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Challenges for Pipeline Compression in Canada's North

by

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Biography

Keith Drysdale is the Project Technical Advisor for the Mackenzie Gas Project, a position he has held since 2003. Keith has been involved in all aspects of developing the project's scope and throughout its current technical and environmental regulatory review process.

Keith joined Imperial Oil Limited (Imperial) in 1980 after receiving degrees in Engineering Sciences from Dalhousie University and Mechanical Engineering from the Nova Scotia Technical College.

Keith's career started in Canada's North as a member of the Norman Wells Expansion Project team. From there, he held numerous technical and management positions supporting Imperial's conventional oil and gas operations and managing the company's Cold Lake expansion development. This was followed by an assignment with ExxonMobil, providing project development and facilities engineering support to ExxonMobil's operations in Nigeria.

Abstract

The Mackenzie Valley pipeline is a major component of the Mackenzie Gas Project. The proposed gas pipeline from Inuvik in the Northwest Territories is planned to interconnect with the NOVA Gas Transmission Ltd. system in northwest Alberta. The pipeline is being designed to initially transport 34.3 Mm^3/d (1,200 MMscfd) of sweet natural gas in the summer and a slightly higher volume of gas in winter, when increased compressor capability is available. With additional compression, the pipeline could be expanded to transport up to 49.8 Mm^3/d (1,760 MMscfd) of gas.

This 1,200-km-long high-pressure, NPS 30 buried pipeline will operate at 18.7 MPa (2,710 psi), a higher pressure than current Canadian gas transmission system designs. The pipeline route would traverse both continuous and discontinuous permafrost in an extremely remote and rugged environment. To prevent melting the permafrost that makes up a significant portion of the pipeline route, the gas will be chilled. The need to accommodate permafrost conditions, combined with the Arctic climatic conditions of extremely cold and dark winters with hot summers and continuous sunshine, present a unique operating environment. These, and other challenges unique to the Canadian North, face the engineers in designing, and assuring the operability of, the gas compressors for the Mackenzie Valley pipeline.

Acknowledgements

This paper would not be possible without the body of knowledge that has been developed on the Mackenzie Gas Project through the efforts of its project team. In particular, the project's machinery specialists, Ian Devenny and Garry Makar, provided support and background information to help prepare this paper. Without that level of support and cooperation, the task of writing this paper would have been daunting.

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1 INTRODUCTION

The Mackenzie Gas Project includes a proposed 1,200 km natural gas pipeline system along the Mackenzie Valley in Canada's Northwest Territories which would connect northern onshore gas fields with North American markets. The design, construction and operation of this pipeline and related pipelines and facilities will bring challenges unique to developing and working in this part of Canada’s North.

Most of the pipeline route will cross either continuous or discontinuous permafrost. Permafrost is ice-rich ground that remains frozen year-round, with only seasonal surface thaw. To protect the permafrost, pipeline operations across areas of permafrost can neither add to the freezing of the ground, nor incrementally increase the surface thaw on a long-term basis.

Ambient conditions along the pipeline route range from extreme cold and continual darkness in the winter, to extreme heat along with continual sunshine during the summer. Equipment and personnel will need to function under these conditions during the construction and operation of the pipeline. In particular, this broad range in temperature will allow an incremental increase of 10% in the volume of gas to be shipped through the pipeline in the winter because of increased compressor capability at low temperatures.

The Mackenzie Valley has a sparse population distributed over a large area. There is limited associated infrastructure in place to support year-round transportation of goods and materials to the isolated locations along the pipeline route. Careful planning and preparation are required to incorporate logistic constraints into the pipeline’s construction and operating plans.

These challenges affect the entire project, including the design and operation of the turbo-compressors that will power the pipeline. This paper discusses three challenges in some detail as an example of the type and scope of challenges that face the project as a whole. The challenges discussed are:

- the selection of operating temperature guidelines that will maintain average ground temperature for the pipeline
- the operation of dry, low-emissions combustion systems over broad temperature ranges
- the logistics associated with long-term operations and maintenance

2 MACKENZIE GAS PROJECT COMPONENTS

The proposed Mackenzie Gas Project consists of five main components (see Figure 1). The first three components are the natural gas wells and field production facilities at the three anchor field developments – Taglu, Parsons Lake, and Niglintgak.

These fields would supply sweet natural gas at a rate of 23.5 Mm^3/d (830 MMscfd) and produce about 2,000 m^3/d (12,600 bbl/d) of associated natural gas liquids (C_{5+} condensate). Each natural gas field will require the installation of well pads and gas conditioning facilities.

