FEASIBILITY STUDY

Evaluation of Technical and Economic Parameters of Natural Gas Delivery Using Compressed Natural Gas (CNG) Technologies

PHASE 1

Prepared for
QUEST Nova Scotia

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PREFACE

QUEST – Quality Urban Energy Systems of Tomorrow – is a national non-profit organization advancing education and research for integrated energy systems (linking energy with land-use, buildings, transportation, waste, water and wastewater at a community, neighbourhood or site level) to develop and support sustainable communities in Canada and is committed to making integrated community energy solutions (ICES) the new standard for land-use and transportation planning and development. QUEST works actively across Canada with its Caucuses. QUEST Caucuses provide a collaborative forum for organizations interested in approaching and managing energy challenges and opportunities in a manner consistent with QUEST's principles, mission and vision.

A QUEST Nova Scotia Caucus was formed in 2010, and includes the following organizations: The Province of Nova Scotia, Efficiency Nova Scotia, Heritage Gas, Dalhousie University, Eco Efficiency Centre, Ecology Action Centre, Clean Nova Scotia, Halifax Regional Municipality, Union of Nova Scotia Municipalities, Clayton Developments, Eastport Developments, Cape Breton Municipality (CBRM), Nova Scotia Community College, Nova Scotia Agricultural College, Green Power Labs, The Construction Association of Nova Scotia, Atlantic Chapter Green Building Council, Canadian District Energy Association, AltaGas, Heritage Gas, Natural Gas Vehicle Association, and the Canadian Gas Association.

The Nova Scotia Department of Energy recently contributed funds to QUEST to investigate ways to advance sustainable transportation in the province; and the economics and supply/demand potential for using compressed natural gas in vehicles in the province and to supply businesses and communities not connected to the natural gas grid. Two working groups were created to explore each of these topics, and membership was drawn from the QUEST Nova Scotia Caucus along with suggestions of other appropriate organizations.

This applied research study entitled Evaluation of Technical and Economic Parameters of Natural Gas Delivery Using Compressed Natural Gas (CNG) Technologies Phase 1 and Phase 2 was commissioned by QUEST Nova Scotia to explore CNG infrastructure development scenarios. The study evaluates the conditions and combination of different parameters that would make the delivery of CNG to Nova Scotia communities economically feasible.

Acknowledgements

We would like to acknowledge the extensive contribution, guidance and advice of the CNG Off Grid Steering members representing the Nova Scotia Department of Energy, Heritage Gas, Enbridge Gas, Stantec, Halifax Regional Municipality and the Canadian Gas Association.

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EXECUTIVE SUMMARY

Due to the recently abundant availability of natural gas in North America, and the resultant economic viability in its expanded use, QUEST Nova Scotia has initiated a study to assess the feasibility of providing natural gas delivery service by road transport to new users located off the distribution grid. The process for delivery includes three key components; (1) a mother station to compress gas from a gas supply pipeline for loading into a mobile storage transport trailer; (2) road transport of fuel to the customer site and; (3) off-loading and pressure reduction to the customer required supply pressure.

The case study of this paper considers a single user with an annual consumption of 250,000 GJ per annum and located 50 kilometers from the mother station. A mother station and de-canting station design is configured and costs are generated to estimate capital costs. Mobile storage trailers are selected and capital cost estimated. An operations scenario is defined and all operating costs for the process are estimated from mother station to customer site. Capital investment financing for 20 years and 6% cost of money is used as the basis for capital recovery. This analysis makes no assumptions with respect to the appropriate capital structure for the facilities owner, and therefore does not include an appropriate return on equity. Nor does it include profit.

An average fuel gas cost of $5.50 per GJ is assumed, which is intended to represent the cost of the commodity but excludes the delivery charges for receiving natural gas from the local distribution company, or the capital costs of developing a Custody Transfer Station to receive natural gas directly from the transmission pipeline. No cost is included for gas supply, meter, regulator, etc.

Jenmar Concept's opinion of total probable capital cost figures for optimal electric driven and gas driven compressor mother stations are estimated at $1,423,000 and $1,536,000, respectively. Underlying assumptions include availability of natural gas and electricity at the site, and exclude cost of land. The capital cost for the de-canting station is estimated to be $144,200. Two mobile storage trailers are required for the fuel delivery at $400,000 per unit. It is assumed that transport operations will be contracted to a trucking company therefore no investment in truck tractors was considered.

The maintenance cost figures were derived based on a combination of rule of thumb, experience and scaling calculations, and assume domicile type transport operations. The operating costs for the mother station and de-canting stations are comprised of natural gas consumption, electrical energy consumption, maintenance and service. Rolling the present value of capital in with station operating and fuel transportation costs provides a total fuel delivery cost. While keeping in mind that several cost elements have been excluded, for or the electric driven and gas engine driven compressors the total fuel delivery cost is estimated to be $8.98 per GJ and $9.05 per GJ, respectively. These costs do not include any additional administration or profit. Electric drive based mother stations are preferred.

As a comparison, average prices in Halifax of propane, heavy fuel oil (#6), heating oil (#2) and electricity in the volumes required to meet the energy needs of the case study, are currently $17.25, $19.00, $24.42 and $37.78 per GJ, respectively. For large users (50,000 GJ and above) and located within a reasonable distance from the mother station, natural gas delivered by CNG transport is a very competitive alternative to conventional energy supplies.

Transport distance is a key cost contributor and as a result longer distances yield higher total delivered cost. A delivery distance of 25 km results in a delivered fuel cost of $8.43 per GJ of natural gas while a distance of 150 km yields a cost of $11.34 per GJ.

A change in per annum load for the base case, from 250,000 GJ to 50,000 GJ increases the fuel cost from $8.98 to $10.50 per GJ. This is mainly due to low capital utilization, particularly in the gas transport equipment.

Operating costs for gas transport equipment is the largest contributor to delivered fuel gas cost. For per annum loads of 50,000 GJ and larger, increased investment in the largest possible mobile storage trailers available is favored in order to reduce operations costs. Reaching the optimum capital investment level in large trailers is limited by allowable road weight.

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1. INTRODUCTION

Jenmar Concepts is retained by QUEST Nova Scotia to provide a study to evaluate the technical and economic parameters of natural gas delivery using compressed natural gas (CNG) technologies. This paper addresses the Phase 1 scope as defined in the QUEST request for proposal (RFP) with focus on the available technology, key process elements (including mother station, user site ("daughter"), transport equipment), and a single user scenario. This paper also provides a roll-up of capital and operations costs for the single user scenario followed by a sensitivity analysis of key variables including transport distance, and load. The sensitivity analysis provides a methodology for optimizing both operations and equipment selection for the lowest cost solution. A total "all-in" delivered cost for natural gas is presented and compared against competing fuels, including propane, fuel oil and electricity.

2. BACKGROUND

Natural gas is becoming increasingly attractive as a potential energy source where it is not currently available. With recent advances in extraction technologies, North America has abundant proven natural gas reserves able to provide decades of supply. The glut of natural gas has caused a decoupling of gas prices from those of oil on an energy basis. Natural gas prices are expected to remain low for the foreseeable future, providing an abundant and low cost supply of energy. In Nova Scotia, the natural gas distribution system is not yet fully developed and many parts of the province are not served. Delivery of natural gas to these regions therefore requires an alternate method. The delivery modes considered by QUEST include road, rail and water. Rail is considered to be too cumbersome in terms of the logistics of loading, unloading, proximity of rails to natural gas supply and consumer locations and scheduling. Transport by water may be feasible in some cases but is also a challenge logistically. For both rail and water, a road transport component of the delivery process is anticipated in all but exceptional cases. Delivery solely by road transport remains and is considered the most viable option and hence the focus of this study.

3. PROCESS DESIGN OVERVIEW

The process by which CNG is delivered to off-grid locations consists of three major steps.

- Compression of gas into mobile storage containers at the mother station
- Delivery of gas by road transport to the client site
- De-canting and pressure letdown for client consumption

3.1. Mother Station

One of the major challenges for the transport of natural gas is its low energy density. To increase the energy density of the fuel, it must be either compressed or liquefied. (As liquefaction facilities are not currently available in Nova Scotia, a consideration of the use of liquefied natural gas (LNG) is not included in the scope of this study). A mother station consists of natural gas compression and loading equipment to deliver a high pressure stream of natural gas to mobile storage equipment. The mother station will be located next to a natural gas distribution pipeline. The gas available from the distribution pipeline will be at a relatively high pressure typically around 1000 psig. This high pressure allows the use of a 2 stage or possibly single stage compressor with substantial savings in capital and operating costs.

At the mother station gas pressure is boosted to a discharge pressure ranging from 2400 psig (16.5 MPa) to 3600 psig (24.8 MPa) depending on the pressure rating of the mobile gas storage equipment. The compressed gas flows to the mobile storage trailer via a high pressure gas line and is connected with a high pressure hose and special connection nozzle.

3.2. Transport Mobile Gas Storage

When a mobile storage trailer is full, it is hauled to the customer site by road. At the customer site the trailer is positioned for off-loading.

3.3. De-Canting Station

The mobile storage is connected to a de-canting post with a high pressure hose and nozzle. Once the connection is completed, a manual valve is opened by the operator and gas begins to flow to the pressure reduction system (PRS). The PRS is equipped with gas heating controls to offset Joule Thompson cooling as the gas is reduced to the low pressures required by the customer's system. As the pressure in the mobile storage is depleted, the PRS must maintain a constant outflow pressure to the customer's system. Upon depletion of the mobile storage, there must be a smooth transition to a newly delivered full mobile gas storage so that there is no interruption in gas supply to the customer.

4. TECHNOLOGY DESCRIPTION

4.1. Mother Station

A flow diagram of a mother station is shown in Appendix A.

4.1.1. <u>Gas Specification</u>

The quality of the gas delivered to the mother station site determines the processing requirements downstream. Table 4.1 shows the average values for gas composition, including maximum and minimum values.

Table 4.1 – Gas Specification

Daily Gas Quality Summary Chart

Chromatograph: 33025 Heritage Gas Halifax Airport

Period: 5/1/2010 To 5/1/2011 **Report Date:** 5/9/2011 12:44 PM

Dt	Heat Value (GJ / 1000 m^3)	Spec Grav	Wobbe Idx	CO2 (% CO2)	N2 (% Nitrogen)	C1 (% Methane)	C2 (% Ethane)	C3 (% Propane)	IC4	NC4	IC5	NC5	C6	C6 Plus	Total	GPM
Avg	39.19	0.613	50	0.018	0.004	0.907	0.062	0.009	0.000	0.000	0.000	0.000	0.000	0.000		0.000
Max	39.72	0.622	50	0.019	0.005	0.912	0.066	0.016	0.001	0.001	0.000	0.000	0.000	0.000		0.000
Min	39.03	0.610	50	0.016	0.003	0.899	0.058	0.006	0.000	0.000	0.000	0.000	0.000	0.000		0.000

The water vapor content is not specified, however the gas specification from the Maritimes and Northeast Pipeline defines maximum water vapor at 80 milligrams per standard cubic meter (P_{std}=101.325 kPa and T_{std} = 15^{o}C). ISO standard 11439 entitled *Gas cylinders – High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles* defines a "wet gas" as one containing water vapor in excess of 23 milligrams per standard cubic meter. NFPA 52 also uses the ISO 11439 guidelines in defining gas quality. According to ISO 11439, wet gases are permissible for introduction into steel and other cylinders as long as particular gases including hydrogen sulfide, oxygen, carbon dioxide and hydrogen do not exceed certain composition limits. The limit for carbon dioxide is 4 mol %. The gas specification of Table 4.1 does not exceed this limit. Hydrogen sulfide, oxygen and hydrogen are not shown so are assumed to be trace at most and therefore not a concern.

4.1.2. Gas Metering And Regulation

Gas metering on the inlet of a CNG mother station is recommended as an accounting of the total gas supplied to the mother station. Metering equipment is often located downstream of a gas regulator (if provided). The gas supply may be unregulated if the gas pressure fluctuation throughout the calendar year is less than about 20%. Unregulated gas pressure provides the highest possible supply pressure enhancing station capacity and reducing energy costs. A gas pressure fluctuation higher than 20% will necessitate regulation of pressure below the bottom range of the fluctuation. This reduces capacity and energy efficiency somewhat but assures a steady input pressure to the compressors and reliable and steady capacity.

