



# **Yukon – British Columbia Interconnection Development Plan**

**Submitted By:** Midgard Consulting Incorporated

**Date:** February 27, 2019

## Document Control and Sign-off

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### REVISION CONTROL

Revision	Description	Date
00	First draft of development plan for client review and feedback.	Dec 21, 2018
01	Final draft incorporating feedback (split Phase 1 into two parts) added executive summary.	Feb 5, 2019
02	Final Report	Feb 27, 2019

### REPORT SIGN-OFF

Prepared By:  Feb 27, 2019  
*Sam Mason, P.Eng., Midgard Consulting Inc.* **Date**

 FEB 27, 2019  
*Scott Seifert, P.Eng., Midgard Consulting Inc.* **Date**

Checked By:  Feb 27, 2019  
*Matt Good, Midgard Consulting Inc.* **Date**

Approved By:  28 Feb 2019  
*Peter Helland, P.Eng., Midgard Consulting Inc.* **Date**



## Executive Summary

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Yukon has the potential to host new mining developments such as the Casino copper-gold mine, which is estimated to have an electrical power requirement of approximately 100 MW. Yukon does not currently have sufficient electrical generation resources to serve a new mining load of this magnitude, however, British Columbia Hydro (“BC Hydro”) does expect to have surplus generation capacity upon completion of the 1,100 MW Site C hydro project in 2024. This report provides a development plan for a new transmission connection between Yukon and northwestern British Columbia to gain access to the power needed to serve new Yukon mining loads such as the Casino mine<sup>1</sup>. Reasons to pursue this transmission project include:

- 1) Stimulating Yukon economic development by enabling large energy consumers (e.g., mines, large industry).
- 2) Reducing greenhouse gases in line with Yukon and Canadian Federal Government climate action goals, by offsetting and replacing diesel generation at Watson Lake and fossil fuel generation at large mines.
- 3) Providing economic benefits to First Nations
- 4) Demonstrating Canadian sovereignty by integrating the Yukon’s electric grid into the integrated Canadian electricity grid.

## Project Description

When fully complete, the Project will perform three (3) primary technical functions:

- 1) Connect the Yukon electrical grid to the Canadian electrical grid via BC.
- 2) Connect mining load (e.g., the Casino Mine) to the Yukon electrical grid.
- 3) Connect Watson Lake to the Yukon electrical grid.

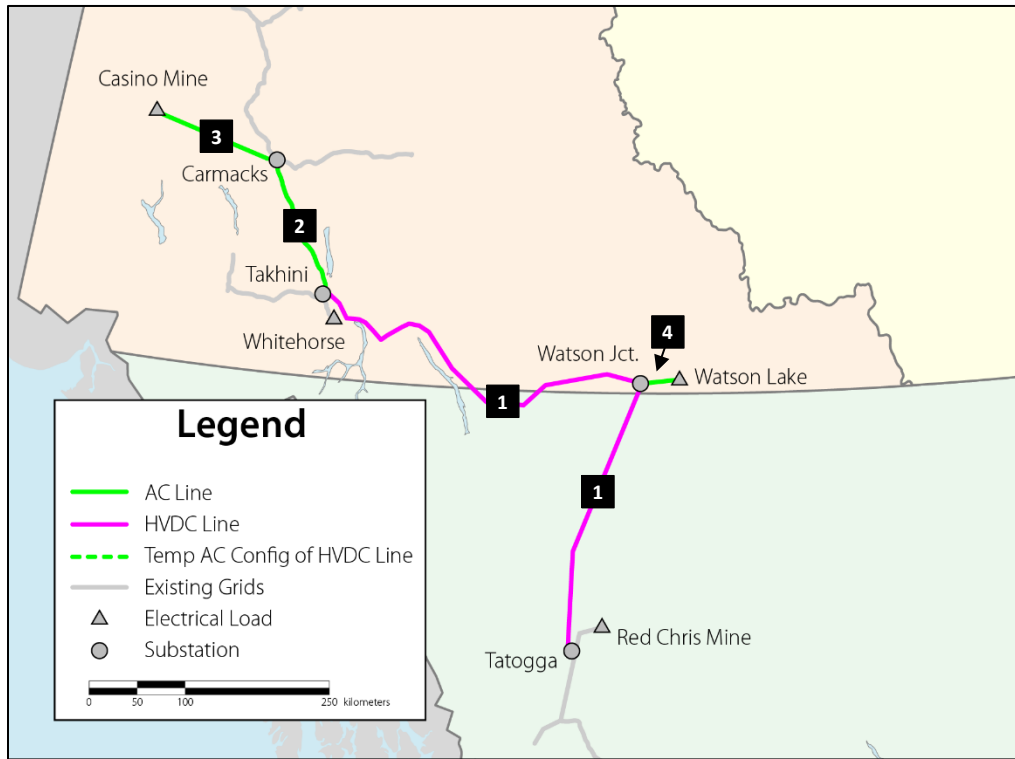
Figure 1 shows the proposed transmission interconnection project (referred to in this development plan as the “Project”) between Northwest BC and a mining load<sup>2</sup>, with the major line segments summarized in Table 1 below.

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<sup>1</sup> Export of surplus (otherwise spilled) summer energy, may provide a marginal supplement to economic benefits, but insufficient to be an actual source of economic justification.

<sup>2</sup> A discussion of the Watson Lake interconnection can be found in Appendix H of the Midgard report “Yukon - BC Interconnection Study” found in Appendix C.

**Figure 1 – Yukon/BC Interconnection Project**



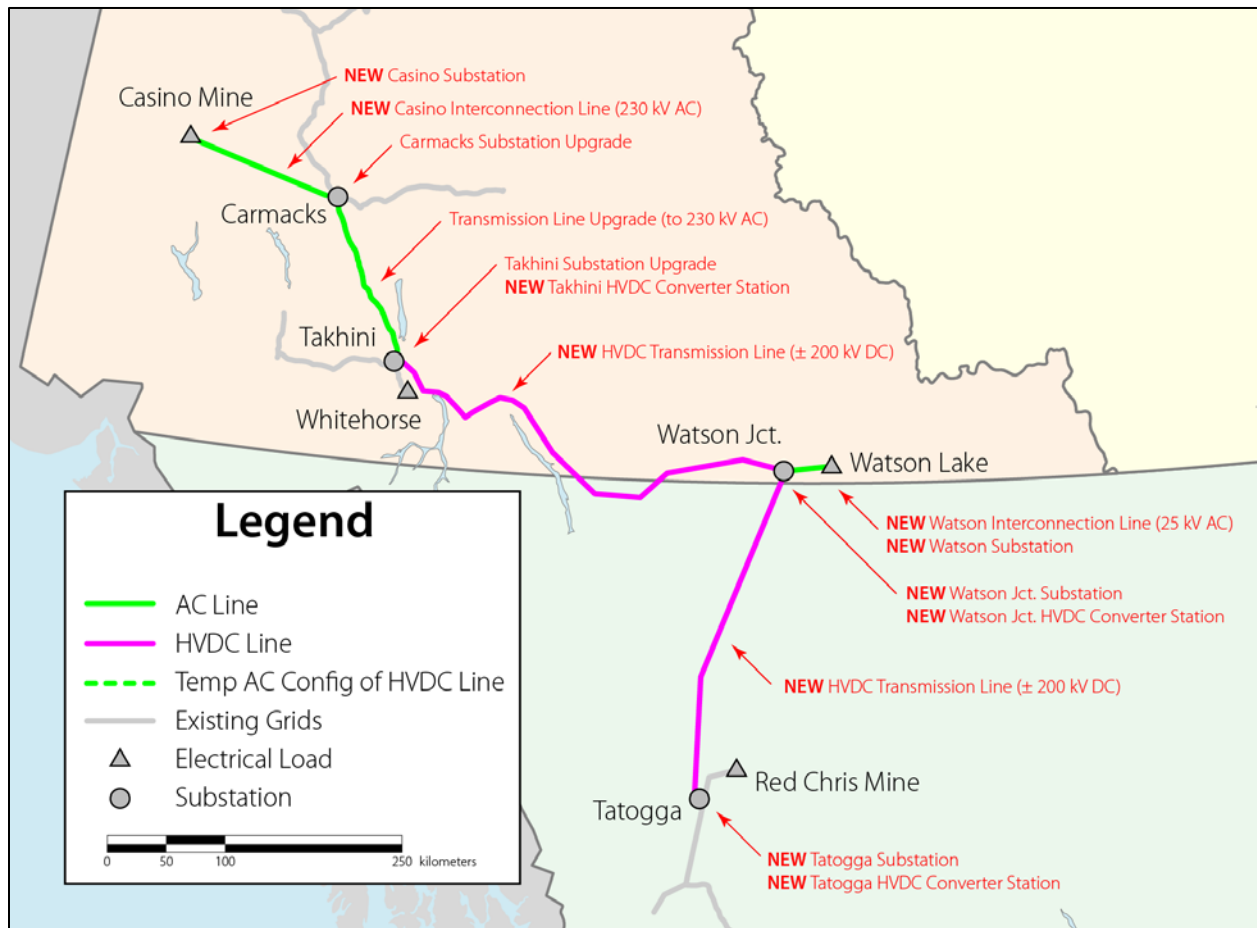
**Table 1 – Summary of Proposed Interconnection Route by Segment**

#	Line Segment	Description	Major Remarks
1	Tatogga to Watson Junction to Takhini	<b>Type:</b> $\pm 200$ kV <sup>3</sup> HVDC Transmission Line <b>Length:</b> 765 km, paralleling Yukon Highway 1 (Alaska Highway) and BC Highway 37	New transmission line; Generally rough terrain (some mountain passes, multiple river crossings)
2	Takhini to Carmacks	<b>Type:</b> 230 kV AC Transmission Line <b>Length:</b> 158 km, following the existing 138 kV corridor parallel with the Klondike Highway	Upgrade / rebuild of existing 138 kV line
3	Carmacks to Casino Mine	<b>Type:</b> 230 kV AC Transmission Line <b>Length:</b> 180 km along the planned Casino access road from Carmacks	New 230 kV AC transmission line
4	Watson Junction to Watson Lake	<b>Type:</b> 25 kV Distribution Line <b>Length:</b> 22 km along the Alaska Highway	New 25 kV AC Distribution Line

Figure 2 presents a labelled map of the Project’s components in their final state.

<sup>3</sup> The “Yukon - BC Interconnection Study” (see Appendix C) did not make a recommendation between  $\pm 200$  or  $\pm 150$  kV HVDC.  $\pm 200$  kV is used in this development plan, however the actual HVDC voltage will be refined as the project progresses through the conceptual and pre-feasibility phases.

Figure 2 – Final State Project Map



The Project's components are as follows (listed from south to north per Figure 4 above).

- 1) **Tatogga Substation and DC Converter Station:** A new  $\pm 200$  kV HVDC converter station will be constructed to supply HVDC power to the Watson Junction HVDC transmission line. The converter station may be operated bi-directionally, but the general direction of power flow will be from south (i.e., BC grid) to north (i.e., Yukon grid). The new converter station will also include a 287 kV AC substation to connect the HVDC converter station to the BC grid.
- 2) **Tatogga HVDC to Watson Jct. Transmission Line:** A new  $\pm 200$  kV HVDC transmission line will be constructed between the Watson Junction DC Converter Station and the Tatogga DC Converter Station.
- 3) **Watson Jct. Substation and DC Converter Station:** A new  $\pm 200$  kV HVDC converter station will be constructed to tap the Takhini and BC HVDC transmission lines and create the source for the 25 kV AC transmission line to Watson Lake.
- 4) **Watson Jct. to Watson Transmission Line:** A new 25 kV AC transmission line will supply power to Watson Lake from the Watson Junction substation.

- 5) **Watson Substation:** A new 25 kV AC substation will be constructed at Watson Lake to transfer power from the 25 kV AC transmission line into the local Watson Lake grid. Depending on the existing voltage and configuration, this facility may comprise only pole mounted reclosers.
- 6) **Watson Jct. to Takhini HVDC Transmission Line:** A new  $\pm$  200 kV HVDC transmission line will be constructed between the Watson Junction DC converter station and the Takhini DC Converter Station.
- 7) **Takhini Substation Upgrade and DC Converter Station:** A new  $\pm$  200 kV DC converter station will be constructed to accommodate the Watson Lake HVDC transmission line. The existing Takhini Substation will be expanded to include a 230 kV bus in addition to its existing 138 kV & 25 kV buses.
- 8) **Takhini to Carmacks Transmission Line Upgrade:** The existing 138 kV AC Takhini to Carmacks transmission line will be upgraded to 230 kV AC.
- 9) **Carmacks Substation Upgrade:** The existing Carmacks Substation will be expanded from its current 138 kV AC voltage to accommodate the upgraded 230 kV AC Takhini to Carmacks transmission line.
- 10) **Casino Interconnection Line:** The new 230 kV AC Casino interconnection line will provide power from the Yukon grid to a mining load (i.e., the Casino Mine in this illustration). The mining load will benefit from inexpensive and reliable grid power, and the Yukon grid will gain a major industrial load customer and a source of Yukon economic development.
- 11) **Casino Substation** The new Casino substation will transform the incoming 230 kV AC power from the Casino interconnection line to a lower distribution voltage that can be used locally at the mine site.

## Staging

It is proposed to develop the Project using a two (2) stage approach. The two (2) Project stages are:

- **Stage 1:** Connect Watson Lake to the Yukon grid
- **Stage 2:** Complete the BC/Yukon interconnection, and interconnect Yukon industrial load (e.g., the Casino mine) to the Yukon grid.

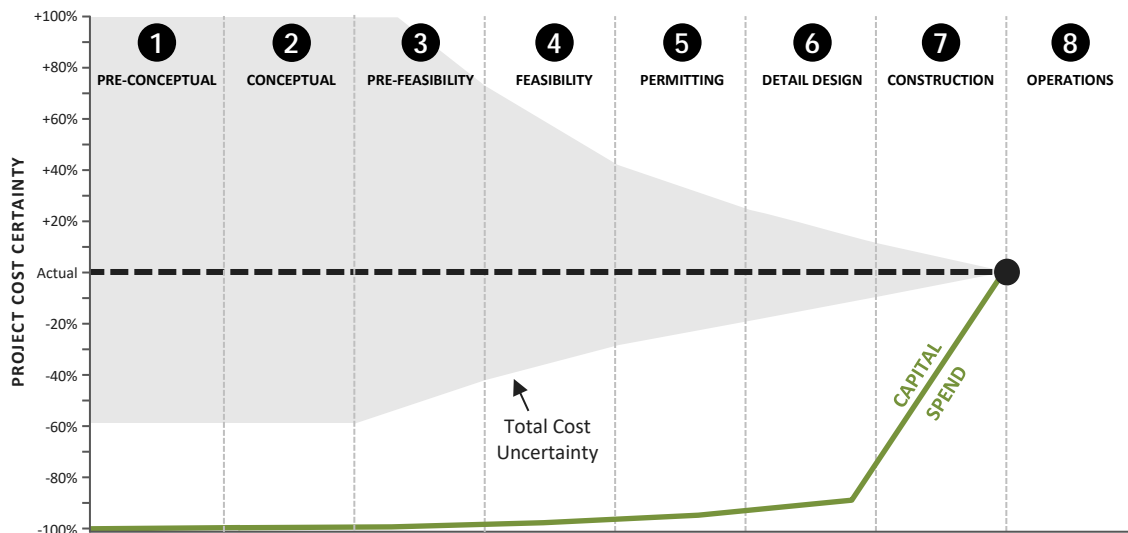
Pursuing a staged approach expedites Watson Lake's integration into the Yukon grid, maintains flexibility to align completion of the BC/Yukon interconnection with the power needs of new large industrial loads, and simplifies coordination between different stakeholder parties by delivering major project components on a schedule that recognizes their different economic drivers and implementation deadlines.

## Development Process Phases

A phased development approach focuses activities and spending on a phase-by-phase basis to reduce major development risks in a disciplined manner that avoids major cost and schedule upsets later in the Project. There are eight (8) phases of development in total. Figure 3 sets out a high-level representation of the relationships between risk, costs, and timing for a typical development process. The purpose of Figure 3 is to show how the certainty of the project improves over time as each phase is completed and that a large

portion of the project cost risk can be mitigated with appropriately targeted early stage investment. Although most project overspending is typically incurred during the construction phase, the risks that cause overspending are often crystallized (or successfully mitigated) during earlier project phases.

**Figure 3 – Development Process Risk Progression**



Gate reviews are to occur between each of the seven (7) development phases prior to operations. Gate reviews ensure a deliberate and comprehensive assessment of the Project silos and associated Project risks are made before spending the next tranche of development budget. Gate reviews are an orderly way to perform development, communicate progress, and review risk with project sponsors, funders, key participants, and key stakeholders.

### ***Project Staging and Phases***

Stage 1 and Stage 2 share common Pre-Conceptual (Phase 1), Conceptual (Phase 2), Pre-feasibility (Phase 3), and Feasibility (Phase 4) phases, to ensure that information sharing and agreement negotiations with key parties occur in an integrated manner that reduces overall project risk prior to the start of detailed design and construction. Once sufficient and genuine support has been garnered for the Project as a whole, the development plan bifurcates into Stage 1 development and Stage 2 development from permitting onward (Phases 5 through 8).

### ***Gate Reviews & Risk***

A primary purpose of gate reviews is to ensure a deliberate assessment of the Project status and associated risks is made before spending the next tranche of development budget (i.e., moving on to the next phase of development, which typically has a higher burn rate than the current phase, as shown in Figure 3).

Broadly speaking, the governing overall risk to the Project is the inherent challenge of coordinating and

reaching agreements with the key parties that are impacted, or potentially impacted, by an infrastructure project of this size and complexity. The key parties include, but are not limited to, Yukon government, British Columbia government, Federal government, First Nations, potential off-takers (e.g., mines), and any other stakeholders that may be impacted by the Project. In many cases these key parties may have different interests, and ultimately all parties will need to be sufficiently satisfied that their interests are being protected to obtain their participation in, or at least not active opposition to, the Project.

In view of the diverse range of parties involved in such a project, the risk assessment is broken down into five thematic risk areas:

1. First Nation Risk
2. Territorial and Federal Political Risk
3. BC Political and Technical Risk
4. Off-Taker Risk
5. Other Risks

In Table 2, the key topics and risks for consideration by project partners are listed for each gate review.

**Table 2 – Gate Reviews: Decisions & Risk**

<b>Gate Review</b>	<b>Decision</b>	<b>Risks</b>
<b><u>Phase 1 → 2</u></b> From Pre-Conceptual to Conceptual	Is the level of BC Government cooperation sufficient to continue with project?	Insufficient BC Government support. Opposition from First Nation(s).
<b><u>Phase 2 → 3</u></b> From Conceptual to Pre-Feasibility	Is the level of First Nation cooperation sufficient to continue with the project?	First Nation participation model inadequately defined.
<b><u>Phase 3 → 4</u></b> From Pre-Feasibility to Feasibility	Do the off-taker potential, refined economics, and refined scheduling support continuing?	First Nation participation aspirations exceed Yukon tolerance threshold. BC Government / BC Hydro participation (permit, build, own) impacts economics and schedule.
<b><u>Phase 4 → 5</u></b> From Feasibility to Permitting	Are the quality of agreements with First Nations, BC Hydro & off-taker sufficient to proceed into permitting?	Permitting agency coordination, jurisdiction & process insufficiently defined. Low off-taker commitment. Lost support of First Nations and/or governments.
<b><u>Phase 5 → 6</u></b> From Permitting to Detail Design	Have permitting constraints impacted project economics beyond limits of stakeholder support?	Fundamental design changes from permitting increase capital cost. Lack of binding agreements with BC Hydro and an off-taker.
<b><u>Phase 6 → 7</u></b> From Detail Design to Construction	Are the recommended contractors capable and appropriately contracted (e.g.,	Detailed design results increase capital cost.

