consecutive days. Barge deliveries may be faced with limitations on movements due to marine waterway icing.

5. Impact of failure to deliver dispatched energy or to offer into market due to unavailability of fuel on plant net revenues. In particular, does failure to generate during a fuel constraint event result in a significant loss of capacity revenue or a penalty with similar effect?

Existing dual-fuel capable plants have distillate fuel tank capacities that can range depending on location and specific plant conditions from one day of full-load operation to five days or more, as shown in Section 2 of the report.

Procedure for Determining Tank Capacity/Target Inventory Levels

Based on a goal of fuel assurance roughly equivalent to firm transportation for natural gas, LAI utilized the following approach for each of the identified locations to set an inventory level, measured in days of equivalent full load fuel burn.

1. Identification of the Relevant Constraint – The appropriate constrained pipeline segment for the location was selected from among those described in Sections 6 and 8 of the Target 2 report for RGDS S0, Winter 2018. This identification provides the fraction of days in the season in which some level of affected generation is likely to occur, along with the extent to which such days are clustered over consecutive day events. Inspection of the Frequency-Duration (F-D) results by pipeline in the recommended constrained region results in a characterization of frequency duration as “high,” “moderate,” or “low.”

2. Identification of the Relevant ULSD Supplier – The closest substantial distillate fuel terminal was identified for each location. The time lag to initiate deliveries upon notification, normal round trip times for trucks, *etc.*, was defined as was a maximum daily delivery rate, based on the normal daily fuel burn.

3. Identification of ULSD Delivery Constraint Events – The likelihood and extent of events which could slow down or stop deliveries for more than a 24 hour period was evaluated, based on the locations of the depot, the plant location, and the intervening route. This constraint was defined as the time that would be required to clear roads from a severe snow fall. Given the development of the transportation market for ULSD, which has resulted in large refinery runs and widespread storage and distribution facilities, there should be fewer winter availability and transportation constraints for ULSD going forward as compared with traditional No. 2 fuel oil supplies observed in the past.

4. Set the tank capacity/target inventory level per the following equation:

   TIL = (DPC + DLC + DCC) * EDF

   where TIL = Target Inventory Level, days of Full Load Equivalent (FLE) Fuel Burn

   DPC = Demand Persistence Component, days

   = 0 days for no identified constraint

   = 1 day for “Low” F-D of applicable constraint

   = 2 days for “Moderate” F-D

   = 3 days for “High” F-D

   DLC = Delivery Lag Component, days

   DCC = Delivery Constraint Component, days

   = Estimated max consecutive days of ULSD delivery constraint

   EDF = Equivalent Dispatch Factor

   = (5 x 16) / (7 x 24) = 0.476 for CC plants

   = (5 x 8) / (7 x 24) = 0.238 for SC plants

Example 1 (Truck Delivery):

For a location linked to a pipeline segment with a "moderate" constraint F-D pattern, a ULSD delivery lag of 24 hours, and a ULSD delivery constraint of 2 days to clear roads after a major snowstorm, the target inventory levels for CC and SC applications would be as follows:

TIL for CC = (2 + 24 / 24 + 2) * 0.476 = 2.38 days FLE

TIL for SC = (2 + 24 / 24 + 2) * 0.238 = 1.19 days FLE

Example 2 (Barge Delivery):

For a location with barge delivery facilities linked to a pipeline segment with a "high" constraint frequency-duration pattern, a ULSD delivery lag of 7 days, and a ULSD delivery constraint of 10 days to clear ice in a major cold spell, the target inventory levels for CC and SC applications would be as follows:

TIL for CC = (3 + 7 + 10) * 0.476 = 9.52 days FLE

TIL for SC = (3 + 7 + 10) * 0.238 = 4.76 days FLE

Note that, in the case of barge delivery, the tank capacity would be increased by the volume of one bargeload to facilitate unloading and to avoid demurrage charges.