4.1.3. Gas Drying

A gas dryer is recommended to be installed downstream of the gas supply and upstream of the CNG compressors. Gas drying provides the following benefits.

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- Assures that gas dew point temperature is well below the coldest temperatures that may be experienced at the site. At high pressures, the dew point temperature is elevated increasing the risk of water condensation. By drying the gas, the dew point temperature is suppressed sufficiently low to prevent this process.
- Dry gas protects cylinders from corrosion. This is particularly important if the gas composition includes some carbon dioxide, sulphur dioxide or hydrogen above specified limits as recommended by ISO standard 11439. In the case of the gas specification of Table 4.1, no further drying is necessary for the purposes of protecting the gas cylinders.
- Operational problems can occur with wet gas related to the decompression process. Joule Thompson cooling can cause gas temperatures to go far below zero. Cold temperatures may cause wet gas to condense. Coupled with freezing temperatures, lines may clog with ice causing flow blockage and operational issues with valves leading to safety concerns in some cases.

The Society of Automotive Engineers SAE J1616 recommended practice guidelines specifies overall requirements for gas drying dependent on prevailing climatic conditions. Winter weather conditions are typically the greatest concern for gas drying.

Gas dryers must also be sheltered in a heated enclosure or building. Ambient temperatures must remain above zero to avoid freezing of entrapped water.

Most natural gas dryers use a process whereby natural gas is passed through a molecular sieve desiccant bed. The water is absorbed by the desiccant and accumulates in the bed over time. The desiccant must have the entrapped water removed periodically otherwise the gas will exit with increasingly higher dew points. It is mainly the process by which the desiccant bed is dried that differentiates the cost and functionality of the different dryer types using molecular sieve. There are primarily three types of dryers used in the CNG industry.

- Twin Tower Regenerative – Provides two desiccant beds (i.e. "towers"). While one tower is on-line drying the gas, the other tower is off-line having its entrapped water removed simultaneously through a heated regeneration process after which it waits on standby. When the on-line tower is saturated with water, switching valves take it off-line and the drying cycle begins. The other dry tower returns to service at the same time. This type of dryer allows the gas to be dried continuously without any downtime; however these dryers are high in cost.
- Single Tower Regenerative – Provides one tower only. Once this bed is saturated with moisture it must be taken off-line and dried. While off-line the gas must be bypassed without drying or gas flow must stop for the tower drying process to be completed. The tower drying process typically takes about 6 hours.

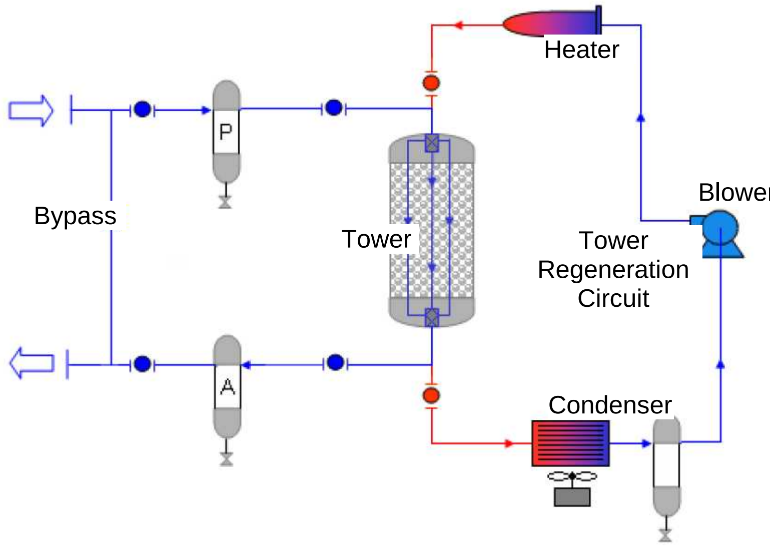

Figure 4.1 – Single Tower Natural Gas Dryer Flow Diagram

Figure 4.2 – Single Tower Regenerative Natural Gas Dryer

- Single Tower Non-Regenerative – Provides a single tower only without on-skid drying equipment. Tower must be regenerated using a portable drying skid that is temporarily connected to the dryer. The portable drying skid is usually shared among multiple dryer locations to save cost. This type of dryer offers the lowest cost.

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4.1.4. CNG Compressors and Packaging

CNG compressor technology is well developed. Most CNG compressors are reciprocating piston type. Compressors come in various configurations including balanced opposed, radial and others. The number of stages used is usually no greater than five and usually no less than two. The greater the gas supply pressure the fewer the number of stages required. The discharge pressure also has some influence on the number of stages but for CNG bulk transport applications the discharge pressure is usually between 2400 and 3600 psig.

Table 4.2 – Number of Compressor Stages 3600 psig (25 MPa) Discharge

Suction Pressure (psig)	No. of Stages
0.2 – 15	5
10 – 130	4
100 – 350	3
305 – 1150	2
1050+	1

High gas supply pressure offers the advantage of increased compressor throughput for a given power rating, lower capital cost, higher efficiency and lower maintenance costs.

4.1.4.1. Electric Motor Vs Natural Gas Engine Driven Units

Most CNG compressors are electric driven with AC induction motors. Electric driven compressors are substantially less complex and costly than those using gas engine drivers. Capital cost savings are approximately 30%. Reliability is also substantially higher and maintenance cost savings of 20% – 25% may be realized in comparison to gas engine driven units. Electric motors are near zero maintenance with only periodic bearing lubrication required. Gas engine driven units require regular maintenance including oil and filter changes, fuel filter changes, spark plug replacement, air filter changes, cooling system maintenance and other maintenance normally associated with spark ignited engines.

The main attraction of gas engine driven compressors is the elimination of the cost for a large electrical service installation and the ongoing electrical energy costs including demand charges. Demand charges can be very significant when starting large industrial motors which may only be operated for a few hours a day. To minimize demand and overall electrical charges, it is important not to oversize an electric driven compressor installation and to provide features in the installation for incremental capacity upgrades as load increases.

4.1.4.2. Packaging

CNG compressors are normally packaged complete on one skid. For most Canadian installations the skid is housed in an enclosure to provide weather protection and heating to maintain minimum temperatures of steel and cast iron materials susceptible to cold temperature embrittlement. For cold climates, weather enclosures large enough to accommodate maintenance operations within the package are provided. These enclosures provide maintenance and minimum egress clearances in accordance with the CSA B108-99 Natural Gas Fueling Station Installation Code.

The gas dryer is also often packaged with the compressor in the same enclosure saving the cost of an additional heated shelter for the dryer. Furthermore expensive field work is also eliminated by completing the low pressure gas connections and wiring at the factory.

Enclosed CNG compressor skids are rated Class 1, Zone 1, Group IIA by the Canadian Electrical Code CSA C22.1, unless equipped with gas detection and ventilation allowing a Zone 2 rating. This mandates that electrical equipment be explosion-proof rated accordingly or located remote from the gas equipment. Instrumentation, motors, lights and other electrical components local to the equipment must comply with Zone 1 or Zone 2 requirements as may be the case. For motor starting, PLCs and other electrical apparatus, these items are usually located away from the equipment in a non-hazardous area. These items must therefore be either (1) sheltered and then field wired to the gas equipment or (2) located in electrical rooms provided on the skid and set back from the gas equipment in accordance CSA C22.1. The latter requires that the electrical room be carefully designed with sealed walls and careful locating of doors and openings to maintain the required code setbacks. The on-skid electrical room is becoming increasingly common for Canadian installations allowing skids to be fully factory wired and tested, thereby eliminating costly field work and the uncertainty of incorrect field wiring and re-work. The electrical field work is reduced to a relatively simple connection of the main electrical power supply.

4.1.4.3. Equipment Redundancy

It is assumed that the mother station must be designed for high reliability and that the delivery of gas must emulate the reliability of gas delivered by a pipeline. The compressor is the least reliable piece of equipment in the entire system. It is recommended that 100% redundancy be provided with the compression equipment. This necessitates that any installation have at least two CNG compressors such that the loss of one compressor still leaves the station capable of delivering the required load. The controls and piping system must be such that one compressor can be taken out of service and isolated for repair without impacting station operation. This philosophy necessitates if two compressors are required to meet the load then at least one additional compressor should always be available on standby. When choosing the number of compressors for an installation, fewer larger compressors is usually advantageous as the incremental cost to increase capacity by selecting a larger compressor is usually much lower than adding an additional compressor. In some cases this philosophy may need to be modified if a single larger compressor is chosen to meet the demand. In this case 100% redundancy then requires that one additional equally large compressor be supplied on standby, whereas if 2 compressors are selected to meet the demand, only one additional compressor of the same smaller size is required for standby. Even in this case, fewer larger compressors usually provide the cost advantage. In general, Jenmar recommends the smallest number of larger compressors as the best solution in terms of capital, installation and even maintenance cost savings.

4.1.5. Communication and Controls

4.1.5.1. Station Control

The mother station is controlled by a programmable logic controller (PLC) based station control. The PLC provides complete station control including equipment start-up, shutdown, gas flow control, pressure temperature compensation, flow metering, equipment monitoring, gas detection, fault detection and alarm shutdowns. The mother station is designed for unmanned operation but can be monitored and communicated with via web enabled human machine interface (HMI) technologies. These usually consist of digital displays that can be read at site or accessed via the internet from remote locations with passwords. The HMI can be configured to communicate with remote or local servers to dispatch emails or make telephone calls to notify operations personnel for imminent maintenance procedures, faults detected or alarms annunciated. Station monitoring can also be provided remotely whereby service personnel can monitor instrumentation such are pressures, temperatures, flow, gas concentration, etc. from remote locations.

Unmanned operation is allowed by the British Columbia Safety Authority (BCSA) for private CNG fueling stations in BC. In BC, the regulations are similar for unmanned propane fueling installations for private access and use only. Unmanned operation of CNG stations in Alberta is also allowed (i.e. Encana Gas in Strathmore, AB). A new unmanned mother station is currently being planned for Saskatchewan. The similarities between fueling of large vehicles in time fill operations and the fueling of mobile storage units is functionally the same. Time fill facilities are routinely unmanned. Stations currently in service include Waste Management in Coquitlam, BC and School District No. 23 in Kelowna, BC.

4.1.5.2. Loading Authorization

The connection of the fueling nozzle and fill authorization process must be executed by an operator. Upon arrival of the mobile storage at the mother station, the operator will connect the filling nozzle and authorize the loading process. This may be done at a local HMI at the fill post. Systems can be configured whereby the fill is authorized by the operator entering identifying information which may include mobile storage number, operator identification, customer identification, passwords or other info as deemed necessary. The system then dispatches CNG to the mobile storage by starting up the compressor(s) (if not already operating) and directing flow to the first hose authorized.

4.1.5.3. Temperature Compensated Filling

The loading system controls for bulk CNG filling must incorporate a temperature compensated pressure fill system like those required by codes such as CSA B51 Part 3 and CSA B108-99. Cylinders designed for road transport of gases are pressure rated by *Service Pressure*. For example a DOT/TC 3AAX-2900 cylinder has a service pressure of 2900 psig @ 21^{o}C gas temperature. This pressure and temperature rating allows for an increase in cylinder pressure if the ambient temperature causing a gas pressure rise. Transport Canada (in conformance with US Code of Federal Regulation (CFR) Title 49) has determined that

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131°F (55°C) is the maximum temperature normally encountered during the transportation and storage of compressed gases. At this temperature a corresponding pressure rise is allowable however temperatures above this limit are prohibited (see Figure 4.3).

