BIODIESEL
America's Advanced Biofuel

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Comments Submitted to the Regional Greenhouse Gas Initiative

Relating to

Clean Power Plan

The National Biodiesel Board

The National Biodiesel Board (NBB) is the national trade association that represents the biodiesel and renewable hydrocarbon diesel industries as the coordinating body for research and development in the U.S. It was founded in 1992 and has developed into a comprehensive association that coordinates and interacts with industry, government and academia. NBB's membership is comprised of biodiesel producers, feedstock and feedstock-processor organizations, fuel marketers and distributors, and technology providers.

Summary of Comments

NBB commends the Regional Greenhouse Gas Initiative (RGGI) for establishing a stakeholder process for identifying and implementing innovative solutions for reducing electricity-related GHG emissions in the northeastern United States. We believe that the RGGI proceeding will be highly valuable in charting a course toward the sustainable energy goals that we all share.

NBB is supportive of the policies and actions under consideration in the RGGI Clean Power Plan proceeding. We would also like to offer the following comments and additional suggestions:

1) Use of biodiesel for power generation – smart fuel switching and renewable energy

   Biodiesel achieves 86 percent savings in greenhouse gas emissions compared to traditional heating oil, and also 70 percent savings compared to natural gas. Biodiesel offers a real opportunity for achieving significant GHG savings in both oil-fired, steam cycle power stations as well as in combined-cycle power plants that currently burn natural gas but which have dual fuel capability.

   The earning of Renewable Energy Credits (RECs) under electric RPS programs, similar to those existing in several New England states, and also under consideration by the Clean Energy Standard proceeding in New York, along with the reduced need by obligated parties for purchase of CO2 allowances under the Regional Greenhouse Gas Initiative (RGGI), currently provides for the economical use of biodiesel for power generation in place of both oil and natural gas.

This interesting scenario has occurred because the current bulk market price for biodiesel is about $1 per gallon after Federal blender tax credits and USEPA RIN values are accounted for. A combined-cycle power plant will produce approximately 20 kWh of electricity per gallon of biodiesel when operating at a fuel-to-electric efficiency of 60 percent. At the prevailing REC value of about 5 cents per kWh in New England, the total REC equivalent value would be approximately $1 per gallon, thus reducing the net, post-REC fuel cost to almost zero. There is thus an immediate opportunity for reducing the cost of power generation to the ratepayer through fuel switching to biodiesel.

There is substantial market availability of gas turbines that are fully rated and warranted for operation with biodiesel. Attached to this letter are an example report and product catalog from General Electric Corporation, which has significant manufacturing operations in Schenectady, New York. The documents indicate widespread availability of high-efficiency, combined cycle power systems that can use biodiesel.

We therefore recommend that the RGGI computer modeling process be expanded to include an analysis of the GHG benefits of switching from both oil and natural gas to biodiesel in existing power plants.

2) Improved Air Quality and Public Health Relating to Oil-fired Power Generation

Biodiesel can be a significant contributor to cleaner and healthier neighborhoods by helping to reduce harmful pollutant emissions from oil-fired, power generation stations. The use of biodiesel instead of, or as a blend with, traditional no. 2 or no. 6 oil, would contribute to improved air quality in nearby communities by reducing emissions of SOx, NOx, PM 2.5 and toxic metals.

Recent testing has also shown that NOx emissions from biodiesel-fired gas turbines can be equal to NOx emission levels from natural gas-fired turbines.

This means that biodiesel can be used in power generation with benefits to public health, while further contributing to reducing the carbon footprint of electricity. This provides an even stronger basis for the smart fuel switching and renewable power generation addressed in the first recommendation above.

3) Development of Renewable Thermal RPS Program

Even though the RGGI and Clean Energy Standard proceedings are focusing on electricity generation, we recommend that RGGI states add a renewable thermal component to future electricity RPS programs. The concept of renewable thermal RPS has been recently established in New Hampshire, is under implementation in several other states across the nation, including Massachusetts and Vermont, and could lead to even broader energy and environmental benefits in New York and other RGGI states.

