WYOMING LNG ROADMAP

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Prepared by

GLADSTEIN, NEANDROSS & ASSOCIATES

www.gladstein.org

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OVERVIEW

Wyoming ranks third among U.S. states for natural gas production, providing about nine percent of the nation's total domestic volume. Over the last few years, there has been significant momentum with both manufacturers and end users to use liquefied natural gas (LNG) as a supplement to diesel fuel for powering North America's high-horsepower (HHP) vehicles and equipment. To date, the State of Wyoming has played an important role in the development of LNG as a fuel for HHP applications that include heavy-duty vehicles, equipment and locomotives. Today, interest across America is strong and the potentials are very large. However, the market for LNG as a mainstream fuel for HHP applications remains young and thus far mostly limited to a pilot-demonstration scale.

This study finds that Wyoming—with its history, strong state leadership, status as a world-class energy producer, and cutting-edge educational system—is well positioned to lead the nation in the development of a robust, sustainable LNG industry for HHP applications. The payoffs for Wyoming's economy and citizens are potentially very large. Four specific types of HHP vehicles and equipment—mine haul trucks, locomotives, drill rigs, and pressure pumping services—are special workhorses of Wyoming's huge (10.35 quadrillion BTU per year) energy economy. Major progress has recently been made towards sustainable commercialization of LNG-enabling technologies for these HHP applications. The net result is that extraordinary opportunity now exists for Wyoming to become a leading producer of "home grown" LNG, which can then be consumed by its own prolific HHP fleets while also being exported to nearby states that have similar needs. Potentially, there will be significant regional demand for Wyoming LNG for use in HHP applications, such as locomotives, mining operations, and oil & gas plays in neighboring states.

Barriers and challenges exist, however, along the road for Wyoming to become a major producer and consumer of LNG, and to realize the associated benefits. Governor Matt Mead has been at the forefront of the state's efforts to identify, address and overcome these barriers and challenges, as evidenced by his "Leading the Charge" energy plan for Wyoming (May 2013). One important theme of the Governor's energy plan is to enhance and expand the value of the state's vast natural gas resources. A specific objective is to "develop the use of LNG in HHP applications such as mine haul trucks, railroads, oil and gas drilling operations, long-haul trucking operations, and other heavy-duty applications."

STUDY ORIGIN AND OBJECTIVE

This Wyoming LNG Roadmap Study was initiated by the Governor's office in mid-2013. The project is equally funded by the State of Wyoming and industry stakeholders. Building on the Governor's vision, this Roadmap characterizes the many choices, considerations, opportunities, challenges and barriers for wide-scale use of natural gas in Wyoming's prolific HHP vehicle and equipment sectors, and it lays out initial steps in the process to attain that vision.

There are three major reasons in general to use natural gas in HHP applications such as mine haul trucks, locomotives, drill rigs, pressure pumping equipment, and large on- or off-road vehicles. These are to:

- Reduce costs of ownership through lower fuel costs
- Reduce emissions of criteria pollutants and greenhouse gases
- Diversify America's fuel mix by using an abundant, domestically produced energy source

The magnitude of benefits that natural gas can provide in these three areas will depend on a number of factors. Achieving attractive economics for a given application is primarily a function of two key parameters: 1) high annual fuel use and 2) a large price differential between LNG and diesel. In Wyoming's very large HHP sectors, both these factors point to very favorable economics for equipment operators that are able to make the conversion over to LNG (or other forms of this abundant, low-cost clean fuel).

The goal of this report is to identify where, when and how such a transition can begin to occur, and what actions can potentially be taken, to help facilitate this conversion. This can provide major benefits to the citizens of Wyoming, as well as the companies that produce and/or sell related products and services within the state.

SUMMARY OF KEY STUDY FINDINGS

To better characterize the potential benefits that could be achieved via a transition to lower cost natural gas, it was first required that a "baseline" inventory be established; this includes the numbers of HHP units (vehicles and equipment) being operated within Wyoming, and the volumes of diesel fuel they collectively consume. Using informed assumptions where hard data are lacking, it is estimated that the total volume of diesel collectively consumed in Wyoming within these six HHP sectors is approximately 634 million gallons of diesel fuel per year.

Vehicle or Equipment Type	Per Unit Diesel Fuel Consumed (gal/yr)	Estimated Units in WY Inventory	Total Estimated Diesel Consumed (gal/yr)
Mine Haul Trucks	273,900	440	120,516,000
Locomotives	300,000	405	121,500,000
Drill Rigs	373,750	50	18,687,500
Pressure Pumping Services	240,000	120	28,800,000
On-Road Semi Tractors	9,500	13,133	124,763,500
Other Large Off-Road Equipment	73,000 to 85,000	2,600 to 3,000	220,000,000
Grand Total			**634,267,000**

Note: "Other Large Off-Road Equipment is a very diverse category, with a wide array of equipment types and sizes. Inventories and fuel usage estimates were back calculated from Wyoming fuel sales and other factors. See Section 3.5 for further details.

"Feasibility factors" were applied to further evaluate which of the six sectors are most conducive to use natural gas in general, and LNG in particular. Four different HHP vehicle and equipment types emerged for further focus: 1) mine-haul trucks, most of which serve coal mines in the Powder River Basin (PRB); 2) freight locomotives that primarily move coal from PRB mines to points throughout the United States; 3) drill rigs that are the staples of Wyoming's oil and gas drilling operations, and 4) pressure pumping services (PPS) that are used to hydraulically fracture ("frack") wells across the state. Applying feasibility factors and other assumptions, the potential "upper bound" demand for LNG in Wyoming over the decade is estimated to be approximately 186 million LNG gallons per year (GPY). This is equivalent to 509,000 gallons per day (GPD) of LNG production, or approximately 38.7 million cubic feet per day (MMcf/D). [1]

This upper bound estimate for LNG demand in Wyoming's HHP sectors refers to an approximate time frame of 10 to 20 years to reach full fruition, although a significant portion may be needed within five to 10 years. For this LNG demand to be fully realized, LNG-ready HHP vehicles and equipment will need to be deployed in careful orchestration with Wyoming's build-out of the supporting fuel production, distribution and dispensing facilities.

Major new sources of LNG supply will need to be developed throughout the state. Driven by market forces, LNG suppliers

[1] Using LNG at 74,720 BTU/gal (LHV) and natural gas at 983 BTU/ft^3.

will site their future liquefaction facilities in close proximity to centers of concentrated fuel demand. It appears clear that Wyoming's greatest concentrations of potential LNG demand will be in and around the PRB (Campbell and Converse Counties), and in the southwestern part of the State (Sublette, Lincoln, Sweetwater, and Uinta Counties).

An estimated $327 to $400 million[2] in capital investments will be required to build out Wyoming's infrastructure capable of producing, distributing, storing and dispensing 509,000 GPD of locally sourced LNG. This level of investment in state-of-the-art gas processing facilities, LNG production plants and supply chain infrastructure will bring compelling economic benefits to Wyoming that are expected to include, but not be limited to, the following:

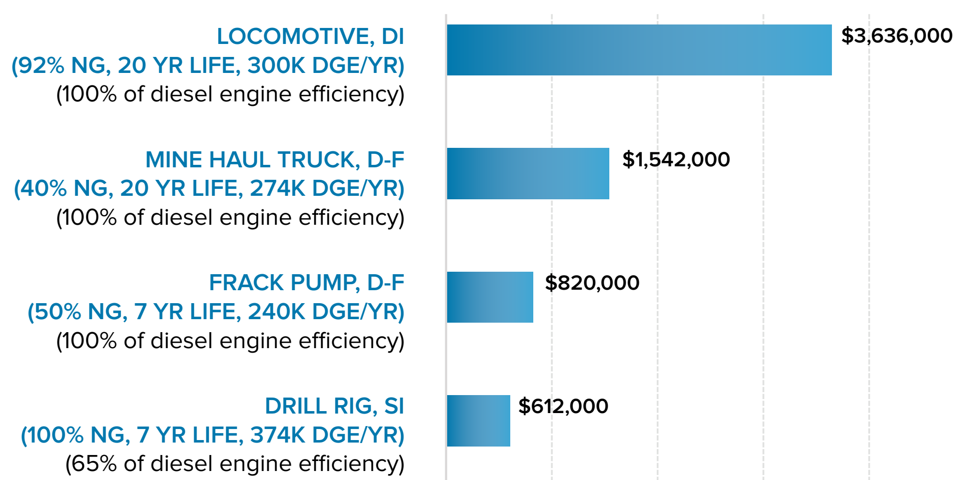
- Direct infusions of capital into the Wyoming economy
- Creation of well-paying technology-based jobs (construction, operations, etc.)
- New opportunities for Wyoming to develop educational programs and curriculum focused on clean energy technology in general, and the HHP LNG sector in particular.

As Wyoming's LNG infrastructure is built and becomes operational, Wyoming's fleets with HHP vehicles and equipment will have progressively greater opportunity to realize very significant reductions in their operating costs. These operational cost savings will accrue over the remaining lives of vehicles and equipment that are enabled to operate on LNG. This study estimates that **end users of mine haul trucks, locomotives, drill rigs and PPS in Wyoming can collectively realize approximately $166 million in fuel cost savings each year** over the remaining useful lives of the natural-gas-powered equipment. This assumes that conversions to natural gas operation will occur in the identified numbers and types. While this analysis does not factor in the capital costs of equipment conversions, all four types of vehicles / equipment provide very attractive net present values (NPVs) over their useful lives to pay back the associated conversion costs (see the graph below, with greater detail provided in Section 4).

[2] GNA's estimate is $327 million; Clean Energy Fuels indicates this would cost "closer to $400 million."

Estimated NPV of Investments (One HHP Unit Operation on LNG)

(Key Variables: Fuel Substitution Rate, Efficiency, Life, Baseline Diesel Usage)



Based on preliminary estimates for incremental capital costs of natural gas equipment and current industry inputs regarding assumed natural gas (NG) fuel substitution rates. Assumes 7% discount rate and a fuel price spread of $1.50 per diesel gallon equivalent (DGE).

D-F = Dual-Fuel (Compression Ignition); S-I = Spark Ignition; DI = Direct Injection using Westport™ HPDI

STUDY CONCLUSIONS AND RECOMMENDATIONS

It is clear that a confluence of market forces will ultimately decide where, how and when an initial Wyoming LNG infrastructure build-out will proceed. This report concludes it is unlikely that a large centralized LNG production plant will be the best approach to supply the state's estimated LNG demand of 509,000 GPD. This is primarily due to 1) the risks developers would face in building large-scale LNG plants in tandem with a one-to-two decade phased LNG market, and 2) the higher costs of LNG for end users if it is transported over distances exceeding about 250 miles.

Instead, the optimal approach appears to focus on multiple localized mid- to small-scale (i.e. 100,000 to 250,000 GPD) "hub-and-spoke" LNG production plants. These centralized but smaller LNG plants may be preceded and/or augmented by micro-scale distributed LNG production plants (5,000 to 10,000 GPD production capacity), in more-remote locations where smaller volumes of LNG are required to support a start-up or smaller-scale operation.

Based on many factors—such as Wyoming's current diesel-use volumes and patterns; sector-specific momentum; application-specific potential to use natural gas; and geographic synergy—it appears that the following numbers of small- to mid-sized (100,000 GPD) LNG plants will / should be built in Wyoming over the next 10 to 20 years, in the following general locations:

1. Three (3) to four (4) in the greater PRB region of Campbell and Converse Counties, and

2. One (1) to two (2) in southwestern Wyoming in the general region of Sublette, Lincoln, Sweetwater and Uinta Counties.

Several core recommendations are put forward to assist the State of Wyoming, Governor Matt Mead and other interested stakeholders towards systematic development of LNG infrastructure in tandem with deployments of LNG-fueled HHP vehicles and equipment in Wyoming:

1. Identify and prioritize potential locations for new LNG production facilities via a basic screening process that assesses compatibility for land use requirements, utility services, and other important siting criteria.

2. Review and assess existing Wyoming state policies and programs that could be expanded to assist in the development of the LNG market for HHP applications.

3. Mobilize available resources to help remove existing impediments to LNG growth; examples of such barriers include: a) the federal highway excise tax on diesel and LNG is set on a volumetric basis, which taxes LNG at a 70 percent higher rate than diesel on an energy equivalent basis[3]; b) off-road diesel fuel is not subject to highway taxes; to avoid a significant price penalty against using LNG in off-road applications, it will need to be taxed comparably; c) weight limits for on-road trucks can reduce the payload of LNG-fueled trucks; and d) restrictions on hauling LNG by rail can limit locomotive deployments.

4. Educate appropriate permitting authorities, officials and other key decision makers about relevant codes, standards, regulations and permitting requirements for LNG facilities of various sizes and configurations.

5. Educate the general public about potential economic, educational, environmental, and energy benefits to Wyoming citizens from large-scale use of natural gas in its HHP sectors.

6. Develop LNG-focused advanced educational programs with the state's university programs, community colleges, vocational and trade schools, and even high schools. Attempt to link these classroom-based training sessions with the emerging market in Wyoming to serve as the world's first LNG "field laboratory" for HHP applications.

7. Expand, extend or initiate new LNG pilot demonstrations within the state of Wyoming.

8. Convene an annual stakeholder summit in Wyoming for interested partners and stakeholders to maintain ongoing dialogue around these issues.

These recommendations, and others presented within the report, will help to remove common initial development barriers to these projects, and will also help to provide guidance and assistance to those working to implement the goals of this Wyoming LNG Roadmap Report.

[3] At least one Congressional bill (H.R. 2202, the "LNG Excise Tax Equalization Act of 2013") has been initiated to address this issue.

1. BACKGROUND AND INTRODUCTION

Although in its infancy, the North American market for liquefied natural gas (LNG) as a fuel for high-horsepower (HHP) diesel-powered vehicles and equipment continues to steadily grow. To date, the State of Wyoming has played an important role in the development of LNG as a replacement for diesel in HHP applications. The two LNG production plants near Evanston were the critical source of fuel for the initial rise of Southern California's LNG market in the early 1990s. Within this same timeframe, Burlington Northern initiated a successful demonstration project to operate one of its locomotives on LNG, hauling coal from the PRB to power plants in the Midwest. Also in the '90s, two Wyoming brothers with experience working in the local gas fields started a small LNG fuel station construction business. This Wyoming-based business (Northstar) quickly grew into the largest and most successful LNG fuel station development company in America, and is now owned by Clean Energy. Companies like Encana are leading efforts in the oil & gas sector to use natural gas in drill rigs and pressure pumping applications, with major deployments in southwestern Wyoming's Jonah field. These E&P operations in Wyoming are supported by large numbers of heavy-duty trucks, and potential exists to power increasing numbers with natural gas engines. In the mining sector, Alpha Resources initiated a groundbreaking project to operate a pilot fleet of three ultra-class mine haul trucks on LNG, and recently announced plans to expand the demonstration to 12 trucks. Arch Coal recently announced plans to host the second PRB demonstration of LNG haul trucks, at one of the world's largest coal mines.

Through combinations of this history, strong leadership at the state level, its status as a world-class energy producer, and a cutting-edge educational system, Wyoming is well positioned to continue and strengthen its leadership in the development of a robust, sustainable LNG industry for HHP applications. The payoffs for Wyoming's economy and citizens are potentially very large. However, to fully realize such benefits, there remain significant barriers to overcome and challenges to meet.

Governor Matt Mead has been at the forefront of Wyoming's efforts to identify, address and overcome these barriers and challenges. Since taking office in early 2011, the Governor has put strong focus on advancing Wyoming's economic growth and energy strategy. In LNG, the Governor has recognized opportunity for Wyoming to address both issues, while also positioning Wyoming's excellent educational system for the future and improving the environment.

The Governor has recognized the need for a government-industry partnership that can move this vision forward, in these very early stages of sustainable LNG markets. In January 2013, he convened a meeting in Cheyenne of key LNG industry stakeholders to further explore the opportunities available to Wyoming and the businesses that operate within the state. From this meeting, the Wyoming LNG Roadmap Study and report were born. This was followed by release in May 2013 of the Governor's energy report, Leading the Charge: Wyoming's Action Plan for Energy, Environment and Economy, and Governor Mead's keynote speech at the September 2013 *Natural Gas for High Horsepower (HHP) Summit* in Chicago. In addition to speaking at the HHP Summit, the Governor convened a second meeting with key industry leaders and stakeholders. Also in 2013, Governor Mead and his representatives met individually with a myriad of LNG industry stakeholders to better understand this rapidly developing market and Wyoming's many related opportunities. The Governor continues to be actively engaged with industry leaders who are leading commercialization efforts for natural gas technologies that hold promise to advance Wyoming's world-class energy, economics, educational, and environmental goals.

This Wyoming LNG Roadmap Report builds on the Governor's vision, by characterizing the opportunities, challenges and barriers for wide-scale use of natural gas in Wyoming's HHP vehicle and equipment sectors, and laying out initial steps in the process to steadily progress towards attainment of that vision. The purpose of the report is to identify tangible developments in markets and opportunities for the Governor and Wyoming to further facilitate these business-driven activities, enabling State benefits to be more quickly realized.

1.1. STUDY OBJECTIVE

The objective of this study is to provide details and information that can assist the State of Wyoming and its private-sector stakeholders to achieve the following LNG Roadmap goals:

- Lead the nation in efforts to utilize domestically produced, low-cost clean fuels such as natural gas;
- Increase the demand for natural gas produced in Wyoming, thus increasing in-state revenues and supporting job creation;
- Reduce the production costs, supply chain and distribution expense, and the environmental footprint of important Wyoming energy sources, thus making Wyoming's energy economy and related products more competitive on the world market;
- Develop progressive Wyoming-based LNG transportation projects in rapidly developing HHP markets that include mining, rail, oil and gas operations, over-the-road trucking, and other large off-road applications;
- Provide major new opportunities for cutting-edge education, technical training, skill development, and high-income employment for Wyoming's residents.

Both short- and long-term goals must be identified and achieved to provide economically sustainable, long-term market development in Wyoming for natural-gas-fueled HHP vehicles and equipment. A key short-term goal is to help identify and assist end users of diesel engines whose operations can best support cost-effective switching to natural gas operations. These priority targets are likely to be HHP fleets that currently use high volumes of diesel fuel in areas most conducive to an efficient LNG distribution system. These fleets—such as those in mining, rail, oil & gas, and other high-fuel-use applications—consume sufficient volumes of diesel fuel that converting to natural gas can provide compelling payback periods for the significant capital investments that will be required.

It is important to note that Wyoming's unique energy-production economy will require a hand-tailored natural gas infrastructure network. For many other states and regions considering an LNG roadmap based on on-road heavy-duty trucks, the general approach has been to initially target a public-access infrastructure corridor that can support NGVs in higher-fuel-consuming regional, intrastate and interstate trucking applications. This necessitates targeting fleets and users along key identified highway routes. While this approach can also work well for Wyoming in its on-road trucking sector, Wyoming's status as a world-class energy producer, consumer and transporter (next section) across many HHP sectors will bring unique opportunities and challenges in expanding its natural gas markets and fueling infrastructure.

1.2. WYOMING'S ENERGY ECONOMY AND BUSINESS ENVIRONMENT

1.2.1. WORLD-CLASS ENERGY PRODUCTION

Wyoming is America's 10th largest state, with an area of approximately 100,000 square miles. With vast natural resources for coal, oil, gas, wind and uranium, it is one of the world's most prolific energy-producing regions. According to the U.S. Energy Information Administration, Wyoming:

- Produced 10.35 quadrillion British Thermal Units (BTUs) of energy in 2011; this was second only to Texas, which produced 12.58 quadrillion BTUs.
- Produced nearly 11 percent of the energy consumed in the United States in 2011.
- Exports more energy than any other state, sending about 10 quadrillion BTUs (95 percent of its energy production) to other states, or abroad.
- Ranks number one in coal production, and produces about 40 percent of all coal mined in the United States.

- Exports its coal by rail to 35 states (2011 data), which is used to power more than 35 percent of America's electricity generation plants.
- Ranks number three among U.S. states for natural gas production (2,143 trillion cubic feet in 2011, or about nine percent of the nation's domestic natural gas production).
- Has an estimated 35 trillion cubic feet of natural gas reserves, amounting to about 12 percent of total U.S. reserves.
- Ranks eighth among U.S. states for oil production, and tenth for proven oil reserves.
- Provides 40% of America's Class 5 – 7 on-shore wind power[4].

[4] This fact provided by the State of Wyoming. Estimates of wind power density and average speed are presented as wind classes ranging from a low of 1 to a high of 7.

1.2.2. ENERGY-RELATED STATE GDP CONTRIBUTIONS

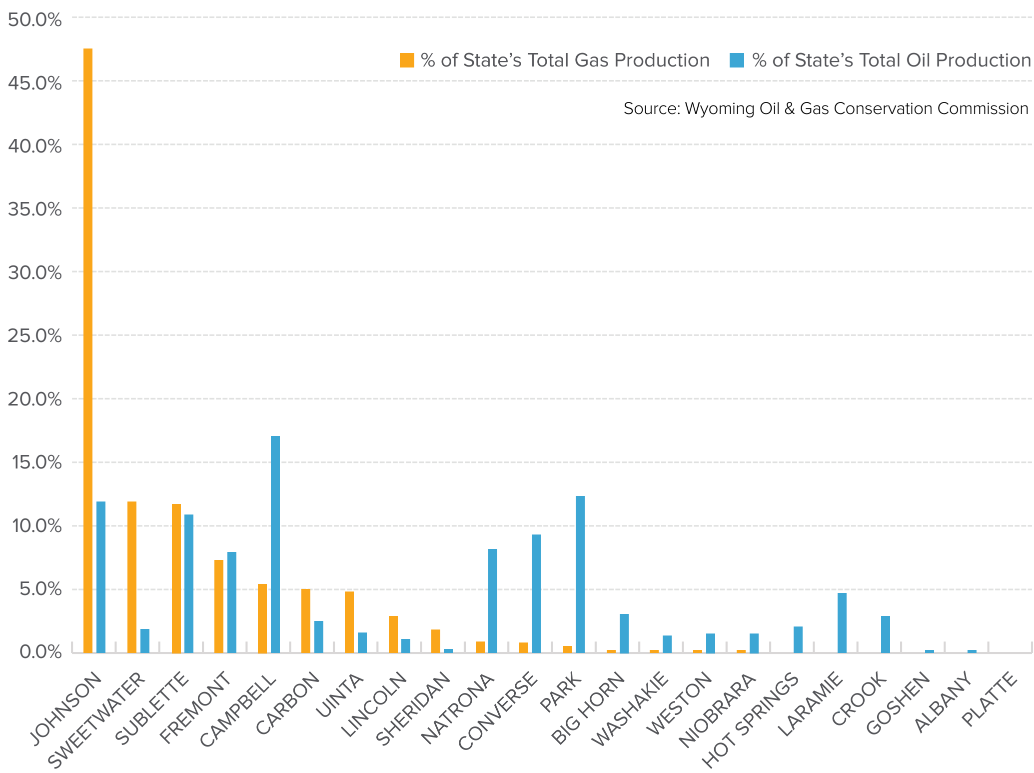
Not surprisingly, business activities associated with harnessing Wyoming's energy resources are major engines of its economy. In 2010, Wyoming's Gross Domestic Product totaled almost $32 billion. As shown in Table 1, about $9.45 billion (30 percent) of that GDP was generated in Wyoming's collective "Mining" sector, which is defined to include exploration and production activities for coal, oil and natural gas. Another $1.64 billion (five percent) of that GDP was generated in the Transportation and Warehousing Sector, the bulk of which came from three modes of transportation: 1) rail ($0.87 billion), 2) truck ($0.41 billion), and 3) pipeline ($0.12 billion)[5]. As further quantified in this report, these activities involve heavy use of HHP engines that collectively burn an estimated 634 million diesel gallons per year in Wyoming. All of Wyoming's 23 counties strongly benefit from this wealth of energy-related activities; however, the magnitude of economic impacts varies significantly by county. This is largely a function of specific commodity production levels in each county. Coal production is dominated by the 11 surface coal mines located within Campbell County, as part of the vast Powder River coal field. Crude oil and/or natural gas are produced in nearly every Wyoming County. Campbell County was the leading crude oil producer in 2012, followed by Park and Sublette Counties. Sublette County was the largest natural gas producer, followed by Johnson and Sweetwater Counties (see Figure 1). While these Wyoming counties benefit the most from revenues directly generated by energy production activities, neighboring counties also benefit significantly by providing goods and services needed by the industry.

[5] Wyoming Department of Administration & Information (Economic Analysis Division), "Wyoming Employment, Income, and Gross Domestic Project Report," 26th Edition, December 2012, accessed online at: http://eadiv.state.wy.us/i&e/Inc_Emp_Report10.pdf.

Table 1. Breakout of contributions to Wyoming's 2010 GDP by key HHP sectors

Wyoming Economy Sector	Subsector	Subsector Contribution to GDP (2010)	Total Sector Contribution to GDP (2010)
Mining	Oil & Gas Extraction	$5,804,000,000	**$9,447,000,000**
	Other Mining	$2,399,000,000	
	Mining Support Activities	$1,244,000,000	
Transportation and Warehousing (excluding U.S. Postal Service)	Rail Transportation	$ 866,000,000	**$1,636,000,000**
	Truck Transportation	$ 406,000,000	
	Pipeline Transportation	$ 122,000,000	
	Other (Air, Water, Transit, etc.)	$ 242,000,000	
All Other Sectors	(Various)		$20,836,000,000
Grand Total: State of Wyoming GDP in 2010			**$31,919,000,000**
Source: Wyoming Dept. of Administration & Information (see footnote)			

Figure 1. Percent of Wyoming's 2012 oil and gas production by county



1.2.3. ENERGY-RELATED STATE REVENUE STREAMS

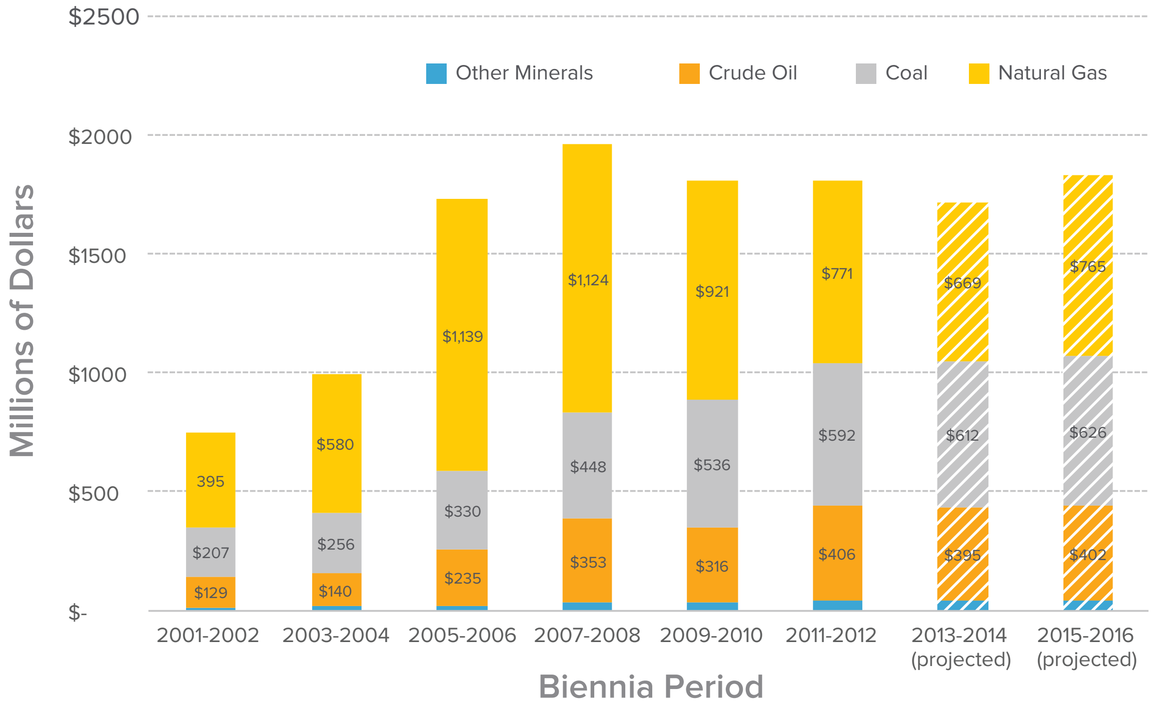
A variety of tax types applicable to minerals are responsible for major portions of Wyoming's revenues. Like many states, Wyoming charges producers of minerals a severance tax that is remitted monthly based on the mineral's "fair market" value at the point of production, before processing or transportation. Severance taxes help insure that costs associated with resource extraction—such as road construction and maintenance, and environmental protection—are paid by the producers, helping to alleviate potential impacts on state and local taxpayers.

Wyoming's severance tax rates for oil, natural gas and coal (surface mines) range from six to seven percent of their respective production values. These severance taxes are extremely important to Wyoming's overall revenue stream; over the last 15 years they have contributed between 15 and 30 percent of the total tax collections in Wyoming. As shown in Figure 2 (data from the Wyoming Taxpayers Association), production of natural gas, crude oil and coal in Wyoming has generated billions of dollars of severance tax revenues over the last decade, and this trend is projected to continue.

Wyoming's severance taxes are allocated towards many budgetary needs, including the General Fund, the Budget Reserve Account, counties, cities / towns, and the state's road infrastructure. In addition, a very significant portion is put towards a permanent endowment for the State that can earn interest and help pay for future needs.[6] Wyoming minerals are also charged a county gross products tax that is based on the value of minerals produced during the previous year. These "ad valorem" taxes, which also total more than $1 billion annually in some years, are used to fund K-12 education (nearly 71 percent) along with counties, cities / towns, and community colleges. Moreover, since a significant percentage of Wyoming mineral production comes from federal land, the U.S. government collects Federal Mineral Royalties (FMR) on such production. Like most states, Wyoming receives very significant revenue from this source; in 2009, Wyoming's share of FMRs was more than $835 million. In addition to Wyoming's General Fund, FMR revenues are distributed to a wide array of educational interests in the State.

[6] Wyoming Taxpayers Association, "Severance Taxes," accessed online at http://www.wyotax.org/severance_taxes.aspx.

Figure 2. Severance tax revenues in Wyoming from mineral production, 2001-2006



"Coal lease bonuses" are another significant source of revenue for Wyoming (about $219 million in 2009). Coal lease bonuses are distributed to four different entities, with the majority going to Wyoming's School Capital Construction Account (nearly $200 million in FY 2009).[7]

Overall, the total taxable value of the various minerals mined in Wyoming is more than $13 billion each year. As indicated in Table 2, Wyoming's "big three" commodities—oil, gas and coal—are responsible for more than 95 percent of that $13 billion in annual taxable value.

[7] Dean Tempte, Senior Legislative Analyst, Wyoming Legislative Service Office, "Wyoming Severance Taxes and Federal Mine Royalties," updated July 2010, Power Point presentation accessed online at: http://legisweb.state.wy.us/budget/wyosevtaxes.pdf.

Table 2. Total taxable value in Wyomingof various mineral types (2012)

Mineral / Commodity	Taxable Value	Percent of Total
Oil & Gas	$8,700,655,927	64.4 %
Coal	$4,178,694,059	30.0%
Trona	$451,440,510	3.3%
Bentonite	$87,579,599	0.6%
Uranium	$47,567,992	0.4%
Sand & Gravel	$27,437,237	0.2%
All Other Minerals	$12,618,760	0.1%
Total Taxable Value	**$13,505,994,084**	**100.0%**
Source: Wyoming Mineral Tax Division, Fact Sheet, Fiscal Year 2013		

Like the overall U.S. economy, Wyoming underwent a severe recession that began in the 2008 timeframe. Wyoming's economy is very closely linked to its energy industry—especially with regard to production, pricing and sales of three commodities: oil, gas, and coal. This is made very clear in the following example findings in Wyoming's "Economic Summary: 1Q2013."[8] The Mining sector comprised 29.0 percent of Wyoming's GDP in 2010; by contrast, it comprised only 1.7 percent of the U.S. GDP.

Wyoming's economic growth is often largely dictated by prices for coal, oil and natural gas.

When one county's mineral extraction booms (e.g., oil exploration in Converse County), neighboring counties that provide many types of services (e.g., Natrona) also benefit.

Taxable sales of minerals play a major role in each county's revenues, e.g., Sublette and Uinta counties experienced significant declines in taxable sales "likely associated with a re-focusing of drilling activity from natural gas to oil production."

Personal income in Wyoming tracks closely to where mining activities are the greatest. Sublette County—home to two of the nation's largest natural gas fields, the Pinedale Anticline and Jonah Field—demonstrated Wyoming's second highest per capita personal income. Higher wages associated with the Mining sector and small population-size were the reasons for Sublette's high PCI.

Sublette County also had the highest average wage per job in 2010 ($56,489); this was followed by mining-rich Campbell County ($55,832), and Sweetwater County ($52,115).

8 Wyoming Economic Analysis Division, "Economic Summary: 1Q2013," accessed online at http://eadiv.state.wy.us/wef/Economic_Summary1Q13.pdf.

1.2.4. DEMOGRAPHICS, LAND USE AND BUSINESS ENVIRONMENT

Wyoming has the second lowest population density among U.S. states. It is dominated by vast open spaces occupied by relatively few people. This helps enable exploration and production of Wyoming's numerous energy resources with minimal adverse impacts on people. It also means there is extensive room for Wyoming to grow its infrastructure for energy production and extraction, while using state-of-the art methods to minimize environmental and natural resource impacts.

Much of these energy resources are located on public lands, managed by Federal agencies such as the Bureau of Land Management and the U.S. Forest Service. Wyoming is home to world-class hunting, fishing, hiking, camping, skiing and many other types of outdoor recreational activities. Wyoming has a long, successful track record of carefully managing and balancing its public lands for multi-use purposes.

Wyoming is known to be a very business-friendly state. As noted by the Wyoming Business Council, there are no state income taxes (corporate or personal). Wyoming also offers low energy costs, an educated workforce, an outstanding quality of life, low operating costs, and low crime rates.[9] In October 2013, the Tax Foundation ranked Wyoming as the top overall State for low corporate and individual income taxes.[10] According to the Pollina Corporate Real Estate's "Top 10 Pro-Business States of 2012" study, Wyoming ranked third in the nation as one of the "best places to do business." This annual study examines 32 "pro-business" factors and how each state ranks in such categories.

9 See Wyoming Business Council website, http://www.wyomingbusiness.org/energy.

10 The Tax Foundation, "2014 State Business Tax Climate Index," http://taxfoundation.org/article/2014-state-business-tax-climate-index.

1.3. WYOMING AIR QUALITY

Wyoming air quality is generally among the most pristine found in any lower 48 state. However, intense energy production and transport results in emissions of ozone precursors (nitrogen oxides and hydrocarbons), and other harmful air pollutants. This has caused intermittent air quality problems in certain Wyoming counties. Many man-made and natural emissions sources contribute to these problems, but the primary direct source of ozone-precursor emissions is combustion of fossil fuels, including heavy-duty diesel engines that power Wyoming's energy economy.

Recently, it was found that elevated levels of ozone can occur during winter months in Wyoming's Upper Green River Basin (UGRB). Most of the UGRB is located in Sublette and Sweetwater counties, which are Wyoming's two largest oil and gas producers. In July 2012, the UGRB was designated by EPA as being in "marginal" nonattainment of federal national ambient air quality standards (NAAQS) for ozone. Multiple sources contribute to the NOx and hydrocarbon emissions that form ozone in the presence of sunlight. Clearly, this includes diesel-fueled drill rigs and pressure pumping equipment used in the heavy E&P operations of these two counties. In addition, significant emissions contributions are being made by a wide array of diesel engines that support oil and gas operations. For example, these oil and gas facilities are located in remote areas that tend to lack electricity connections. Consequently, power for fundamental operations—such as site lighting and pumps that move oil and gas into pipelines—has largely been provided by diesel generator sets.[11]

In April 2012, the Wyoming Department of Environmental Quality (WDEQ) released its "Ozone Strategy for the Upper Green River Basin." The objective is to bring the UGRB back into attainment with federal ozone NAAQS. This strategy includes new controls and compliance checks to reduce ozone-precursor emissions. For example, WDEQ announced in 2013 that it will conduct increased compliance checks on diesel engines at oil and gas production facilities across the state. These additional checks test engine operation "in the real world environment, including the effects of weather conditions, elevation, and loading." Reportedly, these requirements "have been well received by the industry" and have already resulted in improved air quality.[12]

Wintertime ozone nonattainment in southwestern Wyoming remains a significant problem, which is why the State is taking these actions to mitigate ozone-precursor emissions and other harmful pollutants. Figure 3 helps to provide perspective and context about Wyoming's overall air quality; it compares the number of EPA-designated days of unhealthy air quality during 2012 for three states: Wyoming, Texas, and California. In each state, the number of "unhealthy days for the general population"[13] are tallied for all counties that experienced at least one unhealthy day.

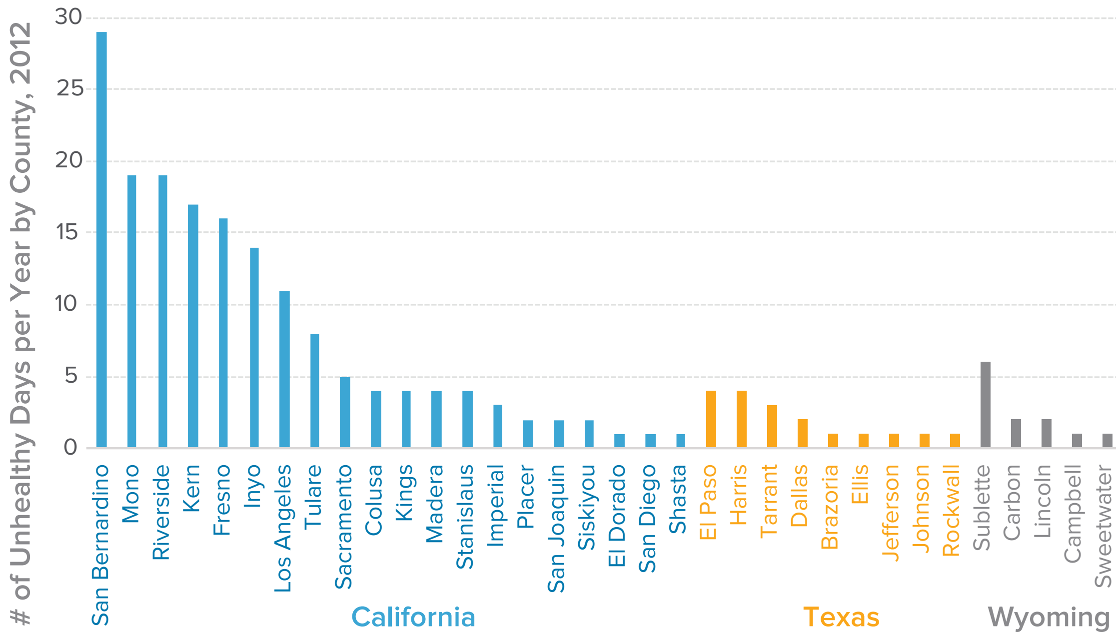
As the graph shows, California sets the benchmark as the state with America's worst air quality. This is reflected in the number of unhealthy days experienced in 20 different California counties, with one county having 29 unhealthy days in 2012. Texas is compared because it is similar to Wyoming in its status as a leading energy producer (and it, too, has a relatively low population density). In 2012, Texas had nine counties with at least one day of unhealthy air quality; two counties experienced four unhealthy days. For comparison, Wyoming had five counties with at least one unhealthy day of air quality, with the worst being Sublette County (six unhealthy days).

[11] Wyoming Department of Environmental Quality, "DEQ to increase compliance checks of engines at oil and gas production sites," new release, April 11, 2013, http://deq.state.wy.us/out/downloads/AQD_Tests_APR_2013.pdf.

[12] Wyoming Department of Environmental Quality, "DEQ to increase compliance checks of engines at oil and gas production sites," new release, April 11, 2013, http://deq.state.wy.us/out/downloads/AQD_Tests_APR_2013.pdf.

[13] EPA does not further define "unhealthy days" for the "general population with no specific health concern." The metric is based on an air quality index that tallies exposure to multiple unhealthful air pollutants, including ozone, carbon monoxide and particulate matter (which may include windblown dust).

Figure 3. Wyoming, California, and Texas: Number of Unhealthy Days for Air Quality by County, 2012



Source: US Environmental Protection Agency

1.4. PROJECT ORIGIN, OBJECTIVES AND CO-SPONSORS

1.4.1. GOVERNOR'S ACTION PLAN FOR ENERGY, ENVIRONMENT AND ECONOMY

In May 2013, Wyoming Governor Matthew Mead unveiled a new report entitled Leading the Charge: Wyoming's Action Plan for Energy, Environment and Economy.[14] The report lays out Governor Mead's strategy for achieving complex, interrelated goals for Wyoming involving energy, environment, economy, and education. It is divided into four main themes, as follows:

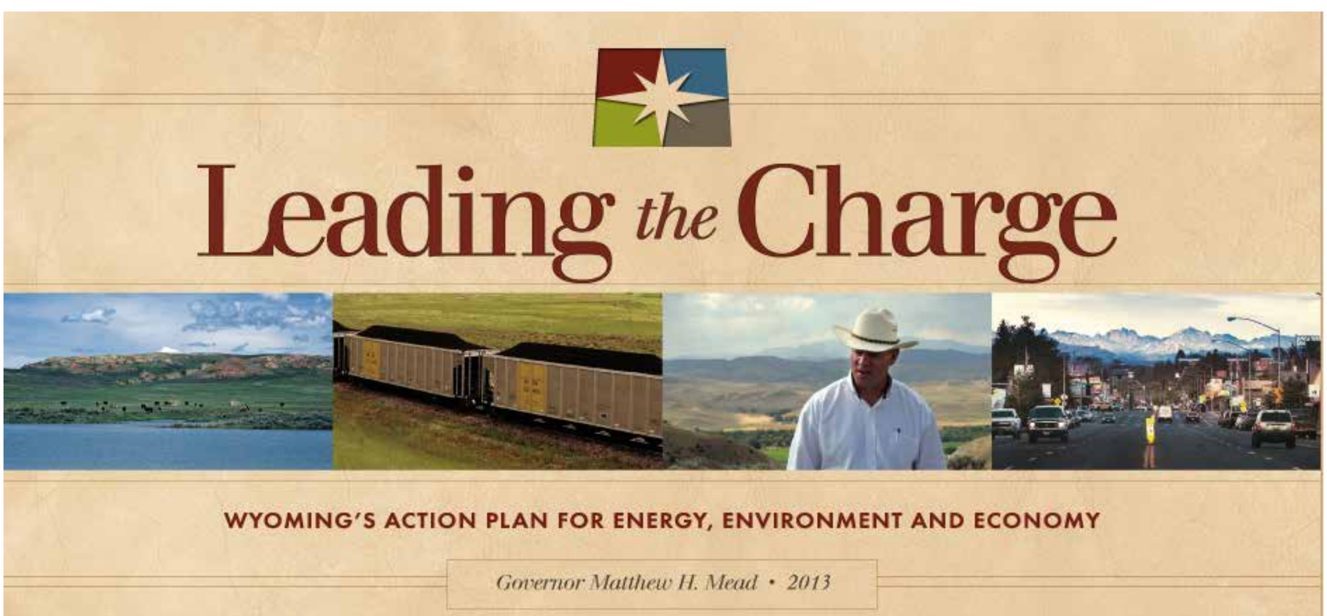
1. Economic Competitiveness, Expansion and Diversification
2. Efficient, Effective Regulation
3. Natural Resource Conservation, Reclamation and Mitigation
4. Education, Innovation and New Technologies

[14] For the full report, see http://wyomingenergynews.com/2013/05/governor-mead-unveils-comprehensive-wyoming-energy-policy/.

