

ASSOCIATED SHALE GAS – FROM FLARES TO RIG POWER

A Thesis

by

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ABSTRACT

From September 2011 to July 2013 the percentage of flared associated gas produced in the Bakken shale formation decreased from 36% to 29%. Although the percentage decreased, the volume of associated gas produced has almost tripled to 900 MMcf/D, resulting in the flaring of approximately 266 MMcf/D. The Bakken area is one of the most produced shale oil and condensate formations in the US. Reported volumes for this formation suggest that the amount of associated gas flared is enough to power drilling and hydraulic fracturing operations.

This research shows the technical feasibility of replacing diesel for powering drilling and hydraulic fracturing operations in the Bakken formation with flared associated shale gas. We show that this is a more efficient solution to powering drilling rigs and hydraulic fracturing equipment while also reducing the amount of gas being flared in shale oil and condensate plays producing associated gas. To do this, we investigated the composition and volumes of gas being flared and the average energy requirements for drilling rigs and hydraulic fracturing equipment in the Bakken area. The investigation reveals that the amount of associated shale gas being flared is more than enough to supply the energy required for power to the drilling rig and frac spreads. After reviewing power sources that can use natural gas (including turbines, dual-fuel, and dedicated spark ignited engines) and associated gas separation technologies, we are able to make recommendations for the best use of flared associated shale gas.

We show that making the switch to natural gas from diesel can result in cost savings for drilling rig and hydraulic fracturing operators. Natural gas costs less than diesel and is more environmentally friendly.

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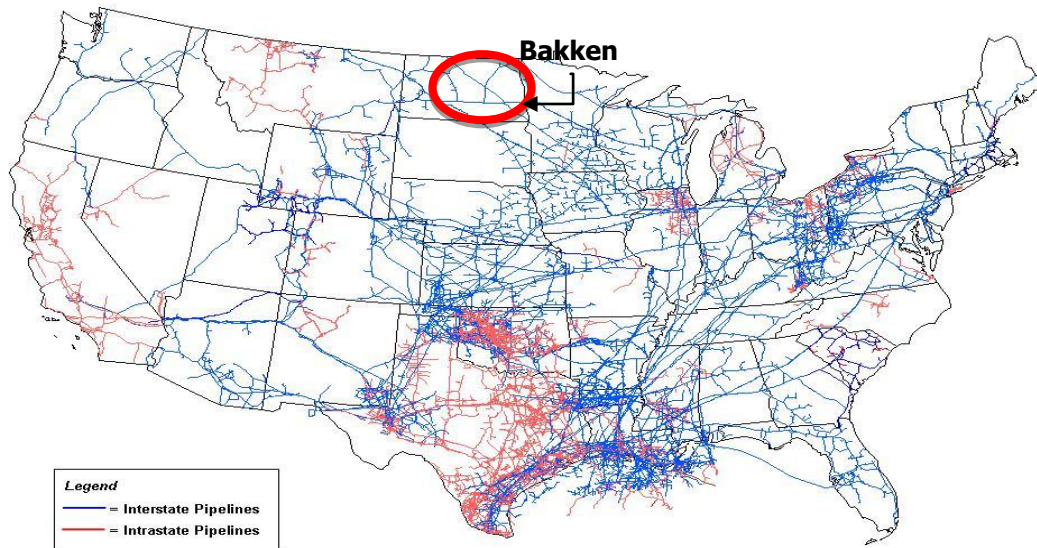
CHAPTER I

INTRODUCTION

In an effort to become increasingly environmentally friendly, the oil and gas industry continuously seeks out ways to become more efficient. This chapter will outline the status of flaring in the US and the current steps taken to reduce it.

Background

Flaring is the controlled burning of hydrocarbons during oil and gas operations. When there is not enough infrastructure to transport gas to market or the demand for gas in a certain region is low, produced associated gas volumes are then classified as stranded and flared (Aliabadi and Shamekhi 2012). This is especially the case in the Bakken shale formation, one of the most produced shale oil formations in the US.



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Figure 1: This map illustrates the pipeline infrastructure in the United States. The Bakken produces so much associated natural gas, that it exceeds pipeline capacity.

About 519 Bcf of gas per year had been flared in the United States in 2011, contributing 5% in total global gas flaring. This makes the US the 5th highest contributor to global gas flaring as shown in figure 2 (Reduction 2012).

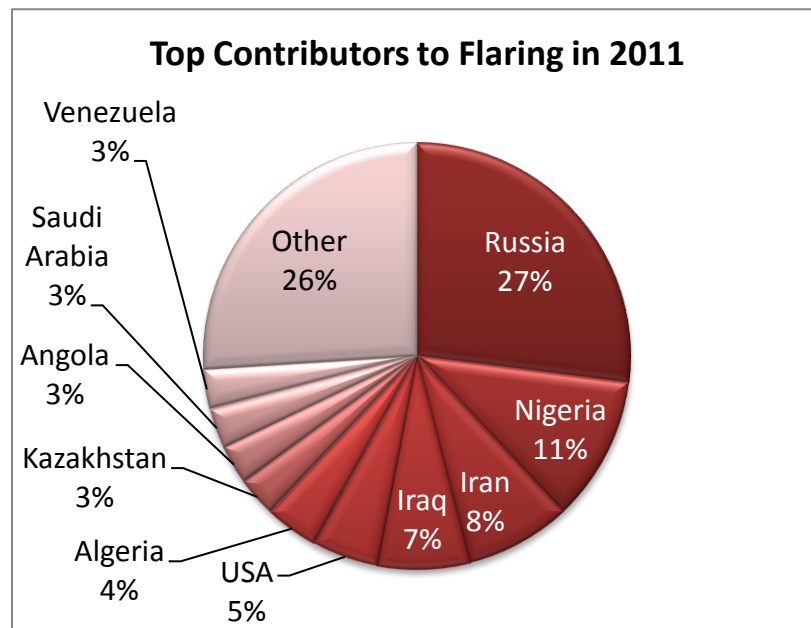


Figure 2: The US is 5th in global flaring (Reduction 2012). Using flared associated gas for drilling rig power could reduce the amount flared in the US.

