



# **Distributed Production of Fuels & Chemicals from Stranded Natural Gas**

Techno-Economic Assessment of Wyoming Stranded Gas Processing

**Draft Final Report  
August 17, 2012**

Prepared for

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### **EXECUTIVE SUMMARY**

In the Sixty-First Legislature of the State of Wyoming 2012 Budget Session House Bill No. 0121, Enrolled Act No. 25, House of Representatives was passed by the full Legislature and signed into law by Governor Mead. This legislation authorized studies to identify:

- Whether a commercial scale facility which converts minerals to value added products would be economically viable in Wyoming given projected energy prices and regulatory trends;
- Attributes unique to the state of Wyoming which mitigate for and against construction of a commercial scale minerals to value added products facility in the state;
- The best available technologies for the commercial scale conversion of minerals to value added products in Wyoming;
- Potential obstacles to the construction of a minerals to value added products facility in Wyoming and possible strategies to address those obstacles, including, but not limited to the following:
  - Regional and national political climate;
  - Economic issues;
  - Regulatory issues; and
  - Transportation.
- Potential input sources of minerals and water for the facility and potential markets for the final value added product and any other products created during the conversion process; and
- Whether, and at what level and in what form, state support is necessary for the development of such a project. The study shall identify possible state incentives available for the construction of commercial scale minerals to value added products facility and determine which incentives are likely to have the most benefit to industry and the citizens of the state of Wyoming.

Western Research Institute (WRI) proposed a techno-economic assessment of Wyoming's stranded natural gas resource emphasizing technologies to convert gas into liquid transportation fuels and chemicals such as gasoline, diesel and olefins. The results of the assessment are presented in this report.

In previous studies, economy-of-scale considerations have dictated that gas-to-liquid (GTL) facilities must become quite large with capital investments approaching several billion dollars. However, recent technological developments in catalysts and smaller, more efficient modular reactors make thermo-chemical conversion of natural gas into fungible fuels and chemicals an attractive option for monetizing Wyoming's stranded natural gas resources even at a smaller scale. Advancements in control systems make remote management of distributed modular plants possible from a central facility. Similarly, a central facility can service modular synthesis reactors and gas clean-up modules. These and other similar concepts and strategies make distributed GTL

conversion possible in remote locations such as conversion at the point of production into an easily transportable, value added, and marketable commodity.

A team of WRI scientists and engineers was assembled to conceptualize a reference GTL plant to produce gasoline from natural gas, and to identify potential candidate sites. Process simulations were conducted to establish key inputs such as water requirements, and to quantify solids and gaseous emissions and effluents. Vendors were solicited for budgetary price quotes, allowing capital cost to be estimated. The operational needs of the plant and costs for those needs were estimated based on information from industry contacts, so that annual production cost could be estimated. Finally, the body of published information including the Energy Information Administration’s reports was consulted for views on the economic outlook of the proposed facility. In order to address the issues of interest to the Wyoming legislature, WRI engaged Associated Legal Group, LLC to address legal issues pertaining to the distributed deployment of the GTL technology. A refinery expert was also engaged to assist with product evaluation and product market assessment for completing a process economic evaluation.

The proposed plant configuration is a compact, modular process that can be assembled at a fabrication shop and delivered to a natural gas field requiring minimal field assembly. Conversion is carried out without expensive oxygen and with minimal water consumption. Advanced controls allow remote operations and process control of a single or distributed set of units by a remotely monitored, semi-automatic control station to produce and store the product. Modular design will also allow field replacement of components such as desulfurization modules and reactor modules. Refurbishing of gas clean-up modules and catalyst reloading/regeneration is similarly affected in central facilities. Small modular units reduce manufacturing costs and provide scalability.

For this study, the term Wyoming Stranded Gas Process (WYSG) refers to gas-to-liquid technology that converts natural gas into a gasoline product. By selecting gasoline as a GTL product we do not intend to overlook that similar concepts apply to conversion of natural gas into a diesel product, mixed alcohols or other chemicals. In the most part, the modularization concepts and related scale-up considerations, permitting requirements and other items are equally valid for nearly all the value added products possible displayed in Figure 1. A reference plant size of 150 bbl/d capacity was arbitrarily selected representing a size suited for a small production facility.

WYSG process involves three basic steps:

- Reforming of natural gas to syngas
- Conversion of the syngas into methanol (STM)
- Methanol transformation to gasoline (MTG)

All of these conversion steps are catalyzed reactions that have been commercially available in different forms for decades.

Stranded gas is described as natural gas reserves that are impeded from getting to market by either

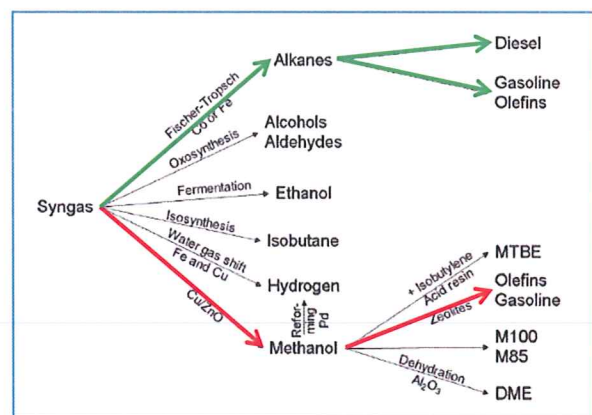


Figure 1 Conversion Pathways

physical or economic hurdles. These hurdles can vary from one well to the next. With the local price of natural gas at around \$2.00/Mscf, all of Wyoming's natural gas could be considered economically stranded.

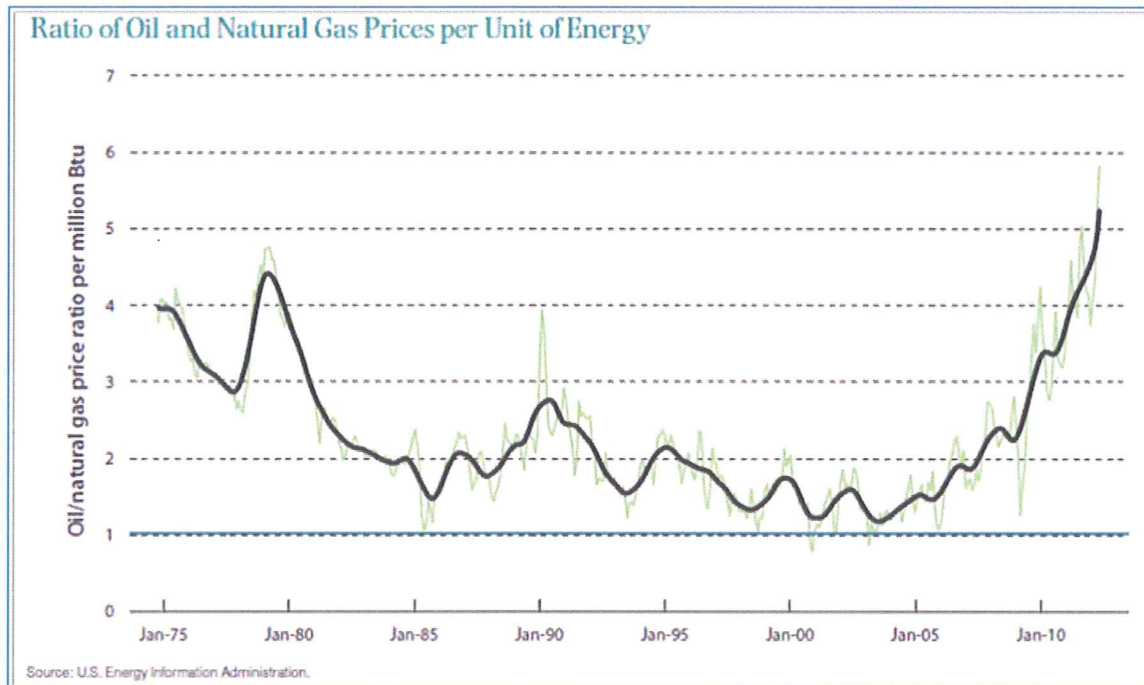


Figure 2 Historical Price Ratios for Oil and Natural Gas

For the last thirty years the price of natural gas and the price of crude oil have been linked. As shown in Figure 2, over the last two years the linkage between the two prices appears to have been broken. A very large percentage of crude oil is used to make fuel for the transportation sector, and the transportation sector makes no significant use of natural gas for fuel. The nationwide natural gas production in 2011 was nearly 12 percent above the 2009 level, and a record production is expected in 2012 and beyond. These large increases in supply are the main reason that natural gas prices have fallen to such lows. As the consumer market takes note of the large price differential between natural gas and fuels derived from crude oil, demand for natural gas will likely increase. However, factors such as increased shale gas, associated natural gas, and coal bed natural gas production will likely keep the prices low into the foreseeable future. Lower gas prices represent a major incentive for WYSG-like GTL conversion into transportation fuels.

A simple block flow diagram of the nominal 150 bpd gasoline WYSG process is depicted in Figure 3. The final product can be sent to refineries. Following sulfur removal, the three conversion steps are catalyzed reactions that have been commercially available in different forms for decades. For each of these three steps there are various choices available in regard to equipment and catalysts, and some technologies are better suited than others to the conditions that will be prevalent at remote natural gas wells. As a part of the study, many decisions were made to exclude various pieces of equipment that are typically included in the design of larger plants. These decisions were made for the sake of minimizing capital cost and facility footprint, two constraints that have the potential to

limit the practical application of this type of plant. Two notable exclusions included eliminating the use of oxygen for reforming and forgoing recycle of unconverted syngas. Unconverted syngas is instead used as a fuel to process a steam-methane reformer.

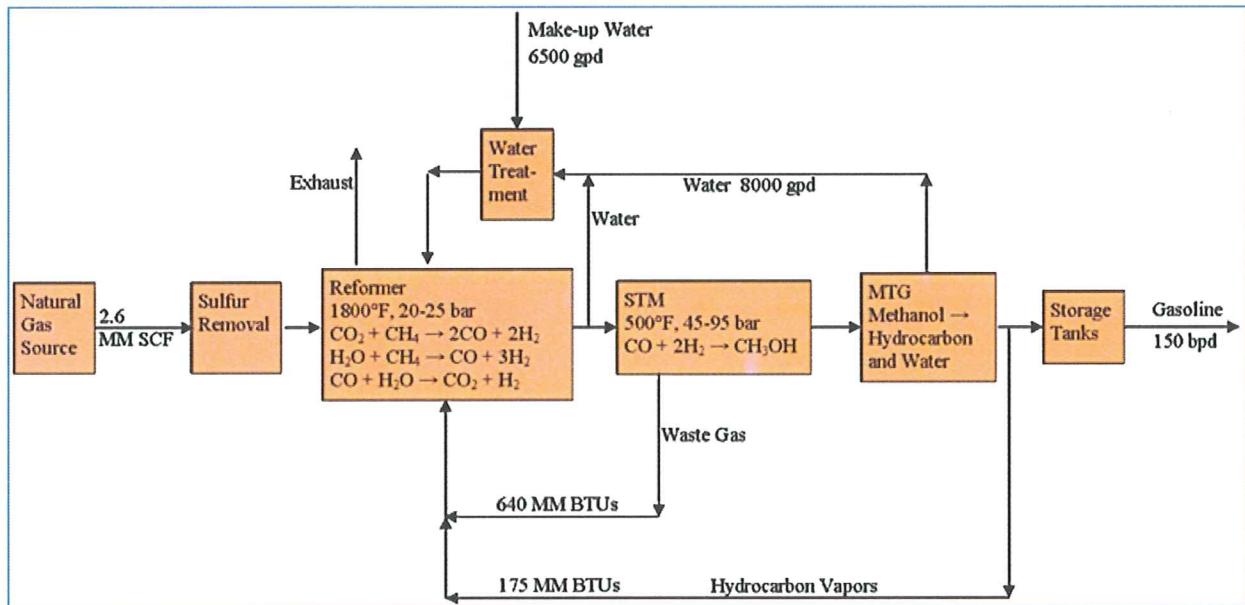


Figure 3 A schematic of proposed WYSG process

Water and natural gas are the main inputs to this process. The water is used to make steam, which is combined with the natural gas in the reforming step to produce syngas (CO and H<sub>2</sub>). Pure oxygen or carbon dioxide could be used in place of steam as a source of oxygen for the reforming step, but the associated costs are prohibitively large for this size of plant. Another advantage of steam-methane reforming is that any CO<sub>2</sub> present in the feed natural gas improves process efficiency. Steam-methane reforming results in a syngas composition with a H<sub>2</sub>/CO ratio around 4 to 1. The ideal ratio for subsequent synthesis is around 2 to 1. Therefore the WYSG process has excess hydrogen which is ultimately used as a fuel. As a result the process has a smaller carbon footprint than a conventional GTL plant.

Syngas is converted into methanol with 60 % carbon conversion efficiency in the syngas-to-methanol (STM) step. Unconverted syngas is separated from the methanol and used as part of the fuel mix to provide heat for the reforming step. Methanol is converted into gasoline, light hydrocarbons such as propane, and water in the methanol-to-gasoline (MTG) step. These three product phases are separated and put to different uses. The gasoline is the final product of the plant, and is stored in tanks and ultimately transported to the customers. Light hydrocarbons are used as another part of the fuel mix to provide heat for the reforming step. Water is recycled with fresh make-up water used to make steam for reforming.

The product of the WYSG plant is gasoline. Based on the composition description presented in Table 1, and the overall product characteristics displayed in Table 2, the WYSG product closely fits the refinery stream description of naphtha based on boiling range. Naphtha can be used as a feedstock for both gasoline manufacturing and petrochemicals depending on its quality, with light or

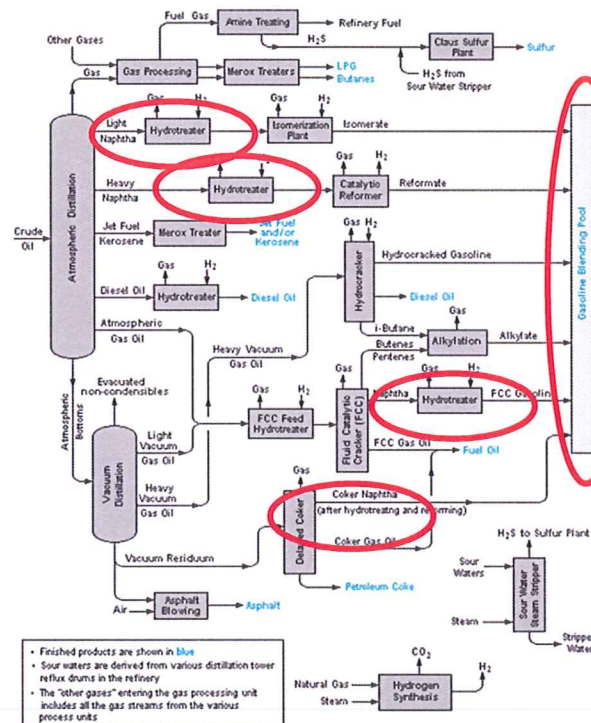
paraffinic naphtha usually used in petrochemical plants and heavy naphtha usually used in reformers at refineries to make gasoline. Figure 4 shows locations in a refinery (circled in red) where the WYSG product could be fed. The easiest refinery disposition is the final product blending whereby the WYSG product goes into the main gasoline blending tanks at the refinery. The most logical location to place the product is upstream of any naphtha hydrotreating unit (coker, FCC, pre-isomerization, pre-reformer). With this approach, any shortcomings with the product such as durenene content would be readily dealt with within the hydrotreater.

**Table 1. Typical product distillation**

Component	Vol%	TBP of C5+'s, Vol%	
		Dist (%)	T (F)
		IBP	87.6
Methane	0.75	10	111.0
Ethane	0.35	30	158.0
Propylene	0.30	50	205.4
Propane	4.20	70	266.3
Butylenes	1.50	90	336.6
Butane	11.20	95	359.1
C5+'s	81.70	98	377.8
		EBP	400.1

**Table 2. Expected product specifics**

C5+ Nonaromatics	51 wt%
Aromatics	49 wt%
Aromatics 6-10	98.7 wt% of total aromatics
A 11+ (includes n)	1.3 wt% of total aromatics
Durenene	2.5 wt%
Approximate RVP	12 psi
Approximate RON	92
Sulfur	0 ppm
Benzene	0.3 vol%



**Figure 4 Typical Refinery configuration (Source: AIChE refinery handbook)**

The WYSG product can be delivered to local refineries as an intermediate product stream in Wyoming (Frontier), Colorado (Suncor-Denver), and in Montana. Connacher in Montana – transports diluent to OilSands via rail (600 Bbl cars) to dilute bitumen for pipeline transport to refineries. A secondary disposition could be petrochemical operators such as ethylene producers (Exxon Joliet, Illinois).

The lowest value disposition for the WYSG product is as feed to a refiner's naphtha hydrotreater or directly to its naphtha reformer. Based on current WTI pricing of \$89/bbl, WYSG product price would be around \$94/bbl or \$5/bbl above WTI before discount/premium. As product grade naphtha for sale to OilSands diluent users the price would be \$98/bbl (+\$9/bbl above WTI). If the product directly is used directly in the gasoline blending pool the price will be \$112/bbl (+\$23/bbl).

Capital investment required for a WYSG plant with production capacity of 150 bpd is estimated to be in the \$20 to \$30 million range. Increasing the size of the plant to 500 bpd is expected to increase the fixed capital investment to about \$40 or \$50 million. We make an assumption that a high CO<sub>2</sub> natural gas could be obtained at a well site for less than pipeline prices. If the cost of carbon dioxide-laden natural gas is \$2.00 per thousand cubic feet and the selling price of WYSG product is \$106 per barrel, annual revenue would be just under \$16 million. The annual production cost would be just over \$11 million, and a \$40 million plant would be paid off in less than 9 years. After feedstock costs, labor costs are a major component of the production cost. Remote monitoring, controls and operations of several facilities from a central facility improve the process economics dramatically.

The basic siting requirements for the WYSG plant are availability of space, supply of natural gas, water, power and year round access. Natural gas requirements for the reference 150 bpd plant are around 3MMscf/d at a pressure about 20 psi. Water needed for the process is in the 10 – 12 gpm range. Excluding product storage, plant can be located on less than an acre. Other needs include about 2.0 megawatts, 3-phase, 480 volt power, and year-round access road.