The Governor's action plan identified the clear need to expand use of natural gas in Wyoming's prolific population of HHP vehicles and equipment. Among the many recommended initiatives is the "…development of policy recommendations that government, industry and the public can use to identify opportunities and impediments to the expansion of LNG production and utilization in Wyoming." Major objectives, which are driven by combinations of the above-listed "E" themes (energy, environment, economy, education), include:

- To develop the use of liquefied natural gas (LNG) in HHP applications such as mine haul trucks, railroads, oil and gas drilling operations, long-haul trucking operations, and other heavy-duty applications.
- To promote CNG as a transportation fuel to increase demand from government, industry, and private fleets; and expand the number of CNG stations in Wyoming.

Figure 4. Governor Mead's 2013 Action Plan for Wyoming



1.4.1. PROJECT CO-SPONSORS

Based on Governor Mead's Energy Plan and follow-up from a January 2013 meeting between the Governor and Wyoming energy stakeholders, the Wyoming LNG Roadmap Study was initiated by the Governor's office. The project is equally funded by the State of Wyoming and numerous industry partners. As shown in Figure 5, co-sponsors from the industry side include energy developers, producers, and providers; oil & gas field service providers; and equipment & vehicle manufacturers, developers and/or providers.

Note: Eagle LNG Partners is a recently announced consortium comprised of Clean Energy, GE Ventures, GE Energy Financial Services, and Ferus Natural Gas Fuels. When this report was being finalized, the logo and "branding" for Eagle LNG Partners were still under development.

Figure 5. Wyoming LNG Roadmap Report Co-Sponsors

State of Wyoming

Energy Developers, Producers, Providers and/or Oilfield Services

Equipment & Vehicle Manufacturers, Developers and/or Providers

2. OVERVIEW OF NATURAL GAS IN HHP APPLICATIONS

There are three major reasons to use natural gas in HHP applications such as mine haul trucks, locomotives, drill rigs, pressure pumping equipment, and large on- or off-road vehicles. These are to: 1) reduce costs of ownership through lower fuel costs; 2) reduce emissions of criteria pollutants and greenhouse gases; and 3) diversify America's fuel mix by using an abundant, domestically produced energy source. The magnitude of the benefits that natural gas can provide in these three areas will depend on many specifics about the technology used and its applications. Further discussion is provided below; greater details in the context of specific applications are provided in subsequent sections.

2.1. ECONOMICS

America's "shale gas revolution" has resulted in an abundance of inexpensive natural gas for powering engines used in countless types of motor vehicles and equipment. This shale gas "is here for the long term" and—as further described in the discussion and graphics below—prices are expected to remain stable at well below diesel on an energy-equivalent basis.[15]

Comparing the costs of implementing a new technology and/or fuel should take into consideration the full life-cycle costs of both the baseline and alternative options. This is done by establishing the net present value of all upfront (year 1) capital costs, combined with any operational costs or savings that accrue over time. In the case of using LNG or other forms of natural gas in large diesel engines, achieving a positive net present value is strongly driven by the fuel price differential between the baseline fuel (diesel) and natural gas. However, there are numerous factors and choices that also affect capital and operational costs.

In addition, a proper comparison should take into consideration a baseline scenario that fairly represents the costs of not converting the targeted vehicle or equipment to operate on LNG. For example, alternatives to LNG might be to replace the existing equipment with new diesel equipment (e.g., to achieve lower emissions), or to rebuild the engine to upgraded specifications.

Traditionally, owners of heavy-duty vehicle and equipment fleets have tended to think in terms of year-to-year capital expenditures needed to purchase new equipment and operate existing equipment. Transitioning to any alternative fuel technology, including natural gas, requires a shift in thinking to better account for full life-cycle costs rather than just capital expenditures. This is because the capital costs of using natural gas and other alternative fuels tend to be significantly higher compared to conventional diesel-fueled vehicles and equipment, but there is compelling potential to repay those investments in relatively short time through reduced fuel costs.

Achieving attractive economics (i.e., a relatively short payback period and a positive net present value) for a given conversion project is primarily a function of two key factors: high annual fuel use and a large price differential between LNG and diesel. In addition, net costs for conversion play a significant role; in the case of heavy-duty vehicles, the cost of adding enough on-board LNG storage to provide acceptable vehicle "range" can account for a large percentage of the overall conversion costs. End users can make decisions that will reduce their capital or operational costs, such as customizing LNG tank installations or installing gas engine technology at a time that major engine work or replacement is already scheduled (e.g., engine overhaul or replacement).

This simplistic type of analysis does not account for the cost of gaining access to LNG fuel. In part, this is because fleet owners that use very large fuel volumes can obtain their LNG from vendors who will own, operate, and maintain an on-site LNG station under a "take or pay" arrangement, with minimal capital investment required for the end user. This analysis also assumes that future prices and costs will remain constant.

[15] U.S. EIA projections, and Dr. Kenneth Medlock III, Rice University Center for Energy Studies, "The Outlook for Natural Gas: Emerging Fundamentals," HHP Summit 2013, September 2013.

2.1.1. INCREMENTAL CAPITAL COSTS

The incremental capital cost of converting any type of HHP vehicle or equipment for LNG operation is a function of many parameters, including but not limited to:

- Combustion technology and natural gas substitution rate (see Table 4)
- Approach to obtain natural gas engine (retrofit, repower, or replace with new equipment)
- Fuel storage (type, location, size and number of storage vessels)
- Fueling infrastructure
- Permitting and approvals
- Safety and personnel training requirements

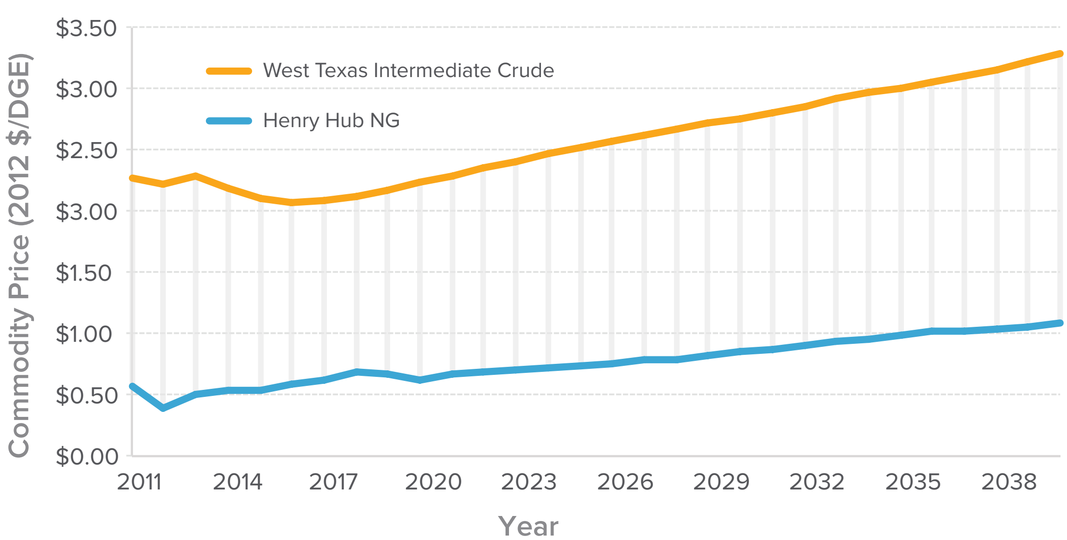
As noted, the cost of LNG storage most dictates the higher capital costs of LNG vehicles compared to their diesel-fueled counterparts. These cost challenges affect all sectors, although to varying degrees due to differences in technologies, use characteristics, fueling logistics, etc. Further discussion about the costs of potentially using LNG in Wyoming's HHP applications is provided below, broken out by capital versus operational costs.

2.1.2. FUEL PRICE AND COST SAVINGS

Total lifecycle costs for LNG usage in Wyoming's HHP vehicles and equipment will be strongly dependent on the price differential between LNG and diesel, for the full life of the investment. The price differential starts with the raw commodities of crude oil and natural gas at the wellhead. Figure 6 compares historical and projected prices for both commodities from 1994 to 2020. As shown, on an energy-equivalent basis (per diesel gallon equivalent, or DGE[16]), the price of natural gas is projected to remain well below the price of crude oil.

[16] A diesel gallon equivalent (DGE) is generally defined by the lower heating value (LHV) of No. 2 diesel as it compares to a given alternative fuel. The U.S. DOE uses 128,450 BTU per gallon for diesel and 74,720 BTU per gallon for LNG. In this case, a gallon of LNG equals 0.582 DGE; conversely, it takes 1.72 gallons of LNG to provide the same energy as a gallon of diesel. However, many other references use 1.68 for this conversion factor. As yet, there is no standardization for a DGE; unless noted otherwise in this report, GNA has used 1.68. The Clean Vehicle Education Foundation is working with industry to standardize a DGE definition.

Figure 6. Projected price spread for crude oil and natural gas commodities (per DGE)



Source: US Energy Information Adminstration, Annual Energy Outlook 2014, DGE: Diesel gallon equivalent, based on 128,450 BTU/gallon

Table 3. Example of a "Fuel Price Spread"

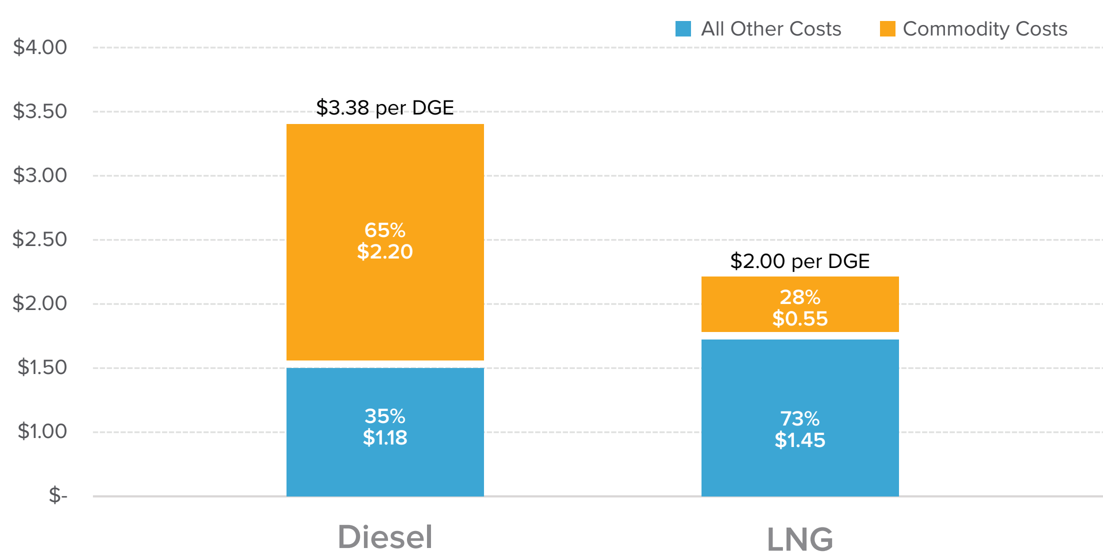
	$/DGE
Diesel price at pump	$3.38
LNG price at pump	$2.00
Fuel price spread = diesel price – LNG price	$1.38
Cost of LNG relative to diesel on energy-equivalent basis	-41%

Figure 6 reflects the relative costs of these two raw commodities on an energy equivalent basis, with natural gas currently costing about 50 to 55 cents per DGE. Of course, end users are concerned about relative prices for the two fully processed transportation fuels (diesel and LNG), including taxes and profit. The "fuel price spread" refers to the price differential between these two fuels in a common unit of energy (one DGE).

Table 3 provides an example of a current fuel price spread that might be available to a potential LNG end user in Wyoming. Diesel is priced at $3.38 per gallon, while LNG is available at $2.00 per DGE. The fuel price spread is $1.38 per DGE. The cost to end users for LNG is 41 percent lower than diesel on an energy-equivalent basis. In this plausible scenario, major fuel cost savings can be realized by switching high-fuel-use HHP vehicles and/or equipment from diesel to LNG operation.

Today's compelling fuel price spread for LNG (and CNG) compared to diesel reflects near-historic price lows for natural gas as a commodity. Of course, price increases could occur for either commodity (natural gas and crude oil). Notably, less than one-third of LNG's pump price is attributed to the commodity cost of natural gas. By comparison, about two-thirds of diesel's pump price is attributed to the commodity cost of crude oil. (See Figure 7.) This translates into LNG's lower price sensitivity to commodity costs as compared to diesel fuel. For example, a 10 percent increase in the cost of crude oil would result in a six to seven percent increase at the pump. By comparison, a 10 percent increase in the cost of natural gas would result in a three percent increase in the delivered cost of LNG.

Figure 7. Percentages of total costs for diesel and LNG attributable to commodity costs



Source: U.S. Energy Information Administration

2.2. TECHNOLOGICAL APPROACHES TO VEHICLE AND EQUIPMENT CONVERSION

Diesel engines dominate the heavy-duty sector because they provide excellent performance, efficiency, durability, reliability, cost effectiveness, and operating time between refueling ("range"). To achieve sustainable viability, HHP natural gas engines must meet the same rigorous expectations of end users.

Currently, three different technological approaches are being used to burn natural gas in HHP engines: 1) "dedicated" spark ignition (100 percent natural gas), 2) "dual-fuel" compression ignition (natural gas mixed with large volumes of diesel fuel), and 3) "direct injection" compression ignition (greater than 90 percent natural gas, injected after a pilot stream of diesel). All three choices have advantages and tradeoffs that help define specific HHP market niches for their current or future use, as further discussed below.

Spark Ignition – Natural gas is a high octane fuel; this and other attributes make it favorable for combustion in gasoline-type spark-ignition engines. In certain HHP applications, spark-ignited engines are available (or under development) that allow end users to obtain the benefits of burning 100 percent natural gas. These dedicated engines use no diesel fuel, which provides superlative emissions performance and other societal benefits. For on-road applications, heavy-duty natural gas engines have been able to meet (and better) applicable federal (2010) emissions standards while using relatively simple, inexpensive exhaust aftertreatment systems. However, there are tradeoffs: dedicated spark-ignited natural gas engines provide significantly lower efficiency and power relative to equivalently sized compression-ignition engine (either of the combustion approaches described below). In addition, these engines lack the ability to operate on diesel fuel, should natural gas fuel become unavailable or too expensive.

Dual-Fuel Compression Ignition – To properly combust natural gas in a compression-ignition (diesel-like) engine, assistance is needed to ignite the natural gas charge. The traditional way to accomplish this has been by fumigation of natural gas with the intake air-stream at higher loads, injecting diesel to provide combustion of both fuels. Today, dual-fuel[17] natural gas engines are commercially available for many HHP applications; they can provide near-equivalent performance to conventional diesel engines. Such engines can enable fleets to gradually transition their HHP vehicles and/or equipment to natural gas, while also allowing a return to operation on 100 percent diesel fuel.

For any dual-fuel application, a key variable is the relative percentages of natural gas and diesel in the fuel mix. The term "diesel substitution rate" refers to the percentage (by energy) of natural gas in the total fuel energy (diesel plus natural gas) used by the engine. Currently, dual-fuel engine manufacturers and "upfitters" offer diesel substitution rates ranging from as low as 20 percent up to 70 or 80 percent, with average substitution rates depending on the duty cycle of the application. The "optimal" substitution rate depends on many factors; these include objectives of the end user, how the specific engine is used, and the commercial availability of natural gas technologies for that application. A lower substitution rate may be desired by end users for some applications to minimize the initial risks of fuel switching, or to meet sector-specific performance requirements (e.g., range). However, retaining high percentages of diesel fuel (a low substitution rate) will generally limit the emissions reductions and fuel cost savings that could be achieved with maximized use of natural gas.

Direct Injection Compression Ignition – Direct injection (DI) of natural gas in HHP engines is another approach for powering large vehicles and equipment. Westport has developed and commercialized a ground-breaking DI technology for HHP applications. Westport's "High Pressure Direct Injection" (Westport™ HPDI) allows for small quantities of diesel fuel and large quantities of natural gas to be delivered at high pressure to the combustion chamber of specialized compression-ignition engines. The result is that more than 90 percent of the diesel fuel (by

[17] Definitions for dual fuel and bi-fuel are not yet standardized. In this report, "dual fuel" refers to compression-ignition engines that can operate on a mix of natural gas and diesel, or 100% diesel. "Bi-fuel" generally refers to engines that can run on two different alternative fuels, but not mixes of the two. This applies to bi-fuel spark-ignited engines that can run on either gasoline or CNG.

energy) is replaced with natural gas, on average over the operating cycle.[18]

Westport™ HPDI can be applied to engines in multiple HHP sectors. It offers all the key advantages provided by diesel engines (high efficiency, good transient performance), while operating almost entirely on clean-burning, domestic natural gas. Heavy-duty on-road engines currently using first-generation Westport™ HPDI technology have been designed to meet the most stringent U.S. and European heavy-duty emissions standards. With its latest "HPDI 2.0" technology (discussed further in this report), Westport states that it is achieving "dramatically lower greenhouse gas (GHG) emissions than conventional natural gas or diesel engines."[19] (See Section 2.4.2 for more about GHG emissions.) A tradeoff for end users is that vehicles and equipment powered by Westport™ HPDI engines are not able to provide full power on 100 percent diesel fuel.

Utilizing these three technological approaches (spark ignition, dual fuel, and direct injection), manufacturers and aftermarket companies are offering various natural gas-powered products for use in a variety of HHP applications. Table 4 provides a snapshot how each of these three approaches and combustion technologies are being collectively applied by manufacturers in specific HHP applications. This situation is dynamic, and progress over the last few years has been rapid.

As this report further addresses, the economics of natural gas for Wyoming's HHP sectors will be significantly impacted by which approach to natural gas combustion is incorporated into a given type of HHP vehicle or equipment. Spark-ignited, direct injection and dual-fuel technologies all offer advantages and have their specific niches. But, it is inescapable that the economic benefits of switching to natural gas—and achieving the shortest possible payback time for a positive return on investments—will be proportional to maximizing the diesel substitution rate.

[18] Definitions for dual fuel and bi-fuel are not yet standardized. In this report, "dual fuel" refers to compression-ignition engines that can operate on a mix of natural gas and diesel, or 100% diesel. "Bi-fuel" generally refers to engines that can run on two different alternative fuels, but not mixes of the two. This applies to bi-fuel spark-ignited engines that can run on either gasoline or CNG.

[19] Westport, "Westport Unveils Next Generation High Pressure Direct Injection (Westport™ HPDI 2.0) System," news release, December 10, 2013, http://www.westport.com/news/2013/next-generation-high-pressure-direct-injection-system-hpdi-2.0.

Table 4. Example approaches, technologies and status of products for high-HP natural gas engines

Approach to Use Natural Gas	General Combustion Technology	Natural Gas Substitution Rate by Energy	Snapshot Status of Known Commercialization, Demonstration and Development Efforts, by High Horsepower Application				
			Oil & Gas E&P	Line-Haul Locomotives	Mine Haul Trucks	On-Road Trucks	Off-Road, Gen-Sets
Dual-Fuel	Compression ignition of NG mixed with diesel (fumigation)	Variable: ~20% up to ~ 80%	✔	✔	✔	✔	✔
Direct Injection	Compression ignition of NG w/ diesel pilot	>90% average		○	○	✔	○
Spark Ignition	Spark ignition of 100% NG	100%	✔			✔	✔

✔ HHP applications are commercial or under demo ○ HHP applications are under development

2.3. MANUFACTURER MOMENTUM WITH NATURAL GAS PRODUCTS

Manufacturers of engines, fuel storage systems, and peripheral equipment that enable use of LNG have responded with major momentum to advance commercialization of LNG in America's HHP sectors. Over the last 12 to 18 months, unprecedented progress has been achieved towards sustainable commercialization of LNG in sectors that include mining, rail and E&P. Examples include:

- Increases in the numbers and applications of products
- Accelerated cooperation between government and industry stakeholders, across all facets including infrastructure
- Emergence of technology leaders in various sectors and/or applications
- Strong interest on behalf of end users to retrofit, convert, or demonstrate

In general, fleet operators have the following needs when phasing in the use of natural gas for their HHP vehicles and equipment:

- Maintain or improve operational performance
- Maximize fuel cost savings and achieve a short payback period
- Maintain fuel flexibility (if diesel or natural gas is unavailable)
- Maintain safe, reliable and durable operations
- Maintain or improve labor costs
- Improve environmental performance
- Obtain equivalent warranty and product support

In response, manufacturers have developed an array of commercial heavy-duty natural gas engines and products that can run on CNG, LNG or field gas (where applicable). For example:

- Caterpillar has announced it is "all in" for natural gas products, from fuel production and distribution to its end use in HHP engine applications. Caterpillar has available a comprehensive engine product line in the petroleum and electric power markets that utilize either spark-ignition or dual-fuel capabilities. Caterpillar is exploring dual-fuel products for its high horsepower, off-road markets. In applications not currently conducive to dedicated spark-ignited natural gas engines (mining, rail), Caterpillar is pushing towards near-complete diesel substitution using HPDI engine technology through its partnership with Westport. In fact, Caterpillar has announced that mining trucks and locomotives will be among its first products to incorporate HPDI technology (also see Westport, below).
- For more-immediate product roll outs, Caterpillar has already introduced its Dynamic Gas Blending™ (DGB™) line of retrofit kits for energy exploration and production (E&P) engines. These hardware kits include the gas fuel system components, engine controls and software, sensors, valves and brackets. DGB engines can be operated on 100% diesel or up to 70% natural gas mixed with diesel, which acts as an igniter for the natural gas charge. DGB will be available in "emissions capable" retrofit kits for existing engines, or incorporated into new dual fuel engines from the factory.[20] Caterpillar is also developing generator sets for power generation and mining equipment that can operate on "flexible fuel solutions" that include coal bed methane and dual-fuel options.
- Westport™ has already developed and commercialized its first-generation HPDI technology, which maintains compression ignition to deliver diesel-equivalent horsepower and torque while burning greater than 90 percent natural gas on average (see Figure 8). Westport currently has strategic alliances with three of the world's top four engine producers to develop and deploy natural gas engine technology; it also supplies or has strategic alliances with six of the world's top ten truck

[20] Caterpillar, "Dynamic Gas Blending," accessed online 09-04-13 at: http://www.caterpillar.com/cda/layout?m=677875&x=7.

producers.[21] In October 2013, Westport announced that its production focus has shifted from an upfit model to a vertically integrated solution with Westport™ HPDI 2.0. The last day for orders of Westport's first-generation HPDI technology was in November 2013.[22]

- However, Westport is building on its extensive experience with its first-generation HPDI technology to expand HPDI natural gas technology into large off-road engines. Specifically, Westport has joined with Caterpillar to co-develop natural gas technology for mine haul trucks and locomotives. Caterpillar's mine haul trucks and locomotives built by Electro-Motive Diesel (EMD)[23] that incorporate Westport™ HPDI technology are targeted to achieve substitution rates greater than 90 percent, as desired by the railroads and mining companies to maximize fuel cost savings. Caterpillar is exploring the use of HPDI technology for mining trucks and locomotives. Beginning in the 2017 time frame, these types of products may be sold and serviced through regular original equipment manufacturers (OEMs).[24] Testing is now underway.[25]

- Cummins intends to market its QSK60DF dual-fuel engine in mine haul trucks (and other HHP applications); initially, this will occur in "unregulated markets" (for emissions), but Cummins intends to follow with Tier 4 engines for North American applications. Cummins is working with OEMs to further develop these products.[26]

[21] Westport, personal communication to GNA, July 2013.

[22] Westport, personal communications to GNA, January and March 2014.

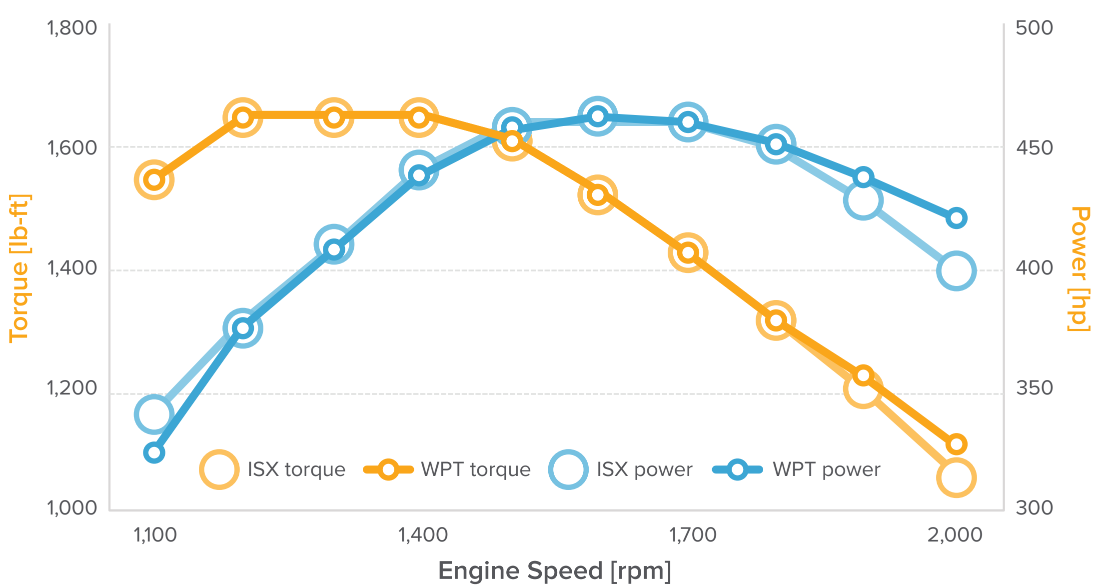
[23] EMD is owned by Caterpillar through its wholly owned subsidiary Progress Rail Services Corporation

[24] Personal communication from Caterpillar to GNA, February 2014.

[25] Bruce Hodgins, Westport, "Off-Road Natural Gas Solutions," presentation to HHP 2013 Summit, September 2013.

[26] Chris Pritchard, Cummins Engine Company, "Cummins Engines with Dual Fuel Technology for Mining Equipment," presentation at HHP Summit 2013, September 2013.

Figure 8. Performance of heavy-duty engine using Westport first-generation HPDI technology



Source: Westport

- Gaseous Fuel Systems (GFS) has designed its EVO-MT system to enable dual-fuel operation of large mine haul trucks (100-ton class and above). GFS currently offers retrofit conversion systems on several makes and models of mine haul trucks, including two Caterpillar models and two Komatsu models. Diesel substitution rates up to 55 percent have been reported by GFS in demonstration efforts. GFS's "product development pipeline" includes future offerings for additional makes and models of mine haul trucks. In addition, GFS is working on similar retrofit conversion kits for stationary power applications and locomotives.[27]

[27] George Aguilera, Gaseous Fuel Systems, untitled presentation at HHP Summit 2013, September 2013.

- Cummins Westport has introduced its 12-liter ISX12 G dedicated natural gas engine. This new, larger-displacement natural gas engine opens up new markets for a variety of heavy-duty vehicles, including on-road tractor applications that are heavily used in Wyoming. With a displacement of 11.9 liters and up to 400 hp and 1450 lb-ft of torque, the ISX12 G competes extremely well with traditional diesel engines in demanding over-the-road trucking applications. It can use either LNG or CNG (compressed natural gas).

- Many fuel supply and infrastructure companies are investing heavily in products, processes and facilities designed to ensure that end users of HHP vehicles and equipment can obtain, transport, store and use the necessary volumes of affordable natural gas to switch their fleets. Extensive details are provided in Section 7.

2.4. AIR QUALITY IMPLICATIONS OF SWITCHING TO NATURAL GAS

Reducing life-cycle cost is the main driver for Wyoming's industrial fleets to substitute natural gas for diesel in HHP vehicles and equipment. In addition, significant air quality and other environmental benefits can be realized for the citizens of Wyoming. These are best characterized and compared over the full "fuel-cycles" of diesel and natural gas (i.e., including fuel exploration, extraction, production, processing, transportation and end use).

The fuel-cycle environmental benefits of natural gas are a complex and evolving topic; potential benefits of natural gas can vary significantly by engine type, technology, duty cycle, age, natural gas substitution rate, and other factors. A complete, sector-by-sector discussion is beyond the scope of this study. The following provides summaries about the potential benefits of natural gas to improve Wyoming air quality by reducing criteria pollutant emissions. (Subsequent sections provide a few specific examples of benefits in key higher-horsepower sectors.) This is followed by a brief discussion about reducing greenhouse gas emissions.

2.4.1. CRITERIA POLLUTANT EMISSIONS

Diesel engines, which power the vast majority of America's heavy-duty vehicles and equipment, are major emitters of two "criteria" air pollutants regulated by the U.S. EPA:

- **Nitrogen oxides (NOx)** – NOx combines with volatile organic compounds (VOCs) in the presence of sunlight to form ozone. Ground-level ozone causes a wide range of human health problems (see http://www.epa.gov/glo/health.html). To attain very challenging health-based ambient air quality standards for ozone, NOx emissions from heavy-duty vehicles and equipment must be systematically reduced, as rapidly as possible.

- **Fine particulate matter (PM)** – very small particles are emitted from diesel (and other) engines; these add to the complex mixtures of particles and liquid droplets that suspend in ambient air. Particles of this size (about 10 microns, and smaller) are deeply inhaled into human airways and lungs, and have potential to cause serious respiratory illness and heart problems. PM from the combustion of diesel fuel is especially harmful to human

> health. EPA has concluded that long-term (chronic) inhalation exposure to diesel exhaust "is likely to pose a lung cancer hazard to humans."[28]

The advantages of natural gas engines for reducing NOx and PM emissions are well documented in the case of on-road heavy-duty vehicles. Today's natural gas heavy-duty trucks and buses are equipped with engines that achieve the benchmark for low NOx and PM emissions. For example, the 2013 model year Cummins ISL G natural gas engine tested at 35 percent below the current (2010) heavy-duty engine standard for NOx, and 50 percent below the standard for PM.[29] This emissions performance is largely due to the inherently simple chemistry of the methane molecule (the largest single component of natural gas), compared to petroleum-based fuels like diesel and gasoline. Methane consists of a single carbon molecule, compared to complex gasoline and diesel molecules with high "carbon intensity" (see Figure 9).

It is important to note that diesel engines will continue to improve their emissions performance. Increasingly stringent emissions standards for NOx and PM are now becoming applicable for new engines in key HHP sectors such as locomotives and mine haul trucks. As diesel engines are modified and improved to meet these new standards, the inherent emissions advantage held by natural gas engines may be diminished.

[28] U.S. EPA, "Health Assessment Document for Diesel Engine Exhaust (Final 2002), http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060.

[29] California Air Resources Board, Executive Order A-021-0588 for engine family DCEXH0540LBH, December 2012.

2.4.2. GREENHOUSE GAS EMISSIONS

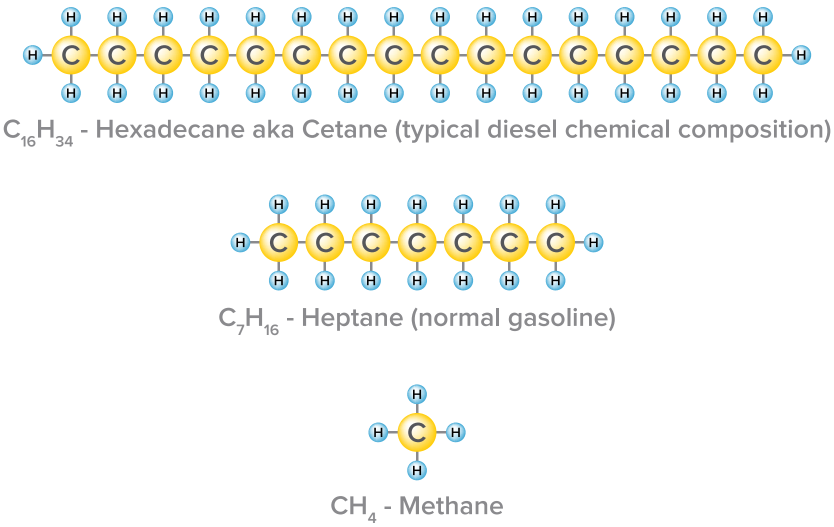
Carbon dioxide (CO_2) is the primary greenhouse gas (GHG) emitted through combustion of fossil fuels for the energy and transportation sectors.[30] Beginning with Model Year 2014, the U.S. EPA has promulgated CO_2 emissions standards for heavy-duty diesel engines used in certain vehicles, including "Heavy Heavy-Duty" tractors for long-haul trucking. Reducing CO_2 emissions from a vehicle or equipment powered by a heavy-duty diesel engine is achieved by combusting less fuel per unit of work performed; this can be accomplished in many ways, including improved aerodynamics and weight reduction. The result is improved fuel economy in miles per gallon and proportionally reduced GHG emissions.

Another way to reduce CO_2 emissions from heavy-duty engines is to "fuel switch" to a less-carbon-intense fuel, such as natural gas. Methane—with just one carbon atom bonded to four hydrogen atoms (Figure 9)—contains much less carbon than diesel for the same amount of energy released upon its combustion. The result is reduced CO_2 emissions at the tailpipe. Natural gas engine technologies that use compression ignition (i.e., dual fuel and direct injection approaches) will produce lower tailpipe CO_2 emissions than spark-ignition technologies.

However, this "downstream" use is only part of the full-fuel-cycle story regarding GHG emissions. To properly compare GHG emissions from diesel and natural gas vehicles or equipment, "upstream" GHG emissions associated with the specific fuel cycles (extraction, production, preparation, transportation, etc.) must also be considered. This is a complex and evolving subject; for example, methane itself is a potent GHG, so its leakage during the full-fuel-cycle must be minimized. This means that industry "best practices" must be exercised for upstream recovery and processing of natural gas, such as during well completions and liquids unloading activities.

[30] U.S. EPA, "Overview of Greenhouse Gases," http://www.epa.gov/climatechange/ghgemissions/gases/co2.html.

Figure 9. Simplicity of methane (CH_4) compared to diesel (top, $C_{18}H_{34}$) and gasoline (middle, C_7H_{16})



Scientific discussion of the methane leakage issue continues to evolve, and new findings are rapidly emerging. The independent nonprofit International Council on Clean Transportation (ICCT) conducted one of the most-thorough analyses to compare upstream CO_2 and methane (CH_4) emissions associated with producing LNG, in this case for use in the marine sector.[31] ICCT explored eight different pathways that are expected to play a role in the supply of LNG as a marine fuel.

The report found that there can be a range of effects, largely as a function of the specific fuel production pathways. But, it summed up by stating the following:

> *"In addition to LNG being a promising environmental solution to various air pollution problems for ships, its desirability would be enhanced by a number of improvements to diminish its direct methane emissions... If best practices to reduce methane leakage are more widely embraced, greater GHG benefits will be realized, and the climate benefits are likely to be higher than those suggested by current methods of extraction, processing, transport, storage, and combustion."*[32]

There has been recent controversy about the impact that fugitive methane emissions from shale gas production have on the GHG implications of replacing diesel with natural gas in heavy-duty vehicles. However, after working with the gas industry and examining new information about industry best practices, EPA reduced its estimate in 2013 down to 1.4 percent for fugitive methane emissions associated with natural gas production. This was a 40 percent reduction from EPA's 2011 estimates. Preliminary indications are that, although there are some outliers, the majority of gas producers follow practices that dramatically reduce the release of methane. This may lead U.S. EPA to reduce its estimates even lower.

Based on solid (albeit evolving) information, natural gas as a replacement for diesel appears to offer an effective strategy for reducing GHG emissions from HHP engines such as those used in rail, mining, marine, and off-road equipment. The magnitude of benefits is likely to significantly vary by "upstream" factors in fuel pathways and "downstream" end use parameters, which include combustion technology[33], vehicle type, duty cycle, fuel substitution rate, and practices to control gas leaks and venting.

[31] The International Council on Clean Transportation, "Assessment of the Fuel Cycle Impact of Liquefied Natural Gas as Used in International Shipping," May 2013 (http://www.theicct.org/sites/default/files/publications/ICCTwhitepaper_MarineLNG_130513.pdf).

[32] ICCT LNG Report, p. 30.

[33] For example, Westport's December 2013 press release states that Westport™ HPDI 2.0 technology provides "dramatically lower" emissions of tailpipe methane through in-cylinder (engine) control, plus overall low GHG emissions through high engine efficiency.

2.5. EXPECTED GROWTH TRENDS

By 2040, the U.S. Energy Information Administration predicts that use of natural gas in America's transportation sector will grow by a factor of 20 compared to 2013 levels. The predominant growth in demand for natural gas is expected to come from heavy-duty vehicles such as on-road Class 8 trucks. However, it is clear from recent industry initiatives that HHP applications such as locomotives, mine haul trucks, and large off-road vehicles will also significantly contribute to this growth.

This expected ramp up of natural gas demand will largely be driven by economics: heavy-duty fleet operators that use significant volumes of diesel fuel can achieve large fuel cost savings by converting to natural gas, with compelling payback on their associated capital investments. This will be especially true in very high fuel usage sectors like rail, mining and E&P, which can generate very strong cost savings on fuel costs that provide paybacks in the 12- to 24-month time frames (see Section 5 for sector-by-sector examples).

However, as further described in this report, many challenges must be addressed and overcome. The largest involves establishment and build out of the necessary LNG fuel infrastructure.

3. CURRENT OPERATIONS AND INVENTORIES IN KEY WYOMING SECTORS

A major objective of this study is to characterize how diesel fuel is currently being used Wyoming's highest-fuel-use sectors: 1) mining haul trucks, 2) locomotives, 3) drill rigs and pressure pumping equipment, 4) on-road heavy-duty trucks, and 5) other types of large off-road vehicles and equipment. Before developing a roadmap in Wyoming for LNG usage, as best as possible it is necessary to quantify and understand the following "inventory" information in each sector:

1. How many HHP engines are being operated?
2. Where they are being operated?
3. How much diesel fuel is being consumed?
4. What are the special opportunities and constraints for using natural gas to replace diesel?

To obtain information about inventories and engine activities, GNA contacted key stakeholders in Wyoming's HHP sectors and researched a wide array of information sources. These included, but were not limited to the following:

- **Federal sources and agencies** – U.S. Energy Information Administration, U.S. Geological Survey, U.S. Bureau of Land Management, U.S. Environmental Protection Agency, etc.
- **State of Wyoming agencies and sources** – Wyoming Business Council, 23 county treasurers, Wyoming Oil & Gas Conservation Commission, Wyoming Highway Patrol, Wyoming Department of Environmental Quality.
- **Industry stakeholders** – Caterpillar, Wyoming Machinery, Encana, individual companies operating equipment in Wyoming (railroads, mining companies, E&P companies), equipment and service providers, etc.
- **Industry associations** – Wyoming Mining Association, Wyoming Trucking Association, Petroleum Association of Wyoming.
- **Other** – Wyoming Taxpayer Association, Mobile Mining Equipment Database.

Almost all fleets, end users and manufacturers that were surveyed for this study were reluctant to share detailed knowledge and numbers about HHP vehicles, equipment and fuel use in Wyoming. This is not surprising; by nature, these are very competitive businesses. The Wyoming coal mining industry serves as a very good example: in the PRB, 13 different active coal mines are located in very close proximity to each other, and competition for customers is strong among these mines.

Fortunately, sufficient information was found about deployments of HHP equipment in Wyoming to piece together and back calculate "high-level" estimated inventories and fuel usage for the HHP sectors of interest. This information is summarized for each sector in the subsections that follow.

3.1. MINING OPERATIONS: LARGE HAUL TRUCKS

3.1.1. OVERVIEW OF MINE HAUL TRUCKS

According to the Mobile Mining Equipment Database, large off-road mine haul trucks are the most ubiquitous type of surface-mining equipment in the world. Currently, more than 38,500 mining trucks with payload ratings of at least 90 metric tons are in operation at surface mines around the world; another 7,500 are categorized as "inactive." This population includes both electrical drive and mechanical drive trucks; rear-dump, bottom-dump and miscellaneous configurations are found. The vast majority of in-use mining trucks were manufactured by Caterpillar, Komatsu, Belaz, Hitachi and Liebherr, although several other manufacturers have sold products.[34] In-use

[34] See http://parkerbaymining.com/mining-equipment/mining-trucks.htm

mine haul trucks range from the 90-metric-ton class up to the "ultra-class" trucks rated at or above 360 metric tons. Shown here is the Caterpillar 777C mine haul truck.

Source: Gladstein, Neandross & Associates

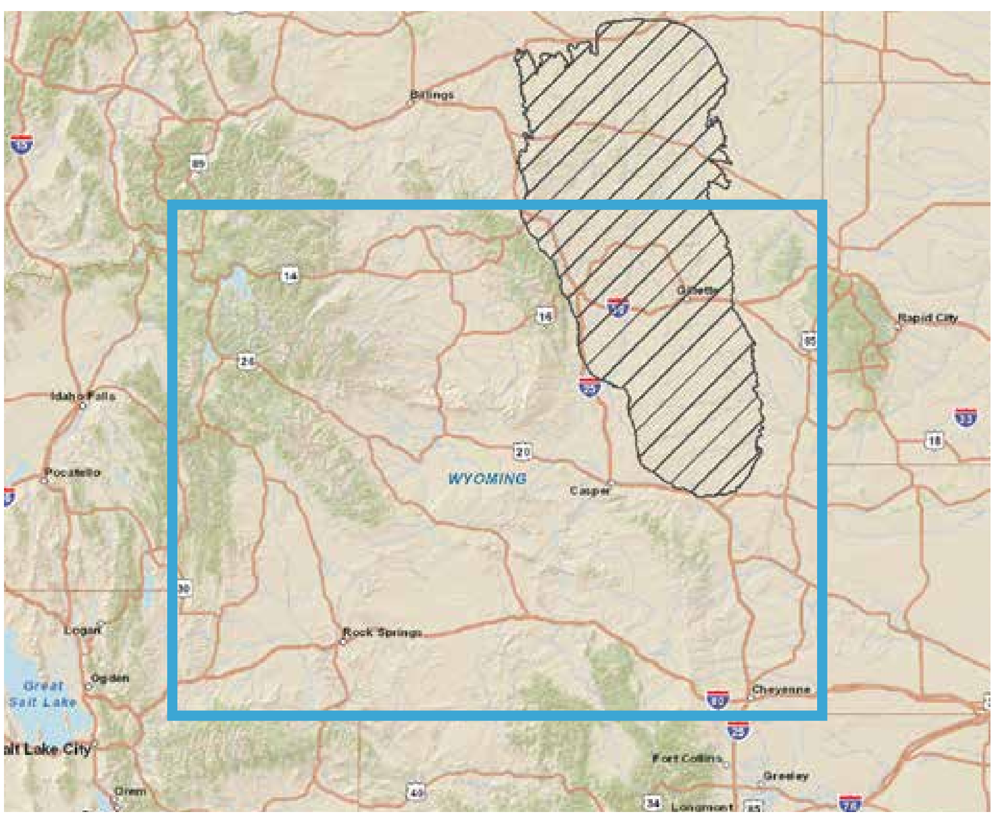
These huge haul trucks are the workhorses of the mining industry. At surface mines across North America, there are an estimated 4,500 mine haul trucks currently in operation[35]; they are the dominant consumers of diesel fuel at these mining operations.

Wyoming's coal mining industry centered in the PRB is among the world's major users of ultra-class mine haul trucks. The PRB holds the world's largest deposits of low-sulfur subbituminous coal; geographically, about two thirds of the PRB is located in northeastern Wyoming (see Figure 10). Thirteen operative coal mines are found in the Wyoming PRB, including the eight largest in the U.S. In 2012, Wyoming produced approximately 401 million short tons of coal, accounting for 40 percent of the U.S. production.[36]

[35] Personal communication from a major coal company executive to GNA's Erik Neandross, May 2013.

