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# Sustainable Methanol for Aeroderivative Industrial Gas Turbines: Emissions Reductions and Performance Enhancements

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**Abstract.** Transitioning to net-zero necessitates innovative approaches to reduce emissions and enhance gas turbine performance. This paper reports three methanol demonstrations on Siemens Energy's SGT-A05, SGT-A20, and SGT-A35 engines. Test objectives included quantifying emissions, power, and efficiency changes and proving fuel system and combustor upgrade methodologies. The SGT-A20 test validated the design methodologies and upgrades, including the increased fuel system capacity, methanol capable fire and gas detection systems, and modified fuel injectors. The SGT-A35 test scaled the approach to higher power output and turbine temperatures in the same facility, while additive manufacturing accelerated prototyping and final hardware delivery. The SGT-A05 ran in a production genset on 100% methanol (M100) and an 80% - 20% methanol-water blend (M80) which targeted further NOx reduction, proving methanol's ability as a diesel alternative. Following minor control changes to address methanol's low volumetric heating value, all engines executed starts, shutdowns, and fast transients fault-free. Results were consistent across tests: at constant power NOx reduced ~80% on M100 and ~90% on M80, and carbon dioxide was ~10% lower than kerosene baselines. These findings demonstrate methanol's viability as a sustainable gas turbine fuel and provide actionable design, test, and operational guidance to accelerate deployment in support of the energy transition.

## Nomenclature

| | |
|---|---|
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| DLE | Dry Low Emissions |
| ECS | Engine Control System |
| EPA | Environmental Protection Agency |
| FID | Flame Ionization Detector |
| FTIR | Fourier Transform Infrared Spectroscopy |
| GHG | Greenhouse Gas |
| HAZOP | Hazard and Operability Study |
| ISO | International Organisation for Standardisation |
| IR | Infrared |
| LHV | Lower Heating Value |
| LNG | Liquefied Natural Gas |
| MCERTS | Monitoring Certification Scheme |
| NDIR | Non-Dispersive Infrared |
| NOx | Nitrogen Oxides |
| NZTC | Net Zero Technology Centre |
| PID | Proportional Integral Derivative |
| PPE | Personal Protective Equipment |
| SOx | Sulphur Oxides |
| TOT | Turbine Outlet Temperature |
| UHC | Unburnt Hydrocarbon |
| WRI | World Resources Institute |
| WBCSD | World Business Council for Sustainable Development |

## 1 Introduction

Siemens Energy in collaboration with The Net Zero Technology Centre (NZTC), RWG (Repair & Overhauls) Limited, and Proman, successfully completed three demonstration tests with methanol on the SGT-A05, SGT-A20, and SGT-A35 gas turbines. This was achieved through developing combustion and fuel delivery systems to take advantage of methanol's potential to reduce NOx, CO, and $CO_2$ emissions. The reduction in $CO_2$ and NOx emissions highlight the potential of green methanol's contribution to achieving net-zero pathways. The findings underscore the importance of continued research and development in alternative fuels to meet the growing demand for sustainable energy solutions.

### 1.1 Methanol background

The increasing urgency to decarbonize offshore power generation has prompted a revaluation of alternative fuels, with green methanol ($CH_3OH$) emerging as a particularly promising candidate. The "Fuel of the Future" report, published by the Net Zero Technology Centre (NZTC) with support from Siemens Energy [1], provided a comprehensive assessment of methanol's potential as a transition fuel. Methanol's recent emergence as an alternative fuel is driven by its favourable combustion characteristics, compatibility

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with existing infrastructure, and potential for low-carbon synthesis.

Environmentally, methanol is a cleaner-burning alternative to diesel and other conventional fuels, helping power generators meet increasingly strict global emission standards. It can be produced via several pathways, each defined by the origin of its feedstocks and associated carbon intensity, as explained in further details in a related paper [2]. Methanol can be produced through renewable and low-carbon methods, offering a viable path to carbon neutrality.