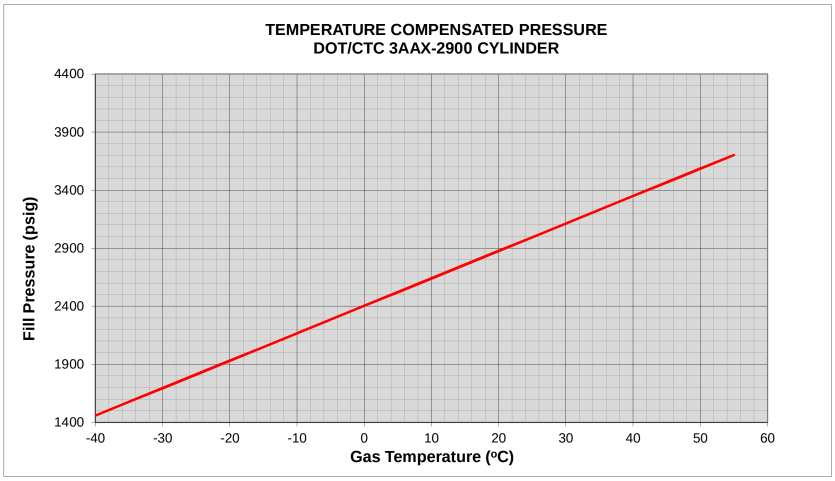

Figure 4.3 – Temperature Compensated Pressure DOT/TC 3AAX-2900 Gas Cylinder

To address these requirements, the filling controls must account for changes in gas temperature due to process changes and also ambient temperature. As the mobile storage is being filled, gas is being discharged directly from the compressor. A high performance after-cooling system is not able to deliver discharge gas that is less than about 10°C above ambient air temperature. In addition, as the gas enters the mobile storage cylinder, there is an additional temperature rise due to the heat of compression (a phenomenon whereby the gas entering the cylinder effectively acts as a piston to compress the gas already in the cylinder causing a temperature rise). The combination of these two processes causes the gas temperature inside the mobile storage to be well above ambient temperature possibly by 30° – 40°C. Most temperature compensated fill systems correct only to ambient temperature. More sophisticated controls account for the aforementioned excess after-cooled temperature and thermodynamic affects by filling storage to higher pressures than would be calculated simply based on an ambient temperature correction. Even with the more sophisticated temperature compensation systems, under-filling remains an issue during warm temperature days due to the maximum temperature limit of 55°C. Generally colder climates such as Nova Scotia will provide some advantage in this regard.

Gas temperature rise during the filling process is a common industry challenge usually causing systems to under-fill. Under-filling is an economic problem resulting in a smaller delivered load size. This results in higher operations costs and marginally increased capital costs as increased storage capacity may need to be provided to make up the difference.

4.1.5.4. Buffer Storage

A buffer storage cylinder or series of cylinders may be necessary at the mother station when high capacity compressors are used. A buffer storage provides some volume for compressors to discharge to during short periods between trailer filling to avoid a short stop/start cycle or at the end of a trailer loading cycle. To reduce under-filling of the trailer due to line pressure drop, some of the flow can be temporarily diverted to a buffer storage to reduce the flow and therefore pressure drop to the loading mobile storage trailer.

4.2. CNG Bulk Transport

4.2.1. Gas Cylinders And Certification

Cylinders used for road transport of gases must conform to Transport Canada (TC) and the Transportation of Dangerous Goods (TDG) Act. Cylinders conforming to TDG must be manufactured and approved in accordance with the following standards or processes.

- CAN/CSA-B339 - This standard is prepared for use in conjunction with TDG regulations. It sets the requirements for manufacturing, inspection, testing, marking and requalification of conventional steel (Type 1) cylinders, spheres and tubes used for transporting gases and other dangerous goods.

- ISO 11119 (Parts 1, 2 and 3) – This is an international standard that is in the process of being adopted by Transport Canada into its TDG regulations. Currently, applications for approval of gas cylinders in accordance with this standard still require an application for a TDG *Equivalency Certificate* however the process is well defined with little schedule impact. The standard applies to new technology light weight composite type cylinders up to and including 450 liters water capacity for the storage of compressed gases up to 650 bar. Compliant cylinders are constructed of a metallic or non-metallic load or non-load sharing liner over-wrapped with carbon, aramid or glass fibre (or mixtures) in a resin matrix. They may also incorporate steel wire to provide circumferential reinforcement. These cylinders are commonly categorized as follows:

    - Type 2 – metal liner with hoop wrapped composite
    - Type 3 – metal liner with fully wrapped composite
    - Type 4 – non-metallic liner with 100% composite

- Equivalency Certificate (Permit) – Transport Canada has provision for application of new gas cylinder technologies and/or transportation processes not fitting the above standards by allowing the proponent to prove an equivalent level of safety to compliance with TDG regulations.

Type 1 steel cylinders is the incumbent technology with a proven track record and established certification processes. The disadvantage of steel cylinder based mobile storage trailers is their high road weight. The road weight limit in Nova Scotia is 41,500 kg for a tri-axle type trailer. This limit is quickly exceeded with steel cylinder type trailers. Type 2, 3 and 4 light weight cylinders offer a key advantage in substantially reduced road weight per unit volume. This allows light weight cylinder trailers to offer the highest transport capacities.

4.2.2. Gas Cylinder Re-Qualification

Gas cylinders designed manufactured to CAN/CSA-B339 and ISO 11119 must undergo re-qualification testing periodically. A summary of these requirements is provided below. For more detailed information, the relevant standards can be consulted.

- Type 1 steel cylinders built to DOT/TC-3AAX designation
  - 10 year inspection interval
  - Includes a cylinder hydro test to 1.5 times service pressure
  - Cylinder life is unlimited

- Lincoln Composite Type 4 cylinders – Titan Module
  - built to ISO 11119-3
  - have a special DOT Permit for US application.
  - 5 year re-qualification interval
  - Re-qualification testing includes internal and external visual inspection and hydro test.
  - 15 year maximum service life
  - Are pursuing service life extension to 30 years – not yet approved.
  - Transport Canada Equivalency Certificate no yet approved.
  - Re-qualification interval may reduce to 3 years in Canada, similar to Dynetek.

- Dynetek Composite Type 3 cylinders – Dynetek BT-30 module
  - 5 year re-qualification interval in USA
  - 3 year re-qualification interval period in Canada (application has been made to Transport Canada for 5 year interval)
  - 15 year maximum service life – no provision for extension
  - Re-qualification requires disassembly/reassembly of modules and testing of each of 39 containers per module (visual and hydro test)
  - Cost for re-qualification approximately $10,000 (cost provided by Dynetek)

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4.2.3. Gas Cylinder Suppliers

Several suppliers of gas storage cylinders exist in both Canada and the US. European and other off shore suppliers are also active in the industry. Most manufacturers will supply storage modules for mounting on transport trailers. Several cylinder module suppliers are listed below.

Fiba Canning (Scarborough, ON)

- Package a variety of sizes of Type 1 steel cylinder trailers
- DOT/TC type with compliance to CSA B339
- Able to supply a 13 tube DOT/TC-3AAX-2400+ cylinder tridem axel trailer with a capacity of 235,760,900 scf @ 2640 psig
- Also package lightweight Type 2 cylinders. TC approvals are pending.

Dynetek (Calgary, AB)

- Build Type 3 cylinders with aluminum liners and carbon fiber wrap
- The Dynetek Model V260 cylinder is the only cylinder model currently approved for road transport with Transport Canada by way of a TDG Equivalency Certificate.
- The V260 cylinder has a volume of 260 liters and is used as part of multiple cylinder assemblies to make up the required transport volumes
- The BT-30 mobile storage has a capacity of 300,600 scf at 250 barg (3600 psig) storage pressure
- Cost for the BT-30 storage trailer is approximately $615,000.

Lincoln Composites (Lincoln, NE)

- Manufacture Type 4 tanks with non-metallic liner and composites
- Titan module has a capacity of 362,200 scf @ 250 barg (3600 psig)
- Cost for trailer packaged module approximately $485,000

4.3. De-Canting and Pressure Letdown Systems

A process flow diagram of a De-Canting System is shown in Appendix A. De-canting point(s) and pressure letdown system skid are necessary to condition the variable pressure gas coming off the mobile storage for introduction to the customer's fuel supply.

4.3.1. De-Canting Post

The customer site must have at least two off-loading bays to accommodate the mobile storage trailers (MST). To guarantee a continuous supply of gas, prior to the depletion of one MST, a full MST must already be in position and connected to the de-canting system. The transition from empty MST to full MST must be without gas flow interruption. Each dispatch bay must have at least one de-canting post. A de-canting post consists of a connection nozzle, flexible hose, hand valve, check valve and possibly an automatic switching valve.

The transition from empty MST to full MST can be initiated upon reaching a low pressure condition at the inlet of the pressure reduction system (PRS). A system that includes a programmable logic controller (PLC), inlet pressure transmitter and switching valve may initiate the transition automatically. Once the automatic valve on the fill post of the full MST opens, the higher pressure on this line will back up the check valve on the fill post of the empty MST and the flow from the empty MST will stop. Consequently, the flow from the full MST will provide the entire gas supply to the PRS. The automatic valve on the empty fill post will close and the empty MST can be disconnected and prepared for dispatch from the offloading bay.

4.3.2. Pressure Reduction System (PRS)

PRS technology can be provided in various configurations however all equipment of this kind has the same basic functionality. Common features include

- Two or more stages of pressure regulation
- Gas pre-heating prior to pressure reduction

4.3.2.1. Gas Preheating System

As natural gas drops in pressure through a throttling process from pressure above 2400 psig to less than 150 psig, the temperature of the gas plunges to very low temperatures. Temperatures below freezing are not permitted

- to eliminate liquid drop out, i.e. water vapor
- to avoid freezing of liquid water
- to protect downstream materials
- to maintain normal gas densities for downstream process equipment

Normally the target downstream gas temperature is between 10^{o}C and 30^{o}C. To condition the gas for these outlet temperatures, the gas must be pre-heated prior to regulation to between 70^{o}C and 80^{o}C. There are several types of heating systems used in PRS equipment including

- direct fired tube heaters
- liquid bath electric heaters
- shell and tube heat exchangers with hot glycol fluid loops

Direct fired tube heaters are simple and reliable but expensive particularly at the small scale typical of PRS equipment. Liquid bath heaters use expensive electric heat, with heating loads in the high tens of kilowatts. Shell and tube heat exchangers with glycol fluid loops are more complex but very economical from a capital and operations standpoint. The process flow diagram of QN-0001-00 shows a PRS made up of a Heating and Controls Module (HCM) and a Pressure Reduction Module (PRM). The HCM consists mainly of an inexpensive packaged industrial boiler, liquid pump and auxiliary items. The PRM consist of the gas section with shell tube heat exchanger, staged pressure regulation and gas meter. The PRM and HCM are packaged on separate skids. The PRM has a hazardous area classification of Class 1, Zone 2, Group D. The HCM is rated non-hazardous and must be located at least 3 meters from the PRM in a non-hazardous area. The two skids are connected with glycol/water heating piping and a small gas line that takes a feed of natural gas from the PRM to the boiler for firing. The PRM provides a Measurement Canada certified custody transfer meter on the outlet that measures net fuel delivered to the customer.

4.3.2.2. Staged Pressure Regulation

Most PRS have a primary regulation stage followed by a secondary regulation stage. The primary regulators are rated for high pressure and are able to make a large pressure reduction from 25 MPa (3600 psig) down to typically 2 – 4 MPa (290 – 580 psig). The outlet pressure of the primary regulator need to be accurate but must be such that the outlet gas pressure is in the range required by the secondary regulation stage. The secondary regulation stage must provide an accurate and steady outlet gas pressure as required by the customer's downstream process. Secondary regulation often consists of one or more pilot regulators that may be configured singularly or as a main and monitor pair. Downstream over-pressure protection (i.e. relief valve, burst disk, etc.) must be provided at the outlet of both primary and secondary regulation stages. These safety relieving devices are particularly important given the high pressure upstream of the regulators should they fail. Careful attention must be paid to design safety measures adequately to relieve pressure in the event of regulator wide-open failures.

