Woodfibre LNG Project

ASSESSMENT OF ALTERNATIVE COOLING METHODS

Response to EAO Supplemental Information Request

April 2015

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1.0 INTRODUCTION

The Application for an Environmental Assessment Certificate (Application) for the Woodfibre Liquefied Natural Gas (LNG) Project was submitted to the Environmental Assessment Office (EAO) on January 12, 2015, and is currently under review. A request was received from the EAO on April 10, 2015 to provide additional information regarding alternative cooling technologies considered for the Project.

This report provides the information requested in Part 2C of the Supplemental Information Request from the EAO as follow-up to the working group review of the Application under the British Columbia (BC) *Environmental Assessment Act*. Part 2C of the EAO Supplemental Information Request reads:

> *Provide additional information, including a detailed description of the methodology and criteria used to evaluate the alternative cooling methods and a detailed rationale for why each criterion was selected. As required in the AIR, for projects undergoing a substituted EA the consideration of alternatives means of undertaking the project and the environmental effects of any such alternative means must include specific reference to environmental effects as they are identified in section 5 of CEAA 2012.*

Consistent with the requirements under Sections 5 and 19(1)(g) of *CEAA* 2012 and the federal guidance document entitled *Operational Policy Statement; Addressing "Purpose of" and "Alternative Means" under the Canadian Environmental Assessment Act, 2012* (Canadian Environmental Assessment Agency (CEA Agency) 2013), the report describes the methodology and findings of the assessment used to evaluate technically and economically feasible alternative methods for cooling the proposed Project process components.

The report is organized as follows:

- Identify the alternative methods for providing cooling during the production of liquefied natural gas (LNG) (**Section 2.0**) –
    - Develop criteria to determine the technical and economic feasibility of the alternative cooling methods; and
    - Identify those alternative methods that are technically and economically feasible, describing each alternative method in sufficient detail.
- Identify the effects of each technically and economically feasible alternative cooling method (**Section 3.0**) –
    - Determine criteria to examine the effects of each remaining alternative method; and
    - Identify those elements of each alternative method that could produce effects, in sufficient detail to allow a comparison with the effects of the Project and to identify the preferred means.
- Identify the preferred cooling method (**Section 4.0**) –
    - Identify the preferred method based on a relative consideration of effects, and of technical and economic feasibility.

2.0 ALTERNATIVE LNG PRODUCTION COOLING PROCESSES

Liquefied natural gas, or LNG, is natural gas in a liquid state. Natural gas becomes a liquid when it is cooled to approximately -162°C. This process, called liquefaction, shrinks the volume of the gas by 600 times, making it easier to store and transport to markets around the world. Heat created during the liquefaction process must be removed through the use of a cooling medium (typically an air, water, or hybrid cooling system).

As described in more detail in the Application (**Section 2.2 Description of the Proposed Project**) liquefaction will occur after the natural gas has been pre-treated to remove impurities and other components, split into two streams, and directed into the two liquefaction trains. In each train, the natural gas will be pre-cooled, liquefied, and sub-cooled in a three-coil wound heat exchanger located in one common shell. In addition to the large duty involved in the cooling of the refrigerant compressor, several smaller process cooling duties are required, including the cooling of the regeneration gas, the amine still reflux condenser, and other instruments.

It is anticipated that the Project will produce a nominal 2.1 million metric tonnes per annum (MMTPA) of LNG. Processed and stored LNG will be transferred to LNG carriers for export to natural gas markets overseas.

As described below, several options are available for cooling the liquefaction process including:

- Option 1: Air cooling
- Option 2: Evaporative cooling (cooling tower, wetted surface air cooler, and hybrid wet-dry wetted surface air cooler)
- Option 3: Freshwater cooling from local streams
- Option 4: Seawater cooling from Howe Sound

In an LNG facility, it is important that the refrigerant stream be cooled to the lowest practical temperature to improve project efficiency. Most of the time at the Woodfibre site, the ambient air temperature will be lower than the design air temperature. However, the Project will be designed for and is anticipated to operate at maximum production in the summer when winter gas pipeline constraints have eased and more gas is available for liquefaction. As a result, the design air temperature is a primary operational concern and the facility must be able to meet production at peak summer temperatures.

In most cases, cooling the refrigerant to temperatures lower than design will improve the overall efficiency of the facility. For mixed refrigerant processes, however, overcooling may lead to excessive condensation of the mixed refrigerant, which in turn may interfere with the ability of the compressor to pump the liquid fraction to the main cryogenic heat exchanger. It is important to be able to control the outlet temperature of the refrigerant within the operating range of the process. The control methodology associated with each alternative cooling technology is described below (see **Section 3.0**).

2.1 INFORMATION SOURCES USED TO IDENTIFY ALTERNATIVE METHODS

During Project planning, technically and economically feasible alternative cooling methods were identified based on the professional judgment of Woodfibre LNG Limited and technical studies undertaken by LNG industry professionals, including:

- The Linde Group – a supplier of industrial, process, and speciality gases that owns and operates over 1,000 LNG production facilities worldwide. Linde is experienced in on-site LNG process optimization and management and LNG production, and is engaged in ongoing research and development in the deployment of new facilities (The Linde Group 2014). Linde Engineering has developed, built, and started up more than 20 LNG plants world-wide since 1967 (Linde Engineering n.d.).
- WorleyParsons Canada Services Ltd. – a company that provides engineering, procurement and construction management (EPCM) services for LNG facilities worldwide.

2.2 TECHNICAL FEASIBILITY CRITERIA

When determining the technical feasibility of cooling alternatives, Woodfibre LNG Limited considered the facility's site-specific requirements and limitations, keeping in mind the Project's environmental philosophy to design for reduced environmental effects during each phase of engineering design, and its commitment to meet or exceed all applicable provincial and federal acts, supporting regulations, codes, and standards.

Technical feasibility criteria considered during the assessment of alternative cooling methods for the Project included:

- Footprint (m^2) requirements
- Water requirements
- Energy requirements
- Stability (e.g., ability to achieve lowest practical approach temperature and control process stream outlet temperature)
- Ability to satisfy environmental requirements and meet the Project's environmental objectives and commitments

2.3 ECONOMIC FEASIBILITY CRITERIA

When an option was considered technically feasible, further evaluation was conducted to determine its economic feasibility based on estimated lifecyle costs, including:

- Capital expenditures (i.e., equipment acquisition and installation costs)

- Operating and maintenance costs

Alternatives were determined to be not economically feasible if their lifecycle cost estimates were considerably higher than those of the other options being considered.

