POWERED BY NATURAL GAS

Natural Gas Fuel for Drilling and Hydraulic Fracturing

May 2014

Diesel Displacement / Dual Fuel & Bi-Fuel

Part of a series of white papers concerning the use of natural gas to power drilling and hydraulic fracturing operations.
Other topics include: Basics of Power & Fuel, Turbine Power, Natural Gas Fueling, LNG, CNG, Field/Wellhead Gas, Cost, Electrification

As the reality of America's natural gas age comes into view, it seems fitting that more of the equipment used to free that gas will also be powered by it. As a cleaner fuel, natural gas offers the promise of ***reducing emissions, site footprint and cost*.**

Operators and service companies are seeking answers even as the questions change. Purveyors of equipment are innovating to improve and adapt their technologies. The solutions for the near term may not be the best fit with the ultimate vision of all-gas power for drilling and hydraulic fracturing. Understanding the state of development for these technologies can assist in making informed decisions about investment in the near and longer term. Together with our partners in industry and academia, the Environmentally Friendly Drilling Systems Program (EFD) is exploring the important issues around natural gas fuel.

Increasing supplies of gas in North America, together with tightening of emissions regulations and volatility in diesel fuel pricing are key factors driving the "switch to gas" as a fuel of choice for drilling and hydraulic fracturing. Synergistically, technologies to more efficiently and effectively deliver and utilize gas fuel are rapidly evolving. Gas fuel will increasingly power not only drilling and hydraulic fracturing, but also railroad locomotives, shipping, and over-the-road transportation.

In recent years, petroleum exploration and development has led adoption of natural gas fuel as an alternative to diesel. Gas power for drilling has been steadily increasing for some time, whereas gas-powered hydraulic fracturing has become a reality only within the past two years. Advances in dual fuel diesel technology, turbines and electrification are drawing increasingly greater interest in gas fuel.

There are three principal categories of engine/power technology being deployed:

- Diesel Displacement (Dual Fuel and Bi-fuel)
- Spark-Ignited Dedicated
- Turbine

Each of these power technologies have advantages and limitations to consider for a specific application. Diesel displacement by means of introducing natural gas into the diesel combustion process is well-developed and flexible, finding broad and growing adoption. Diesel engines can be adapted to utilize gas in co-combustion with diesel fuel, retaining desirable flexibility in power delivery while displacing significant amounts of diesel fuel. These types of systems are referred to as dual fuel, bi-fuel or mixed fuel engines.

Spark-ignited (SI), dedicated gas engines running exclusively on natural gas fuel have a strong history of reliability in high-horsepower service. The burgeoning gas-powered equipment market is driving advances in SI engines for power generation and other applications. SI engines are well-suited for sustained steady load, and are used for electric power generation in drilling. Ancillary electrical system components are used for energy storage to accommodate operational demands. Additionally, conventional diesel or dual fuel diesel engines may be used as a complement with SI engines to supply the high transient load response needed during certain operations such as tripping pipe.

Turbine technology is highly versatile and well-suited to many energy development power needs. Turbines can accommodate a number of combustible fuels, and are configured in varied ways. Smaller turbines are being used to directly power hydraulic fracturing pumps. Larger turbines have been widely used for stationary or mobile electric power generation and will increasing be deployed to utilize the expanding supply of natural gas. In many instances, natural gas turbine and SI engines are also displacing diesel, not as dual fuel or bi-fuel, but because the power produced might otherwise have been generated using diesel fuel.