4.3.2.3. Redundancy

In critical supply applications, redundancy on the most maintenance prone components of the pressure reduction system is recommended. Pressure regulation should be dual trained with isolation valves provided on each train for maintenance isolation. Dual coolant pumps and diverter valves with maintenance isolation valves should also be provided on systems that use a commercial boiler based heating system. Commercial boilers are generally very reliable as long as regular maintenance intervals are observed.

4.3.3. <u>PRS System Performance Limitations</u>

The entire piping system from the MST through to the PRS outlet must be designed to allow the flow of gas from the MST to be sustained even at very low MST supply pressures. If the MST can be drained to a very low pressure (i.e. less than 300 psig), the economics of the process improve. A low MST pressure at "empty" allows more fuel gas to be transported per delivery. Low pressure flow capacity is one of the key system design constraints. A well designed system should be capable of transferring 90% of the volume capacity of the MST with a 2640 psig service pressure. This percentage will increase with a MST with a higher service pressure.

4.3.3.1. MST Piping System

The proper flow design of the MST piping system is often overlooked and can result in poor overall flow performance and economics. The MST piping and manifold designs must be carefully matched to the required flow specifications.

4.3.3.2. De-Canting Nozzle

The connection nozzle is one of the major flow limiting components of the de-canting post. Typical CNG nozzles are generally too restrictive for customers requiring flows rates higher than about 200 Sm3/hr. There are only very few nozzle options that have Canadian Registration Numbers (CRN) and the required flow capacity, one of them being the Hansen 8-HKP 1" Body Size hydraulic coupling (Cv = 10.3). This unit does not have a CSA listing and is made of steel so is not rated for cold temperature (i.e. less than -20^{o}C). For cold temperature application, the stainless steel version should be used but the pressure rating falls from 275 bar to 173 bar which is unacceptable. The Hansen 6-HKP ¾" body size (Cv=7.2) in stainless steel only has a rating of 242 bar. This unit is acceptable with ratings to 200 bar however most new technology light weight cylinders are rated to 250 bar. The availability of high flow coupling technologies with CRNs is an issue. Staubli Corporation provides some very good high flow couplings suitable for the service but without CRNs. Suppliers will need to be persuaded to make CRN applications or the authorities may need to be convinced to provide a variance on these components.

4.3.3.3. De-Canting Post Breakaway Fitting

CNG Dispensers and Time Fill Posts require a breakaway device to protect the equipment from inadvertent drive-away while the fuel nozzle is connected. This is a requirement of CSA B108-99. Similarly a de-canting post must also have provision for a drive-away event or other provision to mitigate the risk. Use of a conventional breakaway device is not feasible for most de-canting post applications due to the restrictiveness of the component. The OPW ILB-1 has a CRN for most provinces but is too restrictive (i.e. Cv=1.17). The larger OPW ILB-5 has no CRN but is still too restrictive for most applications (i.e. Cv = 3.6). Other breakaway products are available but without CRNs or adequate flow capacity. An equivalent safety approach must be adopted in lieu of this. One solution is to provide a brake interlock device whereby the wheel brake system engages when the fuel nozzle receptacle is engaged. For example, when a cover over the fueling receptacle is opened, the wheel break automatically engages on the mobile storage. To release the brakes, the nozzle must be removed from the receptacle and cover replaced.

4.3.3.4. De-Canting Hose

De-canting hoses must be rated for high pressure. A large I.D. CNG hose is required for high flow de-canting operations. The largest I.D. hose available is a 1" I.D. hose made by Parker. These hoses offer reasonable flow capacity but are cumbersome to handle due to their stiffness.

4.3.3.5. Multiple De-Canting Posts

Due to the general flow restrictiveness of the De-Canting Post and the impracticality of upsizing the flow components, it may be necessary to provide more than one post per MST thereby reducing the flow per post. It may also not be practical to upsize the field piping between the post and the PRM above about 1 NPS size, leading to parallel gas piping runs to the PRM to minimize pressure drop.

4.3.3.6. Primary Regulators

Primary regulators require large flow coefficients to assure adequate flow performance at low pressure. Once pressures drop in the MST and the pressure drops below the set pressure of the primary regulator in the PRS, regulators no longer regulate but operate in a wide open condition. The availability of high pressure, high-flow coefficient regulators is very limited and is therefore expensive and may not have the necessary C.R.N. approvals. This will require users to convince manufacturers to obtain the required approvals or apply for a variance on their use.

4.3.4. <u>Codes Standards And Approvals</u>

4.3.4.1. Mother Stations

The design of CNG mother stations is not explicitly included in the scope (Section 1) of CSA B108-99 *Natural Gas Fuelling Stations Installation Code*. Clause 8 however addresses storage vessel dispatch and receiving briefly. In lieu of a specific design code governing mother stations, CSA B108-99 is expected to be the code of design for mother stations adopted by authorities having jurisdiction in Canada.

The design of mother stations is also not strictly included in the scope of CSA B51 Part 3 *Compressor Natural Gas and Hydrogen Refueling Station Pressure Piping Systems and Ground Storage Vessels*, however it is expected that the authorities having jurisdiction will require compliance with this code section also.

4.3.4.2. De-Canting and Pressure Reduction Systems

The design standards to be applied to de-canting and PRS equipment is less clear. Best practices would dictate that the most stringent of the following codes and standards be applied where applicable.

- CSA Z662-11 *Oil and Gas Pipeline Systems* – Applicable to the design or pressure regulation systems and over-pressure protection.
- CSA B108-99 *Natural Gas Fuelling Stations Installation Code* – Applicable to the design of receiving and dispatch facilities, high pressure storage crash protection, de-canting posts and hazardous area locations and general siting set-backs.
- CSA B51 Part 1 – Design of pressure vessels, heat exchangers, fittings and pressure piping systems.
- CSA B149.1-10 – *Natural Gas and Propane Installation Code* – Applicable to the design of field pressure piping systems from the outlet flange of the custody transfer meter to the customers' appliances.

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5. PHASE 1 SINGLE USER CASE STUDY

5.1. Single User Study Case Definition

For the purposes of the study and as required by the QUEST RFP, a single user off-grid customer is defined as a base line case in the following table.

Table 5.1 – Single User Profile

Parameter	Value	Unit
Annual fuel consumption	250,000	GJ/yr
Average consumption	685	GJ/day
Peak consumption	1000	GJ/day
Distance from mother station	50	km
Total round trip distance	100	km
Average travel speed	60	Km/hr
Gas supply pressure at mother station	800	psig

A capital and operating budget will be generated to accommodate this single user to define a base line delivered fuel cost. A sensitivity analysis will follow in Section 6 to understand the changes in delivered fuel cost based on changes in load and delivery distance.

5.2. Base Line Operations Assumptions

The following assumptions are made that impact both process and installation design.

- The customer must have a continuous and un-interrupted fuel supply delivered to the site.
- The mother station capacity is designed and optimized for the single customer.
- The mother station has 100% redundant compression capacity such that with the loss of one compressor due to malfunction or maintenance interval the station remains in service and capable of meeting the full demand.
- Only one compressor operates at any one time to reduce demand charges.
- The station is designed for unattended operation with twice weekly inspections and service as required (See Section 4.1.4.1).
- The transport operators will be trained to execute filling operations, safety procedures and emergency response.
- Two trailer loading positions will be provided at both the mother station and de-canting stations so that there can be seamless transitions.
- The operator will deliver a full trailer and connect it to the de-canting system at the customer site. The newly delivered trailer will be unhitched and the operator will

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transport the empty trailer back to the mother station for fueling. In this way, the operator will have minimum idle time at the de-canting station.

- At the mother station, the empty trailer will be positioned for filling and connected to the fill post. After connection, operator is idle for a determined number of hours while the trailer is being filled and may proceed with other work or go off shift as the schedule dictates. The operations process assumes a minimum of idle time for operators. When the trailer is full at the mother station, it may sit idle for a time before pick-up by the operator. The operator is assumed to have good timing for load pick-up in order to reach the customer site in time before the incumbent trailer is depleted.
- Average travel speed for road transport is 60 km/hr.

5.3. Mother Station System Design

Figure 5.1 provides a schematic of the major equipment components of the mother station facility. The priority/ESD/fill control panel prioritizes flow to one of two fueling nozzles. The compressor boosts line pressure to a buffer storage or directly to the trailers for loading. The size of the buffer storage is small and is mainly needed to provide some system stability during transitions from the loading of one trailer to the next. The filling of trailers will be on a "first in / first out" basis whereby the first trailer to connect will receive a complete load before gas is directed to a 2nd connected trailer. This allows for a seamless transition whereby one trailer is being loaded while a full trailer is being moved out and an empty unit moved into loading position. The empty unit is then available on standby ready to begin loading after the 1st trailer unit completes the loading operation.

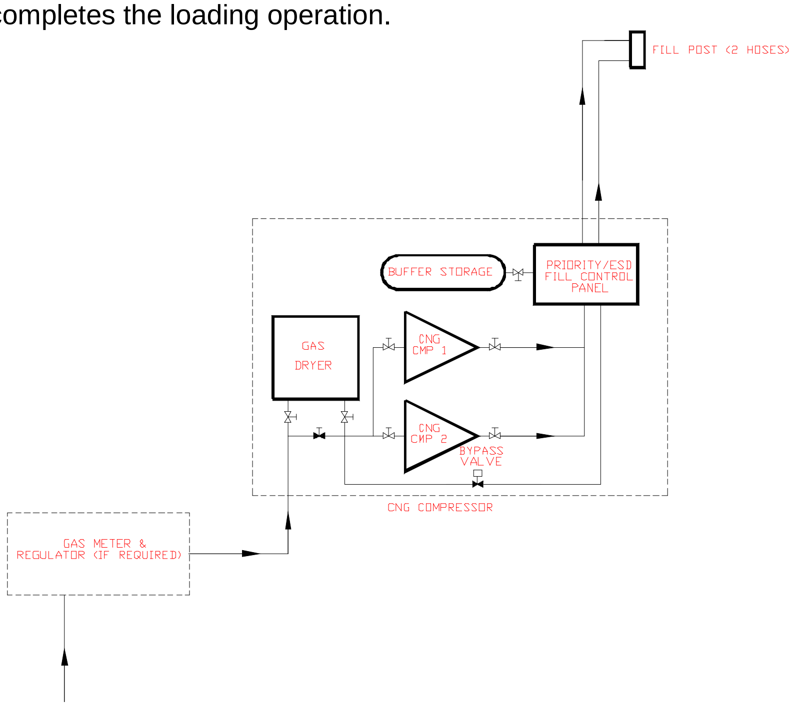

Figure 5.1 – Mother Station Concept Flow Diagram

A supply gas meter provides information on the total gas delivered from the main gas supply pipeline to the mother station compressors. The Fill Control Panel includes a coriolis mass flow meter to record the fueling delivery transactions to each mobile storage trailer. In this way, fuel delivered to each trailer and be tracked.

Since the gas supply pressure is expected to be 800 psig (5500 kPa) or even higher there is an opportunity to partially fill the storage trailers with line gas directly thereby bypassing the need for compression at the start of the loading process. The trailers are expected to arrive with their cylinders having been depleted at the customer site to approximately 150 – 200 psig. It may be possible to fill the storage trailers to about 725 psig if piping is adequately sized. This will provide some savings in operating costs associated with motive energy and maintenance. Cycle time may also be reduced.

The equipment selection for the mother station is based on maintaining a high duty cycle for the compression equipment. This philosophy minimizes the electrical demand charges and maximizes the gas throughput per unit of capital expenditure. High duty cycle also minimizes operations cost, particularly maintenance and service.

Table 5.2 – Mother Station Performance Summary

MOTHER STATION PERFORMANCE	Value	Unit
station load	250000	GJ HHV/yr
station volume	629995	scf
supply gas pressure	800	psig
no. of compressors available	2	
compressor flow per unit	703	scfm
total compressor flow	1406	scfm
no. of compressors operating	1	
trailer filling rate	703	scfm
fueling time per mobile storage	6.7	hours
compressor operating time per day	14.9	hours
compressor operating hours per year	5437	hours
compressor duty cycle	65%	
redundancy	100%	

Note that filling time for one mobile storage trailer is 6.7 hours in the base case at an inflow of 703 scfm. Filling durations can be reduced substantially by increasing inflow with increased compression capacity if needed. A practical limit may be 2500 – 3000 scfm. At 2500 scfm the fill time would be reduced to less than 2 hours. Above 3000 scfm, metering becomes very expensive. In addition deleterious effects including excessive pressure drop and heat of compression induced temperature rise in the gas cylinders increase will flow to cause under-filling issues.

