WHITE PAPER

Decarbonizing Drilling

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Switching from Diesel to Natural Gas Empowers Oil & Gas Industry to Reduce Emissions and Operating Costs

New technologies are in high demand from industry and governments across the energy sector – an industry rooted in innovation, operational efficiency, and environmental sustainability. For nearly a century, oil and gas fields have relied on diesel generators to power critical equipment at each stage of extraction and production. Operators and drillers have long been interested in switching fuels from diesel to natural gas to capitalize on the benefits of lower fuel costs and reduced emissions. Unfortunately, gas engine technologies, thus far, have not proven capable of delivering diesel-like performance and reliability. Today, large displacement-rich burn gas generators are delivering on the industry's request, pushing the capabilities of internal combustion engines to new frontiers. The trend of dual-fuel (also referred to as bi-fuel) generators has moved the industry closer to its goals. Still, dual fuel solutions have not allowed energy companies to take full advantage of the fuel cost savings and emissions reductions of using 100% gas, not to mention the complexities of managing multiple fuel sources and vendors. Drillers and operators can finally increase the global energy supply and reduce their carbon footprint without compromising performance or reliability.

Drilling Industry Trends

Reducing emissions

Since the Paris Agreement (2016), many prominent national oil companies (NOCs) and international oil companies (IOCs) have set targets to achieve a carbon-neutral footprint by the years 2050, 2040, and, in some cases, 2030, to limit global temperature rise by 1.5°C versus pre-industrial levels. These targets typically focus on reducing "scope one" emissions, which are those produced directly due to the businesses' primary operations and activities. The oil and gas industry is a significant contributor to overall energy sector emissions and has been under immense pressure socially and politically to reduce its environmental footprint, mainly greenhouse gas (GHG) emissions driven by carbon dioxide (CO_2) and methane (CH_4).

Following COP26 (2021), over 155 countries joined the Global Methane Pledge, which aims to reduce global methane emissions by at least 30% from 2020 levels by 2030. Since joining, governments are looking to implement legislation to incentivize methane reduction and, in some cases, penalize or tax its emissions. During COP28 (2023), the U.S. EPA announced its latest rule to reduce methane emissions in the oil and gas industry, saying the rule would "phase in a requirement to eliminate routine flaring of natural gas that is produced by new oil wells…require comprehensive monitoring for leaks of methane…and establish standards that require reductions in emissions from high-emitting equipment"[1].

The global population is expected to rise throughout the century, and industrializing regions such as China, India, the Middle East, and Sub-Saharan Africa are expected to increase their demand for energy significantly. Energy companies everywhere are trying to figure out how to increase their production while simultaneously lowering emissions and reducing environmental impact.

Electrification

Bringing the electric grid to the oilfield is a critical enabler in reducing emissions and is an ideal solution for powering many aspects of well construction, completion, and production. Nonetheless, the electric grid is often not within reach of the equipment needing power since oil and gas production frequently occurs in remote locations. For operators in the Permian Basin to reach strategic targets, projected load demand within the basin will need to increase from 4.2 GW (2022) to 17.2 GW by 2032 and 17.6 GW by 2040[2]. In the Middle East and North Africa, an estimated 92 GW of new power generation capacity is needed by 2025 to ensure supply remains above demand with the recommended 15% reserve margin, and this does not even account for the additional capacity required to update existing infrastructure that is aging and inefficient.[3]

The International Energy Agency estimates that new grid infrastructure can take up to 15 years to plan, permit, and complete, particularly for extra high-voltage power lines[4]. Erecting transmission lines across many governmental jurisdictions and land owners is a burdensome process for any company, not to mention lead times for large power transformers can be as much as 210 weeks, according to global research firm Wood Mackenzie[5]. The lack of actual grid availability to oilfield companies makes in-field power a more appealing option and the only realistic path to continue their operations.

Reciprocating internal combustion generators can be deployed and commissioned in a matter of weeks, even faster than gas turbines. Renewable energy sources (mainly solar and wind) are quickly being added to the grid. Large gas, coal, and nuclear plants are being closed in the U.S. and other countries without replacement. The intermittent nature of renewables combined with the effects of retiring these large base-loading plants has strained the grid in many locations and reduced reliability, resulting in unexpected blackouts. Unexpected downtime due to loss of power is unsafe and unsustainable, furthering the case for generating the required power on-site.