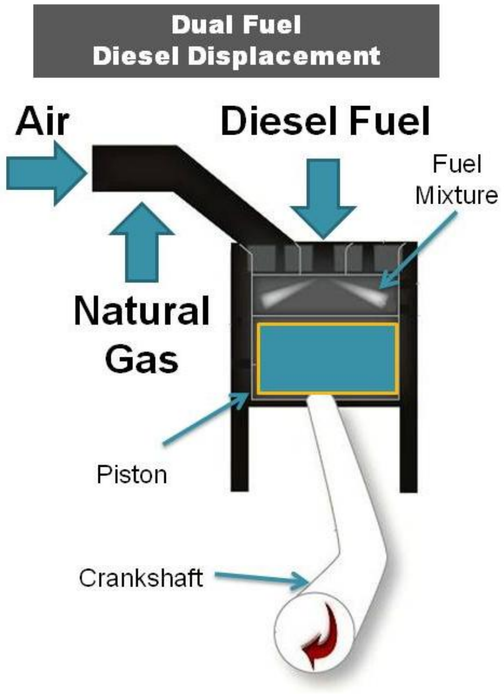
Natural gas is generally regarded as a cleaner fuel that diesel, producing less Carbon Dioxide (CO_2) and Oxides of Nitrogen (NO_x) from combustion. Where natural gas supplants diesel fuel in dual fuel engines, SI engines or turbines, there are significant differences in emissions. Some criteria pollutants are significantly reduced. Ongoing study in the research community is aimed at more complete understanding of the respective engine emission profiles for these evolving technologies.

Diesel displacement by introducing natural gas as a concurrently combusted fuel source is known as “dual fuel” or “bi-fuel” technology. Though both of these terms are used to describe this approach, both can be identified as “mixed fuel”. In general, both terms are broadly used to designate the use of natural gas with diesel combustion. For the purposes of this paper, the term “dual fuel” will be used to designate compression-ignition reciprocating engines that have the capability to co-combust diesel fuel with natural gas. Dual fuel diesel engines can operate on diesel only, offering the flexibility to continue operations even if gas fuel is unavailable. The term “bi-fuel” will be taken to mean any engine that can utilize either gas or diesel, separately, but not both together. An example of this would be turbines that can use a multiple of fuels, such as diesel or natural gas, individually but not together in co-combustion.

Dual Fuel Reciprocating Engines

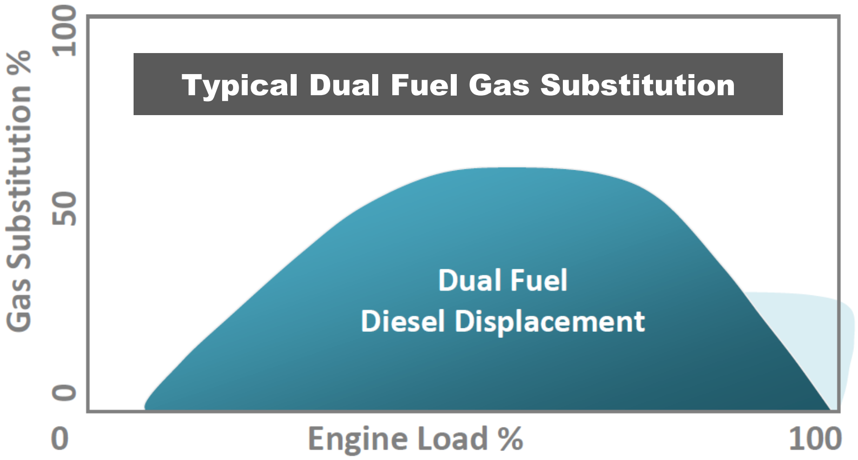
In most dual fuel systems used in the oilfield natural gas fuel in vapor phase at low pressure is introduced into the air intake system of the engine. Diesel fuel is introduced directly into the combustion chamber near the end of the compression stroke. The two fuels blend together in a lean mixture and are ignited by compression (no spark plug) in the engine cylinder. Dual fuel in this configuration offers many of the operational advantages of conventional diesel power. In particular, dual fuel diesels offer similar high transient load response so important in hydraulic fracturing operations and have been proven to function well in this application. Dual fuel diesel engines can also run solely on diesel should gas fuel be unavailable.