[36] U.S. Energy Information Administration, "Wyoming Profile Analysis," updated December 2013.

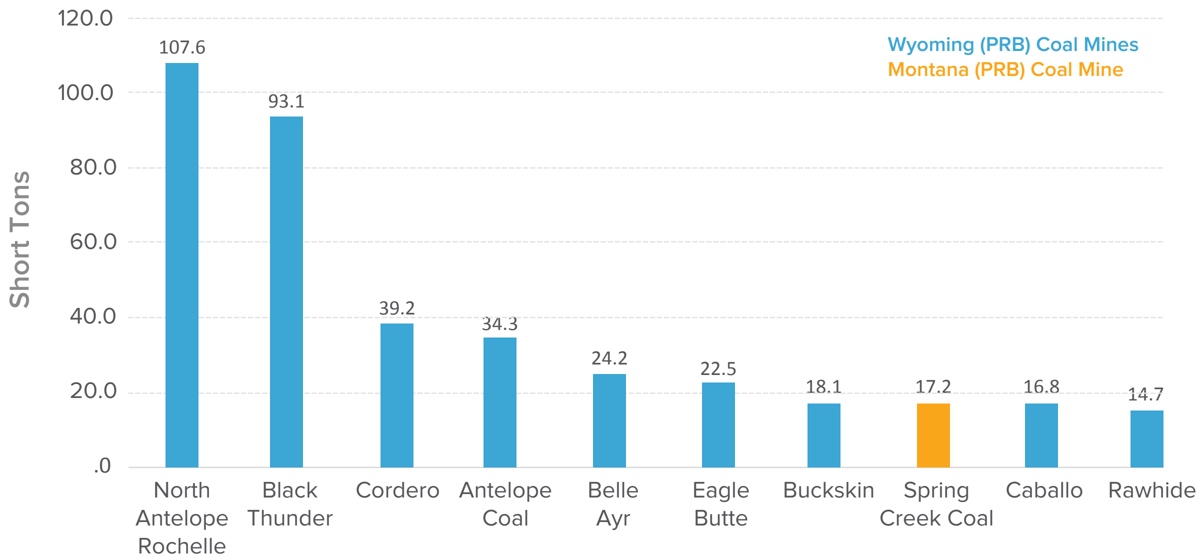
Figure 10. The coal-rich Powder River Basin (black boundary) of Wyoming and Montana



In fact, about 92 percent of the total PRB coal production is provided by the 13 active coal mines in Wyoming's portion of the PRB (predominantly Campbell County).[37] As shown in Figure 11, nine of America's top 10 coal-producing mines (2012 production year) are located here. The vast majority of PRB coal is shipped via train to 35 different states across America, where it is used to power electricity generation plants (see Section 3.2).

[37] U.S. Geological Survey, "Assessment of Coal Geology, Resources, and Reserve Base in the Powder River Basin, Wyoming and Montana," Fact Sheet, February 2013, http://pubs.usgs.gov/fs/2012/3143/fs-2012-3143.pdf.

Figure 11. The top 10 coal-producing mines in the U.S. in 2012



Source: U.S. EIA, http://www.ela.gov/coal/data.cfm#production and http://www.ela.gov/coal/annual/index.cfm

3.1.2. ESTIMATED INVENTORY AND DIESEL FUEL USAGE

A key objective of this study is to estimate, as best as possible, the total inventory of mine haul trucks currently operating in Wyoming's coal mines, and their total annual diesel fuel use. Unfortunately, such details are not readily available. To help obtain detailed inventory numbers and further characterize "typical" mine haul truck operations, GNA worked with the Wyoming Mining Association (WMA). WMA circulated an inventory survey to its members that operate surface coal mines in Wyoming. In response to the survey, GNA received detailed information covering three different PRB mines about their fleets of mine haul trucks.

Table 5 summarizes input that was received. Information was provided about 107 mine haul trucks, consisting of six different make / model combinations. The rated payload varies from 195 tons for the smallest-sized truck (700,000 lbs. gross vehicle weight) up to a payload of 400 tons for the full-sized "ultra-class trucks" that have GVW ratings up to 1.3 million pounds. Notably, about 60 percent of these 107 mine haul trucks are in the 345-ton and above class.

Input from these PRB coal mines helps to formulate a basic characterization of the typical makes and models, duty cycle, size and age distributions, and fuel usage of mine haul trucks used in Wyoming's coal service. These vehicles are operated at least 15 hours per day; many trucks exceed two full shifts (16 hours) of work per day. The smaller trucks tend to use the least amount of diesel fuel, in the range of 390 to 700 gallons per day. Most of the larger trucks (345 tons and above) use diesel fuel volumes ranging from 875 to 950 gallons per day; some reportedly use up to 1,500 gallons per day. A large percentage of the mine haul trucks represented here are more than 20 years old, although some vehicles were recently purchased. Based on these data, mine haul truck chassis undergo major rebuilds after approximately 100,000 hours of usage (once every 17 years, assuming a 16-hour duty cycle). However, the large engines of mine haul trucks may be rebuilt multiple times over their useful lives.

The "snapshot" provided through the Wyoming Mining Association indicates that a total of 107 mine haul trucks are currently operated at three (of 13) PRB coal mines. These three mines collectively accounted for about 35 percent of the PRB coal production in 2011. If we assume this is a typical ratio of coal throughput to the number of mine haul trucks deployed, it is estimated that there are a total of 308 (107 / 0.35 = 308) mine haul trucks (100+ ton class) being used at the PRB's 13 operational coal mines. However, each PRB coal mine has different parameters that affect how many large haul trucks are needed to move a given tonnage of coal. Mine-specific factors that affect this ratio include the distance of each haul, the age and configuration of the mine, the stripping ratio, and other metrics (e.g., the relative use of electric draglines versus haul trucks). This suggests that there may be significantly more than 308 mine haul trucks operating at PRB coal mines. In fact, it is believed that at least 400 mine haul trucks are currently operating in the PRB, based on limited public statements by representatives from the Wyoming coal mine industry.

Statewide, it is believed that approximately 440 large mine haul trucks (100-ton or higher capacity) are currently operational, based on considerations for Wyoming's total coal mine throughput and known details about duty cycles. The average annual diesel fuel use per mine haul truck is estimated to be about 274,000 gallons per year (830 GPD X 330 days per year). This yields a rough estimate of approximately 121 million gallons of diesel that are annually consumed by large mine haul trucks in the State of Wyoming. This number is believed to be conservative.[38]

It is important to understand the synergy and complex relationships that exist between Wyoming's PRB coal mines and the two major railroads (Burlington Northern Santa Fe and Union Pacific) that haul away almost 100 percent of the coal produced. Figure 12 shows the approximate location of the largest PRB coal mines, their coal production in 2012, and the reported number of coal-hauling unit trains that can be accommodated at each mine.[39] Further details about these important relationships and how the two railroads ship Wyoming PRB coal across America are provided in Section 3.2 below.

Of course, large mine haul trucks are not the only types of HHP diesel-fueled vehicles and equipment used by the PRB coal mines and other Wyoming mining operations. Examples of other mining equipment that support surface mine operations include wheel dozers, motor graders, wheel tractor scrapers, excavators, wheel loaders, drills, hydraulic shovels, articulated trucks, and highwall miners.[40] A general "rule of thumb" for PRB coal mine operations is that the mine haul trucks consume 70 to 75 percent of a mine's total diesel fuel usage, with these other miscellaneous off-road equipment using 25 to 30 percent.[41] Some of these "Other Large Off-Road" vehicles and equipment are discussed in Section 3.5.

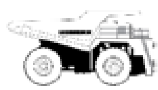
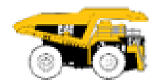
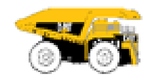
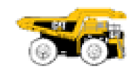
[38] For example, one mining expert estimates that PRB mine haul trucks consume165 million diesel gallons per year, although this may include coal mine operations in Montana's portion of the PRB.

[39] A 2011 Data, Table 9: http://www.eia.gov/coal/annual/index.cfm; BNSF Guide to Coal Mines, 2013: http://www.bnsf.com/customers/pdf/mineguide.pdf; UP Southern PRB Mines: https://www.uprr.com/customers/energy/coal/sprb/index.shtml

[40] See Caterpillar's webpage at https://mining.cat.com/products/surface-mining details.

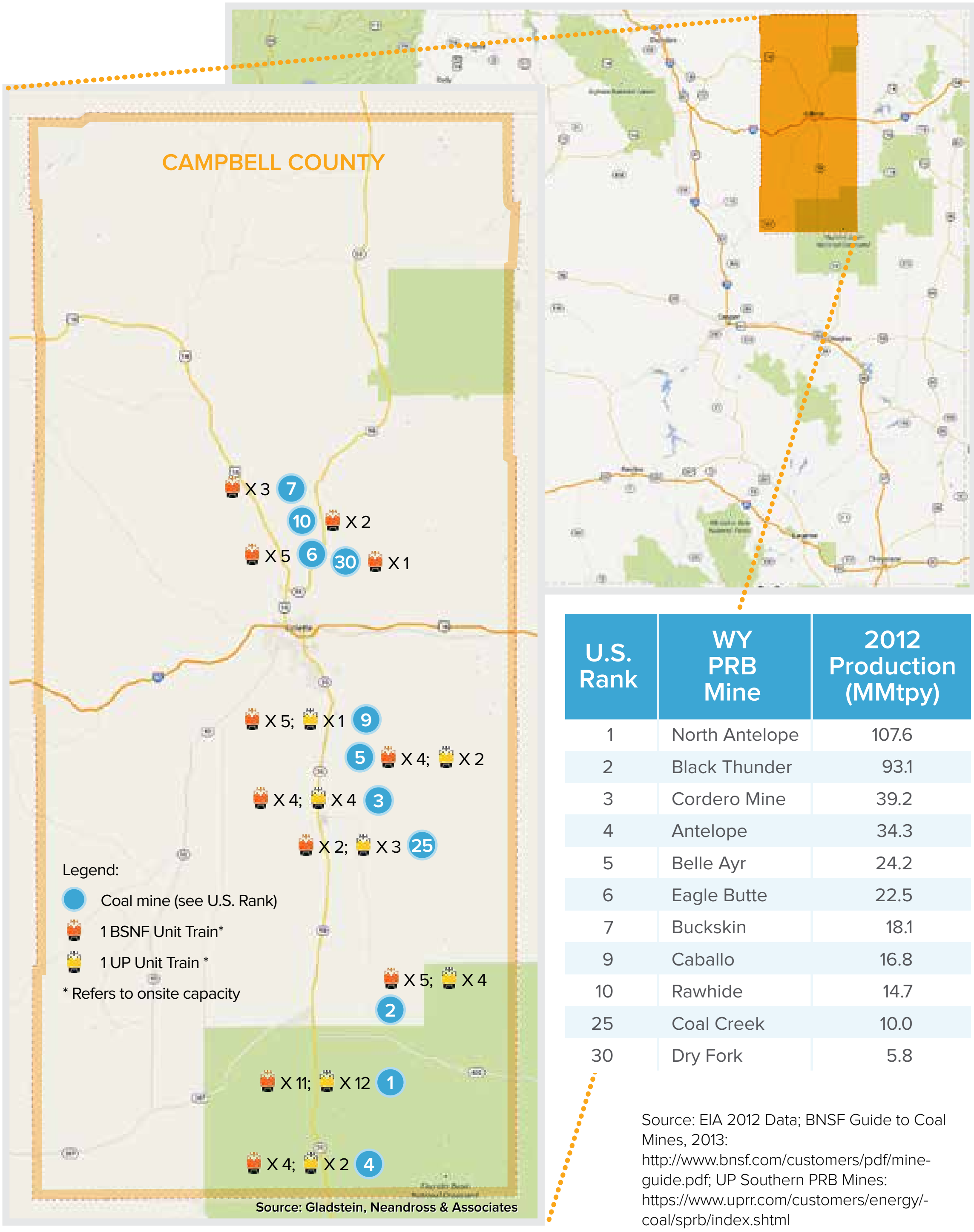
[41] Personal communications to GNA from PRB coal mine representatives.

Table 5. Summary of mine haul truck inventory data received from three major PRB coal mines

	Liebherr T282 B&C	Caterpillar 797	Komatsu 960E	Caterpillar 795F	Caterpillar 793D	Caterpillar 789C
						
Engine Make Model	MTU 20V4000	Caterpillar 3524	Cummins QSK 78	Caterpillar 16V C175	Caterpillar 3516	Caterpillar 3516
Rated Payload	400 tons	400 tons	360 tons	345 tons	240 tons	195 tons
GVW	1,322k lbs.	1,275k lbs.	1,270k lbs.	1,275k lbs.	846k lbs.	700k lbs.
Quantity	41	7	14	2	35	8
Avg. Age of Vehicles	3 years	12 years	5 years	2 years	3 years	3 years
Typical Rebuild/ Repl. Rate	100,000 hrs.	100,000 hrs.	100,000 hrs.	100,000 hrs.	100,000 hrs.	100,000 hrs.
Typical Daily Operation	17.4 hrs.	14.8 hrs.	18.3 hrs.	17.0 hrs.	16.6 hrs.	15.5 hrs.

Source: Three PRB coal mines, August 2013 (via the Wyoming Mining Association)

Figure 12. PRB coal mines: location, U.S. production rank (2012), and estimated unit train capacity



U.S. Rank	WY PRB Mine	2012 Production (MMtpy)
1	North Antelope	107.6
2	Black Thunder	93.1
3	Cordero Mine	39.2
4	Antelope	34.3
5	Belle Ayr	24.2
6	Eagle Butte	22.5
7	Buckskin	18.1
9	Caballo	16.8
10	Rawhide	14.7
25	Coal Creek	10.0
30	Dry Fork	5.8

Source: EIA 2012 Data; BNSF Guide to Coal Mines, 2013: http://www.bnsf.com/customers/pdf/mine-guide.pdf; UP Southern PRB Mines: https://www.uprr.com/customers/energy/-coal/sprb/index.shtml

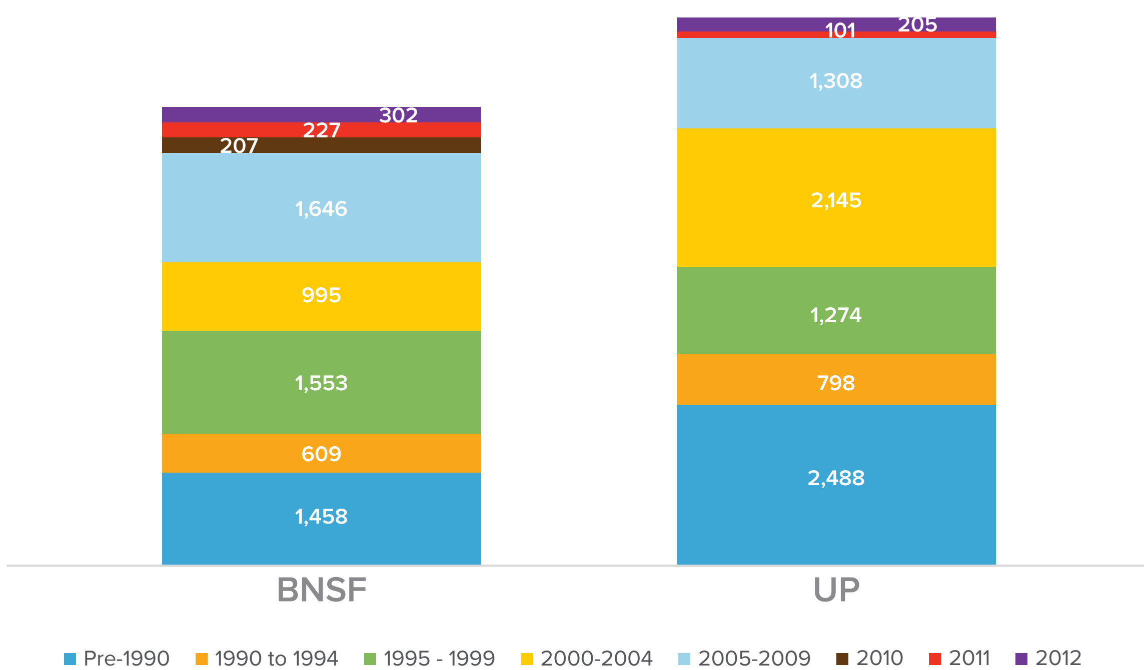
3.2. RAIL OPERATIONS: FREIGHT LOCOMOTIVES

Freight locomotives can broadly be classified as line haul and switcher locomotives. Line haul locomotives are used to move freight over distances; they have large medium-speed diesel engines rated at about 4,500 horsepower that power an electric drive system. They typically carry 5,000 gallons of diesel fuel, which affords a range of about 1,200 miles. The average trip length for a line haul freight locomotive in North America is slightly less than 1,000 miles. Switcher (yard) locomotives are smaller and provide less than half the horsepower; their function is to move freight cars within rail yards and assemble/disassemble trains.

A "unit" train is a single train consisting of multiple line haul locomotives (typically, three to five) powering freight cars (120 to 135 cars) that carry a single commodity to a specific destination. This is how Wyoming coal is shipped out of the PRB to electricity generation plants across America. Typically, unit trains spend only a small percentage of their operating time in the state where they are loaded; and they traverse multiple states using rail lines owned by two or more railroads. This type of operation—combined with increased sharing or leasing of equipment between railroads—drives a strong demand for standardized rail equipment that can be operated in any part of North America.

In the U.S., "Class I Railroads" are defined as line haul freight railroads with operating revenue of a certain minimum (at least $433.2 million in 2011). Today, North American Class I railroads collectively consume approximately four billion gallons of diesel fuel. More than 95 percent of this fuel is typically consumed by line-haul locomotives. Burlington Northern Santa Fe (BNSF) and Union Pacific (UP) are the two largest Class I railroads; together, they dominate U.S. freight rail movements in the American west and mid-west. In 2012, BNSF and UP consumed 1.33 billion and 1.1 billion diesel gallons, respectively, within their U.S. freight locomotive fleets (including switcher operations). Both paid about $3.20 for each gallon of diesel fuel. Thus, in 2012 BNSF and UP spent about $4.3 billion and $3.5 billion, respectively, to purchase diesel fuel.

Figure 13. Distribution of BNSF and UP locomotives by model year



Source: BNSF, UP 2012 reports

On average, each line haul locomotive in the BNSF and UP fleets consumes about 170,000 gallons of diesel fuel per year. However, line-haul locomotives used in the most arduous duty cycles—such as hauling coal out of Wyoming's PRB—may burn significantly larger volumes of diesel per year. Diesel-electric locomotives are very robust technology that can last through decades of tough service; typically, they may undergo multiple rebuilds over their full lifespan.[42] As shown in Figure 13, the national locomotive fleets for BNSF and UP both include thousands of pre-2000 model year locomotives; collectively, these two railroads operate about 4,000 locomotives that are at least 20 years old ("Pre-1990"). The cost to rebuild an existing locomotive is model dependent; the average cost is approximately $300,000 to $600,000. In 2012, BNSF and UP purchased 302 and 205 new locomotives, respectively; with an average cost of approximately $2.3 million per unit.[43]

[42] The average line-haul locomotive lasts 30 years, according to a Class I railroad executive.

[43] From: BNSF's and UP's respective "Class I Railroad Annual Report R-1 to the Surface Transportation Board for the Year Ending Dec. 31, 2012"; both documents can be accessed online.

3.2.1. OVERVIEW OF WYOMING RAIL OPERATIONS

Table 6. Number and percentage of rail route miles in Wyoming, by railroad

Railroad	Route Miles Owned	Percent of State Total
Burlington Northern Santa Fe	965	51%
Union Pacific	879	47%
Wyoming Colorado	24	1%
Dakota Minnesota & Eastern	6	< 1%
Bighorn Divide and Wyoming	4	< 1%
Totals	1,878	100%
BNSF and UP share 106 miles of track in the PRB		

Currently, there are nearly 1,900 miles of operational railroad track (route miles) in Wyoming. Table 6 summarizes the numbers and percentages of Wyoming's rail route miles for each of the five operating railroads. As the table shows, BNSF and UP collectively own and operate 98 percent of Wyoming's route miles. This is indicative that Wyoming rail operations are dominated by line haul freight operations rather than short line or passenger operations.

Wyoming is America's most prodigious state for moving goods via freight rail. As shown in Table 7, it ranks first among U.S. states for rail tons originated, rail carloads originated, and rail tons carried. Wyoming rail cargo was hauled in roughly 27,000 different train trips (four million rail cars), averaging about 73 daily departures of freight trains from Wyoming rail terminals.[44] A typical Wyoming line haul train (i.e., coal) has two or three freight locomotives in front (pulling), with as-needed assistance for steep grades by one to two additional locomotives (situated in the middle or rear of the train as "distributed power").In 2011, 472.4 million tons of Wyoming commodities were shipped by rail (see Table 8); this was about 26 percent of the total U.S. freight tonnage. By weight, coal made up 96.2 percent of these rail-shipped commodities. Wyoming's portion of the PRB is by far America's most-dominant region for rail shipments of coal to U.S. power plants. Only a small fraction (less than 4 percent) of the coal that is rail shipped from Wyoming mines stays within the State. Other major rail commodities in Wyoming include chemical and allied products such as soda ash (11 million tons); ground minerals such as bentonite (3 million tons); and various other products (about 2 million tons).

This strong nexus between the two largest North American Class I railroads and Wyoming's coal industry is further illustrated by the two maps in Figure 14. The top half of the figure lays out the full U.S. rail routes for BNSF and UP. The bottom half of the figure shows major rail delivery locations for Wyoming coal, almost all of which is used to power electricity generation plants in at least 35 states. It is clear from these two related maps that BNSF and UP dominate western rail activities in general, and Wyoming coal shipments in particular.

[44] Estimated by GNA based on EIA data and an assumed average of 135 rail cars per unit train.

Table 7. Wyoming's relative ranking for state freight rail operations

State	Relative Rank Among U.S. States (Top 25)			
	Rail Tons Originated	Rail Carloads Originated	Rail Tons Carried	Rail Carloads
Wyoming	1	1	1	11
Illinois	2	2	3	1
West Virginia	3	7	14	19
Minnesota	4	5	12	18
Texas	5	4	5	2
Kentucky	6	11	11	14
Ohio	7	6	9	6
California	8	3	24	5
Indiana	9	13	10	4
Iowa	11	16	7	7
Montana	12	22	31	34
Florida	13	12	35	33
Virginia	14	15	17	20
Alabama	15	19	21	21
North Dakota	16	25	28	30
Georgia	17	9	16	17
Nebraska	18	26	2	10
Louisiana	19	20	26	29
Colorado	20	24	20	22
Colorado	20	24	20	22
Michigan	21	14	34	31
Washington	22	10	29	26
Kansas	23	23	6	8
Utah	24	28	38	37
Oklahoma	25	34	8	9

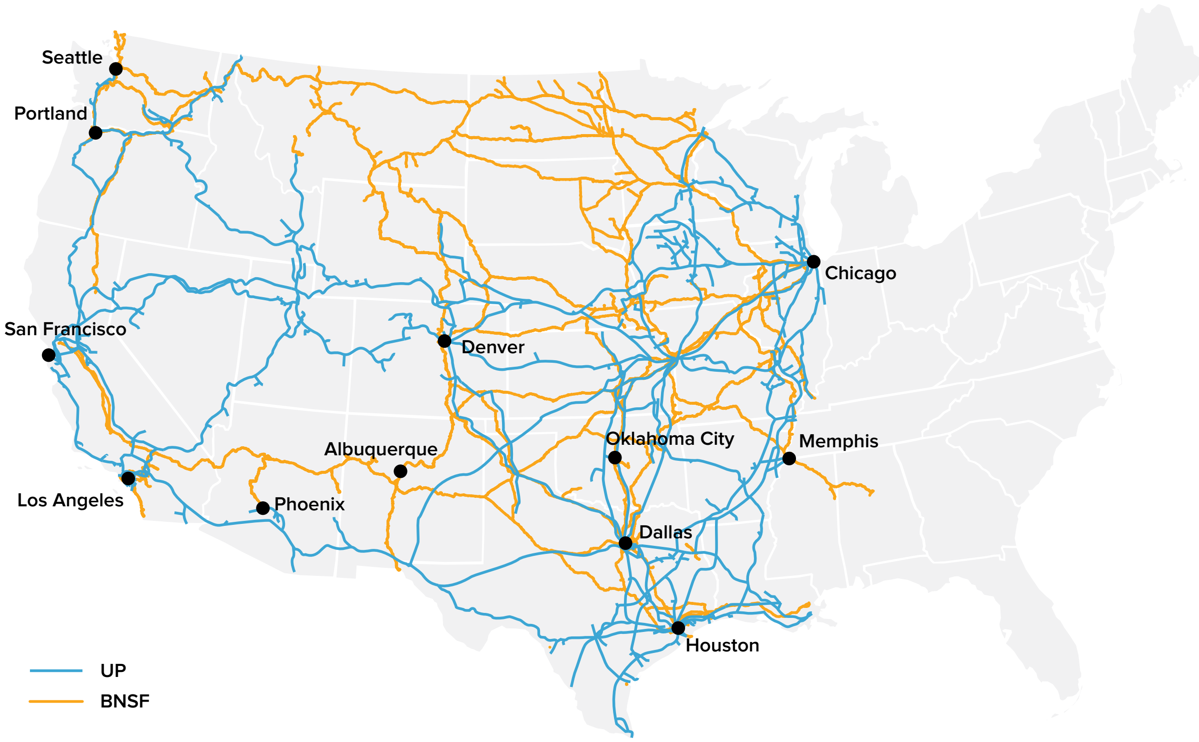
Source: Association of American Railroads, www.aar.org

Table 8. Break-out of commodities shipped by rail in Wyoming (2011)

Commodity	Tons	% of Tonnage	# of Carloads	% of Carloads
Coal	454,692,000	96.2%	3,817,000	95.5%
Chemicals	10,929,000	2.3%	105,400	2.6%
Ground Minerals	2,937,000	0.6%	30,100	0.8%
Petroleum & Coal Products	816,000	0.2%	10,100	0.3%
Fertilizer Minerals	720,000	0.2%	6,800	0.2%
Others	2,359,000	0.5%	26,900	0.7%
Totals	**472,453,000**	**100.0%**	**3,996,300**	**100.0%**

Source: Association of American Railroads, "Freight Railroads in Wyoming"

Figure 14. Top: route maps for BNSF and UP; Bottom: deliveries of Wyoming coal by rail (2011)



Source: GNA with data from UP/BNSF

Source: US Energy Information Administration

This type of synergy between PRB coal mines and the Class I railroads is also very important to the future development of Wyoming's energy economy. For example, Ambre Energy is the operator and co-owner of two PRB coal mines, including the Black Butte Mine in Wyoming and the Decker Mine in Montana. In a joint venture with Arch Coal, Ambre Energy is operating and expanding the Millennium Bulk Terminals-Longview in Washington State, while also developing a proposed coal barging and transloading operation in Oregon. Ambre's proposed coal export terminals will be connected to PRB mines and other western US coal regions through "an efficient rail network, serviced by several carriers." Once port capacity is established, Ambre intends to export PRB coal to supply South Korea and other customers in Asia.[45]

Rail traffic density is generally expressed in terms of gross-ton-miles per mile of track (weight moved per distance, including railcars and locomotives). Wyoming has some of the world's highest-density rail traffic, due to this unique combination of its tremendous coal production and being a major thoroughfare for other transcontinental freight movement. According to the Wyoming Mining Association, BNSF and UP combined to depart at least 80 unit trains each day from the 13 active Wyoming PRB coal mines. Especially dense rail lines are 1) UP's east and south connectors from the PRB in southeastern Wyoming, 2) BNSF's northeast Wyoming operations, and 3) the 106-mile-long joint BNSF-UP line that serves all PRB mines in Campbell County.

Given these dynamics, these two railroads compete intensely for PRB coal hauling contracts. According to a Wyoming rail plan,

> *"High-volume coal contracts are among the most hotly-contested commercial deals in the rail industry. Competition between BNSF and UP has driven down freight rates to levels below those of the 1980s, further enhancing the appeal of Wyoming coal in eastern markets."*[46]

However, BNSF and UP must also work closely together to coordinate train scheduling along their joint four-track main line that serves 11 different coal mines in the PRB. This has necessitated development of a combined dispatching operation, which is implemented out of BNSF's facility in Fort Worth, Texas.

[45] Ambre Energy, "Our Actions," accessed from website, http://www.ambreenergy.com/strategy.

[46] State of Wyoming, "Rail Plan," prepared by Wilbur Smith Associates, October 2004.

3.2.1.1. BURLINGTON NORTHERN SANTA FE RAILROAD

BNSF operates 33,000 route miles covering 28 U.S. states and two Canadian provinces. Its network covers the western two-thirds of the U.S., handling about 43 percent of the rail traffic in its areas of operation. BNSF is a major rail carrier in Wyoming, with 966 miles or just over half the state's rail network. It was the first Class I carrier to begin major rail transport of low-sulfur PRB coal in the late 1970's. BNSF mostly moves coal to electricity producers in the Midwest and Ohio Valley, but it is also serves markets further south (e.g., Texas) and east.

About 23 percent of BNSF's revenues are generated from the transportation of coal. In 2012, BNSF reported that it hauled 2.2 million coal shipments, of which more than 90 percent was mined and loaded in the PRB.[47] In the first half of 2013, BNSF reports that its volume of coal transported increased compared to the same periods in 2012.

Refer back to Figure 12 (page 35) regarding BNSF's apparent capacity to serve PRB coal mines with unit trains. Based on fuel usage and other factors, it's estimated that 44 BNSF loaded unit trains depart from PRB coal mines each day; depending on the destination and route, each train is powered by a locomotive "consist" of two to five freight locomotives hauling up to 135 railcars.

On a daily basis, huge volumes of diesel fuel are consumed by these locomotives moving coal. Attempts were made to ascertain how much—and where—diesel fuel is dispensed in Wyoming to fuel BNSF's coal trains. Reportedly, BNSF has "dispensed about 50 million gallons of diesel into locomotives

[47] BNSF Railway, "Fact Sheet" accessed online at http://www.bnsf.com/about-bnsf/pdf/fact_sheet.pdf.

at Wyoming facilities over each of the last 3 years."[48] This likely includes switcher locomotive operations in Wyoming. BNSF apparently does NOT refuel its freight locomotives at the PRB coal mines they serve. From the limited amount of public information available, it appears that BNSF coal trains are refueled during their approach to, or exit from, the PRB coal mines. For example, approximately 10 million gallons of diesel are pumped into BNSF locomotives at its Guernsey, Wyoming fueling facility,[49] located within about 50 miles of the PRB's southern-most coal mines. It's unclear what other Wyoming BNSF facilities are used to pump the remaining ~40 million gallons per year into its locomotives.

Depending on duty cycle and locomotive type, freight locomotives have a range of 700 to 1,200 miles between refueling events. The longest distance across Wyoming (its east to west border) is 365 miles. Thus, BNSF locomotives do not necessarily need to be refueled in Wyoming, and it appears that many are not.[50] For trains carrying coal to destinations west of the PRB (e.g., Washington), BNSF has opened a 500,000 gallon fueling facility about 800 miles away in Hauser, Idaho. This, however, may be a stretch on range for locomotives hauling PRB coal.

The Alliance Terminal in Nebraska appears to be BNSF's essential hub for supporting PRB coal hauling operations, including major refueling operations. This large terminal about 150 miles southeast of the PRB serves as BNSF's central coal train processing yard. It includes major diesel fueling and maintenance operations. Unit trains loaded with PRB coal stop at Alliance on their way east to electric power utilities in Nebraska, Iowa, Kansas, Missouri, Wisconsin, Colorado, Oklahoma, and Texas. Westbound empty trains also stop on their way back to the PRB mines. According to one source, approximately 65 BNSF trains (50 percent loaded) pass through the Alliance Terminal each day. The Alliance facility is also where BNSF builds each unit coal train to the size required by the particular mine/electric utility pair being served. This ranges from 105 to 150 railcars.[51]

[48] Personal communication from BNSF to Bob Jensen, Wyoming Business Council, July 3, 2013.

[49] BNSF, "Alliance/Guernsey Mechanical News, Fourth Quarter 2009," http://www.newslink.com/pubs/ALMEC/ALMEC0912.pdf.

[50] Trains: The Magazine of Railroading, "Ask Trains," reader's input to question of "Where do BNSF and Union Pacific fuel coal trains?", March 2009, http://trn.trains.com/en/Railroad%20Reference/Ask%20Trains/2009/03/Ask%20Trains%20from%20March%202009.aspx

[51] Railway Age, "Maximizing productivity in the 'heart of coal,' August 27, 2012, accessed online at http://www.railwayage.com/index.php/freight/switching/maximizing-productivity-in-the-heart-of-coal%E2%80%9D.html.

3.2.1.2. UNION PACIFIC RAILROAD

UP operates approximately 27,500 route miles in the United States. In 2011, shipments of "energy-related products" made up 22 percent of UP's revenue; the vast majority of this was coal. The principal artery of UP's transcontinental system includes a central corridor across Wyoming via Cheyenne, Rawlins and Green River. This corridor is one of North America's most important and heavily-used east-west rail networks. UP's Wyoming coal train fleet serves at least seven different PRB coal mines to the south of Gillette. These trains primarily use high-density UP tracks in southeastern Wyoming (Converse, Platte, Goshen and Laramie Counties) as they deliver coal to electricity generation plants across the southern and Midwestern U.S.

Figure 15. UP's Bailey Yard in North Platte

Referring back to Figure 12 on page 35, based on U.S government data it's estimated that UP has existing capacity at seven PRB coal mines to operate approximately 28 trains per day. The actual number of full UP coal trains that make daily departures from PRB mines appears to be slightly greater. According to its own statistics, UP averages more than 30 trains per day hauling coal out of the PRB, with an average train total weight exceeding 15,500 tons.[52]

Based on industry statements, it is believed that UP dispenses relatively small volumes of fuel into its PRB coal trains within Wyoming. UP's South Morrill rail yard in Nebraska, which is located about 130 miles from the PRB's southern entrance, appears to be the closest significant refueling site. Since UP locomotives can easily make the round trip between South Morrill and southern PRB mines on a single tank of diesel fuel, it appears unnecessary to refuel within Wyoming, at least for UP's locomotives that haul PRB coal to the east and south of South Morrill. UP also makes coal deliveries hundreds of miles south of the PRB. For example, one of UP's major coal customers is the W.A. Parish Power Plant near Houston; this is a distance of about 1,200 miles.

UP's massive Bailey Yard in North Platte, Nebraska is about 400 miles southeast of the PRB's southern entrance. The sprawling Bailey Yard complex is a critical component of UP's overall rail network and coal-hauling operations. An average of 139 UP trains per day are serviced at Bailey; PRB coal is the most prevalent commodity carried. Bailey Yard fuels and/or services more than 8,500 UP locomotives each month.[53] Of these, nearly 50 percent serve Southern PRB coal mines; 70 to 80 coal trains pass through Bailey Yard each day. Since these include both loaded and empty trains, this supports the rough estimate that at least 30 loaded trains leave PRB coal mines each day. Reportedly, UP has considered (or already implemented) making Bailey Yard the sole service handler for all its Wyoming coal trains.

[52] Union Pacific Railroad, accessed online on December 2, 2013 at http://www.uprr.com/newsinfo/releases/service/2009/0817_silver.shtml

[53] Union Pacific Railroad, "Bailey Yard," accessed online on September 4, 2013 at http://www.up.com/aboutup/facilities/bailey_yard/index.htm.

[54, 55], UP also uses facilities along its track in northern Kansas to service and/or fuel westbound empty coal trains.[56]

[54] Union Pacific Railroad, "Union Pacific Delivers Record Amounts of Coal to Nation's Utilities," news release September 2007, accessed online on September 4, 2013 at http://www.uprr.com/newsinfo/releases/service/2007/0913_coal.shtml.

[55] Progressive Railroading, "Dwelling on the positive at UP's Bailey Yard," May 2008, accessed online on 9/4/13 at http://www.progressiverailroading.com/class_is/article/Dwelling-on-the-positive-at-UPs-Bailey-Yard--16467.

[56] UPRR, "Union Pacific Moves its 200,000th Loaded Coal Train from Wyoming's Southern Powder River Basin," May 20, 2009.

Figure 16 provides a rough schematic of the BNSF and UP routes that service Wyoming in general, and the PRB coal mines in particular. It shows the location of the four major facilities (two for each railroad) that are believed to be the primary refueling sites for locomotives powering Wyoming's coal trains, as they enter or exit the PRB.

Figure 16. BNSF and UP routes in Wyoming, with diesel refueling facilities for PRB-serving trains

3.2.2. ESTIMATED INVENTORY AND DIESEL FUEL USAGE

Wyoming sales tax records indicate that railroads operating in the state collectively purchase about 230 million gallons of diesel in Wyoming each year. This includes all rail operations. Actual inventories of freight locomotives in Wyoming—and how much diesel they consume—could not be obtained for this study. More than 96 percent (by weight) of rail shipments out of Wyoming consists of coal; the vast majority of this comes from 13 PRB mines. Using industry data for the total weight of coal shipped from the PRB (about 401 million tons in 2012), the number of unit trains (full and empty) needed to move this coal (80 to 85 per day), the estimated fuel efficiency for locomotive's hauling coal (about 0.10 miles per gallon[57]), and other parameters, the rough estimates shown in Table 9 were derived:

Of these estimated 122 million gallons per year, it appears likely that 50 million gallons or fewer are dispensed within Wyoming, based on information provided by the Class I railroads. It is important to note this does not predict the future: the Class I railroads could choose to increase their Wyoming fueling operations, if and when they transition their coal locomotive fleets to LNG.

[57] Annual reports from BNSF and UP reported that the average freight locomotive fuel economy was 0.14 mpg in 2012. GNA has assumed the rigorous PRB coal mine duty cycle would reduce this to approximately 0.10 mpg.

Table 9. Estimated number of Wyoming coal locomotives and diesel gallons consumed

Number of locomotives regularly hauling coal in WY (all WY coal mines)	405
Total annual volume of diesel consumed by WY coal train locomotives (gallons per year)	122 million

3.3. OIL & GAS OPERATIONS: DRILL RIGS AND PRESSURE PUMPING SERVICES

3.3.1. OVERVIEW OF WYOMING OPERATIONS

Crude oil and/or natural gas were produced in 22 of Wyoming's 23 counties during 2012. Figure 17 graphically displays Wyoming's top gas and oil production fields in 2012, and the volumes of gas (thousand cubic feet, or MCF) and oil (barrels, or BBLS).

The Wyoming oil & gas industry entails many players, stakeholders and areas of intense well activity. During 2012, 399 different operators produced Wyoming's crude oil and 252 produced natural gas. That same year, approximately 10,843 wells produced oil and 27,236 produced gas; about half of the gas wells were coal bed natural gas wells. The average daily production was 14 barrels of oil and 201 thousand cubic feet (Mcf) of gas.[58]

Natural gas production in Wyoming primarily occurs from conventional and "tight" gas reservoirs in the Greater Green River Basin, and unconventional (coalbed natural gas) reservoirs in the PRB. Nationally, Wyoming ranked 3rd in natural gas production in 2012; Sublette County was Wyoming's largest natural gas producer, with Johnson and Sweetwater Counties ranking 2nd and 3rd. Nearly 83 percent of Wyoming's gas production in 2012 was processed at 42 different in-state gas processing plants.

[58] Petroleum Association of Wyoming, "Wyoming Oil and Gas Facts and Figures, 2013 Edition," accessed online at http://www.pawyo.org/facts-figures.pdf.

As shown in the top bar graph of Figure 17 below, two of the largest gas fields are Pinedale and Jonah, which are located in the Upper Green River Basin of Sublette County. One major industry stakeholder in this area (and throughout Wyoming) is Anadarko Petroleum. Anadarko is among the largest leaseholders, taxpayers and gas producers in Wyoming, and a key operator in the Green River, Powder River, and Washakie basins, as well as the Salt Creek field. Anadarko's Granger Complex in Sweetwater County gathers and processes natural gas from three different counties across the prolific Moxa Arch / Jonah Field / Pinedale corridor. Anadarko also owns and operates the Powder River coal-bed methane gathering system located in northeastern Wyoming. Its Red Desert Complex in Sweetwater County gathers, compresses, treats, processes and fractionates natural gas and natural gas liquids.[59]

For crude oil production, Wyoming ranked 7th in the U.S. during 2012. The lower graph compares the top 10 oil producing fields during 2012 in Wyoming. The WC field was the top producer in 2012, with about 4.7 million barrels of oil produced. Campbell County was the leading crude oil producer in 2012 followed by Park and Sublette Counties.

In recent years, one particular Wyoming county, Converse, has experienced a rapid increase in oil well permits. In 2012, Converse County recorded a five-fold increase in permits compared to 2010. The full potential of these reservoirs has yet to be realized, but State sources have indicated that Converse County "will likely drive new well permitting and drilling in Wyoming."[60]

Drill rigs and pressure pumping services are the two major diesel-engine-powered exploration and production ("E&P") equipment types used by the oil and gas industry that are of greatest interest to this study. Estimated inventories in Wyoming for these two mainstay diesel equipment types are further described below.

[59] Anadarko Petroleum, "Wyoming Fact Sheet 2013," www.anadarko.com.