5.4. Mother Station Equipment Selection

An equipment list for the mother station site is provided in the following table.

Table 5.3 – Mother Station Equipment List

Item	Equipment	Qty
1	CNG Compressor – Electric Driven – **Option 1** Suction pressure: 800 psig (5500 kPa) Discharge pressure: 3600 psig Stages: 2 Flow Capacity: 702 scfm @ 800 psig suction Speed: 750 RPM Main drive motor: 100 HP Remote non-hazardous control panel	2
2	CNG Compressor – CAT 3306NA Gas Engine Driven – **Option 2** Suction pressure: 800 psig (5500 kPa) Discharge pressure: 3600 psig Stages: 2 Flow Capacity: 878 scfm @ 800 psig (5500 kPa) suction Speed: 900 RPM Main drive motor: 125 BHP Remote non-hazardous control panel	2
3	Compressor block heater	2
4	Gas Dryer - Single tower with off-line regeneration	1
5	Walk-in Weather Enclosure W/ Electrical Controls Room - Class 600 isolation ball valve & flex hose - Electric heating with thermostat - Controls room to include main disconnect, distribution, individual panel disconnects and a transfer switch (for back-up power) - Control panel mounted in controls room and wired to equipment in enclosure. - Enclosure houses both gas dryer and two compressors	1
6	2 Hose Fill Control/Priority/ESD Panel - instrument fittings and tube fittings - For flow to 1500 scfm - ¾" line sizes for main flow lines throughout - ¾" authorization valves (2 units) - Micromotion meters - Pressure transmitters - Relief valve - Ambient temperature transmitter	1
7	Fill Post – Double Hose	2

	- High flow fill post for flow up to 1000 scfm - ¾"" I.D. hoses - ¾" tubing - Heavy duty in-line breakaway – OPW ILB-5 - Heavy duty fueling nozzle – OPW CT5000S - ¾" ball valve - Pressure gauge - Vent valve & Hose retractor	
8	SCADA System - HMI Display suitable for outdoor location - Fill authorization and data logging based on operator I.D. and password. - Tracking of mobile transport I.D., date/time of fill, product transferred, final fill pressure - Data download to PC	1
9	Buffer Storage Assembly - Single ASME high pressure storage vessel, 1000 liter water volume, MAWP=5500 psig, ASME VIII Appendix 22 – Qty 1 - Relief valve - Isolation valve - Vessel bulkheads	1

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5.5. Electrical Load

The mother station site will require an electrical service to be installed. The size of the service is based on the equipment selection and estimated as per Table 5.3.

Table 5.3 – Electrical Load Calculation – Electric Drive

CNG EQUIPMENT ELECTRICAL LOAD LIST - 100 HP ELECTRIC DRIVE											
Item	Load Description	Voltage	Circuit Amp Max Rating	Amps	Efficiency	Power Factor	Mtr Shaft Pwr (hp)	Power (kW)	Power(kVA)	Peak Operation	Station Idle Load
1	IMW50/100 Compressor No. 1										
2	Main Drive Motor	575		98.3	92%	0.9	100	81.09	90.10	YES	NO
3	Cooling Fan Motor No. 1A	575		2.1	88%	0.9	2	1.70	1.88	YES	NO
4	Cooling Fan Motor No. 1B	575		2.1	88%	0.9	2	1.70	1.88	YES	NO
5	Compressor Block Heater	120		2.5	100%	1.0		0.30	0.30	YES	YES
6	Compressor Controls	120		16.7	100%	1.0		2.00	2.00	YES	YES
7											
1	IMW50/100 Compressor No. 2										
2	Main Drive Motor	575		98.3	92%	0.9	100	81.09	90.10	YES	NO
3	Cooling Fan Motor No. 2A	575		2.1	88%	0.9	2	1.70	1.88	YES	NO
4	Cooling Fan Motor No. 2B	575		2.1	88%	0.9	2	1.70	1.88	YES	NO
5	Compressor Block Heater	120		2.5	100%	1.0		0.30	0.30	YES	YES
6	Compressor Controls	120		16.7	100%	1.0		2.00	2.00	YES	YES
7											
8	Gas Dryer										
9	Gas Dryer - blower motor	575		23.4	88%	0.9	2.0	1.70	1.88	NO	NO
10	Gas Dryer - fan motor	575		23.4	88%	0.9	0.25	0.21	0.24	NO	NO
11	Gas Dryer - Heater	575		15.1	100%	1.0		15.00	15.00	NO	NO
12											
13	Other 575V Loads										
14	Enclosure Heater	575		5.0	100%	1.0		5.00	5.00	YES	YES
15											
16	Yard Lighting										
17	Yard Light No. 1	377		0.8	100%	1.0		0.50	0.50	YES	YES
18	Yard Light No. 2	377		0.8	100%	1.0		0.50	0.50	YES	YES
19											
20	Other 120V Loads										
28	electrical room heater	120		4.8	100%	1.0		1.00	1.00	YES	YES
21	Enclosure Lighting	120	15	5	100%	1.0		0.60	0.60	YES	YES
22	120V Outlet Plug/Light #1	120	15	0	100%	1.0		0.00	0.00	NO	NO
23	120V Outlet Plug/Light #2	120	15	0	100%	1.0		0.00	0.00	NO	NO
24	Skada System	120	15	5	100%	1.0		0.60	0.60	YES	YES
25	Spare 1	120	15	0	100%	1.0		0.00	0.00	NO	NO
26	Spare 2	120	15	0	100%	1.0		0.00	0.00	NO	NO
							Total	198.66	217.65	kVA	

Service Voltage	**575**	V
Service Amperage	**218.5**	A
Peak Operating Load	**200.5**	kVA
Station Idle Load	**12.8**	kVA

A peak load of 200.5 kVA is projected. This load includes non-CNG related loads including yard lighting, and provision for some additional small loads. It is expected that a 300 kVA/600V service is required.

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As a comparison, the electrical load for a gas engine driven compressor is provided in Table 5.2.

Table 5.4 – Electrical Load Calculation – Gas Engine Drive

CNG EQUIPMENT ELECTRICAL LOAD LIST - CAT 3306NA GAS ENGINE DRIVE

Item	Load Description	Voltage	Circuit Amp Max Rating	Amps	Efficiency	Power Factor	Mtr Shaft Pwr (hp)	Power (kW)	Power(kVA)	Peak Operation	Station Idle Load
1	IMW50 Compressor/CAT3306NA										
2	Cooling Fan Motor No. 1	575		2.1	88%	0.9	2	1.70	1.88	YES	NO
3	Cooling Fan Motor No. 2	575		2.1	88%	0.9	2	1.70	1.88	YES	NO
4	Engine Radiator Fan	575		20.6	90%	0.9	20	16.58	18.42	YES	NO
5	Compressor Block Heater No. 1	120		2.5	100%	1.0		0.30	0.30	YES	YES
6	Compressor Controls	120		16.7	100%	1.0		2.00	2.00	YES	YES
7											
8	Gas Dryer										
9	Gas Dryer - blower motor	575		23.4	88%	0.9	2.0	1.70	1.88	NO	NO
10	Gas Dryer - fan motor	575		23.4	88%	0.9	0.25	0.21	0.24	NO	NO
11	Gas Dryer - Heater	575		15.1	100%	1.0		15.00	15.00	NO	NO
12											
13	Other 575V Loads										
14	Enclosure Heater	575		5.0	100%	1.0		5.00	5.00	YES	YES
15											
16	Yard Lighting										
17	Yard Light No. 1	377		0.8	100%	1.0		0.50	0.50	YES	YES
18	Yard Light No. 2	377		0.8	100%	1.0		0.50	0.50	YES	YES
19											
20	Other 120V Loads										
21	Enclosure Lighting	120	15	5	100%	1.0		0.60	0.60	YES	YES
22	120V Outlet Plug/Light #1	120	15	0	100%	1.0		0.00	0.00	NO	NO
23	120V Outlet Plug/Light #2	120	15	0	100%	1.0		0.00	0.00	NO	NO
24	Skada System	120	15	5	100%	1.0		0.60	0.60	YES	YES
25	Spare 1	120	15	0	100%	1.0		0.00	0.00	NO	NO
26	Spare 2	120	15	0	100%	1.0		0.00	0.00	NO	NO
							Total	46.38	**48.81**	kVA	
							Service Voltage		**575**	V	
							Service Amperage		**49.0**	A	
							Peak Operating Load		**31.7**	kVA	
							Station Idle Load		**9.5**	kVA	

A peak load of 31.7 kVA is projected. This load includes non-CNG related loads including yard lighting, and provision for some additional small loads. A 50 kVA/600V service is required.

5.6. Site Design Concepts

5.6.1. Mother Station

A concept drawing of the mother station site is shown in Appendix B. The site provides an entrance and exit with two pull through trailer loading positions. A double hose fill post provides two hoses, one for each trailer connection.

The yard has security fencing and locked rolling gates to limit entry to authorized personnel only.

The trailer loading positions are protected by concrete barriers to mitigate the risk of collision in accordance with code (CSA B108-99).

The compressor enclosure includes an on-skid electrical controls room that is unclassified and contains electrical distribution and control panel equipment. The electrical room is sealed separate from the equipment room containing the natural gas drying and compressor equipment. All wiring between the electrical room and equipment room is pre-wired at the factory and tested. Electrical site work is limited to a main power supply connection.

The gas supply is piped from a gas meter and regulator (if required) to the inlet flange of the compressor skid. A buffer storage vessel is mounted outside of the enclosure. High pressure tubing lines and an electrical conduit run between the skid and the fill post.

5.6.2. De-Canting Station Site

A concept drawing of the de-canting station site is shown in Appendix B. The site provides an entrance and exit with two pull through trailer loading positions similar to the mother station. Two de-canting posts, one at each off-loading position are provided.

The yard has a security fence and locked rolling gates to limit entry to authorized personnel only. This feature is not required for de-canting facilities located in a secured customer facility.

The trailer off-loading positions are protected by concrete barriers to mitigate the risk of collision in accordance with code (CSA B108-99).

The pressure reduction system is located between the off-loading positions to minimize high pressure field piping runs. The HCM requires a power supply connection (5 kVA/220V). The PRM requires high pressure gas connections to the de-canting posts. The gas exiting from the PRM must be piped and connected to the customer's gas supply system. Some coolant piping and electrical wiring connections are required between the HCM and PRM. The HCM must be offset from the PRM by 3 meters to avoid the zone 2 hazardous area surrounding the PRM. The HCM is covered by a light shelter or roof.

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5.7. Mobile Storage Transport Equipment

The case study assumes the use of a 14 tube mobile transport trailer based on use of Transport Canada approved high pressure cylinders. For the purpose of this study, a 14 Tube Tridem Jumbo trailer is selected with the following specifications.