Gate Review	Decision	Risks
	risk allocation) to proceed into construction?	

## Cost & Duration

Table 3 summarizes the costs for the Project:

**Table 3 – Summary of Costs**

<b>COMBINED EFFORT</b>				
Phase 1 Pre-Conceptual	Phase 2 Conceptual	Phase 3 Pre-Feasibility	Phase 4 Feasibility	Sub-Total
\$60k	\$700k	\$1,700k	\$3,000k	\$5,460k
<b>STAGE 1</b>				
Phase 5 Permitting	Phase 6 Design & Pre-Construction	Phase 7 Construction	Phase 8 Operations [For First Year]	Sub-Total
\$9,750k	\$36,600k	\$438,550k	\$4,050k	\$488,950k
<b>STAGE 2</b>				
Phase 5 Permitting	Phase 6 Design & Pre-Construction	Phase 7 Construction	Phase 8 Operations [For First Year]	Sub-Total
\$20,250k	\$114,900k	\$1,246,450k	\$4,450k	\$1,386,050k
<b>Total</b>				<b>\$1,880,460k</b>

The estimated overall project duration ranges from 11 to 13 years, as shown below and in Figure 4:

- Early stage development (pre-permitting) – 3 to 4 years
- Stage 1 – Permitting, design & construction – 6 to 7 seven years
- Stage 2 – Permitting, design & construction – 6 to 7 seven years (starting approximately two (2) years after Stage 1 Permitting is complete.

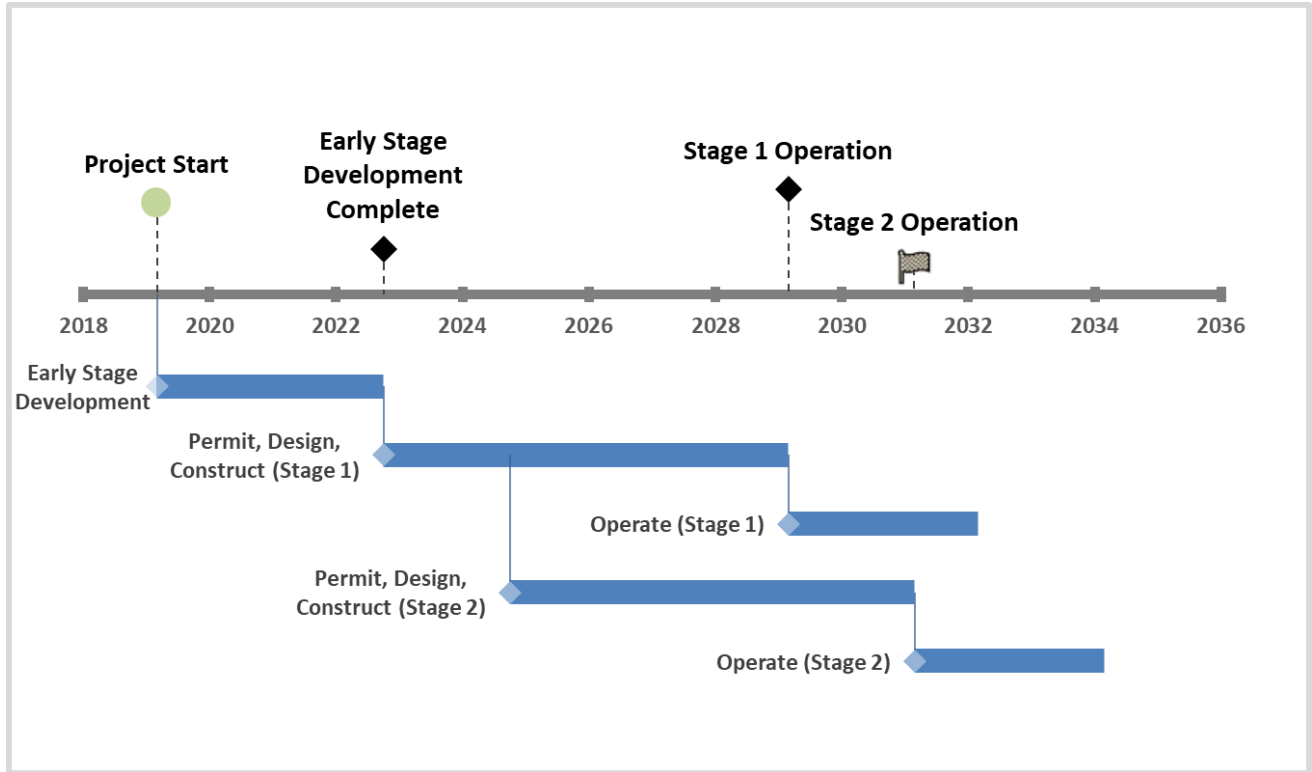


Figure 4 - Project Duration

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## 1 Introduction

Yukon has the opportunity to host new mining developments such as the Casino copper-gold mine which is estimated to have an electrical power requirement of approximately 100 MW. Yukon does not currently have sufficient electrical generation resources to serve a new mining load of this magnitude, however, British Columbia Hydro (“BC Hydro”) does expect to have surplus generation capacity upon completion of the 1,100 MW Site C hydro project in 2024. Therefore, in consideration of British Columbia’s (“BC”) anticipated generation resource surplus, this report provides a development plan for a new transmission connection between Yukon and northwestern BC to gain access to the power needed to serve new Yukon mining loads such as the Casino mine<sup>4</sup>.

An earlier Midgard report examining the potential for a transmission interconnection between Yukon and northwestern BC (titled “Yukon – BC Interconnection Study”; see Appendix C) concluded that a  $\pm 200$  kV High Voltage Direct Current (“HVDC”) line between Iskut, BC and Whitehorse, Yukon, and then a 230 kV alternating current (“AC”) transmission line from Whitehorse to the northern mining loads (e.g. Casino Mine) is the preferred option from a technical and economic perspective. Figure 3 shows the proposed transmission interconnection project (referred to in this development plan as the “Project”) between Northwest BC and a mining load<sup>5</sup>, with the major line segments summarized in Table 3 below.

**Table 4 – Summary of Proposed Interconnection Route by Segment**

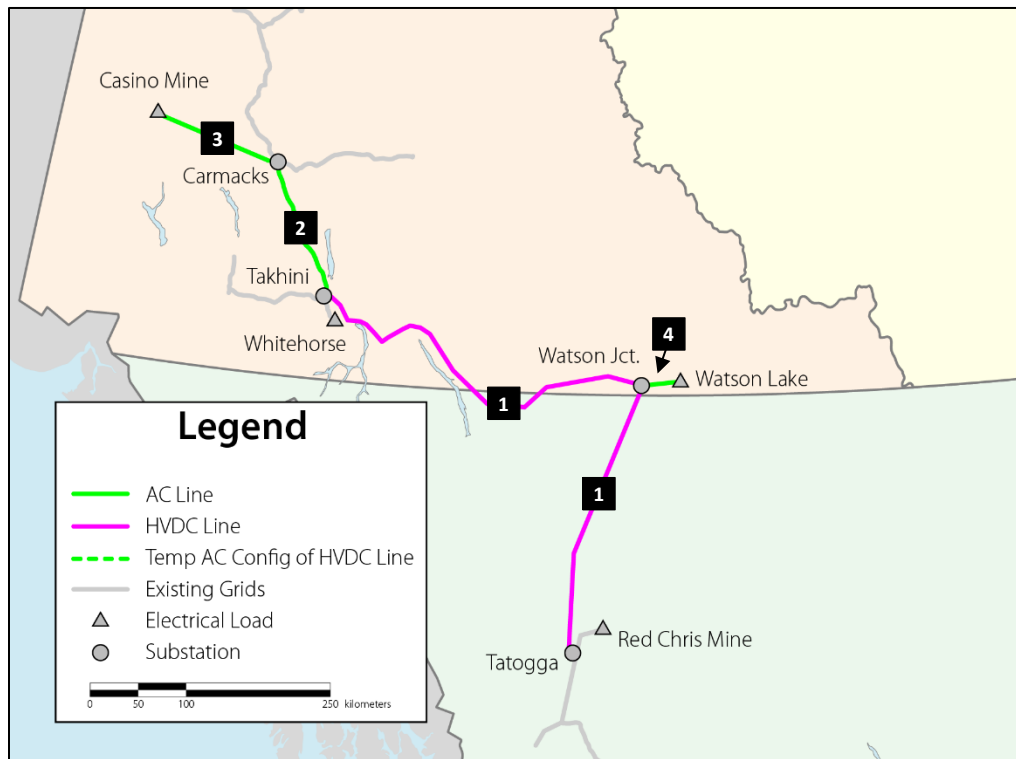
#	Line Segment	Description	Major Remarks
1	Tatogga to Watson Junction to Takhini	<b>Type:</b> $\pm 200$ kV <sup>6</sup> HVDC Transmission Line <b>Length:</b> 765 km, paralleling Yukon Highway 1 (Alaska Highway) and BC Highway 37	New transmission line; Generally rough terrain (some mountain passes, multiple river crossings)
2	Takhini to Carmacks	<b>Type:</b> 230 kV AC Transmission Line <b>Length:</b> 158 km, following the existing 138 kV corridor parallel with the Klondike Highway	Upgrade / rebuild of existing 138 kV line
3	Carmacks to Casino Mine	<b>Type:</b> 230 kV AC Transmission Line <b>Length:</b> 180 km along the planned Casino access road from Carmacks	New 230 kV AC transmission line
4	Watson Junction to Watson Lake	<b>Type:</b> 25 kV Distribution Line <b>Length:</b> 22 km along the Alaska Highway	New 25 kV AC Distribution Line

<sup>4</sup> Export of surplus (otherwise spilled) summer energy, may provide a marginal supplement to economic benefits, but insufficient to be an actual source of economic justification.

<sup>5</sup> A discussion of the Watson Lake interconnection can be found in Appendix H of the Midgard report “Yukon - BC Interconnection Study” found in Appendix C.

<sup>6</sup> The “Yukon - BC Interconnection Study” (see Appendix C) did not make a recommendation between  $\pm 200$  or  $\pm 150$  kV HVDC.  $\pm 200$  kV is used in this development plan, however the actual HVDC voltage will be refined as the project progresses through the conceptual and pre-feasibility phases.

**Figure 5 – Yukon/BC Interconnection Project**



Operationally, the Project will import power from BC to Yukon to meet growing demand from industrial customers, as well as providing a separate grid connection into Watson Lake to replace current diesel generation.

### 1.1 Project Rationale

The primary reasons to pursue the Project include:

- 5) **Yukon Economic Development:** Stimulating Yukon economic development by enabling large energy consumers (e.g., mines, large industry) that have not previously been able to access large quantities of grid based electric power.
- 6) **Greenhouse Gas Reductions:** Reducing greenhouse gases in line with Yukon and Canadian Federal Government climate action goals by offsetting and replacing diesel generation at Watson Lake and fossil fuel generation at large mines (e.g., Casino is currently planned to self-supply generation with Liquefied Natural Gas supplied generation).
- 7) **First Nations Economic Benefits:** Providing economic benefits to First Nations during both development and construction, and operations phases of the Project.
- 8) **Sovereignty:** Demonstrating Canadian sovereignty by integrating the Yukon’s electrical grid into the electricity grid of southern Canada and the rest of North America. As per the Federal government

*“Canada is an Arctic nation and the North is central to its history and national identity. More than 40% of its land mass is in the Northern territories.”<sup>7</sup>*

## 1.2 Development Plan Report

The development plan describes, at a high level, the activities, schedule, and costs associated with the development of an electrical interconnection between Yukon and BC. The development plan focuses on identifying risks, mitigating risks, and facilitating investment certainty for both the Project and potential industrial (e.g., mining) loads.

To minimize capital at risk during the early development phases, the key early-stage objectives are as follows:

- 1) **Objective 1:** Socialize the idea with Yukon First Nations and stakeholders, secure their support for further investigation, and respond to First Nation and BC Hydro feedback to minimize future development risk.
- 2) **Objective 2:** Agree to frameworks for decision making and success criteria.
- 3) **Objective 3:** Evaluate economic feasibility and advance technical concepts.

Getting to agreements with First Nations and BC Hydro will help create sufficient certainty to support commitments from industrial (e.g., mining) loads necessary to move forward with the Project.

Subsequent to the early development phases, the development plan transitions into the permitting, design and construction phases which will continue to advance the project through legislative gates, technical gates, and financial investment gates whose strategies will have been already established during the previous early development phases. At the end of the development plan the Project reaches full operations, both facilitating the import of power from BC to Yukon to meet growing demand from industrial customers and providing a grid connection to Watson Lake to replace current diesel generation.

As a whole, the development plan describes, estimates, and schedules the activities necessary to deliver the Project. It describes what is required to successfully develop the Project, and the interim decisions required to progress the Project from current concept to full operations. As such, the development plan is divided into three (3) major parts:

- 1) **Project Description (Section 2):** A project description of the elements that comprise the Project.
- 2) **Project Risk Assessment (Section 3):** An introduction to the major thematic risks associated with the Project.
- 3) **Development Plan (Section 4):** The development plan proper which describes the delivery plan and phases along with a schedule and budget.

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<sup>7</sup> Extracted on December 21<sup>st</sup>, 2018 from <http://www.forces.gc.ca/en/operations-types/canadian-sovereignty.page>

## 2 Project Description

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The project description section is divided into two subsections:

- **Final State (Section 2.1):** Describes the Final State of the Project when all Project elements are completed.
- **Staged Buildout Approach (Section 2.2):** Describes the rationale and details of the proposed two (2) stage buildout approach of the Project.

It should be noted that the specific design proposed in this development plan is not the only feasible design for achieving the Project's goals, however, it is being proposed as the baseline to which alterations can be made at a later date as needed. It is possible that alternative development plan trajectories may emerge as being more appropriate for achieving the Project's goals (i.e., interconnecting mining loads such as the Casino Mine, interconnecting Watson Lake and other communities, and interconnecting Yukon and BC electrical grids), or that additional goals may emerge that would benefit from an alternative development approach (e.g., connection of other mines/communities, environmental mitigations, First Nation requirements). Further development plan and design optimization is expected to take place at later stages, which will take into account the input of stakeholders and potential off-takers.

### 2.1 Final State Project Description

When fully complete, the Project will perform three (3) primary technical functions:

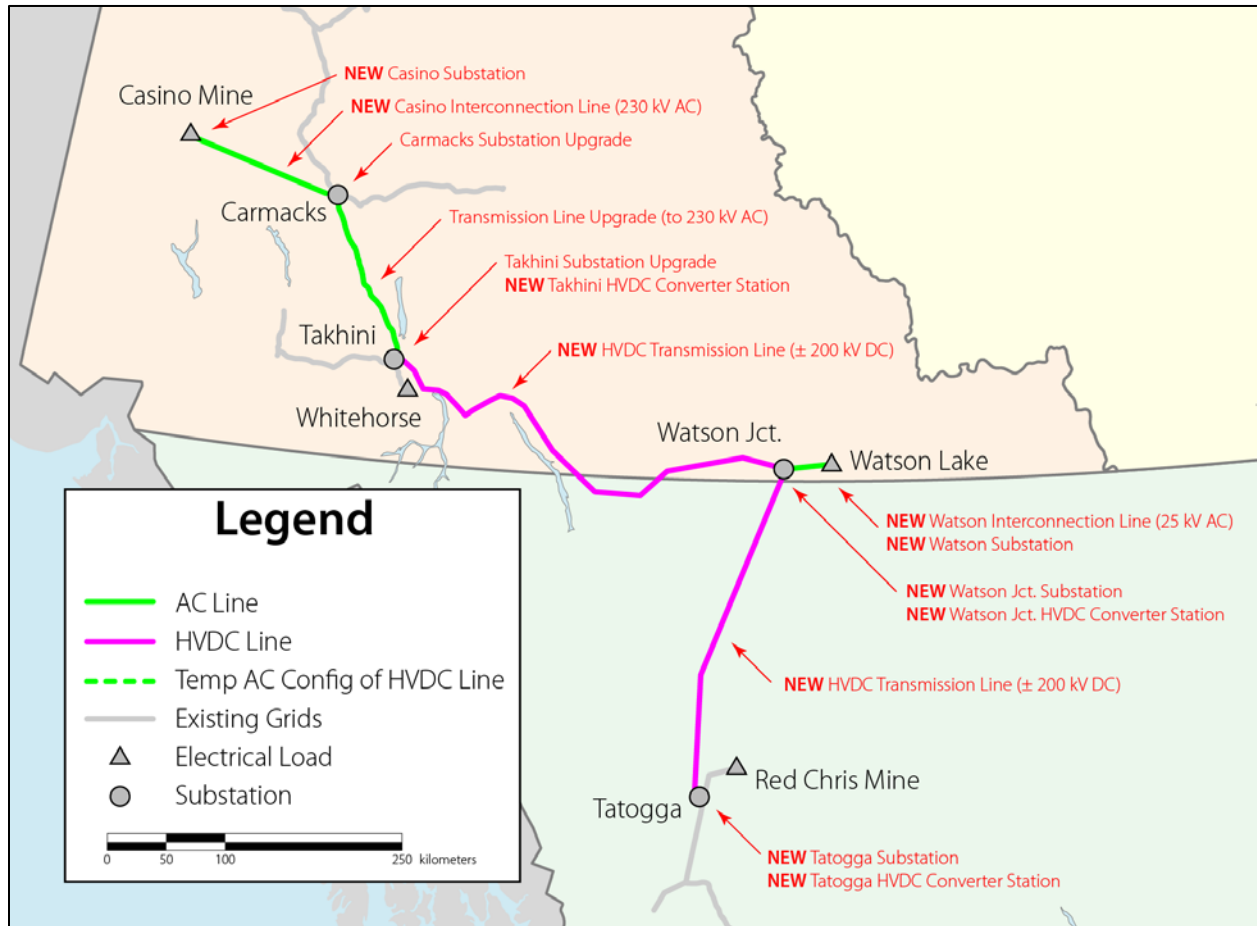
- 4) Connect the Yukon electrical grid to the Canadian electrical grid via BC.
- 5) Connect mining load (e.g., the Casino Mine) to the Yukon electrical grid.
- 6) Connect Watson Lake to the Yukon electrical grid.

At a high level, the Project achieves these three (3) technical functions by developing, constructing, and ultimately operating a:

- 1) **HVDC Interconnection:** HVDC transmission interconnection between Yukon and BC.
- 2) **Yukon Grid Expansion:** Yukon transmission grid extensions and upgrades between the Takhini substation to new Yukon mining load (e.g., Casino Mine).
- 3) **Watson Lake Grid Interconnection:** 25 kV AC interconnection to Watson Lake.

Figure 4 presents a labelled map of the Project's final state.

Figure 6 – Final State Project Map



The Project's components are as follows (listed from south to north per Figure 4 above).

- 12) **Tatogga Substation and DC Converter Station:** A new  $\pm 200$  kV HVDC converter station will be constructed to supply HVDC power to the Watson Junction HVDC transmission line. The converter station may be operated bi-directionally, but the general direction of power flow will be from south (i.e., BC grid) to north (i.e., Yukon grid). The new converter station will also include a 287 kV AC substation to connect the HVDC converter station to the BC grid.
- 13) **Tatogga HVDC to Watson Jct. Transmission Line:** A new  $\pm 200$  kV HVDC transmission line will be constructed between the Watson Junction DC Converter Station and the Tatogga DC Converter Station.
- 14) **Watson Jct. Substation and DC Converter Station:** A new  $\pm 200$  kV HVDC converter station will be constructed to tap the Takhini and BC HVDC transmission lines and create the source for the 25 kV AC transmission line to Watson Lake.
- 15) **Watson Jct. to Watson Transmission Line:** A new 25 kV AC transmission line will supply power to Watson Lake from the Watson Junction substation.

