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CO-PRODUCING LNG FROM CRYOGENIC NGL RECOVERY PLANTS

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ABSTRACT

Although liquefied natural gas (LNG) is a cleaner fuel for motor vehicles than gasoline and diesel, many major metropolitan areas have not yet fully embraced the use of LNG due to lack of a convenient source of LNG to fuel these vehicles. Its use in peak shaving applications may likewise be restrained by the absence of an economical source of LNG. While many of these areas do have cryogenic turboexpander gas processing plants located nearby designed to recover natural gas liquids (NGL), very few of these plants have any provisions for producing LNG. Those NGL plants that do produce LNG are typically capable of producing only limited quantities, often as a batch process, and must sacrifice NGL recovery when doing so.

Integrated designs have been developed for cryogenic NGL recovery plants that allow for co-production of an LNG stream with little or no loss in NGL recovery. For example, a 350 MMSCFD NGL recovery plant could easily produce 50,000 gallons/day of LNG. With the addition of a small amount of recompression or propane refrigeration, the volume of LNG could be increased to as much as 150,000 gallons/day from this plant. These LNG processes can be included in the design of any new plant or retrofit to any existing plant, regardless of the process configuration.

Purity of the LNG product can be easily adjusted to meet a wide variety of specifications. The unique manner in which heat integration is accomplished with these designs gives them better tolerance for carbon dioxide than other LNG designs, reducing or eliminating the need to treat the natural gas feeding the NGL/LNG recovery plant. Several examples are given showing the economic advantages of the new processes.

INTRODUCTION

Most natural gas is handled in gaseous form. The most common means for transporting natural gas from the wellhead to gas processing plants and then to the natural gas consumers is in high pressure gas transmission pipelines. In a number of circumstances, however, it has been found necessary and/or desirable to liquefy the natural gas either for transport or for use. In remote locations, for instance, there is often no pipeline infrastructure that would allow for convenient transportation of the natural gas to market. In such cases, the much lower specific volume of LNG relative to natural gas in the gaseous state can greatly reduce transportation costs by allowing delivery of the LNG using cargo ships and transport trucks. For the same reason, storage of natural gas as LNG is attractive when there is a mismatch between supply and demand (i.e., "peak shaving").

Another circumstance of particular interest today that favors the liquefaction of natural gas is for its use as a motor vehicle fuel. In large metropolitan areas, there are fleets of buses, taxi cabs, and trucks that could be powered by LNG if there was an economical source of LNG available. Such LNG-fueled vehicles produce considerably less air pollution due to the clean-burning nature of natural gas when compared to similar vehicles powered by gasoline and diesel engines which combust higher molecular weight hydrocarbons. In addition, if the LNG is of high purity (i.e., with a methane purity of 95 mole percent or higher), the amount of carbon dioxide (a "greenhouse gas") produced is considerably less due to the lower carbon:hydrogen ratio for methane compared to all other hydrocarbon fuels.

Unfortunately, LNG is not readily available in most metropolitan areas, so it has not been widely applied as a motor vehicle fuel or for use in peak shaving. However, many of these areas do have cryogenic turboexpander gas processing plants located nearby designed to recover natural gas liquids. These NGL recovery plants usually have much of the processing infrastructure (operating and maintenance personnel, control room and maintenance building, plant utilities, etc.) needed for an LNG production plant. If these NGL recovery plants could be adapted to efficiently co-produce LNG, much of the capital and operating costs associated with constructing a stand-alone LNG production plant could be avoided by sharing the resources of the NGL recovery plant.

Although a few such integrated NGL/LNG plants have been built in the past, the efficiency of the integrated design has been poor. The power consumption for producing LNG has been quite high compared to traditional base-load LNG production plants, and the processing efficiency of the NGL recovery plant often drops significantly. Several new patent-pending integrated designs have been developed recently to address both of these issues. The remainder of this paper will give several examples of this new technology and compare key operating measures against current technology.

CURRENT TECHNOLOGY

Figure 1 shows a typical cryogenic NGL recovery plant, based on the Ortloff **G**as **S**ubcooled **P**rocess (GSP). In this example, the NGL recovery plant processes 350 MMSCFD of natural gas to recover a mixed NGL product of ethane, propane, and heavier hydrocarbons. The pertinent operating parameters are summarized in Table 1.

