GE Energy

Addressing Gas Turbine Fuel Flexibility

GER4601 (05/11) revB

Robert Jones,
Manager of Syngas Power Island Products

Jeffrey Goldmeer,
Product Marketing Manager

Bruno Monetti,
Product Marketing Manager

Contents:

Addressing Gas Turbine Fuel Flexibility

Introduction

The global energy landscape is experiencing major changes as current economic issues evolve. There is worldwide pressure to secure and make more gas and oil available to support global power needs. With constrained fuel sources and increasing environmental focus, the quest for higher efficiency and lower emissions targets in the context of security over fuel supplies seems straightforward. As Natural Gas Combined Cycle (NGCC) plants provide very high efficiency, there will be increasing demand for natural gas, which will continue the push for increased availability of Liquefied Natural Gas (LNG). At the same time, countries will continue to look at available natural resources, such as liquid fuels and coal, as ways to increase energy stability and security.

Solutions for reducing CO_2 emissions can be as simple as leveraging increasing energy conversion efficiency or switching to more carbon neutral fuels. Finally, these pressures are drivers for many industries and refiners to examine the potential inherent value within process off-gases or process waste streams as a way to maintain or reduce energy operating expenses for themselves and regional power generators.

This paper focuses on the role that gas turbines play in this changing environment that requires greater flexibility to burn a wider range of fuels, which is a crucial factor to the next generation of gas turbine power plants. Leveraging more than 50 years of fuel experience, GE has developed gas turbine technology that is proven and a more efficient alternative to other technologies, while burning the widest range of alternative gas and liquid fuel.

Fuel classification

The potential fuels to be utilized on high efficiency gas turbines are very large, and in this changing energy landscape, there is a growing interest in turning to non-traditional fuels, capitalizing on the experience gained during the past five decades. As continuous-flow machines with robust designs and universal combustion systems, gas turbines have demonstrated distinctive capabilities to accept a wide variety of fuels. GE gas turbines, in particular, have been operating with most of these fuels (see *Figure 1*).

The most common way to classify fuels is to split them between gaseous and liquid fuels, and within the gaseous fuels, to split by their calorific value. Table 1 shows such a classification of fuels.

- **Natural gas:** This is mainly methane with some small amounts of volatile hydrocarbons and inert gases.
- **High calorific value gases:** These are made of volatile hydrocarbons with minor fractions of inert gases, which are usually very clean and perform well in gas turbines. It may typically be propane, butane or a mixture of the two. They often contain some amounts of hydrogen and are usually available as refinery by-products.

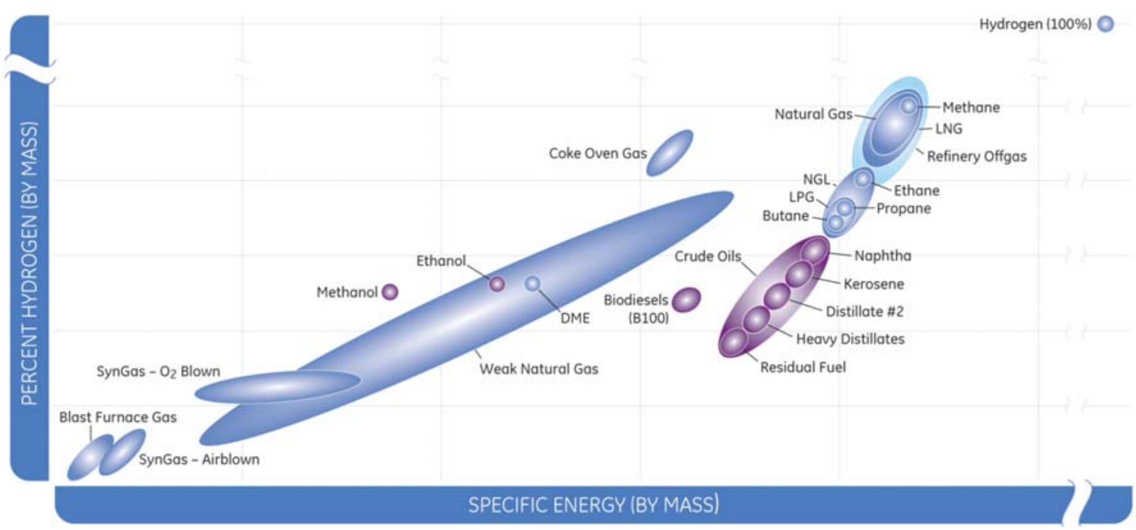

Figure 1. Fuel used on high efficiency gas turbines.