- 16) **Watson Substation:** A new 25 kV AC substation will be constructed at Watson Lake to transfer power from the 25 kV AC transmission line onto the local Watson Lake grid. Depending on the current voltage and configuration this facility consist of only pole mounted reclosers.
- 17) **Watson Jct. to Takhini HVDC Transmission Line:** A new  $\pm$  200 kV HVDC transmission line will be constructed between the Watson Junction DC converter station and the Takhini DC Converter Station.
- 18) **Takhini Substation Upgrade and DC Converter Station:** A new  $\pm$  200 kV DC converter station will be constructed to accommodate the Watson Lake HVDC transmission line. The existing Takhini Substation will be expanded to include a 230 kV bus in addition to its current 138 kV & 25 kV buses.
- 19) **Takhini to Carmacks Transmission Line Upgrade:** The existing 138 kV AC Takhini to Carmacks transmission line will be upgraded to 230 kV AC.
- 20) **Carmacks Substation Upgrade:** The existing Carmacks Substation will be upgraded from its current 138 kV AC voltage to accommodate 230 kV AC power from the upgraded Takhini to Carmacks transmission line.
- 21) **Casino Interconnection Line:** The new 230 kV AC Casino interconnection line will provide power from the Yukon grid to a mining load (i.e., the Casino Mine in this illustration). The mining load will benefit from inexpensive and reliable grid power, and the Yukon grid will gain a major industrial load customer and a source of Yukon economic development.
- 22) **Casino Substation** The new Casino substation will distribute incoming 230 kV AC power from the Casino interconnection line to a distribution voltage that can used locally at the mine site.

Due to the large size and complexity of the Project, rather than completing all of the above items at once, it is proposed that the Project be planned using a two (2) stage approach. These two (2) stages are described in the following section.

## 2.2 Two Stage Buildout

It is proposed to develop the Project using a two (2) stage approach. The two (2) Project stages are:

- **Stage 1:** Connect Watson Lake to the Yukon grid
- **Stage 2:** Complete the BC/Yukon interconnection, and interconnect Yukon industrial load (e.g., the Casino mine) to the Yukon grid.

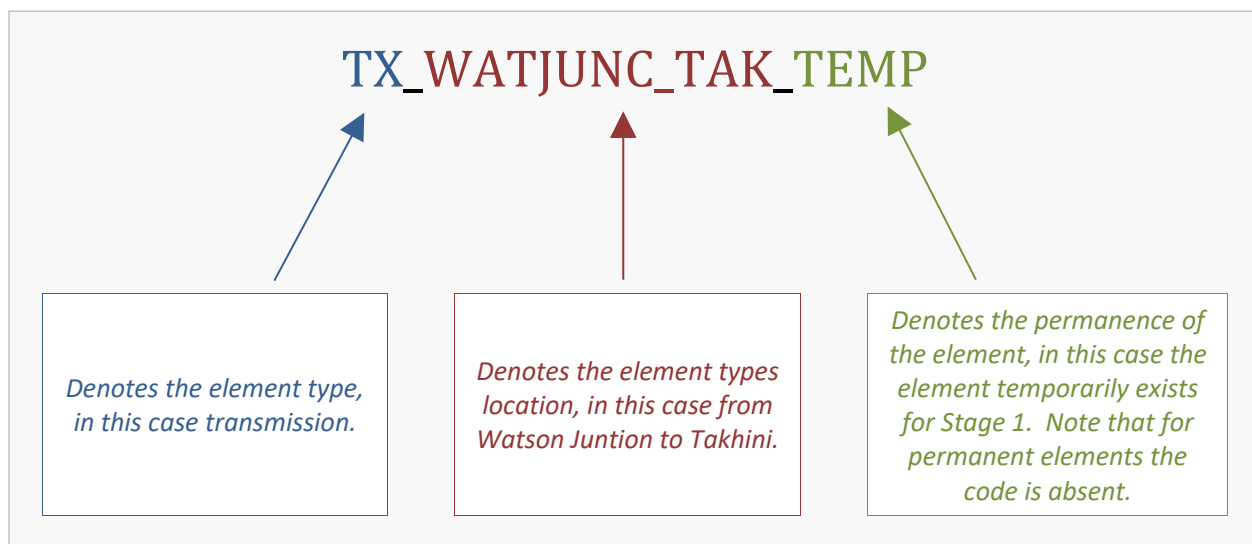
The rationale for pursuing a staged approach is as follows:

- **Staging Rationale 1:** Minimize the time until Watson Lake’s integration into the Yukon grid to therefore reduce greenhouse gas emissions (as Watson Lake is currently diesel supplied).
- **Staging Rationale 2:** Maintaining flexibility to align the construction of the BC/Yukon interconnection component of the Project with the interconnection of large industrial load (e.g., the Casino mine).
- **Staging Rationale 3:** Due to the inter-jurisdictional nature of the Project, staging partially mitigates the complexities of simultaneously coordinating all necessary parties at once.

The development plan contemplates the execution and completion of the two (2) stages within several years of each other, with major Project activities (permitting, design, construction) being sequential relative to each other.

Due to the large number of facilities and the staged approach, a coding system is applied for consistent referencing between the development plan and the detailed technical project descriptions located in Appendix A. The Project element code breakdown is shown in Figure 5.

**Figure 7 – Example Project Element Code Breakdown**



### **2.2.1 Stage 1 Description – Whitehorse to Watson Lake**

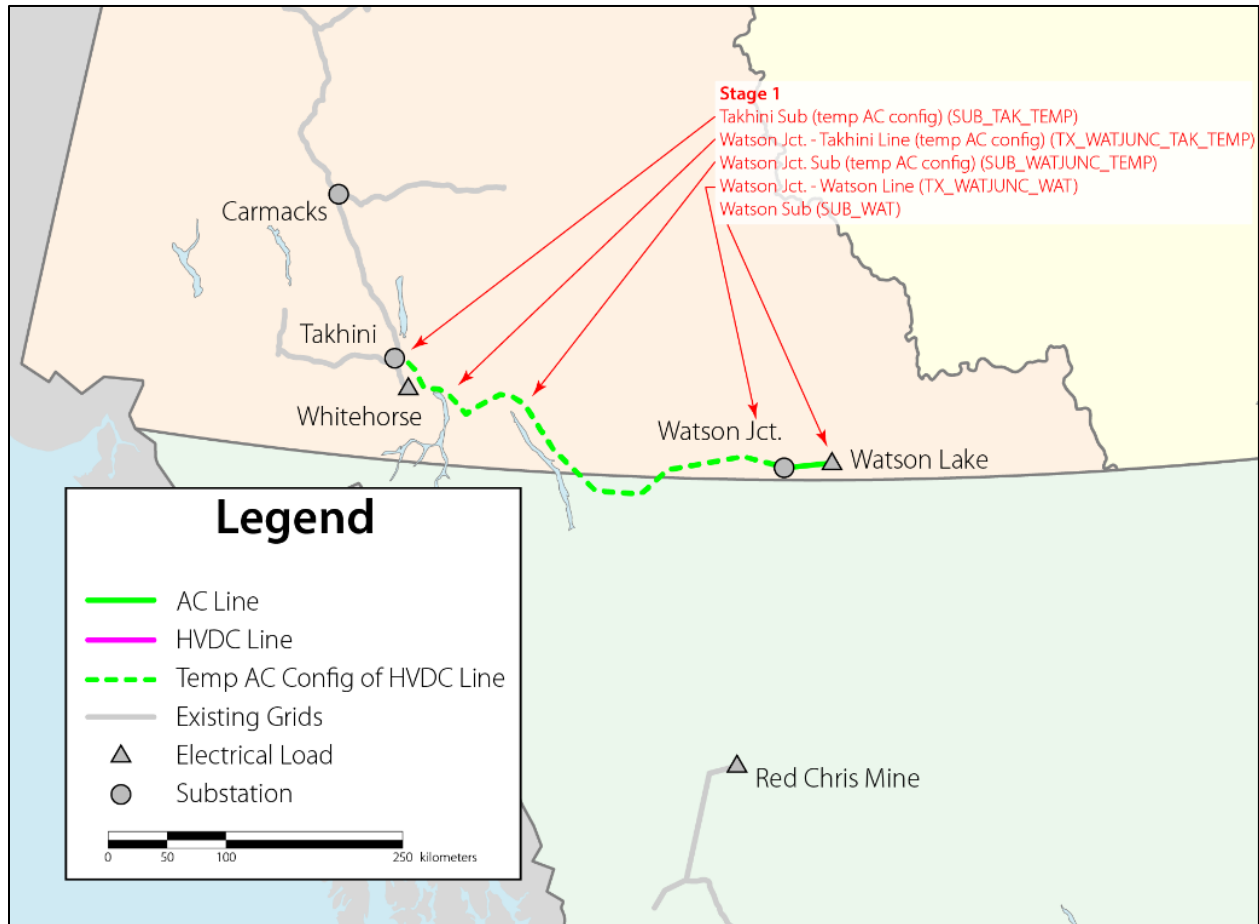
Stage 1 of the Project consists of the following elements:

- **TX\_WATJUNC\_TAK\_TEMP:** The HVDC transmission line will be constructed from Takhini substation to the new Watson Junction substation. Additionally, although the structures will be constructed to ultimately support  $\pm 200$  kV HVDC operation, the transmission line will initially be energized at 66 kV AC. In order to support 3-phase AC operation, the overhead shield wire will be an Aluminum Conductor Steel Reinforced (“ACSR”) conductor, mounted atop the structure using 66 kV post insulators.
- **SUB\_TAK\_TEMP:** The Takhini substation will be upgraded to feed the 66 kV AC service to Watson Junction Substation.
- **SUB\_WATJUNC\_TEMP:** Watson Junction Substation will be partially constructed in order to step down the 66 kV AC service to 25 kV AC.
- **TX\_WATJUNC\_WAT:** A 25 kV line will be constructed from Watson Junction Substation to Watson Lake substation.
- **SUB\_WAT:** Watson Lake substation will be constructed to feed the 25 kV service from Watson Junction substation onto the Watson Lake local grid.

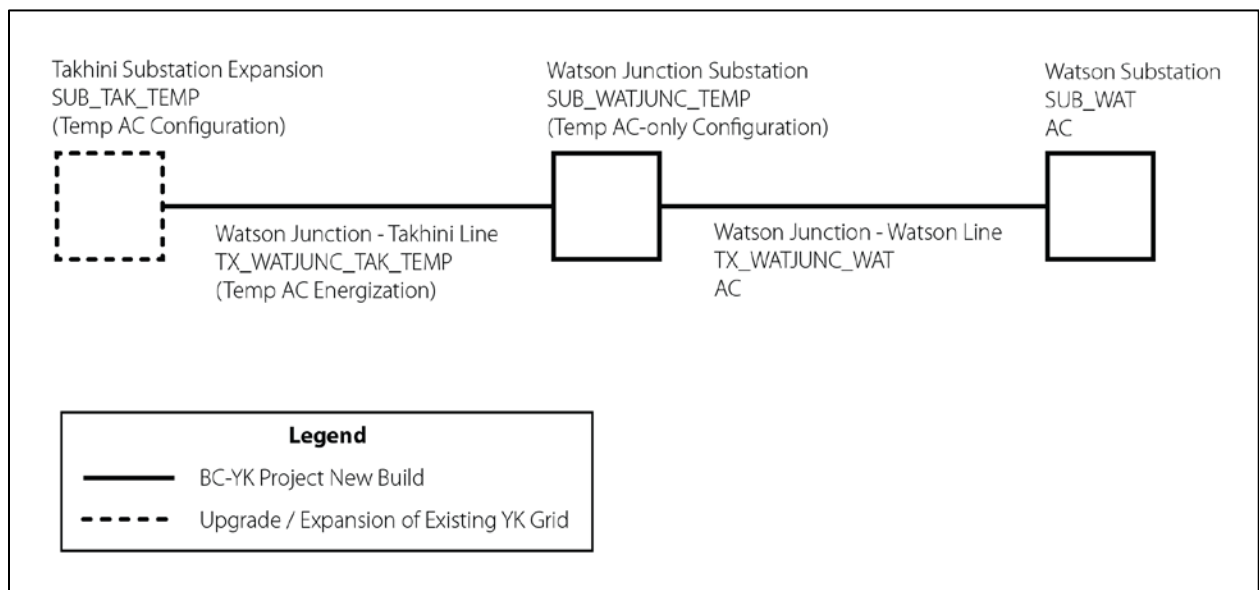
The above elements serve to connect Watson Lake to the Yukon grid prior to completing the remainder of the Project, thus allowing Watson Lake to transition its local diesel generators to emergency backup operations (reducing greenhouse gas emissions).

Figure 6 and Figure 7 show a map and schematic of the Stage 1 work, respectively.

**Figure 8 – Development Stage 1 Map**



**Figure 9 – Development Stage 1 Schematic**



## 2.2.2 Stage 2 Description – Yukon to BC, Yukon to Casino Mine

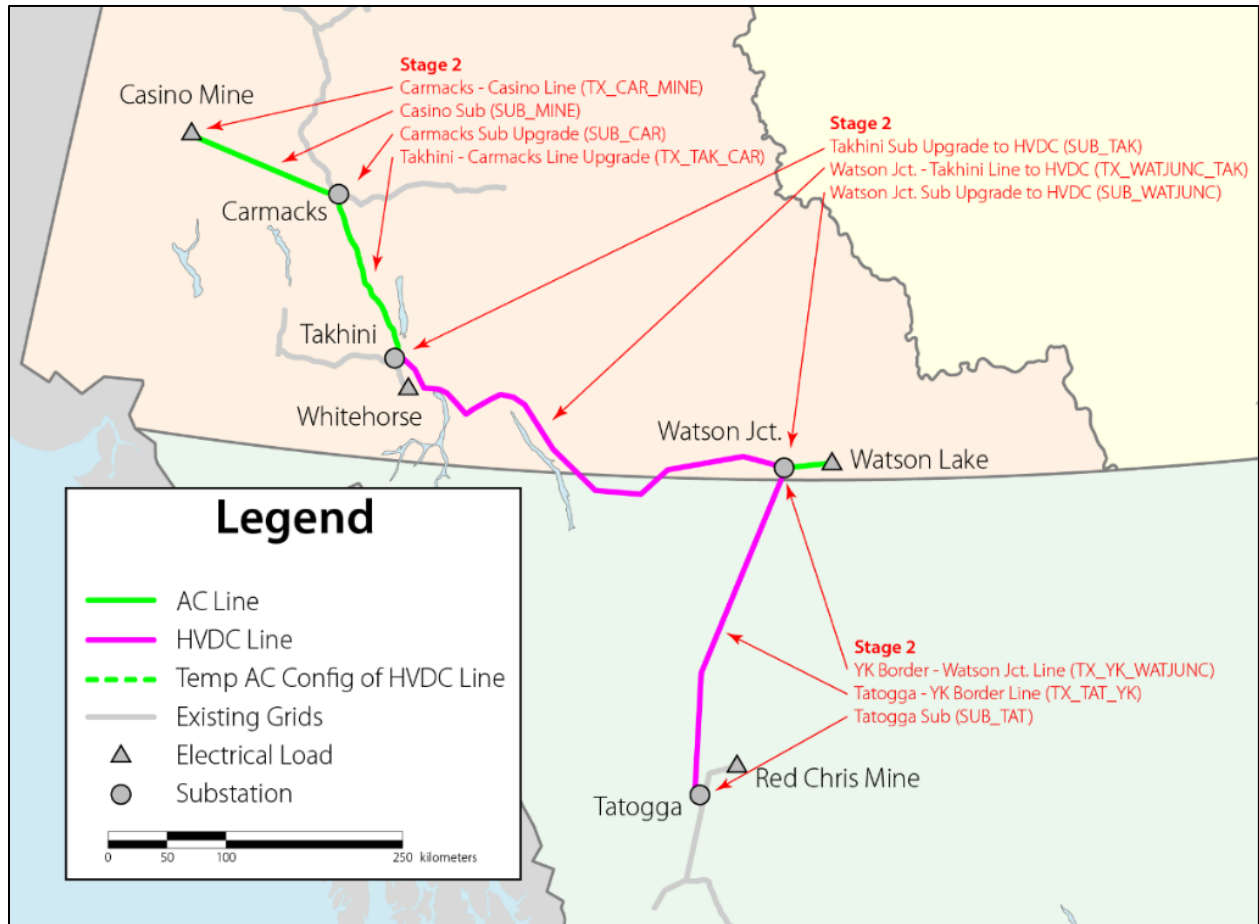
Stage 2 of the Project will consist of the following elements:

- **SUB\_TAT:** Tatogga Substation will be constructed to incorporate a HVDC converter station.
- **TX\_TAT\_YK & TX\_YK\_WATJUNC:** The HVDC connection between Watson Junction substation and Tatogga substation will be constructed as a  $\pm 200$  kV HVDC transmission line. Although this HVDC transmission line is treated as two (2) separate segments for planning purposes (i.e., Tatogga substation to Yukon/BC border and Yukon/BC border to Watson Junction Substation), it will physically be one contiguous HVDC line between the Watson Junction and Tatogga substations.
- **SUB\_WATJUNC:** The Watson Junction substation will be upgraded to include a DC converter station to feed the 25 kV AC service to Watson Lake, after which the 66 kV transformation equipment from Stage 1 will be removed.
- **TX\_WATJUNC\_TAK:** The Takhini to Watson Junction transmission line will be de-energized as a 66 kV AC transmission line, and re-energized as a  $\pm 200$  kV HVDC transmission line.
- **SUB\_TAK:** Takhini substation will be upgraded to remove the 66 kV AC service to Watson Junction, add a HVDC converter station, and upgraded to supply 230 kV AC service to Carmacks on TX\_TAK\_CAR.
- **TX\_TAK\_CAR:** The existing Takhini to Carmacks 138 kV AC line will be upgraded to 230 kV AC operation.
- **SUB\_CAR:** The substation at Carmacks will be upgraded to accept the 230 kV service from Takhini, and to provide 230 kV service to industrial load to the north (e.g., the Casino Mine).
- **TX\_CAR\_MINE:** The 230 kV transmission line from the Carmacks Substation (SUB\_CAR) to the industrial load (e.g., the Casino Mine) will be constructed.
- **SUB\_MINE:** The substation at the industrial load will be constructed (e.g. the Casino Mine substation).