Since manufacturing grey methanol has a high associated carbon footprint, green methanol, including e-methanol and bio-methanol, can enable further $CO_2$ reduction and is therefore likely to become more attractive in the future when availability increases. Lifecycle emissions analysis reveals that e-methanol can achieve up to a 74% reduction in greenhouse gas (GHG) emissions compared to natural gas [1], particularly when produced using renewable electricity and carbon dioxide ($CO_2$) captured from the air or industrial exhaust stacks. Its use can financially facilitate complying with carbon pricing and air quality regulations. Additionally, bio-methanol has been demonstrated to reduce $CO_2$ footprint as described in a related paper [2]. Siemens Energy gas turbines can utilise methanol regardless of the production route, given that specifications are met, which highlights its great potential. For the demonstration tests discussed in this paper, both green and grey methanol were used.

Methanol's combustion properties offer several advantages over conventional fossil fuels; it has a high-octane rating, which supports efficient combustion and reduces engine knock, and its lower flame temperature results in significantly reduced nitrogen oxide (NOx) emissions, a critical factor in mitigating air pollution, as shown in Tab. 1 below. Furthermore, methanol's lean flammability limit enables better fuel economy.

**Table 1.** Fuel Properties vs Conventional Fuels [1, 3, 4]

| Fuel Type | Diesel | Kerosene | Methanol | e-Methanol |
|---|---|---|---|---|
| LHV (kJ/kg) | 44.3 | 43.5 | 19.9 | 19.9 |
| Lifecycle $CO_2$ (kg/L) | 2.7 | 3.1 | 1.6 | ~ 0.2 |
| NOx | High | High | Low | Low |
| Adiabatic Flame Temp (K) | 2268 | 2338 | 2150 | 2150 |
| Heat Of Vapourisation (kJ/kg) | 256 | 251 | 1100 | 1100 |

As detailed in [5] one important prerequisite when using an alternative fuel is availability and potential to be widely deployed for industrial gas turbines. One of methanol's most compelling attributes is its compatibility with existing infrastructure. The offshore oil and gas industry is already familiar with methanol handling, primarily for hydrate inhibition, and has established protocols for its safe transport and storage. Regulatory frameworks such as IMO OSV Chemical Code [1] and MARPOL [6] provide clear guidance on methanol's carriage and use.

Siemens Energy SGT-A05, -A20, and -A35 engines can be retrofitted for methanol operation with relatively minor modifications, such as burner upgrades and control system adjustments. This compatibility enables rapid deployment without the need for wholesale equipment replacement, reducing capital expenditure and accelerating decarbonization timelines.

## 1.2 Market and Opportunities

Methanol is proving to be a cost-effective fuel for power generation, especially in regions with high and volatile electricity prices, due to domestic energy poverty and subsequent need to import energy from abroad. Methanol's pricing can be linked to oil or natural gas and structured with caps, floors, and flexible volumes, which helps keep costs competitive and predictable. Retrofitting existing power plants to use methanol is far less expensive than converting them to Liquefied Natural Gas (LNG), which requires costly regasification facilities and new infrastructure, which can become expensive stranded assets if underutilized over the asset lifetime [7]. This poses a large risk considering energy transition targets including growing electrification through renewables, especially for regions with limited financial strength. Methanol's compatibility with current fuel oil systems and ease of installation of new liquid fuel infrastructure proves beneficial as it shortens implementation time and reduces upfront infrastructure costs, enabling a rapid and affordable pathway for power generation plants of all sizes, complementary to increasing renewables penetration and energy transition strategies.

From an energy security perspective, methanol benefits from a well-established global supply chain, including widespread production, shipping capacity, and terminal infrastructure. This ensures reliable access for power plant operators. As countries aim to diversify their energy sources and reduce dependence on geopolitically sensitive fuels, methanol presents a stable alternative. Its liquid state, favourable energy density, and established logistics chain make it particularly well-suited for regions where electrification is challenging or where hydrogen infrastructure is underdeveloped. Methanol has shown its versatility in engines, turbines, and boilers, requiring only minor equipment modifications for effective use.

Methanol's advantages in cost efficiency, environmental performance, and energy security make it a strong candidate for power generation. Its growing adoption is supported by large-scale commercial projects and increasing commitments from equipment manufacturers across various sectors, reinforcing its technical and economic viability. This paper discusses Siemens Energy's contribution to this growing adoption, through these demonstrations of technical feasibility.