Operators of natural gas-producing wells are necessarily careful to avoid disclosing business-confidential information about their production. Accordingly, the research into the logistics of siting a WYSG-like GTL facility is limited. High-level conversations with several industry contacts were helpful in uncovering information about what sites in Wyoming would be good candidates for this type of facility. In spite of the need to keep certain information confidential, interest in GTL technology is quite high.

It will be difficult to find stranded gas wells that produce singly, or from a pod of wells, the approximate 3MMscf/d required by the smallest WYSG plant. The consensus opinion among operators we spoke with was that wells with such flow capacity would already be connected to commercial production. Because of proximity to power and access issues, newly drilled frontier wells with high productive potential may also not be ideal. With these considerations in mind, first WYSG plant should be located at an established production site. Power considerations also favor locating the WYSG plant relatively close to an established production or gas processing facility. An

alternate possibility is using portable natural gas or diesel fueled generators. Natural gas is significantly cheaper than electricity on a gross power basis.

Water is a protected commodity in Wyoming. Accordingly, the WYSG plant is designed with a water treatment capability to reuse, to the maximum extent possible, the approximate 350 barrels of water per day (bwpd) required by the facility. Although the usage is low in absolute terms, a source of water is critical to the operation of the WYSG plant. Sourcing water is highly site specific. Locating near CBM wells provides the highest probability of finding reasonable quality water. Another possibility is locating near a source of relatively clean water such as rivers, lakes or water impoundments where temporary water rights can be secured. Alternatively the plant may be located near a city where water can be trucked in.

The current expectation is that the WYSG plant can be sited on property leased by the natural gas operator. If this is not the case, additional property will have to be acquired from the landowner. The footprint of the 100 – 500 bpd plant is quite small requiring less than an acre.

The quality of access roads to a well site is generally proportional to the degree of development in an area (i.e. number of wells drilled). Roads to frontier wells might be in rough condition and poorly maintained, making year around access difficult. Regardless of general road condition, a high probability exists that because of adverse weather, that the plant site will not be accessible on a year-round basis. Accordingly, the facility must be designed for remote monitoring and control.

Operators that produce natural gas with elevated levels of CO<sub>2</sub> will benefit from supplying the WYSG plants. The compressor company assesses the gas producer additional fees based on the increased power required to compress CO<sub>2</sub> compared to natural gas, if CO<sub>2</sub> levels are greater than 2-to-3%. A potential additional fee might also be assessed for blending out the contaminant to meet interstate pipeline specifications. The WYSG process operates efficiently using natural gas with elevated levels of CO<sub>2</sub>, so the commodity can be purchased at a price higher than the prevailing rates. Of course, CO<sub>2</sub> considerations suggest that WYSG process should be near CBM natural gas production.

The Wyoming statutes likely authorize oversight of WYSG-like GTL facilities and processes from the following agencies: Wyoming OSLI for siting on state lands; Wyoming DEQ Divisions, Air Quality, Solid and Hazardous Waste, and Water Quality. Each of these agencies may require permits for the following:

- OSLI: Special Use Lease for siting WYSG facility if on State Lands.
- DEQ – AQD: Minor Source Permit regulating entire WYSG facility; however, WYSG facility may qualify for a permit waiver.
- DEQ – SHWD: Oversight required; however, a regulatory determination may be requested to obtain a written opinion as to whether a permit is needed for WYSG facility.
- DEQ – WQD: General Permit Storm Water Pollution Prevention Plan (SWPPP).
- State Engineer's Office: Permit to appropriate surface or ground water necessary to meet the water requirements of the facility and process.



- County Zoning: Potential zoning requirements or permits; potential requirements will vary by County.

Several potential hurdles exist where either the statutes are silent or vague as far as they would affect WYSG-like GTL facilities or the WYSG process, those include:

- OGCC: Regarding whether or not the WYSG process should be considered production or post-production for natural gas operations, and whether or not the OGCC has authority to regulate the sale of natural gas from the producer directly to the end user.
- PSC: Regarding whether or not the PSC or the Supreme Court might view WRI as 'one end user,' the Court's factor for determining if the natural gas sale qualifies as a sale "to or for the public."
- Siting Issues: Including surface leasing and right to use the surface.
- DEQ-AQD: Whether or not the agency should seek to assume primacy over the PSD program, including CO<sub>2</sub> regulation, in lieu of the EPA regulating and issuing PSD permits within Wyoming.

Potential incentives and recommendations for encouraging natural gas value-added products in Wyoming, such as proposed WYSG facility, include statutory changes and tax incentives which include the following considerations.

The OGCC may need to determine whether or not a value-added products facility is part of the natural gas production or post-production. Such a determination may dictate whether or not the OGCC has jurisdiction to regulate natural gas value-added products. The legislature may choose to make such a determination for the agency, in which case a statutory change might provide the necessary certainty for natural gas value-added product production. More research is needed regarding potential OGCC jurisdiction over natural gas value-added products.

Due to the uncertainty regarding PSC jurisdiction, it is recommended that the state legislature examine this issue and consider an additional exemption in W.S. § 37-1-101(a)(vi)(G) that provides a specific exemption for natural gas value-added products from PSC jurisdiction. This issue may need additional research to fully understand the broader implications.

The legislature may consider including WYSG in 30-5-401 for oil and gas operations only for purposes of gaining access under the statute and for ensuring surface use agreements. However, this raises problematic eminent domain issues given the current eminent domain climate in Wyoming. This issue needs more analysis and consideration of the potential siting hurdles for natural gas value-added products facilities before making any changes to the current law.

The Wyoming State Legislature requested the DEQ-AQD to examine the federal PSD permitting program, which includes CO<sub>2</sub> permitting, and study the potential impacts to Wyoming if the state chose to seek primacy authority to regulate PSD permits under the DEQ-AQD. If the state assumed its primacy over the PSD program CO<sub>2</sub>, the state DEQ-AQD then has the ability to work directly with state value-added production facilities and other CO<sub>2</sub> emission producers to coordinate permitting and reporting efforts. The DEQ-AQD may provide a more in-depth analysis of the potential hurdles

and benefits of state primacy in this area. More research is needed regarding PSD and CO<sub>2</sub> permitting and the implications of assuming state primacy for overseeing the PSD and CO<sub>2</sub> program in Wyoming.

In conclusion, Wyoming's statutory and regulatory framework provides some structure for moving natural gas value-added production, such as WYSG-like GTL facility, forward in Wyoming. The identified issues require more research to fully understand the broader implications for addressing those hurdles and/or gaps in the law. The recommendations above are not conclusive and are merely possibilities that the legislature may choose to consider.

Overall, the results of this feasibility study show that it is technologically, logistically, economically and legally feasible to build and operate a properly scaled WYSG-like GTL plant in Wyoming. From a technological standpoint, all of the steps involved in this process are well established and have been commercially available for decades. Although the investigation of logistics for siting a WYSG-like GTL facility were only explored in generalities, feedback from producers was positive. Several entities have shown interest in smaller-scale GTL facilities and a few are seriously exploring sites in Wyoming. After careful economic scrutiny, the arbitrarily chosen size of 150 bpd production maybe a break even proposition and better suited as a demonstration facility. A plant three times larger (around 500 bpd) would have a payoff period of less than 9 years and seems much more attractive as an investment. Such a plant requires about 10 MMscf/d of natural gas and therefore will more than likely be connected to commercial production on a pipeline. Initial research suggests that a plant at this larger size may still fall below the regulatory thresholds as did the smallest plant.

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## Distributed Production of Fuels & Chemicals from Stranded Natural Gas

### Background

In response to the interest in Advanced Conversion Technologies as applied to the upgrading of Wyoming natural resources, Western Research Institute (WRI) presents this assessment of the technical and economic feasibility of upgrading stranded natural gas via a process henceforth referred to as Wyoming Stranded Gas (WYSG) process. WYSG process is a catalytic process that converts natural gas into gasoline. With minor modifications and appropriate catalyst selection, the process can also be used to produce diesel fuel and olefins.

Natural gas is selected as the target resource for upgrading into value-added products due to its abundance in Wyoming and its economic importance to the state. Wyoming ranks among the top five natural gas producers in the US. Recent production data show that natural gas production in Wyoming is declining (Figure 1). One of the reasons for the decline in production is the fact that pipeline capacity does not exist to send all of the gas produced in Wyoming to the consumer markets i.e., natural gas reserves are physically stranded. In addition to wells where production is abandoned due to being physically stranded, production can often be abandoned when natural gas wells are economically stranded by low gas prices. Meanwhile, from the standpoint of the state, each one-dollar drop in natural gas prices costs the state about \$114 million per year in lost tax. Monetization of this huge natural resource is therefore essential to solidify the financial health of the state.

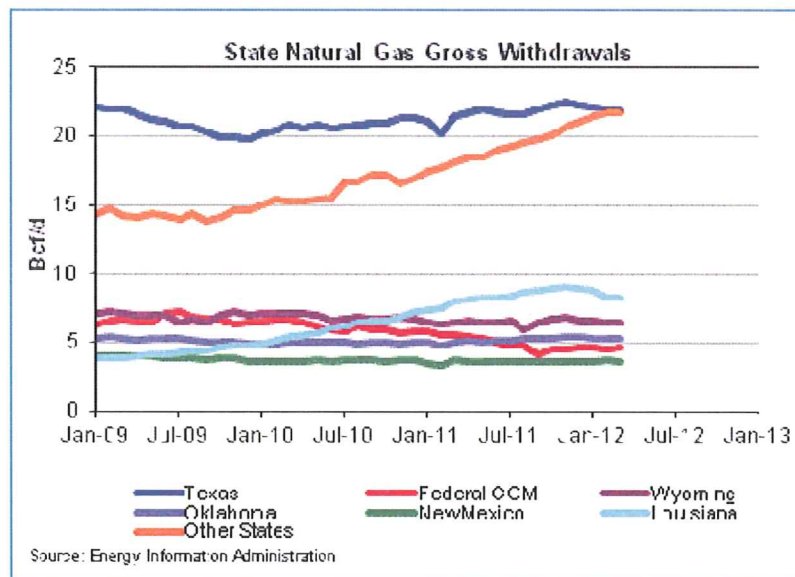
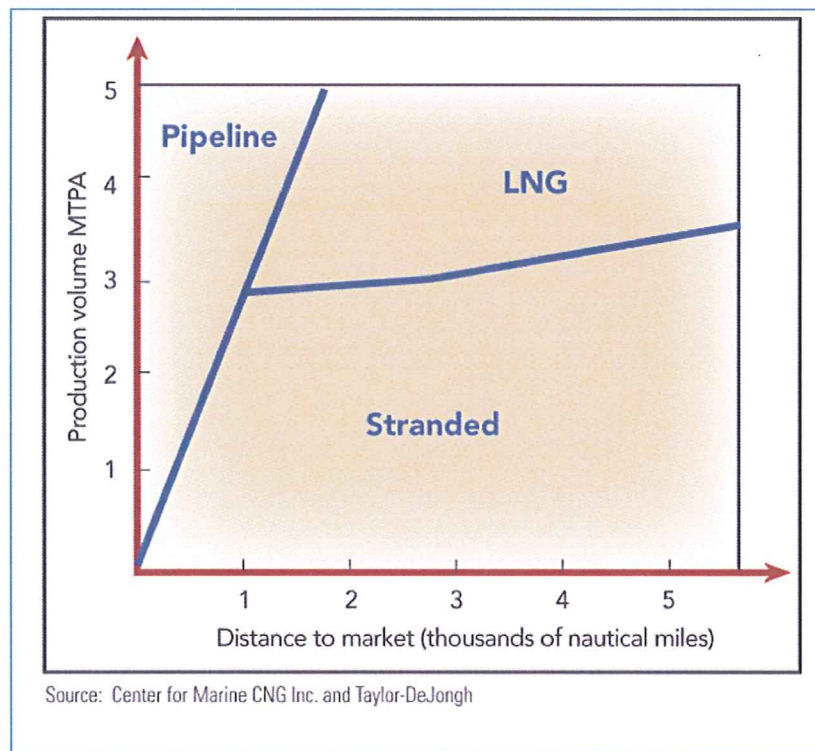


Figure 1. Gross production from gas producing states

## Wyoming Stranded Gas

Stranded gas can be described as natural gas reserves that are impeded from getting to market by either physical or economic hurdles. It would be somewhat more precise to say that stranded gas is blocked from market by combinations of physical and economic hurdles that can vary from one well to the next. If the owner of the well can expect to earn enough income to justify the investment, physical hurdles could be overcome by spending money either on a pipeline connection or on liquefied natural gas (LNG) equipment combined with LNG truck or rail transport. As shown by Figure 2, these available methods to transport gas are not economical when the size of the fields is small and the markets are far away.<sup>1</sup> Wyoming natural gas production often falls into this stranded category and alternate technologies such as thermo-chemical gas-to-liquid (GTL) conversion need to be developed and demonstrated to monetize the resource.



**Figure 2. Natural gas economics**

Information from the Wyoming Oil and Gas Conservation Commission (WOGCC) is useful in estimating the number of Wyoming's stranded natural gas reserves. The WOGCC has tracked oil, natural gas and coal bed methane wells that have been idle since January 1, 2011. Examining the percentages of each type of idle well and estimating how many of each type would be suitable for upgrading via the WYSG

process shows that there may be several thousand wells in Wyoming that are good candidates for this process.

With the ability to locate WYSG plants near reserves, the need for large, long-distance pipeline networks is eliminated. The lack of a nearby market for a particular stranded reserve is overcome by a value-added product output of the WYSG-like GTL process. Because GTL offers to bring natural gas into other product markets and avoid conventional gas transportation issues, this technology is an attractive monetization option for the state of Wyoming.

With the technology available to convert natural gas to gasoline, thoughtful consideration of the economic picture is warranted. Current pricing of natural gas and of gasoline certainly indicate that the economics of the WYSG process are, and can be expected to remain, favorable. In May 2012, the market price of U.S. natural gas fell to less than \$2.50 per MCF while the price of Brent crude oil in the same time frame was \$112/bbl (price ratio around six to seven on heat content basis). Just a few years earlier, in 2005, the price of natural gas was \$15 per MCF<sup>2</sup> and oil was at \$55/bbl (near parity on heat content).

The price of oil and the price of natural gas are expected to be influenced by each other.

- An increase in crude oil prices motivates consumers to substitute natural gas for petroleum products in consumption, which increases natural gas demand and hence prices.
- Increases in crude oil prices resulting from an increase in crude oil demand may increase natural gas produced as a co-product of oil, which would tend to decrease natural gas prices.
- An increase in crude oil prices resulting from an increase in crude oil demand may lead to increased costs of natural gas production and development, putting upward pressure on natural gas prices.
- An increase in crude oil prices resulting from an increase in crude oil demand may lead to more drilling and development of natural gas projects, which would tend to increase production and decrease natural gas prices.

Historically, the two prices have been linked in that the \$/bbl price of oil has stayed about six to ten times larger than the \$/MBTU price of natural gas, but over the last two years the linkage between the two prices appears to have been broken. The nationwide natural gas production in 2011 was nearly 12 percent above the 2009 level, and a record production is expected in 2012 and beyond. These large increases in supply are the main reason that natural gas prices have fallen to such lows. As the consumer market takes note of the large price differential between natural gas and fuels derived from crude oil, demand for natural gas will likely increase. However, factors such as increased shale gas, associated natural gas, and coal bed natural gas production will likely keep the prices low into the foreseeable future. Lower gas prices represent a major incentive for WYSG-like GTL conversion.

## The WYSG Process

WYSG process is proposed specifically for addressing the problem of stranded natural gas reserves in Wyoming. It is conceived to be a smaller scale, modular plant with field operation at the production site in mind. In order to achieve viable operation at a remote site, the process utilizes a once-through design, simple separations rather than full distillations, and equipment that are scaled to an appropriate size. While once-through operation means that some sacrifice is made in conversion, this is offset by using very efficient new technology and accepting the marginally lower price for unfinished gasoline rather than finished gasoline. Utilizing once-through design and simple distillation mean that both footprint and capital cost of the plant are minimized.

The WYSG process as evaluated in this report is a GTL technology that converts natural gas into a gasoline product. For this evaluation, the production capacity was fixed at nominal 150 barrels per day (bpd) of gasoline. WYSG process consists of four main process units: (1) a desulfurization unit where sulfur in natural gas is removed; (2) a steam reforming unit (Reformer) where syngas is produced; (3) a syngas-to-methanol (STM) synthesis unit where methanol is generated; and (4) a methanol-to-gasoline (MTG) unit where crude gasoline is produced. A simple block flow diagram is depicted in Figure 3. The final product, crude gasoline, has several possible market dispositions, including refineries where it could be used as a blending stock in producing finished gasoline.

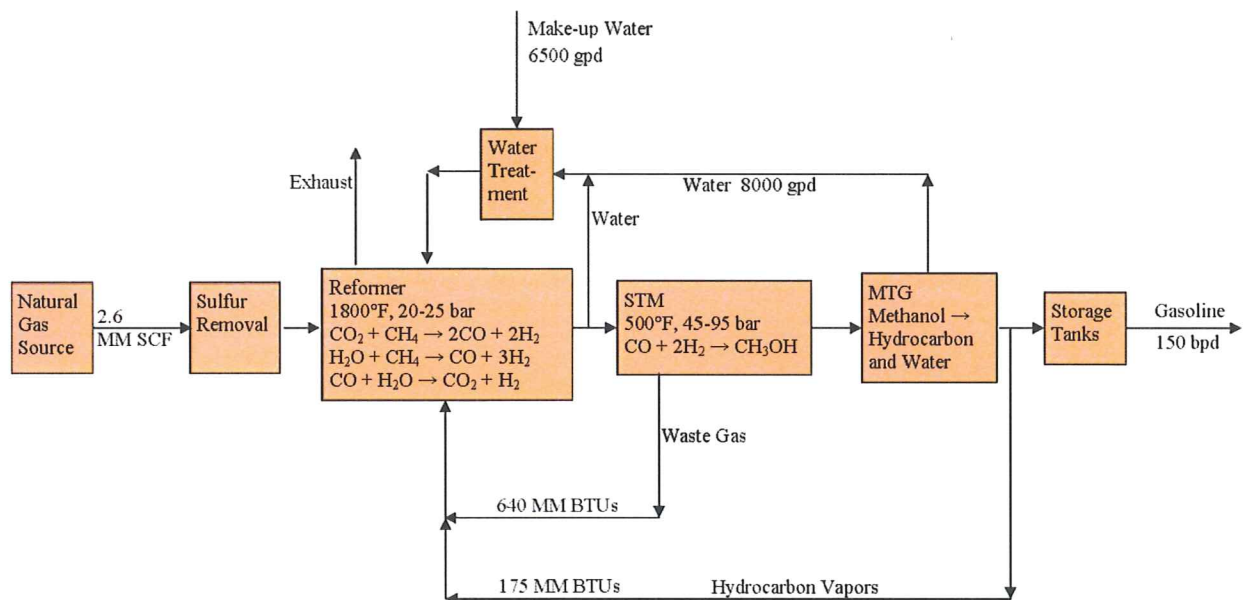


Figure 3. The schematic of proposed WYSG process

Water and natural gas are the main inputs to this process. The water is used to make steam, which is combined with the natural gas in the reforming step to produce syngas (CO and H<sub>2</sub>). Pure oxygen or carbon dioxide could be used in place of steam as a source of oxygen for the reforming step, but the associated costs are prohibitively large for this size of plant. Depending upon the CO<sub>2</sub> content of the natural gas, steam reforming results in a syngas composition with a hydrogen/CO ratio around 4:1. The



ideal ratio is around 2:1. Therefore, the WYSG process has excess hydrogen which is ultimately used as a fuel. As a result the process has a smaller carbon footprint than a conventional GTL plant.