Introduction to Biodiesel

The Biodiesel Industry is Creating Green Jobs and Making a Positive Contribution to the Economy

Biodiesel can be made from a wide variety of feedstock materials. The fuel is produced in accordance with the D6751 fuel specification set forth by the American Society for Testing of Materials (ASTM International). Yellow grease (used cooking oil) and brown (sewer) grease, as well as animal fats, are economical feedstock materials. Several different types of plants, including soybeans, canola, and pennycress, can also provide the base oil for biodiesel production. Biodiesel offers an especially effective outlet for fat-based waste streams that can cause substantial cost for disposal.

Biodiesel Reduces our Dependence on Foreign Oil

Biodiesel plays a constructive role in expanding domestic refining capacity and reducing our reliance on foreign oil. The 1.4 billion gallons of biodiesel produced in the U.S. each of the past two years displaced an equivalent amount of diesel fuel with a clean-burning, efficient fuel that reduces lifecycle carbon dioxide emissions by as much as 86 percent compared to petroleum diesel fuel and creates about five units of energy for every unit of energy that is required to produce the fuel.

Biodiesel Increases Energy Security and Competition

Biodiesel is produced in geographically diverse, local facilities that are often located in close proximity to end-use markets. Production facilities are not concentrated in any particular region and are thus less vulnerable than many other types of energy resources to widespread disruption during weather disasters.

Increasing Availability in the Marketplace

Biodiesel is a renewable, low-carbon, diesel replacement fuel that is widely accepted in the marketplace. It is the only commercial-scale Advanced Biofuel under the U.S. EPA Renewable Fuels Standard (RFS2) program. Biodiesel is one of the best-tested alternative fuels in the country and the only alternative fuel to meet all of the testing requirements of the 1990 amendments to the Clean Air Act. There are currently more than 150 biodiesel plants in the U.S. with a combined production capacity of over 3 billion gallons.

Biodiesel is primarily marketed as a blending component with conventional diesel fuel and heating oil in concentrations between two (B2) and twenty percent (B20). It is distributed utilizing the existing fuel distribution infrastructure with blending occurring both at fuel terminals and "below the rack" by fuel marketers.

Biodiesel is Good for the Environment

Biodiesel is environmentally safe and is the most viable renewable fuel for transportation, power generation and thermal applications based on its low carbon footprint and favorable air quality characteristics. A full life-cycle analysis performed by U.S. EPA for RFS2 shows that biodiesel reduces greenhouse gas emissions by as much as 86 percent.

Transportation and Engine-driven Power Generation

Biodiesel's overall emissions from internal combustion engines are significantly lower than those of petroleum diesel. Biodiesel emissions have decreased levels of all target polycyclic aromatic hydrocarbons (PAH) and nitrited PAH compounds. These compounds have been identified as potential cancer causing agents. Biodiesel is the only alternative fuel to voluntarily perform Environmental Protection Agency (EPA) Tier I and Tier II testing to quantify emission characteristics and health effects. That study found that B20 biodiesel blends provide significant reductions in total hydrocarbons, carbon monoxide, and total particulate matter. Research also documents the fact that the ozone forming potential of the hydrocarbon emissions of pure biodiesel is nearly 50 percent less than for petroleum fuel. Biodiesel reduces sulfur dioxide emissions to virtually zero and complements Ultra Low Sulfur Diesel (ULSD) fuel as an alternative to sulfur-containing fuels.

Power Generation and Thermal Applications

Biodiesel can be easily blended with ASTM D396 heating oil (including no. 2 through no. 6 heating oils) to displace imported petroleum and improve the operational performance of the fuel. Significant laboratory research and field testing have been performed over the past 10 years to show that biodiesel blends are practical and environmentally-friendly fuels for power generation boilers as well as heating systems in residential, commercial and industrial buildings.