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## 2 Test preparations

### 2.1 RWG Gas Turbine Test Facility

This section discusses the test facility upgrades required to conduct the SGT-A20 and SGT-A35 methanol tests. Note that the setup is similar for both tests and is already covered in detail in [2] and is only briefly described here for convenience.

Both tests took place at the RWG gas turbine test facility in Aberdeen, UK, which normally conducts post-overhaul/repair product acceptance tests for both SGT-A20 and SGT-A35 engines. Fig 1 below shows both test engines in their installed configurations.

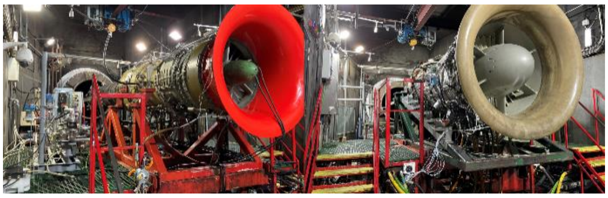

**Fig 1**. SGT-A20 (left) and SGT-A35 (right) at the RWG Aberdeen test facility. [Adapted from [2] with permission from Siemens Energy Copyright © 2024].

This facility is a liquid fuel facility using Jet-A1 (kerosene) and is configured to test these engines in “gas-generator” mode. In this mode, the engines are tested without their power turbine assemblies, with the exhaust section being replaced by calibrated jet pipes that allow performance declarations to be made. To conduct the methanol tests, several additions needed to be made to the test facility to be able to deliver the fuel to the engine, as well as additions to maintain operational health and safety standards whilst operating on methanol.

External to the test cell, a methanol tanker and a high-pressure pump skid were installed, as shown in Fig 2 below. The methanol tanker was a baffled, stainless steel storage tank with a 30,000 L capacity. The tanker incorporated a nitrogen blanketing system to limit the release of methanol vapours, prevent moisture absorption, and to provide positive pressure upstream of the high-pressure pump skid. The tank outlet pipe is connected to the high-pressure pump skid. This skid consists of an electrically driven pump, bypass valves and pressure relief valves. The pump was sized to accommodate twice the nominal high-power fuel flow of the SGT-A35, to account for the lower LHV of methanol. A bypass valve downstream of the pump allowed the pump and the fuel control skid downstream of the pump to operate within its ideal operating range, whilst delivering both the lower and higher required fuel flows of the SGT-A20 and SGT-A35, respectively.


**Fig 2.** High pressure liquid fuel pump skid (left) and methanol tanker (right). [Reproduced from [2] with permission from Siemens Energy Copyright © 2024].

Inside the test cell, a fuel control skid connects the outlet of the pump skid to the engine. This control skid consists of a 3-way electrically actuated control valve feeding the engine and a bypass line that circulates the methanol back to fuel tank. Downstream of the 3-way valve is a double isolation shut-off valve followed by a check-valve just prior to a tee that meets with the kerosene skid feed line upstream of the final engine inlet interface.

Finally, due to the differences in the volatility and flammability characteristics between methanol and kerosene, some changes were made to the fire and gas system, as well as in the Personal Protective Equipment (PPE) and operational requirements from personnel. As methanol flames do not burn within the visible range, Infrared (IR) fire and vapour detection cameras were installed to be able to monitor for methanol flames and leaks. For all personnel working near the fuel skid, gloves, coveralls, eye protection, respirators and methanol detectors were required to be worn. All safety measures were borne from a Hazard and Operability Study (HAZOP) assessment conducted on the facility operating with methanol fuel.

### 2.2 Centrax Package

This section discusses the Centrax Packaging Generator Set (PGS) Test Facility used to conduct the SGT-A05 methanol tests, shown in Fig 3 below.


**Fig 3.** Centrax PGS Test Facility (left) and methanol tanker (right).

To evaluate methanol as a viable fuel, testing was conducted using a pre-owned Centrax CXA05 gas turbine package, powered by an SGT-A05 engine, shown in Fig 4.