[60] Ranie Lynds, Wyoming State Geological Survey, "Wyoming's Oil and Gas Resources," February 11, 2013, accessed online at: http://www.wsgs.uwyo.edu/Public-Info/OnlinePubs/docs/Oil-and-Gas-Summary.pdf

3.3.1.1. DRILL RIGS

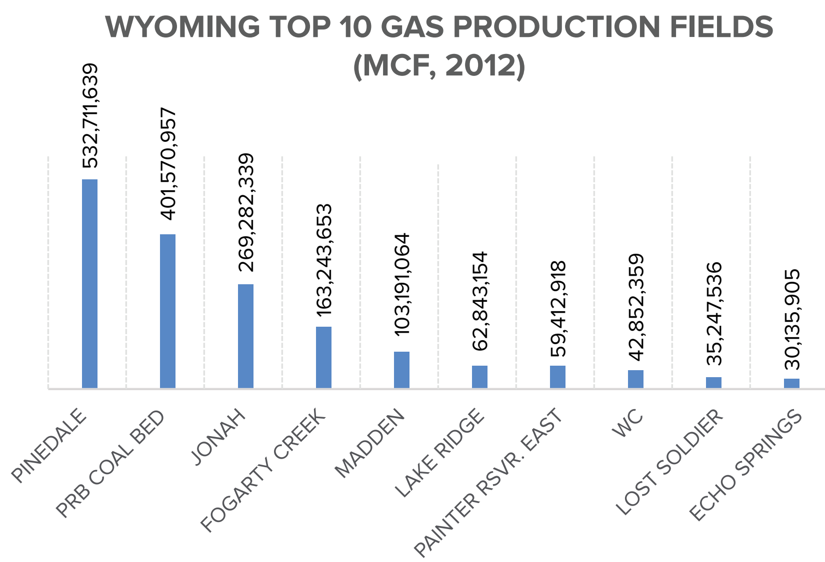
Conventional drill rigs are large machines that drill deep into the earth's crust to release oil and/or natural gas. Older style drill rigs are mechanically powered by diesel engines directly connected to the drilling equipment, whereas modern drill rigs are most often electrically powered units that draw electricity created by diesel-fueled combustion engines at the drill site. For the last several years, there have been an average of approximately 50 drill rigs operating in Wyoming's oil & gas sector. Collectively, these 50 drill rigs use approximately 53,500 gallons of diesel fuel per day, which yields a daily average of 1070 diesel gallons per drill rig.[61]

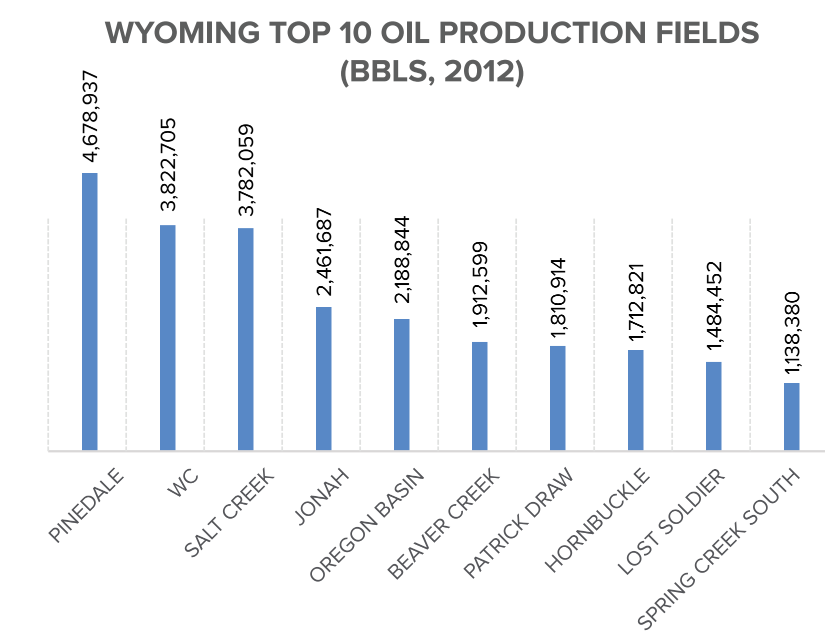
Table 10 provides a breakout of Wyoming drill rigs by the county in which they are located, as of April 2013. The counties with the most drill rigs are Converse (15), Sublette (13), and Campbell (8). Notably, this table further categorizes drill rigs by a horizontal, directional, or vertical orientation. The geography of this distinction is important. Oil and gas E&P activity in Wyoming largely coincides with the location of major shale plays including the Greater Green River, Niobrara, and Big Horn. Differences in the geologies of each play have led E&P companies to deploy horizontal drill rigs in the eastern portion of the state (Niobrara plays) while deploying vertical or directional rigs in the other regions.

As discussed in subsequent sections, horizontal drill rigs are the most likely of the three types to use electric motors (powered by a few large diesel generator sets). These are best suited for conversion to natural gas.

[61] These data were provided to GNA by Encana Corporation, July 2013.

Figure 17. Wyoming's top 10 gas & oil production fields, 2012





Source: Wyoming Oil & Gas Conservation Commission

Table 10. Breakout of current oil & gas drill rigs in Wyoming by county

County	Number of Horizontal Drill Rigs	Number of Directional Drill Rigs	Number of Vertical Drill Rigs	Total Number of Drill Rigs
Campbell	7	0	1	8
Converse	15	0	0	15
Laramie	2	0	1	3
Natrona	1	0	1	2
Niobrara	0	0	1	1
Park	0	1	0	1
Sheridan	1	0	0	1
Sublette	0	11	2	13
Sweetwater	0	5	0	5
Washakie	0	1	0	1
Totals	**26**	**18**	**6**	**50**

Source: Encana Corporation, provided to GNA in July 2013.

3.3.1.2. PRESSURE PUMPING OPERATIONS

Pressure pumping services (PPS) that service a single oil or gas well typically consist of 14 to 20 diesel engines mounted on heavy-duty "pumper trucks." Each pressure pumper engine can consume up to 90 gallons of diesel per hour. Collectively, a PPS fleet is used to pump fluids down drilled wells, thereby helping to free oil or gas from tight rock formations and maximize well yield. Combined with advanced drilling techniques, this hydraulic fracturing ("fracking") process has played an essential role in the advent of America's shale gas revolution.

The total North American PPS fleet for oil & gas operations is estimated to consist of approximately 12 million horsepower of diesel engines that consume approximately 1.15 billion gallons of diesel fuel each year.[62] At the high end, a 12-pump frack spread can burn approximately 10,000 to 11,000 gallons of diesel per day, and be deployed 230 to 250 days per year.[63]

Based on input from the oil & gas industry, it is believed that there are eight currently operational PPS fleets in Wyoming (these data may not include all Shallow Coal Bed Methane Wells). Within these eight PPS fleets, it is estimated that approximately 120 pressure pumping engines are currently deployed, consuming about 79,000 gallons of diesel fuel per day. These data suggest that PPS engines deployed in Wyoming[64] burn an average of 660 diesel gallons per day. However, this may be a conservative estimate, based on various factors and other information from the industry. Thus, it is assumed for this report that the average PPS engine in Wyoming burns 1,000 gallons of diesel fuel per day, and operates a total of 240 days per year. The per-engine fuel consumption for a single PPS engine is therefore estimated to be 240,000 diesel gallons per year.

[62] David Hill, Encana Natural Gas, Inc., "First Movers: Showcasing Today's HHP Projects, Engine Technology and Refueling Infrastructure," presentation to the HHP Summit, September 27, 2012.

[63] Prometheus Energy, "Accelerating Use of Natural Gas in Frac Pressure Pumping Operations," presentation at HHP Summit 2013, September 2013.

[64] Notably, the Wyoming PPS fleet is expected to grow, commensurate with growth in Wyoming's oil & gas operations. In particular, PPS operations in Campbell and Converse counties appear to be expanding, due to widespread use of hydraulic fracturing.

3.3.2. ESTIMATED INVENTORY AND DIESEL FUEL USAGE

Putting together the above estimates, Table 11 summarizes the number of drill rigs in Wyoming by county. This is converted into the estimated gallons per day (GPD) of diesel fuel used for these 50 drill rigs, plus the PPS equipment used to hydraulically fracture this number of wells.

As shown, Sublette County (41,750 GPD), Converse County (31,915 GPD), Campbell County (18,105 GPD), and Sweetwater County (16,058 GPD) lead the state in diesel consumed for these two combined E&P activities. In total, it's estimated that about 132,000 gallons per day of diesel are consumed in Wyoming by this sector. Accounting for the average days of operation for both drill rigs and PPS equipment, we estimate that 48 million gallons of diesel per year are consumed by drill rigs and PPS equipment in Wyoming's E&P sector. Notably, about 40 percent of this diesel (19 million gallons) is consumed by the drill rig fleet, and about 60 percent (29 million gallons) is consumed by the PPS fleet that "fracks" wells after drilling.

Table 11. Summary of Wyoming drill rig and PPS activity / diesel use by county

	Wyoming Drill Rig Counts (April 2013)				Total Volume of Daily Diesl Fuel Use (Gallons per day)		
County	Number of Horizonal Drill Rigs	Number of Directional Drill Rigs	Number of Vertical Drill Rigs	Total Number of Drill Rigs	Drill Rigs Only	PPS Only	Combined Drill Rigs and PPS
Campbell	7	0	1	8	8,833	9,272	18.105
Converse	15	0	0	15	16,742	15,172	31,915
Laramie	2	0	1	3	3,252	4,215	7,467
Natrona	1	0	1	2	2,136	3,203	5,339
Niobrara	0	0	1	1	1,020	2,192	3,212
Park	0	0	1	1	1,020	2,192	3,212
Sheridan	1	0	0	1	1,116	1,011	2,128
Sublette	0	11	2	13	13,260	28,490	41,750
Sweetwater	0	5	0	5	5,100	10,958	16,058
Washakie	0	1	0	1	1,020	2,192	3,212
Totals	**26**	**18**	**6**	**50**	**53,500**	**78,895**	**132,395**

Source: Encana Corporation, personal communications to GNA, June 2013
NOTE: Data may not include all Shallow Coal Bed Methane Wells

3.4. HEAVY-DUTY ON-ROAD TRUCK OPERATIONS

3.4.1. OVERVIEW OF HEAVY-DUTY TRUCKING IN WYOMING

The Wyoming Department of Transportation (WYDOT) indicates there are 6,860 miles of roads in Wyoming, of which about 94 percent are "rural." There are 914 miles of interstate, including east-west routes I-80 and I-90, and south-north route I-25. There were 6.3 billion vehicle miles traveled (VMT) on Wyoming roadways in 2011; trucks made up about 25 percent. Figure 18 shows percentages of Wyoming's highway miles and truck VMT as a function of each county.

This graphic helps to highlight the importance of I-80 as a major east-west goods movement route. Approximately 11,000 vehicles per day are driven on Wyoming's stretch of I-80; about 50 percent are commercial trucks.[65] In fact, I-80 is the busiest east-west trucking corridor in the northern U.S., and one of four major east-west transcontinental freight corridors.[66] Given this, it's not surprising that the five Wyoming counties through which I-80 is routed show the highest percentages of daily truck VMT in Figure 18.

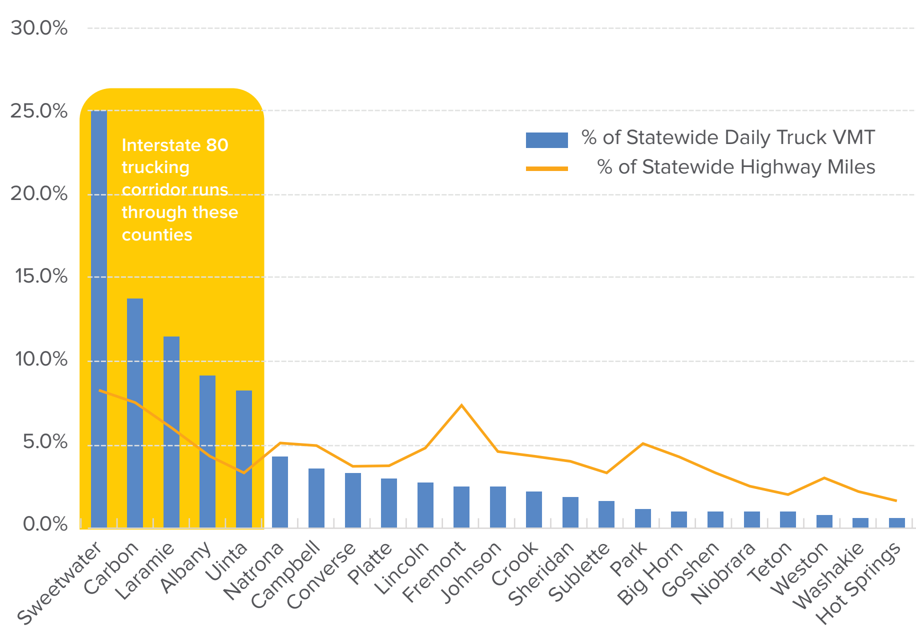
Direct information could not be found about how many heavy-duty (Class 7 or 8) trucks regularly fuel with diesel in Wyoming. The above-noted WYDOT data suggest that 5,500 commercial trucks are driven daily on I-80 alone. Many are likely to be interstate line-haul trucks "passing through" Wyoming. However, large numbers of heavy-duty trucks are also used in intra- and interstate operations throughout Wyoming, to support its booming energy economy (Section 1.2).

To quantify how many on-road heavy duty trucks are registered in Wyoming, telephone surveys were conducted with county treasurer offices in all 23 Wyoming counties. It was found that there are 13,133 Class 7 and 8 heavy-duty trucks (GVWR of 26,000 lbs. or more) registered in the state. As shown in Figure 19, the largest numbers of heavy-duty truck registrations are found in Campbell County with 1,978 trucks (15.1 percent), Natrona County with 1,783 trucks (13.6 percent), and Freemont County with 1,035 trucks (7.9 percent).

65 WYDOT's Commercial Vehicle Operator Portal (CVOP), presentation made at WYDOT Fall 2012 Workshop, September 25, 2012, accessed online at http://www.kimley-horn.com.

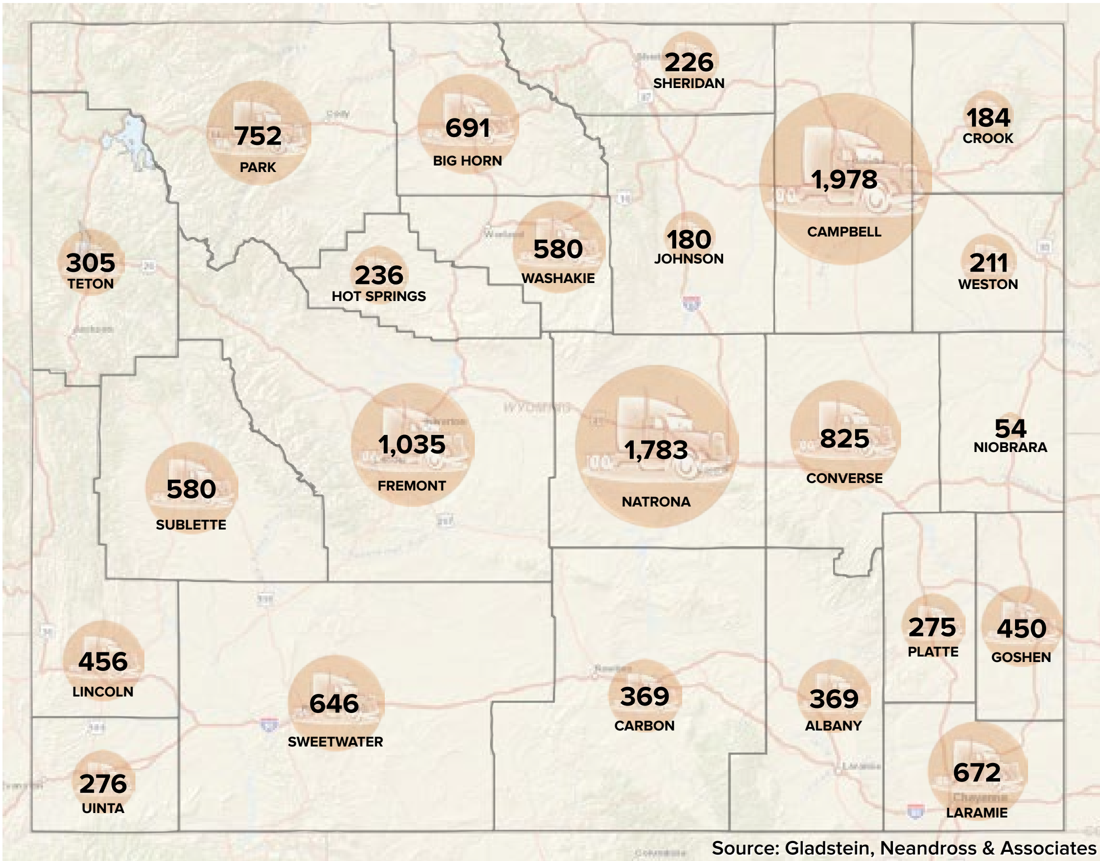
66 Federal Highway Administration, http://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/nhsavglhft2040.htm.

Figure 18. Wyoming traffic by county: percent of highway miles vs. truck VMT



Source: Wyoming Department of Transportation

Figure 19. Number of Wyoming-registered Class 7 and 8 trucks by county



Notably, truck registrations by county (Figure 19 above) do not match up particularly well with percentage of truck VMT by county shown in the Figure 18. Instead, it appears that the highest numbers of on-road heavy-duty truck registrations are found in counties that support high levels of mineral E&P activities (e.g., coal and gas in Campbell County). Proximity to local goods movement corridors (e.g., I-25 and SR 20 in Natrona County) seems to secondarily correlate with truck registrations.

While I-80 is Wyoming's busiest goods movement corridor, the vast majority of commercial truck trips on this highway involve line-haul freight trucks that do not originate or end in Wyoming (see next subsection). This may explain why Wyoming truck registrations in counties along I-80 (Uinta, Sweetwater, Carbon, Albany, and Laramie) are relatively low compared to the corridor's heavy truck activity.

In sum, there are essentially two key types of heavy-duty on-road trucking in Wyoming that combine to consume this large (estimated) volume of diesel fuel: 1) line-haul trucking, and 2) return-to-base local trucking that play major roles in the state's prolific energy economy. Insufficient information exists about inventory and other factors to accurately break out their diesel fuel usage. To better characterize the potentials for and challenges with using natural gas in these two trucking subsectors, further discussion is provided below.

3.4.1.1. LINE-HAUL TRUCKING IN WYOMING

A 2008 study[67] for the U.S. Department of Transportation and WYDOT surveyed more than 2,000 freight truckers traveling through Wyoming's stretch of I-80 (westbound entry at Cheyenne and eastbound entry at Evanston). It was found that only 12 percent of freight truck drivers traveling on I-80 in the westbound direction either began or completed their freight delivery in Wyoming. For those traveling in the eastbound direction, a higher percentage (about 29 percent) either began or completed their freight delivery in Wyoming. As Figure 20 shows, trip origin locations (green dots) as well as trip destinations (blue dots) for the surveyed westbound truckers were scattered in a "bowtie" configuration across the United States.

Key findings for this phase of the study included the following:

- Food products constituted almost one-third of the total freight captured in the survey and were the largest freight category on I-80 across Wyoming. Other prominent categories of freight were building materials, heavy equipment, and general freight.

- Utah's Salt Lake City/Ogden area serves as a major inland freight hub of the west that "pulls" westbound freight and "pushes" eastbound freight across Wyoming I-80.

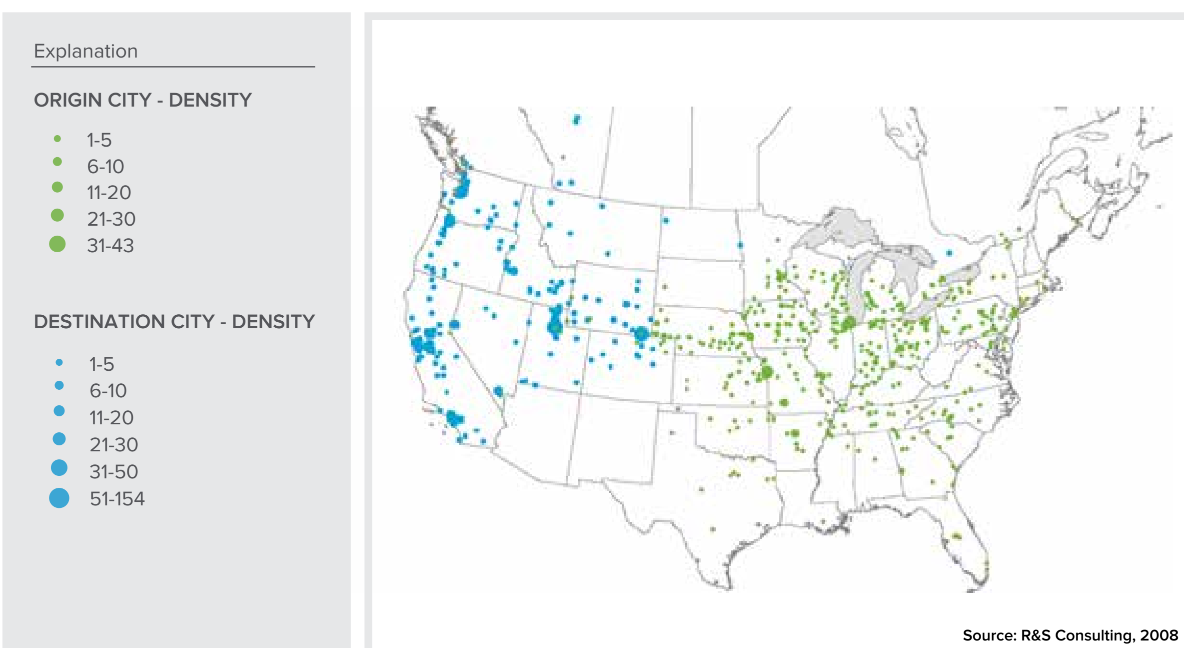
The long-term prognosis is for significant increases in Wyoming's heavy-duty line-haul truck traffic, especially across the I-80 corridor. The U.S. Energy Information Administration estimates that energy demand for heavy trucks will increase by nearly 40 percent by 2035, largely due to "higher industrial output leading to greater growth in vehicle-miles traveled by freight trucks."[68] WYDOT estimates that by 2040, traffic volume along the I-80 goods movement corridor is expected to increase from the current 11,000 vehicles per day to about 20,000.[69]

[67] R&S Consulting, "Interstate 80 Freight Corridor Analysis: Current Freight Traffic, Trends and Projections for WYDOT Policy-makers, Planning, Engineering, Highway Safety and Enforcement;" Final Report to US DOT and WYDOT, FHWA-WY-09/09F, December 2008; http://ntl.bts.gov/lib/44000/44300/44320/R_S_I-80_Freight_Analysis_-_Final_Report_101009_-_Final.pdf

[68] U.S. Energy Information Administration, AEO2013 Early Release Overview, December 2012.

[69] Ray Murphy, US DOT – FHWA, "Traffic Incident Management," presentation to the Wyoming DOT Supervisors Meeting, Cheyenne, Wyoming; March 26, 2013; accessed online at http://es.slideshare.net/raymurphy9533/wydot-tim-3-2613-by-ray-murphy.

Figure 20. Origins & destinations of I-80's (Wyoming) westbound trucks



3.4.1.2. HEAVY-DUTY TRUCKS SUPPORTING WYOMING HHP ACTIVITIES

Section 1.2.1 described Wyoming's world-class energy production activities, especially involving coal, oil and gas operations. These operations require major daily support from heavy-duty on-road trucks to move supplies, products and services. In the oil and gas sector, E&P operations can be extremely "transportation-intensive" regarding the numbers of heavy-duty trucks needed to support a drill and/or fracking site. As illustrated by Table 12, the complete process to prepare a drill site, perform the drill out, conduct hydraulic fracturing, and produce oil or natural gas can require roughly 1,000 heavy-duty truckloads (trips).

Notably, the oil and gas industry is working to reduce the resource impact of these energy-intensive truck trips. For example, efforts are being made to reduce truck trips through improved logistics. In addition, the industry is taking actions to operate as many heavy-duty trucks on LNG or CNG as possible (see Section 4.4.3). Oil and gas industry operations can be conducive to this, when the remote sites served by the trucks are already using LNG or CNG as an alternative to diesel for drill rigs, PPS equipment, and/or power generators.

Table 12. E&P operational modes requiring high levels of heavy-duty truckloads

E&P Mode	Specific Tasks	Number of Truckloads Required	Total Truckloads
Drilling Rig and Site Preparation	Drill Pad and Road Construction	10 – 45	**90 to 175**
	Drilling Rig	30	
	Drilling Fluid and Materials	25 – 50	
	Drilling Equipment	25 – 50	
Drill-out	Remove Drilling Rig	30	**43 to 47**
	Close Reserve Pits	3 – 5	
	Build Facility	10 – 12	
	Well Maintenance	25 – 40	
Completion	Completion Rig	15	**800 to 1,165**
	Completion Fluid and Materials	10 – 20	
	Completion Equipment (pipe, wellhead)	5	
	Pressure Pumping Services Equipment	150 – 200	
	PPS Water	400 – 600	
	PPS Sand	20 – 25	
	Flow Back Water Removal	200 – 300	
Production	Production Equipment	5 – 10	**30 to 50**
	Well Maintenance	25 – 40	
All Operational Modes and Tasks			**963 to 1,437**

Source of table and notes: Matt Most, Encana, presentation at HHP 2013, citing New York State Department of Environmental Conservation – 2009 Marcellus Shale Study (Note from Encana: "Information is for illustrative purposes only: truck traffic has been significantly reduced through development concepts like Encana's Resource Play Hub; multi-well pads, water recycling, multi-phase flow lines, centralized facilities, waster transport by pipeline, etc.")

3.4.2. ESTIMATED INVENTORY AND DIESEL FUEL USAGE

Significant uncertainty exists about how much diesel fuel is consumed in Wyoming by heavy-duty Class 7 and 8 semi-trucks (i.e., the most conducive trucks for using LNG). Weighted for age, a typical line-haul Class 8 truck travels an average of about 57,000 miles per year, consuming approximately 9,500 gallons of diesel fuel.[70] However,

[70] Annual VMT estimated from EPA Motor Vehicle Emissions Simulator (MOVES) Version 2010b.

the newest Class 8 line-haul trucks often travel twice as far and consume up to 20,000 gallons annually. As noted above, there are 13,133 Class 7 and 8 trucks registered in Wyoming. Using the simplified assumption that each truck only travels in state and burns 9,500 diesel gallons per year, the total fuel consumption in Wyoming for State-registered Class 7 and 8 trucks is estimated to be approximately 125 million gallons of diesel per year.

This analysis doesn't fully take into account the thousands of heavy-duty line-haul trucks that traverse I-80 (and other Wyoming highways) each day. According to the U.S. Energy Information Administration, 359 million gallons of diesel fuel were sold in Wyoming for on-highway transportation in 2012; most of this fuel was likely consumed in heavy-duty trucks. It appears that the above estimate of 125 million gallons per year for the fuel consumed by Wyoming's 13,133 registered Class 7 and 8 trucks falls reasonably within the figure of 359 million gallons that were reportedly sold in 2012 for the entire on-road diesel sector.

3.5. OFF-ROAD OPERATIONS: OTHER LARGE VEHICLES AND EQUIPMENT

3.5.1. OVERVIEW OF WYOMING'S OFF-ROAD SECTOR

Figure 21. Caterpillar D11T dozer

The category of "other large off-road vehicles and equipment" is used in this report to capture a wide array of HHP diesel engines that are operated in Wyoming, but are not used in mine haul trucks, locomotives, drill rigs, or pressure pumpers. In Wyoming, such engines are typically used in applications such as mining support, E&P power generation, construction, and agriculture. The specific interest is in vehicles and equipment with diesel engines that are rated from 300 horsepower up to about 1,000 horsepower. For example, Caterpillar's "large dozer" category goes from 317 up to 850 horsepower; a large motor grader offers net power of 533 horsepower, and a large wheel dozer provides 907 gross horsepower.[71] Figure 21 shows a typical HHP off-road dozer used in Wyoming mining operations.

Currently, there are no conversion kits offered by industry to use LNG in these types of equipment and vehicles. For the models and applications that use very high volumes of diesel, this may change in the near future. Based on manufacturer information and other sources of information, vehicles and equipment in this broad category use anywhere from seven to 40 gallons of diesel fuel for every hour of operation.[72] Actual fuel consumption depends on many factors that include make, model, engine rating, duty cycle, and application.

[71] See Caterpillar website, http://www.cat.com/en_US/products/new/equipment/dozers/large-dozers.html

[72] For example: Holt Cat Online Tools, "Estimating Owning & Operating Costs" 2012 PDF, offered online.

3.5.2. ESTIMATED INVENTORY AND DIESEL FUEL USAGE

Very little public information exists about the numbers of HHP off-road vehicles and equipment that are currently operating in Wyoming. However, we can back calculate the rough volume of diesel fuel used, beginning with other off-road vehicles and equipment used in Wyoming's prolific coal mining business. As noted previously, a general "rule of thumb" for coal mine operations is that mine haul trucks consume 70 to 75 percent of a mine's total diesel fuel usage, while other miscellaneous off-road equipment use 25 to 30 percent. For simplicity, we assume the split to be 75 percent / 25 percent. Since the estimate for statewide diesel use for mine haul trucks is roughly 121 million gallons (refer back to Section 3.1), we can "work backwards" to estimate diesel fuel use for the other HHP mine equipment, as shown in Table 13.

This estimate of 40 million annual diesel gallons consumed by "Other Large Off-Road" vehicles and equipment at coal mines can be used to back calculate the associated inventory. Based on manufacturer information, a higher horsepower "Other Off-Road" piece of mining equipment (such as a large dozer) is assumed to use diesel fuel at a rate of 25 to 26 gallons per hour. Assuming a 10-hour daily duty cycle and 330 days per year of operation, this yields an annual per-unit use of about 85,000 diesel gallons. Thus, it would roughly take 470 individual off-road vehicles of this class working in the coal mining sector to consume 40 million gallons of diesel per year.

Although coal mining is Wyoming's dominant type of mining in terms of tonnage moved, the state has many other types of mining operations that use large off-road vehicles and equipment. Based on taxes assessed on off-road diesel fuel sales in Wyoming (2011 data),[73] GNA estimates that an additional 5.6 million gallons of diesel are currently used by "other off-road" vehicles and equipment supporting non-coal mining operations.

These same off-road diesel fuel taxes allow estimates for the very large volumes of diesel fuel that are being used in Wyoming's agriculture and construction sectors. A wide array of HHP off-road vehicles and equipment are used in these sectors, and the inventory numbers appear to be very high. It is estimated that these two sectors collectively consumed about 173 million gallons of diesel in 2011.[74]

Putting all this together (and assuming 2011 reflects typical current usage), Table 14 shows that an estimated 220 million diesel gallons per year are consumed in Wyoming's entire fleet of "Other Off-Road" HHP vehicles and equipment.

Roughly, it is estimated that 2,600 to 3,000 individual HHP vehicles and equipment are operational in Wyoming to collectively consume this large volume of fuel. However, it must be emphasized that this "top down" estimate was calculated through fuel taxes applied in Wyoming's off-road sector. Virtually no information or data are available about actual inventories by types of vehicles and equipment.

[73] May 2012 tax data for off-road diesel fuel sales were provided from the Wyoming Department of Transportation.

[74] Wyoming Department of Transportation, as noted above.

Table 13. Calculation for diesel consumed in Wyoming coal-related "Other Large Off-Road" sector

Diesel Usage Parameter	Derived by	Result / Estimate
Total Volume of Diesel Used in Wyoming Mine Haul Trucks (75% of All Coal Mine Operations)	440 Mine Haul trucks X 274,000 GPY / truck	121 million GPY
Total Volume of Diesel Used in All Wyoming Coal Mine Operations	121 million GPY ÷ 0.75	161 million GPY
Total Volume of Diesel Used in Wyoming's Coal Mine "Other Large Off-Road" Sector	161 million gpy – 121 million GPY	**40 million GPY**

Table 14. Estimated annual diesel usage for Wyoming's "Other Off-Road" sector

Wyoming "Other Off-Road" Sector	Estimated Diesel Usage (gallons per year)
Coal Mining (excluding large mine haul trucks)	40 million
All Other Mining (excluding large mine haul trucks)	6 million
Agriculture	94 million
Construction	80 million
Total Annual Volume of Diesel Used in Wyoming	**220 million**

3.6. SUMMARY OF INVENTORY AND FUEL USAGE ESTIMATES FOR ALL SECTORS

For the six HHP sectors, Table 15 summarizes estimates for 1) per-unit annual diesel usage, 2) inventory of units that are currently operational in Wyoming (the "inventory"), and 3) the total volume of diesel fuel consumed by the sector. The total volume of fuel collectively consumed in Wyoming-serving HHP applications by these six sectors is approximately 634.3 million gallons of diesel per year.

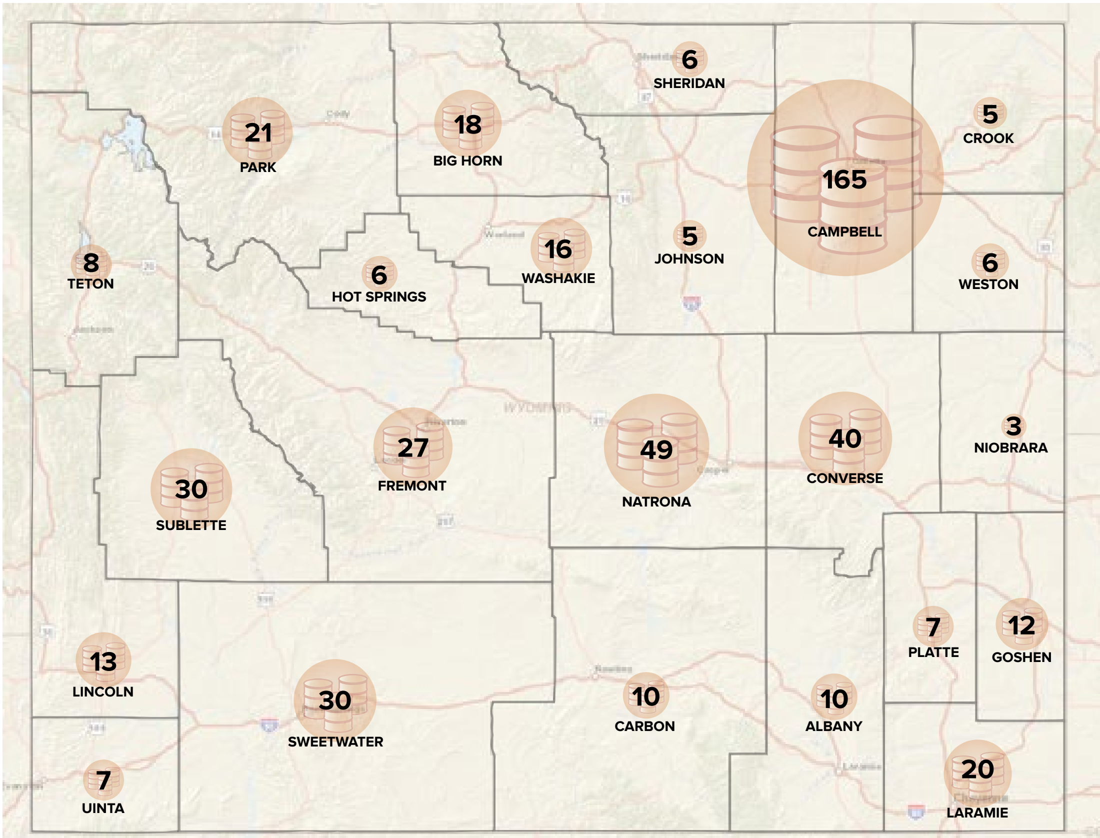
As described in section 4.4.2, one sector (Other Large Off-Road Equipment) in Table 15 provides a range for the per-unit diesel fuel consumption and estimated Wyoming inventory. This sector consists of a wide array of equipment types, sizes, and uses. In this case, the inventory and total estimated diesel consumption were back calculated from fuel taxes assessed on Wyoming's off-road sector. The ranges of estimates in the table reflect greater uncertainty in this sector. A single value for this sector's total annual fuel use (220 million gallons per year) is based on State fuel usage data.

Table 15. Summary of estimated inventories and diesel use for Wyoming's key HHP sectors

Vehicle or Equipment Type	Per Unit Diesel Fuel Consumed (gal/yr)	Estimated Units in WY Inventory	Total Estimated Diesel Consumed (gal/yr)
Mine Haul Trucks	273,900	440	120,516,000
Locomotives	300,000	405	121,500,000
Drill Rigs	373,750	50	18,687,500
Pressure Pumping Services	240,000	120	28,800,000
On-Road Semi Tractors	9,500	13,133	124,763,500
Other Large Off-Road Equipment	73,000 to 85,000	2,600 to 3,000	220,000,000
Grand Total			**634,267,000**

Note: "Other Large Off-Road Equipment is a very diverse category, with a wide array of equipment types and sizes. Inventories and fuel usage estimates were back calculated from Wyoming fuel sales and other factors.

Figure 22. Roughly estimated diesel use in Wyoming HHP sectors by county (millions of GPY)



Source: Gladstein, Neandross & Associates (based on high-level estimates for HHP equipment inventories)

As described in the above table, approximately 635 million diesel gallons per year (GPY) are estimated to be consumed in all HHP sectors during their direct service of Wyoming's energy economy. To roughly estimate the total volume of diesel that is consumed within Wyoming, it is necessary to subtract the estimated diesel fuel consumed by PRB-serving locomotives while they are operating out of state (assumed to be 90 percent of their operational time). After making this adjustment, it is estimated that 514 million diesel GPY are consumed within Wyoming. Figure 22 provides a map that breaks out the total existing diesel use (in GPY) within each Wyoming county. Given the high degree of HHP engine activity in the Powder River Basin—especially for mine haul trucks, locomotives, and E&P drill/frack sites—it is not surprising that this "diesel heat map" is dominated by Campbell County, where an estimated 165 million diesel GPY are consumed.

4. SWITCHING TO NATURAL GAS: ACTIVITIES AND OPPORTUNITIES

Clearly, economics are the main driver for HHP fleet operators in Wyoming to switch from diesel to natural gas. Purchasing diesel fuel typically constitutes the first or second highest expense (with labor costs) for high-fuel-use industries such as mining, oil & gas, and rail. Very compelling fuel cost savings are available to HHP fleets; these savings can offset the incremental capital costs of switching within one to four years. The largest HHP equipment and vehicle types may consume as much as 500,000 gallons of diesel per year, so natural gas versions of these units can provide very compelling payback on capital investments. However, there are many fleet-, sector- and technology-specific variables that affect the actual economics of switching to natural gas, as further described below for each sector.

Major strides have been made towards commercialization of natural gas options in America's high horsepower sectors. However, actual deployments are still in their infancy. In the case of Wyoming's HHP applications, only the oil & gas sector has moved past the pilot-scale demonstration phase, into early commercialization. The following subsections describes examples of existing efforts to switch to natural gas, and the largest sector-by-sector opportunities to expand such efforts. The focus is on LNG, but other natural gas forms (CNG, field gas) are also described (where relevant). In addition, some specific examples are provided about the environmental benefits that can be realized by switching to natural gas.

4.1. MINE HAUL TRUCKS

4.1.1. EXISTING EFFORTS AND PLANS FOR NATURAL GAS DEPLOYMENTS

Mine haul trucks consume very large volumes of diesel and make strong candidates for conversion to dual-fuel engines in the short term, and Westport's HPDI technology over the mid term. Emerging manufacturer products have generated strong interest among end users in this sector.

Referring back to Table 4, various companies are developing products designed to convert existing mine haul trucks for dual-fuel operation on diesel and LNG. In addition, manufacturers are developing new haul truck models that will be powered by dual-fuel or direct injection natural gas engines. Specific "supply-side" examples for LNG technology in mining include the following:

- GFS Corporation is now selling LNG conversion systems for large mine haul trucks. GFS's "Evo-MT™" dual-fuel conversion systems are designed to maintain compression ignition in haul truck engines. Converted haul trucks can still operate on 100 percent diesel if needed, but the normal mode would be to operate on dual fuel with a substitution rate of approximately 50 percent. For example, the GFS "EVO–MT 7930 System" is specifically designed for the Caterpillar 793 series of mine haul trucks. According to GFS, no major modifications are needed for either the chassis or drive engine of Caterpillar 793 haul trucks. GFS has also recently introduced LNG conversion systems for other Caterpillar mine haul truck platforms, such as the 777 Series, as well as for Komatsu haul trucks.[75, 76]
- Caterpillar is leveraging the use of proprietary DGB technology currently deployed in the oil and gas markets to also serve other markets such as mining trucks and locomotives. In addition Caterpillar is also working with Westport to develop HPDI technology,

[75] GFS Corporation, "GFS Corp Announces First Commercial LNG Conversion System for Large Mine Haul Trucks," news archive accessed at http://www.gfs-corp.com/news.php/art/8/yr/2012.

[76] GFS Corporation, "Liquid Natural Gas Mine Haul Truck Conversion 2013 NOVA Award Nomination 22: The EVO-MT System," submitted to the Construction Innovation Forum, 2013 NOVA Award Nominations, accessed online at: http://www.cif.org/noms/2013/22_-_Liquid_Natural_Gas_Mine_Haul_Truck_Conversion.pdf.

which may offer improved economic and environmental benefits to their customers.[77]

[77] Caterpillar, personal communication to GNA, March 2014.

Other companies that are developing LNG technology for mine haul trucks include Cummins and possibly American Power Group.

Figure 23. Close-up of LNG fuel tanks in CAT 793 dual-fuel haul truck at Belle Ayr Mine

Source: Gladstein, Neandross & Associates

Source: Gladstein, Neandross & Associates

Virtually all Wyoming surface mining operations—especially the largest coal mines in the PRB—are probably considering their options to transition towards LNG-fueled mine haul trucks. These operations are highly focused on reducing life-cycle costs to remain competitive. Since factory-built mine haul trucks won't be available until the 2017 time frame, the only current option is to retrofit existing haul trucks for operation on dual fuel.

Alpha Natural Resources was the first Wyoming end user to actually convert mine haul trucks to LNG. In a joint effort with GFS, Alpha converted three Caterpillar 793 haul trucks at its Belle Ayr coal mine near Gillette to dual-fuel (LNG / diesel) operation using GFS's EVO-MT™ System. The main objectives of this pilot-scale demonstration have been to 1) prove viability of GFS's system and dual-fuel natural gas in "a real-world Alpha Coal West operational environment," 2) validate cost savings, and 3) evaluate LNG fueling logistics in this sector. Figure 23 shows one of these demonstration vehicles in operation at the Belle Ayr coal mine. This includes a close-up of the on-board LNG storage system, which was designed and customized by GFS for this special application. Figure 24 shows the 10,000 gallon bulk LNG tank that is being used for on-site fuel storage.

Table 16 summarizes this particular demonstration and the results to date. Reportedly, Alpha hopes to displace at least 50 percent of its diesel fuel needs in its converted haul truck fleet.[78]

[78] "Alternative Fuel Project: Natural Gas + Diesel," Kenneth Ferguson, Alpha Natural Resources, Inc., HHP Summit 2013, September 2013.

GLADSTEIN, NEANDROSS & ASSOCIATES

Figure 24. Bulk LNG tank at Belle Ayr Mine demo site

Table 16. Overview of dual-fuel mine haul truck demo at Alpha Coal's Belle Ayr Mine

Demonstration of Dual-Fuel (LNG-Diesel) Mine Haul Trucks at Belle Ayr Mine	
Project Host Site	Alpha Coal West, Belle Ayr Mine, Gillette, Wyoming
Provider / Technology	GFS Corporation / EVO-MT™ System
Project Objectives	• Prove viability in Alpha Coal's real-world operational environment • Validate fuel cost savings and payback of conversion cost • Evaluate LNG fueling logistic
Demonstration Trucks	Three Caterpillar 793B (mechanical drive) 400-ton class mine haul trucks
Conversion Approach	In-field retrofit with upgraded 797C engines
Target Diesel Substition Rate	At least 40%, up to 50%
Onboard LNG Storage	400 gallons LNG (not all useable)
Operational Target	Achieve 12 hour shift without refueling
LNG Source	Prometheus Energy (Logan, Utah)
LNG Delivery to Site	Over-the-road LNG tanker (10,000 LNG gallons)
LNG Storage at Site	40' ISO LNG container
LNG Fueling to Trucks	Chart mobile vehicle refueling truck (ORCA, 3,000 LNG gallons)
Project Milestones	• Kick off: July 2011 • First LNG fill: July 2012 • Official testing: July 2012 to September 2013 • Original decommissioning planned for October 2013 • *Demo expansion announced; Eagle Butte Mine; 12 LNG trucks: January 2014
Available Results	• Operations, training, maintenance were all successful • Vendor support was good • Continual improvements were made to the trucks during demo • "Significant fuel substitution logged" • No performance difference between diesel and LNG + D mode • Infrastructure arrangements took significant time and planning • Challenges encountered, but were "overcome"

Source: Kenneth Fegusen, Alpha Coal West General Manager, presentation at HHP Summit 2013, September 2013, except*

Alpha, GFS, and the vendors that have supported LNG delivery to the trucks have all gained valuable insight into how to operate ultra-class mine haul trucks on LNG in real-world coal mining operations. In early January 2014, GFS announced that Alpha Coal West "has decided to move forward with the conversion of 12 additional" mine haul trucks at Eagle Butte Coal Mine in the PRB. The 12 truck conversion will reportedly be underway in 2014. Alpha will install "permanent, full scale LNG fuel storage and dispensing infrastructure to replace the temporary solution used during the pilot."[79]

Arch Western Bituminous Coal Inc. intends be the second Wyoming coal operation to demonstrate LNG-fueled mine haul trucks. Arch is working with GFS to convert up to four electric-drive Komatsu 830e haul trucks by 2014 at Black Thunder coal mine in the southern PRB. Black Thunder is one of the world's largest coal producers, at approximately 120 million tons produced per year. Reportedly, total diesel consumption at Black Thunder is 50 million gallons per year, of which 80 percent is consumed by a fleet of 150 large mine haul trucks. Like Alpha at Belle Ayr mine, Arch will deploy a 10,000 gallon onsite LNG storage tank and "wet fuel" the four LNG mine haul trucks at Black Thunder Mine using a 3,000 gallon ORCA mobile refueler from Chart Industries.[80]

Arch's annual fuel cost savings are expected to be significant; however, the actual economics will depend on the fuel price spread available to Arch, the gas substitution rates they are able to achieve, and the duty cycle of the Komatsu 830e haul trucks. More about the potential cost savings across Wyoming's entire mine haul truck sector is provided below.