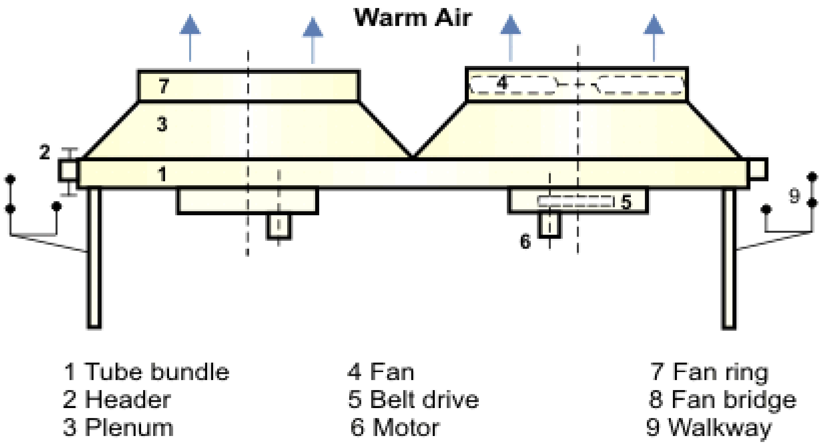
2.4 ALTERNATIVES CONSIDERED

Unless otherwise indicated, the information provided below with respect to the technical and economic feasibility of cooling system alternatives is based on a *Cooling Medium Selection Report* prepared by WorleyParsons for Woodfibre Natural Gas Limited dated August 29, 2013.

2.4.1 Option 1: Air Cooling

An air cooled heat exchanger (ACHE) is a finned tube heat exchanger that cools a circulating fluid by forcing or inducing ambient air over the exterior surface of the tubes (See **Figure A** below). Heat from the circulating process fluid is transferred to the air and rejected to the atmosphere. The most common type, a forced flow air cooler, has fans below the tube bundle. The fan creates a region of high pressure below the bundle so that air is forced over the fin tubes. By contrast, in an induced flow air cooler, as shown in **Figure A**, the fans are located above the bundle and create a region of low pressure air above the bundle, drawing air over the fin tubes.

Air coolers are typically designed to cool the circulating refrigerant to a specific process temperature. To improve project efficiency in an LNG facility, it is important that the refrigerant stream be cooled to the lowest practical temperature. The temperature difference between the process stream and the inlet air dry bulb is referred to as the approach temperature. The lowest practical approach temperature for air coolers is approximately 10°C. The 97.5 percentile design air dry bulb temperature for the Woodfibre LNG facility is 29°C, resulting in a refrigerant process temperature of approximately 39°C (102.2°F).



(**Source:** WorleyParsons 2013).

Figure A Air Cooled Heat Exchanger

In an air cooled heat exchanger, the process stream outlet temperature can be controlled by various means including:

- Increasing or decreasing the number of fans that are running; and
- Providing multi-speed motors, variable pitch fan blades, and louvers.

Louvers and variable pitch fan blades have a higher incidence of failure and require considerable maintenance. The preferred method of temperature control for an air cooled system involves the use of two speed fan motors capable of shutting down the fans. For the Project, winterization of such an air cooling system may be required to facilitate start-up of the heat exchanger during extreme cold weather periods when snow or ice is prevalent. Other than electric power for fan motors, no other utilities would be required.

Based on vendor information, the air coolers required for cooling only the refrigerant compressor discharge of a 2.1 MMTPA liquefaction facility, would require an approximate footprint of 3,250 m^2 with 3.8 MW of motors installed (i.e., 42 bays (4.3 m by 19 m per bay) with three 30 kW fans per bay). To facilitate proper air flow, the minimum clearance between the fans and other equipment or structures would be 7 m (23 ft.).

The cost to purchase and install an air cooled heat exchange capable of meeting the needs of the Project is low compared to other cooling technologies.

Most base load LNG facilities utilize air heat exchangers due to their lower capital cost and reliability. Because air coolers are limited to an approximately 10^oC approach to the ambient air temperature, however, such a system provides the least refrigeration cooling on hot summer days, reducing the compressor efficiency and requiring more energy to operate. Air coolers also require the largest footprint of all the cooling methods considered. The use of air coolers for the Project would require greater refrigerant inventory, increasing the potential magnitude and extent of contamination in the event of a leak or spill from the refrigerant piping or tube bundles.

2.4.2 Option 2: Evaporative Cooling

An evaporative cooler is a type of air cooler in which the cooling duty is enhanced by vaporizing water. Water is distributed by baffles or spray nozzles over an extended surface area to facilitate vaporization. The latent heat of vaporization for water is approximately 2,257 kilojoules per kilogram (kJ/kg) whereas the heat capacity for dry air (i.e., the amount of energy required to raise the temperature by 1^oC) is 4.2 kJ/kg. In an evaporative cooler, the air temperature is cooled to approximately the wet bulb temperature, which is significantly lower than the dry bulb temperature of the air cooler. This allows the refrigerant to return to the inter-stage compressor suction and the main cryogenic heat exchanger at cooler temperatures, improving the efficiency or capacity of the LNG train and lowering the required energy requirements.

Although they use less water than similar capacity once-through cooling systems, evaporative cooling systems require a large and reliable source of fresh water (U.S. Department of Energy 2011). During system operation, water is lost through evaporation, blow down (i.e., system water which, due to evaporative loss, contains a high concentration of dissolved or suspended solids and that must be periodically removed and replaced with make-up water to prevent scale formation and corrosion), leaks, and drift (i.e., water droplets entrained in the air leaving the cooler or top of the cooler tower, or blown from the side of the tower by crosswinds) (U.S. Department of Energy 2011).

In considering evaporative cooling options for the Woodfibre LNG facility, potential sources of make-up water (i.e., water supply needed to replace system water losses due to evaporation, blow down, leaks, or drift) include Woodfibre Creek or Mill Creek. Licences for the withdrawal of water from each of these streams for industrial purposes have recently been transferred from Western Forest Products Ltd. (WFP) to Woodfibre LNG Limited (see also **Section 2.4.3**). However, the purpose of the existing water licences would need to be changed. Also, the flow available for diversion is limited during low flow (summer) months, particularly given the necessity to maintain minimum instream flow releases that are protective of fish. In a cooling tower option, water from either or both of the streams would be incorporated into the system water circulating through the plant. As previously described, over time, some of this water would be lost to evaporation, leaks or drift, while the remainder (i.e., blow down) would require treatment to satisfy discharge permit requirements prior to release into Howe Sound. No water would be returned to the stream(s).

Among the many types of evaporative coolers, those considered with respect to the Project and discussed further below include:

- Wet cooling towers;
- Wetted surface air coolers (WSAC); and
- Hybrid air coolers and WSAC evaporative coolers.