Shale Oil and Gas Drilling

Advancements in hydraulic fracturing and horizontal drilling techniques significantly increased oil and gas well output around 2008[6]. In the U.S., crude oil production had been decreasing for decades until the so-called Shale Revolution, which enabled drillers and operators to

U.S. Natural Gas Consumption, Dry Production, and Net Exports (1980-2022)

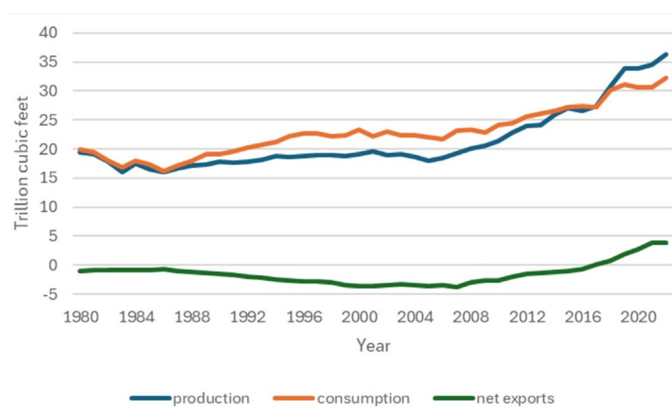


Figure 1 – U.S. natural gas consumption, dry production, and net exports[7] (trillion cubic feet): 1980 to 2022

access tight oil and gas formations that were previously inaccessible. As a result, oil and gas production has increased significantly in the U.S.

The abundance of natural gas availability in the U.S. has turned the country from a net importer to one of the largest net exporters of natural gas resources in the world[7]. Also, this abundance of natural gas has ensured that fuel prices remain low relative to the cost of diesel and other liquid fuels. The U.S. Energy Information Administration projects that from 2022 through 2050, natural gas production and liquefied natural gas (LNG) exports will likely increase by 15% and 152%, respectively, ensuring that natural gas prices will remain low for several decades[8].

U.S. Field Production of Crude Oil (1980-2023)

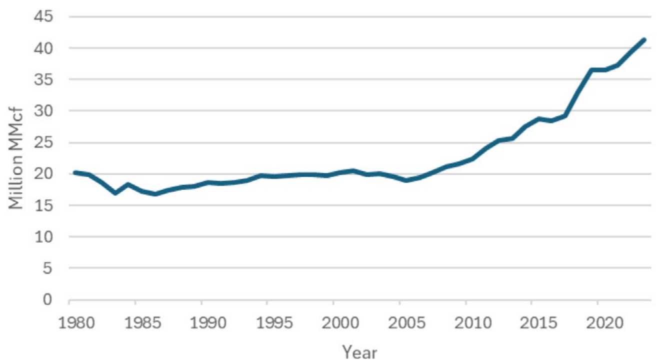


Figure 2 – U.S. field production of crude oil (thousand barrels per day)[9]: 1980 to 2023

Designing a Power System for Drilling and Well Construction

Equipment

Most modern land drilling rigs need 3 MW – 4 MW of electricity to power the draw works, mud pumps, top drive, control room, lighting, and other auxiliaries on the well pad. Most commonly, this is accomplished using four diesel generator sets in an *n*+1 configuration for reliability. Reliability is critical with suspended equipment and high-pressure fluids and gasses, amongst other hazards. Through the years, drillers have experimented with different power systems with varying levels of success, including gas turbines, natural gas and hydrogen-fueled reciprocating engines, fuel cells, battery technologies, grid power, and other hybrid systems. Using highline (grid) power is also possible and is growing in the industry where grid power is available. Drilling rigs have evolved to drill deeper, faster, and safer with each new generation of technology to extract the maximum value out of every well.