[79] GFS Corp Receives Order to Convert Alpha Coal West, Inc.'s, Entire Caterpillar 793 Fleet at Eagle Butte to Natural Gas," GFS press release, prweb, January 15, 2014, http://www.prweb.com/releases/2014/01/prweb11481718.htm

[80] "Arch Western Bituminous Coal's Perspective on Natural Gas," Steve "Skinner" Forbush, Arch Western Bituminous Coal, Inc., HHP Summit, Sept. 19, 2013.

4.1.2. SUMMARY OF OPPORTUNITY FOR LIFE-CYCLE COST SAVINGS

As described in 3.1.2, there are an estimated 440 operational mine haul trucks (90 ton class and above) in Wyoming today; collectively, these haul trucks consume approximately 121 million gallons of diesel fuel per year. On average, this equates to about 274,000 gallons of diesel per haul truck, although the largest trucks in the toughest duty cycles may consume more than 400,000 gallons per year. Mine haul trucks last 20 to 30 years, although their diesel engines may be rebuilt multiple times over that period.

To date, only Alpha and Arch have publically shown action or intent to act; these two companies collectively control four PRB coal mines. It is currently unknown how many or which other PRB coal mine operators are also moving iteratively towards testing and adopting LNG as a substitute for diesel in mine haul trucks. For the interested mine companies, most (if not all) seem likely to initially convert smalls fraction of their fleets. Based on product availability, they will opt for dual-fuel systems with 40 to 50 percent substitution rates that retain capability to switch back to 100 percent diesel fuel. This will help manage perceived risks some have noted with rolling out new LNG technology. These include concerns about robustness of the technology, LNG supply issues, and long-term future of low cost LNG compared to diesel.[81] Given these dynamics, Wyoming coal mine operators that choose to phase in LNG haul trucks are likely to start by converting existing (in-use) mine haul trucks using dual-fuel conversion kits.

Table 17 lists the estimated volumes of diesel that a single large mine haul truck would displace using a dual-fuel LNG system with a 40 percent substitution rate (the current norm for this application). It also shows the estimated fuel cost savings (annual and lifetime), and the timeframe for simple payback. As indicated, each large mine haul truck converted to operate on dual-fuel LNG with a 40 percent substitution rate could displace about 110,000 gallons of diesel each year. The timeframe for an end user to achieve simple payback on capital expenses (CapEx) associated with converting each mine haul truck is estimated to be less than 18 months; this does not include CapEx for refueling infrastructure. The last subsection of this chapter sums up the estimated benefits of converting the entire estimated Wyoming fleet of 440 large mine haul trucks. The real-world challenges and barriers that are likely to define the actual pace and quantities of conversions are discussed further in Section 8.

[81] Conclusions described in this paragraph are based on numerous statements and presentations made by representatives of companies operating major Wyoming coal mines.

Table 17. Estimated Net Present Value of converting one mine haul truck to dual-fuel LNG operation

Baseline Diesel Use (diesel gal/yr)	274,000
Estimated Incremental Capital Cost (CapEX)	$200,000
Diesel Displaced (diesel gal/yr)	109,600
LNG Required (LNG gal/yr)	184,000
Annual Fuel Cost Savings	$164,400
Simple Payback Timeframe	1.2 years
NPV of Natural Gas Option vs. Baseline Diesel	$1,542,000
Assumptions: $1.50 per DGE fuel price spread, 40% fuel substitution rate, 20 year life, 7% discount rate, 100% engine efficiency compared to baseline diesel truck	

4.2. OIL AND GAS E&P

4.2.1. EXISTING EFFORTS AND PLANS FOR NATURAL GAS DEPLOYMENTS

The Oil and Gas E&P sector has led the way for conversion of HHP equipment from diesel to natural gas operation (dual-fuel and dedicated). Deployments of natural-gas-powered drill rigs are in the early stages of commercialization; natural-gas-powered frack pump deployments are in a pre-commercialization stage, but moving into early commercialization. This is borne out by results recently reported by America's Natural Gas Alliance (ANGA). In a 2013 survey, ANGA found that 19 of the 27 responders (70 percent) are either using natural gas drill rigs in a commercial capacity, or have initiated pilot demonstrations (see Table 18).

Table 18. ANGA member natural gas operations experience

ANGA Members: Status of Using Natural Gas for E&P	Drill Rigs	PPS
Already Using Natural Gas in the Noted Application	8	3
Undertaking Pilot Demonstration(s)	11	7
Not Currently Using Natural Gas for Application	4	11
No Response to Survey	4	6
Total Entities Surveyed by ANGA	**19**	**10**
Source: Adaptation of table presented by Amy Farrell, Vice President of Market Development, America's Natural Gas Alliance, HHP Summit 2013, September 2013.		

The ANGA surveys help demonstrate that the PPS sector is significantly moving towards natural gas; 10 ANGA members have already implemented commercial efforts or pilot demonstrations, although 11 ANGA members (nearly half) reported that they were not yet involved with natural gas PPS efforts.

It has been noted that there is no "one-size-fits-all solution" for using natural gas in the E&P sector.[82] This is true partly because there are more options for the natural gas fuel type used in E&P, compared to other HHP sectors. E&P operations are somewhat unique, in that they can utilize four different options for the source and type of natural gas.

[82] Amy Farrell, Vice President of Market Development, America's Natural Gas Alliance, presentation at the HHP Summit 2013, September 2013.

Figure 25. Options for using natural gas to power E&P operations

As illustrated in Figure 25, drill rigs and hydraulic fracturing operations can be powered by field gas, CNG, LNG, or "sales ready" pipeline natural gas. Any one of these natural gas sources can be used in "dedicated" 100 percent natural gas engines, or they can be mixed with diesel at the E&P site for use in dual-fuel engines. (Refer back to Table 4. Example approaches, technologies and products for high-HP natural gas engines.") The optimal choice for the source of natural gas and engine type at a given E&P operation depends on many factors, as further discussed in this report.

For drill rigs and PPS equipment, three different forms of natural gas are being used in Wyoming: LNG, CNG, and field gas. Implications of using each are summarized below:

- **LNG** is a cryogenic liquid (-260O F) that is delivered to E&P sites by over-the-road Class 8 tractors towing specialty cryogenic trailers. The LNG is offloaded from the delivery tankers into an on-site LNG fuel storage tank. An on-site vaporizer is needed to transform the cryogenic liquid back into usable gaseous fuel for use in the engines on site. The footprint at a given E&P site for an LNG fueling system can be fairly large in order to accommodate the on-site LNG fuel storage system (and code-required setbacks) and required vaporization equipment. On-site maintenance personnel may be required to support fuel supply equipment. LNG is very high in methane content, which is favorable for its combustion. Its availability is region dependent, which means supply disruptions can occur. The price of LNG delivered to the site is typically about $2.00 to $2.50 per diesel gallon equivalent (DGE). LNG used in E&P operations can provide significant fuel cost savings (see next section) and a mid-range return on investment. However, the magnitude of these savings will be highly dependent on the distance to the liquefaction facility (fewer than 250 miles is best).

- **CNG** is a compressed gas that is delivered in high-pressure (2700+ psi) tube trailers hauled by over-the-road Class 8 tractors. Unlike LNG where the fuel is transferred into an on-site storage system, high pressure CNG transport trailers are left on site (while an empty trailer is removed; i.e. "drop and swap"). On-site pressure regulation equipment is required to reduce the pressure of the CNG before the fuel is sent to the engine for combustion. Provision of high instantaneous power for fracking can be best met with CNG. However, CNG's lower energy density can require more frequent fuel deliveries than LNG. The footprint of a CNG system is roughly comparable to an LNG fueling system; while vaporizers are not required with CNG, the lower fuel density of CNG compared to LNG may require additional tube trailers be stored on site. CNG fuel quality varies more than LNG, but these variations are generally not significant for E&P operations. CNG's availability is region dependent. The price of CNG delivered to the site is about the same as LNG ($2.00 to $2.50 per diesel gallon DGE). CNG appears to make the most economic sense for E&P when companies have access to high-volume CNG fueling (e.g., for their own fleet and rig operations) within a few hundred miles of the operation.

- **Field gas** (at ambient or low pressure) is available at or near some E&P sites; this can be collected by gathering lines and delivered to holding tanks by short pipelines. However, the availability of field gas is highly site dependent. Provision of high instantaneous power using field gas will vary by site; the available energy from field gas may not be sufficient for hydraulic fracturing operations. A key advantage of field gas can be cost; with minimal gas cleanup, it can cost as little as $0.50 per diesel gallon equivalent (DGE). However, fuel quality for field gas varies more than LNG or CNG. Significant gas clean up can be required at the site; in some cases, this cost may be too high. In addition, there may be royalty issues with using field gas. Other advantages of field gas are that it has a relatively small site footprint and it reduces truck traffic at the site.

A variety of location-, operation-, and user-specific factors determine which of these fuel types is the best option to reduce E&P fuel costs at a given site drilling or fracking site. There are numerous engineering and logistics issues associated with fuel choice, which must be addressed when using natural gas for E&P operations. These include the following:[83]

- High variability in fuel quality requires designing equipment for extremes rather than averages

- Large bursts of energy consumption over short durations are required; onsite fuel storage must be in close proximity to the wells being drilled or fractured

- Frequent relocation of E&P sites means that equipment must be mobile and durable

- Short set-up times require well-devised and tested systems with quick connections

Regardless of the fuel form, a distinct advantage of using natural gas relates to the relative simplicity of its fuel cycle, which helps to reduce overall costs. As stated by Caterpillar:

> *"Natural gas fuel costs will easily be lower than diesel if the fuel is sourced locally, from the well field itself or from a nearby gas pipeline. Because gas engines can be configured to accept raw natural gas ("wellhead" gas) they can realize immediate savings on the cost of fuel processing. Diesel fuel, by comparison, must be processed, transported, and stored on site, all of which accrue to the cost of the fuel consumed. Analysis shows that fuel costs are a significant portion of the charges incurred over the life of the engine, so savings on fuel costs may greatly lower the overall cost of operation."*[84]

The combined effect of these challenges and opportunities makes a compelling case for many companies in the E&P industry to switch to natural gas. Nationally and in Wyoming, it's clear that very large volumes of diesel fuel can be displaced with relatively inexpensive natural gas. For example, one study found that 100 percent conversion of all diesel engines used to drill and frack U.S. horizontal wells (see next subsections) could consume at least 250 million cubic feet (MMCF) per day of natural gas.[85] This is approximately 91 billion cubic feet (BCF) each year.

A broad range of statements have been made about the actual savings that are being realized from fuel switching to conduct drilling and/or fracking operations, in part due to the many variables of these operations (fuel price spread, substitution rate, natural gas type, dual fuel or dedicated, etc.). Below, some specific examples of diesel displacement and cost savings are provided from different companies using natural gas for drilling and/or fracking.

[83] Based on statement by Matt Most, Vice President, Encana Corporation, HHP Summit 2013, September 2013.

[84] Caterpillar, "Gas Engine Power for Drilling," accessed online on October 2013 at: http://www.catoilandgasinfo.com/_downloads/LEBW0005-00.pdf

[85] "Alternative Natural Gas Demand: It's Not Just Trucking Anymore," Rosenblatt Energy Research, April 2013.

4.2.1.1. DRILL RIGS

Many companies involved with E&P operations are routinely operating or testing natural-gas-powered drill rigs. One estimate is that about 75 drill rigs (6 percent) in North America are now powered by dual-fuel or dedicated natural gas engines, and this is expected to increase to 600 (50 percent) over the next seven years.[86] The amount of fuel cost savings from using natural gas in drill rigs depends on many factors, including the form of natural gas fuel. According to one E&P company executive,

> *"A good rule of thumb is that a 20 percent savings can generally be realized in E&P operations by replacing diesel with natural gas in dedicated drill rigs. This could be as high as 30 percent using field gas, and might be lower with LNG or CNG depending on the variable costs of transportation."*[87]

[86] "Accelerating Use of Natural Gas in Frac Pressure Pumping Operations," Prometheus Energy presentation at HHP Summit 2013, September 2013.

[87] Personal communication, ENCANA E&P staff to GNA, November 2013.

Specific examples of companies implementing natural gas drill rigs are provided below. Figure 26 shows a drill rig in Wyoming powered by three Caterpillar natural gas engines.

- Encana Corporation, a leading North American energy producer with a strong presence in Wyoming, is running up to 18 natural-gas-powered drilling rigs in its U.S. and Canadian field operations. About two-thirds use dedicated natural gas engines, which can displace up to 1,500 diesel gallons per day. Encana has designed, built and deployed as many as nine natural gas rigs to operate on field gas in Wyoming's Jonah Field. The company reports saving $45,000 in fuel costs for each drilled well, while also reducing NOx emissions by 85 percent. Encana now operates 57 percent of its drill rig fleet on various forms of natural gas. Annual savings from switching to natural gas in drill rigs are reportedly about $400,000 for a dual-fuel LNG rig, $600,000 for a dedicated LNG drill rig, $800,000 for a dual-fuel field gas rig, and $1.6 million for a dedicated field gas rig.[88]

[88] Matt Most, Vice President, Encana Corporation, statement at HHP Summit 2013, September 2013.

Figure 26. Wyoming drill rig powered by three CAT™ natural gas engines

- ENSIGN Energy Services Inc., an industry leader in the delivery of oilfield services, operates at least 20 natural gas drill rigs in 10 different areas of North America, including Wyoming. ENSIGN reports that a single drill rig powered by a dedicated natural gas power plant (e.g., the Caterpillar G3516LE, the GE Waukesha L7044GSI, or a Caterpillar Solar Turbine Saturn® 20) can save $240,000 per year on LNG, $390,000 on CNG, and up to $1.1 million per year on field gas. In addition, major reductions in NOx, PM and non-methane hydrocarbon emissions are being realized at ENSIGN's natural gas drill rig sites, such as the field gas rig shown in Figure 27. The incremental cost of purchasing the necessary new LNG equipment, with installation, is about $360,000. However, this is nearly $1 million less expensive than retrofitting an existing diesel rig.[89]

- Noble Energy has deployed "multiple turnkey options" for using LNG-powered drill rigs in the Denver-Julesburg (DJ) Basin, most of which is located in Colorado. Noble is running at least four rigs that feature Caterpillar 3512 engines retrofitted with GTI Altronics dual-fuel conversion kits. Average daily fuel cost savings have ranged from $1,100 to $2,000. Fuel substitution rates ranged from 25 to 40 percent across all duty cycles. The capital cost of conversion is approximately $300,000 per drill rig. Noble Energy is building a 100,000 gallon per day LNG plant in Weld County, Colorado, to help supply its fleet of drill rigs and PPS spreads; Noble anticipates using up to one half of its LNG production internally when the LNG plant opens in 2014.[90]

- Apache Energy has five (5) drill rigs operating in the U.S. on dual-fuel or dedicated natural gas engines. Three (3) dual-fuel rigs use LNG and one uses field gas; the fifth rig is powered by field gas and a dedicated natural gas engine. On the dual-fuel rigs, Apache is achieving substitution rates between 50 and 65 percent without loss of power or response in transient conditions. Fuel cost savings range from 18 to 25 percent.[91]

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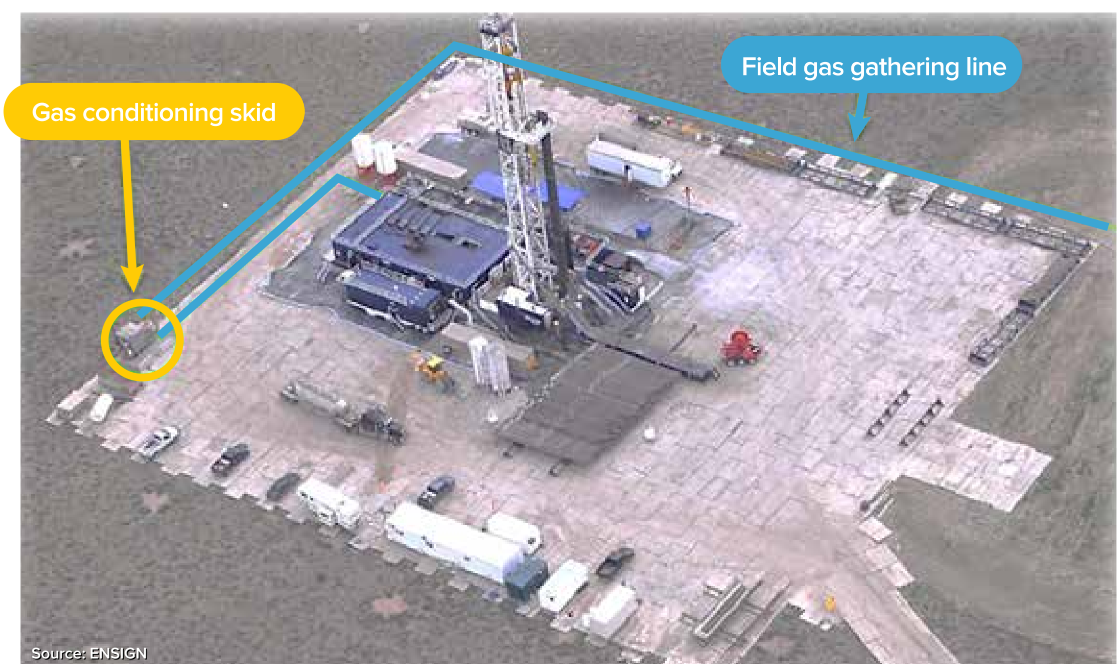
[89] "Natural Gas Fuel: Opportunities and Economics in Modern Drill Rigs," Brian Murphy, ENSIGN Energy Services Inc., presentation at HHP Summit 2013, September 2013.

[90] "Noble Energy's Recent Experience with Dedicated and Dual Fuel Systems for Drilling & Pressure Pumping," Curtis Reuter, Noble Energy, HHP Summit 2013, September 2013.

[91] Mark Bruchman, Apache Energy, untitled presentation at HHP Summit 2013, September 2013.

Figure 27. ENSIGN's layout for a drill rig site using field gas



4.2.1.2. PRESSURE PUMPING SERVICES (PPS)

Compared to drill rigs, at present there are fewer options for using natural gas engines in PPS operations, although new options appear to be steadily emerging. As of late 2013, dual-fuel conversion kits are the only significant option for PPS; however, OEM systems are under development or in pre-commercialization trials. In addition, turbine engines made by GE and other companies are being tested for this sector; these can be fueled by natural gas.

As with drill rig operations, the most suitable and economical form of natural gas for frack pump spreads depends on multiple factors. Much relates to requirements for pre-conditioning the fuel and moving it from the source to the well site. For example, a representative from one major E&P player indicates that the main determinant of economic feasibility for fracking with CNG versus LNG is the distance (in feet) from the fuel storage to the well.[92]

Many North American E&P companies are actively moving towards natural gas for their PPS operations; a variety of approaches to fuel type and other factors are being taken. A few examples are provided below.

- Encana, which has major E&P operations in Wyoming, is using all three forms of natural gas for its PPS operations. Encana reports that annual costs savings are about $415,000 for a dual-fuel frack pump, $625,000 for a dedicated LNG frack pump, $900,000 for a dual-fuel field gas frack pump, and $1.575 million for a dedicated frack pump.[93]

- A Haliburton representative notes that a single hydraulic fracturing job (not necessarily in Wyoming) can realize a 40 percent savings using dual-fuel (LNG-diesel) engines. Using field gas to frack wells can provide a 70 percent reduction in fuel costs.[94]

- Baker Hughes, Inc. (BHI) has converted a fleet of its "most fuel-intensive equipment" used in hydraulic fracturing into dual-fuel units. This has allowed the company to cut diesel use "by up to 65 percent without losing any hydraulic horsepower.[95] Depending on site logistics, BHI uses dual-fuel LNG, CNG and field gas; its focus is on "the most-efficient means of gas delivery" to the sites. BHI currently has converted 78 frack pumps (156,000 horsepower) to dual-fuel operation, and expects to have 124 converted by early 2014. In addition to the cost savings, BHI has reduced NOx and PM emissions by 50 and 70 percent, respectively. BHI is also interested in powering its dual-fuel frack pumps with flared methane at E&P sites; they estimate that five percent of total natural gas production is "wasted by flaring."[96]

- Apache Corporation has been working in recent months with drilling contractors and Caterpillar to advance its use of natural gas in oil field operations. Apache claims to be the first company to power an entire hydraulic fracturing job (12 pumps) with dual-fuel engines. At substitution rates ranging from 50 to 60 percent and using Caterpillar's Dynamic Gas Blending™ technology, Apache reportedly cut its per-frack fuel costs by $25,000 to $30,000. Annual fuel cost savings are projected to be $1.5 to $2 million per frack spread.[97] Apache's projections suggest that "the economic benefit appears enormous for an industry that used more than 700 million gallons of diesel domestically in hydraulic fracturing last year."[98]

[92] Technology and Value Drivers for Today's Frac Pump," Troy Huey, Wellsite Delivery Portfolio Manager, Schlumberger, HHP Summit 2013, September 2013.

[93] Matt Most, Vice President, Encana Corporation, statement at HHP Summit 2013, September 2013.

[94] "Haliburton's Use of Natural Gas for Pressure Pumping Operations," Adam Marks, Equipment Design Team Manager, Haliburton, HHP Summit 2013, September 2013.

[95] Fuel Fix, "Baker Hughes using natural gas in fracturing jobs," posted on November 26, 2012, accessed online at http://fuelfix.com/blog/2012/11/26/baker-hughes-using-natural-gas-in-fracturing-jobs/.

[96] "Hydraulic Fracturing with Nat Gas Power: Integrating a 'Simple Concept' into Complex Operations," Sean Parker, Project Manager, Bi-Fuel Technology, Baker Hughes, HHP Summit, Sept. 19, 2013.

[97] Mark Bruchman, Apache Energy, untitled presentation at HHP Summit 2013, September 2013.

[98] Pipeline, "Fracking industry switching from diesel to natural gas," January 21, 2013, accessed online at http://pipeline.post-gazette.com/news/archives/25000-fracking-industry-switching-from-diesel-to-natural-gas.

- EQT Corporation has teamed with Green Field Energy Services (GFES) to successfully demonstrate multiple-stage fracks using 100 percent field gas. Reportedly, this saves as much as $52,000 in daily fuel costs across six fracking stages, or nearly $16 million per year. GFES notes that they have achieved major overall reductions in NOx and other criteria pollutants, with no special add-on equipment required.[99, 100]

- Natural gas supplier Prometheus Energy reports that more than 10 frack fleets (with 10 to 12 frack pumps each) were converted to dual fuel configurations in the first nine months of 2013. The fuel type mix was about 45% LNG, 45% field gas, and 10% CNG. Some frack spreads have been converted to 100% natural gas (LNG or field gas) using microgas turbine technology. Cost savings have been very significant, although Prometheus' representatives note that the industry is "still on a steep learning curve" with regard to these economics.[101]

- Dresser-Rand (D-R) has announced an "imminent market launch" for its "LNGo" brand small-scale liquefaction units. D-R's specific focus will be to provide distributed LNG for E&P customers that have switched to natural gas drilling and hydraulic fracturing (Figure 28; see Section 6.2.2.3 for more discussion).

[99] "Fracturing with 100% Field Gas," Chris Combs, Director, Fracturing Technology, Green Field Energy Services, HHP Summit 2013, September 2013.

[100] HHP Insight, "First Frack with 100% Field Gas, taken from E&P Operations by Rich Piellisch, September 18, 2013.

[101] "Prometheus LNG for Apache Rigs, Spreads," HHP Insight, December 12, 2013.

Figure 28. Dresser-Rand "LNGo" small-scale liquefaction unit

4.2.2. SUMMARY OF OPPORTUNITY FOR LIFE-CYCLE COST SAVINGS

There are an estimated 50 operational drill rigs in Wyoming today; collectively, these rigs consume approximately 19 million gallons of diesel fuel per year. On average, this equates to about 374,000 gallons of diesel per drill rig, each year. Drill rig engines last approximately seven years, although they may be rebuilt one or more times over that period.

As described in the previous subsection, a number of companies are already deploying drill rigs converted to operate on natural gas; many use dedicated natural gas engines fueled by field gas or LNG. These tend to be horizontal rigs, which are most conducive to such conversion. In Wyoming, there are an estimated 26 horizontal drill rigs that are currently operational. Use of natural gas in drill rigs—especially the horizontal rigs—appears to have reached an “early commercialization” stage of market development.

Table 19 shows the net present value (NPV) of the investment to convert a single drill rig to operate with dedicated LNG-fueled engine (i.e., at a 100 percent substitution rate). It also shows the estimated annual fuel cost savings, and the timeframe for simple payback. The relatively long estimated payback period (3.3 years) is largely a function of its estimated $1 million incremental capital cost (CapEx).

Notably, other options for the form of natural gas (e.g., field gas instead of LNG) and rig engine technology (dual fuel instead of dedicated) would likely yield a faster payback period and a higher net present value return on investment.

Pressure pumping services used to hydraulically fracture (“frack”) oil and gas wells are essentially in a “pre-commercialization” stage, but there is significant momentum for full commercialization. There are an estimated 120 operational frack pumps in Wyoming today; collectively, these pumps consume approximately 29 million gallons of diesel fuel per year. On average, it is estimated that each frack pump consumes 240,000 gallons of diesel per year. Frack pump engines last approximately seven years, although they may be rebuilt over that period.

Table 20 shows the net present value (NPV) of the investment to convert a single frack pump into a dual-fuel LNG configuration using a commonly cited 50 percent substitution rate. It also shows the estimated annual fuel cost savings and the timeframe for simple payback. It’s clear from this that converting an entire frack pump spread to run on dual-fuel will have a rapid payback and yield a very high net present value return on investments.

Table 19. Net Present Value of converting one drill rig to dedicated LNG operation

Baseline Diesel Use (diesel gal/yr)	374,000
Estimated Incremental Capital Cost (CapEX)	$1,000,000
Diesel Displaced (diesel gal/yr)	374,000
LNG Required (LNG gal/yr)	966,000
Annual Fuel Cost Savings	$300,000
Simple Payback Timeframe	3.3 years
NPV of Natural Gas Option vs. Baseline Diesel	$612,000
Assumptions: $1.50 per DGE fuel price spread, 100% fuel substitution rate, 7 year life, 7% discount rate, 65% engine efficiency compared to baseline diesel drill rig	

Table 20. Net Present Value of converting one frack pump to dual-fuel LNG operation

Baseline Diesel Use (diesel gal/yr)	240,000
Estimated Incremental Capital Cost (CapEX)	$150,000
Diesel Displaced (diesel gal/yr)	120,000
LNG Required (LNG gal/yr)	202,000
Annual Fuel Cost Savings	$180,000
Simple Payback Timeframe	0.8 years
NPV of Natural Gas Option vs. Baseline Diesel	$1,542,000

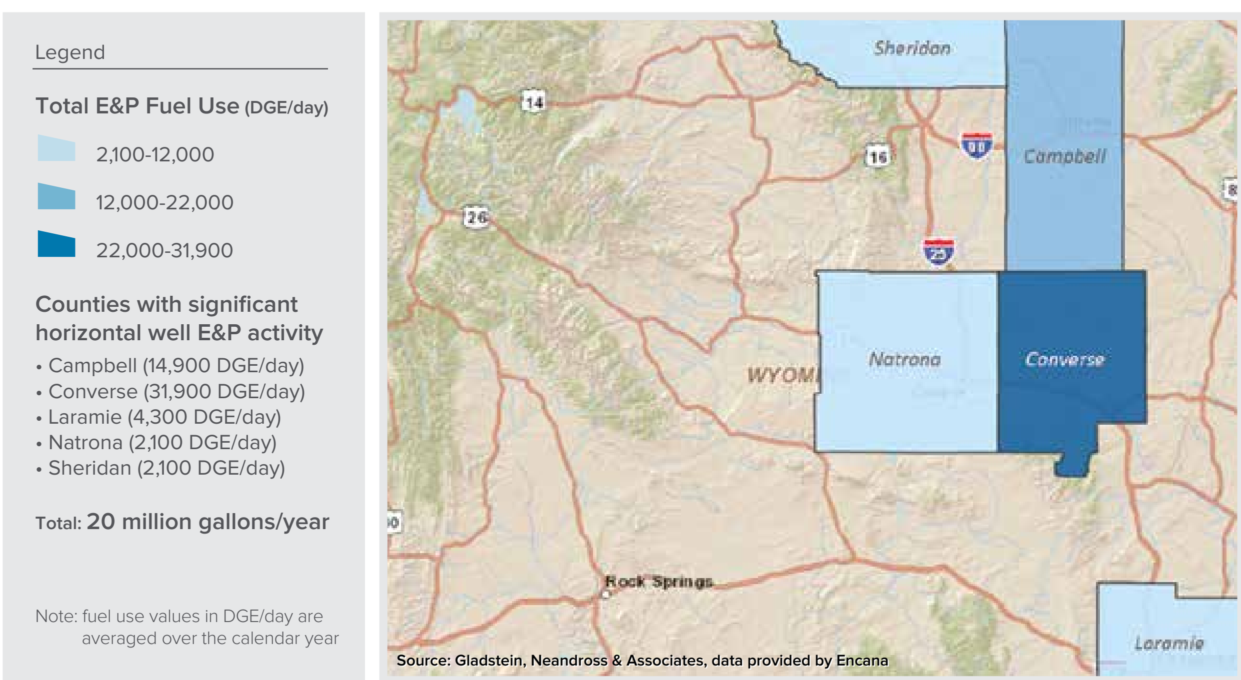
Assumptions: $1.50 per DGE fuel price spread, 50% fuel substitution rate, 7 year life, 7% discount rate, 100% engine efficiency compared to baseline diesel frack pump

It is important to note that not all drill rig and PPS operations in Wyoming are equally conducive to using natural gas. E&P activities centered on horizontal drill rigs may make the best candidates for conversion to natural gas as these tend to be newer rigs powered by electricity (through diesel generator sets). By contrast, directional and vertical rigs tend to be older, mechanical rigs where each piece of equipment on the drill rig is powered by a separate engine; thus making conversion and fuel supply to these various engines more difficult and therefore more complex and costly. The greatest opportunity for natural gas fueled drill rigs appears to lie in those Wyoming locations where horizontal drilling is most common.

As depicted in Figure 29, the eastern half of Wyoming has the most significant horizontal drilling activity. Five counties in particular have high numbers of horizontal drill rigs; combined, they account for approximately 20 million gallons per year of diesel fuel consumption for drilling and PPS activities. This is about 42 percent of the statewide E&P diesel consumption.

Notably, drilling in Sublette and Sweetwater counties of southwestern Wyoming is predominantly done with directional rigs. While the rigs here may generally be more difficult to convert to natural gas, PPS operations in this area have no such constraint. However, there appears to be economic synergy associated with performing natural gas fracturing at locations where natural gas drilling is also being conducted.

Figure 29. Wyoming counties with most-significant horizontal drilling activity



4.3. LOCOMOTIVES

The North American railroad industry is an extremely large user of diesel fuel (approximately 3.5 billion gallons per year in North America). Thus, the Class I railroads have great economic incentive to switch their operations over to natural gas. However, due to their very nature (operating on special tracks across state and international boundaries, maintaining their own on-system refueling infrastructure, etc.), rail operations face complex dynamics in switching to natural gas. There are many logistical, engineering, safety, training, fuel supply, and cost challenges to work through before large scale deployments of commercial LNG trains can be rolled out. On the other hand, certain aspects of the rail industry may help speed up this transition. For example, "the high concentration of ownership in the U.S. railroad industry" could facilitate a rapid switch" toward LNG fuel and equipment, "because there are only a few owners making the decisions."[102]

Based on recent activities and industry statements, there is major momentum towards the use of natural gas in North America's rail sector. The railroad industry generally perceives "huge environmental and economic benefits associated with going to LNG." This includes the industry's expectation to meet upcoming EPA Tier 4 emissions standards while also achieving lower greenhouse gas emissions compared to diesel fuel.[103] Models from one economic study predict that LNG demand for the total North American rail sector by the end of 2020 will reach 0.5 Bcf per day (6.58 million LNG gallons per day).[104]

Initially, conversions of existing locomotives to LNG are likely to lead the way. Freight locomotives have service lives of two to three decades, and they undergo several engine rebuilds over that period. As was demonstrated in Figure 13 on page 37, large percentages of BNSF's and UP's in-use locomotives are near the end of their service lives. In many cases, converting older locomotives to LNG instead of conducting diesel engine rebuilds may offer compelling economics for the railroads. For this reason, one economic study found that "every railroad is looking at LNG closely at the present time." The study concluded that "it is almost inconceivable that if one big rail adopts LNG the others will not follow," given that there are "only 7 Class I railroads in the U.S."[105]

A brief overview of historical efforts by the rail industry to use natural gas is provided below. This is followed by examples of efforts by locomotive manufacturers and their railroad customers to design, build, test and deploy LNG-fueled locomotives.

[102] U.S. Energy Information Administration, Annual Energy Outlook 2013, http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf

[103] Statement by Robert Fronczak, Assistant Vice President, Association of American Railroads, cited in "Experts weigh in on LNG," RailwayAge, written by William C. Vantuono, September 6, 2013, http://www.railwayage.com.

[104] "Alternative Natural Gas Demand: It's Not Just Trucking Anymore," Rosenblatt Securities, April 2013, http://sumzero.com/doc/altnatgas.pdf.

[105] Ibid.

4.3.1. BACKGROUND AND HISTORICAL USAGE OF LNG IN U.S. RAIL SECTOR

For decades, the U.S. railroads have considered LNG as a potential way to reduce emissions. Over the last few years, they have become strongly interested in LNG to significantly reduce operating costs. To date, natural gas use in the U.S. rail sector has been limited to a few demonstration projects. In the early 1990's, Energy Conversions, Inc. (ECI) was the first to commercially and successfully demonstrate a natural gas powered locomotive. The first ECI retrofit system converted a General Motors locomotive engine to a dual-fuel, electronically-controlled direct fuel injection configuration. At roughly the same time, Burlington Northern (now part of BNSF) converted two locomotives to dual-fuel operation; these were successfully demonstrated on a commercial coal line between Wyoming and Wisconsin from 1991 until 1996.

Figure 30. CN's two ECI-converted SD40-2 locomotives

Source: CN

In 1994, MotivePower, Inc. delivered the first ultra-low emissions rail yard switchers in the nation. This project included four (4) LNG switchers that were put into service in Los Angeles. In partnership with Boise Locomotive Company (formerly Morrison Knudsen Rail Corporation) and Caterpillar, Inc., they designed and produced the MK1200G, which was North America's first microprocessor-controlled 1,200 HP locomotive fueled entirely by LNG. Locomotive UP 1298 and LTP 1299 went to Union Pacific in August of 1994 and Atchison, Topeka and Santa Fe (ATSF, now part of BNSF) 1200 and ATSF 1201 went to BNSF in December of 1994. The Caterpillar G3516 spark-ignited, turbocharged and after-cooled (SITA) LNG fueled V- 16 engine normally used in stationary applications was used in these switchers. Very low NOx emissions were achieved.

In late 2012, Canadian National Railway (CN) began testing two EMD SD40-2 locomotives that were converted to dual-fuel by ECI with a single LNG tender car.[106] Figure 30 shows CN's two converted locomotives separated by the LNG tender car. This project served as the harbinger for a new CN collaboration (described below).

[106] "Canadian National Railway Co. Tests Dual-Fuel Locomotives," NGV Global News, September 28, 2012 (http://www.ngvglobal.com/canadian-national-railway-co-tests-dual-fuel-locomotives-0928)

4.3.2. EXISTING EFFORTS AND PLANS FOR NATURAL GAS DEPLOYMENTS

A wide array of new activities are underway in the North American rail sector to develop and demonstrate LNG-fueled freight locomotives. While details are being tightly controlled, it is clear that proof-of-concept test programs for LNG locomotives and tender cars are in the planning stages by BNSF, Union Pacific and CSX. There is speculation that one or more of these railroads could deploy LNG locomotives in revenue service by 2016 or 2017.[107]

Some publicly available information does exist on LNG locomotive development, demonstration and commercialization. Examples are provided below.

- Caterpillar - EMD is well underway with efforts to develop natural gas locomotives. The company is developing Dynamic Gas Blending retrofit kits for existing EMD engines. When installed on older locomotives, this dual-fuel product maintains capability to run on diesel at full power and provides compliance with EPA Tier 3 emissions standards. This solution will enable the railroads to convert existing locomotive fleets in the near term to operate using LNG.[108]

[107] Article in RailwayAge, "Experts weigh in on LNG," written by William C. Vantuono, September 6, 2013.

[108] Caterpillar, personal communication to GNA, March 2014.

Figure 31. An early BNSF prototype LNG switcher locomotive

Source: Gladstein, Neandross & Associates

- For the longer term, Caterpillar and EMD are also developing a High Pressure Direct Injection (HPDI) system in cooperation with Westport. This solution will provide diesel-equivalent power while maximizing fuel cost savings through diesel fuel substitution greater than 90 percent on average. This technology is projected to meet EPA Tier 4 emissions standards (effective in 2015) using minimal emissions-control technologies compared to diesel technology. The first HPDI locomotive will demonstrate Tier 3 emissions in 2014 through a program funded by Sustainable Technology Development Canada, in partnership with Caterpillar - EMD, Canadian National Railway, Gaz Métro, and Westport. EMD anticipates commercial production of HPDI locomotives in 2017.[109]

- GE Transportation is working with BNSF and CSX railroads to demonstrate GE's "NextFuel" Evolution 3000 series locomotives with LNG conversion systems. This is reportedly a low-pressure port injection system designed for "up to" an 80 percent substitution rate,[110] with allowance to run on 100 percent diesel as a backup plan. Tests with BNSF are expected to be underway early in 2014, with CSX trials to follow. GE will use a single BNSF tender to support two locomotives, according to an official at GE Transportation. Initially, at least, the LNG-fueled Evolution locomotive will meet EPA's Tier 3 emissions standards. GE considers this dual-fuel approach to be the most cost-effective initial solution for the railroads.[111]

- BNSF announced in 2013 that it will begin testing a small number of locomotives using (LNG) as an alternative fuel. Chairman and CEO Matthew Rose indicated that LNG could potentially provide a "transformational change" for BNSF and the railroad industry. "While there are daunting technical and regulatory challenges still to be faced, this pilot project is an important first step that will allow BNSF to evaluate the technical and economic viability of the use of liquefied natural gas in through-freight service, potentially reducing fuel costs and greenhouse gas emissions, thereby providing environmental and energy security benefits to our nation."[112]

- Union Pacific has been evaluating LNG and other alternative fuels for its railroad operations for many decades. Recently, UP expressed renewed interest in converting locomotive engines to LNG fuel. UP is now working closely with locomotive and engine manufacturers, cryogenic fuel tank suppliers and natural gas/LNG suppliers to complete its analysis.[113]

- Canadian National (CN) Railroad has converted two EMD 3000 HP SD40-2 locomotives (with EMD 16-

[109] Ibid.

[110] GE Transportation, "NextFuelTM Natural Gas Retrofit Kit with Dual Fuel Technology," accessed online at: https://www.getransportation.com/locomotives/locomotives/nextfuel?qt-product_menu=0#qt-product_menu

[111] Article in RailwayAge, "Experts weigh in on LNG," written by William C. Vantuono, September 6, 2013.

[112] BNSF, "BNSF to test liquefied natural gas in road locomotives," March 6, 2013, accessed online at http://www.bnsf.com/employees/communications/bnsf-news/2013/march/2013-03-06-a.html

[113] Union Pacific Railroad, "Technology: Alternative Fuels," accessed online at http://www.uprr.com/she/emg/technology.shtml.

645E3 engines) to operate on dual fuel (LNG and diesel) using available kits. An existing (circa 1993) 30,000 U.S. gallon LNG tender was borrowed for the demonstration. Canadian "regulatory acceptance" was secured for the demonstration. Locomotive modifications were made to utilize LNG. Encana delivers bulk tankers that are used to fill the self-contained tenders. More than 100 trips have been made by these locomotives, consuming 155,000 gallons of LNG. According to information provided by Encana, the CN pilot project has resulted in numerous fueling-related improvements for the tender car and its integration with the locomotives it serves.[114]

- CN is also working with Caterpillar EMD and Westport to convert a 4,300-hp SD70M-2 EMD locomotive for operation on Westport™ HPDI. Caterpillar EMD will supply equipment and technical expertise to integrate the natural gas engine, related components, and controls into the locomotive, including the HPDI and LNG fuel system technologies. CN has placed an order for four Westport LNG Well Tenders to support demonstration of dual-fuel locomotives in its operations. Locomotive tests are expected to begin in 2014.[115]

- GFS Corporation has announced that it will add a locomotive product for its line of NG+D™ Conversion Systems. In 2014, GFS will begin offering its "EVO-LT™ System for retrofitting on General Electric AC4400 and Dash-9 locomotives. According to GFS, "the EVO-LT System will be compatible with industry standard LNG tender cars and will include a hot fluids control system and tender car communications interface." This system will "utilize state-of-the-art controls to safely maximize natural gas substitution rates while protecting the design integrity of the GE 7FDL engine GFS and drive system." The system will allow the locomotive to "instantly and seamlessly" revert back to 100 percent diesel operation when required."[116]

It's clear from these examples that much is underway by the locomotive manufacturers and Wyoming's two Class I railroads to move LNG locomotives beyond the R&D phase into demonstration and commercialization. There is consensus that such activities are needed to overcome hurdles before LNG can become a major fuel for the North American railroads. The following are adapted from the "top level requirements" enumerated by a locomotive manufacturer representative[117] that must be met before LNG retrofit systems can be commercially offered to its railroad customers:

- Safety: the highest priority; must ensure safe and reliable operation

- Convenience and choice: customers want fuel flexibility, because a transition to new LNG locomotives is expected to take years

- Economics: must maximize gas substitution to provide compelling economics and an attractive payback period

- Reliability and durability: must be comparable in maintenance requirements and costs

- On-board fuel storage: tender interface must work within industry standards

- Performance: no degradation (e.g., tractive effort, adhesion, fuel efficiency)

There are numerous issues, challenges, tradeoffs and barriers to address before LNG-fueled locomotives get deployed in commercial service. It is very difficult at this stage to predict if Wyoming's coal-mine-serving rail operations will be a priority for BNSF and/or UP's efforts to demonstrate LNG locomotives. On the one hand, unit coal trains are "a tight operational process" that may be very conducive for rolling out LNG locomotives and fueling infrastructure. For whatever rail operations go first, perhaps the biggest hurdle to overcome involves the use of tender cars to carry LNG. That critical issue is a high priority of the railroads.

It is also important to consider the timeframe for transitioning into emerging fuels and technologies in a sector like the rail industry.

[114] Matt Most, Encana, "Using Mobility of LNG for Business Transformation," presentation at the HHP 2013 Summit, Sept. 2013.