Brookhaven National Laboratory (BNL) has been the leading organization to study the properties and performance of biodiesel blends under wide ranges of operating conditions. BNL testing has shown that biodiesel blends of up to B20 can be used in oil-fired combustion systems without requiring modifications to tanks, burners or other components. Extensive, carefully-monitored field testing has been conducted in several geographical locations to prove the statistical reliability of biodiesel blend use in existing power plants (including at the NYPA Polletti plant) and building facilities throughout the New York City metro area.

Recent testing has shown further that straight biodiesel (B100) can be used in boiler systems of all sizes with only limited modifications to fuel storage systems and burners. The moderate solvency effect of biodiesel has also been shown to be effective in keeping large, oil-fired combustion systems (especially air swirl vanes on no. 6 oil burners) clean and free of carbon deposits, thus contributing to reduced, smoky exhaust emissions during operation.

Biodiesel is inherently an ultra-low sulfur fuel (sulfur content under 10 ppm) and contributes to the environmental goal of reducing PM 2.5 fine particulate emissions especially in densely populated regions. Biodiesel can thus serve as a renewable component in ultra-low sulfur (ULS) heating oil, which is now required in New York, and soon throughout the northeastern United States, for oil-fired combustion systems.

Laboratory and field testing has shown that biodiesel can also help to reduce NOx emissions in power generation and thermal applications. The natural, 10-12 percent oxygen content of the biodiesel molecular structure can reduce fuel-rich pockets and peak temperatures, which are the primary culprits for NOx formation within the flame.

Data published by Brookhaven National Laboratory show a substantial downward trend of SO2 and NOx emissions from oil-fired combustion systems as the fuel source is switched from traditional heating oil to B100 (100 percent) biodiesel. The SO2 emissions are almost entirely eliminated. NOx emissions are reduced by approximately 20 percent compared to traditional heating oil.

Greenhouse Gas Emissions Savings Compared to Traditional Fuel Oil and Natural Gas

Biodiesel can achieve significant savings in greenhouse gas emissions compared to both oil-fired and natural gas-fired combustion systems. A recent study by ICF International has compared the greenhouse gas emissions of biodiesel with conventional fossil fuels and shows that B100 biodiesel can achieve an approximately 70 percent reduction in greenhouse gas emissions compared to natural gas. A B20 bioheat blend will achieve greenhouse gas emission levels equal to natural gas.

Biodiesel has the potential to achieve considerably more greenhouse gas reductions than would be possible through conversion of oil-fired combustion systems to natural gas. Significant greenhouse gas emissions could be achieved by replacing natural gas-fired combustion systems with liquid fuel-fired systems that use biodiesel in heavy concentrations.

The Biodiesel Industry Stimulates Development of New Low Carbon Feedstocks

The feedstock used to produce U.S. biodiesel has become increasingly diversified, with waste products such as animal fat and used restaurant cooking oil (yellow grease) making up a larger portion of feedstock used to produce fuel. The National Renewable Energy Laboratory (NREL) recently conducted an extensive report on the availability of yellow and brown grease. That report concludes that 9.4 pounds of yellow grease and 13 pounds of brown grease are available on an annual, per capita basis throughout the U.S. These figures should be used to more accurately forecast the amount of feedstock available in the Northeast and Mid-Atlantic states. NBB estimates that, nationally, these feedstocks can produce more than 900 million gallons of biodiesel. In addition, a report commissioned by the NBB addresses the use of animal fat, which has also become a major contributor of waste feedstock.

Biodiesel production is currently the most efficient way to convert sustainable biomass into low carbon diesel replacement fuel. As a result, industry demand for economical, low carbon, reliable sources of feedstock oils is stimulating promising public, private, and non-profit sector research on so-called "second generation" feedstocks such as algae. The NBB is participating in this effort by making substantial investments in algae research in collaboration with the Donald Danforth Plant Science Center. It is estimated that for every 100 million gallons of biodiesel produced from algae, 16,455 jobs will be created and $1.461 billion will be added to the national gross domestic product.

Algae's potential as a source of low carbon fuel has been well documented, and a stable, growing biodiesel end-use industry is necessary if the U.S. is to eventually benefit from the commercial scale production of algal-based biofuels. The NBB estimates that for every 100 million gallons of biodiesel produced from algae, 16,455 jobs will be created and $1.461 billion will be added to the GDP.