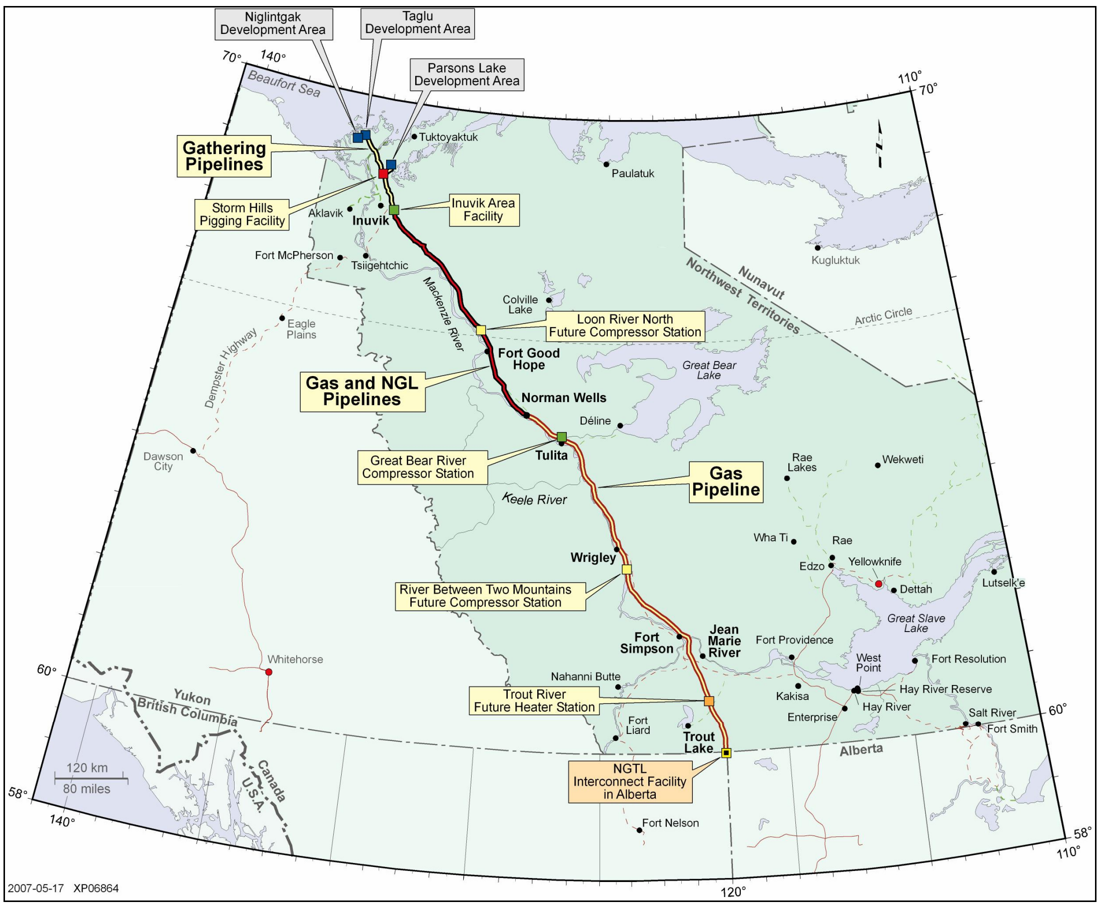

Figure 1: Mackenzie Gas Project Overview

The fourth major project component is the Mackenzie gathering system, which is a network of buried pipelines that would transport the combined natural gas and natural gas liquids (NGLs) produced from the three anchor fields, and other future fields, to a central gas processing facility east of Inuvik. At this Inuvik area facility, the natural gas would be separated from the NGLs, and processed into saleable products. The NGLs would be pumped 457 km south to Norman

Wells through a buried NPS 10 diameter pipeline. In Norman Wells, the NGL pipeline would connect with the existing Enbridge oil pipeline, which will have spare capacity to accommodate the natural gas liquids.

The fifth major component, and the topic of this paper, is the Mackenzie Valley pipeline, a buried NPS 30 diameter natural gas pipeline. This pipeline will start at the outlet of the Inuvik area facility and transport natural gas 1,196 km south to northwest Alberta, where it will connect to an extension of the NOVA Gas Transmission Ltd (NGTL) system. The Mackenzie Valley pipeline will operate at a design pressure of 18.7 MPa (2,710 psig).

2.1 Mackenzie Gas Project Proponents

The proponents of the Mackenzie Gas Project are:

- Imperial Oil Resources Ventures Limited, a subsidiary of Imperial Oil Limited, which will construct and operate the Mackenzie gathering system and the Mackenzie Valley pipeline on behalf of the gathering system and pipeline proponents. Imperial Oil Resources Limited holds the Significant Discovery Licence (SDL) for, and operates, the Taglu gas field.
- Shell Canada Energy, which holds the beneficial interest in the Niglintgak gas field SDL, operates the field, and will have an interest in the Mackenzie gathering system and the Mackenzie Valley pipeline. Effective January 1, 2007, Shell Canada Limited transferred its upstream Exploration and Production assets to Shell Canada Energy. However, Shell Canada Limited, on behalf of Shell Canada Energy, continues to hold legal title to the Niglintgak SDL.
- ConocoPhillips Canada (North) Limited (ConocoPhillips), which holds 75% of the Parsons Lake gas field SDL, and ExxonMobil Canada Properties (ExxonMobil), which holds 25% of the Parsons Lake gas field SDL. The Parsons Lake field is operated by ConocoPhillips. ConocoPhillips and ExxonMobil each have an interest in the Mackenzie gathering system and the Mackenzie Valley pipeline. ConocoPhillips' interest in the Mackenzie Valley pipeline is held by ConocoPhillips Northern Partnership.
- the Mackenzie Valley Aboriginal Pipeline Limited Partnership (APG), which was formed by representatives of various Aboriginal groups to represent the ownership interest of the Aboriginal people of the Northwest Territories in the Mackenzie Valley pipeline

2.2 Pipeline Expansion Capability

To accommodate additional gas discoveries in the Mackenzie Delta and along the Mackenzie Valley, the pipeline is designed to be expandable. Gas pipeline facilities capable of shipping 34.3 Mm^3/d (1.2 Bcf/d) have been applied for in the regulatory process. The pipeline has an expansion capability of up to 49.8 Mm^3/d (1.8 Bcf/d) through the addition of compression facilities.

A single compressor station is all that is required to deliver the volume of gas from the three anchor fields from Inuvik to the terminus of the Mackenzie Valley pipeline in Alberta. This compressor station would be located along the Great Bear River, near the community of Tulita, about 540 km south of Inuvik.

Two additional compressor stations at Loon River North and River Between Two Mountains, and a heater station at Trout River, would be required to ship gas volumes of 34.3 Mm^3/d (1.2 Bcf/d).

A total of 14 compressor stations would be needed to deliver the fully expanded volumes of 49.8 Mm^3/d (1.8 Bcf/d). On average, the compressor stations would be 80 km apart in the fully expanded configuration.

Figure 2 shows the expandability of the pipeline with the addition of facilities.