[115] "CN Progress on LNG Trains," HHP Insight, October 12, 2102, http://hhpinsight.com/rail/2012/10/cn-progress-on-lng-trains/.

[116] GFS Corporation, "EVO LT™ 4400", press release, September 18, 2013, accessed online at: http://www.gfs-corp.com/news.php/yr/2013/art/17/yr/2013.

[117] "GE Dual Fuel Locomotive Development," Eric Dillen, GE Transportation, presentation at HHP Summit 2013, September 2013.

Line-haul locomotives average 30 years of service, which means that the industry replaces about 1/30th of its locomotives each year due to attrition. A Class I railroad that operates 6,000 locomotives purchases about 200 new units per year. Thus, it can take many years to "modernize" a large locomotive fleet through new purchases. However, in-use units can have their existing diesel engines and fuel systems converted over to natural gas systems during the course of their normal rebuild schedules.

4.3.3. SUMMARY OF OPPORTUNITY FOR LIFE-CYCLE COST SAVINGS

Various estimates have been made by the manufacturers and railroads about fuel cost savings that can be realized with LNG locomotives. Like other HHP sectors, much depends on details and specifics about the technology, type of operation, duty cycle, etc. Generally, rail applications that burn the most diesel and utilize LNG technologies with high fuel substitution rates will save the most on fuel costs. One advantage for rail is that the natural gas engines (and conversion kits) under development for freight locomotives all maintain compression ignition (i.e., spark ignition of 100% LNG is not currently under consideration). Thus, diesel-equivalent efficiency is achievable across all of these pending technology options.

Taking these types of factors into account, estimates can be derived about the fuel cost savings that could be realized if BNSF and/or UP converts Wyoming coal train locomotives to operate on LNG. As described in Section 3.2.2, an estimated 405 freight locomotives are routinely operated today in Wyoming today; most serve in the rigorous PRB coal mine duty cycle. Collectively, these locomotives are estimated to consume 121.5 million gallons of diesel fuel per year. On average, this equates to an annual consumption of about 300,000 gallons of diesel per locomotive. Locomotives last 20 to 30 years, although they may be rebuilt multiple times over that period.

Table 21 presents the estimated simple payback period for the investments needed to convert one line-haul locomotive to operate with an LNG engine at an average 92 percent substitution rate. A key assumption on capital costs is that a single LNG locomotive and 50 percent of an associated LNG Tender would cost approximately $1 million. As shown, the estimated annual fuel cost savings are $414,000, and a simple payback timeframe of 1.8 years is achievable. Of the various HHP sectors analyzed, this line-haul locomotive example achieves the most compelling payback period. This results from the combination of high baseline fuel use and a very high fuel substitution rate, which yield excellent annual fuel cost savings.

The below simple payback scenario is essentially based on a purpose-built LNG locomotive using Westport™ HPDI technology. It's important to note that dual-fuel technologies are also being developed and may be commercialized for use in existing locomotives; these entail differing substitution rates and capital costs. Little is known yet about the mix of technologies that will ultimately be adopted to convert existing locomotives, or to build entirely new locomotive models. It does appear clear that very high substitution rates will be required by the railroads to justify large capital expenditures and achieve attractive payback on investments.

Table 21. Illustrative payback period for converting one line-haul locomotive to HPDI LNG operation

Baseline Diesel Use (diesel gal/yr)	300,000
Estimated Incremental Capital Cost (CapEX)	$750,000
Diesel Displaced (diesel gal/yr)	276,000
LNG Required (LNG gal/yr)	463,680
Annual Fuel Cost Savings	$414,000
Simple Payback Timeframe	1.8 years
Assumptions: $1.50 per DGE fuel price spread, 92% fuel substitution rate, 100% engine efficiency compared to baseline diesel locomotive, CapEX includes one tender car @ $1 million, shared by two locomotives.	

4.4. ON-ROAD HEAVY-DUTY TRUCKS

4.4.1. OVERVIEW OF NATURAL GAS TRUCKS

Over the last 25 years, heavy-duty on-road vehicles powered by natural gas have emerged as the most-viable mainstream alternative fuel for America's on-road heavy-duty trucking sector. Today, on-road heavy-duty natural gas engines and vehicles are mature, commercially successful technologies, and very significant displacement of diesel has occurred in this sector. Over the last two years, commercial offerings have been growing in response to the compelling price advantage of natural gas over diesel resulting in high demand for these products from heavy-duty fleet owners. Even with higher capital and market entry expenses, end users recognize that converting to natural can gas yield reduced life-cycle costs and an attractive payback on investments.

In the heavy-duty trucking sector, deployments of return-to-base vocational trucks fueled by CNG and LNG have been particularly successful. Until recently, line-haul trucks have not been major parts of this heavy-duty natural gas vehicle rollout. In part, this was because interstate trucking has lacked point-to-point access to CNG and LNG stations. Today's compelling fuel price differential has spurred strong new interest, because diesel trucks that are driven more than about 450 miles per day (i.e., burn 80 or more gallons of diesel) can provide very acceptable payback periods (fewer than three years).

Figure 32. CWI's ISX12 G engine

Two heavy-duty engine manufacturers, Cummins Westport Inc. (CWI) and Westport, have led the way to develop and market heavy-duty natural gas engines suitable for line-haul trucking. CWI, which is a 50:50 joint venture between Cummins Inc. and Westport, recently introduced its ISX12 G natural gas engine designed for regional haul truck / tractor, vocational, and refuse applications. The ISX12 G is rated up to 400 hp and 1,450 lb-ft torque, which is well suited for line-haul trucking applications. It operates on 100 percent natural gas stored on the tractor as either CNG or LNG. The ISX12 G and all CWI dedicated natural gas engines are manufactured by Cummins, then made available as a factory-direct option from leading truck manufacturers that include Freightliner, Peterbilt, Kenworth, Volvo, and Mack.

Westport focuses on development of heavy-duty natural gas engines that use its HPDI technology, which injects a pilot stream of diesel fuel into the engine to enable auto ignition of the natural gas charge. By maintaining compression ignition, the first-generation Westport™ HPDI technology has been able to provide the same horsepower and torque as a comparable diesel-fueled engine. However, Westport recently announced that its production focus has shifted from an upfit model to a "vertically integrated solution" featuring Westport™ HPDI 2.0, which is expected to first be available on a 13L engine platform.[118] Thus, it's unclear if there will be a 15L HPDI engine offered in North American line-haul trucking applications.

What is clear is that heavy-duty truck manufacturers such as those noted above have responded to growing demand by selling an array of vocational and line-haul Class 8 tractors powered by natural gas engines. To support growing LNG truck sales on a national basis, fuel suppliers are building LNG stations along major trucking corridors—including Wyoming's stretch of Interstate 80.

Other favorable improvements are underway in this sector. For example, Westport has developed a new LNG tank system for on road freight trucks. The Westport iCE PACK is an onboard LNG tank system customized for spark-ignited

[118] Westport, personal communications to GNA, January and March 2014.

engines, and designed to meet the demands of today's trucking fleets by providing increased range, longer hold times and faster fueling times.[119]

[119] Westport, personal communication to GNA, March 2014.

The following subsections provide examples of existing plans and recent developments involving heavy-duty natural gas vehicle technologies and infrastructure; many involve Wyoming either directly or peripherally.

4.4.2. EXISTING EFFORTS OR PLANS FOR NATURAL GAS DEPLOYMENTS

Examples of commercial fleets that are purchasing and/or testing heavy-duty natural gas vehicles include the following:

- United Parcel Systems (UPS) now operates at least 112 LNG-fueled heavy-duty trucks, and plans to extend this fleet to 800 LNG trucks in 2014. UPS intends to buy LNG tractors with the CWI 12-liter engine for most or all of its Class 8 truck purchases in 2014. UPS management acknowledges the relatively high incremental cost for these trucks; this can range from approximately $50,000 to $70,000 depending primarily on LNG tank configurations and the volume of usable LNG carried onboard. However, UPS believes that a payback of less than three years is achievable for their trucks that are driven at least 450 miles per day.[120]

- Other heavy-duty trucking fleets that already operate or are testing natural gas tractors include Lowe's, FedEx, Con-Way, NFI International, PepsiCo, Ryder, Swift Transportation, and Schneider National Inc.[121]

[120] David Abney, COO and Global Transportation Services Manager, United Parcel Systems, statement during morning keynote address at the ACT Expo, June 26, 2013.

[121] "Truckers Tap into Gas Boom," Wall Street Journal, article by Mike Ramsey, October 29, 2013.

- Examples of LNG and/or CNG infrastructure that is being built to support these growing on-road truck deployments include the following:

- Clean Energy has already completed more than 100 natural gas fueling stations as part of America's Natural Gas Highway®, which will allow long-haul trucks to travel across all major corridors through the United States, and has more stations in development. As further described, two of these are LNG stations along I-80 in Wyoming.

- Shell and TravelCenters of America LLC (TA) have finalized an agreement to develop a U.S. nationwide network of LNG fueling centers for heavy-duty road transport customers. The plan is to construct at least two LNG fueling lanes and an LNG storage facility at up to 100 existing TA and Petro Stopping Centers along the U.S. interstate highway system. Construction and opening of the LNG stations will be done in a phased approach.[122]

[122] Shell, "Shell, TravelCenters of America Develop LNG Fueling Network," press release, April 15, 2013, accessed online at http://www.shell.us/aboutshell/us-media-center/news-and-press-releases/2013/04152013-lng-travel-centers.html.

4.4.3. CURRENT USE OF NATURAL GAS IN WYOMING'S ON-ROAD HDV SECTOR

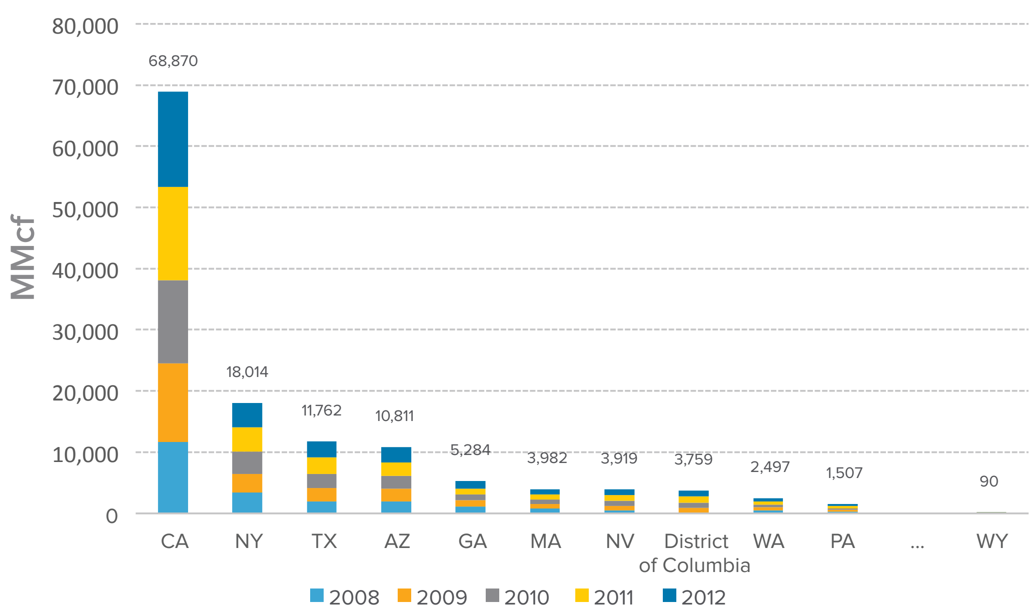
Under the leadership of Governor Mead and others, Wyoming has initiated strong efforts to increase use of natural gas across all vehicle sectors, including on-road heavy-duty trucks. To date, progress has been gradual. Wyoming has a relatively low population density for both people and motor vehicles, and about 94 percent of state roads are rural. Thus, it's no surprise that Wyoming currently ranks 30th among the 50 states and Washington DC for the total volume of natural gas delivered to vehicle fuel consumers during the five-year span of 2008 through 20 (Figure 33).

Wyoming has approximately 13,300 registered heavy-duty Class 7 and 8 trucks. As one of the world's most diverse and productive energy economies, Wyoming strongly depends on these and other vehicles to support countless activities to extract, process and move this energy. Interstate 80 is one of America's busiest freight trucking corridors, with an estimated 5,500 commercial trucks driven on it each day, and major growth is expected in this I-80 truck traffic. For several reasons, it appears that Wyoming may be poised for significant—possibly dramatic—growth in the volumes of natural gas dispensed into heavy-duty trucks.

It appears that free market forces in several key areas are driving Wyoming towards expanded sales of natural gas for on-road trucking: 1) lifecycle cost savings for truckers, 2) new vehicle offerings from several heavy-duty truck manufacturers, 3) an expanding network of LNG stations along I-80, and 4) a large locally available gas supply. Significant fuel cost savings and short payback times are achievable for truck fleets that consume large volumes of diesel. Strong interest has been generated among truck fleet owners to purchase and deploy a variety of OEM truck platforms powered by the CWI ISX12 G (12-liter) natural gas engine. The two LNG stations along I-80 at Flying J truck stops in Rawlins and Cheyenne have been constructed and are scheduled to open in 2014. Initial LNG demand at each station is expected to be up to about three million gallons per year; some of this product will be delivered from Wyoming's Shute Creek liquefaction facility (see Section 6.1.2).[123] Wyoming is producing huge volumes of natural gas, which favors local use to meet expanding demand. Synergy with other sectors is strong; for example, there appears to be significant and growing demand from E&P companies to fuel as many heavy-duty trucks as possible on natural gas as they support natural-gas-fueled drill and frack operations.

[123] Personal communication to GNA by a Clean Energy Fuels executive, November 2013.

Figure 33. Wyoming (30th) vs. top 10 U.S. regions in recent use of natural gas for vehicles



Source: http://www.eia.gov/dnav/ng/ng_cons_sum_a_epg0_vdv_mmcf_a.htm

LNG vendors are closely watching these potential LNG applications along Wyoming's I-80 trucking corridor. However, to make new infrastructure investments, they look for fleets to make volume orders of LNG vehicles and equipment. This is just beginning to materialize in the on-road trucking sector.

4.4.4. OPPORTUNITY FOR LIFE-CYCLE COST SAVINGS

As previously described, there are 13,133 heavy-duty Class 7 and 8 trucks registered in Wyoming. Collectively, these trucks are estimated to consume about 125 million gallons of diesel fuel per year. On average, this equates to an annual consumption of about 9,500 gallons of diesel per truck. Engines that power on-road heavy-duty trucks in line-haul service last about seven years, although they may be rebuilt one or more times over that period.

Table 22 shows the net present value (NPV) of the investment to convert a single Class 8 tractor to operate with a dedicated (100 percent) LNG engine. Key assumptions include an 85 percent efficiency compared to the baseline diesel, and 57,000 annual miles of operation. Also assumed is that the incremental cost of the LNG version (compared to its diesel counterpart) will be at the low end ($50,000) of the range for line-haul trucks. (Notably, in some on-road HDV applications, the per-vehicle incremental cost for volume orders of LNG vehicles can be well below $50,000.)

As shown, the estimated annual fuel cost savings in the Table 22 example are $11,400. Compared to the other HHP sectors analyzed, this on-road Class 8 truck example achieves the lowest net present value ($11,400) and longest simple payback (4.4 years). However, the cited example uses 57,000 miles per year (the current average in government models). Many line-haul trucks log 80,000 to 110,000 miles per year, and could consume as much as 20,000 diesel gallons per year. Heavy-duty trucks used in rigorous duty cycles that include power take off (PTO) requirements will also burn large volumes of diesel. The economics of using LNG in these types of fuel-intensive trucking applications will be much more favorable than the example below.

Table 22. Estimated Net Present Value of converting one heavy-duty on-road tractor to LNG

Baseline Diesel Use (diesel gal/yr)	9,500
Estimated Incremental Capital Cost (CapEX)	$50,000
Diesel Displaced (diesel gal/yr)	9,500
LNG Required (LNG gal/yr)	18,766
Annual Fuel Cost Savings	$11,400
Simple Payback Timeframe	4.4 years
NPV of Natural Gas Option vs. Baseline Diesel	$11,000
Assumptions: $1.50 per DGE fuel price spread, 100% fuel substitution rate, 7 year life, 7% discount rate, 85% engine efficiency compared to baseline diesel truck, CapEX includes on-board storage system for approximately 150 DGE of LNG.	

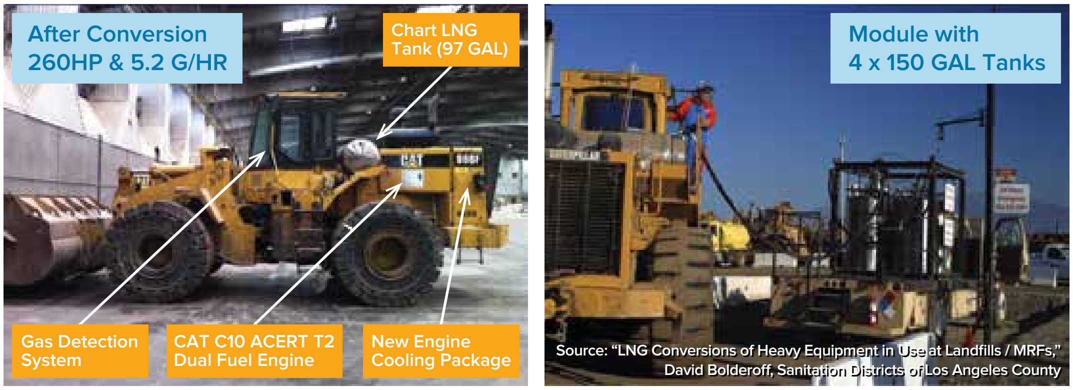
4.5. OTHER LARGE OFF-ROAD VEHICLES

4.5.1. OVERVIEW OF LARGE OFF-ROAD VEHICLES USING NATURAL GAS

To date, this “catch-all” category of Other Large Off-Road Vehicles has not been a focal area for application of LNG and CNG technologies. While the sector uses very large volumes of diesel nationwide (and in Wyoming), to date manufacturers have offered relatively few products that operate on natural gas. That is expected to change significantly over the next five years, given Caterpillar’s “all-in” statement regarding the application of natural gas to its vast product lineups. Other manufacturers in this market are also likely to be working on natural gas products.

To date, some proof-of-concept demonstrations have been conducted. For example, in a pilot project that began in 2003, five Caterpillar 966F wheel loaders were equipped with Caterpillar C-10 dual-fuel (LNG) engines; these were demonstrated at the Los Angeles County Sanitation District. Each vehicle was equipped with a Chart 97-gallon (LNG) fuel tank. LNG fuel was provided at the site via a mobile LNG micro station. The capital cost of each conversion was about $31,000. During 2004 and 2005, LA County Sanitation also converted Caterpillar 824C wheel loaders to natural gas by repowering with dual-fuel natural gas engines. Figure 33 shows one of each type for the test vehicles.

Figure 34. Demonstration of dual-fuel CAT 966F (L) and 824C (R) wheel leaders at LACSD



As of mid 2012, the dual-fuel Cat 966 loaders were still in operation, and had logged approximately 9,000 hours of operation. During that period, LA County Sanitation reports saving 17 percent on its fuel costs at an LNG price of $2.70 per DGE. LA County Sanitation did experience logistics and maintenance issues with these proof-of-concept projects, including mobile refueler problems, overfilling of LNG tanks and excess moisture in the LNG systems.[124]

[124] "Case Study: LNG Conversions of Heavy Equipment in Use at Landfills / MRF's," David Bolderoff, HHP Summit 2012.

4.5.2. OPPORTUNITY FOR LIFE-CYCLE COST SAVINGS

As described in Section 3.5.2, there are uncounted numbers of "Other Large Off-Road Equipment" operating in Wyoming. Based on fuel sales tax data, it is roughly estimated that 2,600 to 3,000 such vehicles exist statewide, consuming about 220 million gallons of diesel fuel per year. On average, this equates to an annual consumption of about 61,600 to 85,000 gallons of diesel per individual off-road vehicle or equipment. Engines in this sector are assumed to last about 10 years, although they may be rebuilt one or more times over that period.

Table 23 shows the net present value (NPV) of the investment to convert a single off-road dozer (an example vehicle in the sector) to operate with a dual-fuel LNG engine. Baseline diesel consumption is assumed to be 85,000 diesel gallons per year (about 26 gallons per hour @ 10 hours per day and 330 days per year). Conversion to dual fuel (CapEx of $100,000) is assumed to provide no change in engine efficiency. The fuel substitution rate is assumed to be 50 percent.

Table 23. Estimated Net Present Value of converting one large off-road dozer to dual-fuel LNG

Baseline Diesel Use (diesel gal/yr)	85,000
Estimated Incremental Capital Cost (CapEX)	$100,000
Diesel Displaced (diesel gal/yr)	42,500
LNG Required (LNG gal/yr)	71,000
Annual Fuel Cost Savings	$63,750
Simple Payback Timeframe	1.6 years
NPV of Natural Gas Option vs. Baseline Diesel	$348,000

Assumptions: $1.50 per DGE fuel price spread, 50% fuel substitution rate, 10 year life, 7% discount rate, 100% engine efficiency compared to baseline diesel dozer, CapEX includes on-board storage system for approximately 150 DGE of LNG.

As shown in the table, the estimated annual fuel cost savings for this scenario are $63,750. Under the stated assumptions, the vehicle-side investments[125] to convert a large dozer to dual-fuel LNG achieves a compelling net present value ($348,000), with a simple payback period of 1.6 years. Notably, these numbers will be less economically attractive for off-road vehicles and equipment that do not use such large volumes of fuel. In addition, it should be emphasized that currently, there are no known commercially available products to convert off-road dozers to LNG. Manufacturers such as Caterpillar are likely to be working towards such products.

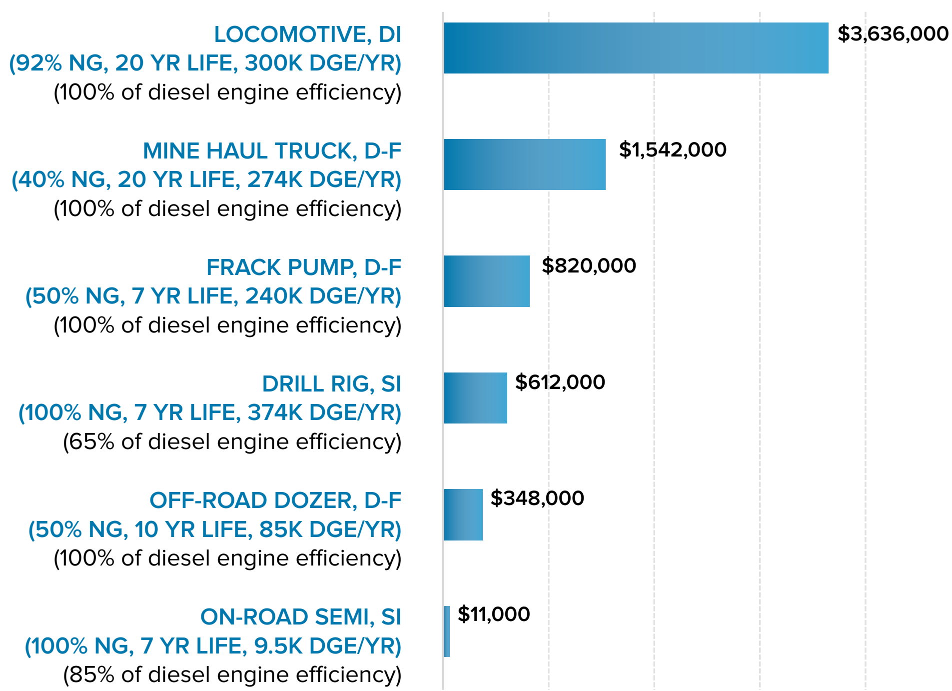
[125] CapEx in this large dozer case was assumed to be ~3X conversion costs cited by LA County Sanitation for converting Cat 966 dozers. Adjustments were made for inflation, more on-board fuel storage, better emissions, and meeting regulatory requirements.

4.6. SUMMARY: PER-UNIT NET PRESENT VALUE OF INVESTMENTS BY SECTOR

Figure 35 summarizes the full-life estimated net present value (NPV) of investments made to purchase (or convert) a single unit in each HHP sector to operate on LNG. Assumptions for key variables (natural gas substitution rate, equipment life, baseline diesel usage, engine efficiency) are provided for each type of application.

Figure 35. Estimated net present value of investments for one HHP unit operating on LNG

(Key Variables: Fuel Substitution Rate, Efficiency, Life, Baseline Diesel Usage)



Based on preliminary estimates for incremental capital costs of natural gas equipment and current industry inputs regarding assumed natural gas (NG) fuel substitution rates. Assumes 7% discount rate and a fuel price spread of $1.50 per diesel gallon equivalent (DGE).

D-F = Dual-Fuel (Compression Ignition); S-I = Spark Ignition; DI = Direct Injection using Westport™ HPDI

As shown in Figure 35, the most compelling lifetime cost savings (i.e., the largest positive net present values) occur for the four applications with very high annual fuel use (240,000 DGE per year and higher). In particular, converting locomotives to natural gas (LNG) using the Westport™ HPDI technology provides a very positive return on capital investments that will be necessary for locomotives and fuel storage in tender car(s). Freight locomotives have high fuel usage and long service lives (at least 20 years, but more likely 30 years). Natural gas locomotives using the Westport™ HPDI technology have potential to achieve an average 92 percent diesel substitution rate.[126] These factors combine to yield very large lifetime fuel cost savings that deliver a highly positive net present value of investments.

It is important to note the following about this analysis:

- All references to capital expenditures (CapEx) involve only the vehicle- or equipment-related costs to convert to LNG. Other costs—building natural gas fueling stations, making facility upgrades to meet code, conducting training activities, etc.—are not included. Section 8 provides analysis on the costs of LNG infrastructure.

- For comparative purposes and convenience, all six examples of vehicle / equipment types have been analyzed for only one form of natural gas (LNG). As noted in this report, drill rigs and PPS can also use CNG or field gas. On-road tractors and "other large off-road equipment" can use CNG or LNG. The economics of using natural gas will vary by these choices. For example, annual fuel cost savings and NPV of investments can be significantly better when using field gas instead of LNG or CNG to fuel drill rigs and PPS. The next section normalizes estimated volumes of LNG to a common unit for all natural gas forms (standard cubic feet).

[126] Personal communication to GNA from Westport Vice President Bruce Hodgins, February 28, 2014.

5. TOTAL DIESEL REPLACEMENT AND NATURAL GAS SUBSTITUTION POTENTIAL

Section 4 discussed the potential fuel cost savings and other benefits (e.g., emissions reductions) that can be achieved using natural gas in the following Wyoming HHP applications: 1) mine haul trucks, 2) freight locomotives, 3) drill rigs, 4) pressure pumping services, 5) on-road heavy trucks, and 6) other large off-road equipment (dozers, etc.). The focus was on the diesel displacement and cost savings that can be achieved with a single representative unit in each sector.

In this section, we quantify the total estimated potential throughout Wyoming's entire HHP vehicle and equipment population to: achieve lifetime cost savings; supplement diesel fuel usage; and consume natural gas.

5.1. ESTIMATED LNG DEMAND FOR HYPOTHETICAL "ALL-IN" SCENARIO

The "all-in" scenario simplistically assumes 100 percent of the estimated inventory in Wyoming for each sector will be converted to use natural gas, using substitution rates that vary by sector and application. Achieving 100 percent penetration is not feasible in the foreseeable future. However, this scenario provides useful upper boundaries for the potential costs and benefits associated with such a massive change.

Based on assumptions described in previous sections for each of the six HHP applications, Table 24 summarizes this "all-in" scenario. It shows estimated units in each Wyoming inventory, volumes of diesel that are currently consumed, and equivalent volumes of natural gas that will be needed for this hypothetical case. As shown, the total volume of diesel fuel currently consumed in Wyoming-serving applications of these sectors is estimated to be 634.3 million diesel gallons per year. If 100 percent of this could be displaced with natural gas, the energy-equivalent volume is approximately 1.1 billion LNG gallons per year. However, for each of the six sectors, factors must be applied for 1) the anticipated fuel substitution rate, and 2) the relative efficiency of the natural gas engine technology that is most likely to be used. Taking those into account, the total volume of LNG needed to operate 100 percent of these Wyoming-based fleets ("all in" for the six applications) on natural gas is estimated to be 758 million LNG gallons per year. This is equivalent to approximately 61.0 billion cubic feet (Bcf) per year of natural gas.

5.2. REVISED ESTIMATE FOR LNG DEMAND BASED ON FEASIBILITY FACTORS

Table 24 reflects a simplistic, hypothetical scenario for conversion of the six HHP sectors from diesel to natural gas. In reality, complex market and sector-specific dynamics will dictate which types of vehicles and equipment will be transitioned over to natural gas, and how fast that can occur. "Feasibility" factors must be introduced for when and how much natural gas will be consumed in each sector. Also, the above table assumes that all natural gas usage will be in the form of LNG. As described, LNG is the most-viable choice for mine haul trucks, locomotives and large off-road equipment that use large volumes of fuel. However, drill rigs and pressure pumping units that are operated on natural gas can be operated on LNG, CNG, or field gas (see previous section). On-road semi tractors that switch to natural gas can also use CNG in addition to LNG.

Based on industry experience, GNA has derived "feasibility factors" regarding the volume of Wyoming-produced LNG that will be needed for each sector over the next one-to-two decades. The following feasibility factors are predicated on the key assumption that major barriers and challenges in each sector (known and to-be-determined) will be systematically addressed and ultimately resolved.

Mine Haul Trucks – Due to very compelling economics, strong product offerings from Caterpillar and other manufacturers, and increasing momentum to demonstrate proof-of-concept vehicles in the PRB, GNA assumes that 100 percent of Wyoming's estimated 440 large mine haul trucks will be gradually (over about one decade) transitioned to LNG operation. Over the near term, these will be conversions of existing haul trucks with dual-fuel systems that offer a substitution rate in the 40 to 50 percent range. Over the longer-term, Caterpillar and possibly other OEMs appear likely to manufacture and sell new mine-haul trucks that use HPDI technology to obtain substitution rates of 90 percent (or higher, depending on what the technology ultimately delivers for that application). We assume all of the LNG for this sector will be produced in Wyoming. Notably, this represents an aggressive scenario for LNG fuel use in Wyoming's mine haul truck sector.

Table 24. Total Estimated Wyoming inventories and LNG needed for 100 percent conversion

Vehicle or Equipment Type	Estimated Units in WY Inventory	Total Estimated Diesel Consumed (gal/yr)	Equivalent LNG Volume (gal/yr)	Assumed Substitution Rate	Assumed Efficiency Compared to Baseline	LNG Volume Needed for 100% Fleet Conversion (gal/yr)	Equivalent Volume of Natural Gas (BCF/yr)	Percent of Total Natural Gas Demand ("All In")
Mine Haul Trucks	440	120,516,000	202,466,880	40%	100%	80,986,752	6.5	10.7%
Freight Locomotives	405	121,500,000	204,120,000	85%	100%	173,502,000	14.0	22.9%
Drill Rigs	50	18,687,500	31,395,000	100%	65%	48,300,000	3.9	6.4%
Pressure Pumping Services	120	28,800,000	48,384,000	50%	100%	24,192,000	1.9	3.2%
On-Road Semi Tractors	13,133	124,763,500	209,602,680	100%	85%	246,591,388	19.8	32.5%
Other Large Off-Road Equipment	2,600 to 3,000	220,000,000	369,600,000	50%	100%	184,800,000	14.9	24.4%
Grand total		**634,267,000**	**1,065,568,560**	**N/A**	**N/A**	**758,372,140**	**61.0**	**100.0%**

Note: "Other Large Off-Road Equipment is a very diverse category, with a wide array of equipment types and sizes. Inventories and fuel usage estimates were back calculated from Wyoming fuel sales and other factors.

Locomotives – Based on very compelling economics, ongoing activities by Caterpillar-EMD, Westport and GE to design and test natural gas locomotive engine technologies, and apparent major new efforts by North American Class I railroads to demonstrate natural gas locomotives, GNA assumes that 100 percent of the estimated 405 locomotives that currently serve PRB coal mines will gradually (one to two decades) be transitioned over to LNG operation. Over the next five years, we assume there will be growing numbers of conversions for existing locomotives to operate on dual-fuel or HPDI systems. Over the next two decades, it appears that new LNG locomotives achieving substitution rates greater than 90 percent will be sold by Caterpillar-EMD and/or GE and deployed by the two Wyoming railroads. For purposes of our fuel-demand model, we assume an average fuel substitution rate of 85 percent will be achieved. It is assumed that 100 percent of the PRB coal locomotive fleet will gradually be transitioned to LNG locomotives, but only 50 percent of the LNG they consume will be produced in Wyoming; this is due to their significant percentage of operating time beyond Wyoming's borders. Notably, this represents an aggressive scenario for LNG fuel use in Wyoming's freight rail sector.

Oil and Gas E&P – With major momentum by manufacturers to offer suitable products, and a clear trend by a large percentage of the E&P industry to increase use of natural gas to power their operations, GNA believes that 100 percent of the drill rigs and pressure pumping services in Wyoming will be aggressively switched to natural gas over the next two to seven years. However, based upon current market trends in Wyoming and extensive surveying of this industry, GNA assumes that only 25 percent of the estimated 50 drill rigs and 120 PPS systems currently deployed in Wyoming will utilize LNG; the other 75 percent will be operated on field gas or CNG. Drill rigs and PPS systems that are converted over to LNG are assumed to use a mix of dedicated and dual-fuel natural gas engines. GNA assumes that 100 percent of the LNG consumed by E&P operations in Wyoming will be produced in state.

On-Road Heavy-Duty Trucks and Other Large Off-Road Equipment – GNA assumes that long-haul trucking in the U.S. will continue to gradually change over to natural gas, including the highest-fuel-use trucks that are regularly operated in Wyoming. Key Wyoming-focused opportunities for this sector appear to involve E&P support trucks, some of which are likely to have ready access to LNG at E&P drilling or frack sites. For the Other Large Off-Road Equipment sector, it is unknown how fast LNG-enabling products will be offered to convert in-use equipment or be incorporated into factory-built new products. Together, these two sectors are expected to drive significant LNG demand in Wyoming, but in relatively small volumes compared to the sectors described above that can serve as large "anchor" tenants for new LNG production. Thus, for the purposes of this analysis, GNA assumes that LNG demand from these two sectors will be a "wash," given our aggressive assumptions that 100 percent of mine haul trucks and locomotives will be transitioned over to LNG. In other words, over the next one to two decades, whatever shortfall there is in meeting the 100 percent assumptions for the mine and rail sectors are assumed to be made-up by LNG deployments from the on-road and other off-road sectors.

Table 25 applies these various assumptions and "feasibility factors" to derive the total estimated annual demand for Wyoming-produced LNG. As shown, it is estimated that the four key sectors will require approximately 186 million gallons of LNG per year over the next one to two decades. This is equivalent to 509,000 gallons per day (GPD) of LNG production, or approximately 38,700 thousand cubic feet per day (Mcf/D).[127]

[127] Using LNG at 74,720 BTU/gal (LHV) and natural gas at 983 BTU/ft^3.

Table 25. Estimated demand for Wyoming LNG in four key HHP sectors

Sector and Type of Vehicle or Equipment	Estimated Inventory of Units Serving Wyoming	Estimated "All-In" LNG Demand (GPY)	Assumed Percent to be LNG Fueled (Mid- to Long Term)	Assumed Percent to be Fueled with LNG in WY	Estimated Demand for WY LNG (GPY)
Mining: Haul Trucks	440	80,986,752	100%	100%	80,986,752
Rail: Locomotives	405	173,502,000	100%	50%	86,751,000
E&P: Drill Rigs	50	48,300,000	25%	100%	12,075,000
E&P: Pressure Pumping Services	120	24,192,000	25%	100%	6,048,000
Total "All-In" LNG Demand (GPY)		326,980,752	**Total Demand for WY LNG (GPY)**		**185,860,752**

5.3. STATUS OF EXISTING LNG SUPPLY AND IMPORTANCE OF PROXIMITY

To put this estimated mid- to long-term demand for LNG (509,000 GPD) in perspective, the two merchant LNG facilities in Wyoming (the Exxon Mobile Shute Creek Plant and the Merit Energy Complex in Painter) currently produce approximately 75,000 GPD. There are roughly 550,000 to 800,000 GPD of LNG available today for the entire U.S. transportation market. Having generally achieved technologically maturity (with continuing innovation), the LNG supply industry is now gearing up to meet growing demand. Major new LNG liquefaction facilities are expected to come on line in North America over the next few years, with total capacity growing to millions of gallons per day.[128]

[128] The US has potential to produce approximately 9.4 million gallons of LNG per day via the liquefaction process. However, a significant quantity of the current liquefaction is produced by peakshaver facilities that are not permitted to sell LNG into transportation fuel markets. Approximately 556,000 GPD of LNG are produced by US merchant facilities designed to sell LNG. More than one million GPD of LNG have been proposed among possible new LNG production projects, all of which are in varying stages of completion.

The end use of LNG in relation to where it is produced is more geographically constrained than in the case of petroleum fuel distribution systems. To achieve attractive fuel cost savings, end users of LNG generally need to be located within 250 or fewer miles of an LNG liquefaction facility. Thus, it's critical to closely pair the location of LNG liquefaction facilities with local demand for the fuel. This is one reason that Noble Energy is building its 100,000 GPD liquefaction plant in Weld County, Colorado. To avoid long trucking distances, Noble plans to "self supply" LNG to its natural gas E&P and trucking operations in that general vicinity.

Clearly, to meet the increased LNG demand estimated in this report, Wyoming will need to systematically phase in new local LNG liquefaction facilities. This build-out will need to be closely correlated with roll-outs of HHP vehicles and equipment that will operate (at least partially) on LNG. LNG suppliers will site their future liquefaction facilities in close proximity to centers of concentrated fuel demand. Based on current demand for diesel fuel and other factors, Wyoming's greatest concentrated LNG demand will be in and around the PRB (Campbell and Converse Counties), and in the southwestern part of the State (Sublette, Lincoln, Sweetwater, and Uinta Counties). Section 7.3 provides further discussion about where new LNG production plants could potentially be located to satisfy this estimated demand growth.

6. LNG FUEL INFRASTRUCTURE OPTIONS FOR WYOMING

6.1. WYOMING'S EXISTING NATURAL GAS FUELING INFRASTRUCTURE

Wyoming has a modest but growing infrastructure to refuel natural gas vehicles (NGVs); all existing stations dispense CNG and are designed primarily to serve on-road vehicles. According to the Wyoming Natural Gas Vehicle & Infrastructure Coalition, Wyoming has seven existing public CNG stations, four private CNG stations, and at least one planned CNG station. There are two newly built LNG stations at Flying J facilities to be opened in 2014; these are located along the busy I-80 trucking corridor in Rawlins and Cheyenne. The Coalition has identified the need for at least 15 additional CNG or LNG stations to meet anticipated demand for on-road NGVs, especially in the busy corridors such as I-80 and I-25. The Wyoming Business Council offers low interest loans for natural gas fueling infrastructure.[129]

A much larger natural gas infrastructure must be planned and developed in Wyoming to realize the potential benefits of wide-scale use of natural gas in the State's prodigious HHP sectors. Through market forces helped along by leadership and assistance from the State, adequate natural gas fuel supply must be made available to accommodate the potentially large increase in the state's user base for natural gas vehicles and equipment. A suitable fuel infrastructure must be built that can ensure regular delivery of very large LNG volumes to key HHP applications, starting with those that are moving forward the fastest (E&P operation, rail, and mining). Two key steps will be for the Wyoming's LNG stakeholders, with some assistance from the State, to 1) assess the currently available supplies of natural gas, and 2) determine where existing LNG infrastructure can be expanded and new infrastructure should be constructed.

There are many complex processes, stakeholders and markets associated with the full "value chain" that will be needed to bring LNG to HHP operations in Wyoming on a large scale. Figure 36 provides an overview of the complete value chain, from "upstream" operations (E&P) to consumption by end users in various sectors.

[129] Wyoming Natural Gas Vehicle and Infrastructure Coalition, http://www.ytcleanenergy.org/wyngvi/.

Figure 36. Links in the general LNG value chain (courtesy of Plum Energy)

Certain challenges must be overcome to successfully ensure that Wyoming's HHP applications will have access to the natural gas needed to meet or exceed the performance of diesel. Some are common to all applications, but many are application- or even site-specific. The sections that follow describe the existing natural gas fueling infrastructure in Wyoming, and some of the key opportunities and challenges to build it out for major expansion. The focus is on LNG fuel and fueling stations; except where other user-specific options exist (e.g., E&P applications), LNG is the most-feasible form of natural gas to use in higher-horsepower NGV applications that consume large volumes of fuel.

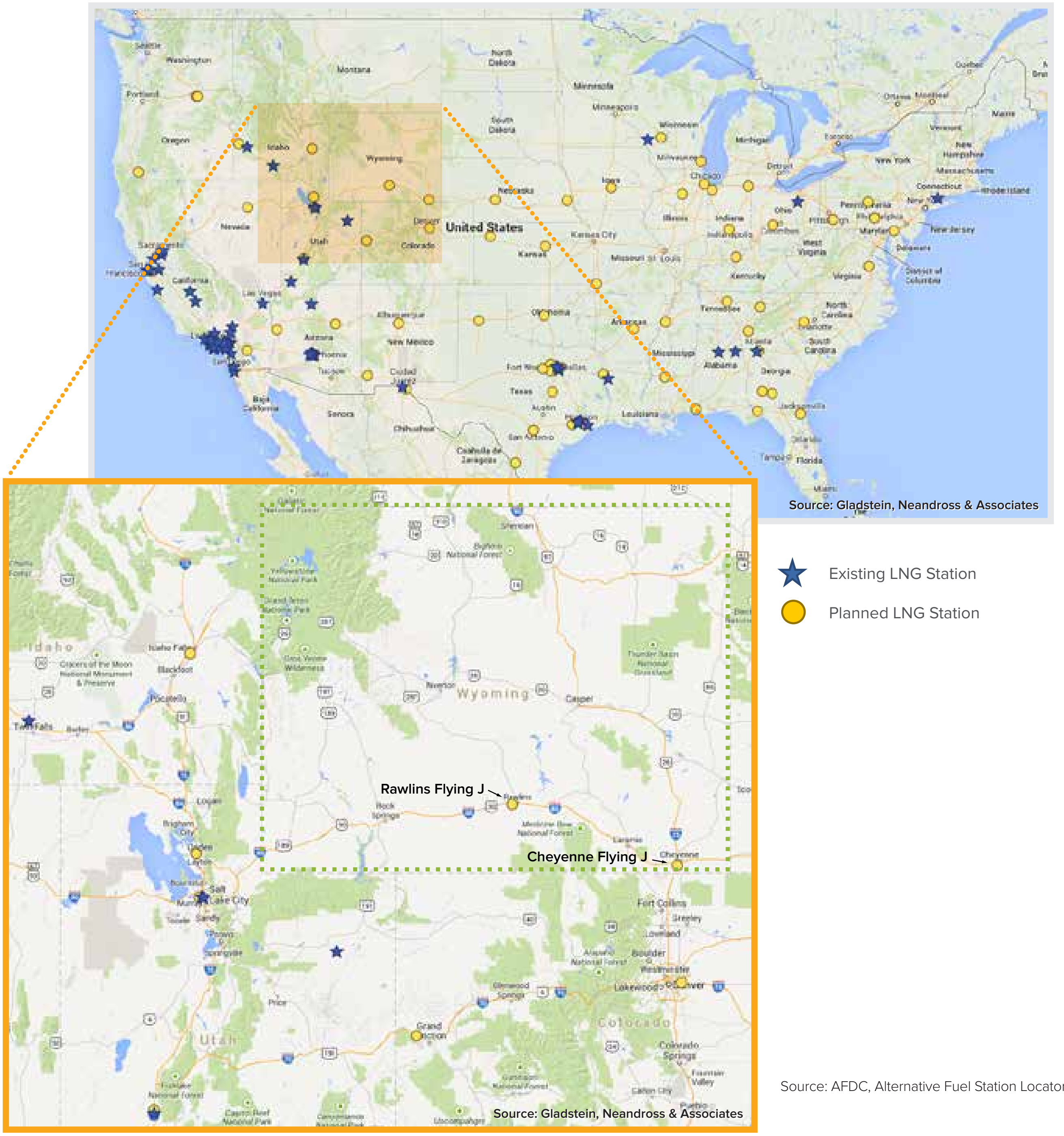
6.1.1. OVERVIEW OF LNG REFUELING STATION TECHNOLOGY

LNG fuel stations are liquid-based systems that use large bulk cryogenic (extremely cold) storage tanks to store fuel on site. LNG is delivered to the site from the point of production by 10,000-gallon capacity tanker trucks (much like diesel and gasoline is delivered to traditional fueling stations with 5,000-12,000-gallon underground or above-ground storage tanks). From the bulk storage tanks, the LNG fuel is then dispensed to vehicles through small 50-horsepower liquid pumps and LNG fuel dispensers. Fuel is dispensed into vehicle on-board fuel tanks as a liquid in a fast-fill application, usually at a rate of approximately 25 gallons of LNG per minute (equivalent to approximately 15 diesel gallons per minute).