	Typical composition	Lower Heating Value kJ/Nm3 (Btu/scf)	Typical specific fuels
Ultra/Low LHV gaseous fuels	H_2 < 10% CH4 < 10% N_2+CO > 40%	< 11,200 (< 300)	Blast furnace gas (BFG) Air blown IGCC Biomass gasification
High hydrogen gaseous fuels	H_2 > 50% CxHy = 0-40%	5,500-11,200 (150-300)	Refinery gas Petrochemical gas Hydrogen power
Medium LHV gaseous fuels	CH4 < 60% N_2+CO_2 = 30-50% H_2 = 10-50%	11,200-30,000 (300-800)	Weak natural gas Landfill gas Coke oven gas Corex gas
Natural gas	CH4 = 90% CxHy = 5% Inerts = 5%	30,000-45,000 (800-1200)	Natural gas Liquefied natural gas (LNG)
High LHV gaseous fuels	CH4 and higher hydrocarbons CxHy > 10%	45,000-190,000 (1,200-5,000)	Liquid petroleum gas (butane, propane) Refinery off-gas
Liquid fuels	CxHy, with x > 6	32,000-45,000kJ/kg	Diesel oil Naphtha Crude oils Residual oils Bio-liquids

Table 1. Fuel classification.

- **Medium calorific value gases:** These fuels are either weak natural gases made of methane with high fraction of inerts (CO_2, N_2), process gases, or gasified coal. Process gas is a broad classification of byproduct gases, with wide range of composition, mainly containing methane, hydrogen and carbon monoxide.

  Also called “syngas” and mostly derived directly from abundant fossil carbon (refinery residuals, coal, lignite, tar sands, and shale oil), they represent great potential for the carbon-constrained economy, provided they are subjected to carbon capture.

  A subset of these syngas fuels is made up of the high hydrogen gaseous fuels, where hydrogen makes up more than 65% of the total gas volume. These fuels are made either by methane reforming or oxygen-blown gasification of coal.

- **Low calorific value gases:** Often called “low-BTU” gases, they contain carbon monoxide and hydrogen diluted with a large fraction of inert components, namely nitrogen and carbon dioxide. Derived from the chemical, oil and gas, or steel sectors, many of these fuels cannot be transported or stored, and their essential appeal will be to reduce fuel supply in industrial plants in the carbon-constrained environment.

Within the liquid classification, one can distinguish three main categories:

- **True distillate fuels:** These are refined products essentially free of ash-forming components. Most common ones are naphtha, kerosene, and diesel fuels, which normally can be used as is or with minor cleanup.
- **Oils:** Includes crudes and other refined residuals that are heated to acceptable levels to enable the needed viscosity for gas turbine combustion.
- **Bio-liquid fuels:** More evenly distributed around the world, they are of prime interest due to their overall neutral carbon balance.

All these categories represent potentially abundant energy sources.

GE operating experience

GE Energy has more than 50 years of experience and the largest fleet of gas turbines operating on alternative gas and liquid fuels, as illustrated in *Figure 2*. If the majority of the nearly 9,000 GE gas turbines are primarily operating on natural gas, more than 140 units are using various alternative gases (refinery off-gases and industrial by-product gases, syngases), and almost 400 turbines are burning liquids other than diesel oil, such as crude oil, residual fuels or naphtha.

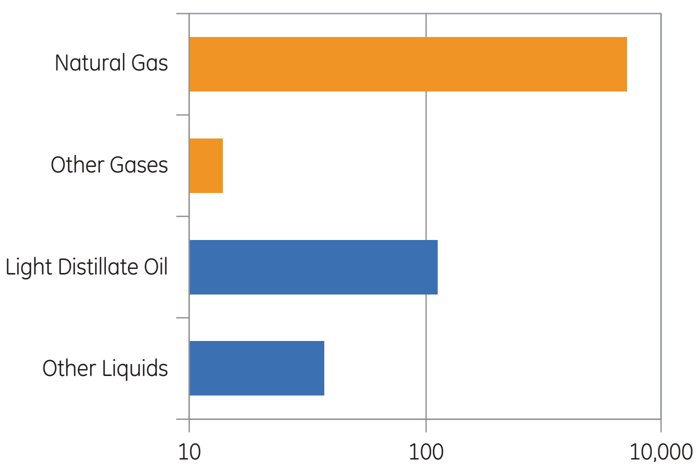

Figure 2. Number of GE combustion turbines by fuel type.

This success has been made possible by introducing incremental enhancements to the main gas turbine E-class and F-class platforms overtime, and leveraging enhancements made on one frame to the other machines. By doing that, GE always ensures it maintains high availability and reliability of the gas turbine. For instance, the 9E gas turbine used to operate with low-BTU steel mill gases has the same robust design as the 600 units operating reliably in the field, with the exception of an enlarged stage 1 nozzle to allow more flow in the hot gas path section, and the use of a scaled version of the Multi Nozzle Quiet Combustion (MNQC) system designed in the early 1990s on the 7F/7FA (*Figure 3*).

Natural gas

Natural gas is a significant fuel source for power generation and will continue to fuel a large share of power additions. World natural gas resources are not distributed equally globally and demand in the Middle East for the limited natural gas supply has led to interest in the use of secondary gases and liquids to meet power generation needs. To supplement the available supply, there has been an increased emphasis on the development of Liquefied Natural Gas (LNG) facilities.