Systems of this type are available as aftermarket retrofit kits for existing diesel engines or as part of an Original Equipment Manufacturer (OEM) package. There are important Environmental Protection Agency (EPA) regulations concerning the certification of diesel engines to meet emissions standards. These regulations and standards also apply to the systems designed to integrate natural gas fuel, either as part of an OEM package or as an aftermarket kit.



GRAPHIC COURTESY OF CUMMINS

Natural gas fuel can be substituted for diesel fuel in varying proportions according to operating conditions. Dual fuel substitution rate is optimized with a system of sensors and control logic integral to the engine equipment package. Though many factors affect actual diesel substitution rates that can be attained, rates of 50 to 70 percent gas on an energy basis have been reported. The graphic below schematically illustrates substitution rates of natural gas for diesel fuel. Importantly, there is an optimal range of operating load and engine speeds at which gas substitution is maximized, sometimes known as the “sweet spot”.



Industry figures for 2013 indicate that dual fuel power for pressure pumping has been adopted only by a small percentage of pumpers. It is estimated that only about five percent of the more than 8,000 hydraulic fracturing pumps currently in service in North America are equipped for dual fuel. This figure is expected to rapidly increase, perhaps to as much as 40 percent over the next two years, as more of the conventional diesel fleet is retrofit / replaced with dual fuel diesel engines.

In addition to OEM systems there are number of aftermarket off-engine gas fuel train systems for conversion of diesel engines to add the capability of operation in dual fuel mode. Systems of this type are variously known as both dual fuel and bi-fuel. Many of these systems have an established track record of successful and effective operation, and feature proprietary equipment designs for fuel mixing, operational control and safety. As with other gas fuel technologies, these types of dual fuel systems are finding increased acceptance.

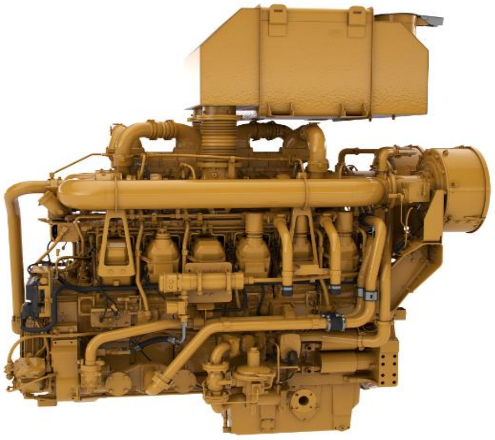


PHOTO COURTESY OF CATERPILLAR

Caterpillar 3512 Diesel Engine with Dynamic Gas Blending 2250 & 2500 HP

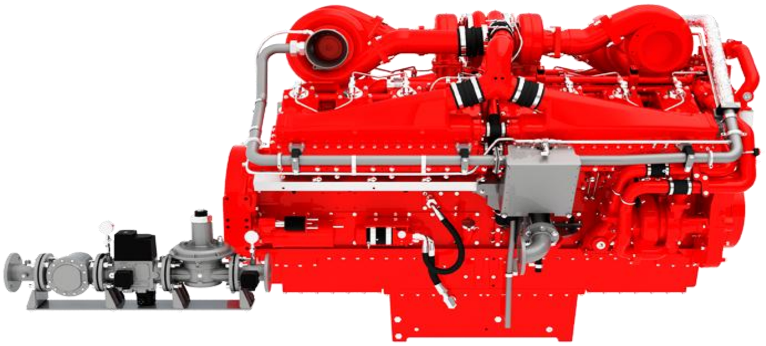


PHOTO COURTESY OF CUMMINS

Cummins QSK50 Tier 2 Dual Fuel Kit   1480 HP

Dual Fuel Pressure Pumping Engines

Industry figures for 2013 indicate that dual fuel power for pressure pumping has been adopted by only about 5% of the more than 8,000 hydraulic fracturing pumps currently in service in North America.