Syngas is converted into methanol with 60 % carbon conversion efficiency. Unconverted syngas is separated from the methanol and used as part of the fuel mix to provide heat for the reforming step. Methanol is converted into gasoline, light hydrocarbons and water. These three product phases are separated and put to different uses. The crude gasoline is the final product of the plant, and is stored in tanks and ultimately transported to the customers. Light hydrocarbons are used as another part of the fuel mix to provide heat for the reforming step. Water is recycled with fresh make-up water used to make steam for reforming.

The technologies for these steps, including the sorbents and catalysts required in each step, have been commercially available in different forms for decades. For each of these steps there are various choices available in regard to equipment and catalysts, and some technologies are better suited than others to the conditions that will be prevalent at remote natural gas wells. The process and technologies chosen in the WYSG process are now described in detail.

#### Desulfurization of Natural Gas:

Natural gas has a small but measurable amount of sulfur containing species, usually hydrogen sulfide. Sulfur removal is an integral part of the process to protect catalysts, such as nickel-based steam-methane reforming catalyst, from poisoning and subsequent deactivation. Sulfur treatment of the gas is accomplished with a zinc oxide sorbent. Other desulfurization methods are available and may be evaluated as more appropriate for a particular site and gas composition. Zinc oxide has been chosen for this study as the best option for removal of hydrogen sulfide (H<sub>2</sub>S), the most likely source of sulfur contamination. Generally two zinc oxide sorbent-filled vessels are used in series. When sulfur can be detected at the outlet of the first vessel in series, it is taken off-line and filled with fresh catalyst. The vessel with fresh catalyst is put online as the second in series, and the process is repeated indefinitely so that virtually no sulfur reaches downstream catalysts.

Prior to this desulfurization, the gas must be heated. Excess heat from the reformer exhaust stream will be used to pre-heat many streams, including the natural gas prior to desulfurization. To avoid the expense of pressure vessels in the desulfurization step, a gas compressor is placed after desulfurization. To accommodate this arrangement, the compressor must be protected from excess heat by cooling the desulfurized gas to 150°F or lower. An aerial cooler purchased with the compressor would easily accomplish this task.

#### Reforming of Natural Gas:

Reforming is a technology that has been used by various industries in many different forms for decades.<sup>3</sup> For methane reforming, a catalyzed reaction is used to produce syngas from methane and oxygen or an oxygen-bearing compound like carbon dioxide or steam. We have selected steam reforming for production of syngas from natural gas because it will be more economical for this type of plant to obtain water and produce steam than to obtain pure oxygen or carbon dioxide gas. Natural gas composition

with a high level of carbon dioxide would increase conversion efficiency of a WYSG plant, reduce steam usage, and will not upset the steam reforming step. There are several technologies available<sup>4</sup> for producing syngas from natural gas, however one-step steam reforming with catalyst-filled tubes inside a fired heater is best suited for the size of the WYSG process plant. The synthesis gas is produced without the use of expensive oxygen gas. An additional benefit of one-step steam reforming is that CO<sub>2</sub> contained in the natural gas is a carbon source that boosts the plant output rather than an undesirable contaminant. Natural gas laden with CO<sub>2</sub> constitutes a less expensive feedstock, and its deployment in this process can reduce CO<sub>2</sub> emissions to the environment by using what would otherwise be an undesirable by-product of natural gas production.

After the desulfurized natural gas is compressed to about 140 psia, it is pre-heated with excess heat present in the reformer exhaust stream. The pre-heated gas is combined with steam and fed to the catalyst-filled tubes of the reformer. The reformer is one of the most complicated pieces of equipment in the plant as it functions as reactor, fired heater and waste-heat boiler. A fuel-and-air mixture is combusted in burners on the fire-side of the tubes in this heater. The hot gasses rise from the firebox up to the waste-heat boiler section. Inside the tubes of the waste-heat boiler section, water flows and is heated past its boiling point to produce the steam that is mixed with the desulfurized natural gas. The tubes in the firebox section of the heater are filled with catalyst and form the reactor section of the reformer. Many brands of steam reforming catalyst are available on the market, and virtually all of them are some form of nickel oxide that is reduced to metallic nickel either during catalyst production or in-situ when the catalyst is installed at the plant. Steam and natural gas react to form syngas in the presence of this nickel catalyst at high temperature (about 1800°F) and moderate pressure (140 psia). This syngas must be compressed to a higher pressure in the next conversion step, so the syngas is cooled in a condenser and any unreacted steam that condenses out as water is removed. This cooling could be accomplished in a heat exchanger utilizing either air or cooling water as the cooling medium. Condensed water will be sent to the water treatment equipment, where water is treated and recycled into the reformer waste-heat boiler.

A large number of catalysts are commercially available for steam reforming of natural gas. Supported nickel-based catalysts are found to be most active and economical.<sup>5</sup> While performance of steam reforming catalyst could be impaired by carry-over of any compound which may deposit as a solid on the catalyst, sulfur is clearly the most common and severe poison to consider. Although the high nickel surface area offered by commercial reforming catalysts can accommodate a relatively large quantity of sulfur, minimization of sulfur levels ensures high activity throughout the catalyst lifetime.

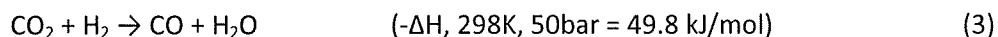
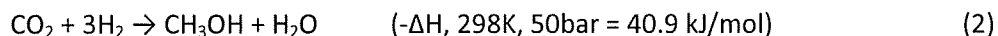
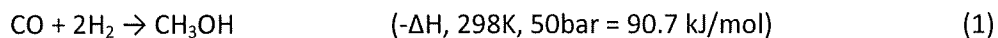
The active nickel oxide component in the catalyst is reduced to metallic nickel during activation. Traditionally, activation of steam-methane reforming catalyst takes place in situ when it is reduced by the steam-feed gas mixture at a relatively high steam to carbon ratio. Reduction is initiated by hydrogen formed by thermal cracking of hydrocarbons. Since elementary nickel becomes available, the steam reforming process is triggered and the additional hydrogen formed accelerates catalyst activation via reduction.<sup>6,7</sup>

### Syngas to Methanol (STM):

After syngas is produced, it is cooled and pressurized for conversion into methanol. Syngas-to-methanol (STM) conversion is accomplished via catalyzed reaction at high pressure (1000 psia) and moderate temperature (500°F). Before being sent to the STM reactor, the syngas is compressed to 1000 psia in a 3-stage compressor with integrated aerial cooler for inter-stage cooling of the syngas. The gas is then pre-heated in a heat exchanger where heat is obtained from heat transfer oil called therminol. The therminol is heated in the STM reactors, which are compact heat exchange reactors (CHERs). CHERs are very good at maintaining constant temperature throughout a catalyst bed. Conversion of syngas to methanol is exothermic and favored at low temperatures. For this reason, it is necessary to remove heat to keep the reaction temperature as close to the set value as possible to increase the conversion of syngas. Optimizing the temperature everywhere in the catalyst bed allows for higher conversion than would be achieved with more traditional reactors. This synthesis step proceeds with selectivity in excess of 99%, yielding methanol, some unreacted syngas, and very little of any other chemicals. Overall conversion efficiency for the STM unit is 60%, and preliminary experimental data indicates that this step could be optimized to have conversion efficiency 10% to 20% higher.

When pressurized, pre-heated syngas is fed to the reactors, the exothermic reaction takes place and produces methanol, some water, and heat. The heat is transferred to the therminol and recycled to pre-heat the feed stream as described above. The reaction is carried out in three reactors in two stages. The first stage consists of two reactors in parallel. After this first stage of STM reaction, the effluent mixture of unreacted syngas and produced crude methanol is cooled in an air- or water-cooled condenser to about 90°F, or below the methanol/water condensing point. Unreacted syngas is pre-heated again in another pre-heater and fed to the second stage STM reactor. After the second stage STM reactor, the effluent is again cooled in an air- or water-cooled condenser and the unreacted syngas is separated from the crude methanol. Unreacted syngas at this point is used as part of the fuel mix for the reformer fired heater. The methanol product from the second stage is combined with methanol from the first stage.

The conversion of hydrogen and carbon oxides to methanol proceeds through the following reactions:<sup>8</sup>



The methanol synthesis from syngas is an exothermic reaction, and maximum conversion is obtained at low temperature and high pressure. A challenge in the design of a methanol synthesis process is to remove the heat of reaction efficiently and economically. Compact Heat Exchange Reactor design meets these challenges.

Six companies provide specialized reactor design for methanol production: ICI, Lurgi, Topsøe, Mitsubishi, M.W. Kellogg, and Uhde. Design figures for reactors can be as high as 2,500-10,000 tons per day. As most commercial reactors deal with very large scale production of methanol, custom methanol

synthesis reactors have to be designed for each individual application of high pressure, high temperature synthesis of methanol from synthesis gas.

Following are some of the commercially available reactor technologies.

- In the ICI adiabatic single bed reactor the heat of reaction is removed by adding cold reagent at different heights in the bed.
- In the Lurgi two multitubular reactors, the heat of reaction is removed in the first reactor by boiling water around the bed, and in the second reactor by gas.
- In the Haldor Topsøe system, several adiabatic reactors are arranged in series and an intermediate cooler removes the heat of reaction.
- In the Air Product-Chem system, there are three-phase fluidized bed reactors and an inert hydrocarbon liquid inside the reactors removes the heat.
- In the Casale isothermal reactor the heat is removed by plates immersed in the catalysts.

WRI and Chart Energy and Chemicals have developed the CHER micro channel reactor that could be appropriate for the WYSG process. This reactor has a higher efficiency and performs better than the conventional slurry and fixed bed reactors. Another advantage of a compact modular reactor is that it can be assembled and filled with catalyst at a fabrication shop and delivered to a remote natural gas site by truck with minimum field assembly.

Typical reaction conditions are as follows:

- Reaction Pressure 50-100 bar
- Reaction Temperature 400-600°F
- Feed composition 59-74% $H_2$ , 27- 15% CO, 8%  $CO_2$ , 3% $CH_4$
- Typical  $H_2$ :CO ratio of 2.17
- Observed CO conversion to methanol per pass is normally 16 - 40 %
- The selectivity to methanol is around 99.8 %

Usually the chemical composition of the commercial catalyst is CuO (60-70%); ZnO (20-30%);  $Al_2O_3$  (5-15%) or  $Cr_2O_3$  (5-15%), plus additives. The catalyst should remain active for about four years with sustained high plant output. Usually sulfur, chlorine compounds, and metal carbonyls poison the catalyst. The total sulfur content in the feed gas to the methanol synthesis loop should be less than 0.1 ppm. Therefore, the sulfur removal process that is integral to the reforming step is also highly important for protecting the catalyst in this STM conversion step. Thermal sintering (copper site clustering) or carbon deposition also deactivates the catalyst.

Commercial catalysts are available to carry out the STM reaction. Currently, there are four major methanol synthesis catalyst suppliers: Syntex (formally ICI Katalco), Süd Chemie (in the US sold by United Catalyst Inc.), Haldor Topsøe, and Mitsubishi Gas Chemicals. Haldor Topsøe's methanol synthesis catalysts are called MK-101, MK-121, and MK-151 FENCETM. These catalysts offer:

- Longer catalyst lifetime,

- Higher conversion and carbon efficiency during its lifetime,
- Lower by-product level in the crude methanol, and
- Operational flexibility at the entire range of synthesis gas compositions

Haldor Topsøe's MK-121 catalyst has been tested with the CHER and is likely the best candidate for use in a WYSG plant.

#### Methanol to Gasoline (MTG):

The final production step is to convert methanol into gasoline-range hydrocarbons with an MTG zeolite catalyst. In the MTG reaction, methanol is first converted to a mixture of methanol, dimethylether (DME) and water. The mixture is then converted into gasoline, light hydrocarbons, and more water. These two steps are carried out at moderate temperature (about 700°F) and pressure (about 250 psia).

Valves between the STM and MTG units reduce the pressure of the methanol to the appropriate level and then the temperature is raised slightly in a pre-heater that utilizes excess heat from the reformer fired heater. Next the methanol is fed to the first reactor, called the DME reactor, where a gamma-alumina catalyst catalyzes the reaction. Like the STM reaction, both steps of the MTG reaction are exothermic. To control temperatures, a cool recycle gas stream is combined with the DME reactor effluent. This combined stream is fed to the second reactor, called the conversion reactor, where a zeolite catalyst known as ZSM-5, developed and licensed by Exxon Mobil, is used to catalyze the reaction that produces gasoline. The effluent from the conversion reactor is cooled in an ammonia-cooled heat exchanger and separated in a three-phase separator. The vapor phase consists of light hydrocarbons, mostly propane, and it is split into two streams. One vapor stream is recycled and fed back into the conversion reactor to make additional gasoline-range material. The remainder of the vapor is sent in a separate stream to the reformer where it is used by adding it to the fuel for heating the reformer. The water phase is sent to water treatment and recycled to make steam for reforming. The liquid hydrocarbon phase is the gasoline product, which is put into product storage tanks and ultimately loaded onto tanker trucks for delivery. A combination of two systems may be necessary to improve separation, depending on the desired product specifications.

Fixed bed or fluidized bed reactors are employed in various commercial sites, and it is clear that fixed bed reactors will be the most economic choice for a WYSG facility. The zeolite catalyst in the conversion reactor will need to be regenerated monthly due to build-up of carbon, so the hardware will be set up with two conversion reactor vessels that are each able to be isolated. Only one conversion reactor will be on-line at a time. As carbon builds up on the catalyst, its ability to convert methanol will diminish. When methanol can be detected in the reactor effluent, the fresh conversion reactor that has been standing idle will be put online and the reactor that needs to be regenerated will be taken off-line. Once it is off-line, the reactor can be removed to a central facility for regeneration and then brought back to stand ready to go on-line when the other conversion reactor needs to be regenerated.

The MTG process was discovered in the 1970s<sup>9,10</sup>, however, it took many years of extensive research to understand the detailed chemistry behind the process. DME appears to be the intermediate for the formation of hydrocarbons on the ZSM-5 zeolite catalyst sites. It is first converted to light olefins (C<sub>2</sub>-C<sub>4</sub>),

and then a final reaction step leads to a mixture of higher olefins, n-paraffins, iso-paraffins, aromatics, and naphthenes. Interrupting the reaction would lead to a production of light olefins instead of a gasoline mixture.<sup>11</sup>

In the MTG process, the conversion of methanol to hydrocarbons and water is virtually complete and essentially stoichiometric. The reaction is exothermic with a heat of reaction of approximately 1.74 MJ/kg of methanol with an adiabatic temperature rise of approximately 600 °C.<sup>11</sup>

Although a number of solid acid microporous catalysts are considered for MTG, ZSM-5 is the most active and well studied zeolite catalyst. The ZSM-5 zeolite has uniformly sized microporous channels<sup>12</sup> of diameter 5.4-5.6 Å in its structure. The zeolite is endowed with tunable acidity, high thermal and hydrothermal stability, and large surface area. Only those molecules whose dimensions fit the channel structure of the zeolite are formed inside the channels during a chemical reaction. As a result, very heavy organic molecules whose sizes do not fit the zeolite dimensions are not formed during the MTG reaction. The process yields an unfinished gasoline product with very low sulfur, low benzene and high octane.

*It should be noted that the same equipment can be used to produce DME, a diesel fuel alternative. As a liquefied gas that becomes liquid under low pressures, DME is an ideal diesel fuel replacement because it has very high oxygen content – 35% by weight – and no carbon-carbon bonds. What that means is that it cannot produce soot particulates or black smoke. DME costs less than diesel; 1.8 gallons of DME will cost less than 1 gallon of diesel. DME requires very low injection pressures, and produces little pollution from combustion. Testing of DME as a diesel fuel alternative is currently being conducted by the Volvo Group and Ford Europe*

### **MTG vs. Fischer Tropsch (FT) synthesis**

MTG and Fisher-Tropsch (FT) are competing technologies. FT synthesis converts syngas into liquid hydrocarbons and thereby represents another option for GTL conversion. Although MTG and FT processes both convert synthesis gas into liquid fuel products, their respective product slates are very different. The FT process produces a broad spectrum of straight-chain paraffinic hydrocarbons, which requires upgrading to produce finished products such as gasoline, jet fuel, diesel fuel, and lube base stocks. MTG, in contrast, selectively converts methanol to high-quality gasoline with virtually no sulfur and low benzene, which can be sold directly to refineries for blending into the gasoline pool, to bitumen producers who need less viscous hydrocarbons to dilute their product for transport, or to chemical companies for use as a chemical feedstock.

Table 1 shows an economic comparison of MTG and FT technologies for coal-to-liquids conversion. The superiority of MTG over FT is evident from the higher overall efficiency and lower construction costs. Similar benefits are indeed expected for GTL processes.

The MTG process uses a conventional gas phase fixed bed reactor, which can be scaled up very readily.<sup>7, 8, 15</sup> In the first commercial application in New Zealand, the process was successfully scaled up from about 4 bpd to about 13,500 bpd of gasoline. In contrast, most of the technology advancement for the

new FT technology options rely on slurry phase reactors, which are inherently more complex.<sup>4</sup> Scale-up of slurry phase reactors requires significantly more sophisticated demonstration and modeling in the absence of a direct commercial operational experience. Additionally, a slurry phase reactor would require more specialized support than is readily available at remote gas well sites.