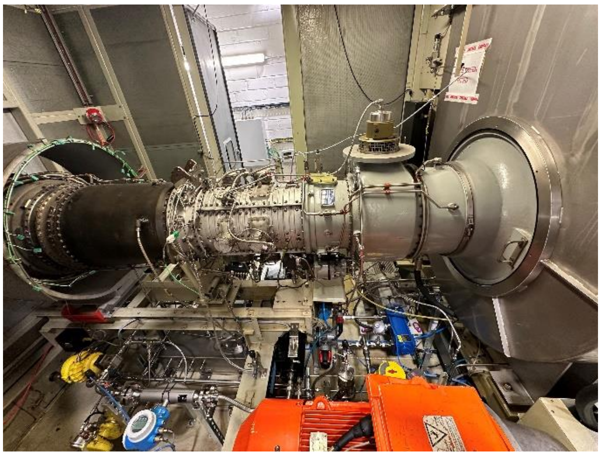

**Fig 4.** SGT-A05 in CXA05 genset package.

For the methanol trials, the original dual-fuel (natural gas and diesel) system was removed and replaced with a custom methanol fuel skid. This included a methanol compliant high-pressure pump, precision fuel metering valve (Fig 5), and associated control valves to ensure accurate delivery of either M100 (neat methanol) or M80 (methanol blended with demineralised water) to the turbine. Two separate fuel tankers were employed during testing: one containing M100 and the other pre-mixed with M80. All test procedures were repeated for both fuel types to ensure consistency and comparative analysis.

**Fig 5.** Methanol HP Pump (left) and fuel metering valve (right).

### 2.3 SGT-A20 and SGT-A35 Methanol Injectors

This section discusses the development of injectors for both the SGT-A20 and SGT-A35, specifically sized to operate using methanol up to full power.

Due to the lower LHV of methanol relative to kerosene (the chosen baseline fuel), a key requirement for an injector that can operate using methanol at the same power conditions, is to increase the flow capability of the injector. To achieve this, the flow orifices within the injector need to be increased to provide approximately twice the amount of flow for the same fuel system pressure drop, thus maintaining fuel system pressure at power. However, to ensure interchangeability with the standard injector, the changes in flow orifice sizes would need to remain within the part envelope of the standard injector. Finally, as the intent of the tests was to use the modified injector for both methanol and baseline kerosene operation, the exit profile of the flow orifices was required to ensure that a workable compromise in spray profiles would be obtained when using either fuel.

For the SGT-A20, the increased flow area was achieved by increasing the number of injector holes at the injector head. This increased the effective flow area by 95%, which was a significant improvement, despite being slightly short on the target value based on the LHV ratio. Furthermore, the injector exit holes were profiled to align the spray profiles of kerosene and methanol. This was validated through spray testing conducted at the injector manufacturer as well as at the University College London spray testing facility [8] as shown in Fig 6.

Similarly, for the SGT-A35, the increased flow area of the injector was also achieved by increasing the number of holes at the injector head, which increased the effective flow area by 110%. However, the key difference from the SGT-A20 injector, is that the SGT-A35 injector head was additively manufactured. This allowed more variations in design of the exit profiles to be spray tested, as shown in Fig 7, and ultimately chosen for the test. Consequently, the flow area target was surpassed, and further optimisations were able to be conducted to consider not just spray characteristics, but also mechanical integrity characteristics. All these optimisations were able to be conducted for the additively manufactured SGT-A35 injector within 12 months, whilst the conventionally manufactured SGT-A20 injector took a similar amount of time for only one design iteration.

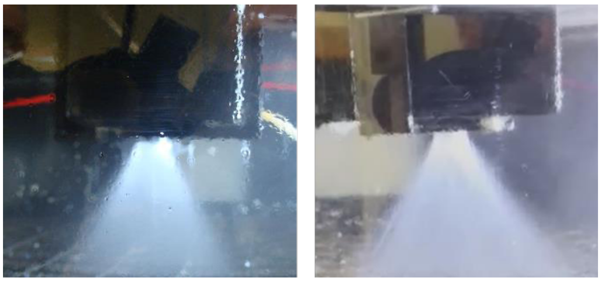

**Fig 6.** SGT-A20 spray characteristics. Standard diesel dual fuel injector (left) and methanol increased capacity fuel injector (right). [Reproduced from [2] with permission from Siemens Energy Copyright © 2024].