As of July 2013, 29% of associated gas produced in the Bakken was flared. Although the percentage flared in this area decreased from 36% since September 2011, the volume of associated gas produced almost tripled to 900 MMcf/D, resulting in

flaring of approximately 266 MMcf/D. This calculates to 3.6 million USD of natural gas resources flared everyday (Scheyder 2013). With oil prices on the rise and gas prices on the decline, the production of oil in the Bakken formation has taken precedence. Due to the higher value of oil there is the projected increase of oil wells being drilled in the Bakken and Eagle Ford which leads to higher oil and gas production. Figure 1 illustrates the amount of flaring done in the Bakken compared to city lights of major cities as seen from space. Figure 3 shows the what flaring looks like in the Bakken. If the infrastructure continues to remain the same, then flared volumes will also continue to increase (Scheyder 2013). Although not the subject of this study, we also note that flaring in the Eagle Ford shale is also easily seen in Figure 4.



Figure 3: This picture shows what gas flaring looks like in the Bakken.

A few technologies are available that can efficiently use natural gas as fuel: natural gas turbines, spark-ignited dedicated natural gas engines, and dual-fuel engines. Although natural gas engines and turbines are usually the more expensive option, they have the ability to run on any form of natural gas, whether it be in its natural state, compressed natural gas (CNG), or liquefied natural gas (LNG) (Soares 2008). Another option that can be considered to use natural gas and meet power load requirements is to convert diesel generators to a dual-fuel engines. Using both diesel and natural gas simultaneously, these engines are slightly less expensive than natural gas engines and turbines. They use up to a 70:30 natural gas to diesel ratio, and diesel engines can readily be converted using conversion kits (Heinn 2013).

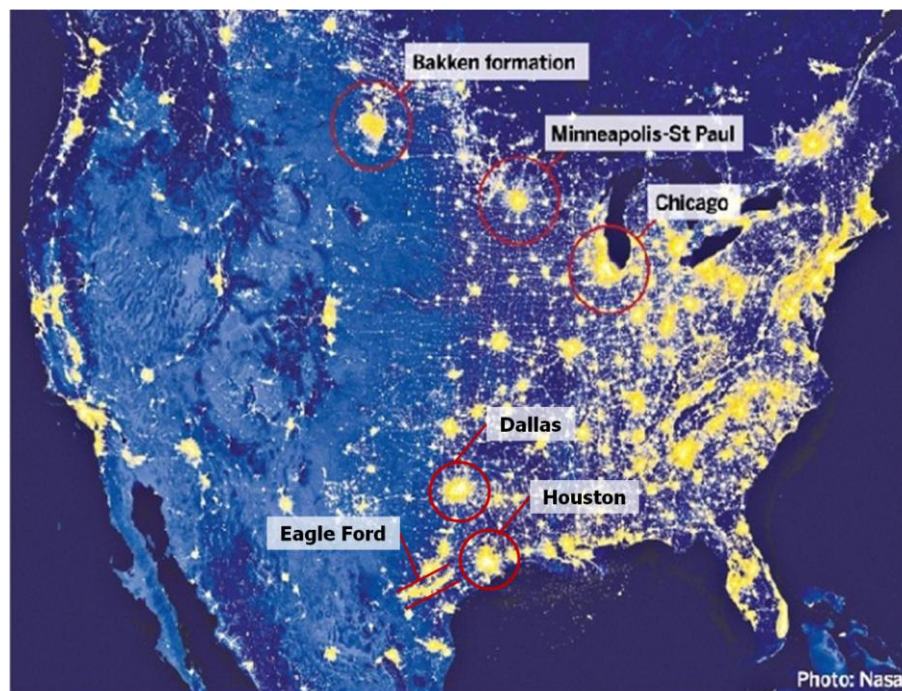


Figure 4: The amounts of flaring going on in the Bakken is comparable to the city lights in major cities seen from space.

Hill et al. (2011) evaluated the pros and cons of using natural gas for power in engines compared to most widely used diesel engines. He mentioned that the benefit to using natural gas as a fuel is that it is cleaner burning, it reduces operational cost, lowers engine maintenance, and promotes domestic energy security. The reported downside to using natural gas is that the amount of supply and availability may vary in different areas along with gas quality, dedicated natural gas engines will have power loss compared to diesel engines, and there will be a slower transient response under a variable load. However, one thing this study didn't evaluate is the difference of using gas from a gas formation compared to using associated gas from a shale oil formation. This study mainly focused on the use of dry shale gas, but not gas associated with shale oil.

Brown (2013) discusses how the SUPERCOOL™ micro-scale gas process could provide the solution to variable gas quality from different locations for use in power sources using natural gas. This micro-scale process is comparable to full scale LNG and CNG processing, first separating the liquids and undesirable components from the gas and then processing into each respective form. The only difference is that it is built on a smaller scale, making it potentially feasible for use in areas where associated gas is produced.

Just recently, companies such as Apache and Baker Hughes announced they were making the switch to use LNG to fuel their hydraulic fracturing operations in the Eagle Ford and Marcellus shale formation areas (Kever 2013; Shauk 2012). Companies within the industry have now started to see the value in using natural gas for their drilling and fracturing operations to take advantage of its economic potential. On average it costs

about 4,500 USD a day to operate a typical three-engine drilling rig being fueled by diesel.

Objectives

Reported data indicate that the current amount of associated shale gas being flared in the Bakken and Eagle Ford shale areas is enough to power drilling and hydraulic fracturing in these areas. The objective of this research is to evaluate the technical feasibility of replacing diesel with natural gas in drilling and hydraulic fracturing operations.

Summary of Remaining Thesis

First, we analyzed the composition and volumes of gas being flared in the Bakken shale area. Second, we collected data to understand the average energy requirements for drilling rigs and hydraulic fracturing equipment in the Bakken. Next, by dividing the amount of natural gas produced and flared by the amount of natural gas required for power we established the economic capacity in which power can be supplied to power these operations. The feasibility of this concept was evaluated by comparing the economic capacity on a per well basis to the amount drilling rig and frac treatments currently active in this formation.