There are a number of methods that can be used for liquefying natural gas.[1] These methods generally include steps in which the natural gas is purified (by removing water and other contaminants such as carbon dioxide and sulfur compounds), cooled, condensed, and expanded. The cooling and condensation of the natural gas can be accomplished in many different manners. "Cascade refrigeration" is often used for large-scale plants and employs heat exchange of the natural gas with several refrigerants having successively lower boiling points, such as propane, ethane, and methane. "Multi-component refrigeration" is more often used for smaller scale applications like those being considered here, and employs heat exchange of the natural gas with a single refrigerant fluid composed of several refrigerant components in lieu of multiple separate refrigerants.

Figure 2 shows one manner in which the NGL recovery plant in Figure 1 can be adapted for co-production of LNG, in this case by application of a multi-component refrigeration process for LNG production similar to that described by Price.[2] This type of LNG process is typical of those used in small-scale peak shaving applications, and is not intended for integration into an NGL recovery plant. As such, it is essentially a stand-alone plant in this application, processing a portion of the residue gas produced by the NGL recovery plant.

The inlet gas to this NGL recovery plant was not treated for carbon dioxide (CO_2) removal prior to processing. Although the CO_2 concentration in the inlet gas (about 0.5% by mole) will not create any operating problems for the NGL recovery plant, a significant fraction of this carbon dioxide

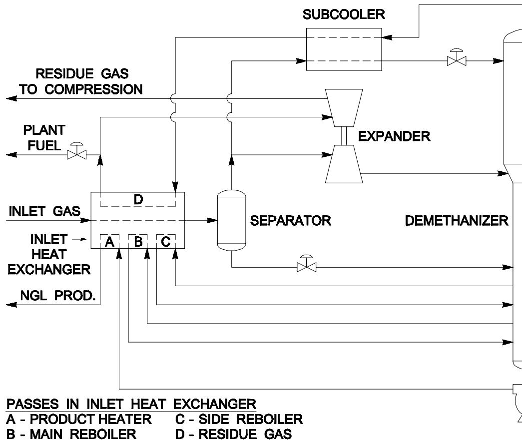

Figure 1 — Typical Cryogenic NGL Recovery Plant

Table 1

Inlet Flow, MMSCFD	350
Inlet CO_2, mole %	0.50
Inlet Gas Pressure, PSIA	740
Tower Pressure, PSIA	320
Residue Gas Pressure, PSIA	740
C_2 Recovery, %	87.52
C_3 Recovery, %	98.92
C_4+ Recovery, %	99.89
Residue Compression, HP	14,517

will leave the plant in the residue gas and will subsequently contaminate the feed stream for the LNG production plant. The CO_2 concentration in the residue gas is about 0.4% by mole, well in excess of the concentration that can be tolerated by this LNG process (about 50 PPM). Accordingly, the feed stream must be processed for carbon dioxide removal before entering the LNG production plant to avoid operating problems from CO_2 freezing. There are a number of processes that can be used for CO_2 removal, but many of them will cause the treated gas stream to become partially or completely saturated with water. Since water in the feed stream would also lead to freezing problems in the LNG plant, it is likely that the CO_2 removal section will also need to include dehydration of the gas stream after treating.

With the stand-alone LNG production plant shown in Figure 2, there is no change at all in the operation of the NGL recovery plant. Following compression and cooling of the residue gas from the plant, a portion of the residue gas is directed to the LNG production plant, with the remainder flowing to the residue gas pipeline. The feed gas to the LNG plant is cooled to very low temperature by the multi-component refrigerant stream, then expanded down to the LNG storage tank pressure (slightly above atmospheric pressure) to produce the liquefied natural gas stream. As shown, a hydraulic turbine is used for this expansion so that no flash vapor is produced when the pressure is reduced. The quantity of residue gas fed to the LNG plant is set so that the LNG production rate is nominally 50,000 gallons/D at the storage tank conditions as shown in Table 2.

All of the cooling for the feed gas is provided by the closed-cycle refrigeration loop. The refrigerant in this example is a mixture of nitrogen and C_1 through C_6 hydrocarbons. The composition of the stream is adjusted to allow the refrigerant to condense at a reasonable pressure using the available cooling medium (ambient air in this case), while giving a suitable evaporating temperature to provide the desired feed gas cooling when flashed down to low pressure. Most of the cooling duty available in the flashed refrigerant stream is actually used to condense and subcool the refrigerant prior to expansion, rather than for cooling the feed gas. The expanded refrigerant stream is vaporized and superheated as it cools the feed gas and the refrigerant, then compressed and cooled to complete the cycle.