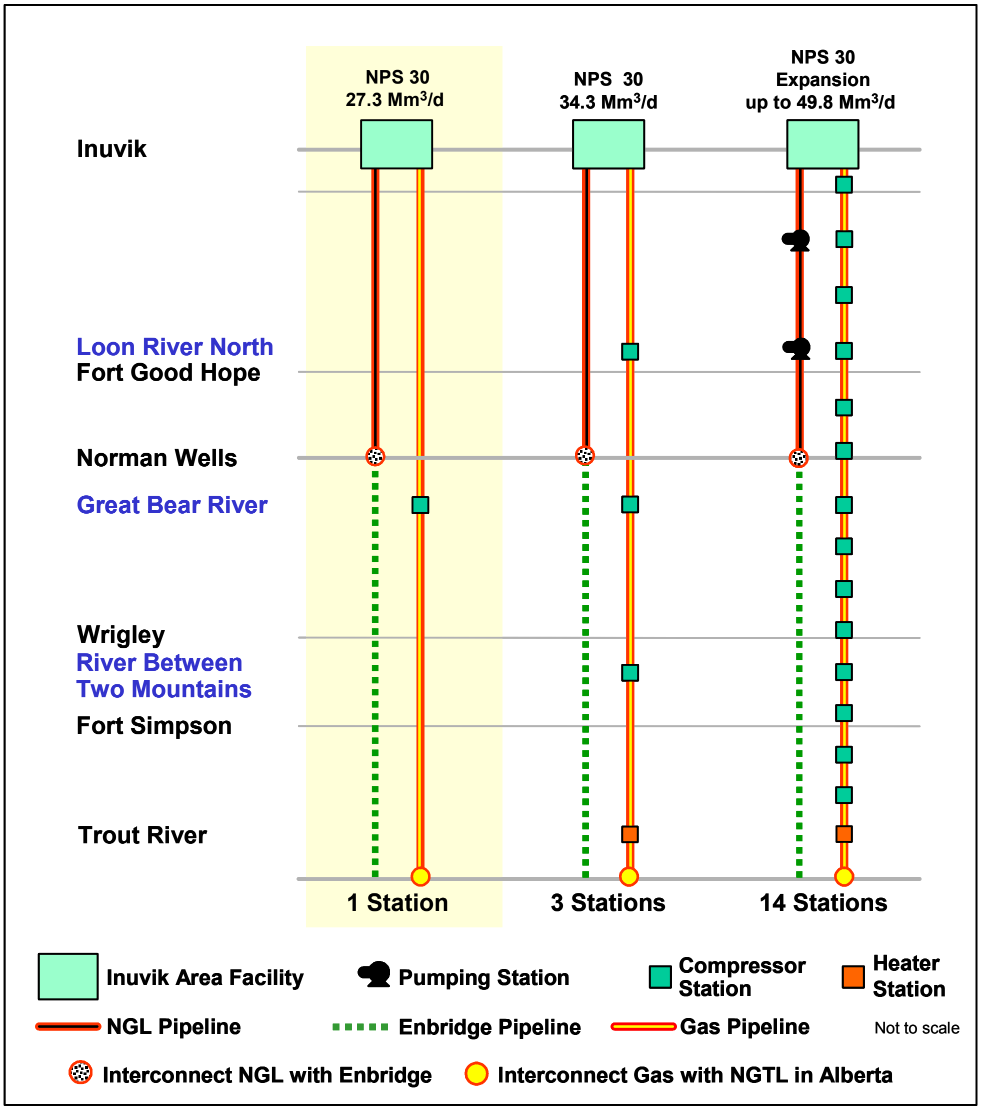

Figure 2: Mackenzie Valley Pipeline Expandability

2.3 Compressor Stations

The Mackenzie Valley pipeline compressor stations each have similar flow capability, compression power requirements and gas cooling duty. Consequently, a single typical compressor design will be developed and applied to all of the pipeline's compressor stations.

Each compressor station will consist of:

- pipeline components, including:

    - a mainline block valve assembly
    - pig launcher and receiver facilities
- an inlet scrubber
- a 15 MW turbo-compressor unit
- aerial coolers
- gas–to–gas heat exchangers
- utility gas equipment, including metering
- fuel gas equipment, including metering
- electrical power generation equipment
- controls and communications equipment
- safety equipment
- living quarters
- workshop, warehouse and storage facilities

The design of the compressor stations take the following key factors into consideration:

- the compressor stations will be remotely operated and will normally be unattended
- the compressor stations will be situated in remote locations with limited access. During construction, access to the compressor stations will be by barge and winter road. During operations, access will usually be by helicopter or winter road.
- the compressor stations will be subject to geothermal constraints. Gas discharge temperatures at compressor stations will be controlled between -8^{o}C and +10^{o}C, to limit pipeline frost heave and thaw settlement in the continuous and discontinuous permafrost along the pipeline right-of-way. In some cases, the geothermal constraints govern the compressor station design and operation, rather than compressor power or discharge pressure.
- the compressor stations will use gas-to-gas exchangers to cross-exchange warm discharge gas with cool inlet gas flows to meet the required discharge temperatures, because aerial cooling alone cannot achieve this requirement in the summer

- the station design pressure will be 19.8 MPa (2,870 psig). Although standard grade materials are available to achieve piping and equipment design pressures, the equipment and piping will have heavier than traditional pipe wall thickness, requiring special consideration for layout, design, and construction.
- third-party electrical power or utilities are unavailable

An artist's impression of a typical compressor station layout is shown in Figure 3.

Typical compressor stations will be designed to meet the flow, inlet and discharge conditions set by the overall pipeline hydraulic and geothermal design. The compressor station design must also accommodate:

- seasonal station outlet gas temperatures
- variation in seasonal flow rates
- variation in ambient temperatures
- turndown requirements

Figure 4 shows a compressor station flow schematic.