Next, we explored the power sources including dual-fuel, and other forms of internal combustion engines for the efficient use of natural gas for drilling and hydraulic fracturing. We collected information on the technical specifications (i.e. gas composition for optimal performance, load constraints, etc.) of various power sources able to use

natural gas. In addition, we reviewed gas separation technologies designed for microscale gas processing by comparing and contrasting them.

CHAPTER II

SUPPLY AND DEMAND QUANTITIES

Our economy, driven by oil and gas, can be defined in two words: supply and demand. What is the need and how can this need be fulfilled? The Bakken is a very popular play because its reservoir and hydrocarbon characteristics are ideal for application of multiple transverse fracture horizontal well drilling and completion technologies. Because this oil is light, with API gravity ranging from 36 to 44 degrees, it will have to go through the least amount of processing by a refinery in order to produce the most valuable products of gasoline and diesel. However, the downside to producing this light crude oil is its high GOR, leading to production of large volumes of associated natural gas. As mentioned in the previous chapter, this is reason why so much associated gas is being flared in the Bakken. The Bakken currently produces so much associated natural gas that it exceeds gas transportation infrastructure capacity to meet demand in more populated areas of the U.S. Due to lack of infrastructure, this gas is effectively stranded.

This research is significant because we are always looking for methods to become more efficient in reducing the environmental impact, as well as increasing the economic value in what we do within the oil and gas industry. Natural gas has a slightly higher energy content and lower CO₂ emission per kilogram of fuel consumed (Table 1), therefore making it have a higher potential to supply energy with less of an environmental impact (Toolbox 2014). However, the type of engine used does make a difference in the amount of emissions emitted. Because a diesel engine typically

operates lean and natural gas engines are mostly stoichiometric, the amount of diesel used is less because of the more air being incorporated into the fuel. Diesel engines in this case would result in less emissions compared to natural gas fueled engines (Jacobs 2014).

Table 1: Natural gas supplies more power and less CO₂ emissions compared to diesel fuel (Toolbox).

Fuel	Specific Energy Content	Specific CO ₂ Emission
	<i>(kWh/kg_{fuel})</i>	<i>(kg_{CO2}/kg_{fuel})</i>
Diesel	11.8	3.2
Natural Gas, Methane	12	2.8

According to the North Dakota Industrial Commission, the Bakken currently produces an average of 1,034,642 Mcf/d associated gas, and only 628,029 Mcf/d is sold (Government 2014). The remaining 406,613 Mcf/d of natural gas can be classified as unmarketed or flared gas, accounting for 39% of daily production. From 1990 to 2014, the rate of gas production has dramatically increased as operators shifted their focus to oil production. If the focal point in this area continues to remain on the production of oil, trends suggest that these gas production volumes will continuously rise. Production

values show that there has been an exponential increase in the amount of gas produced, sold, and unmarketed/flared since 2008 (Figure 5). As the percentage of gas sold from the Bakken decreases, the percentage of unmarketed/flared gas is steadily increasing (Figure 6). The associated gas produced is made up of 55% methane and 22% ethane and contains a higher heating value of 1,495 Btu/Scf, making this good quality natural gas (Table 2).

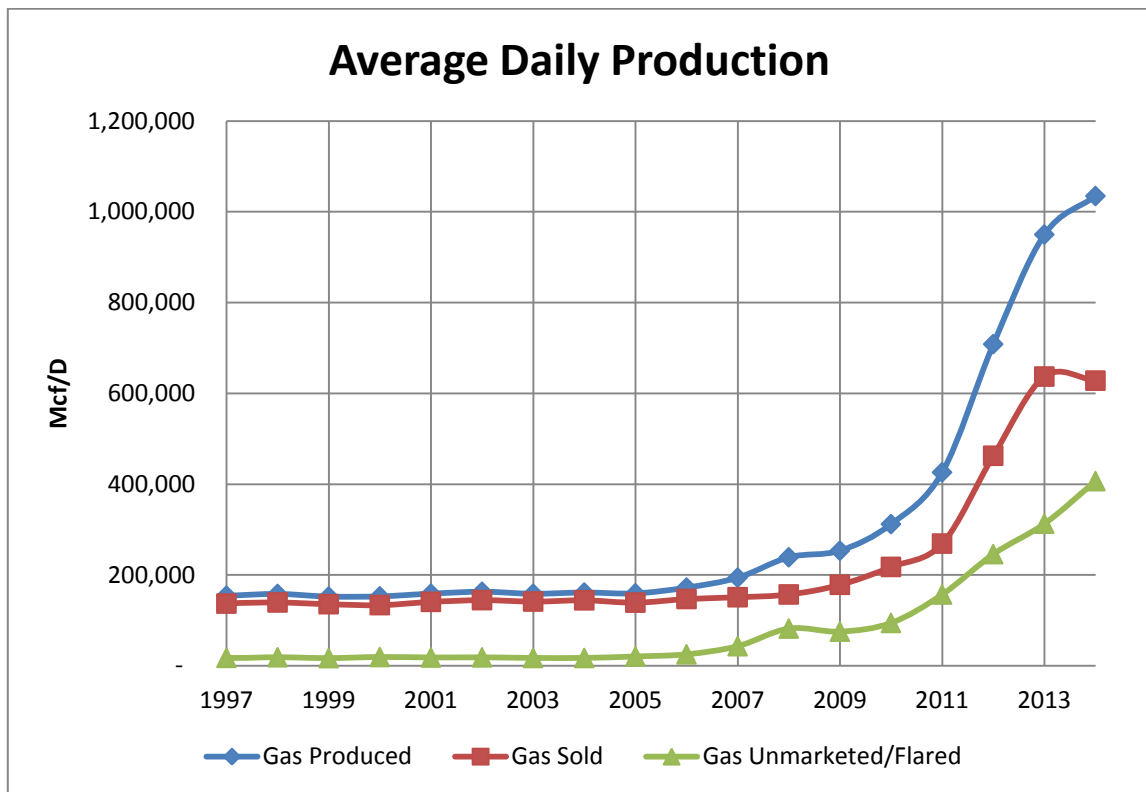


Figure 5: As gas production in the Bakken increases, so does the amount of unmarketed/flared gas. Trends suggest that these values will continue to increase.