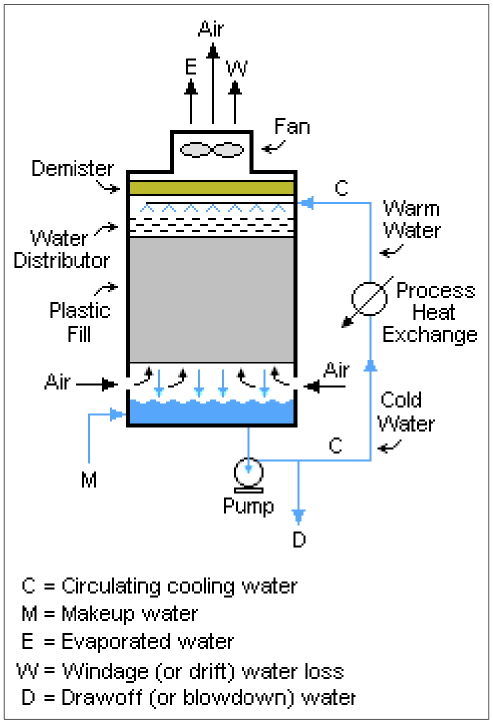
A. Wet Cooling Towers

Wet cooling towers are used to dissipate a large heat load to the atmosphere. Heat is exchanged between the process and the air passing through the cooling tower and escapes to the atmosphere by way of water vapour. Heat transfer is measured by the decrease in the process temperature and a corresponding increase in the moisture content and the wet bulb temperature of the air passing through the cooling tower.

The most common evaporative cooling system involves the use of an induced flow, mechanical draft cooling tower, as shown in **Figures B** and **C**. Warm water that has passed through the process heat exchanger is sprayed and distributed on the top of a wetted medium called “fill”, located inside the tower.

The large surface area provided by the fill promotes evaporation. Fans are used to force ambient air upwards through the fill, countercurrent to the flow of the water. When it contacts the warm water, the air becomes saturated. A small portion of the water evaporates, cooling the remainder of the cooling water stream. By the time the water reaches the cooling tower basin, it approaches the wet bulb temperature. The cooling water pumps circulate the water back to the process stream.

The design summer wet bulb temperature for the Woodfibre LNG facility is 19°C. Assuming the cooling water makes a 5°C approach to the wet bulb and the process makes an 8°C approach to the cooling water temperature, the refrigerant may be cooled to approximately 32°C (89.6°F). On this basis, the use of a cooling tower would allow for a 7°C improvement in cooling when compared to an air coolant system, and in summer, would reduce energy requirements in a refrigerant compressor for the LNG liquefaction trains by approximately 5%.



(**Source:** WorleyParsons 2013).

Figure B Induced Flow, Mechanical Draft Cooling Tower

(**Source:** WorleyParsons 2013).

Figure C Mechanical Draft Cooling Tower

Process temperature may be controlled by varying the cooling water flow to the process heat exchanger or by varying the distribution of warm water returned to the top or basin of the cooler. In cold climates subject to freezing, such as the Woodfibre site, special winterization features such as heat tracing and basin sump heaters may be required.

A cooling tower system requires routine inspection and maintenance, including the use of water treatment chemicals to address issues related to scaling (i.e., precipitation of mineral particles in water to form a hard deposit on heat transfer surfaces), biofouling, and corrosion, all of which can reduce heat transfer efficiency and adversely affect system functionality, and Legionnaires' disease, which can pose a public health risk. While cooling towers provide a suitable environment for the growth of microorganisms, including Legionella bacteria, the use of chemical and physical water treatment and adherence to design and maintenance standards and best practice guidelines developed by the US Center for Disease Control and the Cooling Tower Institute provide an effective means of control.

Direct contact between the cooling water and the air passing through the tower results in the formation of water droplets which may be entrained in the air stream and carried out of the tower as drift. Any minerals or chemical impurities in the water circulating through the tower will also be contained in the drift droplets, creating the potential for airborne emissions (U.S. Environmental Protection Agency (EPA) 1995). Deposition of the droplets can result in problems such as wetting, icing, salt deposition, and/or damage to equipment and vegetation in the vicinity of the tower (US EPA 1995). The incorporation of drift eliminators into tower design can reduce the amount of drift released from a cooling tower.

For the Project, an evaporative cooling tower system would require an approximate cooling water flow of 2.2 m^3/s. Make-up water would be diverted from Mill Creek at a rate of 0.08 m^3/s while blow down would be treated and discharged to Howe Sound at a rate of approximately 0.02 m^3/s. The water licences for the purpose of industrial use allow a maximum of 0.74 m^3/s to be diverted from Mill Creek, subject to flow availability. In addition, Woodfibre LNG Limited has committed to the implementation of minimum instream flow releases that are protective of fish.

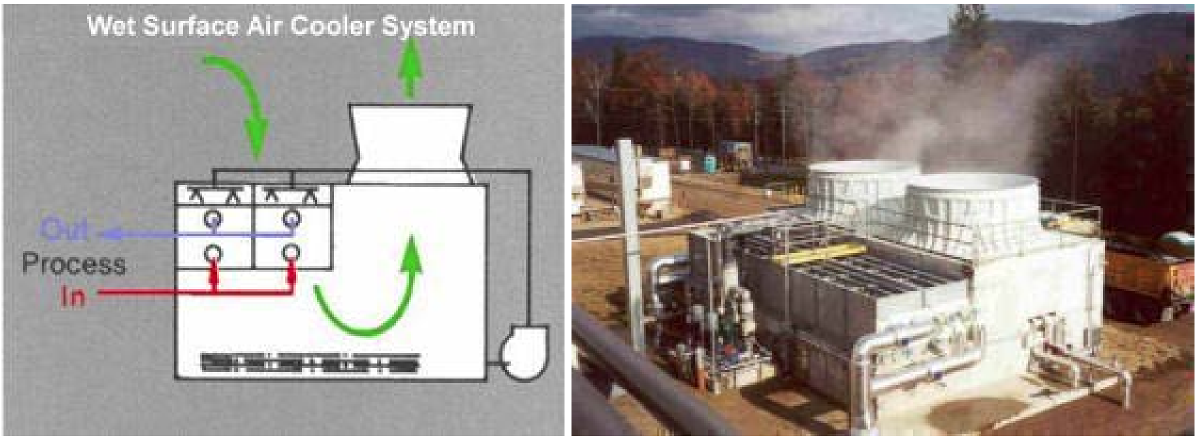
For a 2.1 MMTPA LNG liquefaction facility, the estimated footprint of a mechanical draft cooling tower system would be 14.6 m by 66 m (1,000 m^2). Energy requirements would be 0.60 MW for the fans and 1.5 MW (3 x 50%) for the cooling water pumps.

The equipment and installation costs for an evaporative cooling system involving cooling towers are average when compared to other cooling technologies.