In this example where the NGL recovery plant residue gas is used as the source of feed gas for LNG production, no provisions have been included for removing heavier hydrocarbons from the feed gas. Consequently, all of the heavier hydrocarbons present in the feed gas become part of the LNG product, reducing the purity (i.e., methane concentration) of the LNG product. If higher LNG purity is

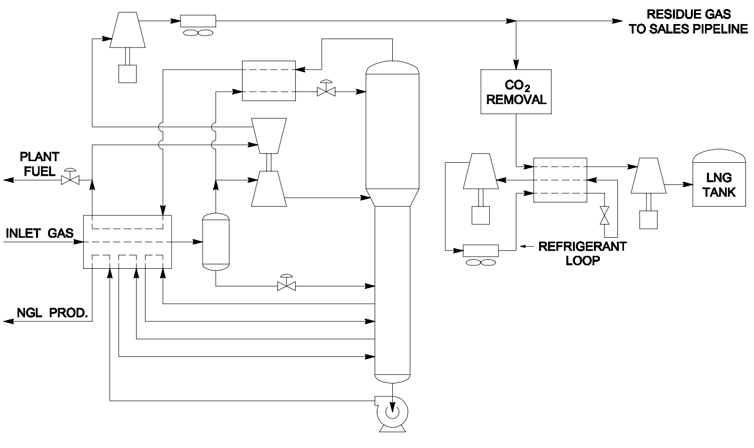

Figure 2 — Non-Integrated LNG Production Plant

Table 2

Inlet Flow, MMSCFD	350
Inlet CO_2, mole %	0.50
Tower Pressure, PSIA	320
C_2 Recovery, %	87.52
C_3 Recovery, %	98.92
C_4+ Recovery, %	99.89
Residue Compression, HP	14,484
Refrigerant Compression, HP	2,282
Total Compression, HP	16,766
LNG Production, gallons/D	50,043
LNG Purity, mole %	98.94
Power Consumption, HP-H/Lb	0.304

desired, or if the source of feed gas contains higher concentrations of heavier hydrocarbons (the NGL recovery plant inlet gas, for instance), the feed stream to the LNG section would need to be withdrawn from the heat exchanger after cooling to an intermediate temperature so that condensed liquid could be separated, with only the uncondensed vapor returning to the heat exchanger for cooling to the final outlet temperature. These condensed liquids would preferentially contain the majority of the heavier hydrocarbons, along with a considerable fraction of liquid methane, which could then be re-vaporized and used to supply a part of the plant fuel gas requirements. Unfortunately, this means that the ethane, propane, and heavier hydrocarbon components removed from the LNG feed stream would not be recovered in the NGL product from the NGL recovery plant, and their value as liquid products would be lost to the plant operator. Further, for feed streams such as the one considered in this example, condensation of liquid from the feed stream may not be possible due to the process operating conditions (operating at pressures above the cricondenbar of the stream, for instance), meaning that removal of heavier hydrocarbons could not be accomplished easily in such instances.

Assuming that the refrigerant compressor is driven by a gas engine or turbine, the plant fuel gas requirements will increase by an amount corresponding to the power consumption of the additional compression. Since plant fuel gas is typically withdrawn prior to compression of the residue gas, the power for residue gas compression is slightly lower in Table 2 compared to Table 1. As the operating conditions for the NGL recovery plant are unchanged from Figure 1, the recovery efficiencies for ethane, propane, and heavier hydrocarbons are the same in Table 2 as the values displayed in Table 1.

The net increase in compression power for this example compared to Figure 1 is 2,249 HP, which is used to produce a nominal 50,000 gallons/D of LNG. Since the density of LNG varies considerably depending on its storage conditions, it is more consistent to evaluate the power consumption per unit mass of LNG. The LNG production rate is 7,397 Lb/H in this case, so the specific power consumption for LNG production in Figure 2 is 0.304 HP-H/Lb (0.500 kW-H/kg).