Duty Cycle and Performance

Drilling rigs are characterized by long periods of low-load operation with brief periods of very high load. Load steps and load sheds of 100% may be required, and the power system must be able to keep up with rig demands without tripping offline. The power system must be able to respond to these transients without significant fluctuations in power quality (voltage and frequency). Oil and gas drilling usually occurs in remote environments in harsh weather and sometimes at high altitudes. The equipment is outdoors and exposed to the environment. For this, it is vital to have a power system that can be flexible in different geographies. Also, because uptime on a drilling rig is so critical, the power system used needs to be capable of running long periods with little to no maintenance or operator intervention. Drilling rigs move constantly, so the power system needs to be mobile and capable of handling the vibrations and impacts associated with relocation.

Switching Fuels: Relying on Natural Gas Instead of Diesel

Using Compressed Natural Gas (“Virtual Pipeline”)

Natural gas infrastructure, consisting of pipelines, compression stations, and transportation services, is widely developed in the United States and Canada and is growing in other major energy-producing countries. These pipelines and “virtual pipelines” can be used to deliver compressed natural gas (CNG) to the well pad in the same way diesel can be delivered. The gas supplied to the site is typically high pressure. Thus, a pressure reduction system is generally offered with the CNG to reduce pressure and reheat the fuel before it is delivered to the necessary equipment.

The largest single constituent of natural gas is methane (CH_4), and natural gas power systems rely on the combustion of that methane into carbon dioxide (CO_2) and water (H_2O). “Pipeline quality” or “commercial quality” natural gas that has been refined may have methane content over 90%. With natural gas, unlike diesel, fuel quality can vary by provider, region, and source, so it is best to have a generator that is capable of a range of fuel qualities, ideally without derating power output.

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

Using Field Gas

Fuel flexibility is particularly advantageous and a top requirement when using field gas. Field- or well-head gas typically refers to natural gas that has not yet been processed or refined. Field gas might have 60% or lower methane content and will include larger amounts of non-methane hydrocarbons (e.g., ethane, propane, butane, etc.) and inert gases (e.g., N_2, CO_2, etc.). One of the significant benefits of using natural gas engines and generators in oilfield applications is the nearby availability of natural gas, which is produced either directly or as a natural byproduct of resource extraction. Rarely is this gas used to power in-field equipment – most of this gas is either flared or sent to midstream collection points. Utilizing fuel already available to drillers and operators eliminates the need for transportation and processing.

Field gas composition can vary by geographic region, basin, or well, and even within the same well over time as wells are depleted. Fuel flexibility is necessary to ensure economic and technical viability to utilize in-field gas sources successfully. The fuel is typically routed with flex hoses from the source to the engine. Fuel inlet pressure to the engine generally needs to be in the range of 30 – 60 psi. Depending on the pressure of the source, the fuel may need to have its pressure increased or decreased, with related temperature management. Gas quality delivered to the engine must be dry, with no liquids present.

Comparing Fuel Costs

Fuel Cost Savings

Operators who drill their wells using a 100% natural gas-powered rig versus a diesel-powered rig can see fuel cost savings of up to 94%. Savings are the highest when transitioning from a conventional Tier 2 all-diesel power system to utilizing 100% field gas (also referred to as well-head gas). The gas may come from a nearby well or pipeline within a few miles of the drilling site. Many operators who drill for oil also own gas that can be used as fuel, which is more affordable than paying a third party to haul in the fuel. Dual fuel (a blend of diesel and natural gas) power systems allow operators to offset some of the costs of diesel; however, the savings are significantly higher when you eliminate the requirement for diesel entirely. Not to mention the complexity and logistics of managing multiple fuels and vendors; this is eliminated when deciding to utilize 100% natural gas.

What further enables such fuel cost savings is the ability to run on a wide range of fuel qualities without derate; that is, a decrease in output power due to a limitation in fuel quality or ambient conditions. Large displacement-rich burn gas generators with modernized control systems can run on fuel as high as 2,350 BTU/ft^3 LHV, making it an ideal technical solution for utilizing field gas without pretreatment. Lean burn gas generators might only accept fuels as high as 1,250 BTU/ft^3 LHV – fuel above this range would typically need pre-treatment to remove the heavier hydrocarbons. However, this is often not required with large displacement-rich burn gas generators. These power systems are an ideal match for drilling and oilfield equipment because they can use the fuel readily available in the oilfield without pretreatment.