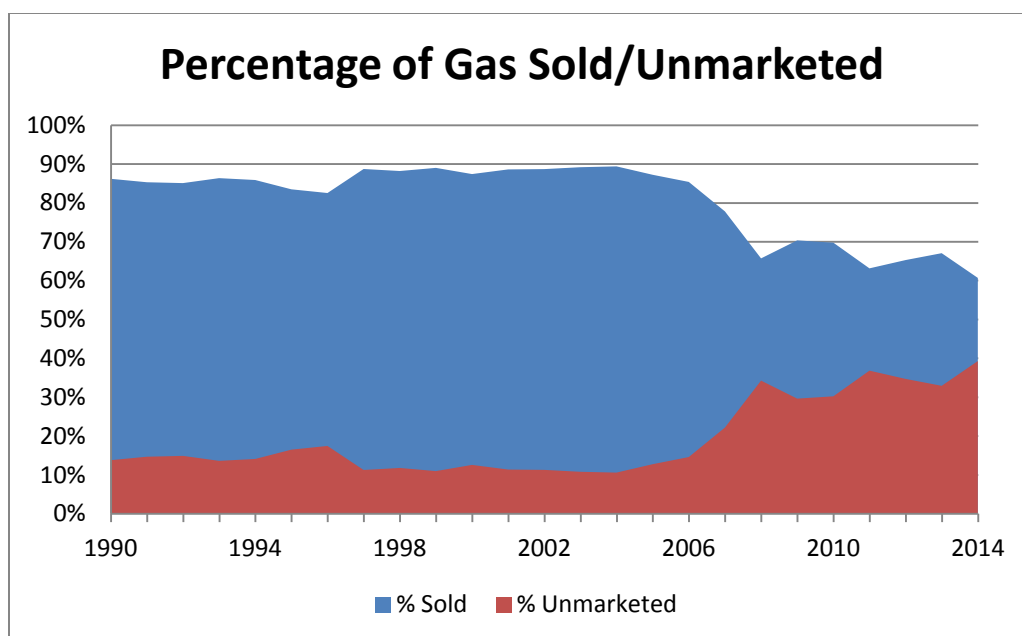


Figure 6: The Bakken currently flares 40% of the natural gas it produces. As shift on oil production continues to be this formation's main focus, the percentage of unmarketed natural gas also increases.

Table 2: Bakken associated gas is high in methane, ethane, and propane in composition attributing to its high BTU content.

Methane, CH ₄	55%
Ethane, C ₂ H ₆	22%
Propane, C ₃ H ₈	13%
Butane, C ₄ H ₁₀	5%
Pentane, C ₅ H ₁₂	1%
Hexane, C ₆ H ₁₂	0.25%
Heptane, C ₇ H ₁₆	0.1%
Nitrogen, N ₂	3%
Carbon Dioxide, CO ₂	0.5%
Higher Heating Value, Btu/scf	1,495

CHAPTER III

DEMAND AND SUPPLY SPECIFICATIONS

In order to assess the feasibility of using this form of stranded associated gas, we must determine how much energy is needed to supply power to drilling rigs and hydraulic fracturing treatments. Through literature reviews and personal contact with service company representatives, we were able to determine these values. Understanding the need will help us further justify the feasibility of this research.

Rig Power

The amount of fuel needed for power generation depends upon the size of the drilling rig operation or the work being done. It typically takes the power of 2-3 diesel engines to power one drilling rig. Fueling these engines take a total of anywhere between 700 to 3,000 gallons of diesel gas per day with an average of 1,500 gallons (Hill et al. 2011). The energy content for diesel is around 139,200 Btu/gallon and natural gas in the Bakken is 1,495 Btu/Scf. If using natural gas from the Bakken, converting on a basis of BTUs, this is the natural gas equivalent to 65.2-279.3 Mcf/D with an average of 139.7 Mcf/D.

According to DTC Energy Group, based upon drilling averages for well lateral length of 10,000 feet and a total well depth of 21,000 feet, the time it takes to drill a well in the Bakken is about 18 days (Siegel 2013). Since it takes about 18 days to drill a well in the Bakken, we estimate that on average 2,514 Mcf of natural gas would be needed to drill one well.

Hydraulic Fracturing

Siegel (2013) also reported that as of 2013 hydraulic fracturing treatments in the Bakken were done with an average of 32 stages per well. Based upon information collected from service company representatives, the main controlling factor for the fuel consumption is the rate at which a company wants their well to be completed. The faster it must be completed, the higher the rate at which the water will be pumped, the higher amount of power needed to support these treatments. We found that on average each hydraulic fracture stage uses water pumped at a rate from 90 to 100 barrels per minute. One stage can take from 30 to 150 minutes in duration to be completed. There are 10-12 different trucks at a frac site being used for different purposes with, therefore, 10-12 different engines. At this rate, the average amount of diesel fuel consumed per stage is about 150 gallons with a total frac time of 30 hours. With this estimate for the amount of diesel consumed, we converted this amount into its natural gas equivalent, once again using the energy content of both diesel and natural gas. The 150 gallons of diesel consumed per stage, on a basis of BTU content, converts to 14 Mcf of natural gas. Since there is an average of 32 stages per hydraulic fracturing treatment, we multiply this number by the natural gas equivalent per stage. This equates to approximately 447 Mcf of natural gas needed per well.

Types of Engines

There are different ways in which natural gas can be used for power within the oil and gas industry. Some of these power sources include the spark-ignited (SI) dedicated engine, dual fuel engine, hybrid power, and gas turbines. Things that must be considered when selecting the optimal engine type for your operation is the quality of

natural gas used as fuel, the speed at which the operation needs to be completed, and power needed to fulfill load demands.

Most drilling rigs are powered by 3 generators. There are two criteria that operators use to select an engine for power: redundancy and reliability. Roughly 30% of the time spent on a well is actually used for drilling; the other time spent is used for other operations. When an operator first drills the well, it is called spudding the well. During this process the first few thousand feet are drilled, cased, and cemented to protect the fresh water supply. Next, another few thousand feet are drilled with a smaller bit and pulls the entire pipe just installed back out; this process is called tripping out. During this time, when the pipe tripping occurs, the load swings on the rig change dramatically. Most drilling rigs used today are AC rigs, and when the power frequency supplied changes more than 5% this could lead to the breakers and main generators tripping off resulting in the blackout of a drilling rig. When a drilling rig blackout happens, there is a lot of downtime incurred trying to get the rig back up and running again. When it comes to drilling, time is money. The other 70% of the drilling operation time there are other transients that occur when pipe is being tripped in and out of the well, cemented, or wire lining. During this time high load swings may occur, and multiple generators will be used to maintain the power frequency. To maintain power frequency sometimes all three of the generators are in used to achieve this (Juergens 2013).