While soybean oil is considered a co-product rather than a waste feedstock, further discussion of this raw material is merited since farmers in several Northeast and Mid-Atlantic states produce soybeans. In 2007, approximately 39 million bushels of soybeans were grown in the states of Delaware, Maryland, New Jersey, New York, and Pennsylvania. The oil derived from this crop should be considered a sustainable, regional feedstock.

It is important to understand that demand for protein meal used as livestock feed is the primary driver for the planting of soybeans since 80 percent of a soybean is comprised of protein meal. Only 20 percent of the bean is comprised of oil. Historically, the demand for protein meal has driven soy production, resulting in a supply of soybean oil that exceeds the demand for food uses (primarily deep frying foods and baking products). The biodiesel industry helps to make economical use of this excess oil. By creating a market for this excess oil, the price of the protein meal is reduced on a proportional basis.

Co-products Have Important Sustainability Benefits

The co-product relationship between soybean oil and soybean meal delivers environmental benefits because no crop land and no inputs, such as water, nutrients, and energy, are used solely for the production of renewable fuel. The co-product relationship optimizes the beneficial uses from crops that will be planted anyway to satisfy demand for livestock feed and other uses. Growth in biodiesel volumes will come from more efficient utilization of existing wastes and additional vegetable oil produced as a result of yield increases on existing acres, the growing demand for livestock feed, and decreasing demand for high-trans-fat vegetable oils.

The federal RFS2 program explicitly prohibits land conversion for the purpose of producing renewable fuel. U.S. EPA requirements notwithstanding, basic economics dictate that the production of oilseed crops must correlate to the demand for protein meal, and cannot expand solely in response to demand for vegetable oil. It is impossible for oil demand alone to drive the planting of oilseed crops in North America.

Conclusion

The National Biodiesel Board urges the Regional Greenhouse Gas Initiative to recognize and implement a greater role for biodiesel. Biodiesel can achieve environmental sustainability while realizing the economic benefits that come from new job creation and reduced dependence on foreign oil.

Sincerely,

Shelby Neal
Director of State Governmental Affairs

GE Energy

Addressing Gas Turbine Fuel Flexibility

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Addressing Gas Turbine Fuel Flexibility

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*.

