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Outlook for Renewable Liquid Fuels in Dual-Fuel Gas Turbine Combustors

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Abstract: Power generation gas turbines in the United States used 7.42×10^7 MMBtu of liquid fuels in 2022 for a variety of purposes, including both primary fuels and backup fuel for natural gas. This accounted for 0.7% of the total fuel energy used for electricity generation by gas turbines during the same period of time. In a decarbonization scenario where gas turbines are still required to provide flexible, dispatchable electricity, low-carbon liquid fuels will be required to run these engines. In this paper, we discuss the outlook for renewable liquid fuels in the power generation sector. We discuss how these fuels are used, what options are available for low-carbon fuels, and the dual-fuel technologies that need to be considered during this transition. We conclude by discussing necessary research areas for supporting this transition.

Keywords: renewable fuels, dual-fuel combustor, gas turbine engine

1. Introduction

Power generation gas turbines are a critical portion of the electricity grid, producing over one third of the electricity in the United States. These engines produced 1060 TWh of power in 2022 using a range of fuels, including a majority natural gas and distillate fuel oil. Figure 1 shows the level of fuels used per month in gas turbine engines for power generation; fuel energy is shown in MMBtu to directly compare fuels and all data in this analysis is provided by the EIA Power Plant Operators Report for 2022 [1]. Natural gas (NG) is used in significantly higher quantities, which is distillate fuel oil (DFO). DFO usage peaks in the months of December and January due to higher heating and power requirements and the prioritization of natural gas for home heating.

Engines in 519 reporting power plants in the U.S. fleet burn both NG and DFO and are referred to as "dual-fuel" engines. Of the sites that use both fuels, 3.4×10^9 MMBtu of natural gas and 3.76×10^7 MMBtu of distillate fuel oil was used in 2022 for generating electricity. Figure 2 shows a plot of dual-fuel use, where each point is a different power plant. Its location on the x-axis indicates how much DFO it used and its location on the y-axis indicates how much NG it used; the orange line indicates the location of equal fuel energy between the two. Most sites burn significantly more NG than DFO (note the logarithmic axes). However, two results of this analysis are important. First, many plants use significant amounts of DFO, even if they are using less DFO than NG. Second, there are several plants that are using more DFO than NG or nearly equal amounts. Not shown on this plot are the 157 sites that use only DFO, accounting for 1.44×10^7 MMBtu in 2022. It is clear that liquid fuels are an important fuel for the resiliency of the current gas turbine fleet and will continue to be a necessity in the decarbonization of the fleet going forward.

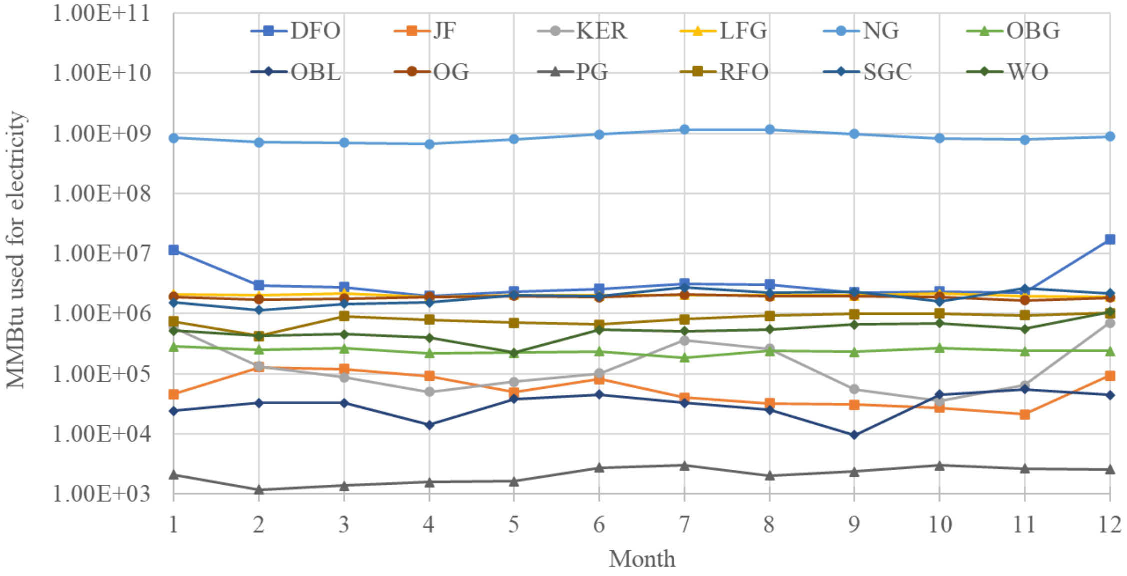

Figure 1. Fuel usage by month in 2022: natural gas (NG), distillate fuel oil (DFO), jet fuel (JF), kerosene (KER), landfill gas (LFG), other biogases (OBG), other bioliquids (OBL), other gases (OG), gaseous propane (PG), residual fuel oil (RFO), synthesis gas (SGC), waste oils (WO).