Table 5.5 – Mobile Storage Transport Specifications

Parameter	**Value**	**Unit**
Model	14 Tube Quad Axle Jumbo	
Supplier	Fiba Canning	
No. of cylinders	14	
Cylinder specification	DOT/TC 3AA-2750	
Service pressure	2750	psig
Water volume (each)	2468	
Total capacity	8520	Sm3
	300,900	Scf
Trailer Weight (empty)	41,000	kg
Loaded Weight (full)	47,152	kg

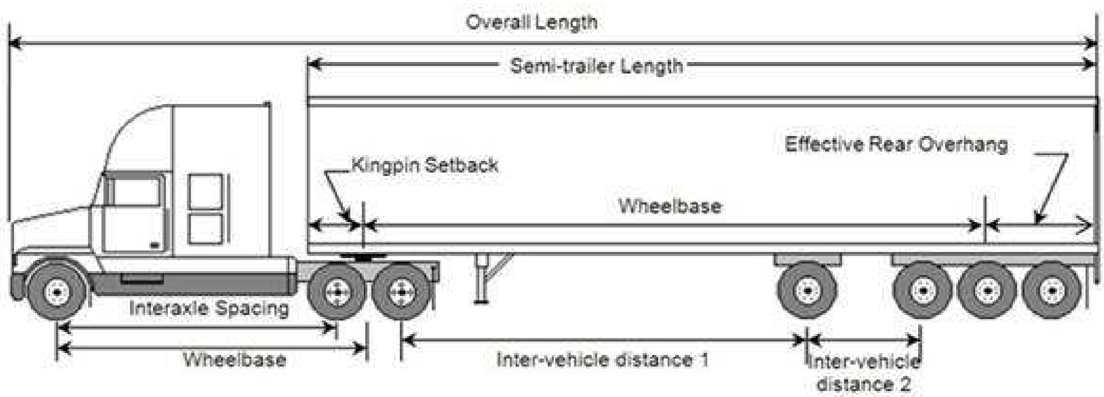

Figure 5.2 – Self-steer Quad-axle semi-trailer

Of the available mobile storage options with Transport Canada approvals, this equipment was the most economical. Based on supplier's quotes, the total budget cost for the trailer assembly is $400,000 (not including the tractor). Fiba Technologies (a US company) has supplied this type of trailer for the Cavendish Farms (PEI) project. It is presumed that J.D. Irving, owner of Cavendish Farms was able to obtain an exemption to allow transport of CNG using quad-axle trailers. This precedent may benefit the case in study.

5.8. Operations Summary

To estimate transport operating costs, a time study was conducted to map the operations process. The results of the time study are shown in the following table.

Table 5.5 – Operations Time Study

OPERATIONS TIME STUDY	Parameter	Unit
Trailer Use Time		
connect nozzle/unhitch empty trailer for filling (mother)	15	min
filling duration	401	min
hitch/disconnect nozzle from full trailer (mother)	15	min
travel time to client site	50	min
connect nozzle/unhitch full trailer (de-canting)	15	min
de-canting time	645	min
hitch/disconnect nozzle from empty trailer (de-canting)	15	min
travel to mother station	50	min
extra margin time	80	min
total de-canting time	10.8	hours
total transport time	10.7	hours
total minimum cycle time	21.4	hours
actual cycle time	22.6	hours
trailer idle time	1.1	hours
minimum no. of trailers required	**2**	
Labor Time		
connect nozzle/unhitch empty trailer for filling (mother)	15	min
hitch/disconnect nozzle from full trailer (mother)	15	min
travel time to client site	50	min
connect nozzle/unhitch full trailer (de-canting)	15	min
hitch/disconnect nozzle from empty trailer (de-canting)	15	min
travel to mother station	50	min
extra margin time	80	min
labor downtime	7.8	hours
total labor useful labor time (per cycle)	4.0	hours
labor half cycle time	11.8	hours

The operations study highlights the following important points.

- 2 mobile storage trailers are required for this customer.
- The cycle time for each trailer (filling to de-canting and back to filling) is 22.6 hours. Of this time, the trailer is sitting idle for only 1.1 hours (i.e. no activity).
- The total labor input per trailer load cycle is only 4.0 hours. This includes 1 hour and 20 minutes of contingency time in the event of an accident, traffic jam or other travel issues. In addition, an additional 1.1 hours of trailer idle time remains to allow for variability in consumption.

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- A labor shift starts every 11.8 hours and extends for 4.0 hours to make a delivery and take an empty trailer back to the mother station for filling.
- If customer demand were to increase and the trailer idle time decreases to zero, this will trigger the required addition of one more mobile transport trailer.

5.9. Project Capital Cost Breakdown

A detailed breakdown of the capital costs for both the mother and de-canting stations is estimated in Appendix C. The capital costs are based on the site layouts of Appendix B and the listed assumptions. For the mother station, costs are particularly sensitive to the location of the utilities, namely the gas supply and electrical service. It is for this reason that the compressors are located close to the road where gas and electricity are assumed to be available. All capital cost estimates are based on year 2012.

Jenmar Concepts' opinion of total probable capital cost for an electric driven and gas engine driven compressor mother stations is estimated at **$1,423,000 and $1,536,000 respectively**. These totals include a 10% contingency. Cost breakdown by major category is shown in the following figures.

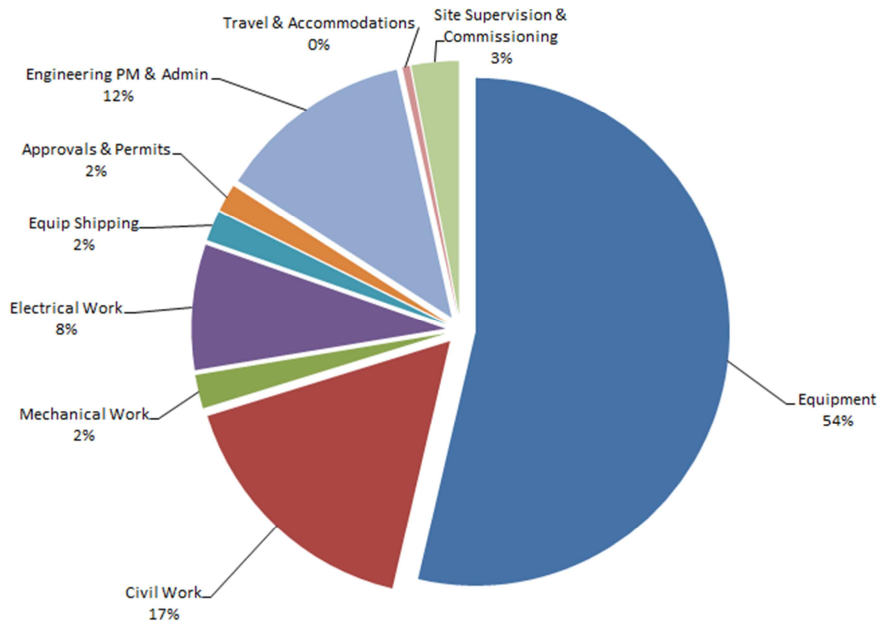

Figure 5.3 – Mother Station Cost Breakdown - Electric Drive

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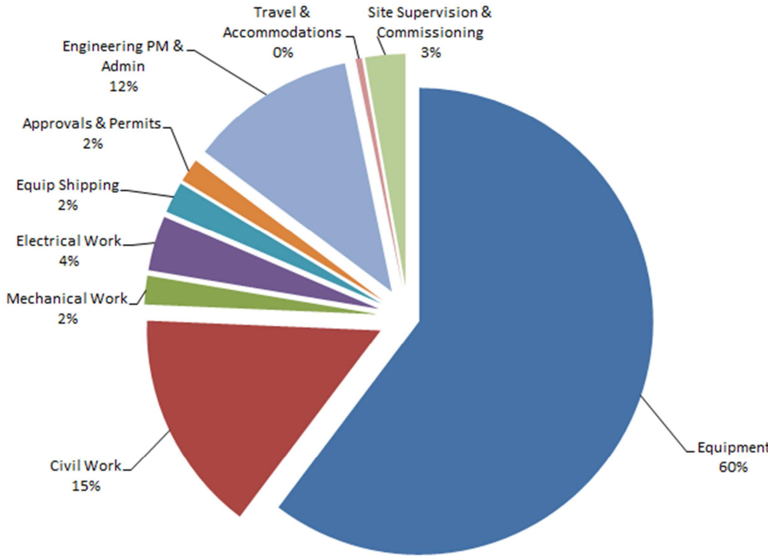

Figure 5.4 – Mother Station Cost Breakdown - Gas Engine Drive

Jenmar Concepts' opinion of total capital cost for the de-canting station is estimated to be $237,300.00 with breakdown as shown.

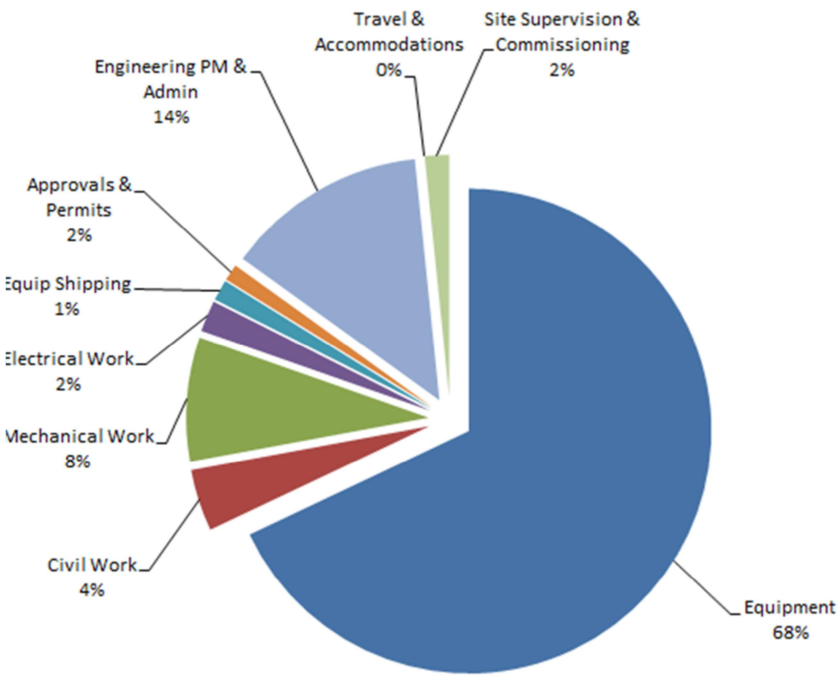

Figure 5.5 – De-Canting Station Cost Breakdown

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5.10. Operations Cost Breakdown

The operations costs for the mother station and de-canting stations are comprised of

- natural gas consumption
- electrical energy consumption
- maintenance and service

5.10.1. <u>Fuel Gas Costs</u>

Some of the natural gas delivered to the station by gas pipeline is consumed in providing fuel for a gas engine driven compressor (if applicable) and for heating at the de-canting station. Some historical data from Heritage Gas for the Gas Recovery Rate (CGRR) is provided below.

Table 5.6 – Historical Natural Gas Fuel Cost Data

Month	GCRR	Month	GCRR	Month	GCRR
Jan-10	85	Jan-11	8.08	Jan-12	5.61
Feb-10	7.35	Feb-11	7.27	Feb-12	
Mar-10	6.23	Mar-11	4.54	Mar-12	
Apr-10	3.44	Apr-11	4.54	Apr-12	
May-10	3.83	May-11	4.29	May-12	
Jun-10	5.27	Jun-11	4.35	Jun-12	
Jul-10	5.15	Jul-11	4.71	Jul-12	
Aug-10	4.97	Aug-11	4.46	Aug-12	
Sep-10	4.11	Sep-11	4.1	Sep-12	
Oct-10	4.02	Oct-11	4.7	Oct-12	
Nov-10	4.03	Nov-11	5.32	Nov-12	
Dec-10	5.47	Dec-11	6.37	Dec-12	

For the purposes of this study an average fuel gas cost of $5.50 per GJ will be assumed. This is intended to represent the cost of the commodity but excludes the delivery charges for receiving natural gas from the local distribution company, or the capital costs of developing a Custody Transfer Station to receive natural gas directly from the transmission pipeline.

5.10.2. Maintenance Costs

Maintenance and service cost estimates for both electric motor driven and gas engine driven mother stations are provided in the following table. A typical maintenance and service contract cost in the industry is $1.00/GJ. This figure is typically applied to CNG stations with suction pressures below 100 psig requiring the use of 4 stage compressors and lower duty cycles. Given the exceptionally high gas suction pressure and high duty cycle of the mother station of the case study, substantially lower maintenance and service costs are expected. There is little available maintenance/service data for the mother station envisioned in this study. The following figures were derived based on a combination of rule of thumb, experience and scaling calculations. The following figures should be considered representative rather than definitive.