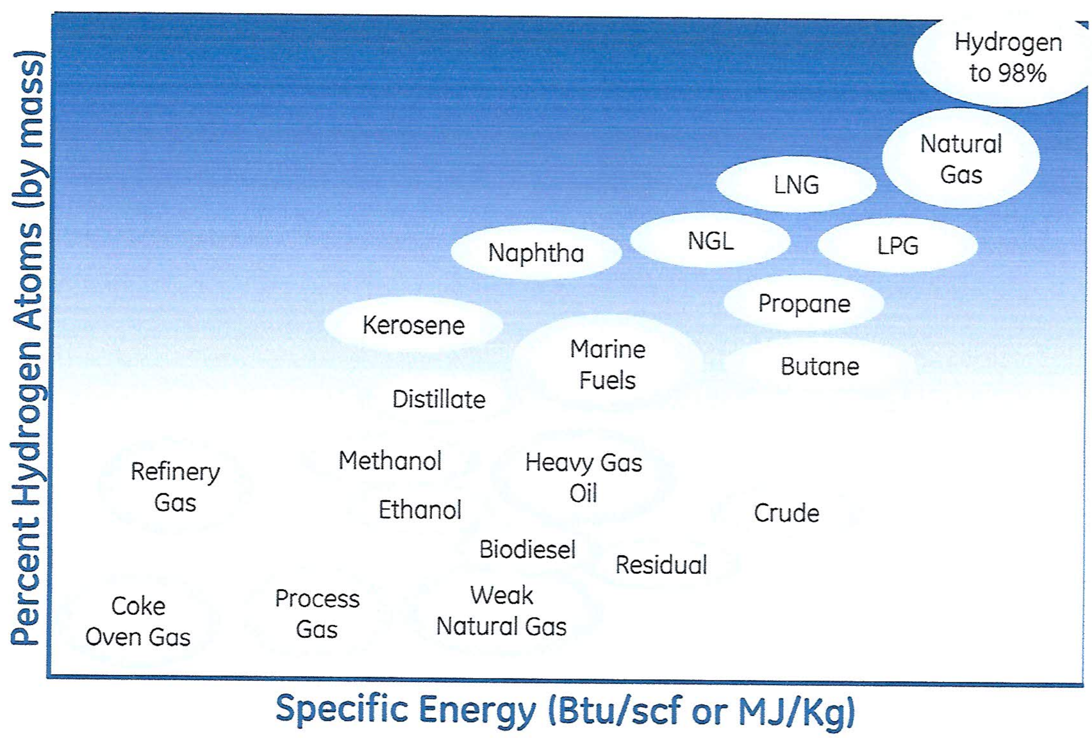

Figure 1. Portfolio of GE's heavy duty gas turbine fuel experience

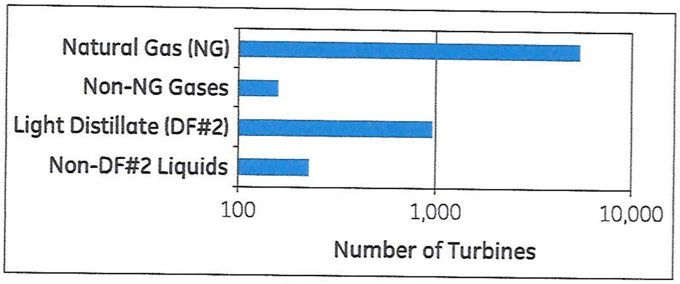

Figure 2. Number of GE combustion turbines by fuel type

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.

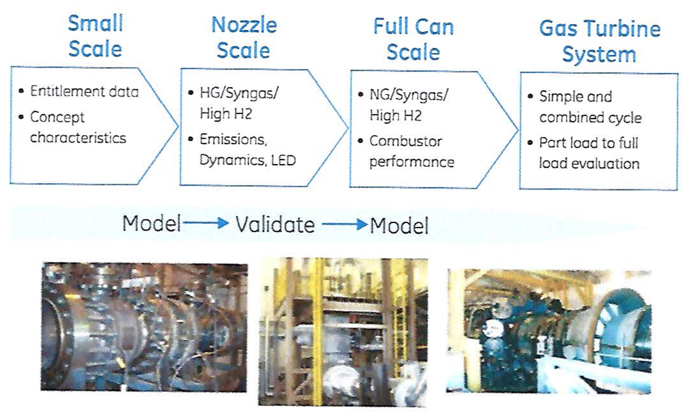

Figure 3. GE's combustion system development process

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).

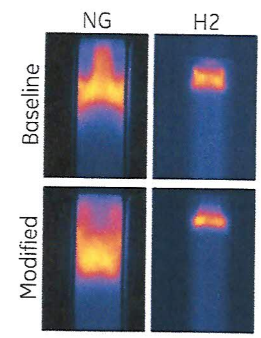

Figure 4. Flame shape visualization

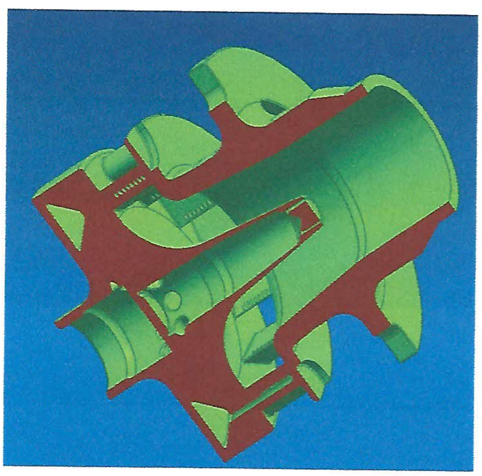

Figure 5. Novel fuel nozzle design

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*.