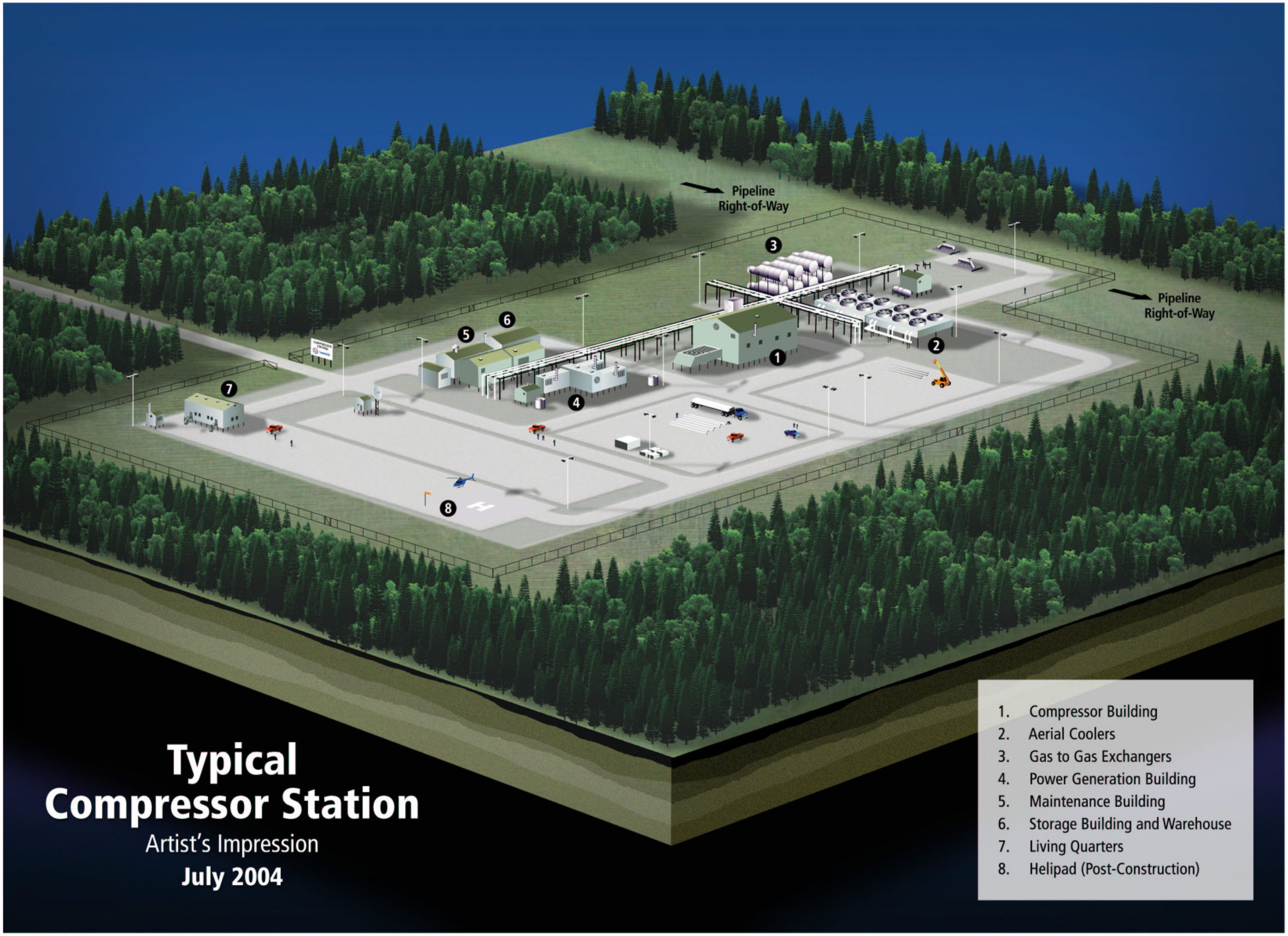

Figure 3: Typical Compressor Station Layout – Artist's Impression

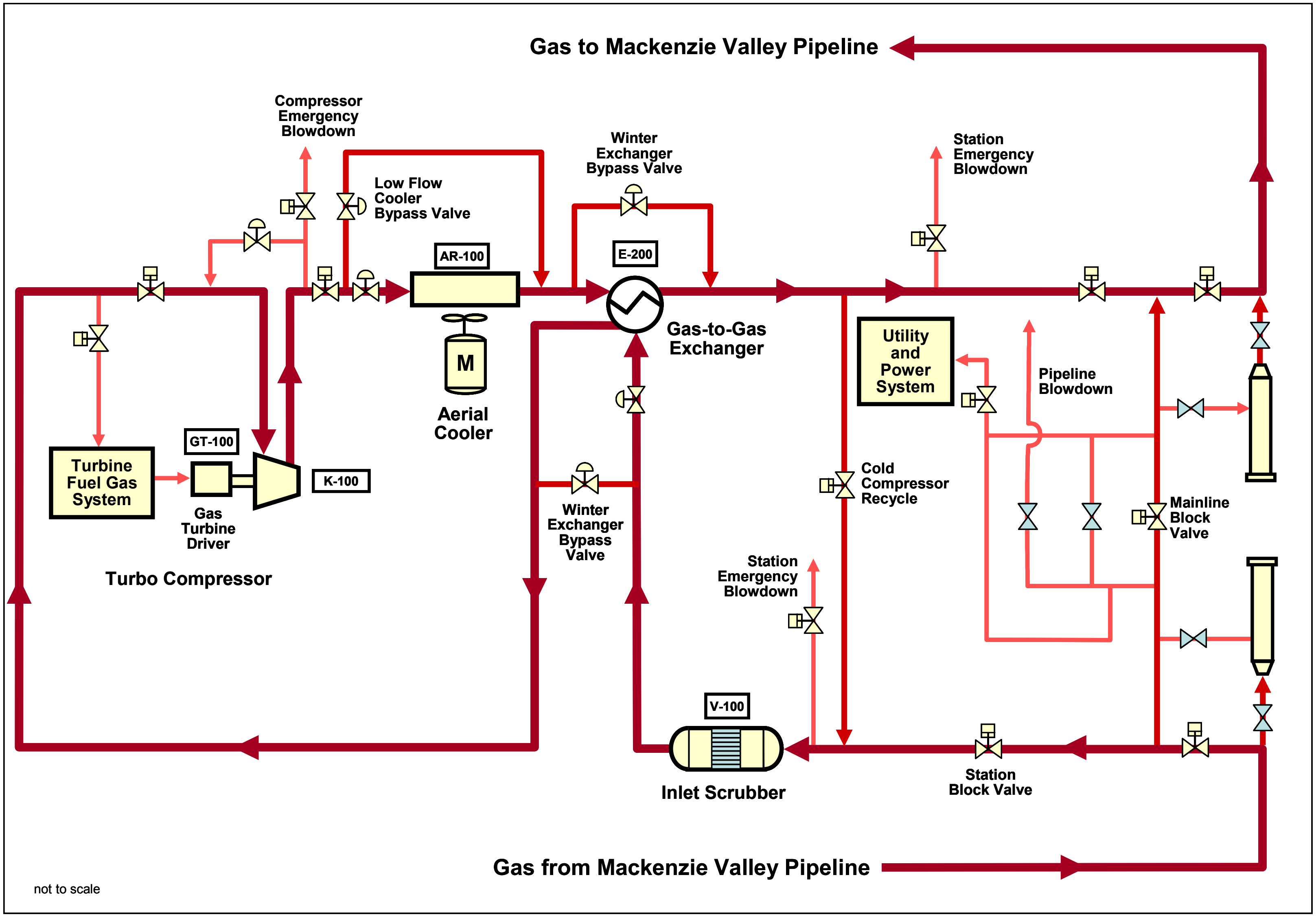

Figure 4: Typical Compressor Station – Process Schematic

3 CLIMATIC CONSIDERATIONS

The Mackenzie Valley pipeline and its associated facilities will operate under extreme and broad-ranging climatic conditions.

The Northwest Territories is within the Arctic climate zone. Winter conditions bring cold temperatures, wind chills, snowfall, frozen ground conditions and poor visibility. Winter temperature lows can hover around -40°C for many days at a time. In the summer, temperature highs can consistently reach between 25°C and 30°C. Temperature extremes of -55°C in the winter to 36°C in the summer have been incorporated into the compressor station design.

Although cold winter conditions are found throughout Canada, the duration of the low ambient air temperatures is longer in the Canadian North. Based on over 55 years of historical data from Environment Canada, average ambient air temperatures in the central Mackenzie Valley can be expected to be below -29°C for about 11% of the year (39 days). Temperatures below -40°C can be expected for about 1.3% of the year (about five days).

Daylight hours vary seasonally, from continuous daylight in June, to no more than two or three hours of twilight in December and January. However, the range of seasonal variation in weather and hours of daylight varies considerably because of the north-south orientation of the project.

Daylight is not critical to the operation of an unattended facility, but it does play a role in facility maintenance and the need to have adequate facilities to deal with the lack of sunlight. In particular, the use of helicopters under night flight conditions requires special considerations, such as a requirement for twin engines.

The pipeline route traverses both continuous and discontinuous permafrost in an extremely remote and rugged environment. To prevent the permafrost that makes up a significant portion of the pipeline route from melting, the gas will be chilled.

The requirement to chill the gas, combined with the Arctic weather conditions of extreme cold and dark winters with hot summers and continuous sunshine, presents a unique operating environment.

4 OPERATING TEMPERATURE GUIDELINES

The maximum discharge temperature allowed for most of the compressor stations currently operating in southern Canada, is usually set by the maximum temperature limits on either the pipe metallurgy or the pipe coating. Operating temperature guidelines have been established for the Mackenzie Valley pipeline to balance the effects of frost heave and thaw settlement. In permafrost regions, extended periods of exposure to cold discharge gas will cause frost bulbs to form and grow around the pipe. Eventually, this will cause the pipe to move upward. Thaw settlement causes the opposite effect on the pipe. Thaw settlement results from extended periods of exposure to warm discharge gas, which cause the permafrost to melt and allows the pipe to settle or sink. Over the long term, frost heave and thaw settlement need to be kept in balance to minimize ground disturbance, increased strain, or pipe deformation.