**Table 1. Liquid Transportation Fuels from Coal/Biomass using FT and MTG technologies<sup>13</sup>**

Process		FT	FT	MTG	MTG
<i>CO<sub>2</sub> capture</i>		no	yes	no	yes
<i>Input</i>	Coal, TPD (as received)	26,700	26,700	22,900	23,200
<i>Outputs</i>	Diesel, BPD	28,700	28,700	0	0
	Gasoline, BPD	21,290	21,290	50,000	50,000
	Total liquid Fuel, BPD	50,000	50,000	50,000	50,000
	Electricity, MWe	427	317	145	111
Thermal Eff. (LHV)		49.10%	47.60%	54.20%	52.90%
Total Plant cost (\$M)		4,880	4,950	3,940	4,020
Total Plant cost (\$K/BPD)		97.6	98.9	78.8	80.4
Est. Breakeven Crude price (\$/BBL)		56	68	47	51

Compact Reactor Modules:

As has been emphasized, the use of compact reactor modules is a key component that makes this small-scale application of WYSG-like GTL technology feasible.

These reactors are compact and more efficient and make modular field deployable GTL synthesis plants possible. A compact reactor (Figure 4) consists of stacks of closely spaced thin plates designed to form channels with specific dimensions, regularity, and connectivity in the spaces between the plates. Process fluids pass through the channels, which are filled with appropriately sized catalyst particles effectively making each channel a fixed bed reactor with a very short heat conduction path. The dimensions of the channels increase the surface area per

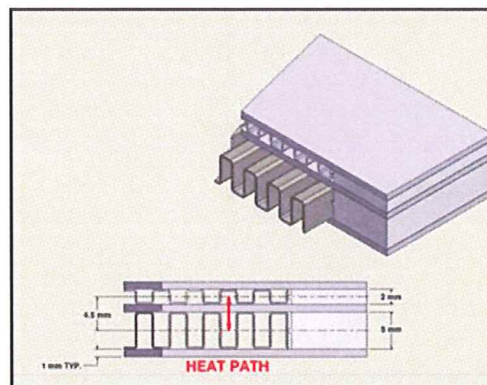


Figure 4 Alternating Process/Cooling Channels in a compact reactor

unit volume significantly increasing the overall productivity of the synthesis process per unit volume. Besides the advantages in heat and mass transfer, the reactor can integrate multi-step reactions into a single unit to simplify chemical synthesis processes. The modular nature of the compact reactors also facilitates scale-up. If a company wanted a bank of these modular reactors, they could choose the option of not performing catalyst changes themselves at their site, but rather sending the modular reactors out for catalyst changes and other maintenance.

### Process Modeling

To validate a number of assumptions about the WYSG plant design, a computer simulation was developed to model the proposed plant. The detailed description of methods used, as well as the detailed flowsheets and stream tables from this model are given in Appendix I. Described below are the inputs used for the model and the outputs from the model.

#### Natural Gas Characteristics

Natural gas is utilized as the raw material for crude gasoline production. It is well known that natural gas is not a commodity with uniform composition, and the precise composition can have important implications for optimal plant design. Of particular importance is the presence of sulfur compounds, non-methane hydrocarbons and hydrocarbon liquids. The simple assumption that natural gas is fairly represented as pure methane would not lead to an adequate plant design. The set of natural gas characteristics provided in Table 1 was chosen for process modeling.

**Table 2. Natural Gas Characteristics**

Pressure, psia	50
Temperature, °F	100
Composition (mol.%)	
Methane (CH <sub>4</sub> )	92.31
Ethane (C <sub>2</sub> H <sub>6</sub> )	3.2
Propane (C <sub>3</sub> H <sub>8</sub> )	0.7
n-Butane (C <sub>4</sub> H <sub>10</sub> )	0.059499937
n-Pentane (C <sub>5</sub> H <sub>12</sub> )	0.059499937
Carbon Dioxide (CO <sub>2</sub> )	3.67
Hydrogen sulfide (H <sub>2</sub> S)	4 ppm

#### Simulation Assumptions

The following assumptions are considered in modeling WYSG-like GTL process:

- Process is steady state
- Constant input flow rate of natural gas
- Catalyst is homogenous and charged with constant void fraction of catalyst bed in the reactor.



## Simulation Results

The following tables 3 and 4 show the intermediate and final product characteristics from the simulation. The main performance results of the GTL plant are summarized in Table 5.

**Table 3. Raw Methanol Composition**

	Mass Fraction (wt %)
Methanol	88.29
carbon dioxide (CO <sub>2</sub> )	0.31
Water (H <sub>2</sub> O)	11.36
Others	0.04
Total	100.00

**Table 4. Gasoline Composition**

Component	Mass Fraction (wt.%)
Light gas	0.2810
Water (H <sub>2</sub> O)	0.2471
Ethylene (C <sub>2</sub> H <sub>4</sub> )	0.0102
Ethane(C <sub>2</sub> H <sub>6</sub> )	0.0337
Propylene (C <sub>3</sub> H <sub>6</sub> )	0.0219
Propane (C <sub>3</sub> H <sub>8</sub> )	2.1399
n-butane (C <sub>4</sub> H <sub>10</sub> )	7.9285
Isobutene (C <sub>4</sub> H <sub>10</sub> )	1.3938
cis-2-butene (C <sub>4</sub> H <sub>8</sub> )	1.3315
C <sub>5+</sub> hydrocarbon	86.6121
C <sub>5+</sub> paraffin	58.8619
C <sub>5+</sub> aromatics	27.7502

**Table 5. Overall Simulation Results**

<b>Feed</b>	
Natural gas, cuf/hr (lb/hr)	33,789 (5026)
<b>Product</b>	
Crude gasoline, barrel/day (lb/hr)	190 ( 1990)
<b>Power Consumption, MW</b>	1.96
<b>Thermal Efficiency, %</b> , higher heating value (HHV) basis (steam from regeneration)	35.25 %
<b>Thermal Efficiency, %</b> , higher heating value (HHV) basis (steam from external source)	32.19 %

### **Economic and Investment Considerations**

The payout time for a conventional GTL plant like the one operated in New Zealand could be in excess of 12+ years. Payout time for the methanol plant itself would generally be seven years.<sup>14</sup> Direct conversion of natural gas to methanol has a payout time of about twice that of methanol synthesis from alternate feedstock. The reason is two-fold. First, the required capital investment is 35% greater than conventional methanol synthesis because of the sophisticated heat removal system, and the high recycle rate needed to prevent reactor temperature runaway. Second, the process has a lower cash margin than conventional methanol synthesis because of the lower product yield and higher associated operating costs.<sup>14,15</sup>

The WYSG process significantly reduces the payout time for a natural gas to gasoline GTL plant. This is largely due to the use of modular compact heat exchange reactors for methanol synthesis, which simplifies the heat removal system and eliminates the need for recycle. Eliminating recycle reduces capital cost because gas flow through the reactor and associated equipment is lower, so the size of the equipment is smaller. Additionally, operating costs are reduced because there is no power being consumed for compression of recycle gas. These reductions in both the capital and operating costs shorten the payout time for the syngas to methanol process equipment and improve the overall economic attractiveness.

Overall, it is possible to build a plant that will economically utilize Wyoming stranded gas reserves by making gasoline. In order to do so, it is necessary to diverge from traditional plant design strategies on several counts and build a simpler, smaller plant that produces an unfinished, but valuable, gasoline.

The product of the WYSG plant is unfinished gasoline. It would have a distillation very similar to the example given in Table 6, with some key characteristic noted in Table 7. This gasoline product would be most useful to refiners in blending finished gasoline and for bitumen producers as a diluent for their viscous product.

**Table 6. Typical product distillation**

Component	Vol%	TBP of C5+'s, Vol%	
		Dist (%)	T (F)
		IBP	87.6
Methane	0.75	10	111.0
Ethane	0.35	30	158.0
Propylene	0.30	50	205.4
Propane	4.20	70	266.3
Butylenes	1.50	90	336.6
Butane	11.20	95	359.1
C5+'s	81.70	98	377.8
		EBP	400.1

**Table 7. Expected product specifics**

C5+ Nonaromatics	51 wt%
Aromatics	49 wt%
Aromatics 6-10	98.7 wt% of total aromatics
A 11+ (includes n	1.3 wt% of total aromatics
Durene	2.5 wt%
Approximate RVP	12 psi
Approximate RON	92
Sulfur	0 ppm
Benzene	0.3 vol%

The use of stranded natural gas limits the scale of production to a relatively small facility. As mentioned earlier, a plant with a production capacity of 150 bpd was set as a starting point. Based on subsequent research, this plant size turned out to be on the small side of the optimum range, yet certainly the right order of magnitude. Preliminary economic analysis suggests that a plant three times larger approaching 500 bpd might be the most profitable, if a site with sufficient low-priced natural gas can be located to allow for this higher production rate. For a plant with 100 bpd or 500 bpd capacity, the small size dictates a distinctive approach from the design engineer's perspective.

## Site Selection for A WYSG Facility

The basic requirements for the reference WYSG plant are:

- Sufficient space on which to locate the reactor skid(s) and associated tankage (excluding storage space required for a WYSG plant is less than an acre)
- Road access sufficient to permit heavy truck traffic to service the facility and haul liquids to and from the site
- Natural gas supply with delivery rate of approximately 3MM scf/d
- Natural gas supply at a pressure of approximately 20 psia in order to reduce the cost of compression within the WYSG plant
- Natural gas supply containing at least 3%Vol CO<sub>2</sub> since there is excess hydrogen available from steam-methane reforming and the presence of CO<sub>2</sub> actually improves the process efficiency
- Source of electricity rated at approximately 2.0 megawatts, 3-phase, 480 volt
- Source of water either at or near the site capable of supplying approximately 750 gal/hr

Ideally, the natural gas will come from a stranded supply, either from a conventional or CBM resource. However because of the stringent site requirements outlined above, WRI will accept gas from a connected source on commercial production if all other site requirements are met.

Defining Stranded Gas: The term “stranded gas” has various meanings to natural gas producers. Some operators consider all natural gas in the state stranded because of the difficulties in moving the product to market and the resulting low prices Wyoming receives compared to other markets in the U.S. Others consider stranded gas as a source of natural gas that is geologically isolated from (i.e. not connected to) a proximate larger source of gas and consequently represents low deliverability potential. Yet others use the term to refer to wells that are "dogs" that do not produce at rates or pressures sufficient for connection to a natural gas collection manifold.

In the context of this report, “stranded” refers to natural gas wells that are good, viable producers--but for reasons of economics such as market value of gas or remoteness from gathering equipment--are not currently connected to commercial gas gathering equipment.

The Wyoming Oil and Gas Conservation Commission (WOGCC) has developed a list of potential economically stranded producers. This list comprises a group classified as "idle wells" with an operator-assigned status of either temporarily abandoned or shut-in. The WOGCC asks operators to attend an Annual Idle Well Review to determine if the subject wells can be placed into service, will become viable after a workover, or should be plugged and abandoned. As of May 2012, WOGCC has identified about 16,500 oil and gas (natural gas and CBM) wells with this designation that have not produced since January 1, 2011. Of this total, slightly less than two-thirds are CBM wells. It is also reasonable to assume that a sizable portion of the remaining 6000 wells are natural gas or combined oil and natural gas producers. The WOGCC data represents a useful reference to assist in identifying stranded gas. Identifying which wells would be viable producers but are currently shut in because of low natural gas prices or current allocation of production resources; which are recently drilled frontier wells with good

production potential but are located a significant distance from established gas gathering facilities; and which wells will yield unacceptable quantities of natural gas, even when reworked or added to gas gathering equipment, however, proves difficult.

Considerations for Siting a WYSG Facility: After discussions with operators and others in the industry, a number of issues were raised that must be considered when siting the WYSG-like GTL plant at remote sites. It should be stressed that these are not insurmountable obstacles, but issues that should be addressed, where appropriate, as part of judicious early planning.

It will be difficult to find stranded gas wells that produce singly, or from a pod of wells, the approximate 3MM scf/d required by the smallest WYSG plant. The consensus opinion among operators we spoke with was that wells with such flow capacity would already be connected to commercial production. Even at \$2/Mscf, such wells represent gross annual revenue around \$1.1 million, a significant income to a company even with a high operating overhead. Because of distance from power and difficult access, newly drilled frontier wells with high productive potential may also not be ideal. With these considerations in mind, first WYSG plant should be located at an established production site.

Estimated 2.0 megawatt electrical requirement of WYSG plant presents a challenge. Such a capacity requires a 13.2kV line and sizable step-down transformer. Running the high voltage electrical line to a relatively distant site might represent a significant cost. Power considerations favor locating the WYSG plant relatively close to an established production or gas processing facility where it will be more economically feasible to lay the line and transformer. An alternate possibility is using portable natural gas or diesel fueled generators. Natural gas is significantly cheaper than electricity on a gross power basis, however the cost of an appropriate onsite natural gas-powered generator must be considered.

Water is a protected commodity in Wyoming. Accordingly, the WYSG plant is designed with a water treatment capability to reuse, to the maximum extent possible, the approximate 350 barrels of water per day (bwpd) required by the facility. For the sake of comparison, Table X shows the water consumption for various energy uses. From the data it is clear that WYSG process consumes very little water. Although the usage is low in absolute terms, a source of water is critical to the operation of the WYSG plant. Sourcing water is highly site specific. Locating near CBM wells provides the highest probability of finding reasonable quality water. Another possibility is locating near a source of relatively clean water such as rivers, lakes or water impoundments where temporary water rights can be secured. Alternatively the plant may be located near a city where water can be trucked in.

**Table 8. Comparison of water use for various purposes**

Purpose:	Oil Shale Plant	Ethanol Plant	Electric Power	Agriculture (alfalfa)	Domestic Use	WYSG Plant
Product/use:	50 bpd	39 bpd	0.80 MW	4 acres	25 people	160 bpd
Water:	7 acft/yr	7 acft/yr	7 acft/yr	7 acft/yr	7 acft/yr	7 acft/yr

The current expectation is that the WYSG plant can be sited on property leased by the natural gas operator. If this is not the case, additional property will have to be acquired from the landowner. The footprint of a 100 – 500 bpd plant is quite small, requiring less than an acre.

The quality of access roads to a well site is generally proportional to the degree of development in an area, or number of wells drilled. Roads to frontier wells might be in rough condition and poorly maintained, making year-round access difficult. Regardless of general road condition, a high probability exists, either because of adverse weather or perhaps environmental restrictions, that the plant site will not be accessible on a year-round basis. The inability to access the reactor site may extend to a week or longer. Accordingly, the facility must be designed to accommodate periods of temporary shutdown.

Operators that produce natural gas with elevated levels of CO<sub>2</sub> will benefit from supplying the WYSG plants. The compressor company assesses the operator additional fees for CO<sub>2</sub> levels greater than 2-to-3% based on the increased power required to compress CO<sub>2</sub> compared to natural gas. A potential additional fee might be assessed for blending out the contaminant to meet interstate pipeline specifications. The WYSG process operates efficiently using natural gas with elevated levels of CO<sub>2</sub>, so WRI can purchase the commodity at a price higher than prevailing rates. Increased levels of CO<sub>2</sub> occur in some conventional reservoirs and to a greater extent in CBM natural gas.

Acquiring natural gas from Producers: Operators sell their natural gas production to pipeline companies based on take-or-pay contracts. In addition, operators with low delivery pressure wells (e.g. CBM producers) need to pay additional fees to a booster compression facility (sometimes referred to as gas gathering plant) to boost the low pressure product to minimum pipeline requirements.

We assume that it will be necessary to negotiate a similar contract with natural gas operators for supplying the WYSG plant. If the natural gas operator intends to supply a portion or all of the natural gas from wells that are already on production, negotiations might be more involved because of an existing agreement with the pipeline company. Regardless, a natural gas supplier might consider supplying WYSG plant riskier than supplying a conventional production pipeline for the following reasons: (a) the duration of the project will likely be limited; (b) there may be temporary upsets in the WYSG plant that cause disruptions (though this should be addressed in the take-or-pay contract); and (c) the WYSG plant owner's financial resources are not proven (this can be addressed through bonding or establishing an escrow account). Although the natural gas operator's concerns can be addressed, we realize that it might be necessary to offer the operator higher than prevailing prices for natural gas, particularly for the first installation. Another possibility for rate adjustment is offering a premium based on the percentage differential between the price of natural gas and generated gasoline product. WRI can certainly benefit producers with elevated levels of CO<sub>2</sub> by offering higher prices for their product, which would be otherwise downgraded in value if sold to pipeline companies. It is anticipated that the ease of negotiating contractual agreements will improve with time and the deployment of additional plants.

Acquiring natural gas from Pipelines: Our preliminary evaluation has identified 36 gas processing or compressor plants and 4 booster or gas gathering plants in the state that have sufficient capacity to operate a WYSG plant. The Wyoming Pipeline Authority identified significantly more collection and

booster compressor stations, which will be discussed later in the report. The former are located generally near major gas producing areas and near interstate highways. The latter are generally close to CBM production.

Locating the plant near a compressor facility and purchasing natural gas from the pipeline offers a number of advantages compared to sourcing directly from natural gas operators. These include (1) pressurized natural gas is sold at a discount; (2) contractual negotiations are simpler; (3) no disruptions in natural gas supply; (4) access roads to compressor facilities are well maintained year around and typically not in regions impacted by environmental access restrictions; (5) water might be available from the gas cleanup equipment, which is relatively clean; and (6) the compressor facility already has installed electrical connection so installing high capacity electrical transmission might be cheaper; or optionally (6a) the use of natural gas powered electrical generation would be cheaper because of discounted natural gas price.

There are disadvantages to using pipeline gas that include: (1) property will have to be leased and a short access road cut; (2) quantity of water produced at the facility might be insufficient for the WYSG plant, necessitating the purchase of additional water; and (3) additional valves might be required to drop line pressure (note that this may also be necessary for conventional wells).

Acquiring natural gas from pipelines simplifies gas clean-up, however at the same time the opportunity to benefit from high CO<sub>2</sub> content that might be available at a well is lost.

Locating a Specific Site: During the course of the study, several prospective natural gas operators were contacted. Most of the operators contacted are interested in such a plant development, but are hesitant to share production details at this time due to proprietary nature of the information and competitive nature of the natural gas market. WRI expected protracted negotiations because of the inherent uncertainty of this new technology, the complexity of sourcing natural gas, and the requirements being made to site the first WYSG plant. It is interesting to note that everyone contacted was at least somewhat familiar with GTL technology. All were intrigued with the concept of a small-scale, reduced cost, modular facility that produces a fungible gasoline product from natural gas.