As of January 2014, there are no operational LNG stations for transportation applications in Wyoming. However, "Flying J" stations in Cheyenne and Rawlins have been built by Clean Energy; these are expected to open in early 2014 (see Figure 37).[130] Nationwide, Clean Energy has plans underway to build a network of LNG truck fueling stations along interstates and in major metropolitan. The first phase includes 150 fueling stations that are targeted to be open in 2014. Of particular interest are those stations being built along the busy I-80 line-haul trucking corridor. Like the Cheyenne and Rawlins stations, many of these corridor-oriented LNG stations will be co-located at Pilot-Flying J Travel Centers already serving goods movement trucking. The opening of these stations is, in part, being timed with the anticipated roll out of new OEM natural gas trucks powered by the CWI 12-liter dedicated natural gas engine, which is well suited for heavy-duty over-the-road trucking.

[130] Clean Energy Fuels, "America's Natural Gas Highway: The Clean Energy Solutions," pdf accessed online at http://www.cleanenergyfuels.com/pdf/CE-OS.ANGH.012412.pdf.

Figure 37. Location of Flying J LNG stations along I-80 in Wyoming



Source: AFDC, Alternative Fuel Station Locator

6.1.2. LNG PRODUCTION FACILITIES

Table 26 lists the top 25 natural gas production facilities in Wyoming (2012). Two of these Wyoming natural gas production plants currently co-produce LNG; both are located in the state's southwestern region. These plants, which both use a "nitrogen rejection unit" pathway to make LNG, are: 1) the Shute Creek Plant operated by ExxonMobil Corporation, and 2) the Painter Plant operated by Merit Energy. These LNG plants primarily provide natural gas to local utilities in the winter months, when pipeline gas availability may not be sufficient to meet Wyoming's heating demand. LNG is typically only produced to account for a peak day's supply necessary to serve the utility load. Therefore, facilities typically do not have storage in excess of what is required to meet this demand. When the utility has surplus gas supply and LNG is not being used to meet its customers' needs, excess LNG may be sold to other markets.

Table 26. Wyoming's top 25 natural gas production facilities in 2012

Name of Natural Gas Processing Plant	Owner Company	County	Plant Capacity (MMcf)
Opal Gas Plant	Williams	Lincoln	1,480
Pioneer Cryogenic Plant	Enterprise Gas Processing, LLC	Lincoln	750
Echo Springs Gas Plant	Williams	Carbon	745
Blacks Fork Gas Plant (I and II)	QEP Field Services	Sweetwater	705
Shute Creek Treating Facility	ExxonMobil Production Company	Lincoln/Sweetwater	690
Pioneer Silica Gel Plant	Enterprise Gas Processing, LLC	Lincoln	600
Granger Gas Plant	Anadarko Petroleum Corp.	Sweetwater	500
Lost Cabin Gas Plant	ConocoPhillips (Burlington Resources)	Fremont	355
Fort Union Medicine Bow Facility	Crestone Energy Ventures LLC	Converse	340
Bison Treating Facility	Western Gas Partners, LP	Campbell	270
Painter	Merit Energy Company	Uinta	270
Rawlins	Colorado Interstate Gas Company, LLC	Carbon	220
Carter Creek Gas Plant	Chevron	Uinta	150
Bairoil CO2 Plant	Merit Energy Company	Sweetwater	143
Douglas	Tallgrass Midstream LLC	Converse	140
Patrick Draw Gas Plant	Western Gas Partners, LP	Sweetwater	130
Pavillion Gas Plant	Encana Oil & Gas (USA) Inc.	Fremont	80
Casper Plant	Tallgrass Midstream LLC	Natrona	65
Anschutz Ranch East	Merit Energy Company	Uinta	55
Beaver Creek Plant	Devon Gas Services LP	Fremont	55
Emigrant Trail Gas Plant	QEP Field Services	Uinta	55
Vermillion Gas Plant	QEP Field Services	Sweetwater	50
Table Rock Gas Plant	Chevron USA, Inc.	Sweetwater	47
Highlight Complex	Western Gas Partners, LP	Campbell	45
Sage Creek Gas Plant	ONEOK Partners*	Converse	50
*Update on Sage Creek Gas Plant ownership and capacity provided by ONEOK Partners, March 2014.			
Source: U.S. Energy Information Administration			

Brief overviews of these two LNG plants are provided below.

Shute Creek Plant – This natural-gas processing plant is operated by ExxonMobil Corporation. Fed by field gas that is captured at LaBarge Field in Sublette County and piped 40 miles to Shute Creek, this Lincoln County facility separates carbon dioxide (CO_2) from methane (natural gas) and helium, and processes each gas for sale. Field gas from LaBarge has very high concentrations (~65 percent) of CO_2, with about 21 percent methane and 7 percent nitrogen. Partly due to this, production of LNG is a relatively minor activity at the Schute Creek Treating Facility (see Figure 38). Located in Evanston, the facility has an estimated 66,000 gallons per day (GPD) of liquefaction capacity, with the resulting LNG having a methane content "greater than 97 percent."[131] For the reasons cited above, on-site LNG storage capacity is limited to about 50,000 LNG gallons.

The primary buyer of gas from the Shute Creek Plant is Lower Valley Power & Light (LVP&L), a local utility serving nearby Wyoming communities. The LNG purchased by LVP&L is trucked to its two storage facilities located in Afton and Jackson Hole. These remote utility locations can store 36,000 and 180,000 LNG gallons, respectively. LVP&L has reported that interested parties have inquired about purchasing LNG for heavy-duty on-road trucking fleets. While the utility is believed to be considering such requests, they do not currently sell LNG for this purpose.

When the needs of LVP&L are met, the Shute Creek Plant itself will secondarily sell LNG as a transportation fuel to additional buyers. Both Applied Natural Gas Fuels and Clean Energy Fuels have purchased LNG from this source for vehicle use. Despite the favorable production economics and vast gas reserves, under current market conditions plant expansion is unlikely, however. This is primarily due to the distance from current markets demanding LNG for transportation. This could change if demand in the region increases, especially in the northwest°≠ shale plays, where freight costs to these locations would be more economically feasible. If the case could be made to convince ExxonMobil to expand this facility, it would be a valuable asset to meet increased demand for LNG.

Painter Processing Plant – This second merchant LNG plant in Wyoming is owned by natural gas producer and processer Merit Energy. Similar to Shute Creek, the Painter Plant extracts nitrogen and hydrocarbon condensate including liquids and "liquefiables" out of the gas stream. The Painter Plant is located downstream of the Carter Creek Processing Plant, owned by Chevron. At the Carter Creek plant, gas is partially processed and then delivered by pipeline to the Painter Plant for additional clean-up. The resulting gas supply is then delivered into the interstate pipeline system.

The Painter Processing Plant, located in Painter Creek near Evanston, has a 35,000 GPD daily liquefaction capacity and a 5,000 GPD maximum daily send-out capacity. Though much smaller in size, this plant has a similar business model to that of the Shute Creek Plant. The plant primarily produces LNG for local off-grid utility use, with very little available for vehicle use. Historically, the company has demonstrated limited interest in supplying LNG as a transportation fuel, though this may change as demand increases.

[131] California Energy Commission, "The California LNG Transportation Fuel Supply and Demand Assessment," Consultant Report #P600-02-002F, January 2002.

Figure 38. Shute Creek Plant in eastern Lincoln County

Other Existing Regional LNG Production Plants – There are other LNG liquefaction plants located outside of Wyoming that could potentially contribute to expanded use of LNG in the state. Descriptions are provided below.

- The Prometheus Energy liquefaction plant in Lisbon, Utah is 170 miles south of the Wyoming border. This facility produces 22,000 GPD of LNG and utilizes residual methane from an Encana cryogenic natural gas processing facility in San Juan County, Utah. LNG produced at the Lisbon plant is transported via tanker to vehicle fleet customers in the Western US, including the pilot demonstration of LNG mining trucks at Belle Ayr mine in the PRB.
- The Intermountain Gas LNG plant is a peak-shave facility with liquefaction located 275 miles west of the border in Nampa, Idaho. In early 2013, Intermountain Gas was granted authority to sell excess LNG to non-utility customers, after they proved they could meet utility-customer needs and still have enough LNG to provide an extra 7.3 million gallons of LNG for year-round non-utility sales. The facility has the capacity to liquefy 42,000 GPD and store more than seven million gallons of LNG.[132]

[132] "Idaho Regulator to Let Utility Sell Surplus LNG to Nonutility Customers," Downstream Today, April 30, 2013, accessed online at http://www.downstreamtoday.com/news/article.aspx?a_id=39399&AspxAutoDetectCookieSupport=1.

6.2. DEVELOPING NEW LNG PRODUCTION AND INFRASTRUCTURE

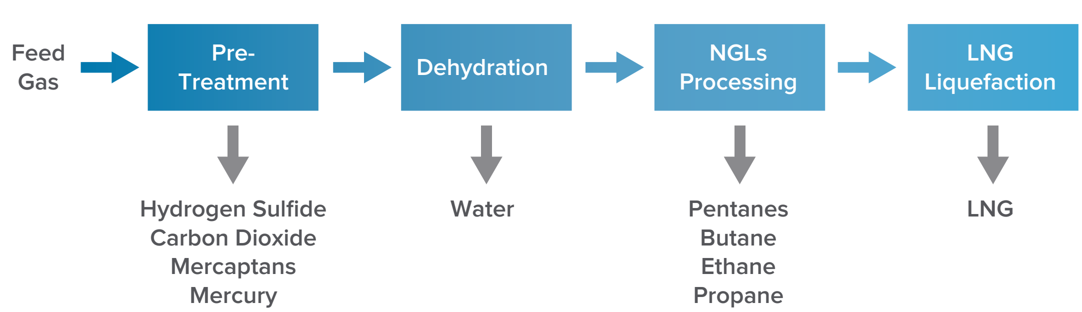
6.2.1. OVERVIEW OF LNG PLANT CONSTITUENTS

Existing LNG production infrastructure in the State of Wyoming is insufficient to meet the potential demand expected by a substantial transition to natural gas fueled equipment (estimated to be 509,000 LNG gallons per day). To increase the available supply in line with future use, a variety of liquefaction strategies could potentially be employed. A basic understanding of the LNG liquefaction process helps to understand how these various strategies might be applicable to Wyoming's needs.

A typical LNG plant includes the following components:

- Feed gas compression, in the event that inlet natural gas pressure is low
- CO_2 removal, mostly by a wash process and a H_2O drying or removal by an adsorber (CO_2 and H_2O would otherwise freeze and cause clogging in the downstream liquefaction equipment)
- Natural gas liquefaction (including compressors and heat exchangers)
- LNG storage
- LNG loading stations
- LNG metering stations

Figure 39. Elements of a typical gas processing and LNG liquefaction plant



Source: "Understanding Today's Global LNG Business," Bob Shively, John Ferrare, and Belinda Petty

LNG as a fuel for HHP applications such as on-road trucks must generally consist almost entirely of methane to meet engine combustion specifications. "Raw gas" produced from a Wyoming oil or gas well usually includes other hydrocarbons (ethane, propane, butanes, and pentanes), water, and other impurities (sulfur, mercury, carbon dioxide, etc.), that must be removed prior to liquefaction. This raw gas is gathered in a pipeline system and delivered to a gas processing plant where the impurities are removed and the other hydrocarbons are recovered as natural gas liquids (NGL), leaving a mostly methane residue gas stream that is suitable as feed to an LNG plant. In some cases, the raw gas may contain very few other hydrocarbons, and only the impurities must be removed.

Wyoming has approximately 42 operating gas plants (2012 data). Some of these only treat gas to remove impurities, but most are gas processing plants that also remove NGL. These facilities process nearly 83 percent of the state's gas production.[133] Figure 40 shows the general locations for existing gas processing facilities Wyoming and throughout the U.S. It is important to note that renewed drilling in the Powder River Basin is expected to produce large amounts of raw gas that will be need to be processed for the removal of NGL. Existing plant capacities will not be sufficient to accommodate the anticipated production, and new gas processing plants are being planned by several companies.[134]

[133] Petroleum Association of Wyoming, "Wyoming Oil and Gas Facts and Figures, 2013 Edition," accessed online at http://www.pawyo.org/facts-figuers.pdf.

Many gas processing plants in Wyoming could be suitable sites for expanding the State's existing LNG production, with relatively low capital investment and incremental operating costs. Since gas processing plants have existing pipeline infrastructure and electricity, in addition to some processing capabilities, co-locating liquefaction plants on these sites can significantly reduce the capital and operating expenditures associated with commissioning a new LNG plant. Incorporating an LNG plant into the construction of a new gas processing plant can yield even more advantages in construction costs and process efficiency.

An LNG plant can also be located on a major transmission line, although permitting may be complicated if the line is subject to FERC jurisdiction. Figure 41 shows the western portion of one Wyoming natural gas pipeline and gas processing system, known as the Tallgrass Interstate Gas Transmission network. As shown, this network includes the Casper and Douglas gas processing plants, the latter which is located at the southern gateway to PRB mines in Converse and Campbell counties. At face value, this would seem to be a good candidate location for an LNG liquefaction facility.

[134] ONEOK Partners, personal communication to GNA, March 2014.

Figure 40. U.S. and Wyoming natural gas processing plants

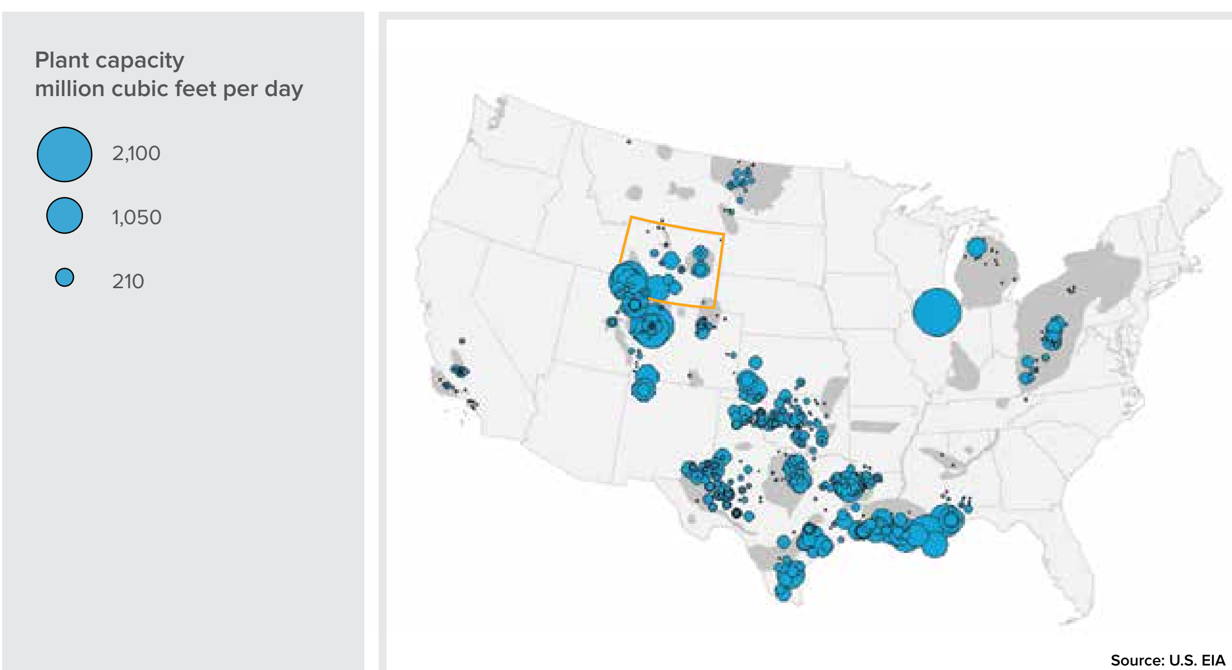
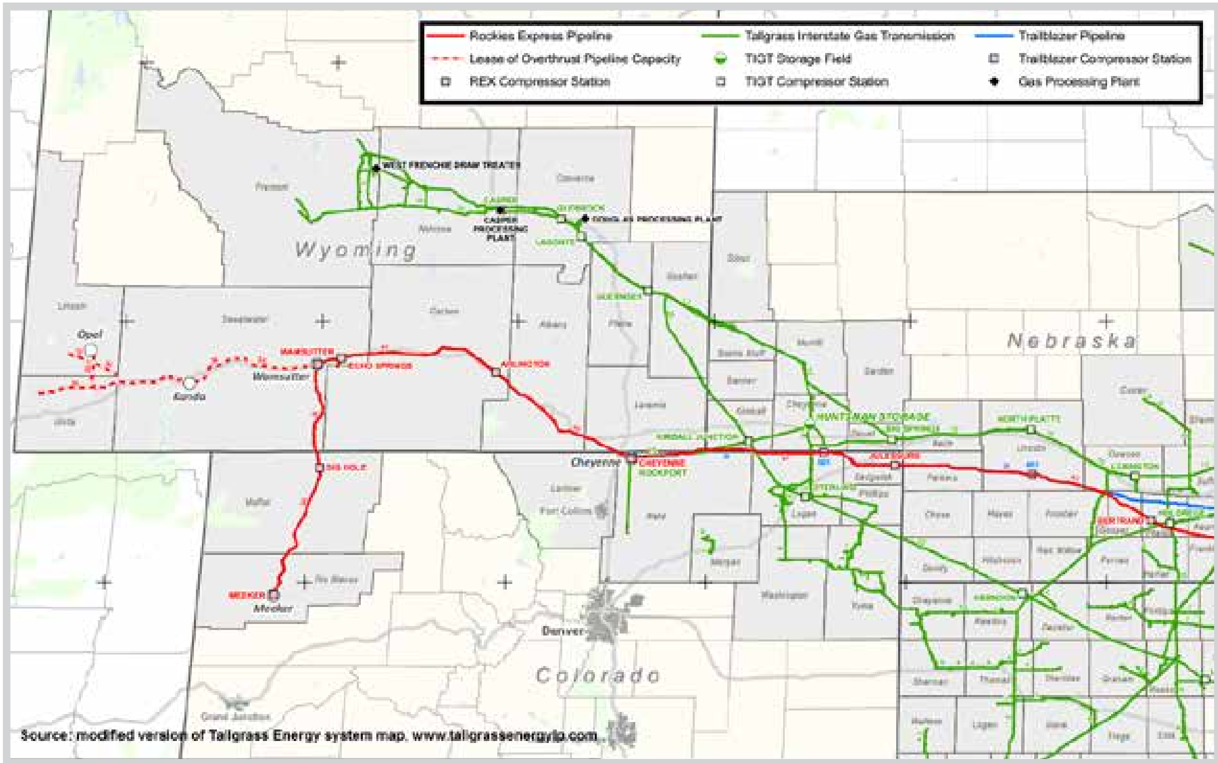


Figure 41. Tallgrass Interstate Gas Transmission network (with Wyoming gas processing plants)



In addition, gas processing plants are situated on large swaths of land that are already zoned for industrial use. Siting an LNG plant in this location would therefore reduce both the preconstruction and construction timelines by eliminating the need for utility installation and some permitting requirements. Ultimately, co-locating LNG liquefiers near existing gas processing plants will reduce the cost of fuel delivered from the site. However, when determining potential cost savings, the distance the final product must travel to reach the end user should be taken into consideration. Savings will diminish if LNG has to travel long distances before being reaching its final destination.

This is type of co-location is already occurring in the State and around the country. The Painter Processing Plant is one such example, where liquefiers were added to an existing gas processing plant. This was a logical location, as the utility infrastructure and land were already available for industrial use. Other industrial sites may also be ideal locations to introduce LNG liquefaction capabilities. Though not situated at a gas processing plant, the Clean Energy plant in Boron, CA was also able to take advantage of nearby industrial activity. Located near the Rio Tinto borax mine, Clean Energy built its California LNG Plant where zoning and existing utilities would support the project, while still remaining in close proximity to its customers in California and Arizona. In addition, there is synergy because the mine can consume tail gas from the liquefier.

Though purchasing LNG from merchant facilities would be favorable for end users nearby, in general, customers will need to determine whether the distance from the plant to their site would be cost prohibitive. The alternative to delivering natural gas from a distant liquefaction facility would be to install one onsite or nearby. It is advantageous to have LNG liquefaction equipment nearby since fuel is close in proximity to its point of use, eliminating or reducing costs associated with transportation of fuel to the site. It also means that the pollution, noise, and traffic that results from delivery vehicles would be avoided or minimized. This becomes particularly pertinent in areas of air quality non-attainment, such as the Upper Green River Basin. Placing liquefaction on a user site or nearby is a solution for fleets in areas where LNG plants have not yet been established, and delivery from a plant farther away is cost prohibitive.

However, the capital cost of such liquefaction must now be at least partially covered by the new LNG user, if they intend to own and operate the LNG plant; or another vendor must deal with those capital costs and potentially find multiple LNG users nearby to provide the necessary revenue stream to payback those costs. As interest in natural gas continues to grow, finding a financial lender to back a new LNG plant may be a viable option for larger operations. An increasing number of financial institutions are entering the market to support LNG projects of all sizes, due to low commodity costs and projections of increased natural gas production and consumption. Investment companies in this space include GE Energy Financial Services, Stonepeak Infrastructures Partners, Pavilion Energy, and many others.

6.2.2. LNG PRODUCTION OPTIONS

There is a range of liquefaction plant options currently available for installation in Wyoming; these vary in size, efficiency, complexity, cost and timeline for completion. A few key options are discussed below.

6.2.2.1. LARGE-SCALE LIQUEFACTION

Traditional base load LNG plants, such as export terminals, are used to liquefy very large quantities of gas. According to supplier Linde, the production capacities of these large facilities can exceed 10 million tons (5.6 billion LNG gallons) per year. They are usually located near navigable waters for distribution by tankers to consumers, but also have truck offloading capabilities for on-road transport. Key players in the construction or equipment of large-scale LNG plants and terminals in North America include GE, Chart E&C, Air Products and Chemicals, Linde, and others. Figure 42 shows an example of a large LNG terminal in Maryland, where a large-scale liquefaction plant has been proposed.

The capital costs for the largest liquefaction facilities can be as high as $2 billion.[135] Costs have been reduced through economies of scale and streamlining of the construction process. In recent years, however, the benefits of this "learning curve" effect have been tempered, and this trend has dissipated. This can be attributed to the relatively rapid increase in natural gas demand over the past two decades, and the lack of experienced engineering, procurement, and construction (EPC) contractors and adequate manufactured components necessary to meet this demand. In this time, the problem has been exacerbated by an increase in the cost of raw materials, along with the devaluation of the U.S. Dollar.[136]

Time of construction strongly dictates costs, so capital expenditures for building an LNG plant can be reduced through maximizing synergies with existing facilities and other efficiencies. Increasing the capacity of the plant can also decrease the incremental cost, if equipment sizes increase proportionally. Capital costs will vary depending on the plant location, cost of labor, feed gas composition and product specification.[137] Due to the site-specific nature of facility capital investment, it is difficult to determine exactly how much a new large-scale LNG plant will cost. Table 27 illustrates the total plant costs associated with a theoretical LNG facility of this magnitude; it also provides a breakdown of LNG liquefaction costs by component.

[135] "Understanding Today's Global LNG Business," by Bob Shively, John Ferrare and Belinda Petty.

[136] Ibid.

[137] Ibid.

Figure 42. Dominion Cove Point LNG Terminal in Lusby, Maryland

Figure 42 provides a break out of liquefaction costs by percentage for an average liquefaction facility. Less than 50 percent of the LNG plant cost is capacity related, with most of the project cost coming from site related conditions, project development and project execution efforts. When considering the development of LNG production infrastructure, it is also important to consider ongoing costs, such as gas necessary for fuel in the plant, taxes, and general operation and maintenance costs. A typical liquefaction plant will consume approximately 11 percent of the feed gas as fuel to run the equipment.[138]

As a result of the custom, project-based nature of individual LNG plants, traditional larger-scale facilities can take an average of 48 months, and up to 72 months, for completion. These projects are highly complex in nature; require engineering, procurement, and construction; and entail intense capital investment.[139] Due to the high costs and long lead times, in addition to potentially high transportation costs for consumers, it is not recommended that the State of Wyoming pursue this path to increase LNG production capabilities.

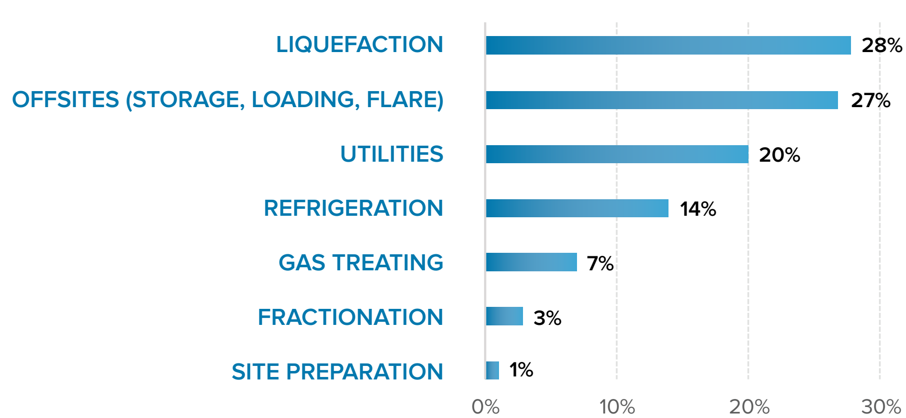
[138] "LNG Liquefaction – Not All Plants Are Created Equal," KBR, http://www.kbr.com/newsroom/publications/technical-papers/lng-liquefaction-not-all-plants-are-created-equal.pdf

[139] "Accelerating Adoption of Natural Gas Fueling Infrastructure, Ujjwal Kumar, GE Oil & Gas, HHP Summit 2013, September 2013.

Table 27. Example of LNG liquefaction costs including plant construction

Total plant capital cost*	$1.2 billion
Plant capacity	5 million tons per annum (238 Bcf/ year, 2.8 billion LNG gal/year)
Utilization rate	90 percent
Annual cost of capital	$155 million
Per Mcf cost of capital	$0.72/Mcf
Fuel	$0.08/Mcf
Taxes	$0.15/Mcf
Operating costs	$0.20/Mcf
Total cost of liquefaction	$1.15/Mcf
*Plant capital cost includes interest during construction.	
Source: "Understanding Today's Global LNG Business"	

Figure 43. Cost breakout for a "typical" larger-scale LNG liquefaction facility



6.2.2.2. SMALL- AND MID-SCALE LIQUEFACTION

Small and mid-scale LNG plants are used primarily to meet local or regional energy requirements for clients that require up to about 600,000 LNG gallons per day. They can be built with a traditional engineering, procurement, and construction approach or a modular, prefabrication approach. The latter will result in a standardized, cost-effective system that can be easily installed in a relatively short timeframe. Smaller, decentralized LNG plants also benefit the smaller, regional players by minimizing transport costs, civil work, and operating costs. Some of the key companies in this market today are GE Oil & Gas (with recently acquired Salof), Chart Energy & Chemicals, Linde Group, Air Products and Chemicals and Cosmodyne. Table 28 lists some of the LNG liquefaction products and systems they currently manufacture and sell.

Due to modularization, these small- to medium-scale liquefaction units have reduced physical footprints compared to large facilities. They typically take from six to 24 months for installation, following a 12-18 month lead time for purchase and delivery. This is a significantly shorter timeframe than can be expected for a large-scale LNG plant. These plants are also easily expandable if there is an increase in gas demand, which can often be the case as deployed vehicles or equipment increase over time.

An LNG plant that produces 100,000 gallons per day will cost between $55 million and $100 million. These costs account for storage, miscellaneous equipment, permitting and installation, and power supply; a 10 percent contingency is included. Permitting and installation alone will count for 50 percent of the equipment costs of the plant.[140]

Clean Energy is partnering with GE to expand America's Natural Gas Highway using GE's MicroLNG technology. Each of the two initial MicroLNG systems will produce 300,000 gallons of LNG per day, with the option to expand capabilities to 1 million gallons per day as demand increases. For these plants, GE Energy Financial Services is providing up to $200 million in financing. The stations will begin operating in 2015, though the two companies are still determining the best locations for these plants.[141]

Clean Energy's LNG plant in Boron, California was completed in 2008 and currently produces 180,000 LNG gallons per day. The plant, which is capable of being expanded to 270,000 LNG gallons per day, cost $75 million to build. This was a complex case and may not necessarily be representative of what it would cost a similar plant in Wyoming today. One cost reduction synergy was that the Boron plant was able to be co-located with gas processing plants near the Rio Tinto borax mine. This proximity to industrial activity resulted in reduced permitting requirements and eliminated or reduced the need for new electricity and natural gas utility infrastructure.[142]

[140] Based on GNA's industry experience.

[141] Clean Energy Press Release, November 2013, http://www.cleanenergyfuels.com/news/2012/11-13-12.html.

[142] Joseph Pak, Cosmodyne, keynote address at HHP Summit 2013, September 2013.

Table 28. Commercially available small- to mid-scale LNG production systems

Company	Product	Liquefaction Capacity
GE Oil & Gas (Salof design)	MicroLNG	• 100,000 LNG gallons/day • 200,000 LNG gallons/day • 300,000 LNG gallons/day • 450 LNG gallons/day
Chart Energy & Chemicals	C100N C250IMR C450IMR	• 100,000 LNG gallons/day • 250,000 LNG gallons/day • 450,000 LNG gallons/day
Linde Group	StarLNG	• 60,000 LNG gallons/day to 1,000,000 LNG gallons/day
Cosmodyne	Natural Gas Liquefaction Plant	• 1,000 to 500,000 LNG gallons/day • 10,000 to 30,000 LNG gallons/day

Figure 44. A mid-scale LNG liquefaction facility from Chart Industries


Source: www.chartlng.com

Noble Energy is building a gas processing plant in Weld County, Colorado that will include an attached 100,000 GPD LNG liquefier. This facility will supply Noble's rig drilling operations, with residual fuel being sold to other operators in the region. The LNG plant is expected to cost $45 million, offering another example of reduced capital expenditures when building a plant in conjunction with gas processing facilities.[143]

As mentioned in the previous section, ongoing costs can be a large expense and should be considered prior to construction of a liquefaction facility. Like the large-scale LNG facilities, these plants also require a certain amount of the inlet gas be used to fuel the equipment, in addition to the electric power consumed for refrigeration and auxiliary power. Below are some example utility requirements necessary for the operation of various LNG production facilities.

This medium-to-small scale range of LNG production appears to provide a good approach to expand LNG infrastructure throughout Wyoming in relatively remote areas with the greatest fuel demand (e.g., the high-fuel-use PRB coal mines).

[143] "Noble to Build LNG Plant in Colorado, Zacks Analyst Blog, Zacks online, March 22, 2013, http://www.zacks.com/stock/news/95475/noble-to-build-lng-plant-in-colorado.

Table 29. General utility requirements for various LNG plant capacities

LNG Production Case (LNG), US Gal/day	Plant Inlet Gas, MMSCFD	Fuel Gas, MMSCFD	Refrigeration Power, kW	Auxiliary Power, kW	Total Power, kW
100,000	10.5	0.42	3,542	708	4,250
500,000	52.5	2.10	17,708	3,542	21,250
1,000,000	105	4.20	35,417	7,083	42,500
1,500,000	157.5	6.30	53,125	10,625	63,750
Based on information provided to GNA by Zoher Meratia, Principal, CDS Research Ltd., 2013.					

6.2.2.3. MICRO-SCALE LIQUEFACTION (DISTRIBUTED LNG)

Micro-scale liquefaction refers to much smaller LNG production plants that can produce from 6,000 up to 25,000 gallons per day. These plants are designed to provide "distributed" LNG to a suitably sized group of high horsepower vehicles or equipment at a single site. They are not ideal for multiple fleets or meeting the needs of an entire region.

Micro-scale liquefaction plants can provide right-sized operations with their lowest upfront capital expenses to obtain onsite access to LNG. However, small LNG plants cannot offer the economies of scale provided by larger plants, and they are less efficient. Thus, they are the most-expensive LNG liquefaction option on a per-LNG-gallon basis. Dresser-Rand estimates that fueling with a small-scale plant will cost approximately $0.80/LNG gallon. This includes equipment costs, assumes gas is received at $4/mmBTU (roughly the current commodity price), and includes capital expense amortized over a 15-year period.

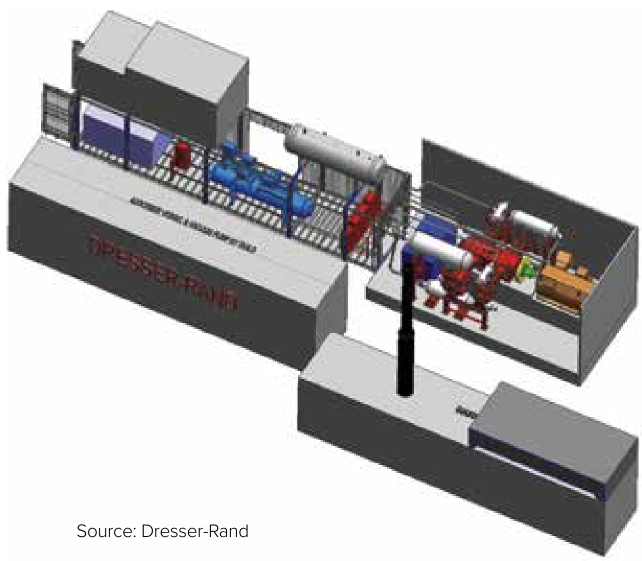
It is important to note, however, that the distributed LNG approach at the site minimizes or negates transportation-related costs for the fuel. This may result in significant cost savings for the end user, as LNG transport can be quite costly. These small-scale, distributed LNG production facilities also have a significantly smaller footprint than their larger counterparts. This reduces the area of land necessary to support liquefaction and storage operations, and can also minimize permitting requirements.

Another advantage of these micro-scale distributed LNG systems is that they remove uncertainty associated with building an expensive large-scale LNG plant. When used to seed the fuel market, there is less risk associated with securing an adequate customer base to utilize the large amount of fuel that would be produced at the bigger plants. They also give fleets the opportunity to control their own fuel supply, as opposed to relying on a third-party vendor. These modular units are rapidly deployable, with highly automated operation. Their mobility allows them to be moved from one location to another, to mirror the operational needs of the fleet. They make a very good alternative when fleets need to gain access to LNG on a short timeframe, with only six to 12 months of lead time for permitting, engineering, product delivery and construction.

Examples of distributed LNG products follow.

Dresser-Rand LNGo – With a production capacity of 6,000 gallons per day, the LNGo system is the smallest of the small-scale distributed LNG options. The system is fully automated and remotely monitored. No onsite personnel are required. Dresser-Rand indicates that the system can operate at 35 psi suction pressure and requires no additional gas cleanup equipment in addition to what is included in the system. The unit does not require any external electric service as all electric power needed is produced from the incoming gas supply. The LNGo will require storage and pumping systems in addition to the equipment provided by Dresser-Rand. Dresser-Rand is now building the first prototype unit and expects it will be completed by the end of 2013. The first unit will be tested at their facility. Until it is built and operational, pricing is not available.

Figure 45. Dresser-Rand LNGo small-scale LNG system



Source: Dresser-Rand

Galileo Cryobox – Galileo's CRYOBOX produces 7,000 gallons per day and operates at a gas inlet pressure of 150 psi. Depending on the pressure of utility line gas, the system may require a booster pump to reach adequate pressure. As with all of the small-scale distributed LNG liquefier options analyzed, LNG storage, pumping, piping, loading assembly, and all necessary fire/life safety equipment is required in addition to the LNG production unit. The system requires 500 kW of 480V power supply from the local electric utility. The cost of CRYOBOX is approximately $3.5 million. The combined cost of the CRYOBOX, additional equipment (storage, pumps, etc.), and engineering, permitting, and construction is estimated to be between $6 million and $7 million for a complete system that could fuel multiple high horsepower vehicles.

GE LNG in a Box™ – LNG in a Box is a containerized LNG solution that produces 10,000 gallons of LNG per day. A plant with 25,000 GPD is currently under development with the GE Salof design. Housed in an ISO box, the system requires a minimum of 700 psi feed pressure, and a booster feed compressor if utility line gas is not of adequate pressure. A natural gas feed of 1.1million scfd is required to produce the daily capacity of 10,000 gallons per GE; the equivalent of 765 scfm. Most likely a dryer would be needed prior to the LNG in a Box when using a booster pump to ensure appropriate condensate levels prior to use by the GE system. The GE equipment requires 1.4 kwh of electric capacity per gallon of LNG produced at 450 kW of maximum electric power. The capital cost of the GE equipment at over $8 million and approximately $5 million for all other costs (storage, pumping, engineering, etc.) results in a total installed cost of approximately $12 to $13 million with dispensing capabilities for multiple high horsepower vehicles.

Figure 46. Galileo Cryobox small-scale LNG system

Source: Galileo

Figure 47. GE LNG in a Box™ micro-scale liquefier

Source: GE

6.2.3. KEY CONSIDERATIONS FOR BUILDING LNG PRODUCTION CAPABILITIES

6.2.3.1. PERMITTING

When constructing an LNG liquefaction facility of any size, the time and costs associated with pre-construction activities must be carefully considered. These activities, which include acquiring the land, completing an upfront study, and completing permitting requirements, can take up to 12 months. The permitting process, in particular, can greatly extend the time necessary to building a plant. For instance, the Clean Energy plant in Boron, CA was delayed many months when an endangered squirrel species was found on the property. Permitting is required in most jurisdictions for new construction, with specific requirements for industrial facilities like those that produce LNG and involve extension of utility transmission lines. Permitting varies by state, region and city, though typical use permits usually include the following:

- Land Use Permits are required for certain types of development, including those for the site's zoning and proposed use.
- Air Quality Permits are issued to industries and facilities that emit regulated pollutants to protect human and environmental health.
- Fire Permits are awarded after an inspection and approval of the described operation or activity, which must conform to all applicable standards.
- Hazardous Material Storage Permits are issued to businesses that must report onsite hazardous materials and complete a hazardous materials business plan.

- National Fire Protection Association (NFPA) 59a Inspections must be completed for facilities that liquefy, store, vaporize, transfer, and/or handle natural gas.

Permitting will be lighter for small-scale distributed LNG plants as well as those built in areas where industrial use is already permitted (including gas processing plants). Permitting will also vary depending on where in the State the plant is located, what type of land is involved (federal, state, etc.), if extension of gas pipeline is required, and myriad other factors. Federal, State and local authorities having jurisdiction all play a part in ensuring a new project will meet applicable codes and regulations.

Federal regulation may require permits and consultation by the U.S. Army Corps of Engineers (USACE), U.S. Fish and Wildlife Service (USFWS), U.S. Federal Highway Administration (FHWA), U.S Federal Aviation Administration (FAA) and others depending on the factors mentioned above. The State of Wyoming also requires various permits be completed prior to new construction projects including the following responsible agencies:

- Wyoming Department of Environmental Quality (Industrial Siting Division, Water Quality Division, and Air Quality Division)
- Wyoming Public Service Commission (PSC)
- Fire Marshal, Department of Fire Prevention & Electrical Safety
- Wyoming Office of State Lands and Investments (OSLI)
- Wyoming Department of Transportation (DOT)
- Wyoming Game and Fish Department (GFD)
- Wyoming State Historic Preservation Office (SHPO)

Individual local regulatory authorities, including counties and incorporated city governments within the State of Wyoming, require that additional permitting and regulation be met. Those needed for construction of an LNG production facility will vary by county and municipality. Some or all of the following elements may be necessary:

- County building permit
- Right of Way permits
- Conditional Use Permit/Special Use Permit.
- Below ground utility permit
- Grading permits
- Consultation with local weed and pest districts

6.2.3.2. TRANSPORTATION

There are two basic ways to transport LNG to end users in land-locked states like Wyoming: by rail or on-road trucking. In either case, proximity of the LNG liquefaction plant to where it will be used is an important determinant of economic feasibility for fleets considering LNG. Beyond a certain distance (e.g., roughly 250 miles for truck transport), transportation costs can make it more difficult to achieve cost-effective LNG delivery; this distance will vary depending on multiple factors.[144]

For most HHP applications in Wyoming, trucks with transport trailers will be used to deliver LNG to end users. Over-the-road transport trailers can hold a maximum of about 12,000 LNG gallons, but they are commonly filled and transported with 10,000 LNG gallons due to U.S. Department of Transportation weight restrictions.

Many manufacturers sell LNG over-the-road transport trailers in the U.S., including:

- Chart Industries, Inc.
- Alloy Custom Products
- Westmor Industries
- INOXCVA
- Dragon Products Limited

[144] LNG vendors generally cite a 250 mile radius for economic feasibility; some indicate that proximity within 100 miles is desirable.

- Applied Cryo Technologies
- Taylor-Wharton International

Westport™ applies equipment from various manufacturers to offer its "JumpStart" program as a mobile, flexible and economic solution for fleets needing delivery of and access to LNG. Westport JumpStart provides in-yard fleets with convenient refueling in the absence of a permanent LNG solution. It offers coordinated fuel delivery and refueling via portable LNG trailers for Westport fleet customers and fuel providers.

As demand and production of LNG as a transportation fuel increase, it is likely that railroads will become increasingly important for transporting LNG to end users, at least those located along rail lines. It is important to note that tank cars carrying LNG as cargo cannot currently travel without approval from the U.S. DOT's Pipeline & Hazardous Materials Safety Administration (PHMSA). Guidelines for the transportation of LNG by rail are currently being established in partnership with the American Railroad's Tank Car Committee and the Liquefied Natural Gas Technical Advisory Group.

Currently, large railcar manufacturers in the U.S. such as Trinity Industries and American Railcar Industries work with cryogenic tank companies like Chart Industries to modify their standard tank cars for cryogenic rail applications. Cryogenic railcars can hold about 30,000 gallons (see Figure 48).