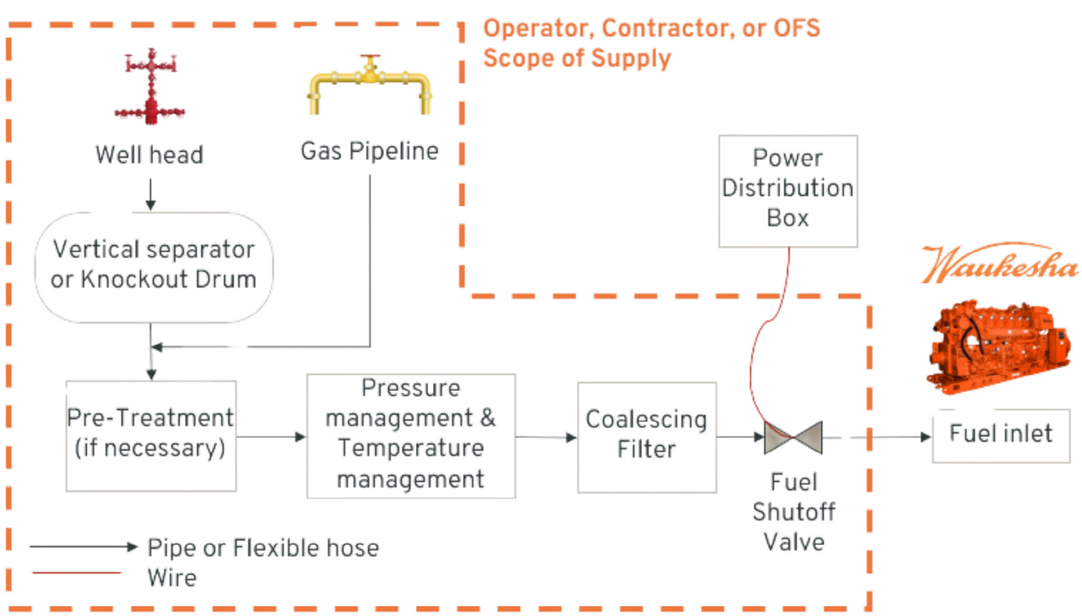


Fig 3 – Utilizing field gas or pipeline gas to power gas generators in the oilfield. Provided by INNIO Waukesha.

Daily Fuel Cost per Rig

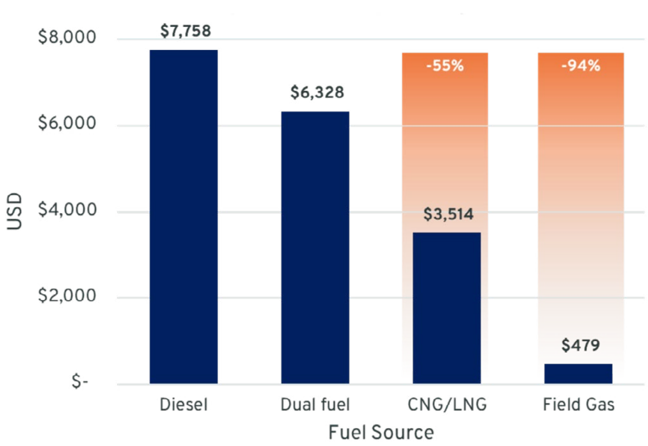


Fig 4 – Comparison of daily fuel costs per rig. Assumes three generators powering one rig, operating 24 hrs per day according to the load profile in Table 1. Assumptions: diesel price @ $4 per gal, CNG/LNG @ $11 per MMBTU, field gas @ $1.50 per MMBTU. Prices are USD. Data provided by INNIO Waukesha.

Typical Drilling Duty Cycle: Time spent in each load range as percent of total runtime	
<100 kWe	35%
100-200 kWe	23%
200-300 kWe	15%
300-400 kWe	13%
400-500 kWe	5%
500-600 kWe	5%
600-700 kWe	3%
700-800 kWe	3%
800-900 kWe	0%
900-1000 kWe	0%
1000-1150 kWe	0%
Total	100%

Table 1 – Typical load profile of a drilling rig. Data provided by INNIO Waukesha.