Table 5.6 – Mother Station Maintenance and Service Costs

MOTHER STATION	Parameter	Parameter	Unit
Maintenance Cost			
compressor type	**Electric**	**Gas Engine**	
fixed yearly cost for maintenance	$ 20,000.00	$ 24,000.00	
incremental maintenance cost per unit	$ 0.016	$ 0.020	per gle
incremental maintenance cost per unit	$ 0.416	$ 0.519	per GJ HHV
monthly maintenance cost	$ 10,324.68	$ 12,822.51	
yearly maintenance cost	**$ 123,896.10**	**$ 153,870.13**	
maintenance cost per unit compressed	$ 0.496	$ 0.615	per GJ HHV
maintenance cost per unit compressed	$ 0.017	$ 0.021	per gle

Gas engine driven installations require greater maintenance than electric driven installations.

Maintenance cost for the de-canting station is very low and is estimated at $0.030 per GJ. This is based on a weekly service call and some spare parts (refer to Appendix D for more detail).

Maintenance on mobile storage trailers is consists of running costs and fixed costs related to cylinder re-certification. Trucking industry "rules of thumb" suggest that trailer maintenance costs be in the $0.012 to $0.030 per km range depending on use, geography and climate. Using this guideline we can predict annual cost for the Phase 1 case to be:

- Distance per trip – 100 kms
- Trips per year – 390 (22.6 hour cycle time, 365 days per year)
- Total kilometers – 39,000

Cost per year (@ $0.03/km) = $1,179

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This calculation does not include the cost of maintaining the cylinders which is mainly due to costs for re-qualification. Re-qualification costs vary depending on the type of cylinders used. For steel cylinders an allowance of $800 per annum or $8000 per 10 year cycle is provided.

A summary of maintenance costs is provided below.

Table 5.7 – Maintenance Cost Summary

	electric	gas engine	unit
mother station	$ 0.496	$ 0.615	per GJ
mobile storage	$ 0.016	$ 0.016	per GJ
de-canting station	$ 0.030	$ 0.030	per GJ
Total	**$ 0.542**	**$ 0.662**	per GJ

5.10.3. Electric Power and Fuel Gas Costs

For the mother and de-canting stations, the operating costs consist of electric power and fuel gas consumption (if gas engine driven compressors are used). For electric power, the Small Industrial rate from Nova Scotia Power was applied. Operating costs are shown in the table below.

Table 5.8 – Energy Cost Summary

Mother Station	electric	gas engine	unit
electricity	$ 0.309	$ 0.105	per GJ
fuel gas	$ -	$ 0.114	per GJ
Total	**$ 0.309**	**$ 0.219**	per GJ
De-Canting Station			
electricity	$ 0.011		per GJ
fuel gas	$ 0.030		per GJ
Total	**$ 0.041**		per GJ

5.10.4. Mobile Storage Transport Operations

The study assumes that fuel deliveries will be contracted to a company similar to the Trimac Group. The fuel provider will own the mobile storage trailers but the transport company will supply and operate its own fleet of tractors. On this basis haulage rates were requested from various companies. The haulage rate is broken down into a

- Cost Per Km Travelled - $3.40 per km
- Non-Rolling Rate – $80.55 per hour (For time spent at the mother or de-canting station making connections/disconnections and possibly some waiting time.)

On this basis operating costs are estimated for each delivery at $527.95 per delivery or $1.73 per GJ, based on the study scenario.

5.11. Capital Cost Recovery

To account for the cost of capital a cost recovery model is used to calculate a present value of capital funds paid over a defined number of annuities and interest rate. For this study, the number of annuities used and the interest rate are 20 years and 6% respectively. This analysis makes no assumptions with respect to the appropriate capital structure for the facilities owner, and therefore does not include an appropriate return on equity. Nor does it include profit. On this basis a yearly cost of capital is estimated and amortized by the number of gigajoules of fuel delivered. The results are shown below.

Table 5.9 – Capital Cost Recovery Summary

Parameter	Electric Driven	Gas Engine Driven	Unit
cost of money	6.0%	6.0%	
number of annuities (years to recover)	20	20	
capital cost recovery factor	0.087	0.087	
MOBILE STORAGE EQUIPMENT			
capital cost per mobile storage	$ 400,000.00	$ 400,000.00	
number of trailers required	2	2	
capital cost for all trailers	$ 840,000.00	$ 840,000.00	
annual cost	$ 73,235.03	$ 73,235.03	
cost per fuel unit	**$ 0.29**	**$ 0.29**	per GJ HHV
MOTHER STATIONS			
capital cost for station	$ 1,422,667.40	$ 1,535,967.40	
annual cost	$ 124,034.63	$ 133,912.64	
cost per fuel unit	**$ 0.50**	**$ 0.54**	per GJ HHV
DE-CANTING STATION			
capital cost for station	$ 237,274.40	$ 237,274.40	
annual cost	$ 20,686.66	$ 20,686.66	
cost per fuel unit	**$ 0.08**	**$ 0.08**	per GJ HHV

5.12. Delivered Fuel Cost

The following table presents the all-in cost of fuel delivered to the customer as defined in the base case. Note that the fuel costs derived from the study do **not** include administration costs and profit.

Table 5.10 – Total Fuel Delivery Cost

	Electric Drive		Gas Engine Drive		Units
Cost Of Fuel Gas	**$**	**5.500**	**$**	**5.500**	per GJ
Sub-Total Operating Cost	**$**	**2.609**	**$**	**2.639**	per GJ
mother station	$	0.804	$	0.835	per GJ
CNG transport	$	1.732	$	1.732	per GJ
de-canting	$	0.072	$	0.073	per GJ
Sub-Total Capital Cost	**$**	**0.872**	**$**	**0.911**	per GJ
mother station	$	0.496	$	0.536	per GJ
CNG transport	$	0.293	$	0.293	per GJ
de-canting	$	0.083	$	0.083	per GJ
Total Delivered Cost	**$**	**8.98**	**$**	**9.05**	per GJ

5.13. Competitive Fuel Comparison

The delivery of natural gas to off-grid locations provides a competitive alternative to currently available energy sources. For comparative purposes a survey was conducted of a number of energy suppliers throughout Nova Scotia to gather information on the costs of those alternative fuels based on supply of 250,000 GJ per year to a single location. Pricing was obtained for delivery to Yarmouth, Kentville, and Halifax to determine distance variations.

Nova Scotia industries not currently served by natural gas supply lines have access to a variety of energy sources, the most common being electricity, propane and fuel oils such as home heating oil (fuel oil #2). Other light and heavy oils (fuel oils #1-6) are also options, albeit less common and in some cases restricted by current emission control legislation. Comparative pricing is shown for electricity, propane, home heating oil #2, and heavy oil #6.

5.13.1. Heating Oil (Fuel oil #2)

Many industries and homes in Nova Scotia rely on heating oil for heating and processing.. According to a 2007 Statistics Canada report, 50% of homes in Nova Scotia turn to oil for heating. Heating oil delivery is common and available from a number of distributors in volumes up to 34,000 litres, or 1312 GJ per trip.

	$/ltr (ex tax)	$/Gj (ex tax)
Yarmouth, NS	0.965	25.005
Kentville, NS	0.940	24.344

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Halifax, NS	0.943	24.416

5.13.2. Propane

Propane is in wider use in Nova Scotia than in the rest of Canada, although it contributes a much smaller percentage of fuel for heating and processing than does heating oil. The 2007 StatsCan survey indicates that the national use of propane fell into the "other" category (fuels other than electricity, natural gas, oil and liquid fuels, and wood) and comprised only 1.2% of all energy consumed nationally. The Canadian Propane Association indicates that propane delivers 2.25% of all energy consumed in Nova Scotia. The Nova Scotia provincial government estimates over 60,000 permanent propane installations in the province, with total annual provincial consumption of 135,000 cubic meters (135 million litres), or 3% of the national total. The only propane production in Nova Scotia is at the Imperial Oil Limited refinery in Dartmouth and the Sable fractionation plant in Point Tupper.

Propane is available from a number of suppliers at service stations or by tanker delivery. Tankers are capable of delivering up to 34,000 litres, or approximately 867 GJ per trip.

	$/ltr (ex tax)	**$/Gj (ex tax)**
Yarmouth, NS	0.457	17.906
Kentville, NS	0.445	17.449
Halifax, NS	0.440	17.253

5.13.3. Electricity

Approximately 25% of all homes in Nova Scotia use electricity as the primary energy source for home heat. Virtually all areas of the province are served by electrical infrastructure, and all businesses will use electricity in varying degrees in the course of business. Current small industrial tariffs provided by NS Power provide the following costs for comparison.

	$/KWh (ex tax)	**$/Gj (ex tax)**
Representative	0.136	37.78

5.13.4. Heavy Oil (Fuel Oil #6, or Bunker C)

Bunker C is a high viscosity residual petroleum compound; (also called bunker, #6 oil, heavy oil etc.) produced from the refining of crude oil. It is used as a fuel for some ships and large boilers but is unsuitable for smaller plants due to the requirement for preheating. Bunker C oil is dark colored, sticky, thick and heavy. It is not as volatile as other petroleum products like gasoline. Fuel Oil #6 (41.73 GJ/m^3) has a higher energy content than Fuel Oil #2 (Home Heating Oil)(38.68 GJ/m^3) and is generally priced lower per litre than other heating oils. Given its high viscosity it is somewhat difficult to deal with. Sulfur content is difficult to control batch to batch and regulations on its use will likely tighten in the near term. In extreme cases sulfur content can rise to as much as 3% by weight. Bunker C releases sulfur dioxide on combustion.

Current rack price for #6 oil is at $0.70-$0.73 per liter yielding delivered costs in the range of $19.00 - $20.00 / GJ.

5.13.5. Justification

Pricing for each of the above fuels was obtained from a selection of suppliers within Nova Scotia and considered supply of volumes adequate to meet the energy consumption requirements of the case study. Prices include delivery to the three points indicated.

The approximate volumes of each fuel required to provide 250,000 GJ per year are:

- Fuel Oil #2 – 6.5 million litres
- Propane – 10 million litres
- Electricity – 69.5 million KwH
- Heavy Oil #6 – 6 million litres

The prices given are considered accurate based on information sourced. Some discount may be achieved through negotiation but it is unlikely that double-digit percentage improvements could be achieved. Larger volumes would yield additional discounts. Phase 2 will consider larger energy requirements although the usage will be spread over multiple users, and so a large volume discount will likely not be applicable.

6. KEY VARIABLE SENSITIVITY ANALYSIS

The key variables impacting the cost of delivered fuel are expected to be transport distance, customer load and trailer size/selection. The electric driven mother station is used in the analysis only.

6.1. Impact of Transport Distance On Fuel Cost

To understand the impact of transport distance the base case is used with the exception of a variable transport distance ranging from 25 to 150 kilometers (one way). The same equipment is used for all cases and the annual load is 250,000 GJ. The results are shown below.

