GE Energy

Addressing Gas Turbine Fuel Flexibility

GER4601 (06/09)

Authored by:

Steve Rahm
Product Line Manager

Jeffrey Goldmeer
Fuel Flexibility Platform Leader

Michel Molière
Principal Engineer

Aditya Eranki
Manager Application Engineering

(This paper was originally presented at the POWER-GEN Middle East conference in Manama, Bahrain on February 17–19, 2009.)

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Abstract

The steady growth of power demand in the Middle East continues to drive governments, power authorities and independent power providers to look for solutions to meet country as well as regional energy requirements. To provide for these increasing energy requirements, these organizations must cope with issues of fuel supplies and cost. Fuel supply is further complicated when considering the global competition for what could be a local generation fuel and increasing environmental awareness. These factors contribute to the region's interests in diversification of supply and the potential in what may have been considered margin fuels for generation. In addition, these factors contribute to a greater interest to consider a diverse fuel spectrum allowing for increased operational flexibility and cost control, with improved plant efficiency and emissions characteristics.

Gas turbine based generation systems offer efficient energy conversion solutions for meeting the challenge of fuel diversity while maintaining superior environmental performance. Combustion design flexibility allows operators a broad spectrum of gas and liquid fuel choices, including emerging synthetic choices. Gases include and are not limited to ultra-low heating value process gas, syngas, ultra-high hydrogen or higher heating capability fuels. Liquid fuels, considered by some outside the Middle East as a "back up" fuel to natural gas, are a mainstay for the region. This includes Heavy Fuel Oil, which is a primary fuel for many power generation applications in the Middle East. This paper will address the broad range of fuel options in the context of proven, available technology and introduces product solutions tailored to meet fuel flexibility demands expected by the larger generation community.

Introduction

The global energy landscape is experiencing major changes as current economic issues evolve. As nations look for domestic energy security, lessened environmental impact and reduced effect from variable fuel costs, they have examined alternate or non-traditional fuel sources for large power generation. The potential fuels utilized on high efficiency gas turbines are illustrated in *Figure 1*. More importantly, GE Energy has significant experience with a large number of fielded units that are operating on a variety of non-traditional fuels, as illustrated in *Figure 2*.