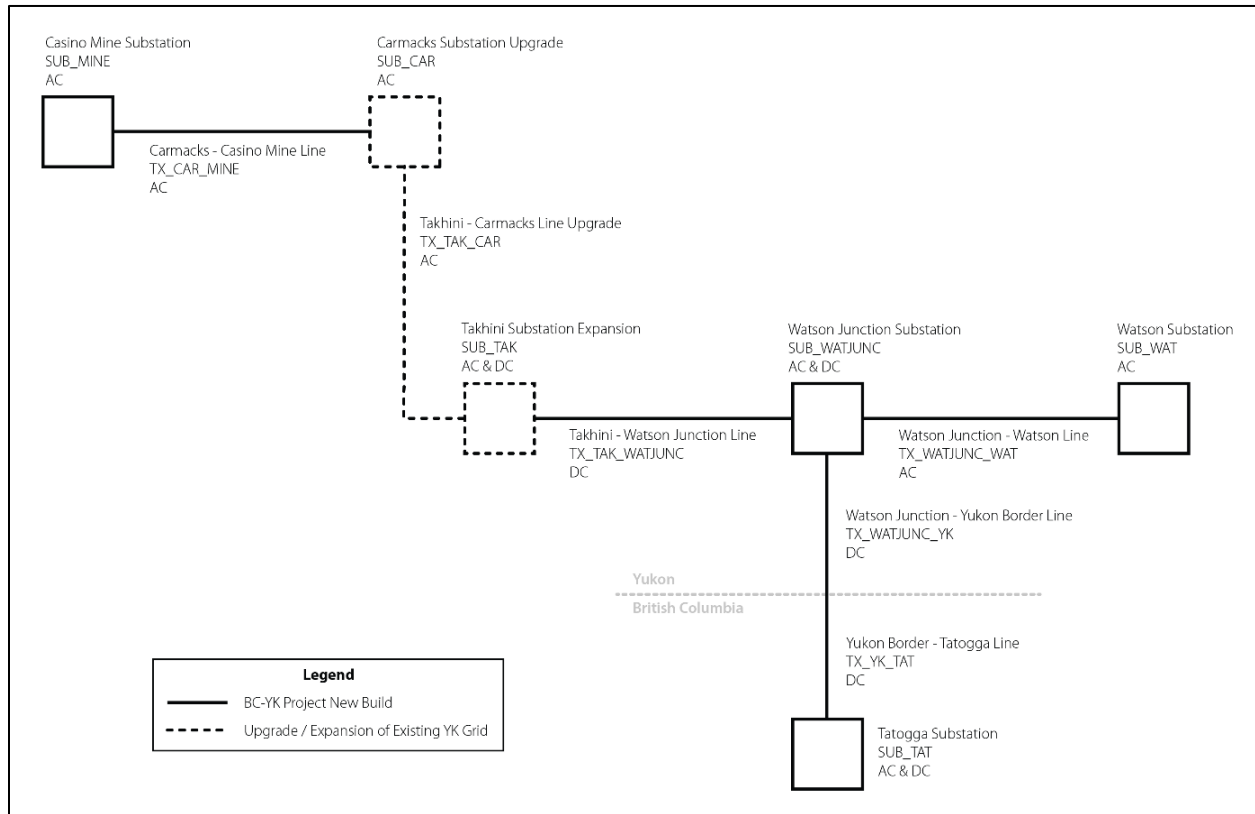
The above stage two (2) elements will contemporaneously connect the Yukon and BC electrical grids and the expanded Yukon grid to large industrial load (e.g., the Casino mine). It should be noted that during the construction period between the de-energization of the 66 kV AC service between Takhini and Watson Junction and the energization of the HVDC line in its final state, Watson Lake will utilize diesel generation for its electrical supply.

Figure 8 and Figure 9 show a map and schematic of the Stage 2 work, respectively.

Figure 10 – Development Stage 2 Map



**Figure 11 – Development Stage 2 Schematic**



### 3 Project Risk Assessment

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The size and complexity of the Project described in Section 2 will necessarily entail a variety of risks during the various development stages. The purpose of the project risk assessment is to explore the major thematic risks to the Project. The project development plan (see Section 4) is formulated to manage and address these identified thematic risks.

Although most risks in a major infrastructure project originate during the early stages of project development, these risks typically do not actually materialize until later stages of project execution. For example, the risk associated with a poor First Nation and/or stakeholder engagement strategy may not actually materialize until construction commences (e.g. manifesting as forms of civil disobedience or protests). In such an example, the risks existed since the inception of the project but were not properly acknowledged and mitigated throughout the development process, whereupon they materialized during project construction as a setback and negative cost consequence. It is therefore crucial for risks to be identified and pre-emptively mitigated at the earliest possible stage of development. Such a strategy de-risks a project by minimizing at-risk dollars and maximizes project certainty during later project phases and key decision points. The concept of identifying and mitigating potential risks as early as possible is core to Midgard's development plan philosophy because it is critical to long term project development success. In the Project development plan detailed in Section 4, many of the risk identification and mitigation activities are purposely located in the first several phases of project development.

Broadly speaking, the governing overall risk to the Project is the inherent challenge of coordinating and reaching agreements with the key parties that are impacted, or potentially impacted, by an infrastructure project of this size and complexity. The key parties include, but are not limited to, Yukon government, British Columbia government, Federal government, First Nations, potential off-takers (e.g., mines), and any other stakeholders that may be impacted by the Project. In many cases these key parties may have different interests, and ultimately all parties will need to be sufficiently satisfied that their interests are being protected to obtain their participation in, or at least not active opposition to, the Project.

In view of the diverse range of parties involved in such a project, this risk assessment is broken down into five thematic risk areas:

6. First Nation Risk (see Section 3.1)
7. Territorial and Federal Political Risk (see Section 3.2)
8. BC Political and Technical Risk (see Section 3.3)
9. Off-Taker Risk (see Section 3.4)
10. Other Risks (see Section 3.5)

### 3.1 First Nations Risk

First Nations participation or opposition to the Project represents a key set of risks as there are multiple impacted First Nations along the Project corridor in both Yukon and British Columbia. Depending on their view of the Project and their participation in the Project, First Nations may be either a negative or positive Project risk<sup>8</sup>, and are therefore key to potential Project success or failure. Specifically, First Nation support has provided many major Canadian infrastructure project the certainty necessary to improve the likelihood of success. Therefore, the approach to First Nation participation, and the form(s) that participation takes will materially impact the nature and extent of risks (positive and negative) faced by the Project. Consequently, these risks will be identified in early phases in order to improve the likelihood of Project success. A high level summary of key First Nation risks is presented in Table 4.

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<sup>8</sup> In the most current version of ISO 31000 2018, risk is defined as “the effect of uncertainty on objectives” in both the positive and negative.

**Table 5 – Key First Nations Project Risks**

Risk	Consequences	Recommended Management Strategy
First Nations may oppose or support the project, or have a different vision regarding their participation therein.	First Nations may actively oppose or support the Project development.	<ul style="list-style-type: none"> <li>• Early engagement with First Nations can encourage active participation and support.</li> <li>• The Project may highlight the opportunity for collaboration, beyond more traditional impact benefit agreement relationships.</li> </ul>
Existing relationships between First Nations and other stakeholders (e.g., governments, YEC, BC Hydro) may impact the Project’s First Nation relationship.	First Nations may be predisposed against the Project based on pre-existing relationships. This could result in additional effort on the Project’s part to manage its First Nations relationship(s).	<ul style="list-style-type: none"> <li>• Focusing on the First Nations as active participants encourages a more collaborative approach.</li> <li>• May consider makeup of the Project partnership (e.g., which levels of government) at an early stage to encourage the greatest possible appeal.</li> </ul>
First Nations may not present a homogenous entity for the Project to interact with.	The Project may be required to manage interactions with a wide range of First Nations with diverse and possibly competing interests (incurring additional effort and expense).	<ul style="list-style-type: none"> <li>• Project will account for the risk in planning of First Nations relationship activities from an early stage (e.g., white paper to be developed in the first development plan phase acknowledging known and contemplated interests).</li> <li>• Project configuration will not be finalized at early stages to allow for flexibility to accommodate diverse interests.</li> </ul>
Community electrification may be a pre-requisite for First Nation support.	First Nations may be disappointed that the Project will not electrify their own communities, and may make their support contingent on receipt of electrification or comparable benefits.	<ul style="list-style-type: none"> <li>• Alternatives Study in the first development plan phase will examine the costs and feasibility of grid-connecting local communities and providing economic development opportunities.</li> <li>• Alternative benefits will be explored for situations in which grid connection is not feasible.</li> </ul>

### 3.2 Territorial & Federal Political Risk

The Project will be exposed to political risk resulting from the involvement of the territorial and Federal governments. The Federal government will be a particularly important risk to manage, as the Project will be dependent on Federal funding support. These political risks will be addressed primarily in early phases in order to identify showstopper issues as early as possible. Table 5 presents a high-level summary of the territorial and Federal political risks.

**Table 6 – Key Political Project Risks**

Risk	Consequences	Recommended Management Strategy
Political will within the Yukon may be insufficient. Likely to depend on the Yukon government’s perception of support from First Nations and stakeholders.	Yukon government opposition would likely present an insurmountable obstacle to Project development.	<ul style="list-style-type: none"> <li>Engage Yukon government before proceeding to Conceptual phase to assess political support and permissible execution strategies.</li> <li>If political support insufficient, terminate Project development efforts before material expense incurred.</li> </ul>
Yukon government and YEC may not be willing to accept an equity partner on the Project.	Limiting the allowable set of participation models for different key parties (e.g. levels of government, First Nations) will constrain negotiating and risk management strategies.	<ul style="list-style-type: none"> <li>Present Project different participation models to Yukon government prior to engagement with key parties (e.g. Federal Government, BC Government and BC Hydro, First Nations).</li> <li>Prepare options for different participation approaches to inform decision making.</li> </ul>
Federal government may not financially support the Project to the extent required if it does not perceive value in the Project (e.g., arctic sovereignty, GHG reductions, First Nations, and northern economic development)	Failure of the Federal government to provide the necessary level funding and/or support to the Project may make it infeasible for the Project to succeed.	<ul style="list-style-type: none"> <li>Provide clear supporting material (e.g., Project costs, benefits) for government-to-government discussions between Yukon and Federal governments.</li> <li>Determine Federal government interest during Conceptual phase in order to determine if “showstopper” exists and terminate the Project if needed.</li> <li>Reassess level of Federal support at each gate review.</li> </ul>

### 3.3 British Columbia Political & Technical Risk

The Project will be exposed to political and technical risks associated with its interactions with the British Columbia government and BC Hydro, respectively. These risks will result from the political will within both entities, as well as technical issues arising from a comparatively large project connected to a remote extension of BC Hydro’s electrical grid. The British Columbia political and technical risks will be addressed primarily in early phases in order to identify both political and technical risks as early as practical (see Table 6 for details).

**Table 7 – Key British Columbia Political and Technical Project Risks**

Risk	Consequences	Recommended Management Strategy
Political will within BC may not exist. Likely to depend on the BC government’s perception of costs, risks, support from other stakeholders.	BC government opposition would hinder or terminate Project development efforts	<ul style="list-style-type: none"> <li>Identify potential benefits to BC (e.g., mining development, community electrification, climate goals, customer for surplus power) that the Project may deliver, and present these to the BC government. Prepare a “BC White Paper” in early phases of the development plan.</li> <li>Determine the participation structures that may be most desirable to BC government (e.g., BC ownership of BC segment), and consider pursuing such approaches.</li> </ul>
BC Hydro may have a differing vision for the development of its northwestern grid, which may be incompatible with the Project.	The Project would either need to be adjusted to accommodate BC Hydro’s needs/plans, or would not be able to proceed if BC Hydro’s cooperation cannot be secured.	<ul style="list-style-type: none"> <li>Interconnection alternatives will be studied in the first phase of the development plan to determine the preferred interconnection option(s) with input from First Nations, local communities, and BC Hydro.</li> <li>BC Hydro System Impact Study (SIS) to be undertaken in the second phase of development in order to reveal any unidentified technical issues specific to the BC Hydro interconnection.</li> </ul>
Interconnection to the BC Hydro grid may be more costly or challenging than expected.	The Project would need to accommodate increased budget and schedule for interconnection.	<ul style="list-style-type: none"> <li>Project shall include contingencies in developing expected interconnection costs during financial modeling.</li> <li>Contingencies shall be revisited and refined through the system impact study and beyond (e.g., during each phase of the development plan).</li> </ul>
The power price offered by BC Hydro may not be economically viable for Project success.	A non-viable power price could either require power price subsidy from government, cause the Project to lose money, or halt Project development.	<ul style="list-style-type: none"> <li>The Project will support government-to-government partnership between the Yukon and Federal governments, with a view to presenting a unified approach to the BC government regarding cost of power and Project funding.</li> <li>Level of up-front subsidies required will be influenced by the power price available to the Project.</li> </ul>

### 3.4 Off-Taker Risk

The Project will be exposed to off-taker risks (i.e., large industrial loads such as mines). Project revenues (and therefore economic viability) will depend on committed energy sales to these off-taker parties. The off-taker risks are presented in Table 7.

**Table 8 – Key Off-Taker Project Risks**

Risk	Consequences	Recommended Management Strategy
Commercial off-takers may not provide long-term commitment to purchase energy.	The Project may not be able to secure long term energy purchase commitments from off-takers, which would make the Project harder to justify economically from a risk adjusted viewpoint.	<ul style="list-style-type: none"> <li>Engage with mining association and/or developers to determine what kind of commitment is possible/reasonable from mines (e.g., sample term, price, line cost allocation, link to commodity or diesel prices, etc).</li> </ul>
Commercial off-takers may have a development schedule that differs from the Project's. <sup>9</sup>	The Project may need to economically justify the potential delay incurred by differing schedules.	<ul style="list-style-type: none"> <li>Staged approach to the Project allows flexibility to accommodate different Project objectives at different times.</li> </ul>
Electricity resale price that the Project can offer may not be economically attractive to off-takers.	Project would either need to find a way to offer lower prices to attract off-takers (in which case the lost revenue would need to be made up elsewhere) or risk losing off-takers altogether.	<ul style="list-style-type: none"> <li>Determine supportable resale price in early phases in order to structure Project to accommodate (i.e., testing off-taker market for pricing requirements).</li> <li>Identify alternative benefits to off-takers of grid power (e.g., carbon credits) in order to incentivize connection.</li> <li>Explore potential to link electricity price with mined commodity pricing and/or natural gas/diesel costs to help eliminate risk for customer</li> </ul>
Off-takers may disappear if the commodity markets on which they rely experience downturns.	Project would lose future revenue, which would require additional revenue from other sources.	<ul style="list-style-type: none"> <li>Attempt to maximize the diversity of the user base in order to minimize exposure to commodity fluctuations.</li> <li>Explore early-exit penalty terms within off-taker supply contracts.</li> </ul>
Insufficient off-taker sales volume to justify their interconnection.	The Project would not be able to economically justify the costs to interconnect off-takers.	<ul style="list-style-type: none"> <li>Attempt to maximize the diversity of the user base in order to minimize exposure to commodity fluctuations.</li> </ul>

<sup>9</sup> Most large industrial developments will require diesel backup in any case due to remoteness and need to operate (even if at reduced capacity) during grid interruptions. Inclusion of this generation in site design is a natural mitigation to the scheduling risk associated with a mine starting up before the project is ready to supply.

### 3.5 Other Risks

Other risks that do not fall into one of the above categories are given in Table 8.

**Table 9 – Other Project Risks**

Risk	Consequences	Recommended Management Strategy
The Project may be more technically challenging than anticipated.	Project costs would be increased, which would require additional funding.	<ul style="list-style-type: none"> <li>• Early development plan phases will include identification of similar HVDC projects that can be referenced as design work proceeds.</li> <li>• Development plan will progressively identify and mitigate technical issues.</li> </ul>
Large number of key parties and stakeholders will result in a complex coordination effort because any party could introduce a “showstopper” objection.	The Project is exposed to potential showstopper objections from many different sources, any one of which may be sufficient to result in Project delay or termination.	<ul style="list-style-type: none"> <li>• Engagement with all key parties and material stakeholders will begin in the first phase of the development plan, and will continue throughout all subsequent development phases.</li> <li>• Commitment to Project support will be obtained and documented with progressively stronger agreements (e.g., non-binding MOU, term sheet, etc.).</li> <li>• Gate reviews will include an assessment of commitments obtained at that phase in order to inform go/no-go decision making.</li> </ul>

## 4 Development Plan

The previous sections described the “what” of the Project and the risks associated with the project. This development plan section lays out the “how” of the Project. In other words, how the Project will be developed and implemented in a structured manner to methodically focus resources on the managing of risks through to operation.

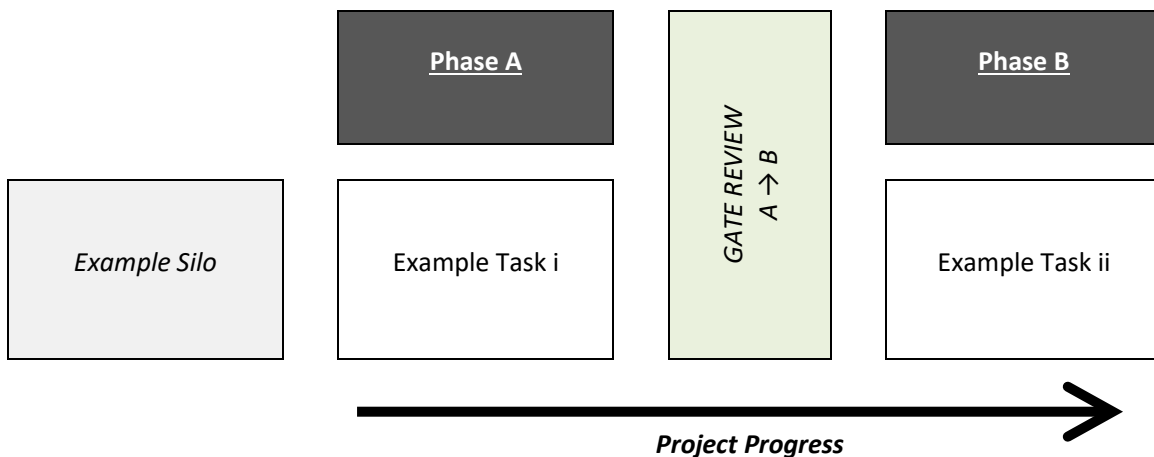
The development plan starts with the foundational philosophy behind project development, followed by general structure, deliverables, gate review decisions, schedule, and budget. Specifically, the development plan is divided into seven (8) parts:

- Part 1: Philosophy of Development (see Section 4.1)
- Part 2: Staging of the YK-BC Interconnection (see Section 4.2)
- Part 3: Development Plan Structure (see Section 4.3)
- Part 4: Key Deliverables (see Section 4.4)
- Part 5: Gate Reviews (see Section 4.5)
- Part 6: Schedule (see Section 4.6)
- Part 7: Budget (see Section 4.7)

### 4.1 Development Plan Philosophy

The overall goal with a development plan is to successfully deliver a project while simultaneously advancing a measured approach to spending and risk reduction. Midgard’s development philosophy, visualized in Figure 10 below, is based on a multi-phase/gate review approach, whereby different aspects of the project (referred to as “Silos”) are advanced through phases of work followed by gate reviews prior to moving on to the next phase.

**Figure 12 – Development Plan Core Philosophy**



The concept of “silos”, “phases”, and “gate Reviews” are the core underpinnings of Midgard’s Development Plan Philosophy. The nuances of each of these core concepts are detailed in subsections that follow.

Silos

Silos represent the different domains of the Project delivery activities, such as First Nations engagement, project economics, technical issues, environmental impacts & permitting, and execution/construction. Presenting the Development Plan by silo is important as different stakeholder groups will often be interested in different silos, and separating the Project into silos collects risks, stakeholders, costs, and potential subcontractors into a grouping which helps provide clarity and focus during development (e.g., the types of groups involved and interested in a particular silo are grouped together so that they can be more easily discussed, evaluated, and managed).