VHP Rich-Burn Fuel Flexibility

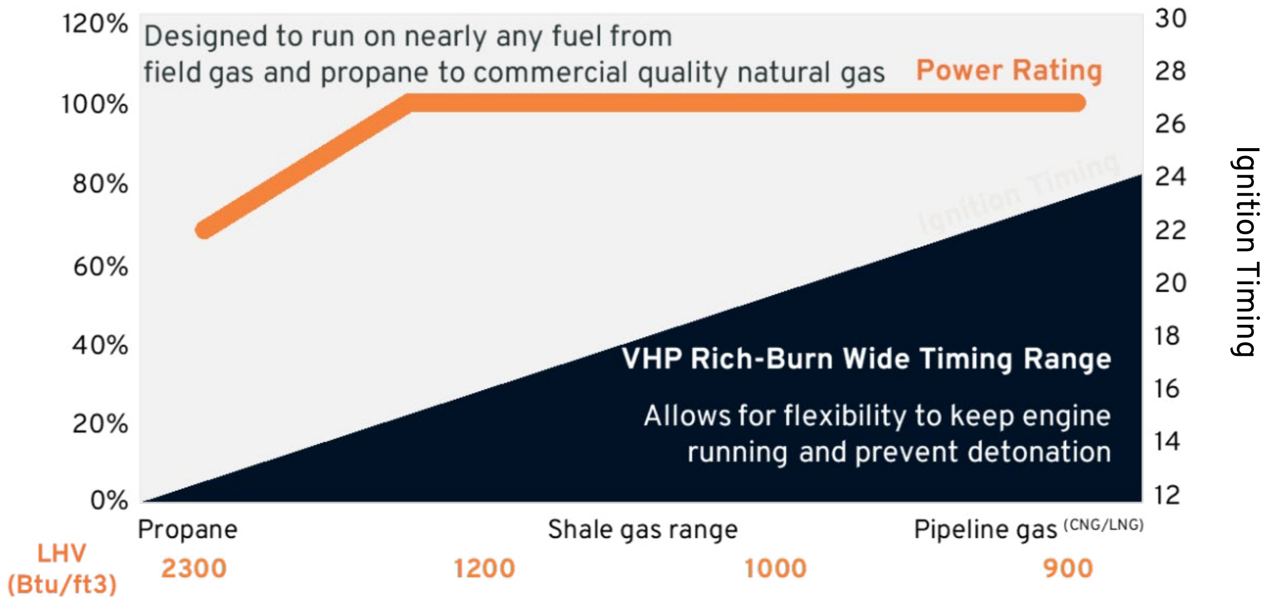


Fig 6 – Fuel range of large displacement-rich burn gas generators. Data provided by INNIO Waukesha