Regarding gas compression facilities, WRI has had no substantive conversations, other than determining compression capacity, and their willingness to supply natural gas. No conversations have been held regarding the specific purchase of natural gas or the quantities of water and electrical available.

First Facility: For relative ease of access and for providing timely service and support, first plant could be located in proximity to Gillette, Casper, or Rock Springs that we have expanded to include Campbell, Natrona, and Sweetwater Counties, respectively, because of the approximate central location of these cities within their counties. According to the WOGCC's most recent figures for the first six months of 2012, Campbell, Natrona, and Sweetwater Counties produced a total of 110.4Bcf, 30.8Bcf, and 111.3Bcf of natural gas, respectively from 6584, 270, and 2995 respective active wells. These are conservative totals because some producers have not yet reported July, 2012 sales. In addition to the productive capacity of the wells, each of these counties contains at least 5 major gas processing/compression facilities dispersed along the existing interstate pipelines. The number of wells and the total natural gas

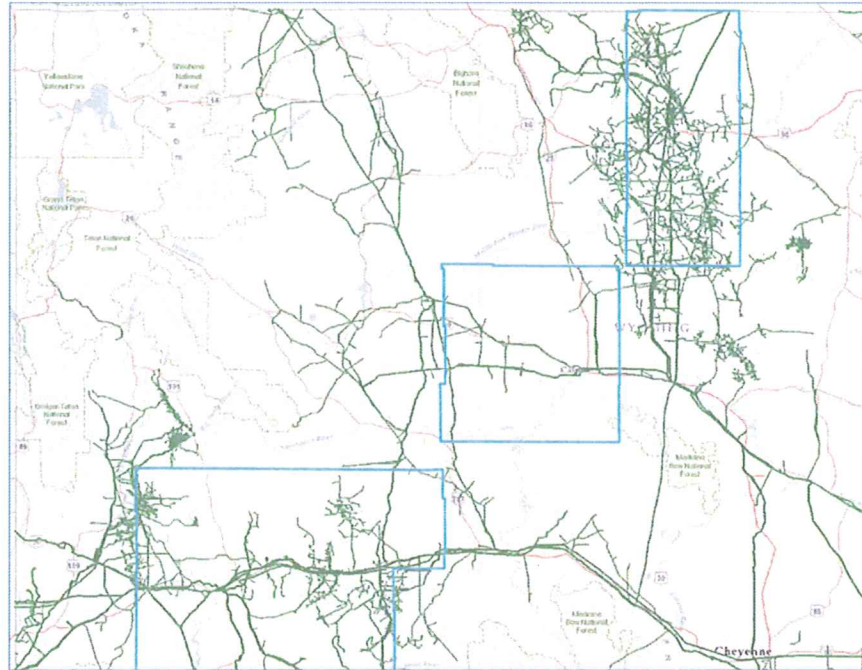
production in these counties can the first WYSG-like GTL plant irrespective of whether fed by wells or compressor.

Based on the natural gas and water requirements of the first plant, Campbell County offers the most opportunities, followed by Sweetwater and Natrona. In the most part, the lack of water production limits prospective operators in Natrona and Sweetwater Counties. Campbell County's list of perspective operators includes all of the major CBM producers, as well as conventional gas and gas/oil producers. The average natural gas production per well in Campbell county is lower than in Natrona and Sweetwater Counties where production is from conventional sandstone sources. Even so, given the average production rate per well in all three counties, sourcing the plant will require production from several wells. The water production per well is considerably higher for the major producers in Campbell compared to the other two counties, indicating the predominance of the Powder River Basin (PRB) CBM source on the data. The majority of waters produced in Natrona and Sweetwater counties are associated with oil and condensate production that will be more costly to clean for reuse.

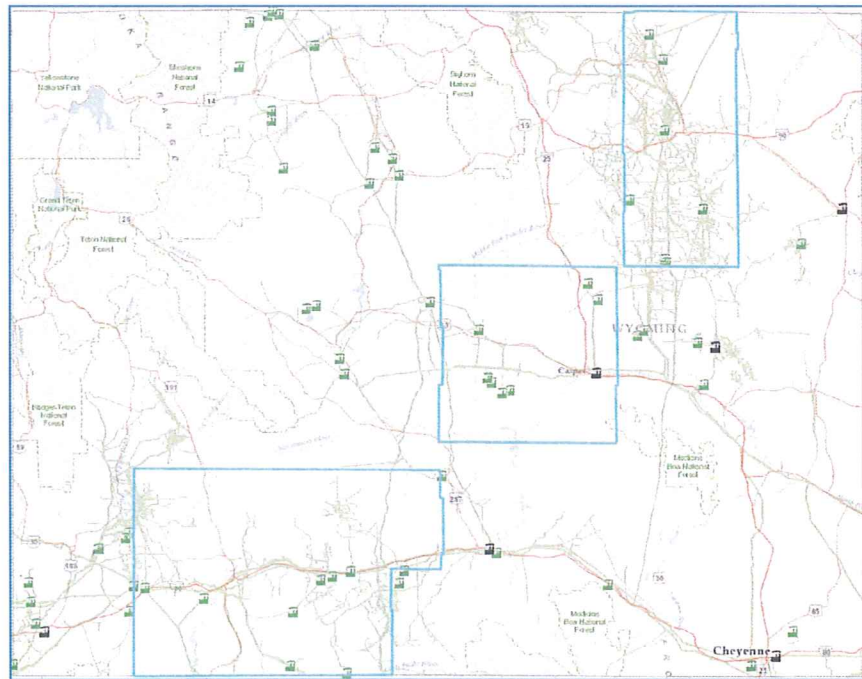
For locating WYSG plant at a natural gas gathering or booster compressor facility or natural gas processing plant, the three counties contain a number of natural gas pipelines. In Figure 5, the green lines shown throughout the State represent pipeline gathering and compression lines as reported by the Wyoming Pipeline Authority. In the general area of Campbell County an extensive network exists for gathering CBNG. Because of the limited life of CBNG well has created a web of feeder lines. Gas processing facilities and associated compressor facilities exist mostly along the interstate pipeline as shown in Figure 6B. Similarly, Figure 7 shows natural gas compression facilities (including gathering, boosting and conventional compression) in the State as reported by the Wyoming Pipeline Authority. A large number of collection and booster facilities in Campbell County is again a reflection of the fact that additional compression is required for CBNG production.

If compressors/pipelines supply the natural gas to the WYSG plant then water would have to be sourced separately. In the CBNG obtaining additional water from a nearby operator's wells is an efficient and convenient resource. Nevertheless, considering the small water needs of the WYSG plant, securing limited water rights from terrestrial sources for the planned life of the WYSG plant is probably the best option thereby potentially opening up all the production in the three counties for GTL conversion.

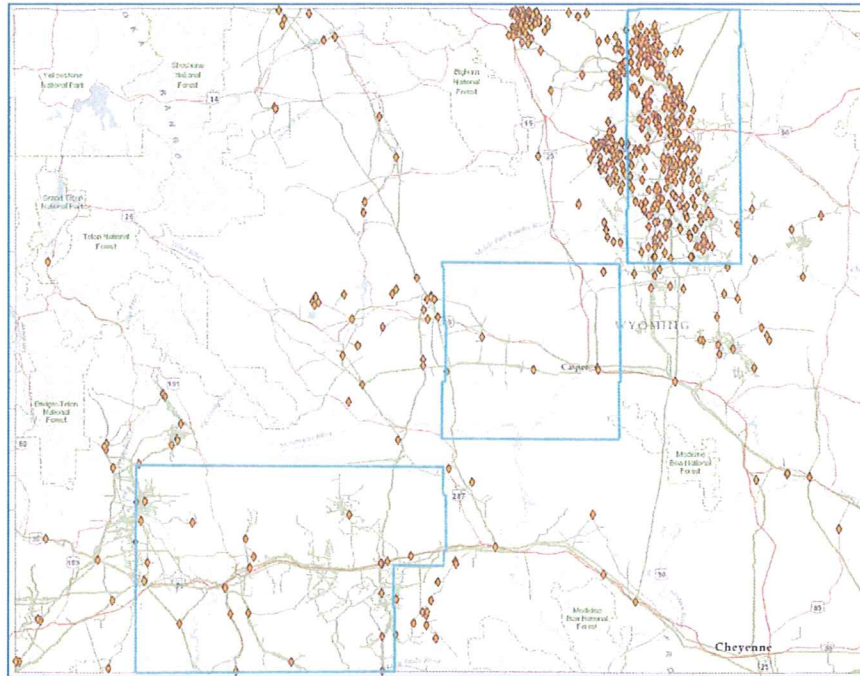




**Figure 5. Natural Gas Pipelines in Campbell, Natrona & Sweetwater Counties**  
 (Figure courtesy of Wyoming Pipeline Authority software.)



**Figure 6. Gas processing plants (Green symbols) in Campbell, Natrona, & Sweetwater Counties.**  
 (Figure courtesy of Wyoming Pipeline Authority software)



**Figure 7. Gas compressor stations (Gold symbols) in Campbell, Natrona & Sweetwater Counties.**  
 (Figure courtesy of Wyoming Pipeline Authority software)

#### **Proposed Alternative Plan for Siting the First MTG Plant**

A primary resource objective of this proposal is to place stranded natural gas into production. Based on available WOGCC data it appears that CBNG is at a significant risk for being eliminated as a resource in the State. The reasons are: (1) generally lower production rates, (2) significant water handling and cleanup costs, (3) and the need for using booster compression to raise the product to minimum pipeline pressures. Because of these considerations CBNG producers may be more open to adopt WYGS technology.

CBNG can meet all of the WYSG plant needs except the electrical power requirements. The CO<sub>2</sub> content in some regions reaches about 8%. Decent quality water is either produced from the wells or is available from water impoundments. Gas is available from well pods at needed rates and at the required minimum delivery pressure of 15psia. In addition, roads to CBNG compressor facilities are well maintained to ensure year-around access.

If power can be produced locally then CBNG sites are ideal for deployment of WYSG Process.

## **Public Perception and Acceptance**

In today's environment, a factor in the site selection process that needs to be considered is public perception of the GTL plant and ultimate acceptance. In addition, the interests of individual landowners and neighbors are important to the planning process if it is beneficial to site a plant where surface rights are privately owned.

The first plant of its kind in Wyoming will likely draw more attention than later constructions. It is the general perception that Wyoming as a whole is receptive to using and benefitting from mineral resources. That general perception may have local consequences, however. Recent gas production related environmental issues such as CBNG produced water, contamination of aquifer with fracking chemicals, and non-attainment areas in western Wyoming are all regularly in the news. It is important to manage the public perception of WYSG-like GTL processes. WYSG process is conceived to be a clean operation with a small area and carbon footprint with minimal emissions and effluents. Therefore it will be important to insure that public perception is accurate. A negative environmental image of new coal-based conversion may or may not be accurate. Yet, to some extent this makes acceptance of new natural gas conversion plants easier. While not perfect, natural gas plants have a better reputation as cleaner and less impactful to the environment. The fact that this plant will produce gasoline for US consumption is positive in that it is a step towards energy independence. What little sulfur exists in natural gas will be removed before reforming, so the products of the plant are quite clean. The relatively low value Wyoming natural gas will be converted into a value added product and develop additional tax revenue for Wyoming. Jobs will be created during construction, operation and engineering support.

It should be understood by all that WYSG-like GTL plants are indeed chemical plants and in that regard it is nearly impossible to build a "pretty" chemical plant. The plant will produce carbon dioxide albeit less than a conventional plant on a per barrel basis. Similarly, the GTL plants will be a net user of water. Although this is also a relatively small number, some locals in the farming or ranching community could see this as an instance of competition for a precious resource. The best approach to public acceptance is to always put these issues in perspective. A rendering of the site will show that this is a small and harmless-looking facility. We must ensure that the public understands that this is not a refinery. As shown earlier in this report, direct comparison of water use and carbon dioxide production should be made to other uses such as agricultural and power plant operations. The comparison is dramatic. Emphasis can be placed on positive aspects such as clean operation and a means to oil import reduction. Process economics are a valuable tool to show jobs creation, positive impact on local economy and addition to state income.

## **Legal Research**

This part of the report examines the legal feasibility for siting WYSG facilities in Wyoming. Research for this report included examining the statutory/regulatory framework for the following: state and federal lands, Wyoming DEQ Divisions (Air Quality, Solid and Hazardous Waste, Water Quality, and Land Quality), WOSLI, OGCC, PSC, WYDOT, the State Engineer's Office, BLM, EPA, taxation, Surface Use Agreements, eminent domain, and county authorities. In addition to studying the existing statutory and

regulatory framework, this report identifies areas where gaps in the law may exist and/or where the current framework presents hurdles for siting WYSG-like GTL facilities. This report identifies possible legislative “fixes” for those gaps and/or hurdles; however the analysis of any legislative “fix” is beyond the scope of this report. Any proposed action for addressing these possible gaps or hurdles will require further analysis, to determine the broader implications on the various interest groups, including the benefits for encouraging WYSG facilities in Wyoming.

The Wyoming statutes likely authorize oversight of WYSG facilities and processes from the following agencies: Wyoming OSLI for siting on state lands; Wyoming DEQ Divisions, Air Quality, Solid and Hazardous Waste, and Water Quality. Each of these agencies may require permits for the following:

- OSLI: Special Use Lease for siting WYSG facility if on State Lands.
- DEQ – AQD: Minor Source Permit regulating entire WYSG facility; however, WYSG facility may qualify for a permit waiver.
- DEQ – SHWD: Oversight required; however, a regulatory determination may be requested to obtain a written opinion as to whether a permit is needed for WYSG facility.
- DEQ – WQD: General Permit Storm Water Pollution Prevention Plan (SWPPP).
- State Engineer’s Office: Permit to appropriate surface or ground water necessary to meet the water requirements of the facility and process.
- County Zoning: Potential zoning requirements or permits; potential requirements will vary by County.

Several potential hurdles exist where either the statutes are silent or vague as far as they would affect WYSG-like GTL facilities or the WYSG process, those include:

- OGCC: Regarding whether or not the WYSG process should be considered production or post-production for natural gas operations, and whether or not the OGCC has authority to regulate the sale of natural gas from the producer directly to the end user.
- PSC: Regarding whether or not the PSC or the Supreme Court might view WRI as ‘one end user,’ the Court’s factor for determining if the natural gas sale qualifies as a sale “to or for the public.”
- Siting Issues: Including surface leasing and right to use the surface.
- DEQ-AQD: Whether or not the agency should seek to assume primacy over the PSD program, including CO<sub>2</sub> regulation, in lieu of the EPA regulating and issuing PSD permits within Wyoming.

Potential incentives and recommendations for encouraging natural gas value-added products in Wyoming, such as proposed WYSG facility, include statutory changes and tax incentives which include the following considerations.

The OGCC may need to determine whether or not a value-added products facility is part of the natural gas production or post-production. Such a determination may dictate whether or not the OGCC has jurisdiction to regulate natural gas value-added products. The legislature may choose to make such a determination for the agency, in which case a statutory change might provide the necessary certainty

for natural gas value-added product production. More research is needed regarding potential OGCC jurisdiction over natural gas value-added products.

Due to the uncertainty regarding PSC jurisdiction, it is recommended that the state legislature examine this issue and consider an additional exemption in W.S. § 37-1-101(a)(vi)(G) that provides a specific exemption for natural gas value-added products from PSC jurisdiction. This issue may need additional research to fully understand the broader implications.

The legislature may consider including WYSG in 30-5-401 for oil and gas operations only for purposes of gaining access under the statute and for ensuring surface use agreements. However, this raises problematic eminent domain issues given the current eminent domain climate in Wyoming. This issue needs more analysis and consideration of the potential siting hurdles for natural gas value-added products facilities before making any changes to the current law.

The Wyoming State Legislature requested the DEQ-AQD to examine the federal PSD permitting program, which includes CO<sub>2</sub> permitting, and study the potential impacts to Wyoming if the state chose to seek primacy authority to regulate PSD permits under the DEQ-AQD. If the state assumed its primacy over the PSD program CO<sub>2</sub>, the state DEQ-AQD then has the ability to work directly with state value-added production facilities and other CO<sub>2</sub> emission producers to coordinate permitting and reporting efforts. The DEQ-AQD may provide a more in-depth analysis of the potential hurdles and benefits of state primacy in this area. More research is needed regarding PSD and CO<sub>2</sub> permitting and the implications of assuming state primacy for overseeing the PSD and CO<sub>2</sub> program in Wyoming.

In conclusion, Wyoming's statutory and regulatory framework provides some structure for moving natural gas value-added production, such as WRI's proposed WYSG facility, forward in Wyoming. The identified issues require more research to fully understand the broader implications for addressing those hurdles and/or gaps in the law. The recommendations above are not conclusive and are merely possibilities that the legislature may choose to consider.

Statutory and/or Regulatory Hurdles or Gaps: While a statutory and regulatory structure exists to provide the framework from which to develop Wyoming's natural gas into value-added products, several gaps or hurdles exist in law that may create obstacles that for construction of a value-added products facility. Each of the potential hurdles or gaps need further analysis to determine the scope of impact on WYSG-like GTL facilities. Additionally, any possible solutions need further analysis and consideration as to the impact to other stakeholders and interests. The possible hurdles or gaps include OGCC jurisdiction, PSC jurisdiction, surface use issues, and CO<sub>2</sub> regulations.

The OGCC may not have the statutory/regulatory authority allowing natural gas producers to sell directly to a products manufacturer straight from the well (outside of sales related to pipeline transportation and distribution). Additionally, it is not clear whether the OGCC jurisdiction extends to natural gas conversion facilities like the proposed WYSG facility. A determination may be needed as to whether a value-added products facility is part of the natural gas production or post-production. Such a determination may decide whether or not the OGCC has jurisdiction to regulate natural gas value-added

products. More research is needed regarding OGCC jurisdiction impacts on natural gas value-added products.

The PSC jurisdiction is not clear as to what constitutes a sale of natural gas “to or for the public.” The Wyoming Supreme Court holds that the sale of natural gas to one end-user does not constitute a sale “to or for the public;” and is not then under the jurisdiction of the PSC. A possible solution includes providing an exemption in 37-1-101 that grants the sale of natural gas for the purpose of value-added products an exemption from PSC jurisdiction.