**Table 10 – Development Plan Silos**

Silo	Silo Description
First Nations (FN)	The First Nations silo covers all First Nation relations starting from an initial identification of potentially impacted First Nation, to impacts benefits agreement (or equivalent) payments, to potential participation of First Nations as project partners. Throughout the development process studies are completed to evolve an acceptable transmission line route to, and to better understand the project impacts upon, First Nations. The studies include Aboriginal Interest and Use studies, Archaeological Overview/Impact Assessments, impact benefits and participation agreement analysis, and the drawing-in of other study silos in a specifically First Nation context. Once a sufficient understanding is established, an impact benefits agreement (or equivalent depending on the First Nation) is executed with each First Nation. Meeting consultation requirements and/or treaty obligations is a legal requirement, but underpinning a long term Project relationship with First Nations is a holistic economic, environmental, and socio-economic agreement that has a basis in fairness and respect that goes beyond meeting purely legal requirements (e.g., an agreement that is based on principles and exchange that will be valid today and seven (8) generations from now).
BC Government / BC Hydro (BC)	The BC government and BC Hydro are key stakeholders and potential partners central to Project success that need to be engaged for basic Project support, and to determine the BC Hydro Point of Interconnection (“POI”), Power Purchase Agreement (“PPA”) terms, and other any other necessary aspects of BC government/BC Hydro participation in the project.
Financial / Economic (ECON)	Project financial modelling and risk assessments inform discussions, negotiations and decision making with First Nation, BC government/BC Hydro, Federal government, and other project participants and stakeholders. Economic evaluation is an iterative process updated regularly throughout project development. Project costs and revenue sources are refined and reviewed as part of the gate reviews between phases. Once construction is close to commencing, efforts are made to negotiate and execute agreements with debt providers for project financing. Post-commissioning, long-term financing arrangements replace the construction debt.

Silo	Silo Description
Technical (TECH)	<p>Engineering studies and project layouts refine the project concept which supports and informs First Nations consultation and BC Hydro discussions. The project design will be updated as it evolves (e.g. in response to BC Hydro’s identification of acceptable point(s) of interconnection, First Nation feedback on lands/routes to avoid or use). As early phase technical silo activities advance, they support increasingly accurate project design, understandings, cost estimates and risk assessments necessary to support activities such as writing a detailed Project Description for the purpose of engaging in the environmental assessment processes of the Yukon and BC, negotiating with and securing the participation of First Nation, and addressing stakeholder issues etc.</p> <p>Later phase technical silo activities depend on the construction contracting option chosen. For example, if a full-wrap Engineer-Procure-Construct (“EPC”) contract is selected, the level of engineering performed by the Project is reduced because the detailed “for construction” and “as built” engineering drawings are provided by the EPC contractor rather than the Project (which provides higher level drawings to ensure key project features are implemented). As well, under an EPC contract, site investigation (including geotechnical work) will be directed by the EPC contractor – which will not be the case under different contracting arrangements. Regardless of contracting option, the project undergoes a design process and a construction process.</p>
Environmental (ENVIRO)	<p>The Environmental silo activities begin with the identification of potential showstoppers and assessment of permitting topics identified during initial discussions with First Nations. As the Project develops, an improved understanding of the Project impacts is established to fully inform First Nation negotiations and develop common project understandings amongst the Project participants. As the Project enters the Environmental Assessment process, field and desktop studies are completed to quantify project impacts and evaluate impact mitigations, including route adjustments, environmental compensation, and environmental monitoring (both during construction and operations).</p> <p>This silo also includes all deliverables relating to authorizations, agreements, and permits to use/access the Project site. These range from investigative use permits to an Environmental Assessment Certificate. Several leaves are required from the government, including one to start construction and another to begin operations.</p>
Execution (EXEC)	<p>The execution silo becomes significant in the transition from development to construction and operations.</p> <p>Activities in the Execution silo begin with developing a contracting strategy and plan that selects a contracting model based on the expertise and risk tolerance of the project partners, and consequently divides the project into construction packages. Execution includes construction (e.g., Design Build, EPC, EPCM, or other) contractor selection(s), high value/ long lead equipment procurement, and construction management. As construction completes the Project will transition to operators in Yukon and BC, include key operational agreements, training, maintenance planning, and other operational activities as required by the Project’s authorizations and agreements.</p>

The intent of the development plan is to advance all six (6) silos together through their respective development phases/gate reviews to ensure spending is allocated efficiently to reduce Project risks within each silo and across all silos.

Phases

A phased development approach focuses activities and spending on a phase-by-phase basis to reduce major development risks in a disciplined manner to avoid major upsets later in the Project. There are eight (8) phases of development in total as detailed in Table 10.

**Table 11 – Development Plan Phases**

#	Phase Name	Phase Description
1	Pre-Conceptual	The pre-conceptual phase focuses on engaging the BC government to gauge interest and potential for support at a political level.
2	Conceptual	Focuses on communications with key Project parties (i.e., First Nations, Yukon, BC government, Federal government) to share the Project concept. Based on feedback the level of interest in the Project, potential for support and/or partnership will be assessed. Of particular note in the Conceptual phase is discussion with First Nations to determine key barriers to their participation in the Project (e.g., key environmental and social concerns). The objective is to obtain feedback so that the Project can be altered in the early stages to better suit First Nation needs, thus mitigating the risk of their active opposition to the Project. Additionally, the Yukon government will also be asked if there are types of First Nation participation that the government is not willing to accept (e.g., Equity (or equity-like) ownership in the Project as a means of risk reduction.
3	Pre-Feasibility	The pre-feasibility phase will further discussions with key Project parties to the point of developing term sheets and non-binding memorandums of understanding with partners and engagement agreements with others. Based on feedback received from First Nations, key studies required to advance discussions and negotiations will be performed. The line route and project design will updated along with a revised cost estimate and initial environmental impact assessment. The presence of any potential showstoppers will be evaluated prior to engaging in more detailed investigations.
4	Feasibility	Feasibility is the last stage before beginning the detailed and more expensive fieldwork required for permitting. The design will be refined to establish a project description for the environmental review process. Participation Agreements with First Nations and governments will be finalized to document Project partners and support.

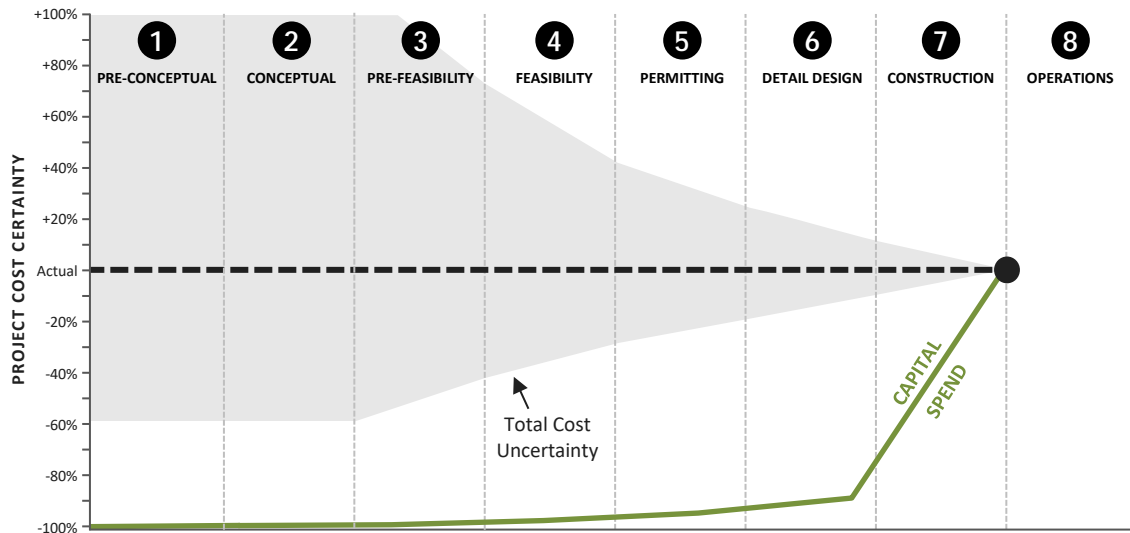
#	Phase Name	Phase Description
5	Permitting	The purpose of permitting is to acquire the necessary licenses, tenure, and other material authorizations required for Project construction. Environmental and socio-economic studies will be completed to establish the project impact and benefits. A contracting plan will be established to guide the delivery of the physical equipment and construction. Depending on the contracting strategy selected (e.g., EPC), at the end of permitting, conditional construction contractor selection may also be made as part of informing the gate review. Once major permits are received and construction costs and risk are defined, the Project can then begin the detailed design and construction phases.
6	Detailed Design	Detailed designs will be completed to prepare the Project for construction, and long-lead equipment will be procured. Depending on the contracting strategy selected, the construction contractor(s) may be engaged during this phase.
7	Construction	The Project is constructed. If the agreements with key parties (First Nations, various levels of government), permitting authorizations, and contracting strategy have been implemented robustly, the construction phase is primarily about executing construction effectively and efficiently (i.e., risks are primarily construction execution risks). However, if prior phase work contains fundamental flaws (e.g. First Nations actively oppose the project or technical risk were not adequately understood), construction will reveal and precipitate those latent project risks (e.g. civil disobedience, construction change orders). Therefore, the key party agreements and stakeholder and partner relationships must be maintained throughout this phase and commitments must be delivered. Construction culminates in testing and commissioning.
8	Operations	Operations is the longest phase and starts by transitioning control of the project from the execution team to the operating entity (e.g., YEC). It will include development and execution of maintenance plans and the implementation of operating agreements between the Yukon and BC. This phase begins after the facilities are commissioned and ends when (and if) they are decommissioned

Although phases are laid out in series, it is possible and sometimes practical, to perform certain activities in parallel or in overlap across strict Phase boundaries. The decision to alter the timing of phase-by-phase activities is a decision that is made by the Project’s project management team as it responds to emerging issues and risks.

Figure 11 sets out a high-level representation of the relationships between risk, costs, and timing for a typical development process. The purpose of Figure 11 is to show how the certainty of the project improves over time as each phase is completed and that a large portion of the project risk can be mitigated with targeted early stage capital investment (i.e., although you might pay handsomely for risks in the construction phase

due to the increased capital spend therein, the risk was crystallized or was successfully mitigated in earlier phases).

**Figure 13 – Development Process Risk Progression**



### Gate Reviews

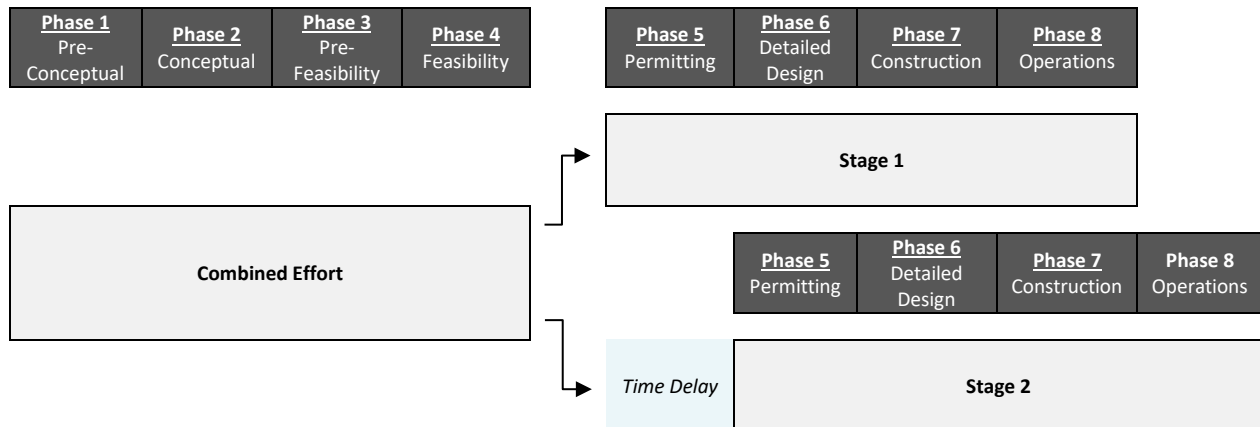
Gate reviews are to occur between each of the eight (8) development phases. Gate reviews ensure a deliberate and comprehensive assessment of the Project silos and associated Project risks are made before spending next tranche of development budget (i.e., moving on to the next phase of development). Gate reviews are an orderly way to perform development, communicate progress, and review risk with project sponsors, funders, key participants, and key stakeholders. If two phases are run in parallel (permitting and detailed design) then an intermediate gate review would be created to maintain the disciplined approach.

## **4.2 Development Plan Staging**

As shown in the development plan philosophy section above, there are eight (8) phases of development. However, as detailed in Section 2.2, the Project is planned with a staged build-out (Stage 1 and Stage 2). Therefore, the development plan requires staged execution as well.

Figure 12 below shows how the staged nature of the Project is applied to the development plan. Pre-Conceptual (Phase 1), Conceptual (Phase 2), Pre-feasibility (Phase 3), and Feasibility (Phase 4) are completed as a combined effort so that the information shared with, and agreements made with key parties are done as an integrated whole that effectively reduces overall project risk prior to the start of detailed design and construction. Once sufficient and genuine support has been garnered for the Project as a whole, the development plan bifurcates into Stage 1 development and Stage 2 development for the permitting phase and onward (Phases 5 through 8).

**Figure 14 – Development Plant Project Flow and Staging**



Delaying the spending associated with Stage 2 development allows alignment of the high cost development phase timing (e.g., design and construction) with the economic driver of the Project (i.e., large industrial load/mining development in the Yukon).

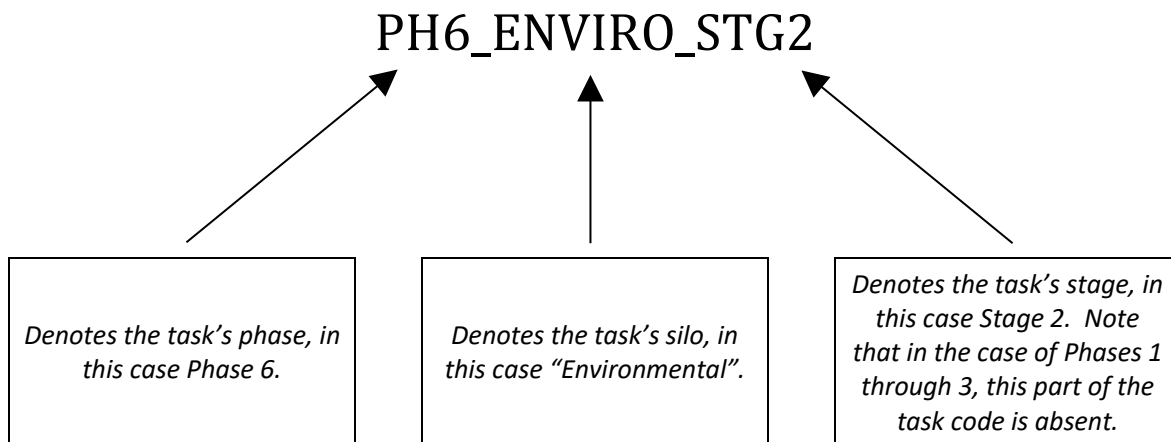
Appendix B of this report contains the individual task sheets for each of the silos across each of the phases.

### 4.3 Development Plan Structure

This section presents the overall structure of the development plan. As discussed previously, there are development silos (e.g., First Nations, Technical etc) which are domains of activity, and there are Project phases (e.g., Phase 1 – Conceptual etc). The development plan is structured to detail the activities and deliverables for each silo during each phase for each stage of the Project.

Each combination of silo, phase and stage is designated with a task code that is assembled as shown in Figure 13.

**Figure 15 – Example Task Code Breakdown**

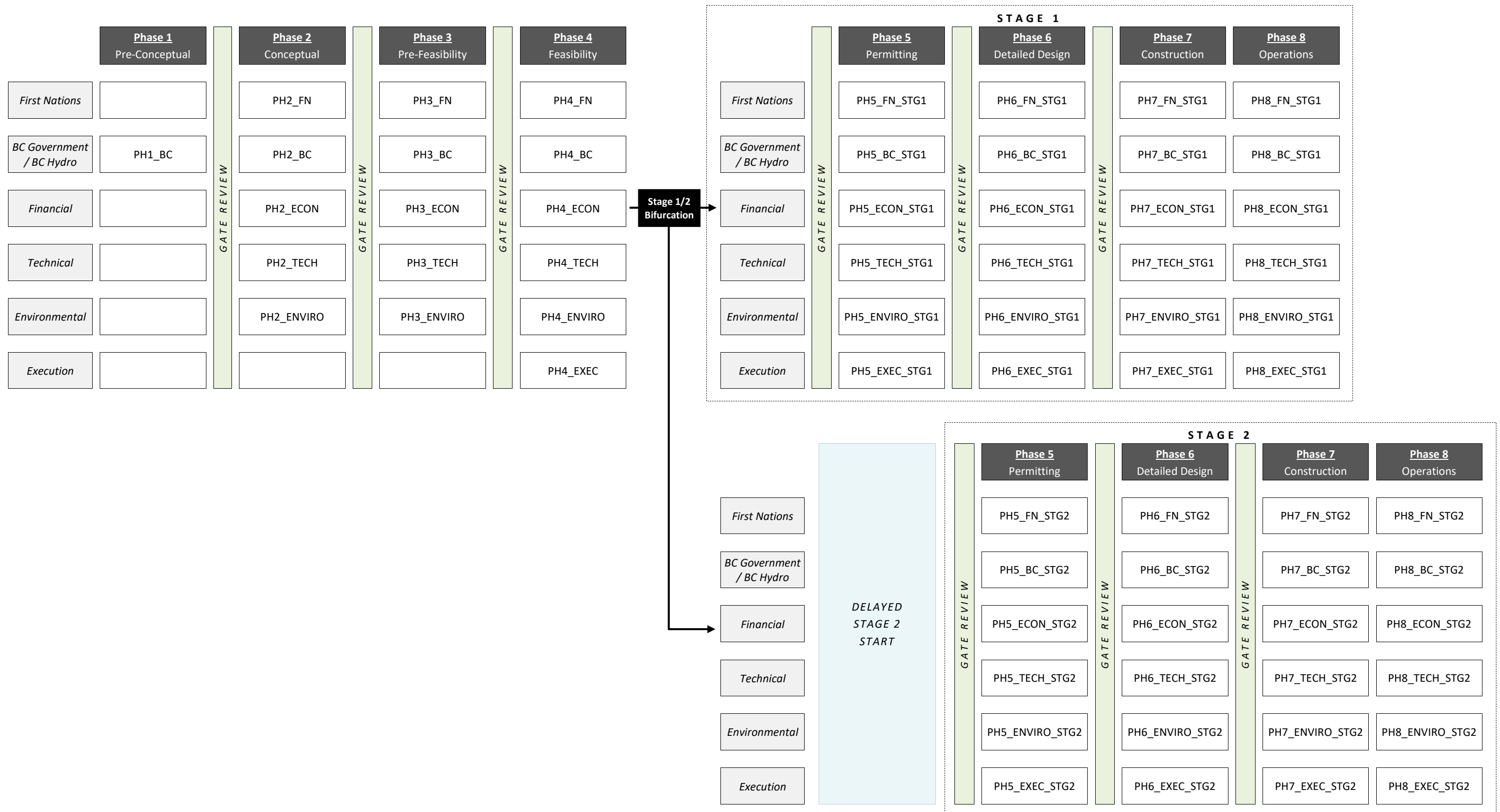


Appendix B contains Task Sheets for each task which are referenced by task code and present the detailed activities and deliverables for each task.

Figure 14 provides a visual representation of the structure of the development plan with silos, phases, stages, and tasks all combined into a single visual. Stage 2 is expected to lag Stage 1 as shown in the diagram, but it is possible that Stage 1 and Stage 2 could occur concurrently (i.e., with zero lag) if the actual situation supported that decision (i.e., Stage 1 interim activities would be superseded corresponding Stage 2 activities).

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Figure 16 – Development Plan Structure (With Task Sheet Reference Codes)



#### **4.4 Development Plan Key Deliverables**

This section presents all of the “key” deliverables within each phase and stage combination. Please note that Table 11 does not contain all of the deliverables, but rather the key deliverables. To give an overall view of the development plan deliverables, silos are ignored and only the key deliverables are presented. For a comprehensive listing of each deliverable under each silo/phase, please see the individual task sheets in Appendix B.