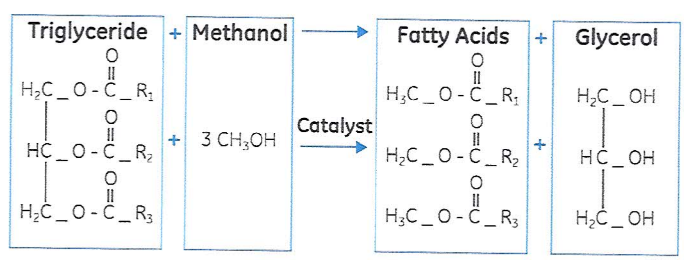

Figure 6. Biodiesel trans-esterification reaction

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.

Figure 7. Biodiesel test platforms

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FUELS AND COMBUSTION

Technology Leadership

With more than 4,500 heavy duty gas turbines installed around the world, GE knows the challenges faced by operators—volatile fuel prices, variability in fuel sources, increasingly strict environmental regulations, and the need for more power generation flexibility. GE continually evolves its proven combustion systems, including the related accessory system hardware, to help customers enhance fuel utilization, reduce fuel costs, and enhance revenues.

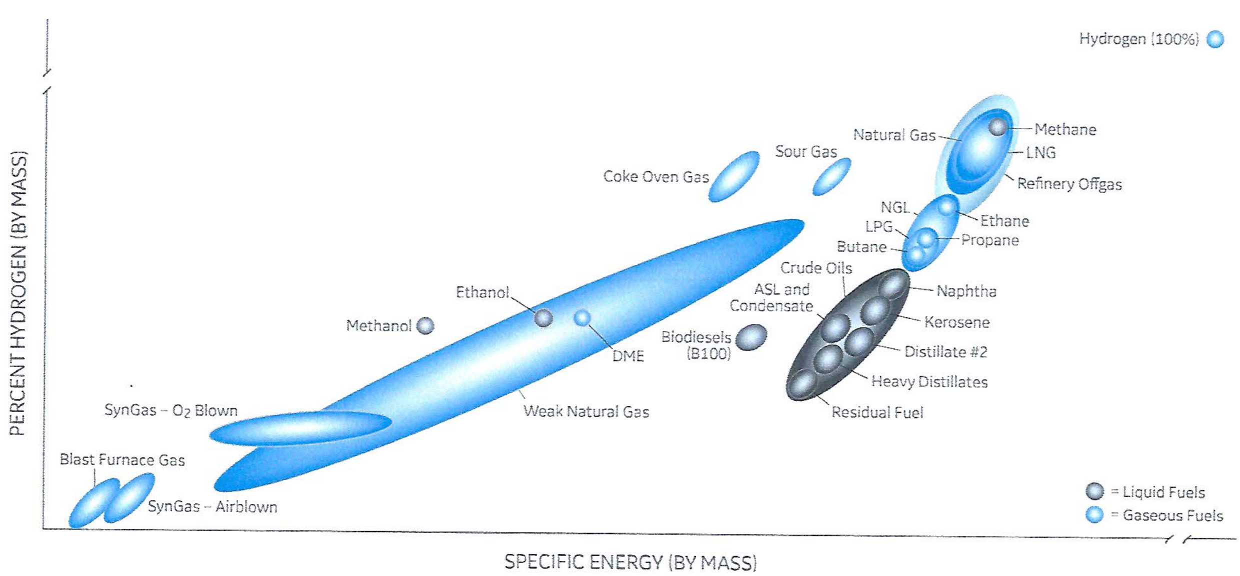
As a result, GE's versatile gas turbines operate on a variety of fuels, including gases with a wide range of heating values, like steel mill gases, syngas, lean methane fuels, natural gas, higher order hydrocarbons, and high hydrogen fuels. They also accommodate liquid fuels, including refined products, such as distillate and naphtha, and a range of ash bearing fuels, including light, medium, and heavy crude oils, as well as HFO. Utilization of a these fuels is important for a wide range of applications, including refineries, petrochemical plants, oil and gas production, and steel mills.