To retain this long-term balance, compressor discharge temperature guidelines have been set. A maximum average annual temperature of -1°C was selected in the continuous permafrost region to avoid progressive thaw from warm pipe effects. In the discontinuous permafrost region, a maximum average annual temperature of 2°C was selected. The thaw beneath the pipe from warm pipe effects at the compressor station downstream pipeline segment will match the expected long-term thaw alongside the pipe trench from right-of-way construction disturbance. During operations, the gas pipeline station discharge operating temperature guidelines are expected to be adjusted occasionally to balance thaw settlement and frost heave effects on the ground and the pipe.

Table 1 shows the pipeline inlet temperature guidelines along the pipeline route**.** To meet the identified temperature guidelines, the pipeline compressors require some form of discharge temperature control. For the Mackenzie Valley pipeline design, gas-to-gas exchangers will be used to chill the gas.

Table 1: Mackenzie Valley Pipeline Inlet Temperatures

Permafrost Region	Locations	Temperature (°C)		
		Mean Annual	Summer	Winter
Continuous	Inuvik area facility	-1	+3	-2
Continuous	Inuvik south to Loon River	-1	+6	-8
Discontinuous	Loon River south to Alberta	+2	+10	-6

4.1 Gas Chilling

The discharge pressure from the compressor stations will be 18.7 MPa (2,710 psig). Suction pressures at the inlet to the compressor stations will range from 12.6 MPa (1,830 psig) in the one-compressor-station case to about 13.7 MPa (2,000 psig) in the three-compressor-station case. With the Joule-Thomson cooling from this pressure drop and the natural low temperature of the soils in the North, the gas will cool significantly as it travels between compressor stations. Temperatures will drop by 6°C to 14°C between compressor stations. This temperature drop provides the cooling energy for the gas-to-gas exchangers.

As is common industry practice, at each compressor station, compressed gas will be cooled through conventional aerial coolers to approach ambient air temperatures. To further cool or chill the outlet gas to the required pipeline operating temperatures, it will then be cross-exchanged with the chilled inlet gas in the gas-to-gas exchangers. The resultant gas discharge temperature will approach the inlet gas temperature. The required discharge temperature will change seasonally.

Through temperature control on both the aerial coolers and the gas-to-gas exchangers, the discharge temperature of gas leaving a compressor station can be seasonally adjusted to meet the temperature guidelines for that site.

This method of gas chilling using the aerial coolers and gas-to-gas exchangers causes the suction temperature to the compressor to be higher than it would be in a more conventional arrangement. This warmer gas increases the overall compression power needed at a station by an average of 15%. However, this is more than offset by eliminating the need for refrigeration power to cool the discharge gas to meet the discharge temperature limits that would be required if a more conventional approach were taken.