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**Table 12 – Development Plan Key Deliverables**

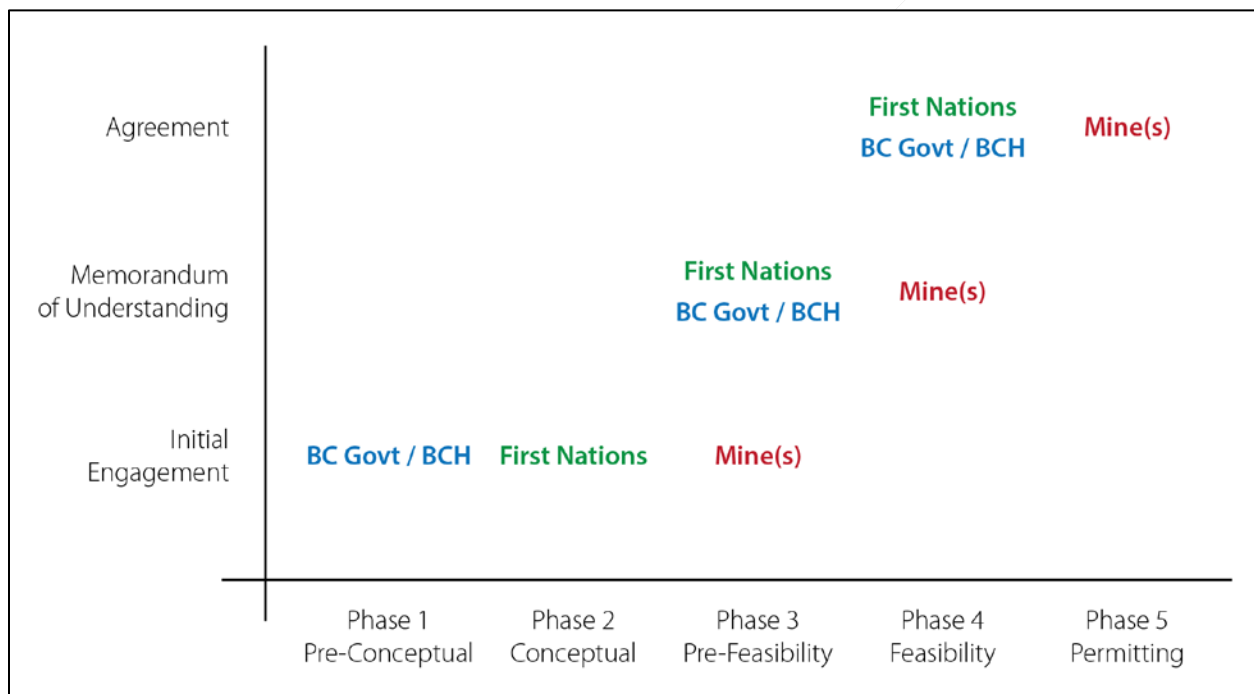
Phase 1 Pre-Conceptual	Phase 2 Conceptual	Phase 3 Pre-Feasibility	Phase 4 Feasibility	Phase 5 Permitting	Phase 5 Detailed Design	Phase 6 Construction	Phase 7 Operations
<b>Combined Effort</b>				<b>Stage 1</b>			
<ul style="list-style-type: none"> <li>▪ List of affected First Nations</li> <li>▪ BC whitepaper (concept, benefits, PPA)</li> <li>▪ YK government to BC government engagement summary</li> <li>▪ YK government to federal government engagement summary</li> </ul>	<ul style="list-style-type: none"> <li>▪ Review of similar successful projects (e.g. Wataynikaneyap Transmission Project) &amp; First Nation participation models</li> <li>▪ First Nation whitepaper (concept/ benefits)</li> <li>▪ First Nation engagement summary</li> <li>▪ Conceptual level line route (using YK/BC data)</li> <li>▪ Conceptual level cost estimate, schedule, &amp; risk assessment</li> <li>▪ Alternatives Study with alternative projects and alternative project configurations</li> <li>▪ Inventory of potential users (industrial loads, off-grid communities, generation and system support).</li> <li>▪ Initial financial model</li> </ul>	<ul style="list-style-type: none"> <li>▪ Field studies with First Nations to support engagement</li> <li>▪ Non-binding First Nation MOU's (including form of partnership)</li> <li>▪ BC Hydro System Impact Study (any unidentified technical issues specific to the BC Hydro interconnection.)</li> <li>▪ BC government non-binding MOU</li> <li>▪ Assessment market appetite for industrial offtake (e.g. mines) and discuss parameters for success (e.g. lead time, power price, capital contribution) including keys to success for Brucejack and Red Chris mines.</li> <li>▪ Pre-feasibility level line route (based on stakeholder feedback to date)</li> <li>▪ Pre-Feasibility level cost estimate, schedule &amp; risk assessment</li> <li>▪ Pre-Feasibility level financial model</li> </ul>	<ul style="list-style-type: none"> <li>▪ Material agreements with First Nations</li> <li>▪ Letter of intent with industrial offtaker(s)</li> <li>▪ BC Hydro power purchase agreement and interconnection agreement</li> <li>▪ Environmental Assessment Terms of Reference</li> <li>▪ Structure family selected</li> <li>▪ Substation footprints established</li> <li>▪ Feasibility level line route and right-of-way cross-sections</li> <li>▪ Feasibility study &amp; drawings to support permitting</li> <li>▪ Feasibility level capital cost estimate, schedule &amp; risk assessment</li> <li>▪ Draft contracting strategy</li> <li>▪ Revised financial model</li> </ul>	<ul style="list-style-type: none"> <li>▪ Yukon socio-economic and environmental review under YESSA</li> <li>▪ Consultation summaries</li> <li>▪ Field Studies &amp; Impact Reports</li> <li>▪ Design: Issue for permit</li> <li>▪ Contracting plan</li> </ul>	<ul style="list-style-type: none"> <li>▪ Design: Issue for construction</li> <li>▪ Tender package</li> <li>▪ Pricing update</li> <li>▪ Detailed Design level financial model</li> <li>▪ Shortlisting of tender bids</li> <li>▪ Recommended contractor</li> </ul>	<ul style="list-style-type: none"> <li>▪ Procurement of long lead time equipment</li> <li>▪ Award construction contracts</li> <li>▪ Create access</li> <li>▪ Construct</li> <li>▪ Towers / stringing</li> <li>▪ Station modifications</li> <li>▪ Test &amp; commissioning</li> </ul>	<ul style="list-style-type: none"> <li>▪ Operating orders (YEC)</li> <li>▪ Maintenance schedule</li> <li>▪ Operation staff trained</li> <li>▪ Diesel back-up at Watson</li> </ul>
<b>Combined Effort</b>				<b>Stage 2</b>			
				<ul style="list-style-type: none"> <li>▪ Binding agreement with industrial offtaker (e.g. mine)</li> <li>▪ CEAA or BC EA and permits</li> <li>▪ Consultation summaries</li> <li>▪ Field Studies &amp; Impact Reports</li> <li>▪ Design: Issue for permit</li> <li>▪ Contracting plan</li> </ul>	<ul style="list-style-type: none"> <li>▪ Design: Issue for construction</li> <li>▪ Tender package</li> <li>▪ Pricing update</li> <li>▪ Detailed Design level financial model</li> <li>▪ Shortlisting of tender bids</li> <li>▪ Recommended contractor</li> </ul>	<ul style="list-style-type: none"> <li>▪ Procurement of long lead time equipment</li> <li>▪ Award construction contracts</li> <li>▪ Create access</li> <li>▪ Construct</li> <li>▪ Towers / stringing</li> <li>▪ Station modifications</li> <li>▪ Test &amp; commissioning</li> </ul>	<ul style="list-style-type: none"> <li>▪ Operating Agreements (BC, mine)</li> <li>▪ Maintenance schedule</li> <li>▪ Operation staff trained</li> </ul>

#### 4.5 Development Plan Gate Reviews

A primary purpose of gate reviews is to ensure a deliberate assessment of the project silos and associated risks is made before spending the next tranche of development budget (i.e., moving on to the next phase of development which has a higher burn rate than the current phase as shown in Figure 17). Figure 10 (from Section 4.1) shows that there are a series of gate reviews over the life of the development plan.

In addition, gate reviews serve as a milestone at which to review the level of commitment of the various Project partners. Project partners will be engaged at a lower commitment level at early Project phases, with the objective of escalating commitment levels in conjunction with the natural escalation of capital expenditures as the Project progresses. Engagement with potential off-takers will lag engagement with partners, as the commitment of partners can serve to increase the comfort of potential off-takers with the Project. This pattern of escalating commitment is represented graphically in Figure 15.

**Figure 17 – Increasing Commitment Level of Project Partners (Outside of Yukon Government)**



Since gate reviews are key decision points where the Project is evaluated as a comprehensive whole (e.g., all silos and key parties are evaluated) gate reviews are presented by phase and stage without distinguishing silos (see Table 12). In Table 12, the key topics and risks for consideration by project partners are listed for each gate review.

**Table 13 – Development Plan Gate Reviews**

<p><b>Phase 1 → 2</b> From Pre-Conceptual to Conceptual</p>	<p><b>Phase 2 → 3</b> From Conceptual to Pre-Feasibility</p>	<p><b>Phase 3 → 4</b> From Pre-Feasibility to Feasibility</p>	<p><b>Phase 4 → 5</b> From Feasibility to Permitting</p>	<p><b>Phase 5 → 6</b> From Permitting to Detail Design</p>	<p><b>Phase 6 → 7</b> From Detail Design to Construction</p>
<b>Combined Effort</b>			<b>Stage 1</b>		
<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Level of BC Government cooperation</li> <li>Approve \$0.7M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Insufficient federal government financial participation</li> <li>Insufficient BC Government support</li> <li>Opposition from First Nation(s)</li> </ul>	<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Level of First Nation cooperation</li> <li>First Nation participation model options</li> <li>Level of BC Government cooperation</li> <li>Level of public support</li> <li>Assessment of market interest to connect mine(s)</li> <li>Refined project scheduling to align with external dependencies (i.e. potential investors, load and other stakeholders)</li> <li>Confirm project preferred among alternatives (Based on Alternatives Study)</li> <li>Optimized configuration, route and POIs (Based on Alternatives Study)</li> <li>Project economics based on refined project understanding</li> <li>Approve \$1.7M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Insufficient federal government financial participation</li> <li>Opposition from First Nation(s)</li> <li>First Nation participation model inadequately defined</li> </ul>	<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Project economics based on refined project understanding (Based on BC Hydro System Impact Study (SIS), better risk understanding and technical &amp; commercial advancement)</li> <li>Refined project scheduling to align with external dependencies</li> <li>Assessment of First Nation MOUs to participate in project</li> <li>Assessment of BC Government MOU</li> <li>Assessment of market interest to connect mine(s) and proposed parameters (e.g. lead time, power price, capital contribution)</li> <li>Assessment of public support</li> <li>Approve \$3M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Insufficient federal government financial participation</li> <li>Opposition from First Nation(s)</li> <li>First Nation participation aspirations exceed Yukon tolerance threshold</li> <li>BC government / BC Hydro participation (permit, build, own)</li> </ul>	<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Assessment of First Nation final agreements</li> <li>Refined project scheduling</li> <li>Assessment of public opinion</li> <li>Refined project economics (risk understanding and technical &amp; commercial advancement)</li> <li>Approve \$10M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Federal government participation</li> <li>Lost support from First Nation(s) (e.g. due to change of leadership) and no execution of material agreements</li> <li>Permitting agency coordination, jurisdiction and process</li> </ul>	<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Refined project economics (permitting conditions, risk understanding and technical &amp; commercial advancement)</li> <li>Refined project scheduling</li> <li>Assessment of First Nation support</li> <li>Assessment of public opinion</li> <li>Approve \$35M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Fundamental design changes from permitting increase capital cost</li> <li>Insufficient federal government financial participation</li> </ul>	<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Refined project economics (selected contractor agreement(s), risk understanding and technical &amp; commercial advancement)</li> <li>Refined project scheduling</li> <li>Approve selected contractor bid</li> <li>Approve \$440M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Detailed design results increase capital cost</li> <li>Insufficient federal government financial participation</li> </ul>
			<b>Stage 2</b>		
			<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Assessment of First Nation final agreements</li> <li>Assessment of BC Power Purchase Agreement (PPA)</li> <li>Assessment of offtaker MOU(s) to connect mine(s)</li> <li>Refined project scheduling</li> <li>Assessment of public opinion</li> <li>Refined project economics (Based on executed PPA, risk understanding and technical &amp; commercial advancement)</li> <li>Approve \$20M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Federal government participation</li> <li>Lost support from BC Government and/or First Nation (i.e., due to change of leadership) and no execution of agmts</li> <li>Low offtaker commitment (i.e. mine)</li> <li>Permitting agency coordination, jurisdiction and process</li> </ul>	<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Refined project economics (permitting conditions, risk understanding and technical &amp; commercial advancement)</li> <li>Assessment of offtaker binding agreement</li> <li>Refined project scheduling</li> <li>Assessment of First Nation support</li> <li>Assessment of public opinion</li> <li>Approve \$115M incremental spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Insufficient federal government financial participation</li> <li>Lack of binding agreements with BC Hydro and an off-taker (i.e. mine)</li> <li>Fundamental design changes from permitting increase capital cost</li> </ul>	<p><u>KEY CONSIDERATIONS</u></p> <ul style="list-style-type: none"> <li>Refined project economics (selected contractor agreement(s), risk understanding and technical &amp; commercial advancement)</li> <li>Refined project scheduling</li> <li>Assessment of Yukon/BC agreement</li> <li>Approve selected contractor bid</li> <li>Approve incremental \$1,250M spend</li> </ul> <p><u>KEY RISKS</u></p> <ul style="list-style-type: none"> <li>Detailed design results increase capital cost</li> <li>Insufficient federal government financial participation</li> </ul>

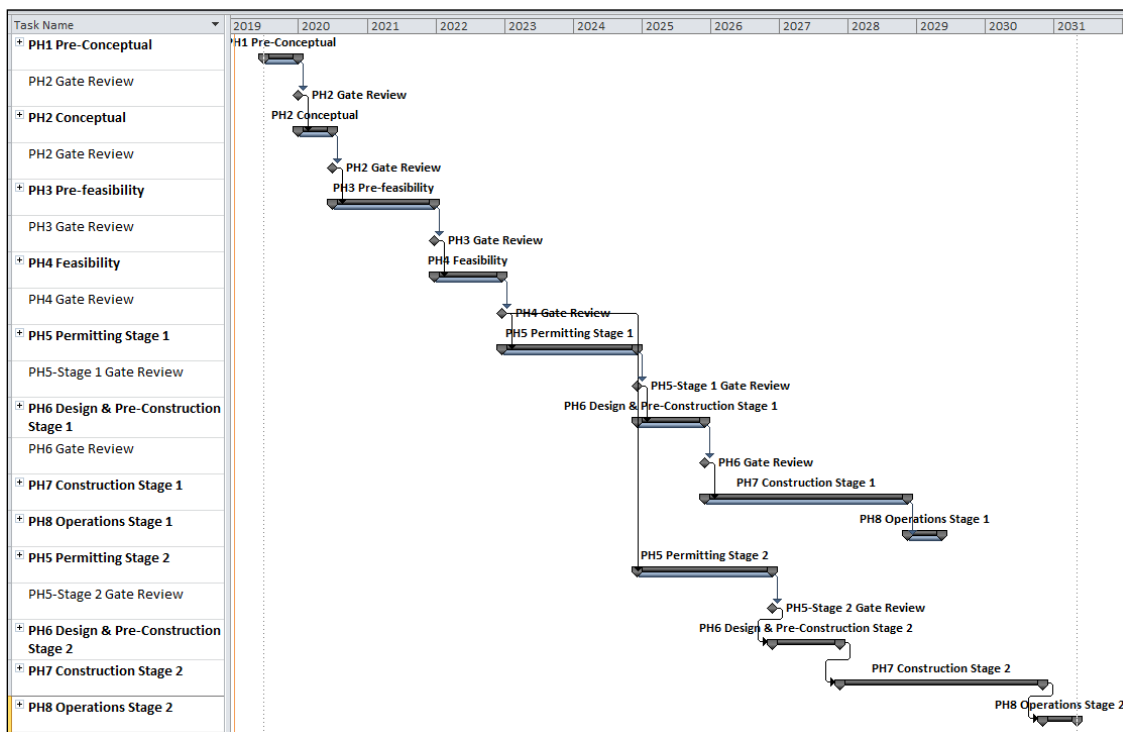
## 4.6 Development Plan Schedule

A schedule for the Project is presented in Figure 16 as a GANTT chart. The schedule is presented at a high level and will evolve as risks materialize, key party feedback is received, and strategic decisions are made (e.g., contracting strategy). The high level schedule estimates that it will take approximately ten (10) years from start of project until Stage 1 is operational and 12 years for Stage 2 to be operational based on a two (2) year lag between the start of permitting activities for Stage 1 and Stage 2.

The activities for Phase 1 (Pre-Conceptual) through Phase 4 (Feasibility) will be carried out concurrently for both Stage 1 and Stage 2. Phase 5 (Permitting) to Phase 8 (Operations) will occur separately for Stage 1 and Stage 2. The schedule assumes that Phase 5 (Permitting) for Stage 2 will begin after Phase 5 (Permitting) is complete for Stage 1.

It is worth noting that there is little/no opportunity to advance the schedule for Stages 1 through 3. These are the critical risk reduction stages and “rushing to construction” transfers unmitigated risks from low cash burn rate phases (i.e. Phases 1 through 4) to high cash burn rates phases (e.g. Phase 7 – Construction).

**Figure 18 – Project Schedule**



## 4.7 Development Plan Budget

The estimated budget of \$1.9B for the development plan and Project is presented in Table 13 below. There is an estimated cost for each task presented by Project stage and phase. Because the first three (3) development phases are executed on a combined effort basis for both Stage 1 and Stage 2, their budget is not divided into stages. Figure 17 shows the cumulative cash flow as the years of the Project proceed.

The budget amounts for each silo demonstrate the focus for each phase:

- **Phase 1 Pre-Conceptual:** First Nation and BC government engagement with minimal financial and technical activities for supporting those discussions.
- **Phase 2 Conceptual:** First Nation and BC government engagement with some financial and technical activities for supporting those discussions.
- **Phase 3 Pre-Feasibility:** Emphasis on getting to term sheets with key parties facilitated by field studies necessary to fully inform negotiations.
- **Phase 4 Feasibility:** Technical effort to firm up the project scope, costs, and potential impacts to finalize key party agreements and before launching into the environmental field work associated with permitting.
- **Phase 5 Permitting (Stage 1 & Stage 2):** Environmental field studies and preparing the environmental assessment application.
- **Phase 6 Detailed Design & Pre-Construction (Stage 1 & Stage 2):** Technical activities associated with completing the design and procuring long lead items prior to the launch of construction.
- **Phase 7 Construction (Stage 1 & Stage 2):** Although the most costly phase of the Project, the risks are primarily execution effectiveness risk (i.e., ability to manage and direct the construction contractors), and latent adequacy risks not addressed during the prior phases (e.g., risk leading to civil disobedience, undiscovered technical issues). Therefore, the focus of this phase is on effective construction management and execution.
- **Phase 8 Operations (Stage 1 & Stage 2):** The cost for the first year of operations includes project close out costs and transition into operation. The cost is presented as approximately 0.5% of the total project cost.