Although cooling towers require an additional cooling water circuit, they are able to provide lower process temperatures, thereby improving compressor efficiency and reducing energy requirements for compression by approximately 5% compared to air coolers. Also, since the cooling water is delivered from remote cooling towers, this option allows the refrigerant volume to be reduced and localized to the liquefaction module, reducing the potential magnitude and extent of a refrigerant spill. Unlike an air cooled system, however, cooling towers require make-up and water treatment, including chemical additions to mitigate against biofouling, scaling, and Legionellosis. Significant heat tracing, sump heating, and winterization may be required.

B. Wetted Surface Air Coolers

A WSAC system (see **Figure D**) cools the process stream directly. Refrigerant lines flow directly to and from the cooler. Water is sprayed on and air flow is induced to flow through the tube bundles. Air and produced water vapor is drawn under a drift eliminator baffle then exhausted upward through the fan discharge volute (see **Figure D**). All water that is not lost to evaporation, blow down or drift remains within the WSAC circuit. The potential for scaling, blow down and water treatment is less than for a system involving a cooling tower where dissolved solids can concentrate and precipitate in the cooling water circuit.



(**Source:** WorleyParsons 2013).

Figure D Wetted Surface Air Cooler

A WSAC system would allow the temperature of the refrigerant inter-stage and discharge streams to approach within approximately 8^{o}C of the 19^{o}C design wet bulb temperature for summer operation at the Woodfibre LNG facility (i.e., approximately 27^{o}C). This represents a 5^{o}C improvement compared to an evaporative, cooling tower system and a 12^{o}C improvement compared to an air cooler system. Further, a WSAC system would require approximately 10% less energy for refrigeration compression during the summer than an air cooler system.

In a WSAC system, process temperature may be controlled by regulating water or airflow. The process outlet temperature can be controlled by varying the water flow rate over the tube bundles or by using the fans to vary the air flow rate. Wetted Surface Air Coolers have the same water treatment and winterization issues as cooling towers.

The amount of make-up water required for a WSAC evaporative cooler is approximately 0.10 m^3/s and, for the Project, would need to be diverted from a local stream (i.e., Mill Creek or Woodfibre Creek). The estimated blow down volume for a WSAC is approximately 0.02 m^3/s. As for a cooling tower system, although reduced, blow down water treatment and disposal would be required. WSACs, however, have the advantage of eliminating the pipe and exchanger fouling that is often associated with cooling tower operations.

The estimated footprint of a conventional co-current, onshore WSAC for direct refrigerant cooling for a 2.1 MMTPA liquefaction facility is approximately 3,600 m^2. A special, minimum footprint, countercurrent WSAC could be constructed that would use approximately 1,350 m^2 based on a minimum footprint module arrangement and could be placed into two 20 m by 40 m modules.

Energy requirements would be 0.62 MW for the fans and 0.32 kW for the cooling water pumps.

The equipment and installation costs for an offshore countercurrent WSAC system with an integral basin for module installation are high compared to other cooling technologies.

A WSAC system cools the process stream directly and offers the lowest process temperatures available in a closed circuit system, reducing energy requirements by approximately 10% in comparison to air coolers. While a WSAC system still requires make-up and blow down water and treatment, these requirements would be less than those of an evaporative system involving cooling towers. As for the cooling tower option, it is likely that heat tracing, sump heating and winterization would be required for a WSAC system at the Woodfibre site.

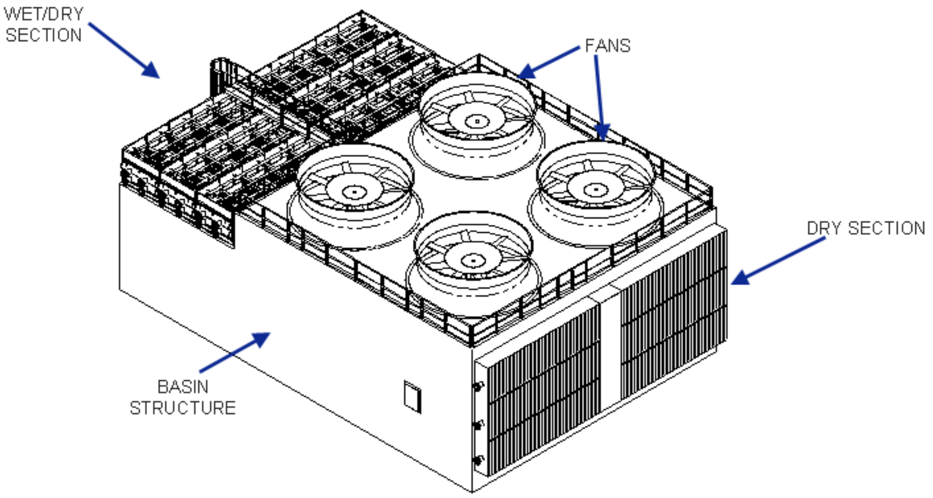
C. Hybrid Wet / Dry Wetted Surface Air Cooler

A hybrid wet / dry WSAC (see **Figure E**) combines all of the advantages of an air cooler and an evaporative cooler. During warmer seasons, the unit uses air coolers and a WSAC evaporative cooler. During colder seasons, when there is a large temperature difference between the ambient air temperature and the required process temperature, the water is drained from the system and all cooling is provided by the air cooler. This feature reduces water consumption and mitigates many of the freezing / winterization and visible fog issues associated with the use of other types of evaporative coolers during winter operation. However, such an arrangement increases the complexity, equipment count, cost and footprint of the compression coolers.

The estimated footprint of a direct refrigerant cooling system using a Hybrid Wet / Dry WSAC for a 2.1 MMTPA liquefaction facility is approximately 3,200 m^2.

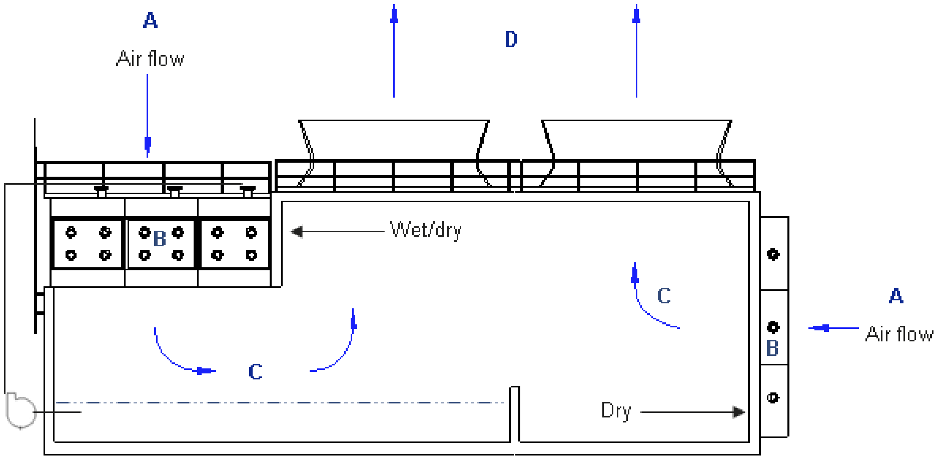
Hybrid wet / dry WSACs combine the best features of air coolers and WSACs, reducing or eliminating water usage in mild and cold periods by transferring the duty to integral air coolers. The risk of freezing and the need for winterization can be eliminated by draining the system and operating it in a dry air cooler mode during the winter. However, such a system is more complex and requires a larger footprint, more equipment, and a greater refrigerant pressure drop than the other options.