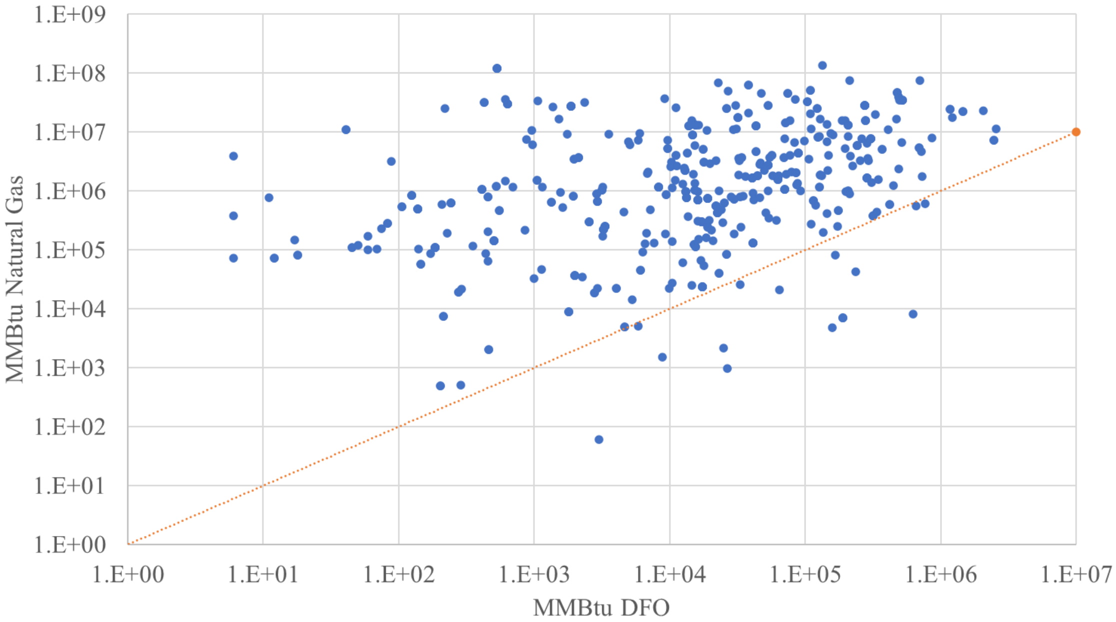

Figure 2. Comparison of fuel energy for NG and DFO in dual-fuel gas turbine engines.

2. Renewable Liquid Fuel Options for Power Generation

Replacing the liquid fuels currently used in power generation with renewable fuels will require significant scaleup of fuel production and, in some cases, infrastructure modifications in fuel-system hardware at power plants. Table 1 shows a comparison of typical lower heating values of potential alternative liquid fuels being considered for power generation, as compared to DFO.

Table 1. Lower heating value (LHV) in [MJ/kg] of potential alternative liquid fuels.

DFO	**Renewable diesel**	**Biodiesel**	**Sustainable aviation fuel**	**Methanol**	**Ethanol**
42.6	42.6	38.1	44.2	19.9	26.7

Distillate fuels, such as renewable diesel fuel and sustainable aviation fuel (SAF) are produced by similar processes and have properties similar to their fossil-derived counterparts [2,3]. For example, renewable diesel meets the ASTM D975 standard for diesel fuel and SAF meets the ASTM D1655 standard for jet fuel. Feedstocks for these fuels include waste oils, cellulosic biomass, and alcohols. Today, the most predominant production method for renewable diesel and SAF is hydroprocessing of esters and fatty acids (HEFA). Other processes include alcohol-to-jet as well as biomass gasification and Fischer-Tropsch (BGFT). The lifecycle carbon intensity depends on the feedstocks and production process [4]. For HEFA diesel, the carbon intensity can range from 18-58 g CO_2e/MJ, for ATJ produced SAF carbon intensity can range from 25-56 g CO_2e/MJ, and initial commercial production of BGFT diesel from Municipal Solid Waste (MSW) is approximately 15 CO_2e/MJ [5]. For reference, natural gas has a typical carbon intensity of around 85 g CO_2e/MJ and unleaded diesel fuel has a carbon intensity just above 100 g CO_2e/MJ [6]. There have been demonstrations with renewable diesel as it is a drop in fuel and meets the original diesel specification. Unlike renewable diesel, which is a hydrocarbon, biodiesel is a methyl ester and as such has significantly different physical properties. It does not meet the ASTM D975 standard and is not a direct drop in alternative to conventional diesel [4].

Ethanol is currently produced in large quantities from bio-derived sources [6] and has been tested in power-generation gas turbine engines [7]. The majority of today's ethanol is produced by fermentation of corn and sugar cane. Carbon intensity typically averages from 50-70 g CO_2e/MJ, but can range from a low of 7 to a high of 86 g CO_2e/MJ [6]. Ethanol can also be produced from the cellulosic biomass, primarily non-food crops and crop residue, with a typical carbon intensity of 22-33 g CO_2e/MJ [4]. In 2010, Petrobras conducted a five-month demonstration running two LM6000s on sugar cane-based ethanol. Operating on ethanol showed no detriment to performance and improved NO_x emissions [8]. Finally, methanol has been proposed as an e-fuel with a significantly higher volumetric energy density than compressed hydrogen and more favorable storage and transportation logistics than gaseous fuels. Methanol can be produced in many ways: gasification and reforming with biomass, renewable electricity electrolysis, reforming natural gas, or gasification of coal. Biomass-based methanol has a carbon intensity of 3-34 g CO_2e/MJ [9]. One notable methanol demonstration was by Siemens Energy in collaboration with RWG where they used methanol in a SGT-A20 gas turbine [10]. The test showed benefits in performance as well as emissions.