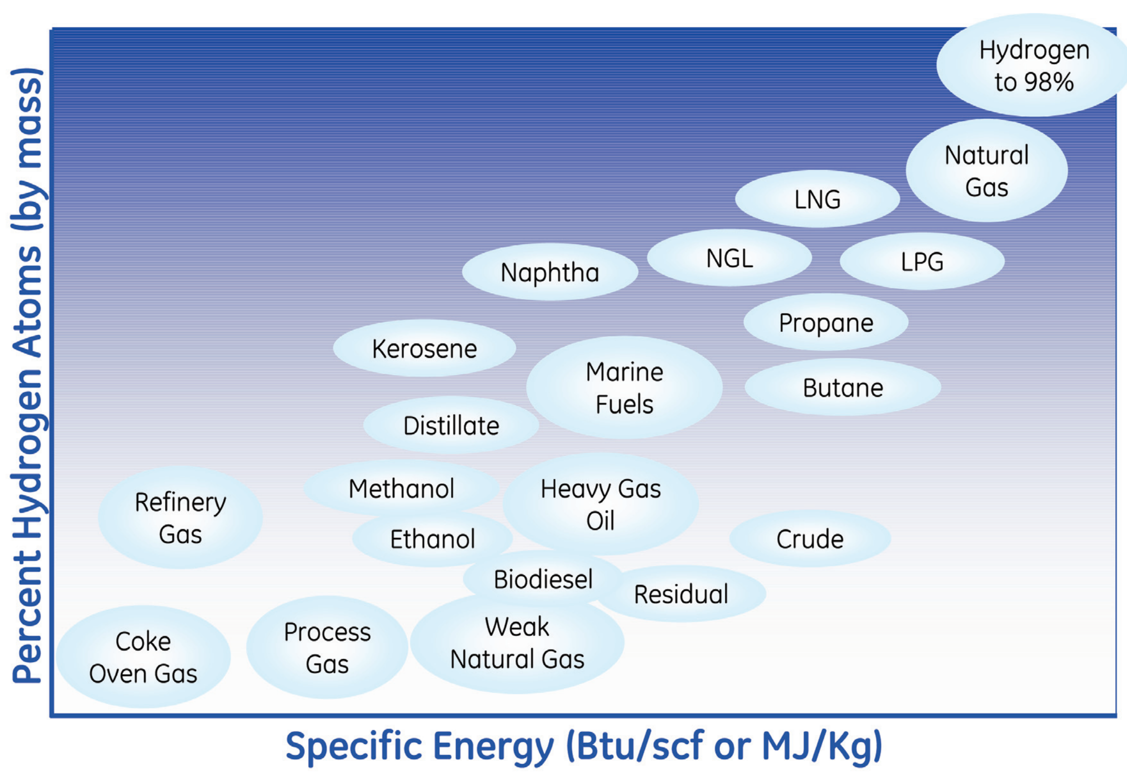


Figure 1. Portfolio of GE's heavy duty gas turbine fuel experience

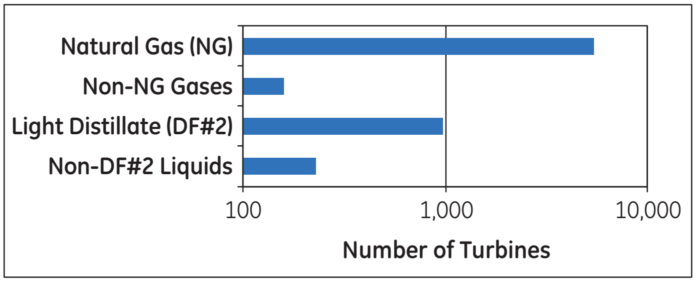


Figure 2. Number of GE combustion turbines by fuel type

The Middle East today is experiencing both strong economic growth and increased environmental awareness. In addition to supporting the growing needs of both the local population and industry, the region is also under continued pressure to make more gas and oil available to support global power needs. The way ahead seems straightforward, driven by a quest for higher efficiency and lower emissions targets in the context of security over gas supplies. As Natural Gas Combined Cycle (NGCC) plants provide very high efficiency, there will be increased 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, including 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 off-process 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 a greater flexibility to burn a wider range of fuels, which is crucial to the next generation of gas turbine power plants. The fuels to be discussed in this paper include traditional fossil fuels (natural gas and LNG), as well as non-traditional fuels: industrial/refinery fuels (low calorific fuels, syngas and higher hydrocarbons) and liquids, including bio-fuels.

Traditional Gas Turbine Fuel

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 adds a degree of complexity with the variation in the gas supplied, as the LNG can have increased content of inert gases (i.e., N_2) and higher 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). 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 (Healy, 2007; Campbell, Goldmeer, et al., 2008).

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 7FA+e gas turbine with a DLN2.6 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 20,000 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 gas turbines and is being transitioned to GE Energy's Frame 9F gas turbines.

Non-Traditional Gas Turbine Fuels

In this changing energy landscape, there is a growing interest in turning to non-traditional fuels, capitalizing on the experience gained during the past three decades. As continuous-flow machines with robust design and universal combustion systems, gas turbines have demonstrated distinctive capabilities to accept a wide variety of fuels. There are many alternative fuels, but they are not all applicable in every region. The alternative fuel classifications listed below are not exhaustive:

- Oils, including crudes and other refiner residuals, which are heated to acceptable levels to enable the needed viscosity for gas turbine combustion.
- Off gases or by-products of industrial processes – 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.
- Syngas and synfuels – 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.
- Bio-liquid fuels – more evenly distributed around the world, they are of prime interest due to their overall neutral carbon balance.

These categories represent potentially abundant energy sources and offer promising prospects. The following sections offer additional detail.

Oils

With the global demand for light sweet crude to support the transportation industry, one might question the idea of these oils being a viable fuel for generation. Just as exploration has moved, so too have oils and gases. Supplies that were lighter and sweeter are evolving to be heavier and more sour fuel. Both viscosity and contaminants are challenges to refiners, but at the same time these changes offer opportunity to all those in the chain. For those holding heavier crude assets, the ability to have a known resource for the sale of products provides the incentives to pursue the find. Those in refining concerned with what to do with the processing residuals now have proven technology in gasification to enhance the refining process, as well as overall yield. Those power providers looking to generate cost-effective power have resources in higher performing gas turbine combined-cycle power plants instead of traditional subcritical steam boiler technology for the potential generation fuels from refiners' processes. Key to the success in oil-based gas turbine generation is the commitment of those holding the resources, those with refinery capabilities and those in generation to explore the alternatives with the abundance of heavier grades, along with the encouragement of governments and regulatory bodies to pursue the alternatives. There is no single answer. For example, a refiner with excess light cycle oil too viscous for use in automotive diesel engines realized a ready use in traditional E-class gas turbines. And a site developer learned that heavy fuel oil was an attractive answer to his need for power earlier than the practical limits of diesel engines.