Private landowner surface use agreements could be a potential obstacle/hurdle and maybe should be included in 30-5-401 for oil and gas operations only for purposes of gaining access under the statute and for ensuring surface use agreements for small conversion plants at the well pad site. However, this raises eminent domain issues which are problematic given the current eminent domain climate in Wyoming. This issue needs more analysis and consideration of the potential siting hurdles for natural gas value-added products facilities.

An issue of regional and national concern includes CO<sub>2</sub> monitoring, permitting, and general regulatory oversight. Currently, the EPA regulates CO<sub>2</sub> emissions under the auspicious of the CAA and administers the federal CO<sub>2</sub> permitting program for CO<sub>2</sub> emissions that exceed the threshold of 100,000 tons per year. The Wyoming State Legislature requested the DEQ-AQD to examine the federal CO<sub>2</sub> permitting program and study the potential impacts to Wyoming if the state chose to utilize the state’s primacy authority and regulate CO<sub>2</sub> under the DEQ-AQD. While regulating CO<sub>2</sub> is a highly controversial topic; such state regulation may provide a benefit to natural gas conversion facilities due to the amounts of CO<sub>2</sub> waste produced during the natural gas conversion process utilizing water and other sources. If a value-added products facility is required to obtain federal permits, the possibility of a lengthy and controversial permitting process may create a significant hurdle for small scale value-added product production. If the state assumes primacy over regulating CO<sub>2</sub> emissions under the PSD program, the state DEQ-AQD then has the ability to work directly with state value-added production facilities and other CO<sub>2</sub> emission producers to coordinate permitting and reporting efforts. The DEQ-AQD may provide a more in-depth analysis of the potential hurdles and benefits a state run CO<sub>2</sub> permitting system may create.

Potential Incentives: Possible state incentives available include potential tax incentives and other possible statutory changes. The discussion and the policy considerations regarding potential tax incentives are applicable to other new technologies such as coal-to-liquids conversion. Potential tax incentives include providing either a tax incentive on the severance tax on the front end or a tax incentive on the sale of the value-added product on the back end. Possible statutory changes may include changes effecting PSC, OGCC, DEQ-AQD, and surface use agreements.

Tax Structure: If the PSC has jurisdiction over the sale of natural gas for a value-added products conversion facility, tax implications may apply. If no PSC jurisdiction applies to the sale of natural gas for value-added products, then no additional tax implications from the PSC may apply. This may require a statutory exemption from PSC jurisdiction; however, current case law may be

enough to provide assurance that no PSC jurisdiction exists. More research is needed to understand the gap in PSC statutory law regarding this type of sale of natural gas for consumption and the potential incentives for restricting PSC jurisdiction.

The Wyoming severance tax requires that natural gas be taxed at the point of sale from the producer to the consumer whether the consumer is a pipeline, a utility, or a conversion facility. No matter the purpose of consumption, the gas is taxed at the point of severance. The severance tax is based on the “fair cash market value” of all produced oil and gas. W.S. 30-5-116(b) and W.S. 39-14-203. Any oil or gas sale in Wyoming is payable by the purchaser; however, “[p]urchasers have the option of paying the tax for producers.” W.S. 30-5-116(b) and (d). Severance tax payment arrangements should be clearly outlined in the contract for purchasing natural gas by a value-added products producer in order to ensure the severance tax is not duplicated. OGCC Regulations, Ch. 3 § 41(d). The statute provides an exemption from the severance tax which includes natural gas “used in producing operations or for repressuring or recycling purposes.” W.S. 30-5-116(b)(iii). This exemption again raises the issue as to whether or not natural gas value-added production is part of oil and gas operations/production or post-production. Another issue includes whether or not a natural gas conversion facility is defined as natural gas “recycling” as used in the exemption above, or if the natural gas is consumed. The above exemption seems to raise more questions than it answers, perhaps indicating that a new exemption may be necessary if the legislature deems a tax incentive on the production to be more advantageous than an exemption for sales.

If the legislature prefers to incentivize natural gas value-added products through sales tax exemptions, the legislature may consider a sales tax exemption for a number of years in order to help a value-added production facility recoup construction costs sooner, making the production facility more attractive for investors. Any decision by the legislature to provide a tax incentive should consider the potential implications on the various stakeholders as well as the long term impact on value-added product facilities in the state.

### Statutory Changes

Several potential hurdles exist where either the statutes are silent or vague as far as they would affect WYSG facilities or the WYSG process within the OGCC, PSC, surface use agreements, and DEQ-AQD statutes. Within each of these areas, the following issues and potential changes may be appropriate for consideration by the legislature. These suggestions are merely for the legislature’s consideration and should not be considered final recommendations as each of these suggestions requires more research and consideration of issues outside the scope of this report to understand the broader legal implications.

- OGCC: The Legislature may consider providing an exemption in the Oil and Gas Act, providing that WYSG process and facility are not considered part of natural gas operations or production. Additionally, the legislature and the OGCC could clarify

whether or not the OGCC has authority to regulate the sale of natural gas from the producer directly to the end user.

- **PSC:** The Legislature may consider providing a statutory exemption that clarifies the PSC and the Wyoming Supreme Court's treatment of the sale of natural gas to end users, that the WYSG process is not a sale "to or for the public," and that the PSC does not have statutory authority to oversee the sale of natural gas to WYSG facilities, nor the WYSG process.
- **Siting Issues:** The Legislature may consider including WYSG facilities within W.S. § 30-5-401 only for purposes of gaining access under the statute and for ensuring surface use agreements; however, the legislature may consider providing that WYSG facilities do not have eminent domain authority.
- **DEQ-AQD:** The Legislature may consider the option of the state assuming primacy over the PSD permitting program, currently regulated under the EPA.

Again, these issues need additional research beyond that provided in this report in order to understand the broader implications.

Wyoming's statutory and regulatory framework provides some structure for moving natural gas value-added production, such as WRI's proposed WYSG facility, forward in Wyoming. Several agencies will likely have regulatory authority for permitting and oversight of WRI's proposed WYSG facilities, including the OSLI, the DEQ-AQD, the DEQ-SHWD, the DEQ-WQD, the State Engineer's Office, and potentially the County in which WRI sites the WYSG facility. The framework that currently provides regulatory and permitting oversight may be sufficient to move a WYSG facility forward.

### **Product Value**

*As a part of this study, a consultant was engaged to establish the value of gasoline product from the WYSG process. This section is excerpted from the consultant's report.*

The product from WYSG process exhibits many positive finished gasoline product qualities (no sulphur, decent RON through aromatic content) but has properties that will cause product to be discounted or not accepted by refiners unless further processed or diluted with other streams. Most refiners should be willing to accept the WRI product as an intermediate feed or gasoline blending component.

Negatives for pricing WYSG process product are:

- Small volume (unless store for a while, but impact of storage on product stability needs to be understood)
- Chemically arranged molecules
- Light Hydrocarbon's in the stream – specifically in summer time ( above RVP spec)
- Durene content if sold as standalone finished product

Positives for pricing WYSG process product include



- + Negligible sulphur
- + Low olefinic content (separate to aromatic content)
- + High in aromatics, good for gasoline pool blending, as an octane enhancer
- + Majority of stream is within Naphtha boiling range
- + Benzene below finished gasoline product specification
- + Can be sold as one stream
- + Can be readily blended/diluted into a final gasoline product

The WRI product could be sold as a wholesale item to Diluent suppliers to the OilSands in Alberta, Canada (i.e. Connacher in Montana), and to local refineries as an intermediate product stream in Wyoming (i.e. Frontier), Colorado (Suncor-Denver), and Montana. A secondary disposition could be petrochemical operators such as ethylene producers (i.e. Exxon Joliet, Illinois).

With feasible dispositions available, the likely and lowest value disposition for this material is as feed to a refiner's naphtha hydrotreater or directly to its naphtha reformer. Based on the analysis of the product, and current WTI pricing of \$89/bbl, WYSG process product price would be around \$94/bbl or \$5/bbl above WTI before discount/premium. A plausible disposition is as product grade naphtha for sale to OilSands diluent users with a price of \$98/bbl (+\$9/bbl above WTI). If refiner can take WYSG process product directly it could be used in Gasoline blending pool at \$112/bbl (+\$23/bbl).

Non-adjusted Suggested Price Range for WYSG process product = \$94-112US/bbl with WTI at 89/bbl. The product should sell between \$5 to \$23/bbl above WTI without applying any major discounts.

With suggested discounts/premiums applied to the WRI product, the WRI product should sell in the \$94-\$106/bbl range or \$5-17/bbl above WTI, with a high probability price of \$98/bbl (\$9/bbl above WTI) as a diluent contributor.

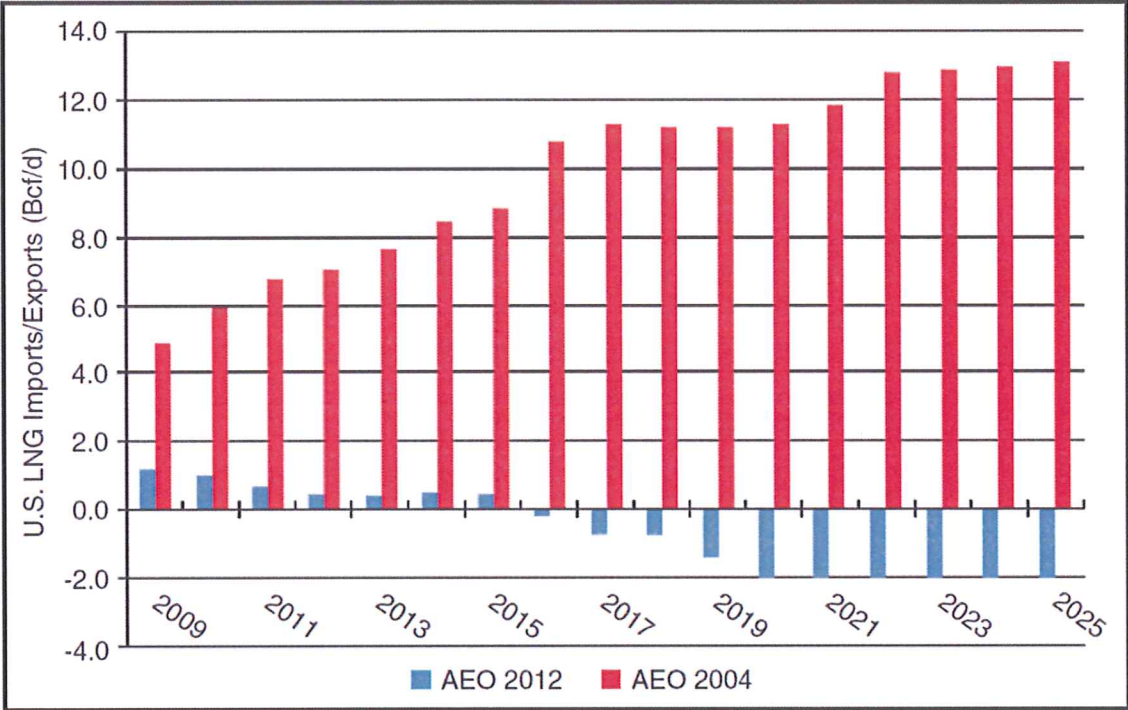
### **Process Economics**

In the past, the price of natural gas and the price of crude oil were so closely connected that investors used a ratio varying from 6:1 to 10:1 to compare the price of oil to the price of gas. Whenever prices deviated from this ratio, investors would invest on the side that was undervalued according to this ratio and they would make money when the market adjusted and prices came back to their historic ratio. It only became possible to observe this ratio after natural gas pipeline technology became available and was applied so that natural gas could be brought to market and become a commodity starting around the 1930's. Once industry and individual consumers were able to easily obtain both natural gas as well as oil-derived products like fuel oil, kerosene, etc., they became able to choose between equipment and appliances that ran on different fuels. Industrial boilers could be designed to run on fuel oil or natural gas. Power companies could use both types of generators and chose to operate one type or the other or a combination based on prices of fuels. As a result of widespread use and substitution of both natural gas as fuel and crude-derived fuels, the prices of these commodities were linked as described above. If the price of crude oil rose rapidly, but natural gas prices stayed low, consumers who were able to switch from crude-oil derived fuels to natural gas would do so. This changed the demand for the different

commodities, driving the price of natural gas up and the price of crude oil down, and the investors who used their price ratio to inform investment decisions would have made money.

Something very different has been happening in recent years. The price of crude oil has soared to record highs and the price of natural gas has persistently stayed so low that new discoveries of natural gas are being plugged and ignored as energy production companies look for profitable oil discoveries. It appears that the prices of these commodities have become disconnected. Experts offer a number of different explanations for the continued low price of natural gas in the face of high oil prices. Many experts point out that substitution between the two commodities has been reduced. Modern power plants and industrial energy consumers are designed to run on one type of fuel or the other. A very large percentage of crude oil is used to make fuel for the transportation sector, and the transportation sector makes no significant use of natural gas for fuel. Another point is the increasingly large domestic supply of natural gas. Advances in technology have changed the domestic natural gas production picture drastically, as can be seen in Figure 1. This graph shows the expected US liquefied natural gas imports and exports as of 2004 and as of 2012. In 2004, experts expected importation of natural gas to increase steadily over two decades. In fact, this upward trend in natural gas imports has not been realized and the new predictions are that the US will become a net exporter of liquefied natural gas in less than 5 years. This large increase in US natural gas is purportedly due to the recent advances in technology that are being used to extract fossil fuels formerly impossible to reach.

**U.S. LNG Imports**



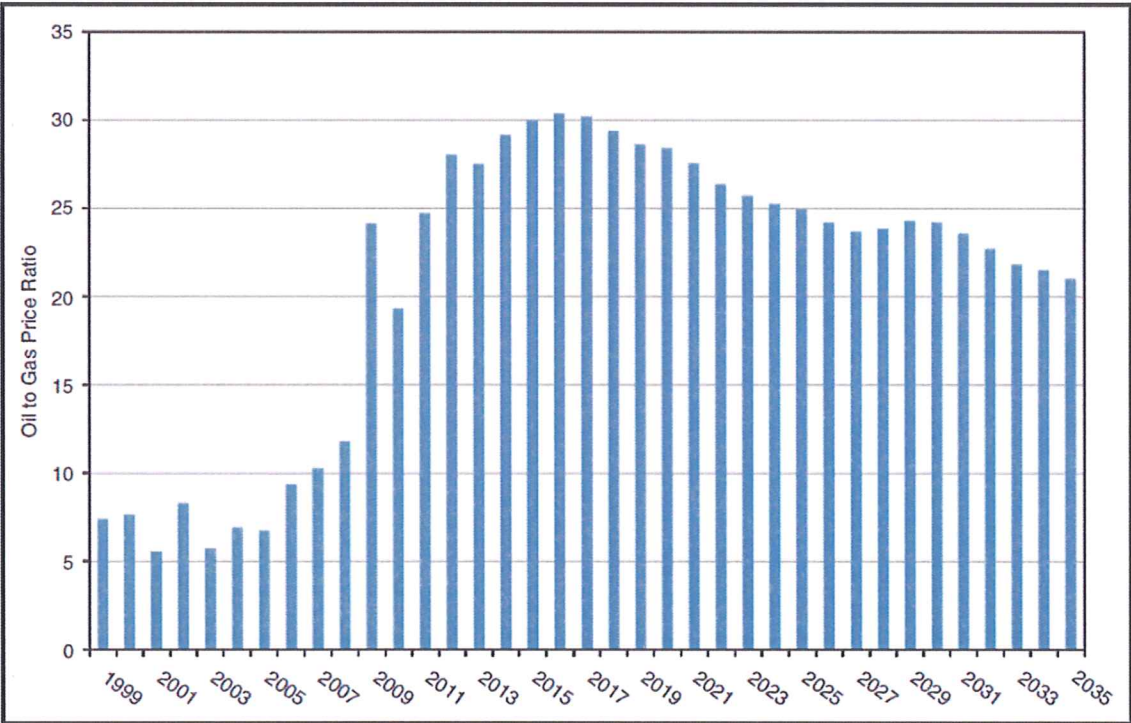
Source: EIA, Annual Energy Outlook Reference Cases, 2004 and 2012

According to the experts, then, the disconnected price of natural gas and crude oil is based on physical realities, not any market malfunction or manipulation. Some economists suggest that prices will not

return to their former lock-step behavior until the physical realities of fuel production and/or consumption change. A potential investor who is interested in profiting from this change in market reality would naturally want to consider gas-to-liquid technology. An important topic to explore when making this consideration is the expected duration of the disconnect between natural gas and crude oil prices. It would not be unreasonable to assume that significant differences in prices like the current trends will result in changing consumption. When the cost of energy from natural gas is much lower than the cost of energy from gasoline or diesel, consumers will be interested in buying cars that run on natural gas or converting their current vehicles to run on natural gas. Many factors affect the pace at which such a change can and will be adopted at a large scale. Technical feasibility, regulatory environment and the habits of the general population will all play a role. While it is impossible to predict if and when large-scale adoption of natural gas-powered vehicles might occur, it is reasonable to say that it would take many years for such a transition to take place if it ever does. The same is true for conversion of industrial equipment to gas.

Assuming that a large increase in natural gas consumption can and will happen, how big would that increase have to be in order to impact prices? According to the EIA Annual Energy Outlook, the oil to gas price ratio is expected to continue increasing slightly until about 2016 and then slowly decrease, but remain above 20:1 and not return to 10:1 or lower during the span of their prediction, which goes to 2035.

**Crude Oil and Natural Gas Price Ratio**



Source: EIA, Annual Energy Outlook 2000-2012

In light of this favorable outlook, it makes sense to invest in gas-to-liquids facilities. The next question for an investor is which type of GTL technology to invest in. The process that WRI presents in this paper has been developed with several issues in mind for the investor.

- Payoff period. Although the outlook for the price disconnect between natural gas and liquid fuels looks advantageous and lasting, it is recognized that this is a relatively new technology and a very new market situation. GTL investments will be perceived as containing more risk than other, more traditional options. Accordingly, we have targeted a payoff period that is shorter than what is typical for more traditional plants.
- Capital cost. Minimizing the capital cost of a WYSG facility without significantly impacting product quality or production rates will play major role in achieving a short payoff period.
- Versatility. The modular design of the equipment used is advantageous for the logistics of physical field assembly, but allow a plant to adapt to changing market conditions. Modest plant alterations would result in a facility that produces methanol, mixed alcohols or olefins instead of gasoline.