Another method for adapting the NGL recovery plant for co-production of LNG is depicted in Figure 3, which is similar to the design used at an NGL recovery plant in the western U.S. In this example, the LNG production plant is integrated with the NGL recovery plant so that the cold demethanizer overhead vapor provides most of the refrigeration needed to produce the LNG.[3] This process has no means for removing heavier hydrocarbons from the LNG, so residue gas from the NGL recovery plant must be used as feed gas to give reasonable LNG purity. This process also requires removal of CO_2 from the feed gas, since concentrations above 50 PPM would result in CO_2 freezing problems in the LNG plant.

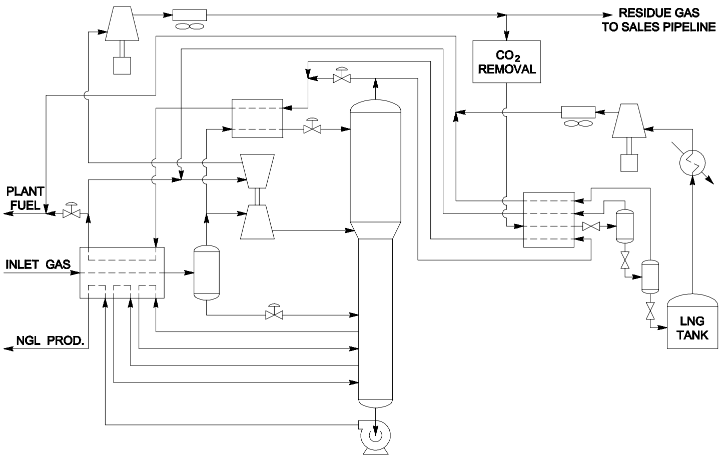

Figure 3 — Integrated LNG Production Plant

Table 3

Inlet Flow, MMSCFD	350
Inlet CO_2, mole %	0.50
Tower Pressure, PSIA	291
C_2 Recovery, %	87.60
C_3 Recovery, %	99.12
C_4+ Recovery, %	99.92
Residue Compression, HP	17,071
Flash Gas Compression, HP	142
Total Compression, HP	17,213
LNG Production, gallons/D	50,063
LNG Purity, mole %	98.91
Power Consumption, HP-H/Lb	0.366

The quantity of cold demethanizer overhead vapor sent to the LNG plant is regulated to provide the desired amount of cooling in the LNG heat exchanger. However, this robs the NGL recovery plant of a significant amount of refrigeration. In order to compensate for this loss of cooling and maintain the desired NGL recovery, the demethanizer must be operated at lower pressure in Figure 3, with the resultant increase in the power consumed in residue gas compression. As shown in Table 3, the power consumption for residue gas compression is about 18% higher in order to hold the NGL component recoveries to about the same levels shown in Table 1. (If additional power is not available for residue gas compression, the ethane recovery in the NGL recovery plant will drop. This will further reduce the LNG purity since the ethane concentration in the residue gas will increase.)

With the increase in residue gas compression, plus the additional compression required for the L.P. flash gas from the LNG plant, the net increase in power consumption to produce 7,365 Lb/H of LNG with this system is 2,696 HP, giving a specific power consumption of 0.366 HP-H/Lb (0.602 kW-H/kg). Thus, the efficiency of this integrated LNG process is about 17% lower than for the stand-alone LNG process. This lower efficiency is directly attributable to the loss in cooling available to the NGL recovery plant from using cold demethanizer overhead to provide refrigeration to the LNG process.

NEW TECHNOLOGY

The disadvantages of the current technology for co-production of LNG from NGL recovery plants can be summarized as follows:

- Considerable LNG plant feed gas conditioning is required (CO_2 removal, dehydration)
- Little control of LNG purity is possible
- Heavier hydrocarbons present in the LNG plant feed gas cannot be captured in the NGL
- NGL recovery efficiency suffers when process cooling is integrated with LNG production

Several new designs for LNG production have been developed that allow integration with any type of cryogenic NGL recovery plant while avoiding the disadvantages of the current technology. These new designs are the subject of a recent patent application, and allow efficient co-production of LNG without sacrificing NGL recovery efficiency.[4] The new designs not only allow control of the LNG purity, but do so without requiring front-end removal of heavier hydrocarbons from the feed gas. The new designs are also much more tolerant of CO_2 in the feed gas, eliminating the need for CO_2 removal (and subsequent dehydration) in most cases.