Adding globally-sourced LNG to the generation mix creates a degree of complexity with the variation in the gas supplied, as LNG can have increased content of inert gases (i.e., N_2) and higher

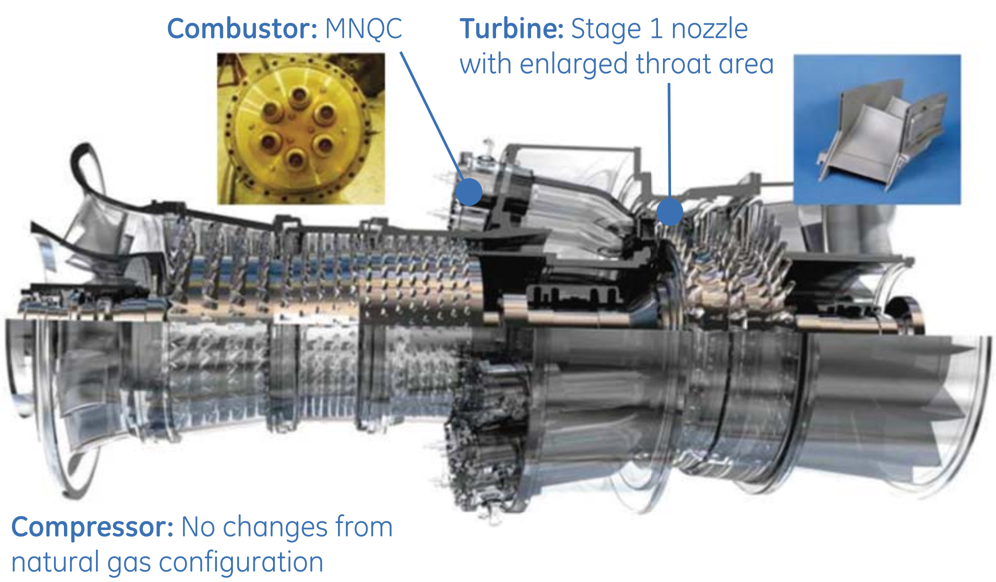

Figure 3. Modifications on 9E gas turbine for low calorific value gases.

hydrocarbons, especially ethane (C_2). This variation in fuel composition can be characterized using the Wobbe Index (WI). The key to adapting to the variations in fuel composition is a control system that is able to measure and adjust to these changes, linking directly to the operability boundaries affected by fuel quality: combustion dynamics, emissions, and blowout. No specialized system hardware is necessary beyond minor redundancy upgrades of existing control sensors (e.g., humidity, fuel manifold pressure, etc.). The control system employs physics-based models of gas turbine operability boundaries (e.g., emissions, combustion dynamics, etc.). The models execute in real time in the gas turbine control computer to continuously estimate current boundary levels. Both simulations and field tests enabled system validation. The closed-loop simulations modeled the gas turbine and control system and included the actual control computer hardware and software coupled to a field-data-matched, real-time system model. Results from the simulations demonstrated the ability of the system to withstand a rapid change in fuel composition with little operational impact. The field-test validation was performed on a GE Energy 7FA+e gas turbine with a DLN 2.6 combustor operating in a 107FA combined-cycle mode with heated fuel. The Modified Wobbe Index (MWI) system, subjected to rapid change, maintained NO_x levels without significant impact on combustion. This control system, first installed on four units at two sites in Florida in 2007, has now accumulated more than 160,000 hours of operation and accommodated transitions from natural gas to liquefied natural gas with wider fuel heating value variation. This system is currently available for GE Energy's Frame 7FA and Frame 9FA gas turbines.

Alternative gaseous fuels

Given the wide range of fuel sources, GE gas turbines have the flexibility to operate in a variety of application spaces, including refineries, steel mills and other petrochemical plant facilities. When it comes to industrial gases, such as steel mill process off-gas (blast furnace gas, coke oven gas, converter gas), GE gas turbines are proven co-generation alternatives to steam boilers. To help customers enhance fuel utilization, reduce fuel costs, and increase revenues, GE's versatile gas turbines can also operate on a variety of gas fuels in a wide range of power applications, including Integrated Gasification Combined Cycle (IGCC).

High calorific value gases

Industrial or petrochemical plants are looking for ways to utilize process gases produced on-site to reduce plant operating costs. Some of these facilities produce hydrogen-containing process gases (sometimes known as off-gas) as a by-product of the main plant chemical processes. Customers desire to reduce the combustion turbine's natural gas consumption by blending some percentage of the process gas with their main natural gas supply.

For example, GE developed a fuel blending system allowing a blend of hydrogen and natural gas to be burned in a 7FA gas turbine with the DLN 2.6 combustion system. Typically, GE's 7FA heavy duty gas turbines equipped with Dry Low NO_x (DLN) combustion systems have operated on 100% pipeline natural gas. Conceptually, this system allows a fuel blend that is nominal 5% H_2 with natural gas making up the remainder of the fuel (*Figure 4*)

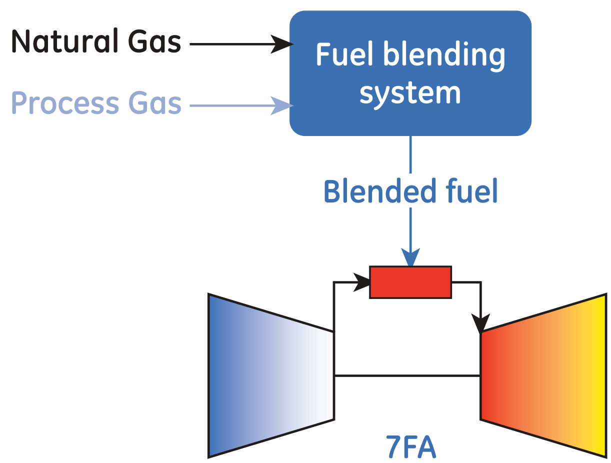

Figure 4. Fuel blending system schematic.