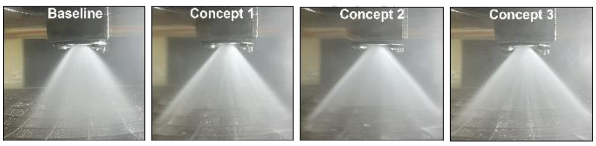


**Fig 7.** Different spray behavior based on the injector design for given liquid and air mass flows.

### 2.4 SGT-A05 Fuel Skid and Combustion Liner

This section discusses any equipment changes required for methanol fuel testing on the SGT-A05 engine.

The SGT-A05 engine and fuel skid required only minor changes for successful operation on methanol fuel, including: a new fuel pump with methanol compatible seals designed for higher flow rates, new methanol compatible pressure regulating and pressure relief valves, a new fuel metering valve designed for higher flow rates, and a new fuel pump motor.

Testing was conducted using the existing combustion liners and dual-entry liquid fuel nozzles. Standard combustion liners were used for the bulk of the testing, however a thermal paint run was conducted using a painted liner, as shown in Fig 8. The nozzles were limited in flow capacity, which constrained engine performance, which is addressed later in Sec. 6.

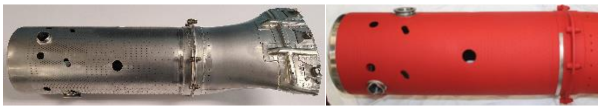

**Fig 8.** Combustion liners, with (left) and without (right) thermal paint.

## 3 Engine tests

### 3.1 SGT-A20 & SGT-A35 Engine Testing

For both the SGT-A20 and SGT-A35 tests, a relatively similar test outline was used. As summarized in Tab. 2 and Tab. 3 for the SGT-A20 and -A35 respectively, the test manoeuvres consisted of performance and emissions curves, transient acceleration and deceleration tests, and ignition mapping, as well as fuel changeover tests between kerosene and methanol.

For the SGT-A20 test, only kerosene was used with the standard injector, and no changeover test was conducted. For the enlarged injector, both kerosene and methanol tests were conducted. Whilst fuel changeover was not explicitly tested for this injector and engine, changeovers were successfully conducted at lower power to purge the fuel lanes.

For the SGT-A35 test, whilst mostly only kerosene was used for the standard injector, a portion of the performance curve was done using methanol to understand the peak fuel pressure in the fuel system without using the enlarged injector.

Similarly to the SGT-A20 test, for the enlarged injector, both kerosene and methanol tests were conducted. However, in contrast, for the SGT-A35 test, an explicit fuel changeover test was conducted to demonstrate changeover capability between kerosene and methanol at a variety of power levels.

**Table 2.** Test matrix for SGT-A20 test indicating which test manoeuvres were done for each fuel injector. Y =Yes. N = No. Y* = full suite planned but not completed. N* = no test planned but completed due to other requirements.

| | Engine | SGT-A20 | | | |
|---|---|---|---|---|---|
| | Injector | Standard | | Enlarged | |
| | Fuel | Kerosene | Methanol | Kerosene | Methanol |
| Test Manoeuvre | Performance and Emissions Curve | Y | N | Y | Y |
| | Acceleration and Deceleration Test | Y | N | Y | Y |
| | Ignition Mapping | Y | N | Y | Y |
| | Fuel Changeover | N | | N* | |

**Table 3.** Test matrix for SGT-A35 test indicating which test manoeuvres were done for each fuel injector. Y =Yes. N = No. Y* = full suite planned but not completed. N* = no test planned but completed due to other requirements.

| | Engine | SGT-A35 | | | |
|---|---|---|---|---|---|
| | Injector | Standard | | Enlarged | |
| | Fuel | Kerosene | Methanol | Kerosene | Methanol |
| Test Manoeuvre | Performance and Emissions Curve | Y | Y* | Y | Y |
| | Acceleration and Deceleration Test | Y | N | Y | Y |
| | Ignition Mapping | Y | N | Y | Y |
| | Fuel Changeover | N | | Y | |

For both tests, exhaust gas emissions were measured using an MCERTS accredited third-party contractor, whose sampling and measurement methodologies complied with ISO standards, specifically EPA methods, ISO 11042-1, and BS2742. Emissions species measured included NOx, CO, $CO_2$, SOx, UHC and formaldehyde. The measurement methods used were: chemiluminescence cells for Nox, NDIR for SOx, CO, and $CO_2$, paramagnetism for $O_2$, Fast FID for UHC, and FTIR for formaldehyde.