Figure 4 shows one method for integrating the new LNG design into the NGL recovery plant shown in Figure 1. (Due to the patent-pending status of the new designs, some of the process details are not shown.) In this example, a portion of the inlet gas is diverted from the NGL recovery plant and fed to the LNG production plant. The new LNG design uses a unique fractionation step to separate the heavier hydrocarbons from the methane, allowing the concentration of C_2+ hydrocarbons in the LNG product to be controlled at any desired value. Essentially all of the heavier hydrocarbons are captured from the feed gas and routed to the demethanizer in the NGL recovery plant to become part of the NGL product. In addition, this fractionation step removes nearly all of the CO_2 present in the feed gas (sending it to the demethanizer along with the heavier hydrocarbons) before the methane enters the low temperature LNG cool-down section, eliminating the need for CO_2 removal from the feed gas to the LNG production section. The C_2+ liquids recovered in the LNG plant can enter the demethanizer at a separate feed point as shown, or can combine with another feed stream (such as the separator liquids) to enter at an existing feed point on the column.

Much of the refrigeration required in the LNG purification and cool-down section is provided by internally generated process streams. The balance is supplied by a slipstream of the cold demethanizer overhead vapor from the NGL recovery plant, which is recompressed after being warmed in the LNG plant and flows to the sales gas pipeline. Unlike the integrated design shown in Figure 3, however, diverting this slipstream from the NGL recovery plant has much less impact on plant efficiency, as the NGL recovery plant does not process as much inlet gas since part of the inlet gas is used as the feed gas for the LNG plant. As shown by the first set of values in Table 4, the NGL recoveries and the power consumption for compressing the NGL recovery plant residue gas when producing about 50,000 gallons/D of LNG are essentially the same as shown in Table 1 for the base case plant. Alternatively, the LNG production can be increased to over 150,000 gallons/D by increasing the gas compression power as shown by the second set of values in Table 4. (For richer feed streams, propane refrigeration could be added instead. For this case, increasing the gas compression is the more attractive option.)

For the first case, the net increase in power consumption to produce 7,333 Lb/H of LNG is 1,498 HP (including compression as needed to allow low pressure flash gas generated within the LNG plant to be used as part of the fuel gas for the facility). This gives a specific power consumption of 0.204 HP-H/Lb (0.336 kW-H/kg). For the second case, producing 21,943 Lb/H of LNG uses an additional 5,754 HP, giving a specific power consumption of 0.262 HP-H/Lb (0.431 kW-H/kg). The efficiencies of these new integrated LNG designs are about 49% and 16% higher, respectively, than for the stand-alone LNG process shown in Figure 2, and even greater (79% and 40%, respectively) compared to the integrated design shown in Figure 3. In addition, the LNG purity is higher for the new designs (99.8% versus 98.9%) even though the new design is processing a richer feed gas (i.e., plant inlet gas rather than plant residue gas) that has not been treated to remove CO_2.

For some applications, the plant inlet gas may be unsuitable for use as feed gas to the LNG plant. For instance, some inlet gases contain hydrocarbons such as heavy paraffins or benzene that may solidify at cold temperatures. In these cases, a variation of the new design like that shown in Figure 5 could be used instead, where the NGL recovery plant itself serves as a feed conditioning unit for the LNG production section by recovering these compounds with the NGL product. The residue gas leaving the NGL recovery plant will not contain significant quantities of heavier hydrocarbons, so processing a portion of the plant residue gas for co-production of LNG can be accomplished using the new integrated design without risk of solids formation in the heat exchangers in the LNG production