The development process for this innovative product included a series of feasibility tests in GE's combustion test facility in Greenville, USA, to determine the capability and limitations of the current DLN 2.6 combustion system with regard to burning a fuel blend of natural gas and hydrogen. The final product design includes an off-base fuel blending system capable of blending process gas with the natural gas to create a blended fuel mixture, as well as a system of instruments for measuring fuel flow and gas composition and valves for controlling flow.

The first four 7FA fuel blending systems were delivered to the customer site in 2010 (*Figure 5*) and operations on blended fuel took place in May of the same year. To date, all four 7FA units at this customer site have operated on blended fuel.

Figure 5. Fuel blending system installation at launch customer site.

Medium and low calorific value (LCV) fuels

To date, there are more than 40 GE turbines operating on low-BTU fuels and these turbines have accumulated over two million operating hours, including over 380,000 fired hours and over 25,000 fired starts on F-class units (with MNQC systems.) A timeline illustrating some of GE's low-BTU gas turbine installations, including both E and F-class turbines operating in America, Europe, and Asia, is shown in *Figure 6*.

Given the wide range of fuel flexibility inherent in gas turbines, these units can operate in a variety of application spaces, including coal-based IGCC, refinery based IGCC, and in steel mill plants. A detailed list of units operating in these applications is shown in *Table 2*.

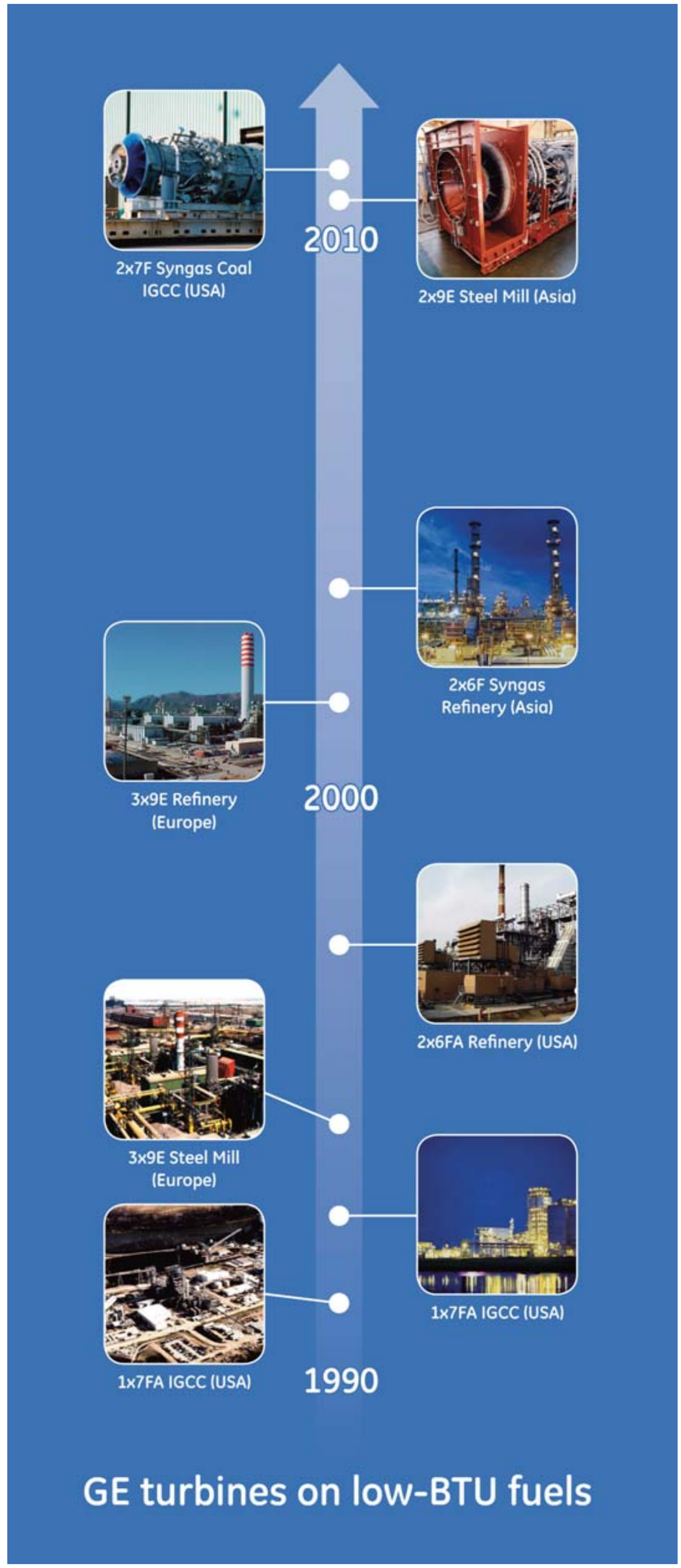

Figure 6. Timeline of low-BTU experience.