Finally, for the SGT-A35 tests, instead of using the standard single-point exhaust temperature probes, several probes were replaced with multi-depth exhaust temperature probes that measured the radial distribution of temperature at the exit of the final turbine stage. This gave an indication of how the combustor exit temperature profile changed with both the change in injector and fuel type.

### 3.2 SGT-A05 Engine Testing

The test plan for the SGT-A05 operating on methanol fuel included light-off tuning, performance and emissions testing, and stability testing in the form of step load acceptance and rejection. Testing was first conducted on M100 fuel and then repeated with M80. In both cases, the engine power was limited by the fuel nozzle flow restrictions, with a more pronounced impact when using preblended M80 fuel (see Sec. 6).

Testing began with light-off tuning, during which control parameters were adjusted to achieve stable and consistent ignition. Engine starts were noticeably quieter than those on diesel or natural gas. Once the Engine Control System (ECS) parameters were optimized for methanol, the engine consistently achieved reliable starts throughout the remainder of the test campaign.

Following start tuning, performance and emissions testing was conducted. Engine load was gradually increased to full power, with each power point held until emissions stabilized. Performance and emissions data were collected for both M100 and M80 fuels. Formaldehyde emissions were specifically measured during M80 operation.

Subsequent step-load acceptance and rejection testing evaluated engine stability during load transitions. Load was step-increased from 0% to 20% and then reduced back to 0%. Proportional-Integral-Derivative (PID) gains were adjusted as needed to maintain acceptable engine speed deviations during load changes.

This process was repeated for 40%, 60%, and 80% load levels. A full 0–100% step-load acceptance test could not be performed due to nozzle flow limitations (see Sec. 6), however the engine successfully completed a full-load rejection without triggering an overspeed condition.

NO, $NO_2$, $O_2$, and $CO_2$ emissions were measured using electrochemical sensors in a calibrated Testo 350 system, which sampled flue gas from the engine's exhaust duct. Emissions data were collected during operation on both M100 and M80 fuels. Unburned hydrocarbons and formaldehyde emissions were measured during M80 operation using Dräger gas detection tubes. These tubes rely on a colorimetric chemical reaction to quantify gas concentrations.

$CO_2$ emissions measurement equipment was unavailable during M100 testing. For M100 operation, $CO_2$ emissions can be estimated by assuming complete combustion, which is standard industry practice, per WRI/WBCSD GHG Protocol, and provides a slightly conservative estimate. The molar ratio of methanol to $CO_2$ is 1:1. Given methanol's molecular weight of 32.04 g/mol, this translates to approximately 1.374 kg of $CO_2$ per kilogram of methanol combusted.

# 4 Test Results

## 4.1 SGT-A20 & SGT-A35 Test Results

The efficiency results are quantified in Fig 9. This shows that operating on methanol offers a significant decrease in exhaust gas temperature at the same power condition. This implies overall improved cycle efficiency and theoretically shows scope for either improved life at-a-power, or higher power capabilities at-a-life. Note that Fig 9 - Fig 12 below are normalised by the kerosene full power value for each SGT-A20 and SGT-A35 engine separately, shown as a relative difference.

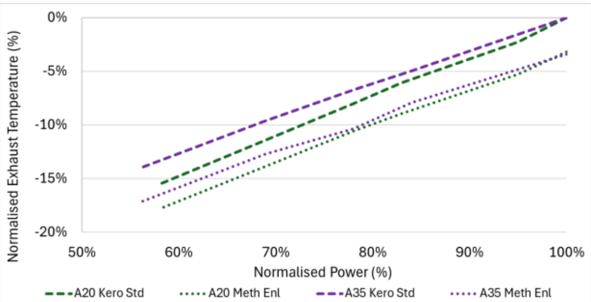


**Fig 9.** Exhaust temperature results across power, for the SGT-A20 and SGT-A35 when operating on kerosene with the standard burner and on methanol with the enlarged burner.

As shown in Fig 10, $CO_2$ measurements show an overall decrease across power range when operating on methanol. This result is expected, as the lower carbon content of methanol as well as the improved combustion efficiency from the oxygen content push $CO_2$ to lower values.