Reducing Emissions in Drilling and Well Construction

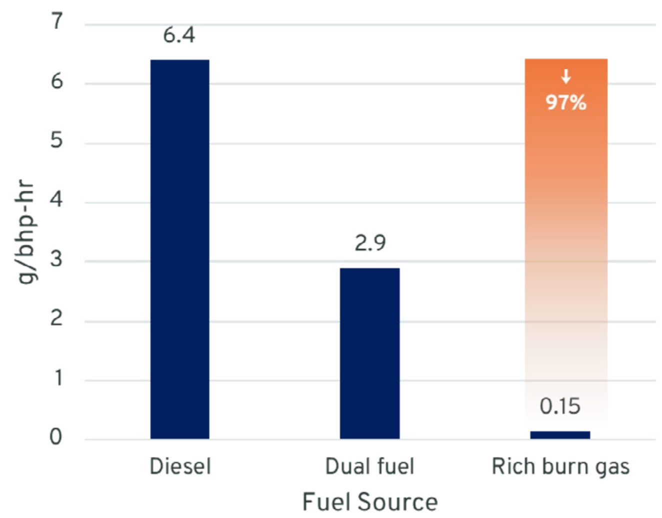
Reducing NO_x and CO

Large displacement-rich burn gas generators offer significant advantages over dual fuel and lean burn natural gas power systems in reducing methane and NO_x (nitrous oxides), enabling operators to achieve their emission reduction targets. NO_x forms during the combustion due to the reaction of nitrogen and oxygen under high temperatures. Carbon monoxide (CO) typically forms due to incomplete fuel combustion. While it can be mitigated, it is an inevitable byproduct of combustion. Switching from diesel to natural gas in drilling can reduce NO_x emissions by over 90%. Rich burn engines have hotter exhaust temperatures than their lean burn counterparts, enabling the use of a three-way catalyst. This, paired with automatic air-fuel ratio control and post-catalyst oxygen (O_2) sensing, reduces overall emissions footprint to ultra-low levels. The O_2 sensor indirectly measures NO_x and CO concentration in the exhaust stream; then, the air-fuel ratio is adjusted as necessary and used in addition to the catalyst to maintain the minimum achievable emissions without operator intervention. To minimize NO_x emissions, diesel engines use a selective catalytic reduction (SCR) system to strip the NO_x from the exhaust stream before it enters the atmosphere. The SCR system is often used in addition to an oxidation catalyst to remove CO. SCR systems are complex, using a diesel exhaust fluid (DEF), a solution of urea and water, to convert the NO_x into nitrogen and water vapor. This additional system adds cost and maintenance to the overall power system, but with rich burn technology, the need for an SCR system is eliminated.

Reducing Particulate Matter

Particulate matter (PM2.5) can also be reduced by over 90% when switching from diesel to 100% natural gas. Natural gas is primarily composed of methane, a simple hydrocarbon with one carbon atom. This leads to a cleaner burn than diesel fuel, which is composed of complex hydrocarbons with many carbon atoms. The more complex the hydrocarbon, the higher the likelihood of incomplete combustion, which can lead to soot and particulate matter. Also, natural gas engines use spark ignition, which allows for better control of the combustion process and can reduce soot formation. Diesel engines use compression ignition, where the fuel-air mixture is ignited by the heat of compression, which can lead to less controlled combustion and more soot.

Nitrogen Oxide Emissions (NO_x)



Particulate Matter Emissions (PM2.5)

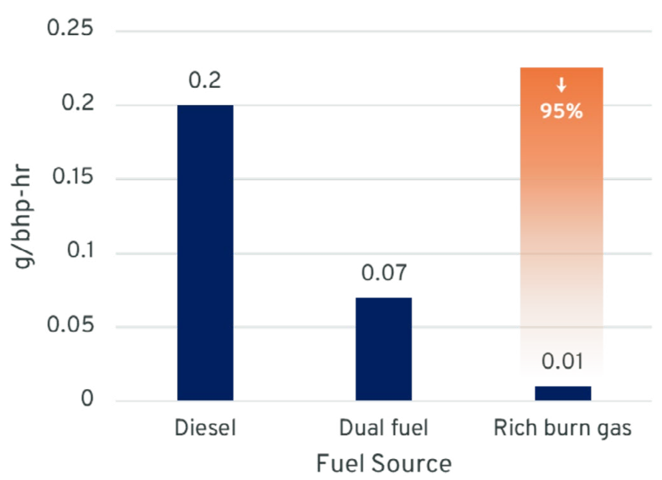


Fig 7—Comparison of nitrogen oxide and particulate matter emissions for drilling power systems. Data provided by INNIO Waukesha.

Reducing Methane and Greenhouse Gas

Dual fuel engines and generators have received much attention due to their ability to combine a diesel engine's load tolerance and responsiveness with the fuel savings of a natural gas engine. However, the blending of these fuels has proven to result in a significant increase in methane emissions versus pure diesel or pure natural gas. Operators can reduce their CO_2-equivalent (CO_2e) emissions by over 40% by switching to a full-gas solution. In a West Virginia University and Marcellus Shale Energy and Environment Laboratory, the exhaust emissions were compared for a typical drilling application between diesel and dual-fuel generators. Depending on the stage of well construction, as much as 25% of the exhaust stream consisted of unburned methane, resulting in up to three times higher greenhouse gas (GHG) emissions[10].