Type	COD	MW	Power Block	Application	Integration	Gasifier	Fuel
Coal IGCC Experience							
IGCC	1984	120	107E	Power	Steam	GE	Coal
IGCC	1996	350	209E	Cogen	Steam	ZVU	Coal
IGCC	1996	70	1x106B	Cogen/ MeOH	Steam	GSP	Coal
IGCC	1996	250	107FA	Power	N2	E-Gas	Coal/Pet Coke
IGCC	1996	250	107FA	Power	Steam/N2	GE	Coal
Refinery IGCC Experience							
Refinery	1996	40	6B	Cogen	Steam/Air/N2	GE	Pet Coke
Refinery	1997	120	206B	Cogen/H2	Steam	Shell/Lurgi	Oil
Refinery	2000	550	3x109E	Cogen	Steam	GE	vis breaker tar
Refinery	2000	180	2-6FA	Cogen	Steam/N2	GE	Pet Coke
Refinery	2000	173	2-6FA	Cogen	None	GE	Oil
Refinery	2006	160	2-7EA	Cogen	Steam	Shell	Asphaltene
Refinery	2009	253	2-9E	Cogen	N2	Shell	Oil
Steel Experience							
Steel	1996	520	3x109E	Cogen	None	Steel Mill	BFG/COG/LDG
Steel	2001	180	1x109E	Cogen	None	Steel Mill	BFG/COG/LDG
Steel	2003	50	1x106B	Cogen	None	Steel Mill	BFG/COG
Steel	2008	450	9x106B	Power	None	Steel Mill	BFG/COG
Steel	2008	174	1x109E	Cogen	None	Steel Mill	COREX
Steel	2010	174	1x109E	Cogen	None	Steel Mill	COREX
Steel	2010	328	2x109E	Cogen	None	Steel Mill	BFG/COG

Table 2. GE syngas experience by application.

Improving the LCV solution for the steel industry

In steel plants, the primary fuel is blast furnace gas (BFG), which is a by-product fuel gas produced during the combustion of coke in blast furnaces. BFG is an ultra-low calorific value gas (700-800 kCal/Nm3), which can be effectively recovered and used, mixed with coke oven gas (COG-4200-4800 kCal/Nm3) and possibly, converter gas (LDG 1900-2200 kCal/Nm3), which are other by-products of manufacturing, as fuel for power and steam generation. Leveraging its E-class gas turbines with flexible fuel handling capabilities, GE has developed efficient, proven, and reliable solutions for steel industry applications with the following benefits:

- Wide range of low-BTU fuels (BFG, basic oxygen furnace gas, COG, LDG converter gas, Corex export gas) to support customers with unique generation solutions.
- Improved performance compared to subcritical steam boilers – more power and heat with reduced fuel costs and efficiency improvement.
- Reduced CO_2 and greenhouse gas emissions, as well as reduced COG volume consumption for BFG enrichment.
- High reliability, long maintenance intervals, and shorter maintenance outages result in lower maintenance costs and higher availability.

As shown in *Table 2*, GE experience with steel gases was started more than 15 years ago, with the development of a combined-cycle power plant in Italy, which has become a major reference plant for recovery gas utilization. In commercial operation since the end of 1996, this plant consists of three CHP/CCGT units, has a total generating capacity of 520 MW, and supplies 150 t/h of steam for the process (*Figure 7*). Each combined-cycle configuration, built around a GE 9E gas turbine, has an ISO output rating of 130 MW and is able to burn mixtures of recovery gas and natural gas. The combustion system is a dual gas type, with natural gas for startup and shutdown operations. The gas turbine drives a 103 MW double-end generator and a 27 MW fuel gas compressor in an integrated single-shaft arrangement. A horizontal heat recovery boiler produces steam at two pressure levels (95/25 bars) and reheats the low-pressure steam that is fed back into a 68 MW steam turbine generator set. Supplementary firing provides extra system flexibility in utilizing available recovery fuel gas to raise gas temperatures at the super-heater inlet.

Figure 7. Gas turbine and heat recovery steam generation (HRSG) for the first GE combined cycle power plant in Italy burning BFG/COG/LDG mix.

Another example of fuel flexibility using steel mill gas is a 1x9E multi-shaft combined cycle power plant which is operating on Corex gas since 2008 (*Figure 8*). Corex gas, which is made of roughly 20% H_2, 45% CO and 30% CO_2, has a low heating value of about 1,950 kcal/Nm3 (~208 BTU/scf).