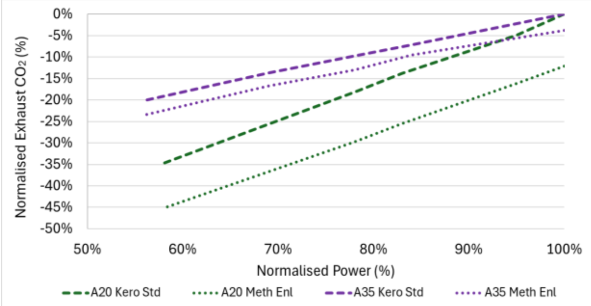


**Fig 10.** Exhaust CO2 results across power, for the SGT-A20 and SGT-A35 (orange) when operating on kerosene with the standard burner and on methanol with the enlarged burner.

This outcome is like the CO measurements shown in Fig 11, which also shows an overall decrease across the power range.

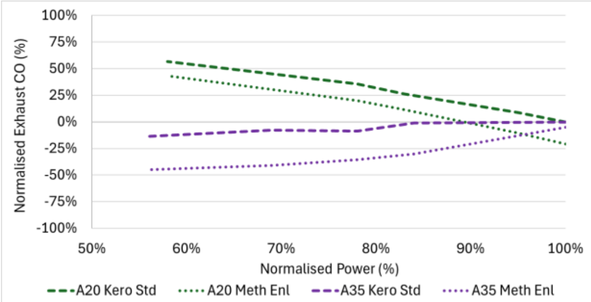


**Fig 11.** Exhaust CO results across power, for the SGT-A20 and SGT-A35 when operating on kerosene with the standard burner and on methanol with the enlarged burner.

Finally, Fig 12 shows that the NOx emissions when operating on methanol are approximately 80% lower than the corresponding kerosene operating point. This is consistent with the lower operating temperatures shown in Fig 9, which discourages NOx generation.

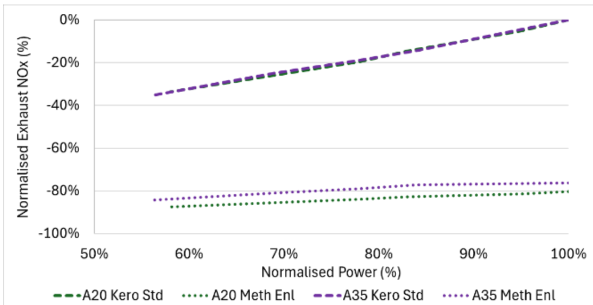


**Fig 12.** Exhaust NOx results across power, for the SGT-A20 and SGT-A35 when operating on kerosene with the standard burner and on methanol with the enlarged burner.

Aside from emissions results, the operability tests (acceleration/deceleration and ignition) showed that product capability is not compromised when operating on methanol, for both SGT-A20 and SGT-A35. Finally, the fuel changeover tests conducted for the SGT-A35 enlarged injector showed that the engine, and the injector, is capable of changeover across a wide range of power conditions. This shows impressive robustness and flexibility.

### 4.2 SGT-A05 Test Results

As expected, NOx emissions increased with engine load. Higher power levels require more fuel, increasing the equivalence ratio and promoting thermal NOx formation. This trend is illustrated by the upward-sloping curves in Fig 13. Notably, NOx emissions were significantly lower when operating on methanol compared to diesel, and also methane (not shown) in fact. This is likely due to methanol's lower combustion temperature and higher reactivity. The additional water content in M80 further suppressed NOx formation in the SGT-A05.

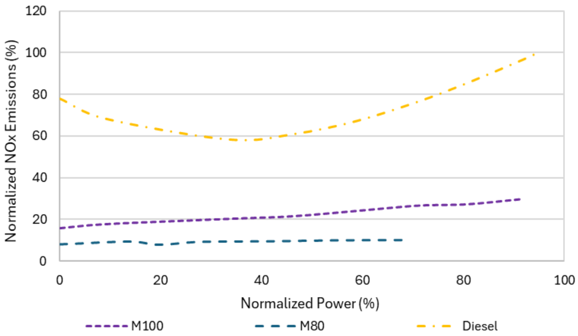


**Fig 13.** Corrected NOx measurements against corrected generator power for M100 and M80 fuel.

Carbon monoxide (CO) emissions are typically inversely related to combustion temperature. During operation on M100 fuel, CO emissions exhibited a clear linear decrease with increasing engine power, as shown in Fig 14. In contrast, the CO emissions during M80 operation initially increased, before following a downward parabolic trend as power continues to rise. Overall, CO emissions are substantially higher when operating on M80 compared to M100. This is consistent with the results in [9], a demonstration test from an older SGT-A05 standard, which shows a trend of increasing CO emissions as water fraction in methanol is increased. Whilst this older engine standard has generally poorer CO turndown capability than what was tested in this campaign, nevertheless, the impact on CO emissions from methanol-water fuel remains consistent.