Due to these technical limitations, cost estimates were not pursued for this option, and it is not considered further in this assessment.



(**Source:** WorleyParsons 2013).

Figure E Hybrid Wet / Dry WSAC



A. Air is induced
B. Process stream is cooled
C. Air path
D. High velocity discharge

(**Source:** WorleyParsons 2013).

Figure F Hybrid Wet / Dry WSAC Operation

2.4.3 Option 3: Freshwater Cooling from Local Streams

As anticipated in the Application, **Section 5.9 Surface Water Quantity**, WFP's water licences for water diversion and storage in Mill Creek and Woodfibre Creek have been transferred to Woodfibre LNG Limited. The licences for the purpose of industrial use, allow a maximum of 0.74 m^3/s to be diverted from Mill Creek. Stream water temperature in Mill Creek ranges from approximately 3°C in winter to 12°C in late summer.

The volume of water required for direct freshwater cooling at the Woodfibre LNG facility for refrigeration compression alone would be approximately 1.0 m^3/s, exceeding the permitted diversion rate for the two existing industrial water licences combined. Further, beneficial use of this water for process cooling would require that it be strained / filtered and chlorinated to mitigate biological fouling and corrosion of the heat exchangers.

It is considered unlikely that either Mill Creek or Woodfibre Creek could provide an adequate supply of water to support a direct freshwater cooling system. The need for biocide treatments and the elevated temperature of the water that would be discharged to Howe Sound represent impediments to this option. Consequently, its technical and economic feasibility are not explored further in this assessment.

2.4.4 Option 4: Seawater Cooling from Howe Sound

A detailed description provided of the seawater cooling system is provided in the Application **Section 2.2.6.2.10 Seawater Cooling System**. A brief summary of this information, focusing on the technical and economic feasibility of this option, is provided below. An artist's rendering of a seawater cooling system is shown in **Figure G**. The Woodfibre LNG facility would utilize an indirect cooling system which would prevent direct contact between the seawater and refrigerants. In such a system, a freshwater intermediate cooling water loop would be used to distribute the cooling water to the various parts of the facility.

Seawater is commonly used for cooling at coastal power plants and offshore facilities. Seawater characteristics at the Woodfibre site, including marine surface water temperature and clarity, make it suitable for use as a coolant for the LNG refrigerant compressors.

As described in the Application, the intake structure for the Woodfibre seawater cooling system will be fixed to the ocean floor at a depth greater than 25 m and capable of withdrawing approximately 17,000 m^3 of seawater per hour. It will be elevated approximately 2 m off the ocean floor to minimize the potential for sediment entrainment and screened to avoid entrainment of large debris. From the intake, seawater will be conveyed via a pipe to an onshore stilling basin where it will be screened using travelling screens, or similar means, to prevent small fish, larvae, and other aquatic life from entering the cooling system intake lines. These organisms will be returned to the ocean. A sodium hypochlorite solution (less than 1% as active chlorine) will be added to the seawater to discourage the growth of marine organisms inside the seawater cooling system. The seawater will be passed through heat exchangers and into a de-aeration tank, and, if required, a de-chlorination agent will be added to the water. The temperature of the seawater as it moves through the coolant system will increase by a maximum of 10^oC.

The seawater will be returned to Howe Sound via a discharge diffuser located at a depth of greater than 25 m which will promote mixing of the cooling water with ambient water to minimize the volume of water affected by the cooling system. The system will be designed to ensure that the temperature and biocide or active chlorine content of the seawater that is returned to Howe Sound comply with the values set out in the water quality discharge permit.

The energy requirements associated with operation of the seawater intake pumps and cooling water pumps would be approximately 1.0 MW and 1.8 MW, respectively.

The equipment and installation costs for a seawater cooling system are high compared to other cooling technologies.

2.4.5 Summary of Alternative Cooling Methods

Table 2-1 compares the technical and economic factors considered in the evaluation of alternative cooling methods for the Woodfibre LNG facility.

Two options, the evaporative system involving a hybrid wet/dry air cooler (Option 2C) and freshwater cooling from local streams (Option 3), were determined to be technically infeasible and are not considered further in this assessment. The hybrid wet/dry air cooler was determined to be too complex for the Woodfibre site, while the volume of freshwater required for Option 3 would exceed the maximum diversion rate provided for in the existing water licences for Mill Creek. Further, beneficial use of the stream water for process cooling would require screening and treatment prior to use, and treating and testing prior to discharge into Howe Sound, both of which detract from this option’s technical and economic feasibility.

Cooling options that may be technically or economically feasible for the Project and that are considered further in this assessment include:

- Option 1: Air cooling;
- Option 2: Evaporative cooling, including wet cooling towers (Option 2A) and WSACs (Option 2B); and
- Option 4: Seawater cooling.

Although air cooling systems require a relatively large amount of energy, they avoid issues associated with water intake, use, treatment, and effluent discharge. Due to both daily and seasonal variations in temperature, such systems must be able to operate over a relatively wide range of air temperatures. In summer, warm temperatures reduce compressor efficiency, resulting in increased energy requirements and costs.

All evaporative cooling systems require a reliable water supply to continually replace water lost to evaporation, blow down, leaks, and drift. In addition, make-up and blow down water require chemical treatment to avoid scaling, biofouling, and corrosion. In addition, blow down water requires treatment prior to its discharge to the receiving environment. As with air cooling systems, compressor efficiency is reduced during periods of elevated temperatures and high humidity, resulting in increased energy requirements and costs.

Because it is a once-through system, seawater cooling involves the withdrawal, circulation, and discharge of relatively large volumes of seawater. Project design measures to minimize the environmental effects of a seawater cooling system at the Woodfibre facility are described in the Application (**Section 2.2**). While the discharge of treated and warmed seawater represent a potential issue, it is possible to effectively mitigate these effects through project design.

Seawater cooling systems, in contrast to air cooling systems, provide greater stability of production and require less energy to operate due to the narrow and predictable range of seawater temperatures, particularly when withdrawn at depth. In addition to providing a more energy efficient option, seawater cooling systems produce less noise and visual impacts than air cooling systems.