High Pressure Direct Injection (HPDI) is a means of introducing natural gas fuel directly into the combustion chamber at high pressure. Though these systems are also a means of implementing the co-combustion of methane with diesel fuel in a compression ignition reciprocating engine, HPDI is significantly different from fuel blending systems that introduce gaseous methane at relatively low pressure into the engine air intake. Though more costly than systems feeding low pressure gas fuel via the air intake, HPDI technology enables the use of much higher proportions of gas, on the order of up to 90 percent. Some amount of pilot fuel such as diesel is still needed to initiate compression ignition. With this significantly greater amount of gas in the fuel blend, HPDI engines afford improved efficiency and fuel cost savings with further emissions reductions. HPDI engines are increasingly being used in on-road freight transportation. HPDI engines of the horsepower range typically used in hydraulic fracturing are not readily available at present.

Emissions Reductions

Field experiences with dual fuel hydraulic fracturing reported in industry literature describe significant reductions in emissions and noise with increased methane substitution.

Among the most attractive benefits in the use of natural gas fuel is reduction in combustion emissions as compared with conventional diesel. It is well-established that there is a range of operating conditions in which natural gas is more thoroughly combusted, optimizing fuel substitution and minimizing undesirable emissions. Understanding the combustion characteristics and performance efficiencies of dual fuel engines is important to realizing the greatest economic and environmental benefit.

Of particular interest is the significant reduction in Oxides of Nitrogen (NOx) and Particulate Matter (PM) that have long been a concern with diesel engine emissions. Supplanting diesel fuel and the sulfur it may contain avoids formation of Oxides of Sulfur (SO_x) in exhaust gas. Impact on Carbon Monoxide (CO) in dual fuel emissions is less clear. In some instances, reduced CO has been reported, in others CO is significantly higher than with conventional diesel. With advanced exhaust aftertreatment, CO can be substantially reduced.

Diesel and natural gas have distinctly different combustion characteristics, with natural gas having a significantly higher ignition temperature than diesel fuel. Methane has an auto-ignition temperature of 1103^{o}F, whereas diesel fuel ignites at a much lower temperature of about 410^{o}F. Speed of flame front propagation for gas combustion is slower as compared with diesel. This phenomenon, together with the basic geometry of the combustion chamber and other factors and can result in incomplete combustion within the cylinder. Blending and mixing of the two fuels for thorough and efficient combustion is critically important.

Many factors affect combustion stability and relative completeness of combustion of the two fuels. Incomplete combustion that can occur particularly at low loads results in elevated CO and Non-Methane Hydrocarbon (NMHC). Similarly, Volatile Organic Compounds (VOCs) and Unburned Hydrocarbon (HC) levels may also be elevated. Optimally reducing the rate of natural gas substitution at low load can ameliorate this condition. Sophisticated engine controllers that monitor and regulate the rate of natural gas substitution for diesel fuel are essential elements of these systems for this reason also, as well as maintaining needed power output to avoid interruption of operations.

Exhaust treatment with Diesel Oxidation Catalyst (DOC) is needed to further reduce CO and NMHC and attain compliance with some Tier 2 regulatory limits for some certain criteria pollutants. DOCs can be incorporated as part of the engine exhaust system to provide effective treatment of these substances. Operating conditions can greatly affect emissions characteristics and the effectiveness of DOC treatment. As with other technologies evolving to improve dual fuel engine system performance, DOCs are important elements being studied and refined.

With a lower fraction of carbon by mass, combustion of methane reduces the amount of Carbon Dioxide (CO_2) produced, offering a theoretical reduction in Greenhouse Gases (GHG). While CO_2 is reduced, there remains concern with the possibility of fugitive methane, a GHG many times more potent than CO_2. There is little information from published field studies on the amount of fugitive methane that may be present in dual fuel exhaust. Standard oxidation catalyst exhaust treatments typically will not reduce uncombusted methane in the exhaust gas stream.