There are different engines available to use natural gas. In the following sections we will outline the inner workings of the different engine types available to supply power to hydraulic fracturing and drilling rig operations using natural gas.

Spark Ignited (SI) Dedicated Engine

The SI engine is a form of internal combustion engine that uses a spark plug to ignite the air/fuel mixture within the combustion chamber of the engine. The energy produced within the combustion chamber of the engine then in turn directly applies force to a component on the engine, transferring chemically produced energy into mechanical. Figure 7 illustrates what the one of the Caterpillar dedicated natural gas engines looks like. SI dedicated engines can completely be powered off natural gas and can offer maximum fuel savings for operators. However, these engines tend to be heavier and larger in size compared to diesel engines and are not good for instantaneous high



Figure 7: Caterpillar dedicated natural gas engine

transient loads due to slow flame speed in the combustion chamber and a greater potential for engine knocking. Essentially, it takes a while for these engines to ramp up into high gear. A white paper composed by Environmentally Friendly Systems (LaFleur, H.H.C. 2013) suggests that hydrogen can be added to enrich the fuel and improve

combustion characteristics. These engines are capable of using a wide range of fuel from LNG to propane, they produce low GHG emissions, and are mobile.

Part of the challenge with using wellhead associated gas for power is the high BTU content and natural gas liquids that are contained within associated gas. There are some engine types available that are able to use high BTU wellhead gas, however, in these types of engines you will face a longer transient response time. The higher the BTU content of the natural gas used the slower the engine will take to ramp up to those higher engine load swings. Companies are now in the process of designing engines that can run on variable natural gas BTU content; this cannot be achieved without the sacrifice of transient load time. However, one thing to consider is when using wellhead gas of higher BTU content there will be degradation in engine parts decreasing the component life of the overall system, leading to higher maintenance. Caterpillar and GE both have engine types and parts available with the capacity to run off higher BTU quality wellhead gas. However, these must be retrofitted for use in these particular applications, which can take a long time and additional capital to do (Juergens 2013). Also, you would need a control system for the engine to manage the variable quality of wellhead gas which will lead to additional costs as well (Jacobs 2014).

Dual Fuel Engine

With the capacity to can run off both natural gas (LNG or CNG) and diesel fuel, dual fuel engines are mostly being used in industry today. You can either buy a new dual fuel engine or get a conversion kit and retrofit your old diesel engine to become dual fuel. A study was done by Mustafi et al. (2013) which discussed differences in the

performance and pollutant emissions when using natural gas with dual fuel engines compared to the use of diesel fueled engines. The testing of these engines using different types of fuel has shown that when using natural gas there is a significant reduction in CO₂, NO_x, unburned hydrocarbon, and particulate matter emissions. Results also show low brake specific fuel consumption versus using diesel fuel. The brake specific fuel consumption is the ratio of fuel used to the amount of power produced by the engine. Being that this ratio is low means that the engine will use less natural gas compared to diesel for the amount of power produced. According to Caterpillar, they have developed a dynamic gas blending dual fuel technology that can substitute up to 70% of diesel with natural gas while the engine is functioning at a 30 to 80% load. This type of engine can use natural gas with the lower heating value BTU content ranging between 800-1250.



Figure 8: Cummins dual fuel engine

This technology also has the capacity to dynamically adjust while continuing to substitute diesel with natural gas as fuel quality changes (Ternes 2013). Figure 8 shows what a typical Cummins dual fuel engine looks like.

When using these engines all natural gas liquids must be removed from the fuel. Small amounts of water in the fuel are okay but it must contain absolutely no hydrogen sulfide. These engines can be fueled using natural gas with the methane number between 30 to 100, however, the higher the methane number the lower the amount of natural gas that can be substituted for diesel (Gore 2013).

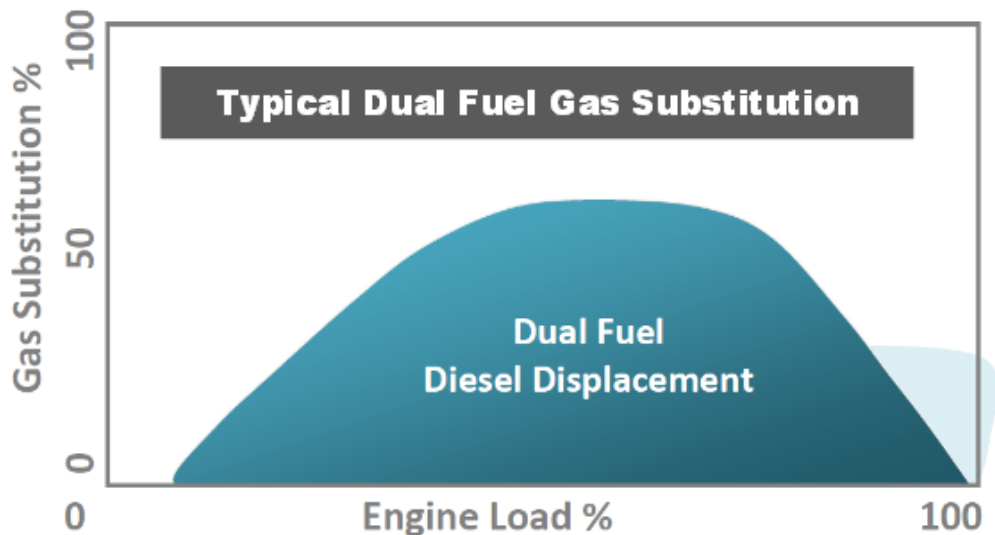


Figure 9: For dual fuel engines there is a "sweet spot" operating zone where maximum diesel fuel displacement occurs. When operating dual fuel engines above or below the "sweet spot" power range, diesel displacement rates decrease. Operating outside of the sweet spot ranges too frequently may lead to the uneconomical use of these engines for operators (LaFleur, R.H.C. 2013).