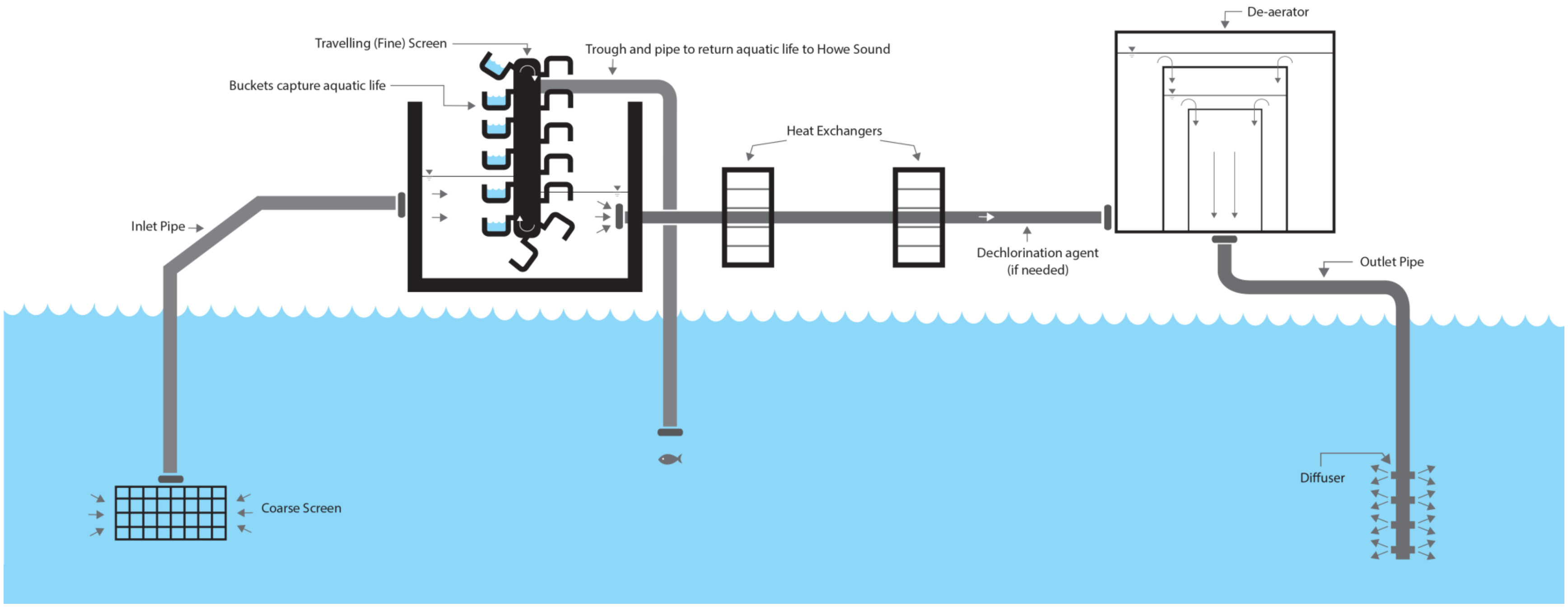


Figure G Seawater Cooling System

Table 2-1 Summary Comparison of Technical and Economic Feasibility of Alternative Cooling Methods

Footprint (m^2)	Water Requirements	Energy Requirements	Stability	Estimated CAPEX (Rank)[1]	Comments
Option 1: Air Cooling					
42 bays, each 4.3 m x 19 m (3,250 total)	None	Fans: 3 x 30 kW per bay (3.8 MW total)	Less stable. Cycles daily, and affected by weather conditions	4	Minimum 7 m clearance under fans required for proper inflow. Provides the least cooling on hot summer days, reducing compressor efficiency and requiring more energy to operate. ***Carried forward to effects assessment.***
Option 2: Evaporative Cooling					
A. Cooling Towers					
1,000 to 3,200 m^2	Make-up: 0.08 m^3/s Blow down: 0.02 m^3/s	Fans: 0.6 kW Pumps: 1.5 MW	Less stable. Affected by weather conditions	3	Can provide lower process temperatures, improving compressor efficiency and reducing energy requirements relative to air coolers. Requires less refrigerant that other options, thus reducing potential magnitude and extent of a refrigerant spill. ***Carried forward to effects assessment.***
B. Wetted Surface Air Coolers					
1,500 to 3,600 m^2	Make-up: 0.10 m^3/s Blow down: 0.02 m^3/s	Fans: 0.6 MW Pumps: 0.3 MW	Less stable. Affected by weather conditions	2	Offers lowest process temperatures available in a closed circuit system, reducing energy requirements relative to air coolers. Potential for scaling and blow down and need for water treatment is less than for a system involving a cooling tower where dissolved solids can concentrate and precipitate in the cooling water circuit. ***Carried forward to effects assessment.***

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[1] Capital cost is ranked with 1 being the most expensive cooling option.

Footprint (m^2)	Water Requirements	Energy Requirements	Stability	Estimated CAPEX (Rank)[1]	Comments
C. Hybrid Wet / Dry Air Coolers					
3,200 m^2	Information not available	Information not available	Less stable. Affected by weather conditions	Information not available	Considered too complex a system for the Woodfibre LNG facility. ***Not considered further.***
Option 3: Freshwater from Local Streams					
Information not available	1.0 m^3/s	Information not available	Information not available	Information not available	Water requirements exceed available water supply (i.e., maximum diversion rates set out in Mill Creek and Woodfibre Creek water licences). ***Not considered further.***
Seawater Cooling from Howe Sound					
100 m^2	Seawater: 17,000 m^3/h	Seawater Pump: 1.0 MW Freshwater Pump: 1.8 MW	Stable – seawater temperature remains within predicted range	1	Discharge plume would contain residual concentration of hypochlorite and temperature would be elevated relative to receiving environment. ***Carried forward to effects assessment.***

3.0 IDENTIFICATION OF THE EFFECTS OF TECHNICALLY AND ECONOMICALLY FEASIBLE COOLING METHODS

3.1 KEY VCS CONSIDERED IN THE ANALYSIS OF ALTERNATIVE COOLING METHODS

Section 4.0 Effects Assessment Methods and the *Valued Components Selection* document (WLNG 2014) describe in detail the process used to select the 20 Valued Components (VCs) to be considered during the Project's environmental assessment (EA). From these 20 VCs, eight key VCs were selected for consideration in the analysis of the alternative cooling methods. The key VCs (**Table 3-1**) were chosen based on their potential to be directly or indirectly affected by one or more of the cooling options identified in **Sections 2.4.1, 2.4.2,** and **2.4.4.** Although other VCs have the potential to be affected by these alternatives, the anticipated effects to the selected key VCs were considered the main drivers for comparing effects and determining the preferred cooling method. While other VCs may be equally affected and not be a good proxy for clearly differentiating between alternatives, this does not diminish their importance within the main Project EA.