Combustion System Fundamentals

Modern gas turbines that utilize a wide variety of gaseous and liquid fuels must operate within a series of constraints, with NO_X and CO emissions being the most recognizable.

The formation of NO_X compounds is dependent on the temperature of the reaction in the combustor. If fuel and air are allowed to mix in a stoichiometric proportion (a balanced chemical reaction), they will burn in a diffusion flame, similar to the flame of a candle, near the highest possible temperature of the reaction. A consequence of burning fuel at a high flame temperature is the production of a large amount of NO_X. However, if extra air is introduced into the reaction, the resulting lean mixture will burn with a lower flame temperature and the reaction will generate significantly less NO_X. This is known as lean combustion.

In addition to developing combustion technologies that reduce emissions, GE's advanced gas turbine combustion systems mitigate the potential risk of combustion dynamics while simultaneously meeting other key operability requirements. The overall system configuration is a balance of parameters that require a deep domain expertise in fuel and combustion technology.



Gas Turbine Combustion Systems

GE has multiple combustion systems that can be applied across its gas turbine portfolio. Since the 1970s and 80s when GE introduced DLN, development programs have focused on evolutionary systems capable of meeting the extremely low NO_X levels required to meet current and future regulations, while providing customers with a range of operational and fuel flexibility options. GE has DLN combustion systems available for all heavy duty gas turbines:

- The DLN1 and DLN1+ combustion systems are available on B- and E-class gas turbines.
- The DLN2 family of combustion systems (DLN2.5, DLN2.6, DLN2.6+, DLN2.6+AFS) is available on F- and HA-class gas turbines.

DLN1/DLN1+

The DLN1 and DLN1+ combustion systems are proven technology platforms that help power plant operators meet increasingly strict environmental standards, while providing operational and fuel flexibility.

- Installed on more than 870 B- and E-class gas turbines globally.
- More than 28 million operating hours, including more than 730,000 fired hours on the DLN1+ combustion system.
- DLN 1+ system guarantees NO_X emissions of 5 ppm or less for GE's 6B, 7E and 9E gas turbines.
- Highly fuel flexible and capable of operating on a wide variety of gas fuels, including gases with high ethane and propane content, as well as distillate oil and other liquid fuels.
- Available in a gas only or dual fuel configuration.

DLN2

The DLN2 family of combustion systems enables GE's F- and HA-class gas turbines to reduce NO_X emissions while extending outage intervals. GE's DLN2.6+ combustion system, which is the base combustion configuration on the 7F, 9F and HA gas turbines, has been installed globally on more than 75 gas turbines and has accumulated over 1.4 million fired hours.

- Installed on more than 1,150 gas turbines globally.
- Over 26 million operating hours; proven operational experience in providing customers with a multitude of benefits, including increased operational and fuel flexibility, reduced emissions, extended intervals, and higher performance while maintaining life cycle costs.
- Can operate on a wide variety of gas and liquid fuels.
- Available in gas only and dual fuel configurations.

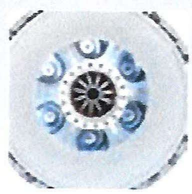
Diffusion Flame

In addition to the DLN combustion systems, GE offers two diffusion flame combustion systems for use in non-traditional fuel applications:

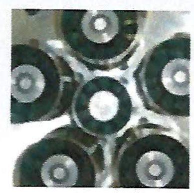
- Single nozzle.
- Multi-nozzle quiet combustors (MNQC).

GE's diffusion flame combustion systems have been installed on more than 1,700 gas turbines, providing robust power generation solutions using a variety of non-traditional fuels for more than 30 years. Applications include refineries, steel mills, petrochemical plants, IGCC power plants, as well as power in a variety of oil and gas settings.

- More than 270 E-class gas turbines configured with the single nozzle combustor operating on HFO.
- Single nozzle and multi-nozzle combustors have been installed on more than 50 B-, E-, and F-class gas turbines in low calorific gas applications, such as syngas, blast furnace gas, coke oven gas, and other process gases. These units have accumulated more than 2.1 million operating hours, with the fleet leader in this application space having more than 100,000 fired hours.