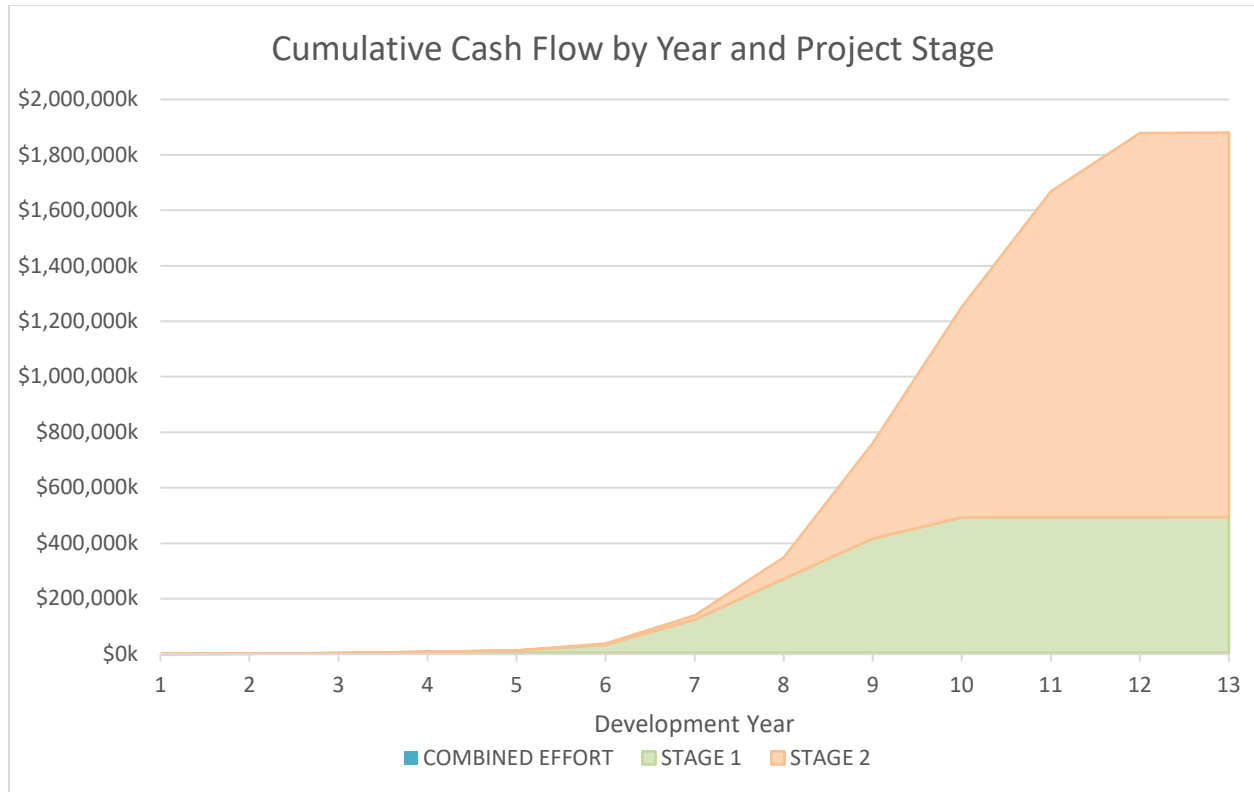
**Table 14 – Budget by Project Stage and Phase**

	<i>COMBINED EFFORT</i>			
	<b>Phase 1 Pre-Conceptual</b>	<b>Phase 2 Conceptual</b>	<b>Phase 4 Pre-Feasibility</b>	<b>Phase 4 Feasibility</b>
<b>FN</b>	\$0k	\$425k	\$500k	\$450k
<b>BC</b>	\$60k	\$125k	\$450k	\$300k
<b>ECON</b>	\$0k	\$75k	\$100k	\$150k
<b>TECH</b>	\$0k	\$75k	\$150k	\$1,500k
<b>ENVIRO</b>	\$0k	\$0k	\$500k	\$600k
<b>EXEC</b>	\$0k	\$0k	\$0k	\$0k
<b>SUB-TOTAL:</b>	<b>\$60k</b>	<b>\$700k</b>	<b>\$1,700k</b>	<b>\$3,000k</b>

	<i>STAGE 1</i>			
	<b>Phase 5 Permitting</b>	<b>Phase 6 Design &amp; Pre- Construction</b>	<b>Phase 7 Construction</b>	<b>Phase 8 Operations [For First Year]</b>
<b>FN</b>	\$3,000k	\$4,000k	\$12,750k	\$450k for Yr 1
<b>BC</b>	\$0k	\$0k	\$0k	\$0k for Yr 1
<b>ECON</b>	\$750k	\$300k	\$500k	\$200k for Yr 1
<b>TECH</b>	\$1,500k	\$28,500k	\$34,000k	\$850k for Yr 1
<b>ENVIRO</b>	\$4,500k	\$3,000k	\$17,000k	\$850k for Yr 1
<b>EXEC</b>	\$0k	\$800k	\$374,300k	\$1,700k for Yr 1
<b>SUB-TOTAL:</b>	<b>\$9,750k</b>	<b>\$36,600k</b>	<b>\$438,550k</b>	<b>\$4,050k for Yr 1</b>

	<i>STAGE 2</i>			
	<b>Phase 5 Permitting</b>	<b>Phase 6 Design &amp; Pre- Construction</b>	<b>Phase 7 Construction</b>	<b>Phase 8 Operations [For First Year]</b>
<b>FN</b>	\$3,000k	\$4,000k	\$12,750k	\$450k for Yr 1
<b>BC</b>	\$4,500k	\$8,000k	\$25,500k	\$400k for Yr 1
<b>ECON</b>	\$750k	\$300k	\$500k	\$200k for Yr 1
<b>TECH</b>	\$3,000k	\$91,500k	\$102,000k	\$850k for Yr 1
<b>ENVIRO</b>	\$9,000k	\$10,500k	\$68,000k	\$850k for Yr 1
<b>EXEC</b>	\$0k	\$600k	\$1,037,700k	\$1,700k for Yr 1
<b>SUB-TOTAL:</b>	<b>\$20,250k</b>	<b>\$114,900k</b>	<b>\$1,246,450k</b>	<b>\$4,450k for Yr 1</b>

**Figure 19 – Cumulative Cash Flow by Project Phase and Stage**

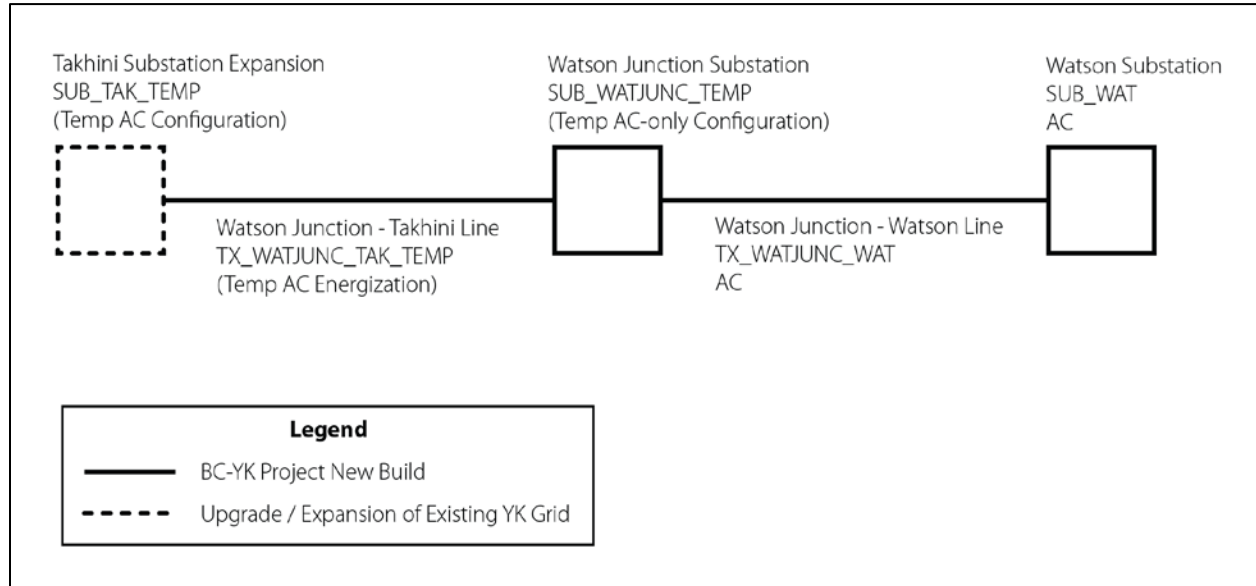


Please note that Figure 17 also displays the first year of operations for Stage 2. Stage 1 reaches operation in year 10 and Stage 2 in year 12.

## Appendix A – Segment Descriptions

### A.1 Stage 1 Elements

**Figure 20 – Development Stage 1 Schematic**



**Table 15 – Development Stage 1 Element Descriptions**

Segment	Description
SUB_TAK_TEMP	Existing Takhini Substation. Upgraded to feed the 66 kV AC service to Watson Junction Substation.
TX_WATJUNC_TAK_TEMP	HVDC line from Takhini Substation to Watson Junction Substation, constructed with the eventual overhead shield wire will be an ACSR conductor, mounted using 66 kV post insulators. Temporarily energized at 66 kV AC.
SUB_WATJUNC_TEMP	Watson Junction Substation. Partially constructed in order to step down the 66 kV AC service from Takhini Substation to 25 kV AC.
TX_WATJUNC_WAT	25 kV line from Watson Junction Substation to Watson Lake Substation.
SUB_WAT	Watson Lake Substation. Constructed to feed the 25 kV service from Watson Junction Substation onto the Watson Lake local grid.

## A.2 Stage 2 Elements

Figure 21 – Development Stage 2 Schematic

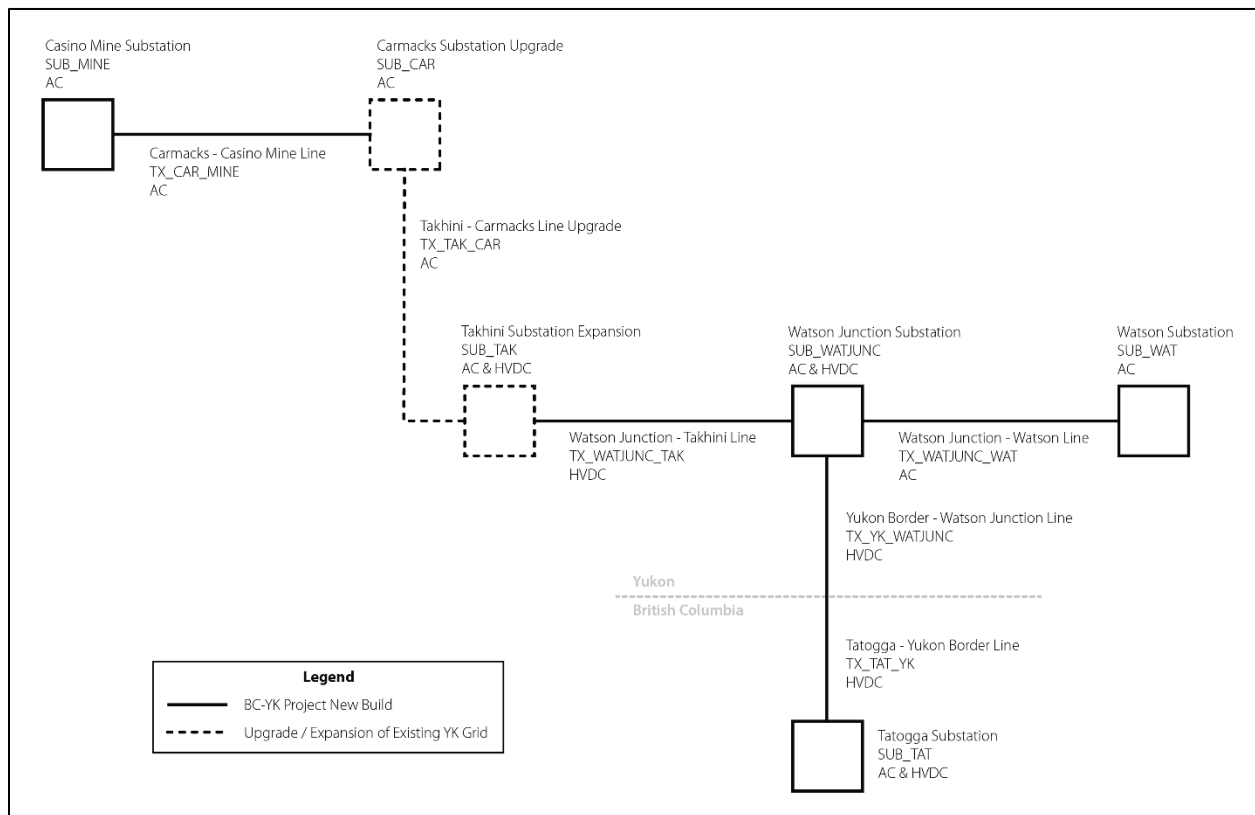
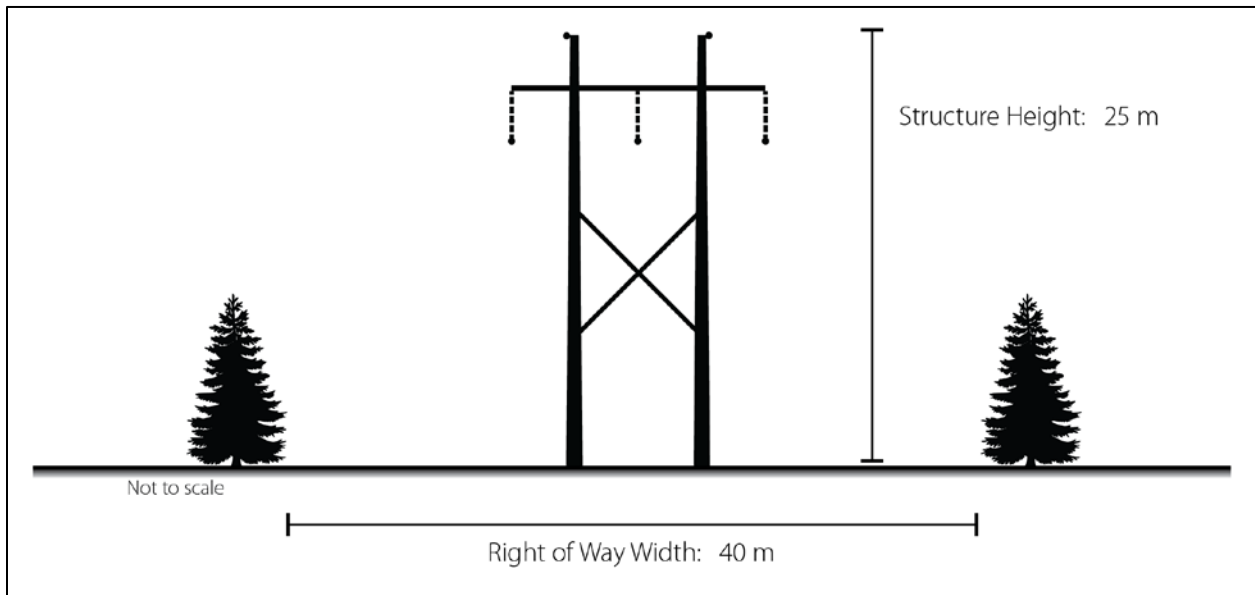


Table 16 – Development Stage 2 Element Descriptions

Segment	Description
SUB_MINE	Casino Mine Substation. Constructed to use 230 kV AC service to power mine.
TX_CAR_MINE	230 kV AC Carmacks Substation to Casino Mine Substation interconnection line.
SUB_CAR	Carmacks Substation. Upgraded and expanded to accept the 230 kV service from Takhini, and to provide 230 kV service to Casino Mine.
TX_TAK_CAR	Takhini Substation to Carmacks Substation 138 kV AC line upgraded to 230 kV AC.
SUB_TAK	Takhini Substation, including DC converter station. Remove the 66 kV AC service to Watson Junction. Expand to include 230 kV AC service to Carmacks.
TX_WATJUNC_TAK	± 200 kV HVDC connection from Takhini Substation to Watson Junction Substation (de-energized as 66 kV AC, and re-energized as HVDC).
SUB_WATJUNC	Watson Junction Substation, including DC converter station. 66 kV AC equipment removed, converter station to feed the 25 kV service to Watson Lake.
TX_YK_WATJUNC	± 200 kV HVDC line from Watson Junction Substation to Tatogga Substation (YK).
TX_TAT_YK	± 200 kV HVDC line from Watson Junction Substation to Tatogga Substation (BC).
SUB_TAT	Tatogga Substation, including DC converter station. Connects HVDC to BC grid.

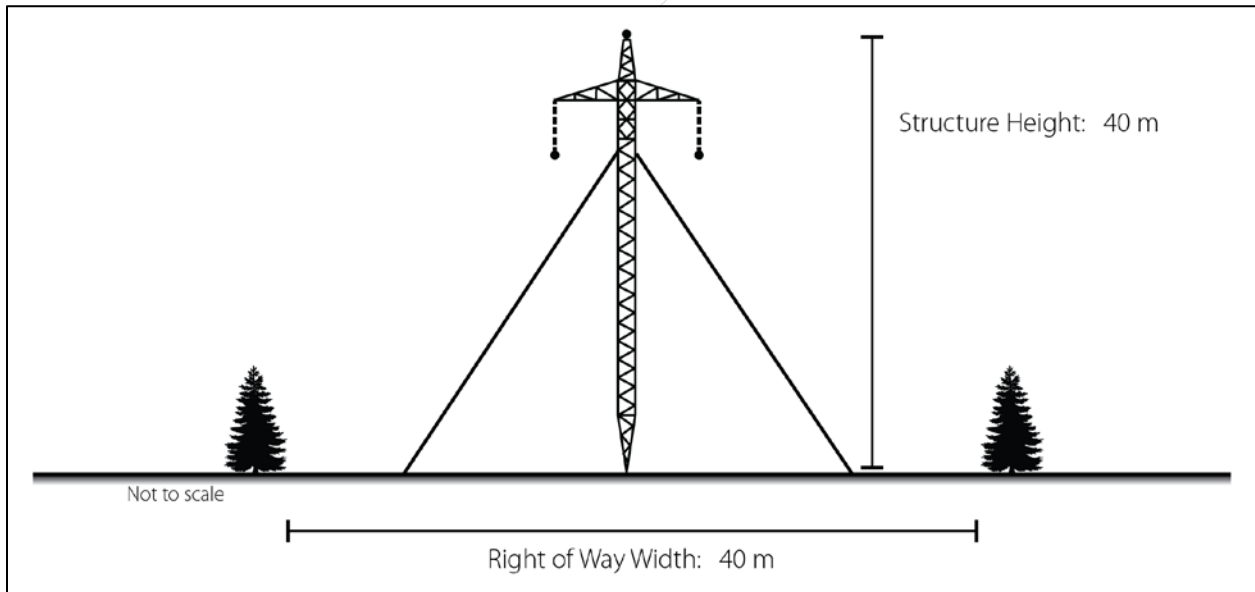
### A.3 Right-of-Way Diagrams

**Figure 22 – 230 kV AC Right of Way Diagram**



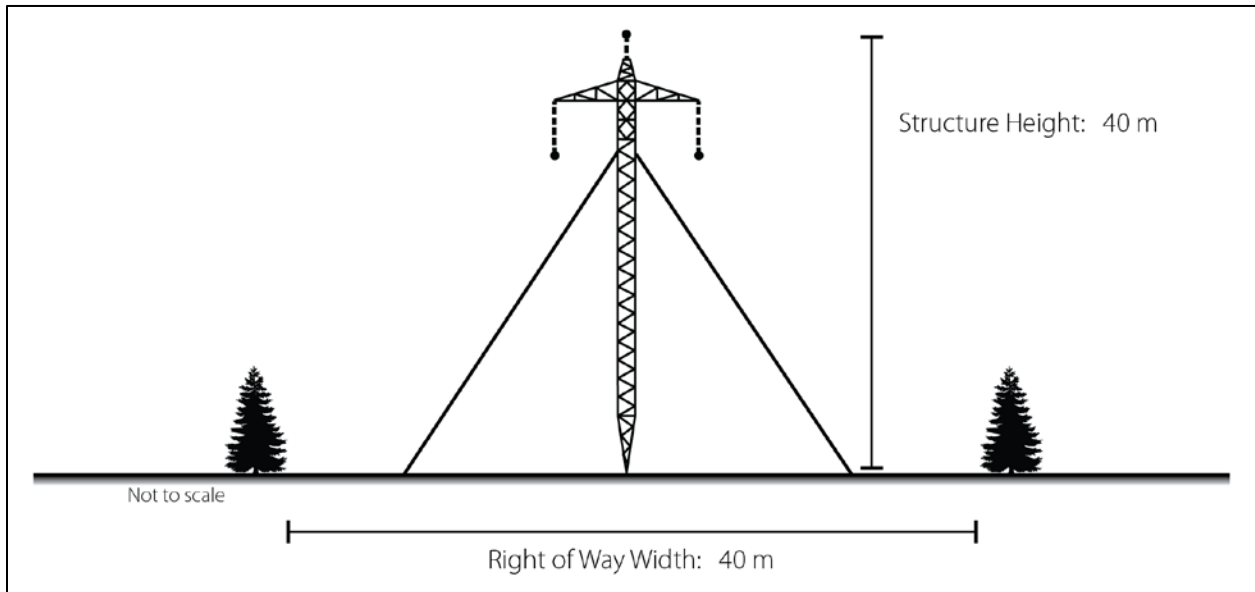
Relevant element(s): TX\_TAK\_CAR; TX\_CAR\_MINE