Table 3-1 Key Valued Components Considered in the Analysis of Alternative Cooling Methods

Key Valued Components
Atmospheric Environment
Avifauna
Freshwater Fish and Fish Habitat
Marine Birds
Marine Benthic Habitat
Forage Fish and Other Fish (Marine)
Visual Quality
Public Health

Consistent with guidance provided in the *Operational Policy Statement: Addressing "Purpose of" and "Alternative Means" under the Canadian Environmental Assessment Act, 2012* (Canadian Environmental Assessment Agency (CEA Agency) 2013), a detailed assessment of the effects associated with each alternative means is not required. The key VCs are used to compare effects at a high level for each feasible alternative considered. Detailed assessments of the preferred means (as described in **Section 2.2 Description of the Proposed Project**) are presented in the effects assessment sections of the Application. **Table 3-2** summarizes the criteria used to evaluate the environmental effects of the feasible alternative cooling methods.

Key Valued Component	Criteria Considered
Atmospheric Environment	• Amount (less or more) of emissions, including water vapour and "drift" droplets, with the potential to result in localized changes to meteorological conditions and pollution
Avifauna	• Amount (less or more) of direct wildlife habitat loss or change resulting from placement of structures • Amount (less or more) of sensory disturbance during operations (e.g., noise emissions) with the potential to reduce habitat effectiveness (i.e., indirect habitat loss) • Amount (less or more) of direct or indirect habitat loss due to potential accidents
Freshwater Fish and Fish Habitat	• Amount (less or more) of direct habitat loss or change resulting from placement of intake structures or changes to instream flows or surface water quality • Amount (less or more) of freshwater fish injury or mortality due to impingement and entrainment at freshwater intake • Amount (less or more) of sensory disturbance during operations with the potential to reduce habitat effectiveness (i.e., indirect habitat loss) • Amount (less or more) of direct or indirect habitat loss due to potential accidents
Marine Birds, Marine Benthic Habitat, Forage Fish and Other Fish (Marine)	• Amount (less or more) of direct intertidal and subtidal habitat loss or change resulting from placement of structures or changes to marine water quality • Amount (less or more) of forage fish injury or mortality due to impingement at seawater intake • Amount (less or more) of sensory disturbance during operations with the potential to reduce habitat effectiveness (i.e., indirect habitat loss) • Amount (less or more) of direct or indirect habitat loss due to potential accidents
Visual Quality	• Amount (less or more) of potentially visible Project activity or components
Public Health	• Amount (less or more) of risk related to public health during operation • Amount (less or more) of risk due to potential accidents

3.2 COMPARISON OF EFFECTS OF REMAINING ALTERNATIVE COOLING OPTIONS

Table 3-2 compares the potential effects of the technically and economically feasible cooling system alternatives (see **Section 2.0** and **Table 2-1**) to key VCs.

Table 3-2 Comparison of Potential Effects of Alternative Cooling Methods for Key Valued Components

Valued Component	Comparison of Potential Effects for Key Valued Components
Option A: Air Cooling	
Atmospheric Environment	• Water vapour plume could result in changes to local meteorological conditions, including fog associated with air cooling.
Avifauna	• Although the system footprint is among the largest of all options, its location within an existing brownfield area would minimize direct habitat loss for avifauna. • Vertical profile (i.e., need for 7 m of vertical clearance below fans) and highest level of atmospheric noise of all options could result in sensory disturbance resulting in alteration of avifaunal flight paths and, in turn, increasing energy requirements and reducing the effectiveness of adjacent upland or foreshore habitats (i.e., indirect habitat loss).

Valued Component	Comparison of Potential Effects for Key Valued Components
Freshwater Fish and Fish Habitat	• Potential for localized disturbance and sedimentation of adjacent riparian areas and streams during system installation. • No effects would be anticipated during routine operations.
Marine Birds, Marine Benthic Habitat, Forage Fish and Other Fish (Marine)	• Since the system would not have a marine footprint, no effects related to direct or indirect marine habitat loss or forage fish injury or mortality would be anticipated during construction or operation. • Vertical profile (i.e., need for 7 m of vertical clearance below fans) and highest level of atmospheric noise of all options could result in sensory disturbance resulting in alteration of marine bird flight paths and, in turn, increasing energy requirements and reducing the effectiveness of adjacent foreshore habitats (i.e., indirect habitat loss).
Visual Quality	• Increase in the vertical profile of the facility due to the need to maintain a vertical clearance of 7 m below the fans, and the potential for a steam plume and fog associated with air cooling, would increase the visibility of the Project.
Public Health	• Due to the absence of noise receptors in the Project area, health effects due to noise emissions would not be expected. • System is considered moderately safe; however, leaks are difficult to detect and cannot be contained, resulting in potential exposure of site personnel to contaminant emissions. Leaks, however, are usually not explosive due to a dilution effect with air (U.S. EPA 1995).
Option 2A: Evaporative Cooling – Cooling Towers	
Atmospheric Environment	• Due to release of water vapour and drift droplets containing water impurities, water treatment chemicals, and particulates from the top of the cooling towers, this option has the highest potential to emit pollutants and result in localized changes to meteorological conditions.
Freshwater Fish and Fish Habitat	• Potential for temporary disturbance and direct habitat loss due to installation and operation of intake structure(s) in Mill Creek or Woodfibre Creek. Requirement for make-up water supply would increase the facility's overall water requirements with potential adverse effects on instream flows and surface water quality. • Potential for impingement and entrainment and sensory disturbance of aquatic organisms, including fish, at the freshwater intake. • Although the requirement for refrigerant would be less than for other cooling systems, the potential remains for a change to surface water quality due to the accidental leakage of system water or blow down containing treatment chemicals and other impurities.
Avifauna	• Additional clearing may be required to accommodate one or more towers, increasing facility footprint. Combined with increase in Project height, this could result in additional adverse effect to avifauna due to direct habitat loss • Potential for indirect habitat loss during operations due to increased proximity of facility footprint to adjacent habitats. • Although such a system would produce less atmospheric noise than an air cooler, noise emissions and the water vapour plume could result in increased sensory disturbance to and displacement of avifauna.
Marine Birds, Marine Benthic Habitat, Forage Fish and Other Fish (Marine)	• Potential for direct habitat loss and change due to installation and operation of a structure for discharge of blow down into Howe Sound. • Failure at the water treatment plant could result in the release of untreated blow down resulting in a change to marine water quality with the potential for adverse effects on marine birds, benthic habitat, and fish.
Visual Quality	• Cooling towers would increase the vertical profile of the facility. Combined with the presence of the water vapour emitted from the top of the tower(s), this would increase the visibility of the Project.

