EXECUTIVE SUMMARY

LOW-CARBON FUEL PATHWAYS FOR GAS TURBINE APPLICATIONS

The abatement of fossil fuel emissions in existing end-use applications will be critical for achieving net zero emissions. For gas turbines (GTs), decarbonization options include the utilization of carbon capture or the replacement of fossil fuel use with low-carbon fuels. This report focuses on low-carbon fuel conversion pathways for existing gas turbines within the scope of land, marine, and aviation applications. The report introduces promising options and pathways for the adaptation of the existing GT fleets from fossil fuels to low-carbon fuels and defines the combustion and emissions-related issues and the R&D needed for these transitions to occur.

Key insights from the full report include:

- The dominant non-aviation industries using GTs are industrial (defined as off-grid power generation) utilities generating electricity, oil and gas, industrial mechanical drive, and generated electricity by independent power producers (IPP). The marine applications make up a very small part of the market with less than 100 GTs in only the 20- to 100-MW size range, dominated by GE LM2500 and LM6000 models. The utility and IPP power generation sectors dominate all other industries with 82% of overall capacity, and the GT fleet between 100 and 300 MW makes up 54% of this capacity. This GT fleet size range is primarily made up of the F-class models that dominate the 50- and 60-Hz 2×1 GTCC power plant configurations.
- The F-class, 2×1 GTCC power plants located throughout the world represent the greatest opportunity within the overall GT industry to provide decarbonization. This is because of the increased demand to replace large, centralized coal power plants and provide power reserve for the rapidly increasing installment of renewable energy assets.
- Currently the aviation industry is striving to overcome the effects of the coronavirus disease (COVID-19) pandemic that has taken a heavy toll on air travel and aerospace manufacturing. Prior to the pandemic, the aviation industry was already facing challenges to reduce carbon emissions and get in line with multiple international goals to achieve net-zero carbon by 2050. In 2009, the aviation community set an ambitious target that included carbon neutral growth by 2020 and cutting the net carbon emissions in half from 2005 levels by 2050. Improving efficiency and retiring aging aircraft are currently the easy options. Using alternative propulsion systems such as electric batteries, fuel cells, or burning low-carbon fuels such as hydrogen, ammonia and liquid biodiesel is possible, especially for smaller aircraft. However, using a fully electric aircraft with more than 100 passengers is unlikely within the next 30 years.
- Hydrogen has historically been burned in GTs but is usually diluted with other fuel constituents. The highest concentrations of H_2 combustion in GT fuels have typically been opportunity fuels, such as refinery fuel gas, coke oven gas, and H_2 from steam reforming in petrochemical plants. These engines typically operate at factories to produce steam and/or power for the factory. Additionally, syngas with elevated H_2 concentrations (typically up to roughly 30%) is used as a GT fuel.
- Ammonia as a fuel for GTs is in earlier stages of development, and all potential issues are not fully understood. In the shorter term, this may limit its use. However, the advantages of deploying ammonia, such as relative ease of transport and storage (addressed in other LCRI technical subcommittees), may make ammonia utilization attractive as a longer-term solution. Combustion issues associated with ammonia that would need to be addressed include fuel NOx conversion as well as ammonia's lower limits of flammability.

- Bio-derived fuels such as biodiesel offer a carbon-neutral option for liquid fuels. These fuels recycle carbon from the atmosphere. This is in contrast to fossil fuels, which take carbon that was sequestered under the ground and introduce it into the atmosphere. Development of bio-derived fuels is driven largely by the aviation industry. It is important to note that some fuels are "drop-in" replacements for conventional liquid fuels, while others may require hardware modifications.
- Renewable natural gas is also a low-carbon gaseous fuel option but will not be considered in this report since it is a "drop-in" fuel with properties like natural gas.
- Using alternative low-carbon fuels for the different gas turbines classifications and industrial applications will require unique design modifications. These design modifications will need to be applied to frame, aeroderivative, industrial, micro-turbines, and aviation GT combustor configurations. The combustion systems are different configurations (can, can-annular, annular, silo) depending on the application and duty cycle requirements.
- The GT industry needs dry low NOx emissions (DLN) combustion designs to eliminate the requirement of purified water or steam for injection into the GT combustors for NOx control. The existing DLN GT fleet can burn only up to 30–50% hydrogen. The non-premixed GT fleet can burn up to 100% hydrogen; however, these combustor designs require water or steam injection for NOx control.
- Moving forward, the GT industry needs breakthroughs in DLN combustion technologies that can burn 100% hydrogen and/or ammonia and produce NOx and CO emissions similar to existing natural gas burning designs. A public domain database of NOx and CO emissions as a function of low-carbon fuel blends with natural gas, especially blends with hydrogen or ammonia, is needed to assist in confirming and solidifying the research path toward the development of these advanced GT combustor designs. The potential to retrofit existing GTs with these advanced combustion systems also needs to be investigated.
- Operability, durability, and reliability of these newly developed combustors and hot section parts need to be confirmed for GTs burning low-carbon fuels. Implications to the GT during startup, ramping, and shutdown on 100% low-carbon fuels need to be explored.

The report also includes a general description of existing GT types within the power generation and industrial sectors. A summary of combustion, heat transfer, and emissions-related system components is also included. However, the level of detail has been limited to not go beyond the primary objectives. Numerous references are provided for additional detail covering design, operation, fuel properties, and emissions.

The Low-Carbon Resources Initiative

This executive summary was published under the Low-Carbon Resources Initiative (LCRI), a joint effort of the Electric Power Research Institute (EPRI) and Gas Technology Institute (GTI) addressing the need to accelerate development and deployment of low- and zero-carbon energy technologies. The LCRI is targeting advances in the production, distribution, and application of low-carbon energy carriers and the cross-cutting technologies that enable their integration at scale. These energy carriers, which include hydrogen, ammonia, synthetic fuels, and biofuels, are needed to enable affordable pathways to economy-wide decarbonization by mid-century. For more information, visit www.LowCarbonLCRI.com.

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3002023579 February 2022

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