Table 6.1 – Fuel Cost Vs Transport Distance

Distance (kms)	Fuel Cost (per GJ)	No. of Trailers
25	$ 8.43	2
50	$ 8.98	2
75	$ 9.68	3
100	$ 10.23	3
125	$ 10.79	3
150	$ 11.34	3
200	$ 12.44	3
250	$ 13.55	3

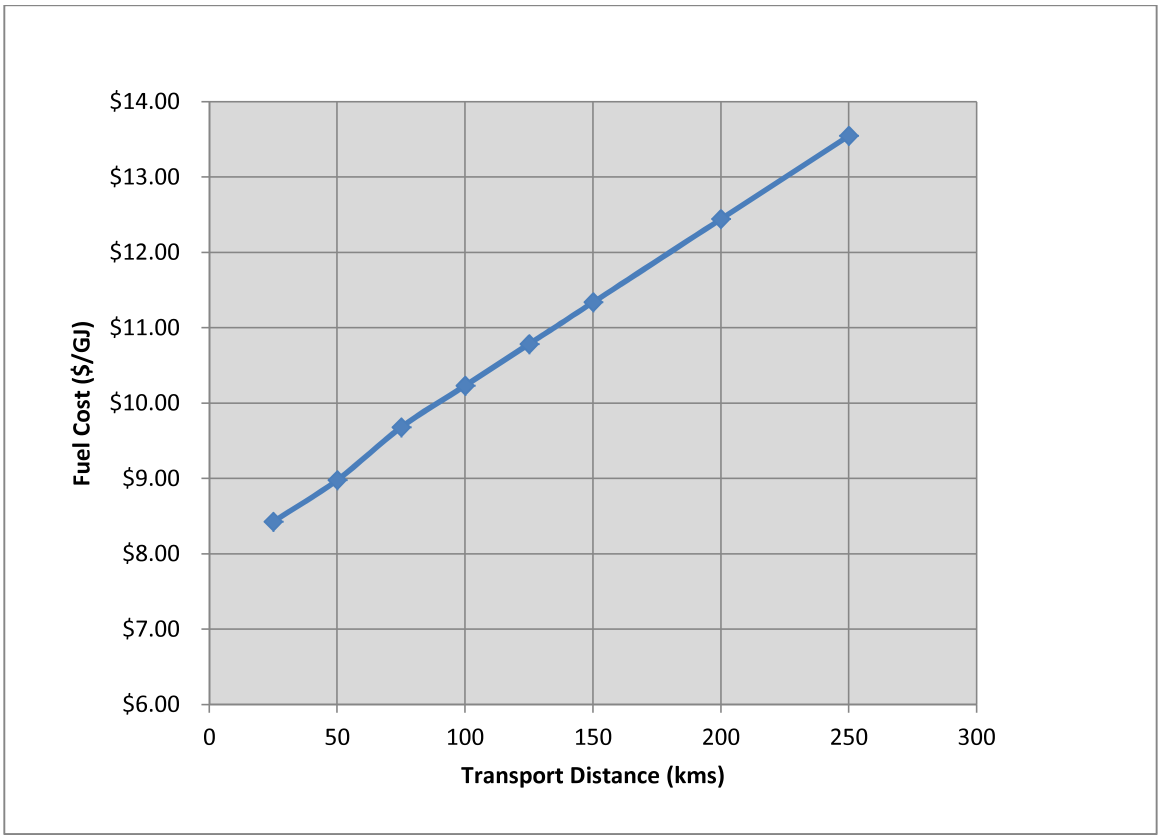

Figure 6.1 – Fuel Cost Vs Transport Distance

Note that at a distance between 75 and 100 kilometers an additional mobile transport trailer must be added to the fleet.

6.2. Impact of Annual Load On Fuel Cost

The impact of fuel cost on annual load is analyzed based on the following assumptions.

- Constant travel distance of 50 km (one way).
- The cost per GJ of the fuel delivered into the mobile storage trailer is constant at the base case cost. It is assumed that the mother station serves numerous customers to maintain a high station load equivalent to the base case.
- The same trailer size is used in all cases as the base case. Reducing trailer size within the load range is considered sub-optimal.
- The De-Canting system capital cost is scaled down with load in accordance with the following table.

Table 6.3 – PRS Installed Cost

Annual Load	PRS size (GJ/day)	Equipment Cost	Total Installed
250000	1000	$ 146,600.00	$237,274.40
200000	750	$ 130,000.00	$220,674.00
150000	500	$ 105,000.00	$185,000.00
100000	250	$ 75,000.00	$145,000.00
50000	160	$ 52,000.00	$112,000.00

The following chart shows the variation of delivered fuel cost with annual load.

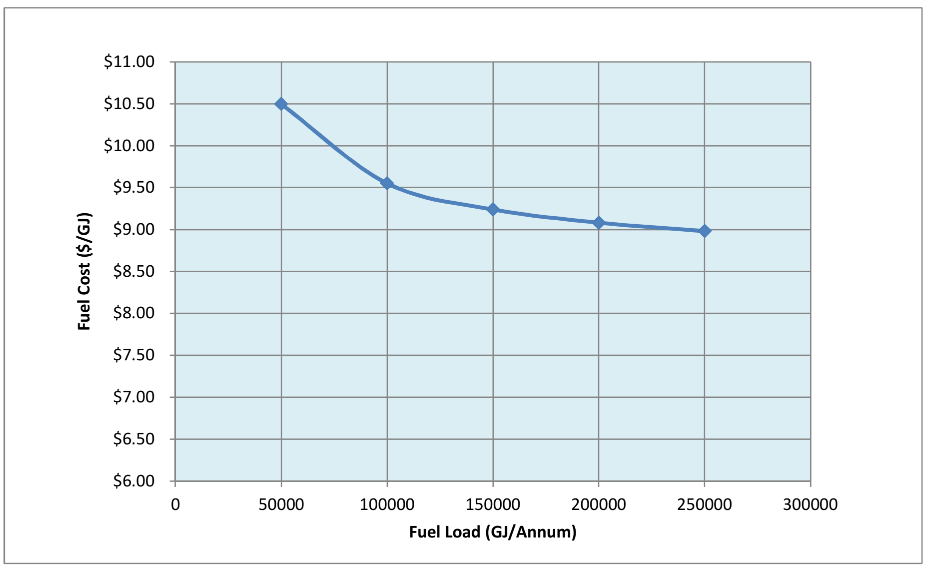

Figure 6.2 – Fuel Cost Vs Fuel Load for 50 Km Travel Distance

6.3. Impact of Various Mobile Storage Trailer Selections

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The impact of trailer selection on delivered fuel cost for the base line case is considered by varying the trailer selection only. The results are shown below for a variety of selections.

Table 6.4 – Trailer Specifications Vs Delivered Fuel Cost

Manufacturer	Lincoln Composite	Fiba Canning	Dynetek	Fiba Canning	CP Industries Inc.
Cylinder Technology	Type 4	Type 1	Type 3	Type 1	Type 1
Unit	Titan Module	4 Tube Quad Axel Jumbo	BT-30	13 Tube Tridem Jumbo	ISO IMDG/MRGC /CSC
Canadian TC Approvals	None	TDG	TDG Equivalency Certificate	TDG	TDG
Design Standard	ISO 11119	CSA B339	ISO 11119	CSA B339	CSA B339
Total CNG Transferred Per Delivery (GJ HHV)	375	308	311	234	196
Fill Pressure (psig)	3612	2750	3250	2640	3624
Capital Cost	$ 485,000	$ 400,000	$ 615,000	$ 300,000	$ 252,100
Capital Cost/GJ Capacity	$ 1,294	$ 1,300	$ 1,978	$ 1,282	$ 1,289
Delivered Fuel Cost ($/GJ)	**$ 8.79**	**$ 8.98**	**$ 9.20**	**$ 9.56**	**$ 9.95**

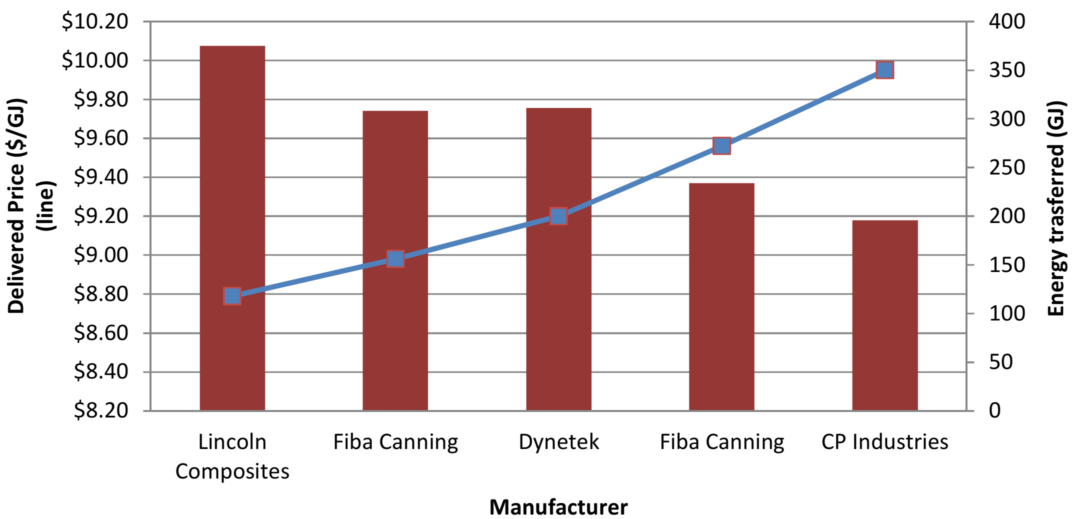

Figure 6.3 - Fuel cost Vs Trailer Selection

7. SUMMARY AND CONCLUSIONS

Off-grid transport of CNG in Canada has been used by utilities for years as a source of make-up gas during distribution piping maintenance; however, the application of CNG gas transport to off-grid customers on a continuous and high volume basis is new in Canada. Most of the activity to date has been off shore. Recently there has been increased interest to deliver CNG to oil and gas field operations in British Columbia, Alberta and Saskatchewan. The economics are increasingly favoring use of CNG to displace expensive diesel fuel used to operate equipment in the field. The technology to load, de-cant and pressure reduce high pressure gas at high volume rates from mobile storage trailers on a continuous basis is a new application. The technology is advanced enough for viable and economic operation; however there continue to be technology issues that can create challenges. These include (1) the lack of approved high capacity connection nozzles; (2) under-filling of gas storage cylinders due to warm compressor discharge gas and the heat of compression within the cylinders; (3) the lack of high capacity drive-away safety devices; (4) controls issues with pressure reduction systems due to the large and sudden variations in process conditions from high pressure to lower pressure de-canting operations and (5) the high cost, high road weight and limited capacity of gas storage cylinders to provide for large CNG transport loads. Innovative ideas to overcome these challenges continue to come forward in the industry.

The single user case study provided a base line for delivered fuel cost to a customer with a 250,000 GJ load and located 50 kilometers from the mother station. The all-in delivered fuel cost was estimated to be $8.98 and $9.05 per GJ for an electric driven and gas engine driven mother station respectively. Based on this analysis, an electric driven mother station is preferred not only from a cost standpoint but also by way of increased simplicity and reliability.

A sensitivity analysis was undertaken to evaluate the impact of key variable changes. This analysis leads to the following conclusions for fuel users in the 50,000 GJ and higher range.

- The largest contributor to fuel cost is the operating costs associated with gas transport. To reduce operating costs, the transported load size must increase for large users. The smallest load size considered in the load sensitivity study was 50,000 GJ per annum. For loads above this size, increased investment in the highest transport capacity available is favored and will reduce overall delivered fuel cost.
- Operating costs for gas transport are highly impacted by travel distance. The relationship is linear until the increase in travel time reaches a threshold where an additional mobile storage trailer must be added to the operation. After a storage trailer is added the cost versus distance relationship remains linear except for an added cost offset.
- Reductions in customer load increases the cost of fuel delivered substantially. Increased costs are mainly associated with the lack of utilization of capital tied up on the gas transport equipment. Operating costs also increase slightly due to fixed costs amortized over few energy units delivered.
- Operating costs for mother stations is the second largest contributor to delivered fuel gas cost. The mother station must be sized to operate with a high duty cycle. Maximizing throughput of the mother station significantly reduces operations costs including maintenance and energy. Electrical demand charges favor continuous

loading. Maintenance costs have a large fixed cost component which becomes less significant with high throughput.

- High gas supply pressure to the mother station provides substantial savings in all cost categories.
- De-canting system capital and operating costs are not significant where per annum loads are 50,000 GJ and up. Capital costs for De-canting systems do not turn down very well with load and are expected to be much more important cost contributors as per annum loads much smaller than 50,000 GJ are considered.

A comparison of conventional energy sources including electricity, propane, and heating oil reveals that CNG can be very competitive with these conventional fuels. The most competitive fuel is propane with an average cost in Nova Scotia of approximately $17.25/GJ. For a 250,000 GJ per annum load at a 50 km distance the estimated cost was $8.98/GJ. This leaves ample room for some additional administration and profit, while maintaining competitiveness.

Based on the above findings, sale of CNG transported natural gas to large users of at least 50,000 GJ per annum and located within reasonable travel distances provides a competitive alternative to conventional energy sources.

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APPENDIX A

Process Flow Diagrams

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