The transients in this type of engine are handled by injecting more diesel instead of natural gas. One of the challenges most drillers find when running multiple engines at low loads is that the amount of diesel being displaced by natural gas substitution becomes uneconomical. It takes more diesel to power these engines at lower speeds than natural gas, leading to not much of a reduction in engine emissions (Juergens 2013; LaFleur, R.H.C. 2013). For dual fuel engines there is a "sweet spot" operating zone where maximum diesel fuel displacement occurs. When operating dual fuel engines above or below the "sweet spot" power range, diesel displacement rates decrease. Operating outside of the sweet spot ranges too frequently may lead to the uneconomical use of these engines for operators (Figure 9).

Gas Turbines

Gas turbines are another form of internal combustion engine. They provide significant benefits due to versatility, high power to rate ratio, and ability to be powered by several forms of combustible fuels (including those that contain CO₂ and H₂S) (LaFleur, R.H.C. 2013). However, this form of engine is best used for applications where constant high power operations need to be done. These engines do not take transient loads very well. They are typically designed to work optimally for a certain operating range. As power output decreases so does the engine's efficiency. Turbines are typically designed to operate a peak loads greater than 50%. These loads are able to be sustained for 2-3 years, but 3-4 years after use these maximum loads drop off to 20-30% less than what they are rated for and power capacity decreases (Juergens 2013).

Hybrid Power

Hybrid power is a new technology that has been developed where an ultracapacitor is used in conjunction with an engine to supply power. One type pictured (Figure 10) is called the FlexGen ultracapacitor system. There are different battery storage capacities available for use which can be customized for the type of job needing to be done and the amount of power needing to be supplied. It is also scalable and modular, making it feasible for use in remote areas. Since the market for these systems hasn't really been established yet in the oil and gas industry, this option may be more expensive. Pricing for this option majorly depends on the battery chemistry used, the number of battery cycles needed, and the duration needed to meet high energy demands. The battery chemistry determines performance quality, lifespan an operator would like to get out of this type of system, and the deep battery cycles. Lifespan on an ultracapacitor could range anywhere between 5-12 years. The maintenance required for this type of system is roughly 2 hours downtime on an annual basis. Since this system allows engines to operate in its most efficient capacity, it has the potential to reduce fuel need up to 15% (Juergens 2013).

For SI engines, during the time when the rig is tripping pipe and the load changes the ultracapacitor will harness excess power supplied from the generators when there is not a huge load demand. When those high load demands are needed, the ultracapacitor has the ability to sustain 20-30 seconds of a high amount of instantaneous power that will supplement the other power generators in use until they can ramp up and meet those load demands. Knowing that dedicated natural gas engines have a slower transient response time compared to diesel engines, this option may be the solution. What is

unique about this system is it offers the flexibility to use a wider range of natural gas qualities to fuel SI engines providing all the transient capabilities needed for the rig (Juergens 2013).



Figure 10: FlexGen ultracapacitor system

With dual fuel engines, at low loads, the amount of diesel being displaced by natural gas is very low, sometimes making them uneconomical, causing higher emissions, and incurring more maintenance. Hybrid systems can offer an advantage to offset power loads for 1-2 generators into that higher operating range so that the engine can become more economically efficient, reducing maintenance, and lowering emissions (Juergens 2013).

Gas Processing Technologies

Small scale gas processing technologies may enable wellhead gas composition to be optimized for various engine requirements.

SUPERCOOL™

The SUPERCOOL™ process converts gas into LNG while separating unwanted liquids from the wellhead. This process virtually recovers 100% ethane plus natural gas liquids (NGL), separates CO₂ and nitrogen to produce pipeline grade LNG. When converting pipeline gas to LNG approximately 11,000 gallons of LNG per MMSCF of gas fed into the system will be produced. However, when processing a gas that contains more heavier hydrocarbon gas components, less LNG will be produced and more natural gas liquids. This technology comes in three different sizes: 1.5 MMSCF per day, 5 MMSCF per day, 10 MMSCF per day, with the potential in the future for development of a 20 MMSCF per day processing unit. These different sizes can supply LNG from 5,000 gallons per day to 10,000 gallons per day. The process was designed in a small frame making it portable. For the systems designed on a smaller scale, it is more economically feasible to truck in nitrogen refrigerant to cool the natural gas. However, for larger scaled processes Brown (2013) suggests to install an air separation unit or nitrogen liquefier to produce the nitrogen refrigerant.

CNG in a Box

GE also has a CNG/LNG in a box technology. This technology was originally designed to use pipeline gas to convert into CNG and LNG for use in transportation vehicles, however, it can be used to process wellhead gas with the use of an additional mobile gas processing unit (Krauss 2013).

CHAPTER IV

TECHNICAL FEASIBILITY FOR USING FLARED GAS

With the drilling of a well and a hydraulic fracturing treatment constituting for one completion, we add the total amount required for one completion. It would take about 31,800 gallons of diesel fuel per completion, the natural gas equivalent to 2,961 Mcf. Based upon the 1302 well completions took place between April to August 2013, we averaged 9 well completions per day (Blanchard 2013). The amount of natural gas flared in the Bakken is enough to complete 137 wells per day (Figure 11). This is significantly above the amount needed to complete wells in this formation. This shows that the Bakken produces more than enough unmarketed gas to power both drilling rig and hydraulic fracturing treatments. Other measures will need to be taken to remediate or reduce the flared production.

Although operational cost will be significantly reduced with the use of shale associated gas depending on the engine type used, for drilling rigs. Understanding the technical capacities and limitations may justify the pricing for the various mentioned in this study. Table 3: Shows the pricing for the separation technologies reviewed in this paper. The price for SUPERCOOL™ was based on a 10MMCF/D unit, and could be more or less depending on the capacity of your separation unit (Brown 2013). The pricing of GE's CNG in a Box is based upon a NY Times news report (Krauss 2013). Although the SUPERCOOL™ process is significantly higher in price than GE's CNG in a Box, it does have the ability to condense the natural gas into LNG making it easier for

more natural gas to be transported and sold to other local drilling and hydraulic fracturing operations.