Methane Emissions (CH4)

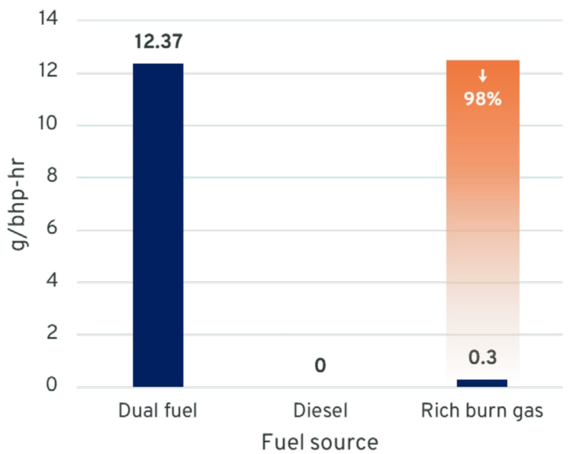


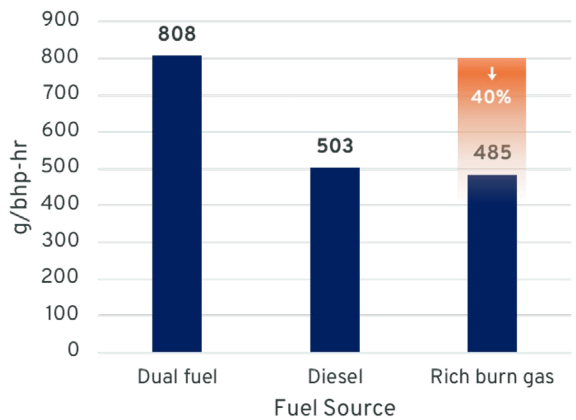
Fig 9 – Frequency response of large displacement-rich burn gas generator under sequential, increasing load steps. Data provided by INNIO Waukesha.

Achieving Diesel-like Performance Using 100% Gas

Designed for Drilling

For years, operators have said gas generators could not perform like diesel generators, particularly in drilling. Today's large displacement-rich burn gas generators are uniquely designed for long periods of low-load operation, with pistons designed to minimize low-load oil consumption and CO, VOCs, and formaldehyde emissions. Traditional lean burn gas generators are limited to 25% load steps, but large displacement rich burn gas generators can add 60% load in a single step while limiting frequency drop to less than 5%. Load steps of 100% are also possible with longer recovery times (ISO 8528-5 G1). Using lean burn gas generators in drilling requires a battery energy storage system (BESS) to be paired with the generators so the battery can absorb the transients since the generator alone cannot maintain power quality requirements. Large displacement-rich burn gas generators do not require a battery energy storage system.

Greenhouse Gas Emissions (CO2e)



VHP7104GSI Load & Frequency

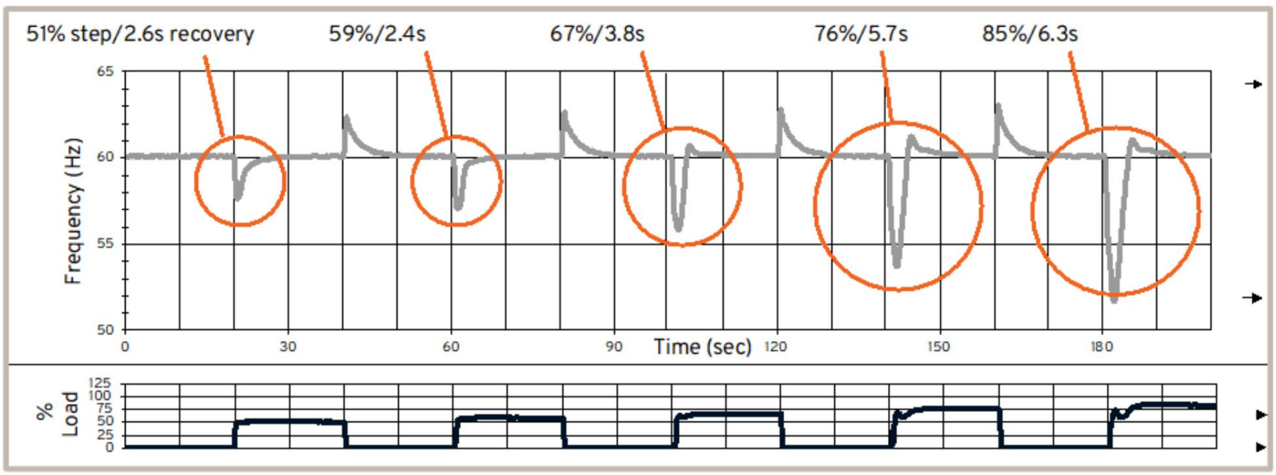


Fig 8 – Comparison of methane and greenhouse gas emissions for drilling power systems. Data provided by INNIO Waukesha.