DLN1/DLN1+



DLN2.6+

Diffusion Flame Combustors

Fuel Handling Systems

As a world leader in the development of gas turbine combustion system technology, GE is not only focused on delivering quality system hardware, but also on systems and components for cleaning and conditioning fuel prior to combustion in the gas turbine. With the largest fleet of gas turbines operating on non-traditional fuels, GE's "flexible fuel" solutions outperform comparable technologies in both efficiency and reliability.

- **Heating** – Maintain desired viscosity, keep waxes in solution, and provide performance heating.
- **Cleaning** – Remove harmful contaminants and entrained particulates.
- **Drying** – Remove entrained moisture and condensates.
- **Blending** – Mix fuel streams to precondition alternative fuels for combustion and to maintain consistent Wobbe value.
- **Additives** – Apply to ash-bearing liquid fuels to inhibit or mitigate the corrosive effects of vanadium, or to liquid fuels low in natural lubricity.

Fuel Flexibility

For more than 50 years, GE has developed close collaborative relationships with owners, operators, and fuel suppliers, with the goals of understanding new fuel trends, expanding fuel flex capabilities for existing fuels, qualifying new fuels, and actively investing in new combustion technologies. This legacy of fuel flexibility has led to GE having the broadest experience in the industry to reliably convert the full spectrum of fuels to mechanical, electrical, and thermal energy. GE's model-based gas turbine control systems provide real time, closed-loop tuning of the combustion system, which allows for stable operation even as gaseous fuel energy content varies. Liquid fuels include refined products, such as distillate and naphtha, and a range of ash bearing fuels, including light, medium, and heavy crude oils, as well as HFO.

- GE gas turbines have operated on more than 52 different fuel types.
- Over 7,000,000 operating hours on heavy fuels, more than 25 combined cycle plants operating with crude/residual.
- More than 140 GE gas turbines operating on various alternative gases (refinery off-gases and industrial by-product gases, syngas), and almost 400 GE gas turbines are burning liquids other than diesel oil, such as crude oil, residual fuels, or naphtha.
- More than 50 GE gas turbines operating on low-BTU fuels and these turbines have accumulated more than 2.1 million operating hours, including over 400,000 fired hours on F-class units.
- GE is the only gas turbine manufacturer running F-class machines on Arabian Super Light (ASL) crude oil.

Fuel Flex Matrix

		6B	7E/9E	6F.01	6F.03	7F.04	7F.05	9F (.03/.04/.05)	7HA (.01/.02)	9HA (.01/.02)
GASSES	High C2+ (Ethane, etc.)	●	●	●	●	●	●	●	●	●
	LPG	●	●	●	●	●	●	●	●	●
	Natural Gas	●	●	●	●	●	●	●	●	●
	LNG	●	●	●	●	●	●	●	●	●
	H2 Blends	●	●	●	●	●	●	●	●	●
	Lean Methane (weak NG)	●	●	●	●	●	●	●	●	●
	High H2	●	●	●	●	●	●	●	●	●
	Syngas (O2 blown)	●	●	●	●	●	●	●	●	●
	Blast Furnace Gas (BFG)	●	●		●	●				
	Coke Oven Gas (COG)	●	●		●	●				
	Sour Gas	●	●	●	●	●	●	●	●	●
LIQUIDS	Distillate Oil (#2)	●	●	●	●	●	●	●	●	●
	Naphtha	●	●	●	●	●	●	●	●	●
	Condensate (NGL)	●	●	●	●	●	●	●	●	●
	Biodiesel (GE DO#2 spec)	●	●	●	●	●	●	●	●	●
	Alcohols (i.e. Ethanol)	●	●	●	●	●	●	●	●	●
	Kerosene	●	●	●	●	●	●	●	●	●
	Dimethyl Ether (DME)	●	●	●	●	●	●	●	●	●
	Light Crude Oil (ASL)	●	●	●	●	●	●	●	●	●
	Medium Crude Oil	●	●							
	Heavy Crude Oil	●	●							
	Heavy Fuel Oil (residual)	●	●							