In today's steel industry, increasingly fierce competition is driving a trend to reduce energy production costs and replace conventional power plants with GTCC power plants—raising electrical efficiency from about 30-35% to about 40-45%. While initial investment is higher, net electrical efficiency increases by 8-10 points. Since BFG

Figure 8. Combined cycle power plant using Corex gas.

is the predominant fuel, the calorific value of the fuel mixture is generally between 1,000 and 1,600 kCal/Nm3, depending on the type of plant and on the hourly iron and steel production. Blended fuel gas requires cleaning to remove particulates and tars to comply with the gas turbine gas fuel specification. This cleaning also achieves the objective of reducing gaseous emissions, to make the new power plant compliant with local regulations and possibly eligible for carbon monetization. Leveraging its considerable medium/low heating value experience, GE Energy has recently successfully expanded its large-frame gas turbine product line to burn ultra low calorific steel mill gas fuel blends, especially mixtures of BFG and COG.The first two GE frame 9E gas turbines in China with this capability have been put into service in 2010 and have thus far accumulated more than 8,000 hours operating on BFG/COG blends below 1,050 kCal/Nm3. The China site comprises two complete power trains, including GE 9E gas turbines, generators, fuel cleaning equipment, and fuel gas compressors.

Refinery and Coal IGCC

At the front end of the gasification process is the IGCC plant, which takes a carbon-based fuel source such as coal, refinery residuals or biomass, and under high heat and pressure, converts it into a synthesis gas (or syngas) comprised of H_2 and CO. Impurities and carbon can be removed easily and economically from the syngas stream on a pre-combustion basis—leaving a net low carbon hydrogen-rich fuel which is subsequently burned to create electricity.

From both an efficiency and an environmental prospective, IGCC is a promising technological solution for long-term power needs. IGCC offers the following:

- Advanced conversion efficiency
- Solid and liquid feed stocks from local sources
- Competitive capital expenses (CapEx)
- Favorable pollution emissions control (NO_x, SO_2, mercury, PM10)
- CO_2 capture readiness, when combined with Carbon Capture and Storage (CCS)
- Fuel flexibility
- Generation of industrial feedstock gases (Syngas, H_2, etc.)

Gasification plants with GE Energy designed gas turbines (operating or under contract) combine for more than 2,500 MW. This turbine fleet has accumulated a total of more than one million hours of operation on low-calorific syngas fuels, as well as significant operation with co-firing of alternative fuels. Several recent refinery-based gasification projects boast exceptional performance and fuel flexibility. Process feedstock includes coal, lignite, petroleum coke, heavy oil, and waste materials converted by six different gasifier types. An example is the gasification that is part of the expansion of a refinery located in China. This project expands the crude oil processing capacity of the existing refinery from 4 million to 12 million tons per year. GE Energy has supplied two Frame 9E gas turbines (both rated at nearly 130 MWe) and two generators for the IGCC plant, which are burning a syngas containing around 40% hydrogen and 45% CO (*Figure 9*).

Figure 9. 9E plant located in China using syngas.

For the near-pure hydrogen used in combustion gas turbines, GE Energy benefits from existing gas turbine experience on high-hydrogen fuels derived from a variety of process plant applications. F-class gas turbines with hydrogen content up to 45% by volume have been in operation for more than 10 years, with more than 80,000 operating hours on the fleet leader. GE Energy continues to develop advanced gas turbines with syngas fuel capability to meet market demand in order to improve gasification cycle efficiencies with increased output and reduced capital costs.

Advanced F technology results in bigger units that provide the benefits of reduced CapEx and higher combined-cycle efficiency. The latest example of this continuous effort is the development of the 7F syngas gas turbine, GE's latest F-class turbine product focused specifically on using syngas and low-BTU fuels. This turbine has an ISO rating of 232 MW, operating with oxygen blown, medium BTU syngas fuel. There are a number of physical differences between the 7F syngas and existing syngas and natural gas turbines. This turbine uses the 7FB compressor, which enables a higher flow/pressure ratio capability to significantly improve output and efficiency across the base load operating range. This turbine also includes an enhanced Hot Gas Path (HGP) for use with syngas fuels, which includes aerodynamic improvements to the turbine section to accommodate the increased mass flow that occurs with syngas and diluent. The 7F Syngas turbine also uses 7FA HGP materials with proven corrosion resistance in syngas operating environments for high reliability, and GE's proven MNQC syngas combustion system.

The first two units have been manufactured and were shipped to the Duke Edwardsport IGCC plant in 2010. This plant, located in southwest Indiana, USA, will have a net output of nearly 620 MW

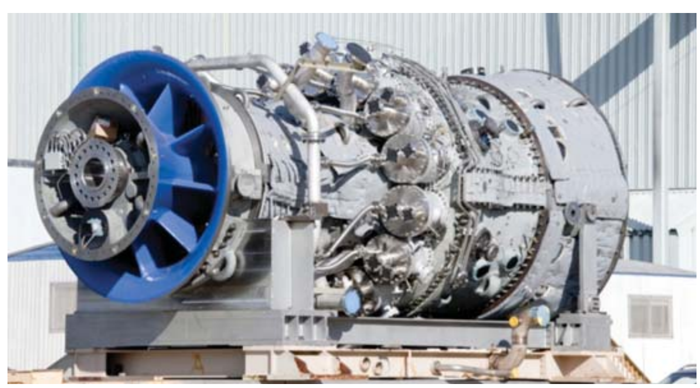

Figure 10. 7F Syngas turbine.

and COD is scheduled for 2012. *Figure 11* shows a picture of the site in 2011 while still under construction.