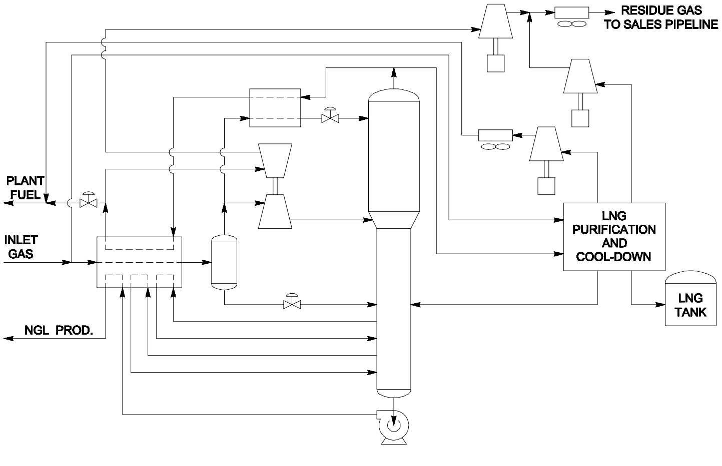

Figure 4 — New Design for Integrated LNG Production Plant

Table 4

Inlet Flow, MMSCFD	350	
Inlet CO_2, mole %	0.50	
Tower Pressure, PSIA	301	251
C_2 Recovery, %	87.47	87.64
C_3 Recovery, %	99.09	99.38
C_4+ Recovery, %	99.91	99.94
Residue Compression, HP	14,529	15,499
Other Gas Compression, HP	1,486	4,772
Total Compression, HP	16,015	20,271
LNG Production, gallons/D	50,034	150,016
LNG Purity, mole %	99.77	99.80
Power Consumption, HP-H/Lb	0.204	0.262

and cool-down section. Other factors, such as the relative pressure levels of the inlet gas and the plant residue gas, could also cause the Figure 5 variation to be more attractive in some circumstances.

As shown in Table 5, the additional power required for the Figure 5 process to produce 7,330 Lbs/H of LNG is 2,222 HP, giving a specific power consumption of 0.303 HP-H/Lb (0.498 kW-H/kg) for LNG production. Although the NGL component recoveries have been maintained at the same values as for the base case process in Figure 1, the processing efficiency is somewhat lower in this case than for the Figure 4 variant because all of the plant inlet gas is processed in the NGL recovery plant. Compared to Figures 2 and 3, however, the LNG production efficiency of the process in Figure 5 is as good or better than the current technology, does not require pretreatment of the LNG feed gas, and can achieve higher LNG purity.

CONCLUSIONS

These new integrated designs for co-production of LNG in NGL recovery plants offer many advantages over current technology. Among these are:

- Reduced capital and operating costs from eliminating (or minimizing) the need for feed preconditioning

- Reduced capital and operating costs due to higher LNG production efficiency with minimal impact on NGL recovery efficiency

- Recovery in the NGL recovery plant product of the valuable C_2+ components present in the LNG feedstock

- Production of high purity LNG regardless of the C_2+ content of the LNG feed stream.

These advantages can greatly improve the economics for co-producing LNG from NGL recovery plants, and can provide an economical source of LNG for multiple uses in many locations. This new technology can be applied to new NGL recovery plants, and can also be easily retrofitted into existing NGL recovery plants.

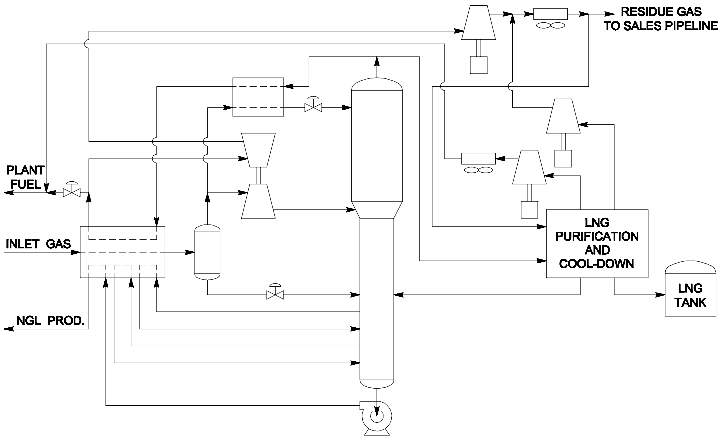

Figure 5 — New Design for Integrated LNG Production Plant

Table 5

Inlet Flow, MMSCFD	350
Inlet CO_2, mole %	0.50
Tower Pressure, PSIA	306
C_2 Recovery, %	87.52
C_3 Recovery, %	99.05
C_4+ Recovery, %	99.91
Residue Compression, HP	15,315
Other Gas Compression, HP	1,424
Total Compression, HP	16,739
LNG Production, gallons/D	50,070
LNG Purity, mole %	99.84
Power Consumption, HP-H/Lb	0.303

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