The gas temperature profiles along the pipeline for the design rate of 34.3 Mm^3/d (1.2 Bcf/d) are shown in Figure 5.

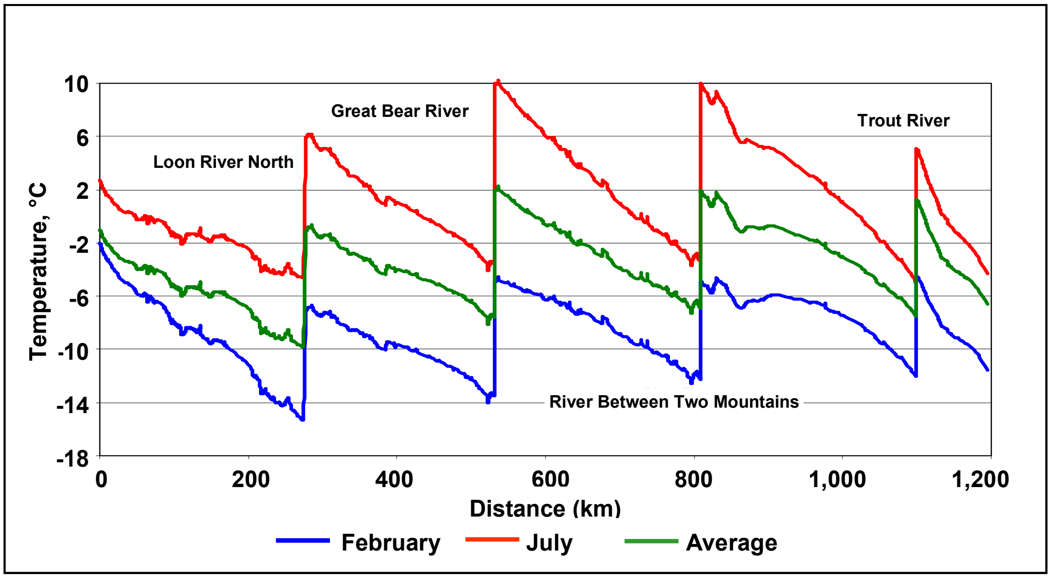

Figure 5: Gas Temperature Profiles

4.2 Conventional Refrigeration

The option of using conventional refrigeration units for chilling the gas was evaluated early in the project. This option was not selected for several reasons, including the need to meet the project objectives to:

- minimize the pieces of mechanical equipment required on-site
- reduce site emissions
- lower operating costs

Another reason for not using conventional refrigeration units for chilling the gas was that a constant discharge gas temperature was not required.

Overall fuel gas consumption is reduced by about 27% by using the gas-to-gas exchangers instead of a conventional refrigeration system (see Figure 6). Although refrigeration systems offer a higher level of temperature control than gas-to-gas exchangers, they cannot be efficiently used in the Canadian North with its long, cold winters and short, hot summers. For most of the year, the conventional refrigeration system would either be bypassed or would only be operated at partial load.