### Economics of Scale

Preliminary estimates of fixed capital investment from \$20 to \$30 million for a new WYSG plant with production capacity of 150 bpd range. Various sources provide a confidence that the estimates are in the right range. Increasing the size of the plant to 500 bpd could be expected to increase the fixed capital investment to about \$40 or \$50 million. We make an assumption that a high CO<sub>2</sub> natural gas could be obtained at a well site for less than pipeline prices. If the cost of carbon dioxide-laden natural gas is \$2.00 per thousand cubic feet and the selling price of crude gasoline to be used as a blendstock is \$106 per barrel, annual revenue would be just under \$16 million. The annual production cost would be just over \$11 million, and a \$40 million plant would be paid off in less than 9 years. Under the same conditions, a \$20 million, 150-bpd capacity plant would take decades to pay off. Thus, there is strong incentive to further investigate the 500-bpd sized plant. One key component of further investigation will have to be more in-depth legal research. If a 500-bpd plant is large enough to trigger significant permitting issues, those complications will have to be taken into consideration. It will also be necessary to find a good source of low-cost natural gas that can produce enough gas to fill a larger plant. However, our preview of the regulatory issues and gas production sites suggests that a plant with a capacity of 500 bpd may be feasible.

Based on these assumptions, economic figures were calculated for a 500 bpd facility. Summary results are displayed in the Table 8.

Table 8 Summary Process Economics

<b>Product:</b>	<b>Gasoline</b>	
<b>Operating Time:</b>	300	days/year
<b>Capacity:</b>	500	bbl/day
<b>Capacity:</b>	20.83	bbl/hr
<b>FCI:</b>	\$ 40,500,000.00	
<b>Product Price:</b>	\$ 106.00	per bbl
<b>Annual Revenue:</b>	\$ 15,900,000.00	per year
<b>Production Cost:</b>	\$ 11,473,430.00	per year
<b>Profit:</b>	\$ 4,426,570.00	per year

## **Future Developments**

First step in building a GTL industry in Wyoming is to build and operate a single plant at a scale between 150 and 500 barrels per day. This plant will serve as a technology demonstration unit and with state support it could be designed to be flexible enough to produce diesel, gasoline, dimethyl ether and other chemicals. Plant could be designed to be modular and flexible enough to be operated as an FT, MTG or a mixed alcohol synthesis facility. Such a plant could be financed jointly by the state and industrial developers. Successful operation of the first plant could spur demand by other gas developers for new plants at other locations around Wyoming. The new plants could include alternative liquid products such as butanol, olefins, dimethyl ether, mixed alcohols or Fischer Tropsch diesel. We are aware of several groups who are interested in either FT, or MTG or mixed alcohol synthesis from natural gas.

It should be noted that the limited scale of the first plant will limit the profitability, as the labor costs per barrel are significant. The path forward from the first plant creates options, and analysis of those options is critical to future financial success. In that regard, a central facility for controlling and servicing several distributed plants is a way to reduce labor cost. All future options would have to consider the natural gas price versus the market value of gasoline and other liquid fuels.

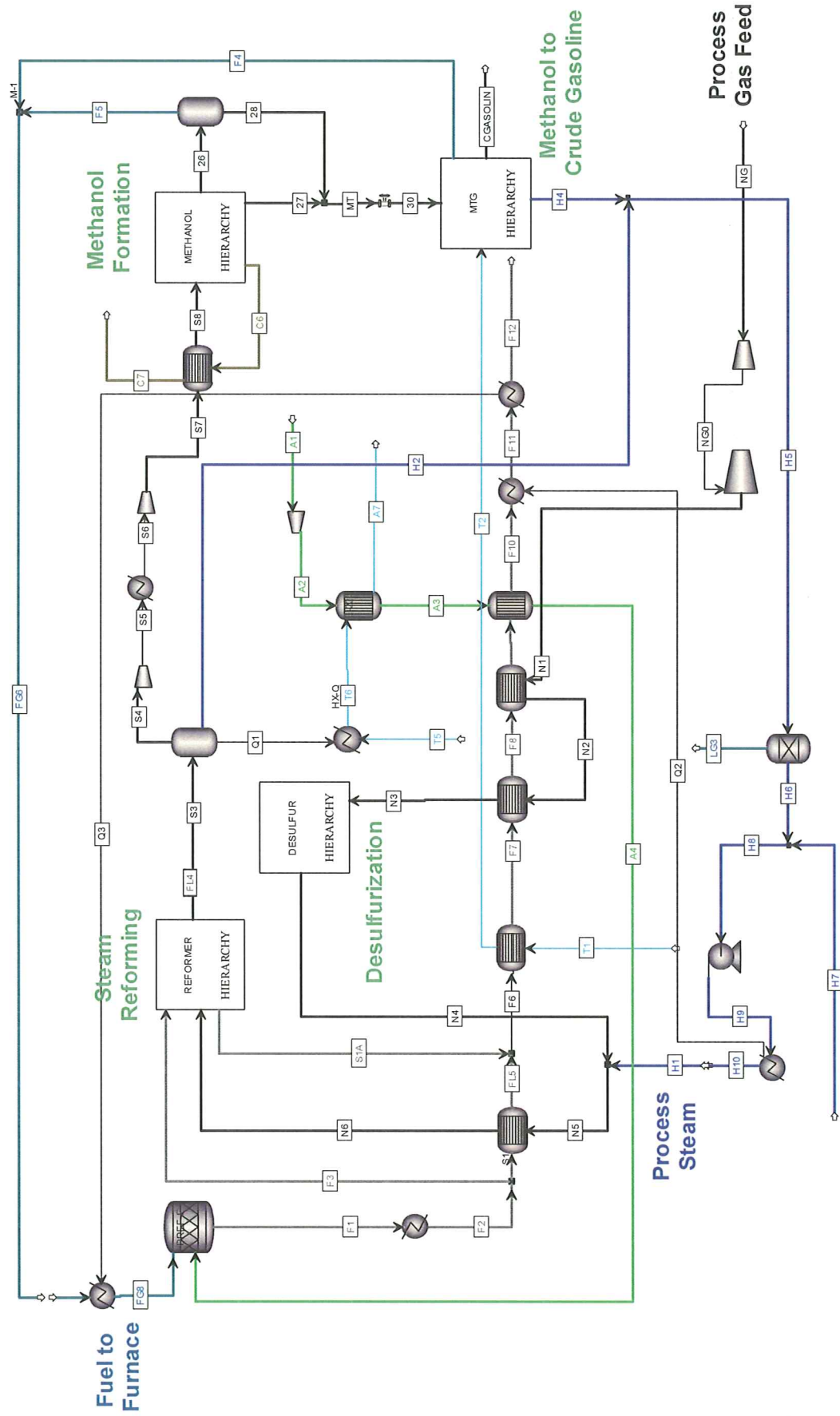
Most of the hardware for conversion of synthesis gas from the natural gas reformer to liquid fuels would be identical for a coal to liquids plant. Instead of the reformer, a gasifier and gas clean up system would be built. In that regard, development of a GTL industry can be used as a stepping stone toward larger coal-to-liquids plants.

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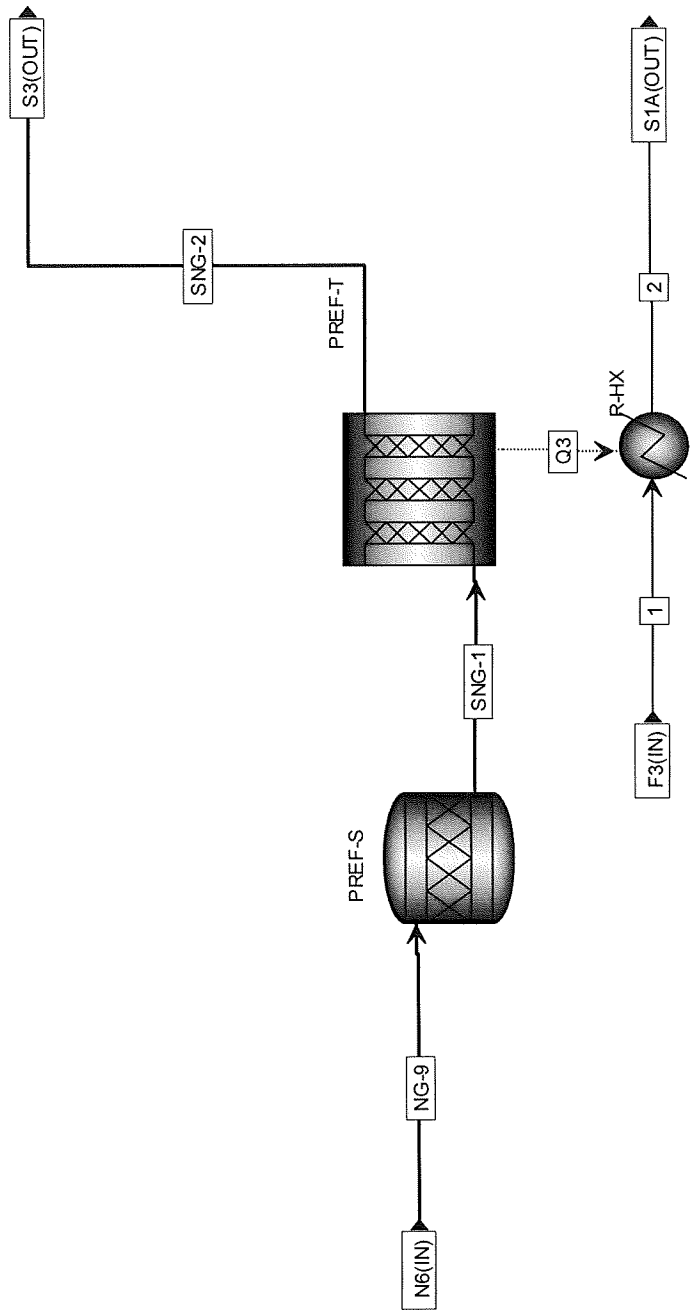
**APPENDIX I**  
**Process Flow Diagrams Used in Modeling**

# Overall System





# Steam Reformer







**APPENDIX II**  
**Product Economics Evaluation Report**



August 4, 2012

Western Research Institute  
365 North 9th St  
Laramie, WY 82072-3380

Attention: Amanda K Hansen (ahanse15@uwyo.edu)

CC: Thomas Barton (TBarton@uwyo.edu)

SUBJECT: Products Economics Evaluation, Revision 1

Number of pages: 9

Please accept this report prepared to provide insight into suggested price valuation for the gasoline-quality product produced from the WRI conversion process noted in Figure 1.

**Summary:**

The WRI product exhibits many positive finished gasoline product qualities (no sulphur, decent RON through aromatic content) but has properties that will cause product to be discounted or not accepted by refiners unless further processed or diluted with other streams. Most refiners should be willing to accept the WRI product as an intermediate feed or gasoline blending component.

Negatives for pricing WRI product

- Small volume (unless store for a while, but impact of storage on product stability needs to be understood)
- Chemically arranged molecules
- Light Hydrocarbon's in the stream – specifically in summer time ( above RVP spec)
- Durene content if sold as standalone finished product

Positives for pricing WRI product

- + Negligible sulphur
- + Low olefinic content (separate to aromatic content)
- + High in aromatics, good for gasoline pool blending, as an octane enhancer
- + Majority of stream is within Naphtha boiling range
- + Benzene below finished gasoline product specification
- + Can be sold as one stream
- + Can be readily blended/diluted into a final gasoline product

The WRI product could be sold as a wholesale item to Diluent suppliers to the OilSands in Alberta, Canada (i.e. Connacher in Montana), and to local refineries as an intermediate product stream in Wyoming (i.e. Frontier), Colorado (Suncor-Denver), and Montana. A secondary disposition could be petrochemical operators such as ethylene producers (i.e. Exxon Joliet, Illinois).

With feasible dispositions available, the likely and lowest value disposition for this material is as feed to a refiner's naphtha hydrotreater or directly to its naphtha reformer. Based on analysis in



report, and current WTI pricing of \$89/bbl, WRI product price would be around \$94/bbl or \$5/bbl above WTI before discount/premium. A plausible disposition is as product grade naphtha for sale to OilSands diluent users with a price of \$98/bbl (+\$9/bbl above WTI). If refiner can take WRI product directly it could be used in Gasoline blending pool at \$112/bbl (+\$23/bbl)

Non-adjusted Suggested Price Range for WRI product = \$94-112US/bbl with WTI at 89/bbl. The WRI product should sell between \$5 to \$23US/bbl above WTI without any major discount applied to the WRI product.

With suggested discounts/premiums applied to the WRI product, the WRI product should sell in the \$94-\$106/bbl range or \$5-17/bbl above WTI, with a high probability price of \$98/bbl (\$9/bbl above WTI) as a diluent contributor.

**Introduction:**

The WRI process takes Natural Gas from local wells and transforms it to a naphtha boiling range product as shown in Figure 1.

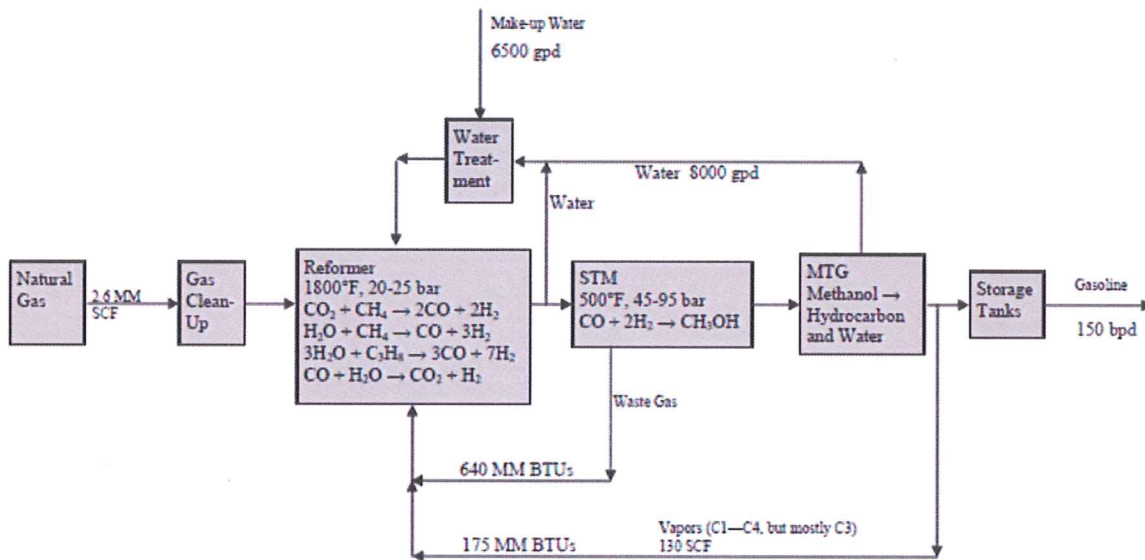


Figure 1 Generalized gas processing scheme for Gasoline production

**Product Description:**

Table 1 is the expected product characteristics as provided by WRI. The WRI product does exhibit some favourable finished gasoline product values (RON, sulphur) but the RVP value, and durenene concentrations will create at minimum a discount for the WRI product or in the case of durenene, may prevent refiners from accepting the material. However, dilution through blending should alleviate any concerns for a refiner to meet all final product specifications. As constituted in Table 1, the WRI product could not be considered for direct sale for transportation consumption.

Of positive note, there are a lot of aromatic molecules in the stream which help with the octane number (RON). With the high aromatic content, the WRI product will be considered an octane enhancer. There is no sulphur so no further sulphur treatment is needed. Also, benzene is at low levels, well below the EPS MSAT requirement for annual average benzene content of 0.62vol% in gasoline (reformulated and conventional).

The RVP value is high for summer gasoline specifications (7-7.8 psi in July, August and less than 9 in May/June) but acceptable for winter conditions (< 15 psi). The WRI



product will likely get discounted slightly for RVP unless the dilution argument is successful or the light hydrocarbons can be separated out before sale.

Durene is normally present in gasoline in the 0.2-0.3wt% range. The WRI product is expected to be 10 times greater at around 2.5wt%. The problem with durene is its high melting point that has caused carburettor “icing” when present in large amounts in the gasoline (above 5wt%). Durene’s boiling point at atmospheric conditions is approximately 378°F which is at the heavy end of the WRI gasoline product (98 vol% boiling point based on table 2 information).

C5+ Nonaromatics	51 wt%
Aromatics	49 wt%
Aromatics 6-10	98.7 wt% of total aromatics
A 11+ (includes n)	1.3 wt% of total aromatics
Durene	2.5 wt%
Approximate RVP	12 psi
Approximate RON	92
Sulfur	0 ppm
Benzene	0.3 vol%

Table 1 – WRI supplied expected product specifics

Component	Vol%	TBP of C5+, Vol%	
		Dist [%]	T [F]
Methane	0.75	IBP	87.6
Ethylene	0	10	111.0
Ethane	0.35	30	158.0
Propylene	0.3	50	205.4
Propane	4.2	70	266.3
Butylenes	1.5	90	336.6
Butane	11.2	95	359.1
C5+'s	81.7	98	377.8
		EBP	400.1

Table 2 – compiled typical product distillation from various sources

**Refinery Stream Options:**

Based on the composition description from table 2, and the overall characteristics of table 1, the WRI product closely fits the refinery stream description of naphtha based on boiling range.

Refiners define Naphtha as a light gasoline-like fraction of crude oil having a boiling range of 86-392°F. The WRI product has an expected boiling range of 88-400°F which





fits the range for Naphtha. For interest, the next boiling range of refined material is kerosene at 302–572°F . The WRI product isn't a good fit for kerosene range material.

Naphtha can be used as a feedstock for both gasoline manufacturing and petrochemicals depending on its quality, with light or paraffinic naphtha usually used in petrochemical plants and heavy naphtha usually used in reformers at refineries to make gasoline.

Naphtha that naturally occurs in crude is classified as virgin naphtha, while any naphtha created in a thermal or catalytic conversion process is labelled cracked naphtha. Naphtha molecules are created from longer chained molecules being cleaved. Cracked naphtha has many contaminants (i.e. sulphur compounds, naphthenic acids, olefins) that need to be treated before being blended to gasoline. Technically, the WRI product is a “converted product” and could be mis-classified as a cracked product. The WRI process is a combination of molecules to create naphtha which is not a cleaving so should not be categorized as a cracked naphtha.

Using naphtha as a representative stream for the WRI product, Figure 2 shows locations in the refinery (red circles) where the WRI product could be fed. The easiest refinery disposition is the final product blending. With such a small quantity of 150 BPD, the WRI product can easily be blended/diluted into the main gasoline blending tanks at the refinery. So, the high durene and high RVP values can be diluted to easily meet the final product specification.