Figure 11. Duke Edwardsport IGCC plant (2011).

GE's portfolio of syngas capable gas turbines (*Figure 12*) includes units for both 50 and 60 Hz segments, simple-cycle configurations with output ranging from about 46 – 300 MW, and combined cycle configurations with outputs ranging from about 70 – 880 MW, depending on fuel and site specific conditions. Each gas turbine is capable of operating on syngas with or without carbon capture; syngas with a large percentage of carbon capture will generate a high H_2 fuel.

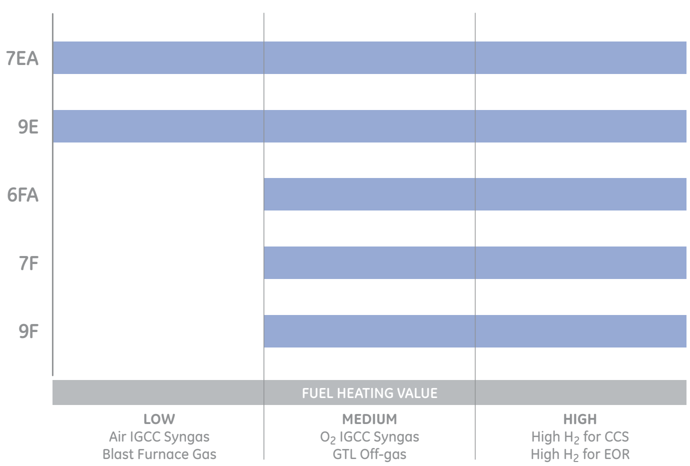

Figure 12. GE gas turbines for syngas applications.

Oils

With increasing energy demand and often-limited supplies of fuel available, numerous regions are seeking crude and residual oils commonly known as heavy fuel oils. Rather than utilizing traditional subcritical steam boiler technology that uses fuels from refinery processes, power providers are turning to GE's higher-performing gas turbine technology to generate cost-effective power. To that regard, gas turbine combined-cycle power plants offer better efficiency than traditional subcritical steam boiler technology, and GE's recent fuel flexibility technologies have significantly increased the availability of gas turbines fueled by heavy fuel oils.

Figure 13 shows an example of a recently commissioned 310 MW combined cycle power plant in Sri Lanka operating on residual fuel oil, which is supplying 10% of the country's electricity needs.

Figure 13. 310 MW combined cycle power plant operating on residual oil.

With more than 300 E-class heavy duty gas turbines operating with such heavier fuels (*Figure 14*), GE has accumulated more than seven million hours of operation, and is using its experience to continuously improve the performance and availability of its fleet.

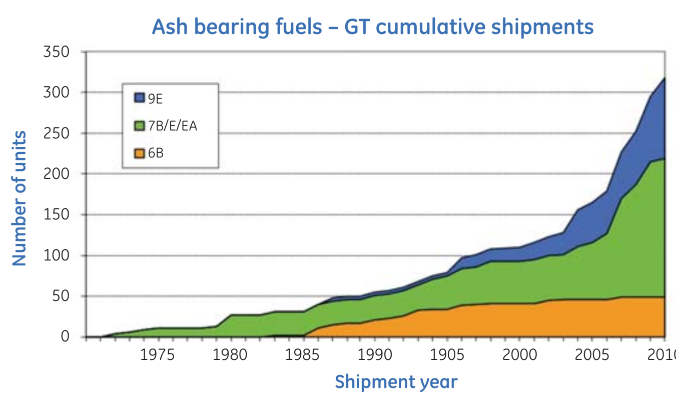

Figure 14. Cumulative number of 6B, 7E and 9E gas turbines operating with ash bearing fuels.

The technical challenge with crude oil or residual fuels involves preventing the harmful effects of these ash-bearing fuels on the turbine: metal and ash contained in the fuel can cause corrosion, erosion, and fouling. As a consequence, salts (sodium, potassium) are removed by washing the fuel with water, the corrosive vanadium is inhibited by using magnesium based additives, and frequent turbines offline water washes need to be performed to remove ash deposits.

The latest example of GE technology enhancements is the development of the HFO (heavy fuel oil) Availability Package on 7EA and 9E gas turbines. This package consisting of three features, significantly shortens the time required to perform the turbine offline water wash cycle, and reduces the rate of output and heat rate degradation due to fouling by as much as 25%:

- Automated water wash: The process to water wash the turbine and compressor which is labor intensive and lengthy can be fully automated.
- Smart cool down: Improves shutdown and startup profiles to shorten turbine cool down time without impacting parts life.
- Firing temperature control with Model-Based Control (MBC): As the ash deposits build up on the hot gas path airfoils for gas turbines operating with HFO, the turbine efficiency drops due to increasing surface roughness and decreasing nozzle throat areas. With traditional schedule-based gas turbine controls, this loss of turbine efficiency results in a gradual drop in firing temperature, effectively magnifying the performance loss due to fouling. Using MBC, an on-board simulation model directly calculates the firing temperature using sensor inputs, enabling the control system to compensate for the loss in turbine efficiency and thus maintain firing temperature and recover lost performance (*Figure 15*).