3. Dual-Fuel Combustion Technologies

Dual-fuel is a term usually used to describe a combustor that can burn either gaseous fuel or liquid fuel. These combustors have fuel injectors that are designed with separate gaseous and liquid fuel passages. For example, some designs have the liquid fuel cartridge inserted through the centerline of the gas fuel nozzle, as is shown in a generic example in Figure 3. Combustion of liquid fuel for many land-based gas turbine units is generally used as a backup fuel, as NG is typically more cost competitive. These units would then use liquid fuel in case of interruption of gas supply and to provide functions such as black-start capability. However, there are cases where liquid fuel is the main fuel source for the power plant. This scenario often occurs in areas where natural gas supply is limited, such as islands.

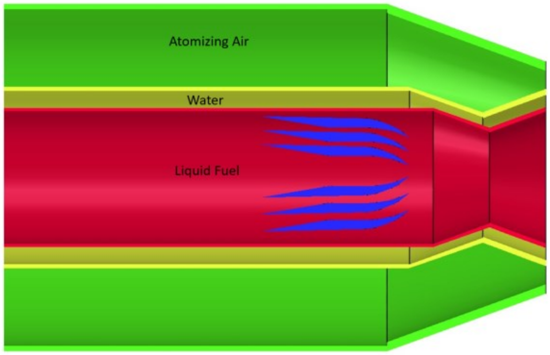

Figure 3. Generic gas turbine liquid fuel injector.

Figure 3 illustrates a typical liquid fuel injector, though there are many other variations in the field. The injector shown uses high liquid pressure to atomize the fuel; some designs also use air-assisted atomization. In some designs, water is also injected into the combustor to decrease the flame temperature reduce thermal NO_x. The blue orifice within the liquid fuel passage is designed to set the flow number of the injector, which is sized to improve atomization at certain operating conditions, usually base-loaded operation. Current liquid fuel designs are focused on burning DFO. If currently installed gas turbines intend to burn renewable fuels, the flow number of their liquid fuel injector may have to change. For renewable diesel, the same hardware could be used as it is a drop-in replacement for DFO. For fuels such as methanol and ethanol, the heat per unit volume is much lower: diesel is ~139,000 Btu/gal, methanol is ~57,000 Btu/gal, and ethanol is ~76,000 Btu/gal. For these fuels, the fuel metering area will need to increase to operate with the same fuel pressure and achieve the same level of atomization at the same load.

Many dual-fuel injectors can be installed from the aft of the combustion casing without removing the combustor from the engine. This design makes them relatively easy to change if a power plant decided to switch to a new renewable liquid fuel. However, there are other considerations besides the combustor itself. Changing the fuel LHV will cause a necessary change in the control logic to command a different fuel flow to match the necessary heat input at a given load. Also, the fuel handling equipment will be impacted. For example, pipe sizes may need to be changed to accommodate the higher flow rate of a lower LHV fuel. Also, both methanol and ethanol have lower lubricity than DFO, which may require additional additives to the fuel for the pumps.

4. Remaining Research Questions

Several remaining research questions must be studied in order to pave the way for renewable liquid fuels in power generation gas turbines. There is a wide range of research questions related to the combustion of these fuels and how they impact key operability metrics, including flameholding, turndown, lean blowoff, combustion instabilities, and emissions. Given the differing physical and chemical properties of the fuels, there could be significant differences in combustion processes. Recent work on SAF [11] has provided important context for these kinds of combustion research questions, but key differences in the geometry and operation of land-based gas turbines require dedicated research for power-generation systems.

Additionally, we must understand the impact of alternative liquid fuels on hardware life. For example, manufacturers have tight restrictions on the amount of alkali metals in their liquid fuel. These are removed from DFO by mixing with water and then filtering since alkali metals are water soluble [12]. However, this process does not work with ethanol or methanol as they have specific densities close to that of water, which makes separation difficult. Another possible impact of fuel is on seal materials, particularly for liquids like methanol and ethanol that do not have any aromatic molecules. Further, there is a significant viscosity difference between DFO and the alcohol fuels, which can impact the life of the liquid fuel pumps without proper additives. The extent to which varying fuel properties will have a long-term impact on the operation and maintenance of the fuel supply system is unknown. Finally, we must consider the storage of these alternative liquid fuels. Ethanol and methanol are more corrosive than diesel or renewable diesel, which could lead to changes in tank material for long term storage. The shelf life of these fuels is also a question. Fuel stabilizers can be added to diesel to extend its shelf life, but remaining research needs to be done to determine the shelf life for renewable liquid fuels and if fuel stabilizers can extend this life.

5. Acknowledgements

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