With regulation of GHG on the horizon, offsets of CO_2 attained with substitution of natural gas for diesel will be tempered by the potential for emissions of uncombusted methane (CH_4). Though it is known that uncombusted methane can be emitted in dual fuel, bi-fuel and turbine engines, quantification of this phenomenon is less clear. As with other emissions parameters, uncombusted methane amounts will vary as a function of engine load, geometry, controls and other factors. Because of its importance as a greenhouse gas, sources and amounts of fugitive methane are an important topic for further study so that these can be addressed with engineering solutions and management practices.

Reducing emissions is especially important when operating in sensitive airsheds, such as near residential areas. In shale plays that are near a major metropolitan area, existing concerns of urban ambient air quality draw greater scrutiny to drilling and hydraulic fracturing. Emissions from drilling and hydraulic fracturing activity in the airshed of a major city are sometimes targeted as an impediment to attaining compliance with federal ozone standards. Along with heightened emphasis on environmental performance in general, these kinds of concerns underscore the importance of reducing emissions and are further driving adoption of gas fuel.

There is debate on just how much emissions reduction is attainable, and this continues to be an area of intense interest. Sources in literature suggest reductions ranging from 25% to 50% of NO_x emissions, and as much as 70% reduction of PM. While some of these figures are plausible as a maximum attainable proportion of emissions reduction, it is important to remember that exhaust characteristics will vary greatly with operating conditions as well as engine speed and load.

Further research is needed to better characterize emissions profiles for high-horsepower engines used in these applications. Measurements of specific exhaust gas parameters and particulate matter will further our understanding of the benefits and limitations of these systems. The potential to reduce fuel cost, emissions and other environmental impacts is certainly present and will undoubtedly be increasingly realized with advances in technology and continued research.

Fueling Options

Natural gas fuel can be obtained in the form of Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), or may be delivered from a nearby location where it is produced or processed. Where available, pipeline gas may be a desirable option. Transportation distances become a key factor in deciding which form of fuel is suitable for a particular situation and site. The most practical solution for fueling will be a function of proximity and availability of supply.

The energy value, expressed as heat content, for gas produced in North America typically ranges from 950 to 1,650 Btu per cubic foot (Btu/cf), with a total average approximate heat content of 1,022 Btu/cf reported for 2011. As a replacement for traditional liquid fuels such as diesel and gasoline, heating value of can be stated as an energy equivalent of these two common fuels. Since natural gas fuel is replacing diesel in drilling, hydraulic fracturing and other high-horsepower applications, natural gas fuel requirements are often calculated in Diesel Gallon Equivalent (DGE). This equivalency basis also serves as a means of calculating the relative cost of natural gas fuel as compared with diesel. Natural gas can deliver an equivalent amount of combustion energy at a fraction of the cost of diesel fuel.

Approximate energy relationships between liquid diesel fuel and natural gas:
1 DGE = 132 scf
1 DGE = 1.68 Gallons LNG
1 MMBTU = 6.8 DGEs

LNG is typically about 90 percent methane gas that has been liquefied by cryogenic cooling to -260 degrees Fahrenheit. LNG is transported and stored at relatively low, near-atmospheric pressures. LNG is delivered and stored on site as a liquid which is then vaporized on site with special equipment.

When longer transport distances are involved, LNG is often a preferred fueling option that offers a high quality fuel delivered to the site in an energy-dense liquid form. At present, LNG availability is often limited, though high volumes of LNG production capacity are expected to come online in North America and elsewhere around the globe within the next two to five years.

PHOTO BY CAROLYN LAFLEUR

LNG Integrated Storage and Vaporization Tanker

PHOTO COURTESY OF PROMETHEUS ENERGY

LNG Storage and Revaporization Equipment

LNG may be delivered to the field in tanker trailers having volumes on the order of 13,000 to 16,000 gallons. The transport vessel may also include integrated vaporization equipment, or separate, stand-alone revaporization may be situated on site to support multiple storage vessels. A volume of 16,000 gallons of LNG would provide approximately 9,500 DGE of fuel.