Process By-products Fuels

A number of industry processes generate by-products streams that are suitable for combustion in power plants. For instance: crude oil topping, platforming, dehydroalkylation, de-ethanisation in refineries and thermal crackers and aromatics plants within petrochemical plants generate valuable gases that are called "Fuel Gas" (or "Net Gas") and are generally mixed together to constitute the Fuel Gas network of the plant.

Heavy Duty Gas Turbine (HDGT) units can achieve an enhanced benefit from alternative fuels for the following reasons:

- They develop better power generation performances than steam cycles.
- The power/heat ratios of GT-based Combined Heat and Power (CHP) match the requirements of modern industrial plants.
- They meet the stringent reliability/availability standards placed by refiners and petro chemists.
- They can run over 8,000 hours without interruption.
- They accept other alternative fuels: fuel oils, naphtha, C3-C4 gas, and heavy distillates.
- Heavy duty gas turbines have demonstrated an unequalled integration capability in the energy schemes of the hosting plant.

For instance, liquefaction units in LNG production plants produce C2+ tail gases that can feed the gas turbines used as mechanical drivers for the compression units. Crackers and reformers in refineries produce hydrocarbon or hydrogen-rich by-products utilized in the plant cogeneration with performances close to that of NG in CHP plants. The steam produced by the CHP serves plant processes and any excess of power is available for export to an external grid.

Another example is the case of petrochemical plants that want to reduce the amount of hydrocarbon and/or hydrogen gas that is flared. These gases offer the opportunity for blending into an existing natural gas stream used to fuel an onsite gas turbine. The resulting system could increase net plant efficiency and reduce fuel costs.

Low Calorific Value (LCV) Fuels

These synthetic or recovery gases stem from industrial processes and ultimately derive from the oil and gas or steel industry sectors. Many of these fuels cannot be transported or even stored cost-effectively, and are essentially of interest for their ability to minimize fuel input to industrial plants in a carbon-constrained environment. Based on considerable medium/low heating value experience, GE Energy has developed an improved Low Calorific Value gas version of the well-proven Frame 9E gas turbine. This product is commercially available for various LCV applications—such as gasified refinery pet coke, Corex export gas, and blended recovery fuel gas—with several projects currently in implementation.

In terms of LCV gas experience, a combined-cycle power plant in Italy 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. 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. Each combined-cycle unit has a total net output of 168 MW and supplies 46 MW thermal to the process. Considering the steam generated for the process, the net electrical efficiency is 41.5%. Without process steam generation, it rises to 43.9% net.

Improving the LCV Solution for BFG Mixed Fuel

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 30-35% to 40-45%. While initial investment is higher, net electrical efficiency is improved 8-10 points higher. The primary fuel is blast furnace gas (BFG), which is a by-product fuel gas from the steel works. BFG is an ultra low calorific value gas (700-800 kCal/Nm^3), which can be mixed with coke oven gas (COG-4200-4800 kCal/Nm^3) and possibly converter gas (LDG 1900-2200 kCal/Nm^3) to meet gas turbine minimum fuel calorific value constraints.

Since BFG is predominant, the calorific value of the fuel mixture is generally between 1,000 and 1,600 kCal/Nm^3, depending on the type of plant and on the hourly iron and steel production. Blended fuel gas requires extensive cleaning to remove particulates and tars to comply with the gas turbine gas fuel specification. This cleaning also achieves the objective of drastically reducing gaseous emissions, making the new power plant compliant with local regulations and possibly eligible for carbon monetization. Using this technology, GE Energy can effectively support end-users hoping to add substantial value to their project.

Syngas and Synfuels

Carbon fuels such as heavy refinery bottoms, coal or lignite that are in the syngas/synfuel category of alternative fuels described, will play an increasing role—provided their combustion is performed in efficient and environmentally-conscious conditions. From both an efficiency and an environmental prospective, Integrated Gasification Combined Cycle (IGCC) is a promising technological solution for long-term power needs. IGCC actually combines:

- Advanced conversion efficiency
- Solid and liquid feed stocks from local sources
- Competitive capital expenses (CapEx)
- Most 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 1,000,000 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 will be part of the expansion of a refinery located in China. This project will expand the crude oil processing capacity of the existing refinery from 4 million to 12 million tons per year. GE Energy will supply two Frame 9E gas turbines (both rated at nearly 130 MWe) and two generators for the IGCC plant—which will support operations at the expanded petrochemical complex.