While it is not yet clear who will build commercial LNG railcars, it appears likely that current railcar manufacturers will continue to work with cryogenic vessel manufacturers for the actual LNG storage cylinder. Those cryogenic vessel makers for rail applications will likely be:

- Chart Industries, Inc.
- INOXCVA
- Taylor-Wharton International

Finally, so-called "ISO" (International Standards Organization) containers may also be important components of intermodal LNG transport. LNG ISO containers are already being produced and used in the U.S. and rely on standard and very robust ISO packages. ISO tanks come in 40-foot long lengths that can be easily transported by truck trailer, rail flat car or marine vessel. A 40-foot long ISO container can hold 10,000 gallons of LNG, which is less than 6,000 DGE. Despite their small capacity, the prospect of intermodal transportation means that a combination of movement by rail and truck could be facilitated.

Manufacturers of LNG ISO containers include:

- Chart
- Westport/INOXCVA
- WesMor
- Liquiline
- Taylor Wharton

Figure 48. Typical rail transport for LNG storage tank (approximately 30,000 LNG gallons)

Source: www.cvatanks.com

7. COSTS AND RECOMMENDED APPROACH FOR LNG INFRASTRUCTURE

7.1. ESTIMATED COSTS OF INFRASTRUCTURE TO MEET LNG DEMAND

Section 6 provides an overview of the many LNG infrastructure technologies and options that are already commercially available in the U.S., or under development. Applying this information helps narrow down the best approach for a potential LNG infrastructure "roadmap" in Wyoming. As estimated in Section 5.2 using "feasibility factors," an estimated 509,000 LNG gallons per day will be needed over the next one-to-two decades to fuel Wyoming's inventory of mine haul trucks, locomotives, drill rigs, and PPS equipment.

This subsection applies general industry cost factors to estimate the capital cost of building an LNG infrastructure that could meet the estimated daily LNG demand in Wyoming. Table 30 lists the types of LNG infrastructure investments needed to produce, distribute, store and dispense approximately 509,000 LNG gallons per day. As shown, it is estimated that approximately $327 million (2014 $) in LNG infrastructure investments will be needed to meet this daily LNG demand; these costs are believed to be at the low end of the spectrum.[145]

[145] Personal communication from Clean Energy Fuels to GNA, February 2014. Clean Energy's estimate is about $400 million.

Table 30. Total estimated LNG infrastructure costs to meet 509,000 GPD demand

LNG Infrastructure Investment Type	Cost Assumptions	Total Estimated Capital Cost
LNG Plant Development	LNG plants in the 100,000 GPD size; $400 of investment for each LNG GPD required	$203,600,000
LNG Tanker Trucks	67 LNG tanker trucks (9,000 LNG gal each) @ $200,000 per tanker truck (includes 20% spare ratio of trucks)	$13,573,333
LNG Fuel Storage	3 days of storage (1.5 million LNG gallons) @ $12 for each gallon stored	$18,324,000
LNG Fuel Process Equipment and Dispensing	5 times the "LNG Fuel Storage" investment	$91,620,000
Grand Total of Estimated Investment Costs for Above Types		**$327,117,333**
Source: GNA's knowledge of industry "rules of thumb" on LNG infrastructure costs		

The above capital cost estimates are based on industry standards; insufficient information exists to establish detailed estimates for Wyoming. There are many factors that could affect these cost estimates, many of which can't be known until the projects proceed. Others can be further described. For example, one or more of the LNG plants may be built onsite at a PRB coal mine or a Wyoming rail yard. This would enable "direct loading" of LNG into the equipment, and thus reductions in the cost to handle and transport the fuel to that mine or rail yard. On the other hand, if an LNG plant is built at a coal mine, there might be increased need for remote on-site storage equipment and mobile fueling units to move the LNG product down into the working area of the mine where the haul trucks are fueled. In these cases, costs might shift towards more mobile refueling units and fewer trips by LNG tanker trucks. For the level of analysis provided in this report, it is assumed that these "plusses and minuses" with respect to the cost estimates will largely balance out, and that the estimates provided herein can be considered "in the ballpark."

These needed "up-front" investments in LNG infrastructure must be compared to the major fuel cost savings that will accrue each year over the remaining lives of the vehicles and equipment that operate on LNG. Applying the previously described "feasibility factors" for all four HHP sectors, these annual fuel cost savings are summarized in Table 31. As shown, it is estimated that approximately $166 million in fuel cost savings will be collectively realized each year.

To summarize, approximately $327 million in "upfront" capital investments would be needed to build an LNG infrastructure in Wyoming to meet the estimated demand of 509,000 LNG gallons per day. By replacing diesel with natural gas to this magnitude (under the noted feasibility factors), end users of mine haul trucks, locomotives, drill rigs and PPS will realize approximately $166 million in fuel cost savings each year, over the useful lives of the natural-gas-powered equipment.

Note that this analysis does not factor in the capital costs of equipment conversion. Refer back to Figure 34, which assesses the net present values of vehicle-related investments to convert single units in each sector to operate on natural gas. All four types of equipment provide very attractive net present values over their useful lives.

Section 10 takes a closer look at the total estimated costs and economic benefits of building out an LNG infrastructure in Wyoming that can deliver the estimated future demand of 509,000 GPD.

Table 31. Estimated annual fuel cost savings in Wyoming's key HHP sectors

Wyoming High-Horsepower Sector for LNG Conversion (with Feasibility Factors for Percentages of Inventory)	Estimated Annual Fuel Cost Savings After Conversion to LNG
Mine Haul Trucks (100% on dual-fuel LNG)	$72,309,600
Locomotives (50% on HPDI LNG)	$77,456,250
Drill Rigs (25% on dedicated LNG	$10,788,462
PPS (25% on dual-fuel LNG)	$5,400,000
Grand Total of Estimated Annual Fuel Cost Savings	**$165,954,312**

7.2. RECOMMENDED APPROACH FOR LNG INFRASTRUCTURE

Many choices, considerations, challenges and opportunities associated with building out Wyoming's LNG infrastructure are described in Chapter 7. Some important considerations that will play into Wyoming's actual LNG build-out include the following:

- LNG demand details (dates and locations for commercial-scale roll outs of LNG vehicles and equipment)
- Availability and location of gas processing plants
- Considerations for other existing infrastructure (gas pipelines, gas storage facilities, electricity lines, etc.)
- Optimal approach for liquefaction facilities (large- to mid-scale centralized, micro-scale distributed)
- Plant modularity, scalability, flexibility
- Ease of siting, permitting and building plants

It is clear that free market forces—not the State of Wyoming—will ultimately decide how an initial Wyoming LNG infrastructure build-out should proceed, and how fast. LNG fuel providers know their markets and business models best. Solely on the basis of market momentum (emerging manufacturer supply of product and high customer demand), several organizations appear to be actively exploring new market opportunities for building LNG infrastructure in Wyoming. The State can provide guidance and assistance to help remove barriers and address challenges, and continue playing a very significant role guiding early adopters of LNG vehicles and equipment towards Wyoming deployments (see Chapter 10).

The following conclusions and recommendations are provided to assist all stakeholders in a build-out of LNG infrastructure in Wyoming, for whatever form it ultimately takes.

- It does not appear that the large-scale liquefaction pathway makes sense, at least initially, to increase LNG production capabilities in Wyoming. This is due to transitional growth of the market characterized by demonstration projects and small LNG fuel demand; the high costs and long lead times required to build a single large plant; and likely high transportation costs that would result in high delivered-LNG costs to consumers over the long term. Large-scale liquefaction may ultimately become part of Wyoming's LNG-production portfolio for its long-term energy roadmap, but it likely presents too much risk in the early years; while there is strong interest and anticipation, the market is still immature at this time.
- A hybrid approach centered on medium-scale "hub-and-spoke" centralized LNG production—augmented by micro-scale "distributed" LNG—appears to be a logical and cost effective approach for Wyoming. The hub-and-spoke portion would entail multiple strategically located small-to-medium liquefaction plants, such as those provided by Chart Industries, GE, and other vendors. Given the synergies and cost-efficiencies that result, it is likely that these LNG production facilities will be located in conjunction with Wyoming's many gas processing plants. These LNG liquefaction plants can provide hundreds of thousands of LNG gallons per day to HHP fleets within a relatively short distance of the closest facility (preferably, well within 250 miles). This approach might best serve E&P operations (including the thousands of daily on-road truck trips that support them), rail operations at entry points to the PRB, and mine haul trucks or other types of HHP equipment that are located close enough to make truck transport of LNG to their worksite economical.
- Augmenting these "hub-and-spoke" infrastructure elements could be targeted deployments of skid-mounted, micro-scale distributed LNG systems, such as those made by GE Oil & Gas (LNG in a Box), Dresser-Rand (LNGGo), and others. These systems will help the most remote end users to have confidence in transitioning their fleets to LNG while taking control of their own LNG-production needs. Numerous PRB coal mines in particular seem potentially well suited to this approach given the small footprints, fast permitting times, and relatively small up-front capital investments required, in addition to the "scalability" of these units. As a mine operator converts or purchases its first few LNG haul trucks, a single micro-scale LNG plant would be sufficient to serve this initial demand. These micro-scale LNG plants can likely service between five and 10 LNG-powered haul trucks. As an

operator converts or buys an additional five to 10 LNG-powered units, additional micro-scale LNG plants can be installed in parallel. Ultimately the mine may operate three to five LNG production plants, which then provides valuable redundancy for the operation. In addition to these multiple benefits, in the highly competitive PRB coal mining business, some operators may also prefer the relative privacy of handling their own fuel production.

- However, even the micro-scale LNG options entail significant capital expenditures and processes that can involve multi-month lead times. To help get past the classic "chicken or egg" dilemma, mobile transport of LNG—even from out of state—is likely to be needed over the near term. This model is currently being used by Prometheus to supply Alpha Coal (and also Arch, soon) in Wyoming; Encana uses truck transport of LNG to supply Canadian Rail; and the development of the on-road LNG transportation market in California in the mid-1990s was supplied from the existing LNG plants in Wyoming. Until additional production capacity is built in Wyoming, mobile transport of LNG will continue to play an important role to enable longer-term expansion of LNG fleets and infrastructure.

7.3. RECOMMENDED FOCUS AREAS FOR INFRASTRUCTURE BUILD OUT

In Chapter 4, Wyoming inventories for HHP vehicles and equipment across six different sectors were estimated. Insufficient information exists to pinpoint the exact locations of these vehicles and equipment, or the volumes of diesel they consume in Wyoming. However, it is believed that accurate characterizations have been derived through the best-available information. In the subsections above, the volumes of LNG were estimated that would be needed for an "all-in" scenario of conversion to LNG in each of four HHP sectors (mine haul trucks, locomotives, drill rigs, and pressure pumping services, or PPS). "Feasibility factors" were applied to account for sector-specific parameters and derive reality-based estimates. This yields an estimated 509,000 GPD of LNG that will be need to be produced, transported, stored and dispensed over the next one-to-two decades, to meet the established potential demand.

So far, it's clear that all four key sectors are progressing towards natural gas, albeit at different rates. Understanding the unique status of each sector helps better define how the State of Wyoming can provide useful assistance. Clearly, the E&P sector is well underway for converting drill rigs and PPS equipment to LNG (or other forms of natural gas). Natural gas market growth in this sector appears rapid and destined to lead, given that America's gas producers have the means and incentive to power their own operations with the fuel that they produce.

With later starts than the E&P sector, the mining and locomotive sectors are just beginning to demonstrate the use of LNG-powered equipment. Currently, only a few proof-of-concept units are operating in each sector. Additional prototype units will likely be deployed within one to two years. Assuming the early demonstration projects go well, growth in these two sectors could accelerate. It is this potential growth that will likely have the most direct and immediate impact on the development of the LNG industry within (and beyond) Wyoming's borders.

Related to these sector-specific dynamics, geographical patterns are emerging about where the greatest needs exist to install Wyoming's LNG liquefaction facilities. It appears that the north end of the PRB near Gillette and/or the south PRB entrance near Douglas are strong locations to initiate Wyoming's LNG infrastructure build out. The two Class I railroads, UP and BNSF, appear to be well incentivized to gradually move their U.S. rail operations towards LNG, and they share 106 miles of track in Wyoming to serve 13 active PRB coal mines. While it is unknown if either railroad considers their Wyoming coal train operations to be high on the list for early adoption, it must be assumed that this is the case, given the significant contribution the coal industry makes to each railroad's annual revenues. If strategically located LNG liquefaction facilities can be built within Wyoming along major rail routes into the PRB, and can provide attractive economics, one or both railroads may choose to purchase LNG in Wyoming to meet some or all of their future potential needs in the region. Given the volumes of fuel consumed by the two leading Class I railroads and the cost-efficiencies gained by producing LNG as close to the wellhead as possible, there are strong incentives for the railroads to establish fuel contracts and facilities in Wyoming, which produces nine percent of America's natural gas.

Ultimately, traditional market forces will determine the development of LNG production in Wyoming to meet future potential demand from these HHP sectors. This process is believed to already be underway, at least on a preliminary basis. Based on Wyoming's current diesel-use volumes and patterns, sector-specific momentum and potential to switch from diesel to natural gas, and geographic synergy, it appears that the following numbers of mid-sized (100,000 GPD) LNG plants will / should be built in Wyoming over the next one-to-two decades, in the following general locations:

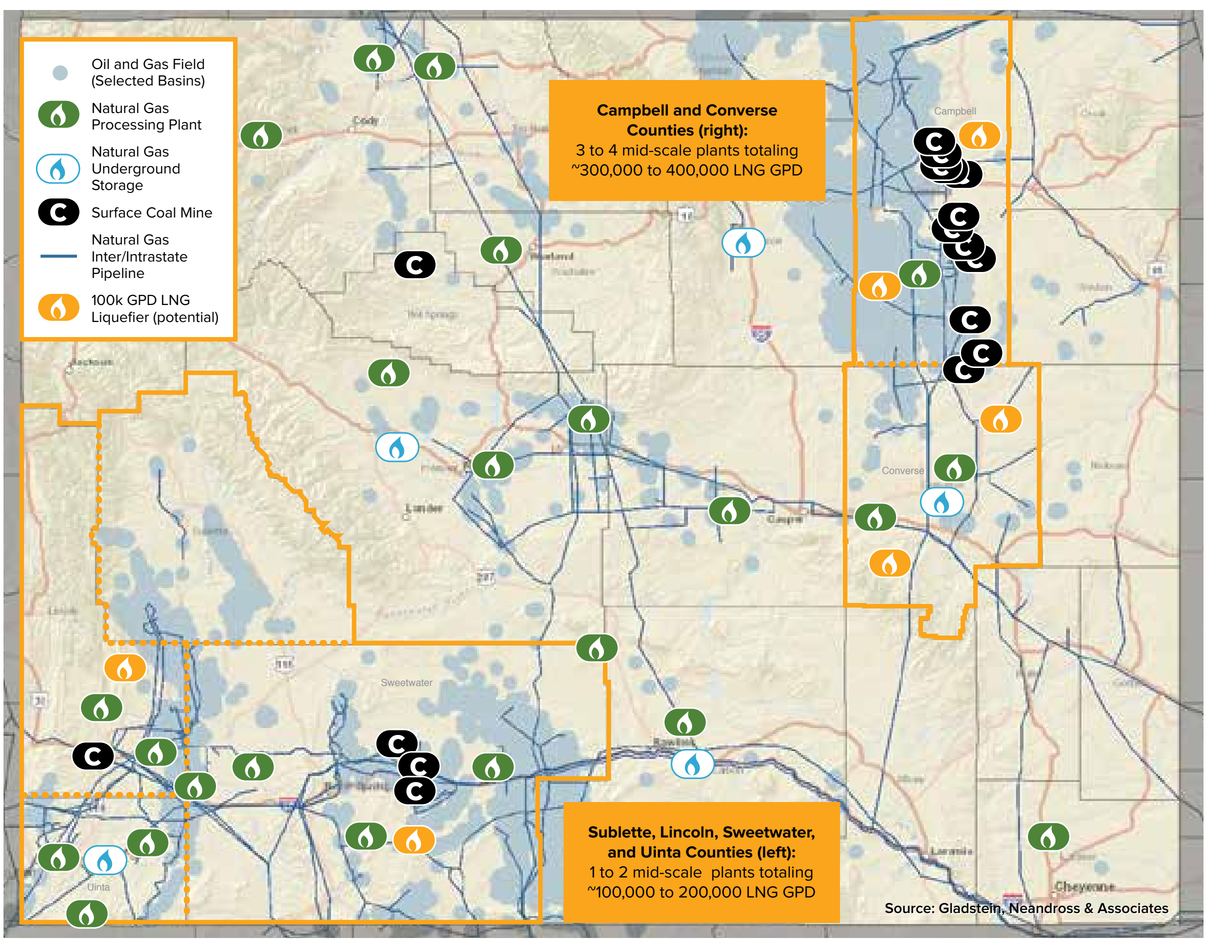
1. Three (3) to four (4) in the greater PRB region of Campbell and Converse Counties

2. One (1) to two (2) in southwestern Wyoming in the general region of Sublette, Lincoln, Sweetwater and Uinta Counties

Strictly for illustrative purposes, Figure 49 provides a preliminary map where mid-scale liquefaction plants might be (roughly) located to best serve Wyoming's needs in the initial LNG build-out plan. The map includes locations of energy production sites and Wyoming's existing energy infrastructure. Collectively, these mid-sized LNG plants can serve multiple customers and industries in Wyoming—mining, rail, E&P and on-road trucking. Multiple LNG plants will provide redundancy for end-users and back-up supply options amongst the producers. Of course, exact locations can only be determined by the LNG industry, accounting for many factors that include land availability and prices, potential to co-locate with existing gas-processing plants, proximity to other infrastructure, local permitting requirements, etc.

There also appears to be opportunity to deploy micro-scale (e.g., 5,000 to 10,000 GPD) LNG plants in Wyoming's more remote locations. These portable systems can meet the needs of smaller-scale LNG users such as PRB coal mines that seek alternatives to trucking in LNG from centralized liquefaction plants. Such deployments, which appear to be under discussion now among some LNG providers and potential end users, are (and will continue) being driven by market forces and individual customer demand.

Figure 49. Example locations for 100k GPD LNG liquefiers to meet local Wyoming demand



8. UNCERTAINTIES, CHALLENGES, BARRIERS, AND RISKS

This section briefly summarizes the known or anticipated uncertainties, challenges, barriers and risks associated with a potential large-scale shift of Wyoming's HHP sectors to operate on natural gas, where feasible. General categories of uncertainty or potential risk that could impact end users in all six sectors include 1) availability of commercially viable products, 2) cost of capital investments, 3) future price of natural gas relative to diesel; 4) reliability and sustainability of fuel supply; 5) engine performance (durability, reliability, fuel efficiency) in real-world operations; 6) safety and training needs; and 7) warranty provisions.

Examples of some sector-specific uncertainties and risks are briefly discussed below. Consistent with the "feasibility factors" previously discussed, the focus in on mine haul trucks, locomotives and E&P operations (drill rigs and PPS); these sectors face clear Wyoming-specific challenges, barriers and risks. Challenges for the on-road heavy-duty truck sector are largely being addressed at a national level, either through the "corridor model" for line-haul trucking or through national E&P companies like Encana, as they deploy natural gas trucks to support drilling and fracking operations. The Other Large Off-Road Vehicles and Equipment sector is not yet far along to discuss specific issues.

8.1. MINING SECTOR

Individual companies that make up Wyoming's coal mining industry are focused on reducing costs and managing economic risk. These companies are cautious about making large capital investments in technologies and fuels that might not prove to be sustainable, or could become "stranded" investments. The highly competitive coal mining industry in Wyoming operates on very small margins. Individual companies strive to minimize costs per ton of coal produced; saving even a few pennies per ton can make a major difference in profitability.[146]

Large mine haul trucks are massive, expensive and unique vehicles that operate under very rigorous off-road duty cycles. Their diesel engines provide excellent performance, power, reliability, durability, fuel efficiency, and rapid refueling time. Diesel fuel tanks carry enough energy for multiple shift operation between refueling events, and they fit on the chassis of mine haul trucks in a relatively small space. Despite their very large size, mine haul trucks have very little extra space for adding large cryogenic tanks needed to store LNG.

Given all these factors and others, Wyoming's coal companies have a general "fear of the unknown" about switching from diesel to natural gas, as is the case in most industries where significant change occurs. Specific concerns that have been expressed include engine performance, reliability and durability; fuel system placement on the vehicle chassis; OEM support and warranty; future fuel costs; and ability to achieve a simple payback within prescribed times.[147] Wyoming coal mine operators are particularly concerned about making large commitments to a new fuel like LNG if it precludes or hinders them from switching back to diesel operation, should the need arise for any reason.

[146] This point was reinforced at the HHP Summit (September 2013) by executives from two major PRB coal operations.

[147] Personal communication to GNA from general manager of a major PRB coal mine, September 2013.

8.2. RAIL SECTOR

According to an executive from a major locomotive manufacturer, progress towards commercialization of natural gas locomotives is rapidly advancing. However, there are many variables "that still need to be quantified," and "it will take several years to evaluate/quantify the potential benefits of LNG use in rail operations."[148] In general, the locomotive manufacturers and their customers, the North American

[148] Locomotive manufacturer representative, "paraphrased" by a Class I railroad executive during personal communication to GNA, December 2013.

railroads, are "cautiously optimistic" about the potential to gradually significantly shift over from diesel to natural gas locomotives for the most-conducive operations.

However, transitioning to natural gas in the rail sector may be more complex than in the cases of "captive-service" sectors like mining and E&P, due to the nature of interstate rail operations. The industry cites numerous specific hurdles, risks and challenges that must be addressed before mainstream use of natural gas locomotives; many of these are "unknown outside of the rail industry."[149] Examples provided by industry representatives are listed below.

[149] Personal communication to GNA from an executive of a major Class I railroad, December 2013.

The below examples refer to general deployment of LNG locomotives in the U.S. Additional barriers and challenges may exist for switching Wyoming's PRB coal locomotives to LNG. If Wyoming coal trains are prioritized by BNSF and/or UP for conversion to LNG, significant uncertainty exists about the likelihood that they will be refueled with LNG in Wyoming. According to a Class I railroad executive, "LNG fueling in Wyoming for rail would require a dramatic shift in fleet/operational strategy, significant fleet modifications, underutilization of existing diesel fueling facilities, and massive development of new LNG infrastructure."[150]

[150] Ibid.

Table 32. Challenges and concerns cited by locomotive / rail industry representatives

Categories	Barriers / Challenges / Concerns About Transitioning to Natural Gas Locomotives
Economic Implications	• Long-term price spread between diesel and LNG • "Other complex economic factors" including train delay, crew time, LNG transportation costs, potential additional trackage or access points needed to re-fuel tenders, training, safety equipment, and maintenance requirements
Operational Issues	• Potential train delay resulting from fueling and servicing of locomotives • Possible new variables introduced by LNG that must be factored into design and day-to-day operations (maintenance for added equipment, use on lines without readily available LNG supply, reconciliation of crew change points, route optimization)
LNG Engine Technology	• Uncertainty about performance, cost, substitution rates, warranty implications and responsibilities (in the case of conversion systems), how to transition from conversion approaches to OEM systems
Tender Cars	• Uncertainty about cost • Interface with locomotives • Location of fueling point on existing major freight corridor at or near existing locomotive servicing facility • Emerging codes and standards
Safety	• Worker exposure requirements • Training for "hazmat" responders • Emergency preparedness for communities along routes served by LNG-fueled locomotives • FRA's requirement for safety contingency plans • Publicity: recent fuel-related rail accidents
LNG Supply	• Sufficient supply and quality • Location of liquefaction plant near point on rail system where tender cars will be fueled
Environmental Impacts	• Regulatory uncertainty (e.g., methane leakage rates) • Potential unintended consequences of moving into new fuels and technologies

Source: Presentations by and personal communications from representatives from locomotive manufacturers and Class I railroads

8.3. E&P SECTOR

The E&P sector is among the leaders for adoption of natural gas (field gas, CNG, and LNG) in high horsepower sectors. LNG-powered drill rigs are in the early commercialization stage, while PPS operations using LNG are in a pre-commercialization stage. While there are many logistical and engineering issues to work out, the only major barrier for expanded and sustainable use of LNG in E&P applications appears to be its economic competitiveness compared to using field gas or CNG. For example, the economics of powering drill rigs and PPS operations with field gas are significantly better than using LNG—as long as field gas of sufficient quality is available at the site. LNG will generally not be an economically viable choice (even compared to diesel) if the LNG supply is not close enough to the site to minimize transportation costs.

9. ANTICIPATED STATE BENEFITS

Very significant direct and peripheral benefits for the citizens of Wyoming can result from a systematic, phased build-out of Wyoming's LNG fueling infrastructure in tandem with gradual deployments of HHP natural gas vehicles and equipment. These statewide benefits are expected to include annual fuel savings (as described, an estimated $166 million per year); significant economic investments in large high-tech infrastructure projects; short-term and long-term creation of good-paying high-tech jobs; environmental improvements; educational programs that will train "the workforce of tomorrow;" and additional revenue for the state.

Detailed estimates for the various benefits that may accrue to the State of Wyoming are beyond the scope of this report. General discussion is provided below about the potential types and magnitude of benefits that may result from the build-out of the Wyoming HHP LNG sector.

9.1. JOB CREATION

Table 33. Estimated fuel savings, costs, and job creation for initial Wyoming LNG build-out

Total Annual Fuel Savings to Equipment Operators	$166,000,000
Annual Diesel Displaced (gallons per year)	108,100,000
LNG Infrastructure Spending for 509,000 GPD System (CapEX)	$333,800,000
Ongoing Annual Costs for Natural Gas Equipment Operation & Maintenance (OpEx)	$10,400,000
Estimated Full Time Employees (FTEs) Supported by CapEx and OpEx	**4,760**

Table 33 summarizes the estimated fuel savings, infrastructure spending, ongoing annual costs, and full time employees (FTE) that will be associated with the gradual LNG infrastructure build-out in Wyoming. As shown, an estimated 4,760 FTEs will be needed to support build-out and ongoing operation of Wyoming's initial LNG infrastructure build-out costing about $334 million.

This job creation scenario is calculated by applying a factor of 13.829 jobs for $1 million of estimated capital expenses (CapEx) and operational expenses (OpEx) required for to build out a 509,000 LNG gallon per day LNG production and supply chain in the State of Wyoming.[151] This factor includes direct and indirect jobs, but not induced job creation.[152]

It must be emphasized that these jobs will be gradually created over the full course of the Wyoming LNG infrastructure build out, which is estimated to entail ten to twenty years. In addition, some new jobs will likely be offset by loss of jobs that currently exist for the petroleum fuel industry, within and/or outside of Wyoming.

Based strictly on the estimated LNG fuel consumption in each sector (from Section 5.2), these job creation benefits (direct and indirect) will roughly be distributed as follows: mining (2,307 FTEs, or 48 percent), rail (2,096 FTEs, or 44 percent) and E&P operations (357 FTEs, or 8 percent). However, it must be emphasized that such estimates are inherently speculative.

It is expected that jobs associated with Wyoming's LNG infrastructure build-out will generally involve good pay. For example, building LNG plants and fueling facilities will require engineering resources, concrete suppliers, electrical contractors, pipefitters, welders, steelworkers and general contracting services. The range of jobs involved in a station construction project include: specification engineer, estimator, bid writer, project manager, purchasing agent, design engineer, drafter, cryogenic engineer, plan checker,

[151] Heintz, J., Pollin, R., and Garrett-Peltier, H., "How Infrastructure Investments Support the U.S. Economy: Employment, Productivity and Growth," Political Economy Research Institute report for the Alliance for American Manufacturing, January 2009.

[152] Direct jobs relate directly to construction activity; this would include construction workers, inspectors, etc. Indirect jobs support the project in some way; for example, LNG tank manufacturing or supplying steel to the tank manufacturer. Induced jobs are created due to the overall increase in economic activity, e.g., income spent elsewhere in the economy.

site foreman, equipment operator, laborer, electrician, electrician helper, mechanic, mechanic helper, carpenter, pipe fitter and administrative support. According to the U.S. Bureau of Labor Statistics, Wyoming wages are among the highest in the nation for some of these job types. U.S. Table 34 provides examples of potentially relevant existing job categories and their annual mean wages in Wyoming.[153]

[153] U.S. Bureau of Labor Statistics, May 2012 State Occupational Employment and Wage Estimates, Wyoming, http://www.bls.gov/bls/blswage.htm.

Table 34. Relevant existing job categories and annual mean wages in Wyoming

Existing Wyoming Job Category	Annual Mean Wage
Civil Engineers	$82,720
Environmental Engineers	$82,720
Electrical and Electronics Repairers, Powerhouse, Substation, and Relay	$78,610
Bus and Truck Mechanics and Engine Specialists	$54,710
Mobile Heavy Equipment Mechanics	$53,210
Electric Motor, Power Tool, and Related Repairer	$49,400
Installation, Maintenance and Repair Occupations	$48,950
Welders, Cutters, Solderers, and Brazers	$48,130
Automotive Service Technicians and Mechanics	$40,360
Heavy-Duty Trailer Truck Drivers	$40,960
Source: U.S. Bureau of Labor Statistics, http://www.bls.gov/oes/current/oes_wy.htm	

9.2. AIR QUALITY AND ENVIRONMENTAL IMPROVEMENTS

As described, Wyoming air quality is generally among the most pristine found in any lower 48 state. However, intense energy production, processing and transport brings air quality problems, as has been the case in certain Wyoming counties. The primary direct source is combustion of fossil fuels, especially in heavy-duty diesel engines that power Wyoming's energy economy.

There are many issues that make it challenging to estimate the potential air quality benefits of using natural gas in Wyoming's key HHP sectors. The biggest issue that precludes this (in a report of this nature) is the lack of detailed inventories for existing (baseline) diesel sources, which makes it impossible to set baseline emissions and also brings uncertainty about the optimal natural gas alternatives (e.g., combustion technology choice, fuel substitution rate, source and/or type of natural gas fuel).

Despite this current inherent difficulty in quantifying benefits, there is good reason to believe that the magnitude of reductions for both criteria pollutants (NOx, PM and others) and greenhouse gases (primarily CO_2) will be significant. As noted, today's on-road heavy-duty natural gas vehicles achieve the benchmark for low NOx and PM emissions, and significant evidence exists that their full fuel cycle emissions of greenhouse gases are also lower than comparable diesel engines. In the E&P sector, many companies are documenting major reductions of NOx, PM and reactive hydrocarbons by using field gas, LNG or CNG to power drill rigs and frack pumps. Emissions reductions are also expected to be realized with mine haul trucks and locomotive that operate on LNG, especially with high substitution rates achievable with the Westport HPDI technology.

However, actual air quality benefits associated with any transition to natural gas in HHP vehicles and equipment would need to be assessed over time, on a sector-by-sector basis, taking into account all important parameters for each type of deployment. Also, it must be emphasized that the air quality "baseline" will continually change. Through natural fleet turnover combined with new regulations becoming effective, the emissions performance of in-use diesel engines that power these sectors will continue to improve. Of particular importance is the fact that new engines in off-road sectors such as mining and rail will soon meet federal Tier IV emissions standards, which entail stringent NOx and PM levels.

9.3. EXPANSION OF EDUCATION AND TRAINING PROGRAMS

New business and job opportunities associated with Wyoming's LNG Roadmap implementation will require development, expansion, or enhancement of the state's existing educational and professional training programs. Through his "Leading the Charge" action plan (May 2013), Governor Mead has already laid out strategies for achieving complex, interrelated goals involving energy, environment, economy, and education in Wyoming. He has recognized that planning and implementing Wyoming's LNG Roadmap entails new opportunities—and challenges—to train larger numbers of the skilled workers who can design, fabricate, permit, install, and operate all types of equipment described in this report. Through systematic planning, Wyoming has opportunity to transition its excellent statewide academic system towards becoming a world leader in curriculum and programs that support wide-scale use of clean, domestically produced natural gas in HHP engine applications. While the focus of this report is on the development of an LNG roadmap within the State of Wyoming, it is recognized that the growth of the LNG HHP sector will also be occurring at a rapid pace beyond the state's borders; thus providing a significant job placement opportunities for those educated and trained within Wyoming's educational institutions.

These efforts will likely be led by the University of Wyoming, which provides high quality undergraduate and graduate programs to 13,800 students from all 50 states and 94 countries. UW is a nationally recognized research institution offering 200 areas of study, with accomplished faculty and world-class facilities. One example of a relevant existing educational curriculum that could lead the U.S. in clean natural gas technologies is the UW Wyoming Technology Business Center, which focuses on developing early stage, technology-based companies, with an emphasis on high-growth firms.[154] Many other areas of academic excellence at UW—including engineering programs across all disciplines—will be able to take advantage of new and emerging opportunities associated with clean energy technologies.

There are numerous examples of how Wyoming's higher education system is already integrated into the state's energy economy, including partnerships with industry stakeholders that help train and employ the state's workforce. For example, Anadarko Petroleum has partnered with the University of Wyoming to recruit qualified graduates, and support academic and athletic programs. According to Anadarko, it contributes towards energy research that benefits the state's educational system and workers.[155] These are the types of relationships that can be created (or augmented) with a focus on Wyoming's emerging LNG industry.

Table 35 lists Wyoming's higher education institutions and provides examples (of many) existing curriculum that could be expanded or enhanced to focus on LNG Roadmap-related technologies, services, processes, and products. As shown, Wyoming's LNG build-out program can also bring opportunity for new coursework at the community college level. In fact, this could be extended down into high school and vocational school curriculum.

The continued growth of natural gas powered HHP equipment throughout Wyoming's economy will offer the state's educational system an unparalleled opportunity to provide real-world in-the-field training to students at various levels. Existing LNG production plants, LNG mine haul trucks, refueling stations and supply chain infrastructure, and related projects can be linked to Wyoming's energy-focused educational system to serve as the world's leading field laboratory. The cutting-edge nature of the development of the natural gas powered HHP sector will provide the state with a unique opportunity to train the workforce that will be required to continue to grow and mature this rapidly developing and exciting new energy-economy.

[154] University of Wyoming, Wyoming Technology Business Center, http://www.uwyo.edu/wtbc/.

[155] Anadarko Petroleum, "Wyoming Fact Sheet 2013, www.anadarko.com.

Table 35. Wyoming's higher education institutions and examples of relevant curriculum

Wyoming Educational Institution	Examples of Relevant Existing Educational Curriculum
University of Wyoming	• Wyoming Technology Business Center • Engineering (all disciplines) • Energy Resource Management and Development
Casper College	• School of Business and Industry, Construction Technology • School of Science, Extractive Resources Technology
Central Wyoming College	• Facilities Maintenance Technology • Automotive Technology
Eastern Wyoming College	• Welding & Joining Technology • Machine Tool Technology
Laramie County Community College	• Engineering Technology: Drafting & Design / Welding
Northwest Wyoming College	• Advanced Welding • Mathematics • Robotics Technology
Sheridan College	• Computer Aided Design • Diesel Technology • Environmental Engineering
Western Wyoming Community College	• Diesel & Heavy Equipment Mechanics • Business & Computing
Source: websites of individual academic institutions	

10. RECOMMENDED STATE ACTIONS

With strong leadership and encouragement from Governor Mead and various state agencies, market forces are moving Wyoming forward to use large volumes of natural gas (LNG in particular) in the six HHP sectors described in this report. Industry will continue to lead this effort, but the state of Wyoming wishes to continue assisting in the most meaningful ways that can accelerate the pace of progress. This section discusses recommendations that were provided by industry leaders themselves about how the state can help, followed by six recommendations provided by the authors that feed and expand on these ideas.

10.1. SOLICITED INPUT FROM INDUSTRY STAKEHOLDERS

In September 2013, the Governor convened a meeting of leaders from companies and organizations that hold a significant stake in Wyoming's energy future. The objective was to solicit input about how the State can help private industry to develop, commercialize and/or deploy the products and processes needed to achieve the Governor's vision for Wyoming's expanded use of natural gas. The Governor described his general philosophy about reducing Wyoming's standard budget, cutting the size of government, and streamlining state regulations. He asked the participants about actions that the state can take—with minimal or no fiscal impact—that can help Wyoming systematically move towards build-out of an LNG Roadmap as described in this report. Table 36 summarizes input received by the Governor at the meeting.

10.2. RECOMMENDATIONS DERIVED FROM THE ROADMAP STUDY

Via the input received from various industry stakeholders throughout the development of this report, numerous core recommendations have emerged that are thought to have the greatest potential to advance the goals and vision of the Wyoming LNG Roadmap Report. Generally, these recommendations are put forth for consideration by Governor Matt Mead and the State of Wyoming. However, to successfully implement these recommendations, it will be important for the leadership of other stakeholders, in both the public and private sectors, to also play leading roles.

1. **Siting of LNG Production** – Using basic screening criteria (gas pipeline and electrical utility availability, available real estate, access to distribution networks, near to points of use, etc.), Wyoming officials can evaluate potential locations where LNG production facilities can be located to produce and cost-effectively deliver approximately 500,000 GPD of LNG in Wyoming within three to five years. Such an assessment will help to facilitate the identification of possible locations where suitable LNG production assets can be located in order to support the implementation of the roadmap concept. The Wyoming Business Council and Wyoming Pipeline Authority are likely well suited to assist in the implementation of such an analysis.

2. **Policies and Programs** – State officials and stakeholder can evaluate existing or potential policies and programs that are designed to support the state's robust energy economy, to determine if and how they could be expanded to assist the further proliferation and build-out of the expanding LNG industry in Wyoming. Governor Mead, the state legislature, and the Wyoming Business Council, among others, are all likely well positioned to complete such an analysis and also identify potential relevant opportunities and next steps.

3. **Weights, Measures and Taxation** – State officials can use available resources to help remove existing impediments to LNG growth; examples of such barriers include: a) the federal highway excise tax on diesel and LNG is set on a volumetric basis, which taxes LNG at a 70 percent higher rate than diesel on an energy equivalent basis,[156] b) off-road diesel fuel is not subject to highway taxes; to avoid a significant price penalty against using LNG in off-road applications, it will need to be taxed comparably; c) weight limits for on-road trucks can reduce the payload of LNG-fueled trucks; and d) restrictions on hauling LNG by rail can limit locomotive deployments.

[156] As of January 2014, efforts are underway by the steering committee of the National Conference on Weights and Measures to standardize LNG on a DGE (diesel gallon equivalent) basis, primarily to address this issue of over-taxation.

Table 36. Input received at Gov. Mead's Wyoming LNG industry stakeholder meeting, 2013

Summarized comments received from industry leaders, by topic
TAXATION / WEIGHTS & MEASURES • LNG is taxed by volume instead of its energy content. This overtaxes LNG (compared to diesel) by a factor of about 1.7. Wyoming can help encourage the federal government to change this. • The federal excise tax on heavy-duty trucks has a disproportionate impact on end users that choose LNG, because LNG vehicles already entail high incremental cost. Wyoming can help encourage the federal government to change this. • The tax implications of using in-state vs. out-of-state LNG need to be assessed and made clear to LNG user fleets. • Diesel fuel used in off-road applications is not subject to state and federal excise taxes applied to retail sales of on-road diesel fuel (i.e., diesel sold for vehicles generally operating on public roadways). This reduces the price of off-road diesel by about 13 percent, relative to on-road diesel. LNG for off-road uses should be taxed comparably, to avoid a significant price penalty against using LNG in off-road applications.
REGULATIONS • Wyoming should strike a balance with permitting and regulatory requirements as it adopts regulations affecting natural gas infrastructure • Wyoming can help mediate and improve significant, unpredictable differences between how federal, state, and local authorities apply codes and standards • To offset heavy on-board fuel storage systems, Wyoming should allow LNG-fueled on-road trucks to carry additional weight (e.g., an extra 2,000 lbs). Some other states have already done this. • Class I railroads cross multiple state lines and must comply with many federal and state regulations. If LNG on rail is to work, regulations must be cost effective, user friendly and harmonized. • Railroads face restrictions for use of locomotives based on weight and other factors. This may cause problems when switching to LNG tender cars. Wyoming should help encourage the federal government to adopt balanced requirements that provide safety without discouraging use of LNG. • Rail shipments of fuel have gotten even more difficult due to recent accidents in Quebec, North Dakota, etc. Further regulation is not needed, however. Wyoming can help emphasize how infrequent such accidents are, and how the industry is working towards zero incidents. • Wyoming can help provide clarity and harmonization of regulations for manufacturers. For example, dual-fuel kits are largely unregulated, and there is regulatory uncertainty about what will come next. This can slow down LNG adoption rates. • Wyoming can help ensure that fire codes and other regulations that apply to the E&P industry do not discourage switching to natural gas. For example, regulations can make it difficult to supply LNG to drill rigs, make connections on drill pads, etc.
TRAINING AND EDUCATIONAL PROGRAMS • Wyoming can develop training and education programs, which are essential to help end users and stakeholders safely and properly use emerging technologies and new fuels like LNG. • Wyoming can develop standardized training programs for local officials, to help ensure that requirements are enforced in uniform fashion • Wyoming can help educate potential end users about special programs and options. For example, there are financing options for specialized maintenance bays.
ENVIRONMENTAL BENEFITS • Wyoming can champion the environmental benefits of natural gas to help potential end users embrace adoption • Wyoming can help "monetize" environmental benefits of natural gas

4. **Codes, Standards and Regulations** – Given the lack of wide scale market penetration, there is an overall lack of experience in reviewing, permitting and approving new LNG production, storage and dispensing operations. Consequently, there is a need to plan and implement educational and instructional sessions for federal, state and/or local personnel involved with codes, standards and regulations related to such supply chain infrastructure. The Governor's office, working with the state fire marshal's office, the state's education systems, and/or other relevant state agencies can develop and implement such education and training curriculum for relevant stakeholders. This can take place via the assembly and distribution of written materials, online resources, information sessions and stakeholder meetings, and other such means.

5. **Advanced Educational Programs** – Via a continued focus on the development of Wyoming's world-class energy-focused educational system, the state of Wyoming can work with stakeholders and end users to identify advanced educational development opportunities focused on training an LNG-ready workforce for Wyoming, the U.S., and the world. Through the identification of key educational and job-training needs, the state will be able to develop the curriculum within its university, community colleges, vocational and trade school, and even at the high school level to train this high-tech workforce for good paying jobs. The existing and developing LNG projects throughout Wyoming can be leveraged as some of the world's leading field laboratories that provide highly valuable hands-on learning and training as part of the curriculum development. With an existing focus on developing such educational opportunities, Governor Mead can continue to play a leadership role in this arena.

6. **Expanded Pilot Programs** – Additional opportunities can be identified to facilitate the further development and expansion of existing LNG pilot demonstration programs in Wyoming's various HHP sectors, and to find opportunities where entirely new LNG deployment projects can be initiated. Such proliferation of the use of natural gas HHP technologies will not only widen the knowledge base for end users and educational programs, and thus feed into many of the recommendations above, but will also continue to increase LNG demand within the state, which will subsequently attract the natural gas market forces of the LNG supply industry and venture capitalists. The identification of such growth opportunities will result from consistent ongoing dialogue among the key stakeholders within the state, including the Governor's office, the Wyoming Business Council, the Wyoming Mining Authority, the Wyoming Pipeline Authority, large individual end-users (i.e. the mining companies, railroads, and E&P companies), and associated industry associations. Such dialogue can be facilitated by the organization of an annual stakeholder summit, as noted in the following recommendation.

7. **Goal-Oriented Annual Progress Updates** – To maintain continued active dialogue and monitor progress versus goals and milestones, an annual Wyoming LNG Stakeholder Summit can be planned in targeted regions of the state. This summit will provide an opportunity to provide updates and reports on ongoing and new demonstration projects, LNG fuel supply options, the latest technologies, new policies, regulations, educational opportunities and related topics, helping to continue advancing the goals of the Wyoming LNG Roadmap Report. Wyoming's initial annual event could include a Development and Deployment Strategy Workshop similar to those periodically conducted by the U.S. Department of Energy.

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