Valued Component	Comparison of Potential Effects for Key Valued Components
Public Health	• Atmospheric noise emissions would be less than for an air cooler system but, in any case, due to the absence of noise receptors in the Project area, health effects due to noise emissions would not be expected. • Reduction in the refrigerant volume, with cooling water delivered from remote cooling towers, represents an improvement in safety relative to the other options. • Increased risk of localized public health effects in the event of a malfunction of system water treatment resulting in microbial colonization and the potential release of micro-organisms in the vapour plume. • Increased risk of on-site injuries to workers due to drift emissions resulting in wetting or, in winter, icing of facility surfaces, relative to the seawater cooling system.
Option 2B: Evaporative Cooling System – Wetted Surface Air Coolers	
Atmospheric Environment	• Since WSAC uses less water than cooling towers, water vapour and drift production would be reduced. It is assumed that this would result in relatively lower emissions of atmospheric pollutants and changes to local meteorological conditions.
Freshwater Fish and Fish Habitat	• Potential for temporary disturbance and direct habitat loss due to installation and operation of intake structure(s) in Mill Creek or Woodfibre Creek. Although the requirement for make-up water supply would be reduced relative to the cooling tower option, the facility would still require long-term withdrawal of water from one or both creeks, with potential adverse effects on instream flows, surface water quality, and fish habitat. • Potential for impingement and entrainment and sensory disturbance of aquatic organisms, including fish, at the freshwater intake. • Although it would require less refrigerant than other cooling systems, the potential remains for a change to surface water quality due to the accidental leakage of system water or blow down containing treatment chemicals and other impurities.
Avifauna	• The footprint of a WSAC system and thus the potential for direct and indirect habitat loss would be similar to or somewhat greater than for the cooling tower option. • As for the cooling towers, although such a system would produce less atmospheric noise than an air cooler, noise emissions and the water vapour plume could result in increased sensory disturbance to and displacement of avifauna.
Marine Birds, Marine Benthic Habitat, Forage Fish and Other Fish (Marine)	• Potential for direct habitat loss and change due to installation and operation of a structure for discharge of blow down into Howe Sound. • Failure at the water treatment plant could result in release of untreated blow down resulting in change to marine water quality with the potential for adverse effects on marine birds, benthic habitat, and fish.
Visual Quality	• Combined with the presence of the water vapour emitted from the top of the tower(s), the structures used in the WSAC to vent water vapour to the atmosphere would increase the visibility of the Project.
Public Health	• Atmospheric noise emissions would be less than for an air cooler system but, in any case, due to the absence of noise receptors in the LAA, health effects due to noise emissions would not be expected. • As in the cooling tower option, increased risk of localized public health effects in the event of a malfunction of system water treatment resulting in microbial colonization and the potential release of micro-organisms in the vapour plume. • Increased risk of on-site injuries to workers due to drift emissions resulting in wetting or, in winter, icing of facility surfaces, relative to the seawater cooling system.

Valued Component	Comparison of Potential Effects for Key Valued Components
Option D: Seawater Cooling System	
Atmospheric Environment	• No atmospheric emissions associated with seawater cooling.
Freshwater Fish and Fish Habitat	• No freshwater withdrawals associated with seawater cooling.
Avifauna	• No interaction with or adverse effects to avifauna or terrestrial habitat anticipated with seawater cooling.
Marine Birds, Marine Benthic Habitat, Forage Fish and Other Fish (Marine)	• Temporary re-suspension of sediments due to seafloor disturbance during installation of seawater cooling system, including intake and outlet structures. Elevation of intake structure above the sea floor could be used to minimize sediment entrainment, and use of coarse screen could avoid entrainment of large debris. • Potential for entrainment of marine organisms at seawater intake. Entrainment could be prevented through use of travelling screens and return of seawater containing small marine organisms to Howe Sound. • Potential localized change to marine water quality due to release of once-through heated seawater (17,000 m^3/hour) containing residual chlorine (to be added at intake to prevent biofouling of seawater cooling system intake lines) with the potential to result in injury, mortality, or displacement of marine organisms, including forage fish and other fish, and indirect effects to marine birds (and marine mammals) that rely on these organisms for food. Adverse effects to marine water quality can be mitigated through de-aeration and de-chlorination of seawater prior to discharge and use of a diffuser to promote mixing of the cooling water with ambient water.
Visual Quality	• Since seawater intake and outlet will be anchored at depth in Howe Sound, and seawater cooling system will be contained within the LNG facility, no visual effects are anticipated.
Public Health	• Atmospheric noise emissions would be less than for an air cooler system but, in any case, due to the absence of noise receptors in the Project area, health effects due to noise emissions would not be expected. • No atmospheric emissions (water vapour, drift) or blow down discharges, resulting in fewer risks to human health. • Leaks of hazardous substances, such as hydrocarbons, are less likely to result in environmental contamination since they will be confined in a closed pressure vessel and piping system, rather than being potentially vented to the atmosphere as they would be in an air cooling or evaporative cooling system.

4.0 IDENTIFICATION OF THE PREFERRED COOLING METHOD

Based on a high level comparison of the relative environmental effects associated with the technically and economically feasible cooling alternatives, as described in **Table 3-2**, the seawater cooling system was identified as the preferred cooling method for the Woodfibre LNG facility. Seawater cooling systems provide greater stability of production and require less energy to operate than air cooling systems due to the narrow and predictable range of seawater temperatures, particularly when withdrawn at depth.

In addition to stability of production, seawater cooling would require the smallest footprint and, due to its relatively lower energy requirements, the lowest operating costs of the technically feasible cooling methods. However, it does have the highest costs for purchasing and installing the equipment. Seawater cooling does not require the withdrawal of surface water from either Mill or Woodfibre creeks, which would avoid effects to freshwater fish and fish habitat and limitations associated with availability of fresh water. Finally, seawater cooling is associated with lower atmospheric noise emissions and will not result in adverse effects to visual quality.

Mitigation measures, to be incorporated in Project design, will prevent changes in marine water temperatures in excess of Canadian water quality guideline and BC water quality guideline of 1°C outside the initial dilution zone. The initial dilution zone will extend no more than 11 m from the seawater discharge point. A de-chlorination process will be used to treat seawater discharge (when required), such that concentrations of residual chlorine in the seawater will be within the Canadian Council of Ministers of the Environment (CCME) water quality guidelines for the protection of aquatic life (CCME 1999). By incorporating these mitigation measures, seawater cooling systems have the ability to satisfy environmental requirements and meet the Project’s environmental objectives and commitments.

A detailed description of the seawater cooling system is provided in the Application (**Section 2.2 Description of the Proposed Project**).

5.0 REFERENCES

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