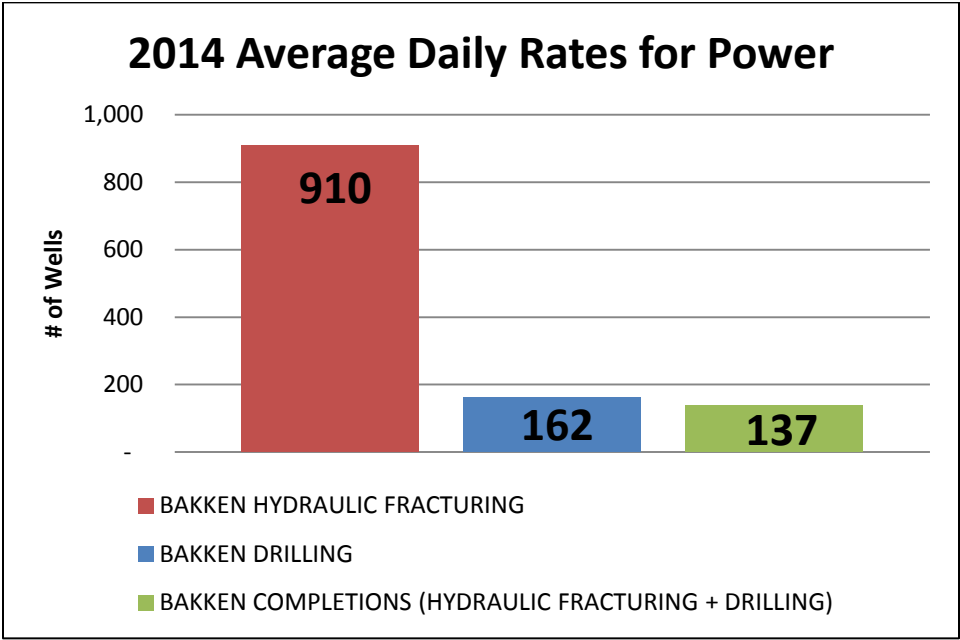


Figure 11: Based upon daily associated gas production, the Bakken has more than enough natural gas to supply power to hydraulic fracturing treatments and drilling rigs in this area.

Table 3: Shows the pricing for the separation technologies reviewed in this paper. The price for SUPERCOOL™ was based on a 10MMCF/D unit, and could be more or less depending on the capacity of your separation unit (Brown 2013). The pricing of GE's CNG in a Box is based upon a NY Times news report (Krauss 2013).

Separation Technologies	CAPEX
SUPERCOOL	\$ 14,500,000
<i>Nitrogen Liquefier</i>	\$ 18,000,000
GE CNG in a Box	\$ 1,100,000
<i>Gas Processing Unit</i>	\$ 500,000

Compared to diesel engines, dual fuel engines seem to be the most economical and provide very similar characteristics to diesel. However, operation outside of the "sweet spot" zone will lead to a decrease in diesel displacement rates, potentially making it uneconomical if frequently operating in these ranges. Also, since this process does use diesel to reach transient loads, operators will have to factor in this operational cost with their expenses.

Estimates in Table 4 for diesel and SI engines are based off the study done by Hill et al. (2011). Both technologies allow for maximum use of associated natural gas, as they can operate off 100% natural gas. However, technical specifications mentioned in the previous chapter may inhibit them from being the optimal selection for power. If using these engines in conjunction with an ultracapacitor, one may be able to overcome these technical challenges.

Ultracapacitor hybrid power is meant to be used simultaneously with a diesel, SI, dual fuel, or gas turbine engine. Pricing for a 150kW- 2MW unit ranges in price from

\$900-1000/kW for small scale oil and gas operations. The number of power cycles, the type of battery chemistry used, and the instantaneous power duration needed to meet high energy demands is what determines pricing.

Table 4: Pricing estimates per drilling rig includes the use of 2-3 engines per rig (Hill et al. 2011; Kulkarni 2013). For hybrid power, only one ultracapacitor would be needed with the use of 2-3 engines generating power (Juergens 2013).

	Engine Technology				
	Diesel Engine	SI Engine	Dual fuel	Gas Turbine	Hybrid Power
<i>Transient response</i>	Instantaneous	Limited	100% with diesel	Equivalent to diesel	Equivalent to diesel
<i>Diesel displacement</i>	0%	100%	up to 70%	100%	100%
<i>Price per rig</i>	\$860,000	\$1.1 MM	\$ 800,000	\$1.5 MM	\$135K-2MM

CHAPTER V

CONCLUSIONS

The Bakken currently produces about 400,000 Mcf/d of unmarketed gas. This unmarketed gas accounts for 40% of total production. With the amount of unmarketed gas produced per day, the Bakken produces enough gas to support drilling rig power for close to 160 wells and 900 hydraulic fracturing treatments, and if completing a well with the drilling and a hydraulic fracturing treatment there is enough natural gas to complete 125 wells per day. With 9 wells on average being completed per day by these operations, the available gas is 15 times greater than the amount that could be used at the current activity level, leading to a surplus of unmarketed gas that a market must be found for.

Various technologies are currently available to allow wellhead gas effectively power drilling rig and hydraulic fracturing treatments. Power sources such as spark ignited engines, dual fuel engines, hybrid power, and turbines are available to use natural gas as a fuel. Spark ignited engines would be able to maximize the use of the produced unmarketed gas in the Bakken, however, these engines are not good for high transient loads due to slow flame speed in the combustion chamber and a greater potential for engine knocking. If this engine is used in conjunction with a hybrid power technology, this might be the solution to high transient loads as power can also be drawn simultaneously from the ultracapacitor. Dual fuel engines are the most common engines used in industry now for companies that want to make the switch to natural gas powering their operations. This is due to the fact that the standard diesel engine can easily be converted using a dual fuel conversion kit to integrate natural gas into the fueling

system. Gas turbines are also an option to utilize natural gas for power as they can be very efficient and have a high power density. Turbines, however, drastically lose efficiency with a reduction in power output making those best for constant high-powered operations.