Compressed Natural Gas (CNG) is transported at relatively high pressures, on the order of 3,000 to 3,600 psi, in cylindrical or round containers specifically designed and constructed for safe containment. CNG has become increasingly used in fleet and passenger vehicles, spurring development of fueling stations and related infrastructure accessible to the public.

For oilfield operations, CNG can be delivered and stored on site in pressurized cylinder trailers. A typical cylinder trailer may be capable of containing about 110,000 Standard Cubic Feet (scf) of gas, equivalent to approximately 830 DGE. Because of this relatively lower energy density as compared with LNG, CNG has been perceived as best suited for situations where transport distances are relatively short. However, advances in compression, filling and transport technologies are extending the range of feasible transport, perhaps to hundreds of miles. Stations capable of “fast fill” can greatly reduce the time required to fill a cylinder trailer, a factor that has been an impediment to the use of the large volumes of CNG needed for drilling and fracturing.

Smaller scale CNG processing units are increasingly seen as a solution for field and pipeline gas utilization. Placement of small-scale or temporary CNG infrastructure near field development locations can provide gas fuel that would otherwise be unavailable while also supporting the use of field gas and diversion from flaring.

Recognizing the limitations of centralized facilities and infrastructure to produce and deliver LNG and CNG, more small scale and modular processing technologies are becoming available. These types of systems are being used in energy production, transportation and mining.

Enclosed CNG Cylinder Transport Trailer

PHOTOS BY CAROLYN LAFLEUR

CNG Cylinder Trailers On Site

Where available, pipeline gas is a desirable fueling solution. Gas in pipeline has been treated to remove hydrogen sulfide and other undesirable contaminants, though moisture is still present and must be removed for use as fuel. Pressure regulation and other important steps are also needed. The greatest frustration to the use of pipeline gas is the absence of pipelines in developing fields. Greater demand may facilitate the technical and financial methods to bring early value to placement of piping for fuel delivery in field development, later to function as gas gathering in production.

Pipeline Gas Fueling

PHOTO COURTESY OF THIGPEN ENERGY

Sometimes referred to as "Field Gas" or "Wellhead Gas", locally sourced produced gas is a highly desired option. The great appeal in utilizing field gas is in reduced need for processing energy and transportation, thereby reducing cost and environmental impact.

Field gas composition and quality can vary greatly from one location to another, and must be conditioned for use as fuel. Field gas may not be suitable if heating value is significantly higher than methane. Natural Gas Liquids (NGLs) present in raw gas must be removed, along with other troublesome impurities such as Hydrogen Sulfide (H_2S). Innovative technologies and practices adapted to effectively treat and convey field gas for use as fuel are rapidly evolving. Advances in utilizing field gas will also support monetization of stranded gas and development of beneficial alternatives to flaring. Ultimately, the greatest economies and impact mitigation will be realized as fueling technologies, including CNG and LNG, can be developed most proximate to gas sources and points of use. Reducing the steps and distances involved in the supply chain will not only reduce cost but also reduce impacts associated with processing energy consumption, transport, and potential for methane leakage.

All fueling options, including conventional diesel, have accompanying health, safety and environmental considerations. Planning should include a review of applicable federal, state and local regulations. In some situations local authorities may not be familiar with material-specific handling and safety concerns such as firefighting, so engagement with local first responders is advisable so that all are properly prepared.

Looking Ahead

A greater abundance of natural gas is boosting development of technologies that utilize this resource as fuel. The enormous economic attraction to provide these technologies, equipment and services is driving innovation and commercialization. Reducing emissions, site footprint and overall environmental impact are key elements in these endeavors.

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"**POWERED BY NATURAL GAS**" is an ongoing research initiative of the Environmentally Friendly Drilling Systems Program.

"Utilizing Natural Gas as a Primary Fuel Source for the Equipment Used in Drilling and Hydraulic Fracturing"

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