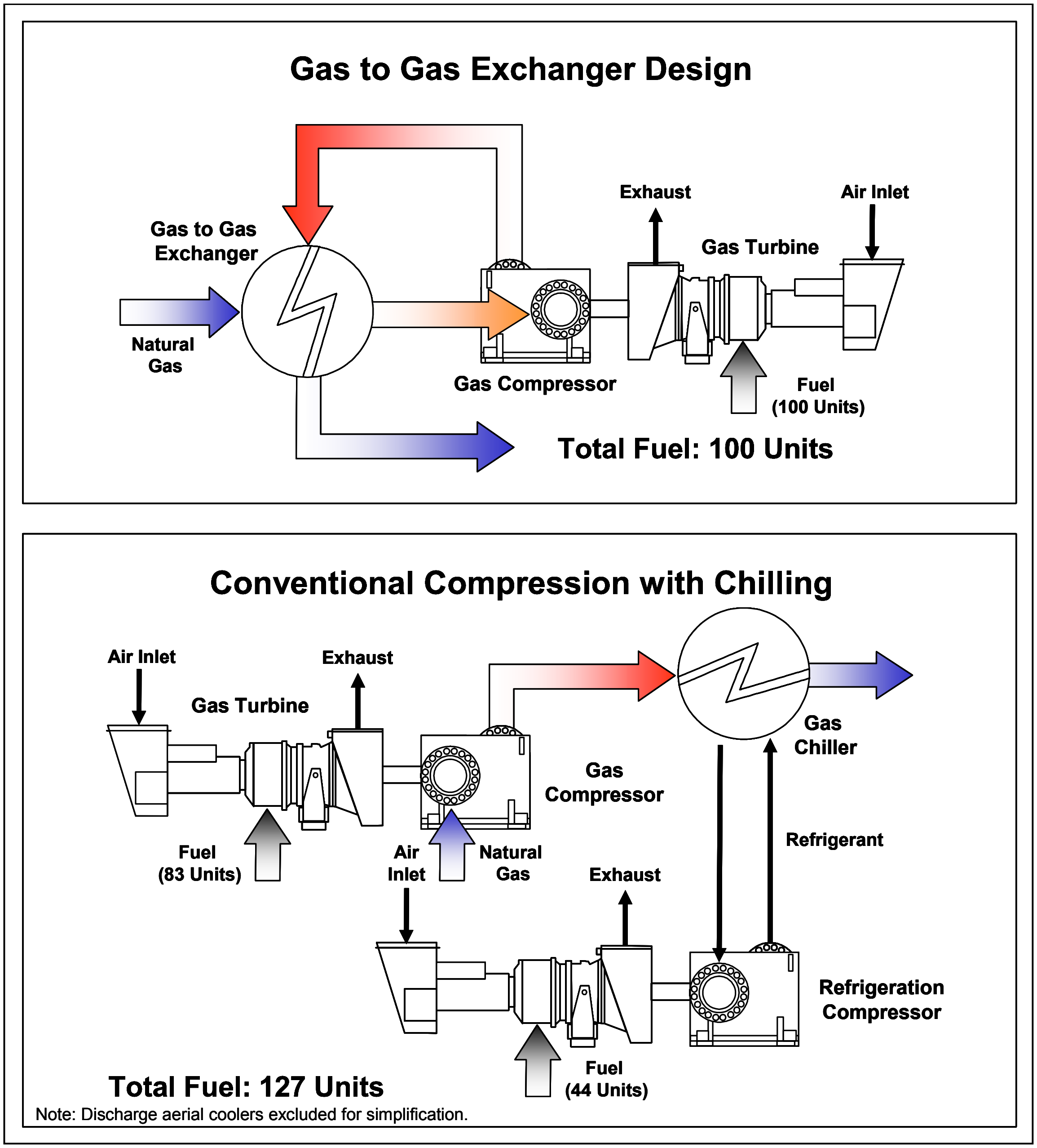

Figure 6: Gas-to-Gas Exchanger and Conventional Compression Designs

5 DRY LOW-EMISSION COMBUSTION

The gas turbine-compressor packages proposed for the project will be fitted with dry low-emission (DLE) combustion systems designed to comply with the Canadian Council of Ministers of the Environment (CCME) guidelines.

DLE is a generic term used to describe emission technology for gas turbines. This technology is being used to reduce nitrous oxides (NO_x), carbon monoxide (CO) and unburned hydrocarbons (UHC). The DLE system premixes the air and fuel before combustion occurs and tightly controls the flame temperature via a lean fuel-to-air mixture. DLE systems are susceptible to combustion-induced oscillations and flame instability. Cold ambient temperatures can further reduce the stability of the flame.

Although all turbines that have been considered for the project have demonstrated operation with DLE systems, there is limited trouble-free experience at the low ambient air temperatures expected. This is an important consideration for DLE systems, because extended low ambient temperature conditions might reduce combustion stability and introduce the potential for operating problems, such as combustor pulsation or rumble and flame extinction. Partial load operation typically experienced with mechanical drive turbo-compressors can also contribute to combustion stability problems at low temperatures.

Different gas turbine vendors have advanced a number of strategies to improve the operation of DLE-equipped turbo-compressors, including:

- improving combustor design, tuning and on-line dynamics monitoring. For example, gas turbines might require seasonal tuning to allow stable operation as the ambient temperature range changes.
- scheduling the fuel control system to bleed air at partial load to maintain reduced CO levels. This strategy, which was primarily developed to meet US emission target requirements, results in increased specific fuel consumption and carbon dioxide (CO_2) production. However, Canadian regulators consider increased CO production as being less significant than delivering optimum fuel efficiency. The Mackenzie Gas Project will follow Canadian regulatory guidelines and specify the fuel control system and fuel schedules that deliver optimum fuel efficiency.
- introducing heat to the inlet air to bring temperatures to a level where stable DLE operation can be expected, usually warmer than -29°C

For this project, the design objectives for the DLE system will be to:

- deliver reliable, low-cost operation of DLE gas turbines, i.e., eliminate risk of outages resulting from the DLE system, and any related availability and cost impact of component failures
- align with Canadian regulatory guidance and specify a DLE fuel control system and fuel schedules that eliminate or reduce bleed air requirements

Based on these design objectives, gas turbine inlet heating is currently expected to be used to maintain gas turbine inlet air temperatures above minimum levels proven for continuous operation without shutdowns or integrity issues and resulting costs.

The compressor stations already require a process heating system, so inlet air heating is an incremental load to an existing system. The current planning basis allows for preheating the inlet air by up to 20°C, requiring a heat duty of about 1,200 kW. The use of glycol and water heating for the inlet air duct heating on the turbo-compressor is a low technology, low capital cost solution. Based on average ambient data, this system might be required about 10% of the time.

The use of process heat for inlet air heating reduces capital costs and provides inlet air temperatures that will satisfy integrity concerns. Not providing inlet heating where required might mean accepting performance uncertainty related to gas turbine shutdowns, additional DLE tuning impacts, and potential component failures linked to extreme cold weather operation. Continued discussions with turbine vendors and industry experience will be used to optimize both design and operational criteria.

6 Operations and Maintenance Logistics

The logistics of working in the Canadian North will force operations staff to pre-plan maintenance to take advantage of available transportation, such as trucks and barges. It will also force maintenance planning in the design stage to ensure that:

- maintenance can be done, even when transportation options are limited
- appropriate modularization techniques have been identified and selected

The operational philosophy for the pipeline compressor stations is based on normally unattended operation with supervisory control from a control centre in Calgary. An operations support and maintenance base is expected to be established in Norman Wells, where Imperial already has a well-established operation. Remote monitoring and diagnostics data from the compressor stations will be provided to the control centres to allow personnel in Norman Wells and Calgary to access data for maintenance and trouble-shooting purposes. Operations and maintenance planning and work execution will emphasize forecasting and planning work with particular consideration for the project's unique logistical challenges.

In the North, transportation logistics and logistics planning are a critical component of both planned and unplanned maintenance. Because of the large or heavy loads associated with the pipeline turbo-compressor components, operations and maintenance need to schedule the work and transportation to take advantage of relatively easy and inexpensive modes of transportation, such as using trucks and river barges, when they are available. These logistics and transportation considerations will likely result in the project developing a more highly developed operations and maintenance strategy.

6.1 Transportation Infrastructure

The transportation infrastructure in the Northwest Territories is configured differently than it is in southern Canada. Consequently, there is limited road infrastructure available for transporting the project's large turbo-compressor components. The all-weather Mackenzie Highway, which follows the Mackenzie Valley as far north as Wrigley, is only available for about 10 months of the year. The highway is not available in the shoulder season, which is about one month each spring, and again in the fall when ferries are unable to operate and the river ice is not thick enough to support heavy loads. Ground access to Inuvik is available with the same limitations as access on the Mackenzie Highway. This route to Inuvik is about a 3,700 km one-way trek from Calgary and involves travelling on both the Alaska and Dempster highways.

For about 10 to 12 weeks each winter, ground access is available for destinations north of Wrigley up to Fort Good Hope. This includes the Great Bear River compressor station, located near Tulita.