When selecting various power technologies one must not only consider the initial capital cost, but also the power capacity and performance they are looking to gain. Although of all the natural gas power technologies, dual fuel cost the least one still has to consider the cost for diesel fuel. Technologies such as, SI engines and gas turbines cost the most, but running off 100% natural gas, offers the maximum use of flared associated gas resulting in virtually \$0 in fuel operational costs. Ultracapacitor hybrid power compensates in technical areas where SI engines and gas turbines cannot. Pricing may be on the higher end, but will allow gas turbines and engines to optimally operate with the maximum use of flared associated gas.

Small scale gas processing technologies are available that can process wellhead gas into pipeline quality LNG and CNG that can be used effectively in different types of natural gas fueled engines. SUPERCOOL™ is able to process associated wellhead gas and separate the CO₂ and the NGL's processing it into LNG. In addition, if using this process nitrogen would need to either be bought from a gas supplier or a separate nitrogen liquefier would need to be purchased depending on the size of the processing units. Since the design of CNG in a Box was originally designed to process pipeline gas for vehicular fueling stations, an additional gas separation unit would need to be purchased to separate all unwanted components before condensing into CNG.

Switching diesel powered oil and gas operations to natural gas offers many positive benefits: reduction in greenhouse gas emissions, less operational costs, as well as, a reduction in the amount of taxes and royalties paid. If measures are taken as outlined in this research, we will continue to progress into a greener economy.

REFERENCES

- Aliabadi, A. and Shamekhi, A. 2012. Recent Developments in Gas Flaring and Venting Reduction. Paper presented at the SPE Middle East Health, Safety, Security, and Environment Conference and Exhibition, Abu Dhabi, UAE. Society of Petroleum Engineers SPE-152024-MS. DOI: 10.2118/152024-ms.
- Blanchard, R. Analysis of Well Completion Data for Bakken Oil Wells. Resilience.com. <http://www.resilience.org/stories/2013-11-22/analysis-of-well-completion-data-for-bakken-oil-wells>. Accessed 11/25/2013.
- Brown, T., Minton, B. Small Scale LNG Liquefaction and Ngl Recovery Is Supercool. S-Con, Inc. http://www.sconinc.com/index.php?page_id=52&id=1. Accessed 7/1/14.
- Gore, J.A. 2013. Dual Fuel Engines. In *Powered by Natural Gas Workshop:32*. San Antonio, TX: Cummins.
- Government, N.D.S. Historical Monthly Gas Production and Sales Statistics. <https://www.dmr.nd.gov/oilgas/stats/statisticsvw.asp>. Accessed 7/1/14.
- Heinn, E. 2013. Dual-Fuel Progress in Reliability and Performance for the Oil and Gas Market. Paper presented at the 2013 SPE / IADC Drilling Conference and Exhibition, Amsterdam, The Netherlands. SPE-163493-MS. DOI: 10.2118/163493-ms.
- Hill, D.G., Johnson, J., Bell, J.W. et al. 2011. Natural Gas as a Fuel in Drilling Operations-Analysis, Testing and Implementation. Paper presented at the SPE/IADC Drilling Conference and Exhibition, Amsterdam, The Netherlands. SPE-140357-MS. DOI: 10.2118/140357-ms.
- Juergens, J. *Personal communication*. Flexgen Power Systems. jjjuergens@flexgenpowersystems.com. Communicated on 7/23/14.
- Keever, J. Natural Gas-Powered Rigs on the Rise in Oil Fields. Fuelfix. <http://fuelfix.com/blog/2013/01/24/natural-gas-powered-rigs-on-the-rise-in-oil-fields/>. Accessed 8/2/2013.
- Krauss, C. Applying Creativity to a Byproduct of Oil Drilling. http://www.nytimes.com/2013/12/18/business/energy-environment/applying-creativity-to-a-byproduct-of-oil-drilling-in-north-dakota.html?pagewanted=all&_r=0. Accessed 12/20/13.

- Kulkarni, P. Gas-Driven Hydraulic Fracturing and Drilling Cut Costs, Reduce Environmental Impact. Gulf Publishing Company. <http://www.gasprocessingnews.com/features/201307/gas-driven-hydraulic-fracturing-and-drilling-cut-costs,-reduce-environmental-impact.aspx>. Accessed 9/5/2014.
- Lafleur, R.H.C. 2013. Natural Gas Fuel for Drilling and Hydraulic Fracturing: The Basics of Natural Gas Power & Fuel. www.efdsystems.org Accessed 8/3/2014.
- Mustafi, N.N., Raine, R.R., and Verhelst, S. 2013. Combustion and Emissions Characteristics of a Dual Fuel Engine Operated on Alternative Gaseous Fuels. *Fuel* **109** (0): 669-678. DOI: <http://dx.doi.org/10.1016/j.fuel.2013.03.007>
- Reduction, G.G.F. Estimated Flared Volumes from Satellite Data, 2007-2011. Global Gas Flaring Reduction. <http://go.worldbank.org/D03ET1BVD0>. Accessed 8/2/2013.
- Scheyder, E. Exclusive: Bakken Flaring Burns More Than \$100 Million a Month. Reuters. <http://www.reuters.com/article/2013/07/29/us-bakken-flaring-idUSBRE96S05320130729>. Accessed 8/2/2013.
- Shauk, Z. Baker Hughes Using Natural Gas in Fracturing Jobs. Fuelfix. <http://fuelfix.com/blog/2012/11/26/baker-hughes-using-natural-gas-in-fracturing-jobs/>. Accessed 8/2/2013.
- Siegel, H. Bakken 5-Year Drilling & Completion Trends. <http://www.dtcenergygroup.com/bakken-5-year-drilling-completion-trends/>.
- Soares, C. 2008. 7 - Gas Turbine Fuel Systems and Fuels. In *Gas Turbines*, Burlington, MA: Butterworth-Heinemann.
- Ternes, S. 2013. Drilling & Production with Natural Gas. In *Powered by Natural Gas Workshop*, ed. Ternes, S. San Antonio, TX: Caterpillar.
- Toolbox, T.E. Combustion Fuels- Carbon Dioxide Emmission. http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html. Accessed 4/25/14.