$CO_2$ emissions were measured during M80 operation at 3.4 MW, with a recorded concentration of approximately 2.5% by volume.

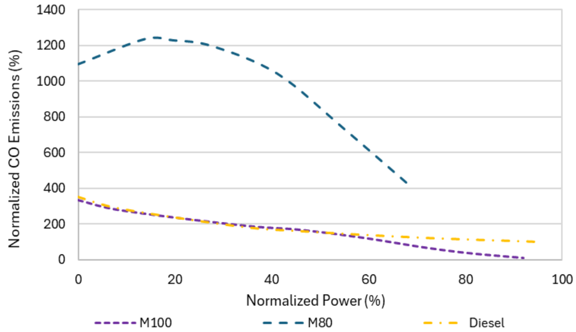


**Fig 14.** Corrected CO measurements against corrected generator power for M100 and M80 fuel.

Fig 15 presents corrected generator power versus turbine outlet temperature (TOT). This shows a similar decrease in exhaust temperature at-a-power that was previously observed in Fig 9 for the SGT-A20 and -A35. This again reinforces the thermal efficiency benefit of operating on methanol and further improves the case for methanol as an alternative fuel for aeroderivative gas turbines to support the energy transition.

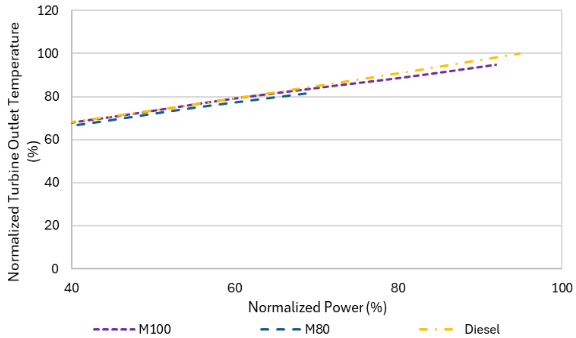


**Fig 15.** Performance results: Corrected power vs corrected turbine outlet temperature.

## 5 Conclusion

This study demonstrates methanol as a practical, lower-emissions fuel pathway for gas turbine engines. Testing showed approximately 80% NOx reduction when operating on methanol (M100) compared to kerosene or diesel and a further approximately 10% reduction, ~90% total, when operating with M80 methanol/water blend.

$CO_2$ also reduces at a given power level. Overall $CO_2$ footprint can be reduced further by switching from grey to green methanol. Required engine changes compared to diesel operation are incremental, focused on fuel delivery, injection, and controls, avoiding intrusive redesign.

Operability tests across all three engines showed product capability is not compromised when operating on methanol. On the SGT-A35 test, fuel changeovers between kerosene and methanol were completed across a wide power range, confirming the engine and injector's flexibility. Package and test-facility upgrades include fuel system capacity, fuel control skid, fire and gas detection, and control system logic which enabled safe and repeatable operation.

Collectively, these results show the SGT-A05, -A20, and -A35 are capable of operating with methanol and provide an attractive route to decarbonizing current gas turbine operations and new power generation projects. The results show the progress and commitment of Siemens Energy in providing future-proof products for existing and new customers in the face of the changing energy landscape.

## 6 Future Work

Future development for the SGT-A05 platform includes the design of larger fuel nozzles to accommodate the increased flow rates required to achieve equivalent power output on methanol compared to diesel.

The limitation will be addressed with newly designed, additively manufactured fuel nozzles. The new design will also incorporate a separate circuit for water injection, enabling emissions optimization through variable water-to-fuel ratios. Development is currently in progress and is scheduled for demonstration during a package test in early 2026.

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