The most logical location to place the WRI product is upstream of any naphtha hydrotreating unit (coker, FCC, pre-isomerization, pre-reformer). All the shortcomings with the WRI product (Durene, RVP) would be readily dealt with within the hydrotreater.

Likely customers:

Taking into account the naphtha like properties of the WRI product the following dispositions should be pursued:

- i) Diluent Producers
  - a. Connacher in Montana – transports diluent to OilSands via rail (600 Bbl cars) to dilute bitumen.in northern Alberta.
- ii) Petrochem Operators
  - a. Crackers for ethylene production – Exxon Mobil Joliet
- iii) Local refiners
  - a. Frontier Refinery – Cheyenne Wyoming and Sinclair Refinery- Sinclair Wyoming
    - i. Naphtha pool upstream of Naphtha Reformer, or HF Alkylation unit
    - ii. Feed to Gasoline Hydrotreater
    - iii. Final Product blending – dilute the WRI stream with other gasoline streams to meet specs.

- b. Suncor Refineries – Commerce City, Colorado
  - i. Naphtha pool upstream of Naphtha Reformer
  - ii. Final Product blending – dilute the WRI stream with other gasoline streams to meet specs.
- c. Other Wyoming Refiners (see Table 3 below)
- d. Montana Area Refiners

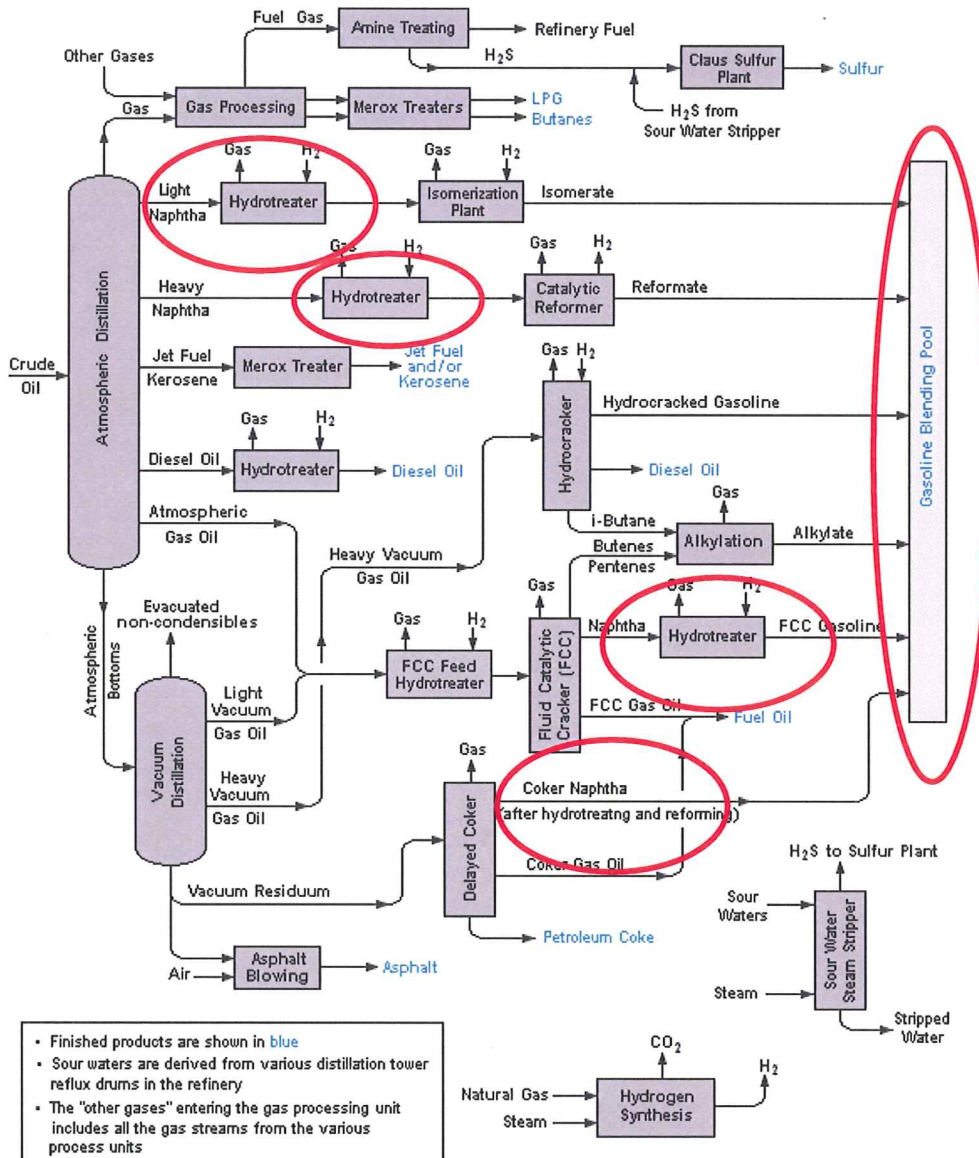


Figure 2 – Typical Refinery configuration (Source: AIChE refinery handbook)



Table 3 provides some specific processing info on local refiners. Local refiners are fairly complex operations with nearly all having catalytic conversion units (ex. FCC – fluidized catalytic cracking) suited for light to medium crude feeds. The refiners with delayed coking units can accept heavier crudes (<15 API). As an example, the Frontier Refiner has a gasoline hydrotreater where the WRI product could be injected upstream to be treated so the durene concentration can be reduced and the lighter fraction distilled away before sent to the gasoline blending pool.

All refiners in the list could accept the WRI product into its gasoline blending pool and be diluted while still meeting all gasoline product specifications. Each refiner on the list should be engaged to determine where they would accept the WRO product.

Company	Location	Crude	Vacuum	Delayed Coking	FCC Fluid	Semi-Regen Reformer	Diesel Hydrotreat	Kero/Jet Hydrotreat	Gasoline Hydrotreat	FCC Pre-HT	Alkylation	Poly unit	C4 isom
Frontier Refining	Cheyenne	52,000	28,000	13,200	12,000	7,600	16,500		17,500	8,900	4,200		1,600
Little America	Casper												
	Evansville	24,500	6,000		10,000	5,500	8,500			7,500		1,000	
Sinclair Oil Corp.	Sinclair	85,000	65,000	20,000	20,600	14,000	16,000	15,000		7,500	4,500	300	
Wyoming Refining	Newcastle	14,500	1,800		7,000	2,750	4,000			3,500	1,300		
Garco	Douglas	4,500											
Silver Eagle	Evanston	3,300			2,150					3,200			
Suncor	Commerce City	67,000	25,000		20,000	10,000	21,000	12,100		10,900		2,600	
Suncor	Commerce City	36,000	8,500		8,500	10,000				9,000		900	985

Table 3- Local Refining Dispositions with Select Unit Capacities in BPD  
 Source: USEIA Jan 1, 2012, Oil and Gas Journal Jan. 2012 (validated Frontier and Sinclair via phone call; worked on Revamps for Suncor Commerce City)

**Refinery Specs and Pricing:**

Table 4 illustrates the prices of various refinery streams that can be used to correlate prices that could be secured for the WRI product along with other refinery products for reference. Prices noted are before any discount/premium is added to the WRI product pricing.

Likely and lowest value disposition for this material is as feed to a refiner’s naphtha hydrotreater or directly to its naphtha reformer. Based on table above, price would be around \$94/bbl or \$5/bbl above WTI before any discount/premium is applied. A plausible disposition is as product grade naphtha for sale to OilSands diluent users with a price of \$98/bbl (\$9/bbl above WTI). If refiners would take WRI product directly it could be used in the gasoline blending pool at \$112/bbl (\$23/bbl above WTI).

All refineries have loading/unloading racks for trucks and rail cars carrying various types of crude material. With storage tanks used to mitigate upsets and changes in flow capacities between units, the WRI material could be offloaded by truck and sent to storage tanks for processing at the refinery or for final blending. The WRI product does not appear to have any contaminants that would degrade catalyst in the hydrocrackers, reformers or hydrotreaters.



Non-adjusted Suggested Price Range for WRI product = \$94-112US/bbl with WTI at \$89/bbl. The WRI product should sell between \$5 to \$23US/bbl above WTI without any major discount applied to the WRI product.

Stream	\$/GAL (Q2 2012)	\$/BBL (Q2 2012)	Comments
Finished Gasoline product	2.78	116.76	Sells at 20-25% above WTI (NY harbor)
Feed for gasoline blending	2.67	112.09	95-97% of finished gasoline price
Feed to Naphtha Hydrotreater or Reformer direct	2.24	94.09	95-97% of naphtha product price
Naphtha product Stream	2.33	98.01	Light end 86-194oF Heavy 194oF-392oF
Naphtha for bitumen diluent	2.33	98.01	1.0-1.1 x WTI
Naphtha for petrochem feedstock	2.33	98.01	
Crude to Refinery – WTI	2.12	89.10	If have coking capacity, refiner will take heavier crude @ lower price
Kerosene-jet fuel	2.91	122.22	
Diesel	2.95	123.90	
LPG	1.91	80.19	sells at 88-92% of WTI

Table 4 – Relevant Refinery Stream Prices: Q2 2102

Sources: USEIA, Oil and Gas Journal, CAPP

Factoring in Characteristics of WRI Product to determine Expected Price Range:

Assumption – WRI Product will be considered a feed for gasoline blending - \$112/bbl starting point (or \$23/bbl above WTI)

*Negatives for pricing WRI product*

- Small volume of 150 BPD (\$1-2/bbl discount)
  - o Anything less than 10,000 BPD or 10% of feed capacity is considered a small volume



- Storing quantities to increase sales volume may not be positive since stability of product is currently unknown. Durene degradation and/or settling could cause transport issues (plugging, wax-like build-up etc..)
- Chemically arranged molecules (\$0-1/bbl discount)
  - Refiner may argue that WRI product should be classified as a non-virgin stream that requires further processing
- Light Hydrocarbons in the stream (\$1-2/bbl discount)
  - specifically in summer time (above RVP spec of 7-9 in summer)
  - Will need to be processed to get RVP below limit in summer
- Durene content if sold (\$3-4/bbl discount)
  - Unless can argue that the small volume discount covers this since dilution mitigates the slightly elevated durene concentration, then the WRI stream (or the higher boiling range portion) will have to be hydrotreated.

Note: If WRI product is considered a feed to a naphtha hydrotreater (\$98/bbl or \$9 above WTI), then durene discount not above should not apply.

*Positives for pricing WRI product*

Note: no premium assigned to each positive noted below. Value included in the assumed base price as a direct feed to gasoline blending

- + Negligible sulphur
- + Low olefinic content (separate to aromatic content)
- + High in aromatics, good for gasoline pool blending, as an octane enhancer
- + Majority of stream is within Naphtha boiling range
- + Benzene below finished gasoline product specification
- + Can be sold as one stream
- + Can be readily blended/diluted into a final gasoline product
  - Counter argument to a small volume supply (may erase small volume discount)

Taking into account the specific attributes of the WRI product, the product will likely be discounted by \$6/bbl if starting negotiating point is treated naphtha sent to the gasoline blending pool. The highest expected price should be \$106/bbl or \$17/bbl above WTI.

The low end of the pricing should be the value of intermediate naphtha prior to hydrotreating which is around \$94/bbl or \$5/bbl above WTI.

An interesting option is selling WRI product as OilSands diluent. OilSands diluent sells for around 5-10% above WTI. Currently, diluent is selling \$9/bbl above WTI or \$98/bbl. Diluent does not have the same tight specifications as being a direct feed for refiners would require except for having zero tolerance for olefins.



WRI product should sell in the \$94-\$106/bbl range or \$5-17/bbl above WTI, with a high probability price of \$98/bbl (\$9/bbl above WTI) as a diluent contributor.

Some sensitivity examples:

- a) Aromatics - If Aromatics content is 20% higher, increasing the RON above 96, then the WRI product can be considered an octane enhancer and could get a \$1/bbl premium.
- b) Benzene- if benzene content is increased 10-20% from 0.3vol%, pricing should not be impacted, since it is still below the 0.62vol% final gasoline specification.
- c) Durene – Increasing durene above any value of the currently expected 2.5% will increase the discount that will be applied by a refiner. Durene has a very negative perception due to its high melting point, which causes combustion issues. At elevated values above 5%, the refiner may not even accept the product. Durene content should be carefully controlled.

An attempt has been made to relate WRI product pricing to WTI since the WTI value is readily available in public domain. Also, there are many forecasts for WTI, so a future prediction of the WRI product price can be formulated. Figure 4 takes information from various sources to provide a trend for WTI from current pricing out to 2035. It appears WTI pricing and by extension, the WRI product will increase in value in the future.

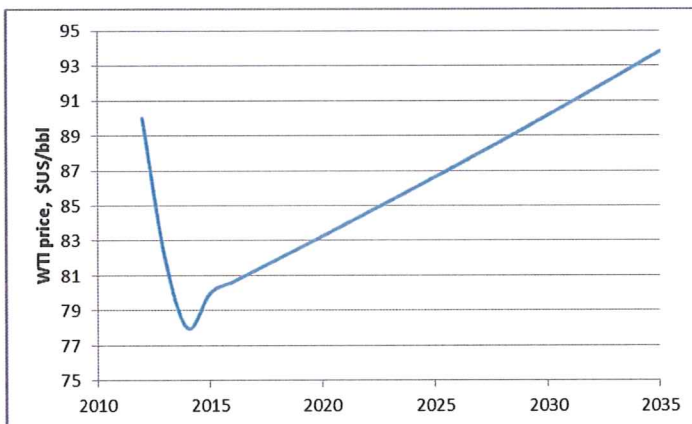


Figure 4 – Forecasted WTI pricing as of June 2012  
(Average of Various Sources – Muse Stancil, Purvin&Gertz, Oil and Gas Journal, CAPP, USEIA)

Sincerely,

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### Appendix:

Other Crude stream descriptions:

#### Crude Distillation

Simple refinery process whereby crude oil is heated and the different fractions collected and cooled to form -- from lightest to heaviest -- liquefied petroleum gas, gasoline, naphtha, kerosene, gas oil and fuel oil. Crude distillation units are often referred to as distillation towers.

#### Naphthas

Naphthas are refined or partly refined light distillates with an approximate boiling point range of 27 degrees to 221 degrees Centigrade. Blended further or mixed with other materials, they make high-grade motor gasoline or jet fuel. Also, used as solvents, petrochemical feed stocks, or as raw materials for the production of town gas.

##### Light Naphtha

A category of naphtha that can be rich in paraffins and is used for ethylene cracking to make petrochemicals. However, if it is rich in aromatics and naphthenes it is used for reforming into gasoline or as blendstock for making gasoline.

##### Paraffinic Naphtha

Naphtha with a high paraffinic content suitable for petrochemical use as an ethylene cracker feedstock.

##### Naphtha uses

Naphtha is used primarily as feedstock for producing high octane gasoline (via the catalytic reforming process). It is also used in the bitumen mining industry as a diluent, the petrochemical industry for producing olefins in steam crackers, and the chemical industry for solvent (cleaning) applications. Common products made with it include lighter fluid, fuel for camp stoves, and some cleaning solvents.

#### Distillates

The result of crude distillation and therefore any refined oil product. Distillate is more commonly used as an abbreviated form of middle distillate. On the other hand, there are mainly 4 types of distillates. Light and middle distillates consist of kerosene and gas oil - automotive diesel, heating oil and general purpose gas oil. The term distillate is also used in refinery nomenclature to label units designed predominantly for middle distillate production, e.g. distillate hydrotreater or distillate hydrodesulfurization unit. Middle distillates generally refer to petroleum products in the boiling range beginning at above 160°C and ending at below 420 C -- i.e., between gasoline and heavy fuel oil. These include gas oil, diesel and jet fuel (kerosene).



#### Very Light Oils or Light Distillates

This oil type includes Jet Fuel, Gasoline, Kerosene, Light Virgin Naphtha, Heavy Virgin Naphtha, Petroleum Ether, Petroleum Spirit, and Petroleum Naphtha. These oil types are highly volatile, and normally evaporate within 2 days. With these oils there is a high concentration of toxic compounds, and the impact to water and intertidal organisms. Clean up is not possible.

#### Light Oils or Middle Distillates

This oil type includes Fuel Oil (grades 1 and 2), Diesel Fuel Oils (grades 1 and 2), Domestic Fuel, and Marine Gas Oil - Light Crude falls into this category. Oils of this type are moderately volatile, and normally leave up to 1/3 of the spill after a few days. The toxic concentration is moderate, however the intertidal organisms will have long term contamination. Clean up can be effective.

#### Medium Oils

Most types of crude oil fall into this category. This type of oil may cause long term, severe damage to fish, waterfowl, fur bearing animals and intertidal organisms. About 1/3 of medium oils evaporate within 24 hours. Clean up is effective when done very quickly. The response time to a clean up of this type will greatly influence whether this oil type may or will adversely affect fish, birds, animals and other organisms.

#### Heavy Fuel Oils

This category includes heavy crude oil, Fuel Oil No. 3 & 4), Fuel Oil No. 5 (Bunker B), Fuel Oil No. 6 ( Bunker C), Marine Intermediate Fuel, and Marine Heavy Fuel. There is little evaporation with heavy oils. Severe contamination of intertidal areas, along with fish, birds, and fur bearing mammals. Long term contamination of sediments are also possible. This oil type weathers very slowly. Clean up is extremely difficult.

#### Condensates

Liquid hydrocarbons that are produced in conjunction with natural gas. They are chemically more complex than liquefied petroleum gases and are sometimes similar to crude oil or naphtha.

#### Jet Fuel

A high-quality kerosene product primarily used for fuel in commercial-military aircraft engines. Jet fuel is obtained by distillation and sweetening. The latter removes all trace of mercaptans (very light molecules containing sulfur atoms). Jet fuel is a white product, so-called because it is transparent.

#### Kerosene

A middle-distillate fraction that is produced at higher temperatures than naphtha and lower temperatures than gas oil. It is usually used as jet turbine fuel and sometimes for domestic cooking, heating and lighting.





Diesel Fuel/Gas Oil

Gasoil is an intermediate distillate product used for diesel fuel, heating fuel, and sometimes as feedstock. The term is often used interchangeably with No. 2 heating oil. It is produced at higher temperatures than kerosene and lower temperatures than residual fuel. Usually used as diesel fuel or home heating oil.