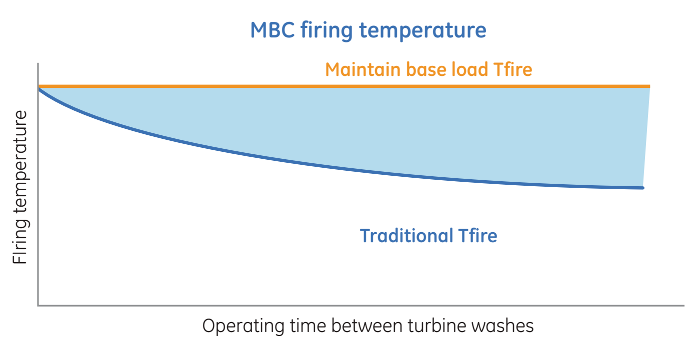

Figure 15. How MBC helps maintain performance.

The HFO Availability Package was successfully tested on a 7EA gas turbine located in Saudi Arabia in 2010 and is being implemented on three 9E gas turbines in Morocco.

Bio-liquid fuels

As many countries in the world look for new fuel opportunities, there is a growing concern about greenhouse gas (GHG) emissions. One approach in resolving this concern is to use carbon neutral fuels; that is, fuels that do not add any additional carbon to the current environment. One such solution is biofuels, which essentially "recycle" carbon already in the environment. There are many diverse biofuels and biofuel feed stocks under consideration across the globe. These feed stocks can include corn, soy, palm, rapeseed, and jatropha.

Multiple chemical processes take these raw plant-based elements and convert them into alcohol-based fuels, such as methanol and ethanol, or petroleum like fuels, such as biodiesel. Most popular bio-liquid fuels classifications are:

- Vegetable oils (VO) as virgin or recycled product.
- Alcohols, such as methanol or ethanol.
- Esterified VO or Fatty Acid Alkyl Esters (FAAE), also known as biodiesel.

GE has performed successful tests on several of these fuels.

Biodiesel: A test using biodiesel (rapeseed methyl-ester) was performed in 2006 on a 6B gas turbine located in Switzerland, demonstrating the performance of biodiesel over a range of operational conditions. Power and efficiency levels were very close to the ones achieved with diesel oil (DO), and emissions were at least as low as with DO.

- SOx is reduced (lower than 1 ppm).
- No visible plume; smoke opacity lower than with DO.
- CO and Volatile Organic Compounds (VOC) are as limited as with DO.
- NO_x emission is lower than with DO.
- The NO_x abatement effect of water injection is normal and similar to that with DO.
- Particulate Matter (PM), Polycyclic Aromatic Hydrocarbons (PAH) and aldehyde emissions are below the detection limits.

Bioethanol: In 2008, another test using bioethanol was performed in India on another 6B gas turbine. Being that Ethanol is highly volatile and has poor lubricity properties, the site chosen for the test was normally operating with Naphtha, a fuel having very similar properties to ethanol. Here again, the results were very conclusive, showing that performance and emissions are at least as good as the ones achieved with DO. Similar results using ethanol have also been achieved on an aeroderivative LM6000 during a 1000 hour demonstration test in 2010 in Brazil.

Considering the potential for a reduced carbon footprint and proven capability of gas turbines to accommodate biodiesel, ethanol, etc., biofuels may be an attractive alternative to distillate fuels.

Summary and Conclusion

An analysis of emerging fuels shows that the power generation community will face major challenges. The predictability of fuel resources and environmental commitments will weigh heavily on long-term plans. As a result, there is a need to explore all sustainable alternative energy channels. Any sensible utilization of alternative fuels, including process streams from industrial plants such as refineries, petrochemical plants, iron plants and steel plants, can generate economic and environmental benefits. In a carbon-constrained environment, the technology trend is for combustion systems capable of burning syngas and hydrogen-rich fuels in combination with delivering the required operability. In this new context, the strong operational experience gained by gas turbines with a wide variety of fuels creates favorable prospects, both for robust E-class machines and for F-class machines that deliver high performance.

Appendix

List of abbreviations and acronyms

BFG = Blast Furnace Gas

BTU = British Thermal Unit

COG = Coke Oven Gas

DO = Diesel Oil

FAAE = Fatty Acid Alkyl Esters

MBC = Model-Based Control

MNQC = Multi Nozzle Quiet Combustor

PAH = Polycyclic Aromatic Hydrocarbons

PM = Particulate Matter

VO = Vegetable Oil

List of Figures

List of Tables

Notes

Notes

©2011, General Electric Company. All rights reserved.

GER-4601B (05/2011)