There's No Replacement for Displacement

Dual fuel engines and generators have received much attention due to their ability to combine a diesel engine's load tolerance and responsiveness with the fuel savings of a natural gas engine. However, the blending of these fuels has proven to result in a significant increase in methane emissions versus pure diesel or pure natural gas. Operators can reduce their CO_2-equivalent (CO_2e) emissions by over 40% by switching to a full-gas solution. In a West Virginia University and Marcellus Shale Energy and Environment Laboratory, the exhaust emissions were compared for a typical drilling application between diesel and dual-fuel generators. Depending on the stage of well construction, as much as 25% of the exhaust stream consisted of unburned methane, resulting in up to three times higher greenhouse gas (GHG) emissions[10].

Rich-Burn Technology Outperforms Lean Burn in Drilling

Natural gas engines and generators fall into two categories: lean burn and rich burn (also referred to as stoichiometric). In simple terms lean burn natural gas engines utilize higher air-fuel ratios (more air, less fuel) which is ideal for engine-out emissions and fuel efficiency. Rich burn engines operate closer to the stoichiometric air-fuel ratio, which enables faster transient response and lower overall emissions when used with a three-way catalyst. Rich burn technology does not offer the high electrical efficiency of lean burn, but it is more suitable for the duty cycle required in drilling applications.

Proof of Success

A natural gas drilling company in Monongalia County, West Virginia, switched from Tier 2 diesel generators to Waukesha's large displacement-rich burn gas generator using 100% natural gas fuel. The shift offset an average of 2,000 gallons of diesel fuel consumption daily. They achieved emission reductions in NO_x and PM2.5 of over 99%. They also achieved CO and CO_2 reductions of 34% and 7%, respectively. Waukesha's large displacementrich burn gas generators for drilling have been deployed to the Permian, Denver, Appalachian Basins, China, and Argentina. Over 20 rigs have converted to large displacement-rich burn gas generators using CNG, field gas, pipeline gas, and even propane (HD-5).

Conclusion

Large displacement-rich burn gas generators are uniquely suited for drilling applications. These power systems can power the rig and all critical equipment more reliably than using grid power and with lower fuel costs and emissions than diesel. Multiple drilling contractors and operating companies have specified 100% gas to power their drilling and well construction activities. Using 100% gas versus dual fuel eliminates the need to manage multiple fuels on-site and surpasses the fuel cost savings and emissions benefits of blending diesel and gas. Increasing energy production while simultaneously lowering emissions and operating costs is the most critical challenge facing the oil and gas industry – large displacement-rich burn gas generators are a proven technology capable of moving energy forward.

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Waukesha – an INNIO brand - INNIO's Waukesha engines are at the forefront of the energy transition, providing reliable and compliant energy solutions for distributed gas compression and power generation applications. The brand's rich and lean-burn engines, ranging from 335 hp to 5,000 hp, set an industry standard for low emissions, high reliability, and fuel flexibility.

Waukesha products are continuously upgraded to help operators stay emission-compliant without sacrificing operational excellence. These upgrades include new and remanufactured engines and parts, as well as conversion and modification kits, all of which are backed by OEM warranty and more than 115 years of engine expertise. Additionally, our Waukesha digital solutions include a collaborative solution with Detechtion Technologies for gas compression applications and INNIO's myplant platform for power generation applications. Both solutions provide customers with enhanced monitoring and optimization capabilities, resulting in improved performance and reduced downtime.

We connect locally with our customers to enable a rapid response to their service needs, providing enhanced support through our broad network of distributors and solution providers with parts, services, and digital offerings.

Waukesha engines are engineered in Waukesha, Wisconsin, U.S., and manufactured in Welland, Ontario, Canada. To learn more about the company's products and services, please visit INNIO's website at **www.waukeshaengine.com** or follow Waukesha engines on **LinkedIn**.

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