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 over more than 10 years, with collected operation hours of more than 80,000 hours on the fleet leader. GE Energy continues to develop advanced gas turbines with syngas fuel capability to meet market demand to improve gasification cycle efficiencies with increased output and reduced capital costs. The 9F Syngas turbine, which will be the unit for the 50 Hz market, builds upon F-fleet experience, reliability and maintainability, and combines the performance of the 9FB Natural Gas Combined Cycle (NGCC) unit, coupled with GE Energy's proven diffusion combustion system and syngas hot gas path components. In addition, the 9F Syngas turbine has potential for operation on Syngas and High H_2 fuels.

Advanced F technology results in bigger units that provide the benefits of reduced CapEx and higher combined-cycle efficiency. Since early Dry Low NO_x (DLN) type combustors are limited to a maximum H2 content of <10% (due to the potential for flashback), the contemporary combustor for F-class machines that operate with hydrogen content syngas is the diffusion-flame IGCC-version of the multi-nozzle combustor.

Current research and engineering efforts funded under U.S. Department of Energy (DOE) Contract # DE-FC26-05NT42643 may lead to Dry Low NO_x (DLN) systems for future Syngas and High-Hydrogen applications. This program follows GE's proven development approach as illustrated in *Figure 3*. The results of sub-scale testing of multiple new combustor designs have demonstrated potential pathways to reach the DoE NO_x goal.

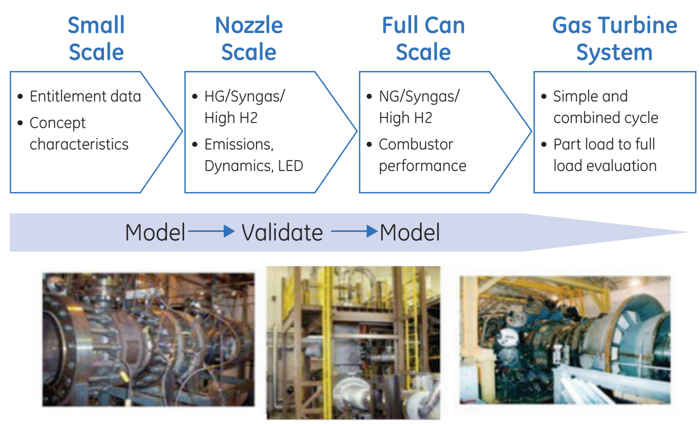


Figure 3. GE's combustion system development process

Initial efforts focused on examining chemical kinetics and physics of high H_2 combustion. This included experiments performed with state-of-the art imaging systems as illustrated in *Figure 4*. In addition, this program has been evaluating new combustion system concepts that have the potential to improve operating performance for a DLN High-H2 system. An early fuel nozzle design concept evaluated by this program is illustrated in *Figure 5* (Ziminsky and Lacy, 2008).

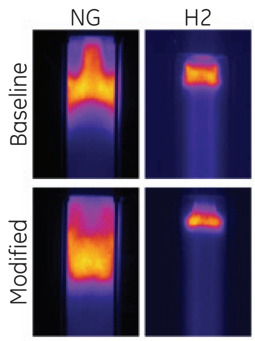


Figure 4. Flame shape visualization

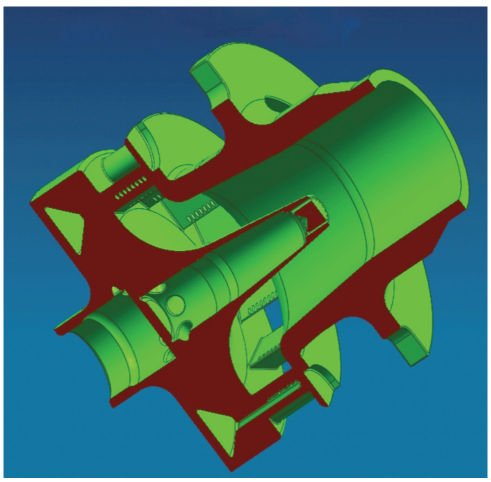


Figure 5. Novel fuel nozzle design

Renewable Liquids – Bio-Fuels

As many countries in the world look for new fuel opportunities, there is a growing concern with Green House 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 bio-fuels, which essentially "recycle" carbon already in the environment. (Fossil fuels on the other hand, put carbon back into the environment after thousands or millions of years of sequestration.) There are many diverse bio-fuels and bio-fuel 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 liquid bio-fuels classifications are:

- Vegetable oils ("VO") as virgin or recycled product
- Alcohols
- Esterified VO or Fatty Acid Alkyl Esters (FAAE)

When looking more closely at the ample sphere of bio-fuels, one sees that there is actually a progressive path between products having a genuine farming origin and those derived from the fossil origin. Methanol is a dual-faceted product originating from either Biomass-to-Liquid (BTL) or Gas-to-Liquid (GTL) processes. Some products can include in their preparation both renewable and fossil feedstocks. For example, Fatty Acid Methyl Ester (FAME) is obtained from a triglyceride and methanol: on one hand, 98% of methanol is derived from natural gas, on the other hand the triglyceride portion often contains (in addition to VO) some used cooking oil, "yellow greases" or tallow that are wastes of the food industry, therefore yielding biodiesels of poorer quality. For that reason, there are emergent regulations in the EU and US regarding what can qualify as a bio-fuel or renewable fuel.

A fuel that is attracting significant attention for gas turbine power generation is biodiesel. Biodiesel or "Fatty Acid Alkyl Esters" (FAAE) are modifications of triglycerides that are obtained by reacting one molecule of triglyceride with three molecules of a mono-alcohol that displaces the glycerol from the triglyceride, within a so-called trans-esterification reaction illustrated in *Figure 6*.

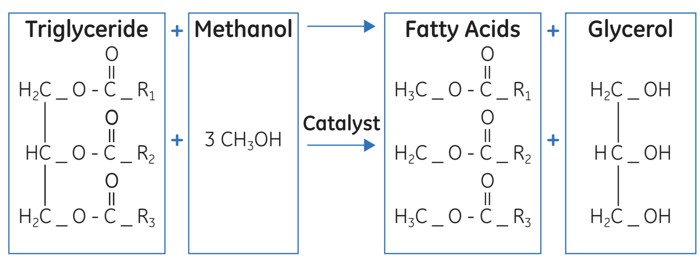


Figure 6. Biodiesel trans-esterification reaction

The most used mono-alcohol is methanol, which then yields a Fatty Acid Methyl Ester (FAME). However, ethanol could also be used, leading to a Fatty Acid Ethyl Ester (FAEE). Moreover, if bio-ethanol is used in conjunction with a VO, one gets a 100% bio-FAEE. As FAME is by far the most widespread product, it will be used hereafter as a synonym for FAAE or biodiesel. A more complete description of biodiesel production can be found in Molière, M., Panarotto, E., et al (2007).

GE has demonstrated the performance of biodiesel on both its heavy-duty industrial and aeroderivative gas turbines over a range of operational loads. The units tested, as illustrated in *Figure 7*, were the 6B, 7EA and LM6000. There have also been various reports of GE aeroderivative turbines operating on biodiesel blends. In all field tests, the NOx emissions were at least as low as the baseline comparison to operation on Diesel Oil (DO), and in some cases, the emissions were lower. More specifically, the results of the 6B biodiesel field test can be summarized with the following points (Molière, Panarotto, et al., 2007), taking Diesel Oil as a comparison basis:

- SO_x is minimal (lower than 1 ppm), as expected
- No visible plume; smoke opacity lower than with DO
- CO and VOC are as minute 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
- PMs, PAH and aldehyde emissions are below the detection limits

Considering the potential for a reduced carbon footprint, biodiesel may be an attractive alternate to distillate fuels when available.

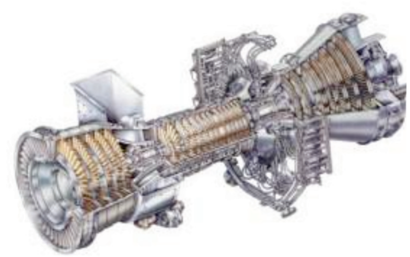
Summary and Conclusion

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 an overwhelming priority to explore all sustainable alternative energy channels.

Any sensible utilization of alternative fuels - including process streams from industrial plants such as refinery, petrochemical, iron and steel - 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 cluster of fuels create favorable prospects, especially for F-class machines that deliver high performances.

6B – Standard combustor
Fuel: B20 – B100

7EA – DLN1 combustor
Fuel: B20 – B100



LM6000 SAC
Fuel: B100

Figure 7. Biodiesel test platforms

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