Barge transportation is available for about three months each summer and is the main transportation method along the Mackenzie Valley. Each compressor station located close to the Mackenzie River will have road access to the river to allow cargo to be transported from barge landings to the compressor station site.

Air transportation for the project is also available to the hub airports of Inuvik, Norman Wells, and Fort Simpson. Boeing 737 and Lockheed L100 Hercules aircraft can land at these locations. From these hubs to the other project sites along the valley, smaller aircraft, such as Twin Otters, Dash 7 or Dash 8 aircraft, or helicopters, can be used all year.

6.2 Maintenance Planning

Proactive maintenance planning is required to manage the challenging transportation logistics for the project. Planned maintenance of the compressor stations will occur either in the summer, when parts and equipment can more easily be brought in by barge, or in the winter, via winter roads. Transporting material during the shoulder season is complicated, tends to be expensive, and will be avoided as much as possible. However, unplanned maintenance will be required over the life of the project and will require significant pre-planning by operations in the design phase to deal with the logistical challenges of working in the North. Planning will include working with the turbine manufacturer to make early decisions regarding engine or component packaging.

The transportation of a complete turbine, or any significant component, presents challenges during periods when there is limited or no ground access to the sites. A complete turbine assembly can be transported via Hercules aircraft to the hub airports along the pipeline route. Transportation from there to compressor sites is more difficult. The ability to break a turbine down into smaller components and lighter loads is crucial. Although it is preferable to move a gas turbine or its major components as a single unit, only medium-lift helicopters with lifting capability of 1,585 to 3,625 kg, are widely available in the Northwest Territories. Most emergency maintenance planning is based on using this type of helicopter. This limitation on lift capability necessitates disassembling turbines for transport.

Factors for consideration in transporting turbine components include:

- weight and size of components to be shipped
- handling considerations
- distance to be covered

- time of year, road and ground conditions
- level of urgency and time available for transport
- available transport, including final transportation to the site

Currently, the best way to ship a complete turbine engine is believed to be by disassembling it into modules, such as the power turbine, the gas producer, and the accessory drive gearbox. In some cases, transportation considerations, such as a requirement for air transport into a compressor site or rough transport conditions might require a major engine component to be disassembled into even smaller components of specific dimensions or suitable for special packaging. Ideally, this disassembly and packaging would be done in the turbine manufacturer's workshop.

The same methods described for preparing and transporting turbine engine modules will be used for preparing and shipping the components and tools required for field repairs.

6.3 Air Transport

Larger engine components and tools might require dedicated transportation. Certain modules, such as a complete gas producer, present major challenges because of their weight and size. Aircraft selection will be limited by:

- structural payload limits
- factors, such as:
  - door sizes and clearances
  - fuselage dimensions and shape
  - floor loading limits
  - distribution of weight
  - methods of loading and unloading
- runway requirements for take-off and landing
- aircraft availability

Many aircraft have the payload capacity, but do not have the door or fuselage dimensions to carry an assembled gas producer. Combi-version planes tend to have either entry or height restrictions during the conversion to cargo service. This is a disadvantage relative to transporting a long circular load, such as a gas producer module. Large planes, such as a Boeing 747 freighter and former Soviet military transports have the necessary cargo capabilities, but are too big for the northern hub airports to accommodate. The Lockheed L100 Hercules is designed to accommodate equipment loads up to 22,000 kg. It has the necessary range, and is easily loaded. Hercules aircraft routinely operate in the Canadian North.

Where practical, transportation between hub locations and the project's compressor station sites will be by truck. Air transport will be used when there is a lack of suitable ground access. Smaller components could be transported by air either by using smaller helicopters or fixed-wing aircraft to transport components to a nearby community airstrip. From there, the components could be transported to the compressor site either by ground or helicopter. Air transport of heavy and large engine components and tools is likely to require the use of medium or heavy-lift helicopters.

Light and medium-lift helicopters could be used to transport components and tools needed for field repair activities. Medium-lift helicopters can transport loads ranging from 1,585 kg using a Bell 212 and up to 3,625 kg using a Sikorski S-61. The largest of the currently available heavy-lift helicopters is the MI–26, which has a load capability of 19,960 kg. This helicopter could transport a fully assembled turbine engine inside its hull. Two types of heavy-lift helicopters are capable of transporting a fully assembled turbine module within their hulls:

- the MI–26, with a load capability of 19,960 kg
- the Chinook, with a load capability of 11,340 kg

To date, work on reducing the weight of the gas turbine components for transport indicates that it would be practical to disassemble the turbine into smaller components, transport them to a compressor site and reassemble them. This strategy could be effective in situations where the availability or cost of helicopters capable of lifting complete turbine modules is constrained. Being able to break large modules into smaller components would significantly expand the number of helicopters available to accomplish the task of getting the gas turbines to the site. The disadvantage of this modular strategy is that the more components that a turbine is disassembled into, the more field repair work is required. At some point, there is an increased risk to achieving high reliability and availability in a multi-component field repair.

The on-demand availability of large helicopters and specialized fixed-wing aircraft remains an area of concern for the project. The larger the helicopter, or the more specialized the aircraft, the less likely it is to be available in the North, unless contracted for a specific purpose. Helicopter and fixed-wing aircraft flight might also be adversely affected by weather conditions. Generally, summer conditions in the North bring good visibility and long hours of daylight. This is especially advantageous for helicopter flights and cargo-sling operations, where loads are transported suspended from the helicopter. However, thawed and wet ground can make airstrips soft and impede fixed-wing flight operations. The short amount of daylight in the winter months, or a period of extreme cold or poor visibility, can impede both fixed-wing aircraft and helicopter operations.

7 CONCLUSION

To date, the Mackenzie Gas Project has presented a number of unique challenges to its designers and planners. Significant effort has been, and continues to be, made to meet these challenges while achieving the project objectives. The challenges presented on the turbo-compressors provide a few examples of the type and scale of issues that need to be dealt with on a broader scale for the entire project.

The Mackenzie Gas Project offers a unique opportunity to foster engineering innovation while meeting the principles of ensuring worker and public safety, demonstrating care for the environment, and respecting the people, the land, the wildlife and the environment of the North.