**Figure 23 – ± 200 kV HVDC Right of Way Diagram**



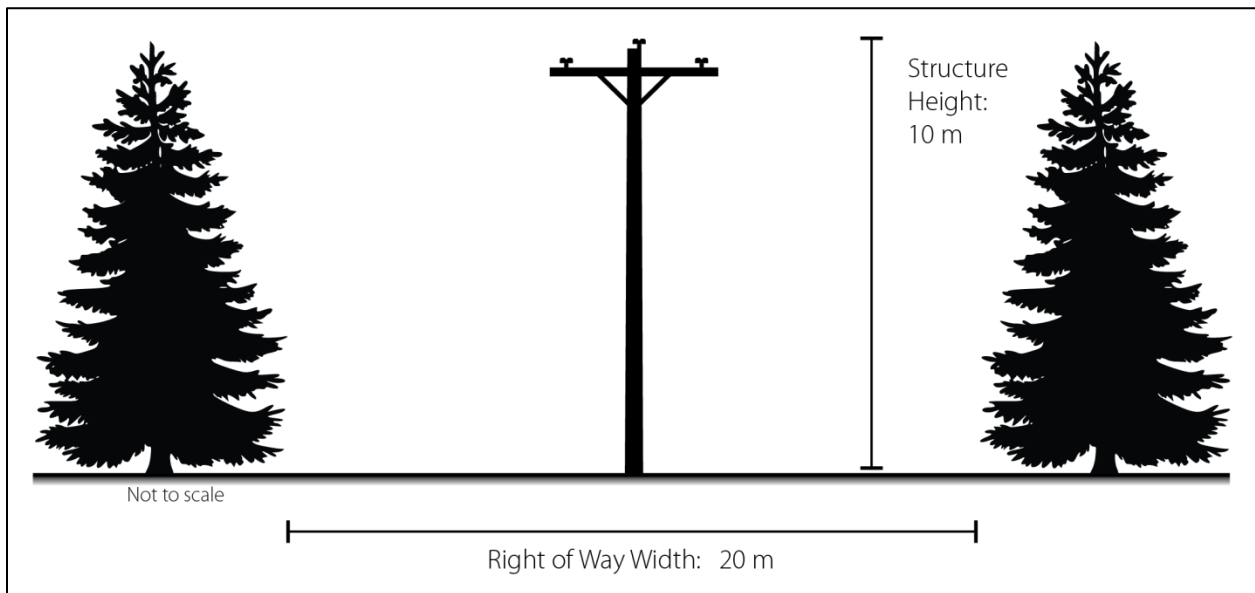
Relevant element(s): TX\_YK\_WATJUNC; TX\_TAT\_YK

**Figure 24 – ± 200 kV HVDC (with temporary 66 kV AC accommodation) Right of Way Diagram**



Relevant element(s): TX\_WATJUNC\_TAK\_TEMP; TX\_WATJUNC\_TAK

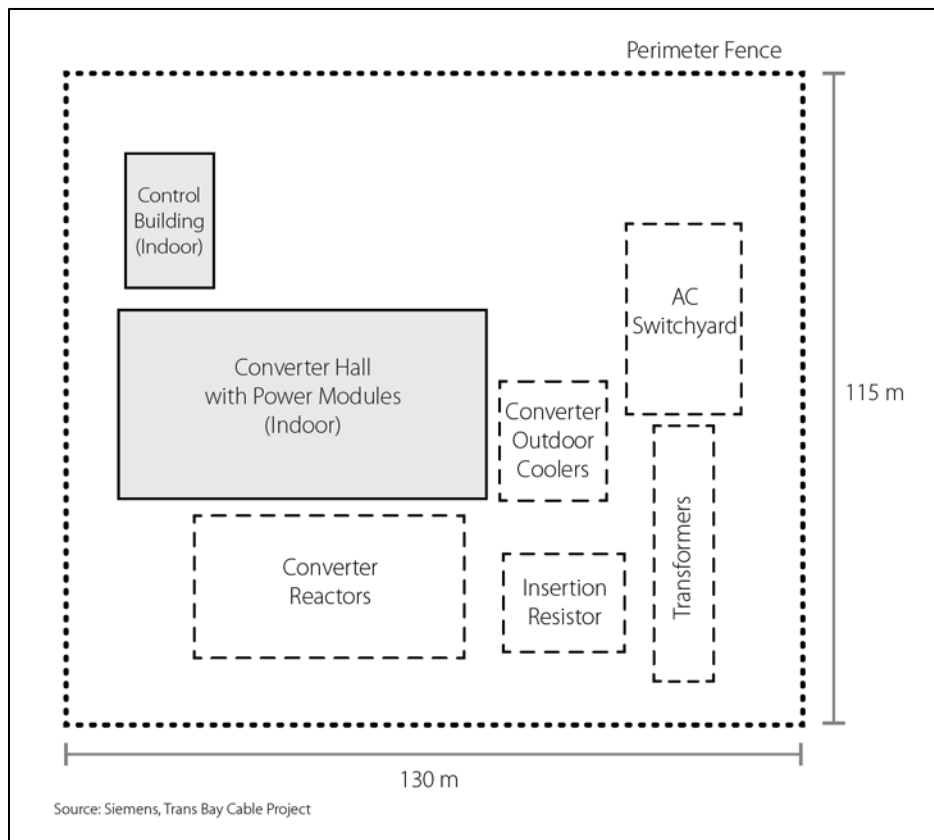
**Figure 25 – 25 kV AC Right of Way Diagram**



Relevant element(s): TX\_WATJUNC\_WAT

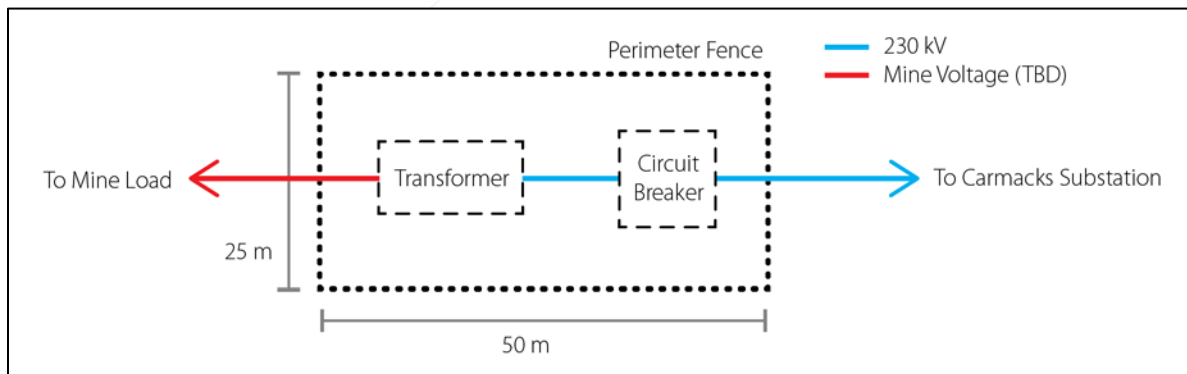
### A.4 Station Footprint Diagrams

**Figure 26 – DC Converter Station (Typical)**



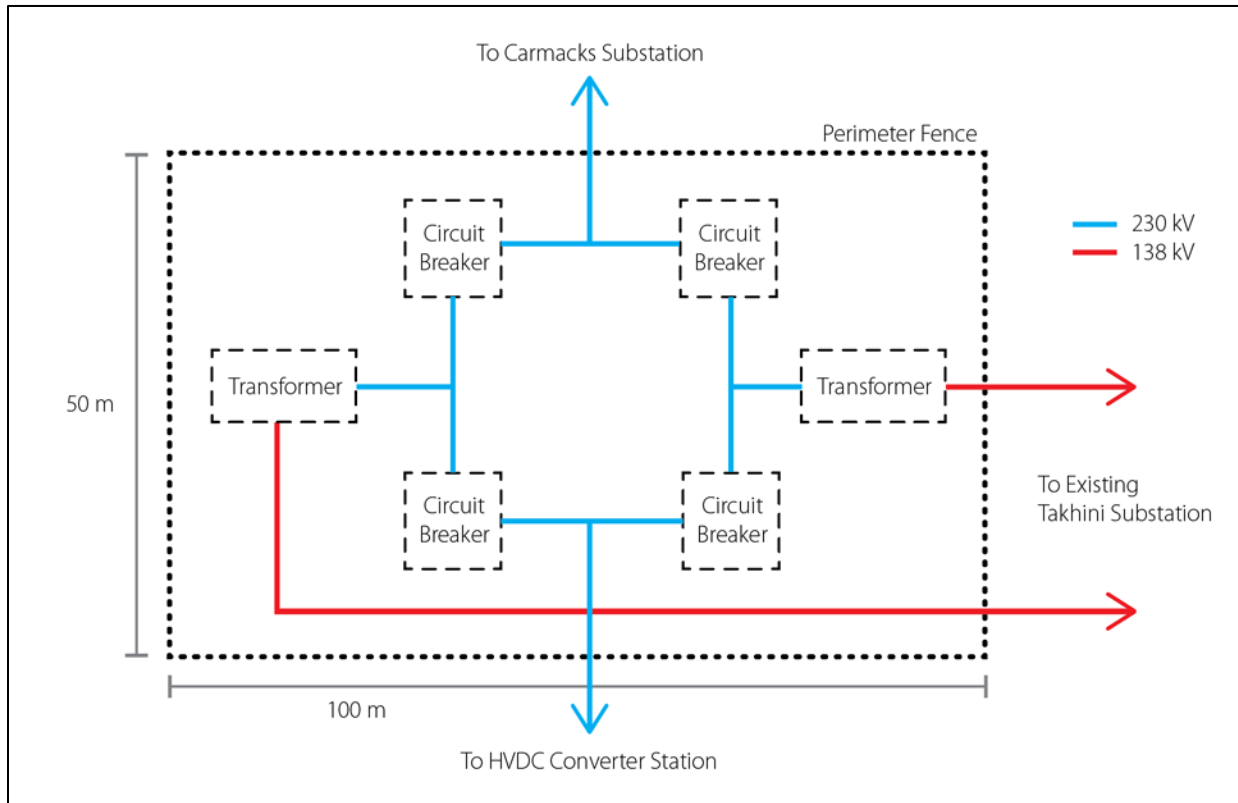
Relevant element(s): SUB\_TAT; SUB\_WATJUNC; SUB\_TAK

**Figure 27 – Casino Mine Substation**



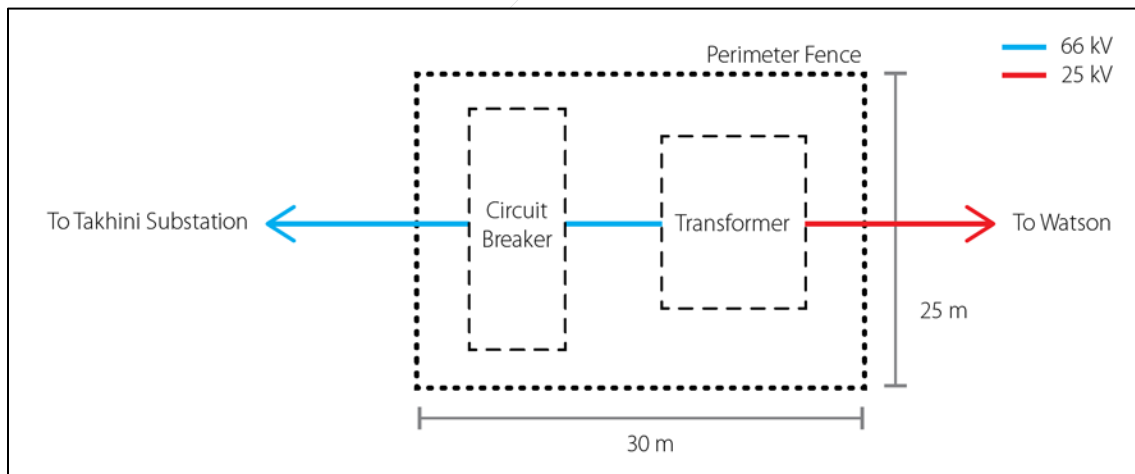
Relevant element(s): SUB\_MINE

**Figure 28 – Takhini Substation Upgrade**



Relevant element(s): SUB\_TAK

**Figure 29 – Watson Lake Junction (Temporary AC Configuration)**



Relevant element(s): SUB\_WATJUNC\_TEMP

## Appendix B – Development Plan – Task Sheets

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## Task Sheet PH1\_FN

<b>Phase</b>	Phase 1 – Pre-Conceptual	} <b>Task Code</b>	PH1_FN
<b>Silo</b>	First Nations		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Using line route mapping, confirm list of potentially affected First Nations to engage in the Yukon and BC and their treaty status.</li> <li>• Communicate that Yukon is considering a YK/BC interconnection and will return with more information if there is appetite in BC.</li> <li>• Create a consultation summary template and log. Populate for all interactions and create a summary of highlights.</li> <li>• First Nations will be funded for their participation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Confirmed list of affected First Nations</li> <li>• First Nations notification of project investigation.</li> </ul>

## Task Sheet PH1\_BC

<b>Phase</b>	Phase 1 – Pre-Conceptual	} <b>Task Code</b>	PH1_BC
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Seek Yukon (YEC / government) input on draft BC whitepaper.</li> <li>• Draft BC whitepaper (project concept and alternatives, potential BC benefits, ownership model options, power purchase).</li> <li>• Benefits may include: sale of power, connection of northern BC industry, electrification of non-grid communities.</li> <li>• Finalize whitepaper and distribute to BC stakeholders (government and BC Hydro).</li> <li>• Yukon government engages BC Minister of Energy and BC Hydro executive to build support for project at the policy level.</li> <li>• Yukon government engages federal representatives to build support for project and gauge possible level of financial participation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• BC whitepaper (concept, benefits, PPA)</li> <li>• Yukon government to BC government engagement</li> <li>• Yukon government to federal government engagement</li> </ul>

## Task Sheet PH1\_ECON

<b>Phase</b>	Phase 1 – Pre-Conceptual	} <b>Task Code</b>	PH1_ECON
<b>Silo</b>	Economics		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• none</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• none</li> </ul>

## Task Sheet PH1\_TECH

<b>Phase</b>	Phase 1 – Pre-Conceptual	} <b>Task Code</b>	PH1_TECH
<b>Silo</b>	Technical		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• none</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• none</li> </ul>

## Task Sheet PH1\_ENVIRO

<b>Phase</b>	Phase 1 – Pre-Conceptual	} <b>Task Code</b>	PH1_ENVIRO
<b>Silo</b>	Environmental		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• none</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• none</li> </ul>

## Task Sheet PH2\_FN

<b>Phase</b>	Phase 2 – Conceptual	} <b>Task Code</b>	PH2_FN
<b>Silo</b>	First Nations		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Seek YDC / Yukon government input on draft First Nations whitepaper (forms and levels of participation acceptable for presentation).</li> <li>• Draft whitepaper communicating project concept &amp; potential First Nation benefits to build support and form a basis for further discussions with First Nations regarding project participation. The case study prepared in the ECON silo will inform the whitepaper.</li> <li>• Engage First Nations in early stage consultation on a government-to-government basis seeking them as potential project partners via written agreement. The form of partnership (ranging from none to equity partner) will be explored first with Yukon government &amp; YEC before holding the First Nation engagement sessions.</li> <li>• Populate consultation template &amp; log for all interactions and create a summary of highlights.</li> <li>• First Nations will be funded for their participation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• First Nations whitepaper (project concept, benefits)</li> <li>• First Nations engagement</li> </ul>

## Task Sheet PH2\_BC

<b>Phase</b>	Phase 2 – Conceptual	} <b>Task Code</b>	PH2_BC
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Yukon government engages BC Minister of Energy and BC Hydro executive to maintain support for project at the policy level.</li> <li>• Yukon government engages federal representatives to build support for project and gauge possible level of financial participation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Yukon government to BC government engagement</li> </ul>

## Task Sheet PH2\_ECON

<b>Phase</b>	Phase 2 – Conceptual	} <b>Task Code</b>	PH2_ECON
<b>Silo</b>	Economics		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• A case study examining the characteristics of other similar successful projects based on First Nation partnerships, such as the Wataynikaneyap Transmission Project line in Northern Ontario. Focus will be placed on how the First Nation(s) were engaged and the form of their participation.</li> <li>• Perform an inventory of potential project users. Users include any load (industrial or community) or supply (generator project) that may feasibly connect to the project. Sources of information will include mining association reports and staff, community representatives, YEC, BC Hydro and Clean Energy BC.</li> <li>• Revise and elaborate project development schedule and risk assessment.</li> <li>• Initial development of a financial model to capture cost assumptions (CAPEX, O&amp;M, capital structure, energy costs &amp; sales) and different participation models for YK government, First Nations and BC Hydro.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Case study of similar successful projects (e.g. Watay)</li> <li>• Inventory of potential project users (e.g. mines, non-grid communities &amp; generation projects)</li> <li>• Cost estimate, project schedule &amp; risk assessment</li> <li>• Financial model</li> </ul>

## Task Sheet PH2\_TECH

<b>Phase</b>	Phase 2 – Conceptual	} <b>Task Code</b>	PH2_TECH
<b>Silo</b>	Technical		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Assess and update conceptual line route using preferred Points of Interconnection (Iskut BC, Tahkini YK, and Carmacks YK), and GeoYukon/GeoBC GIS layers (e.g. First Nation settlement lands (Category A&amp;B), land tenure (e.g. surface &amp; subsurface rights), and protected lands (e.g. wildlife areas, historic sites)).</li> <li>• Assess and revise cost estimate based on route adjustments from GIS work &amp; engagement (e.g. terrain type, linear distance, crossing etc.).</li> <li>• The Alternatives Study, which is a resource plan that places the selection of the Project in the context of available Yukon alternatives. It will include: (1) a high level assessment of potential project risks and benefits (e.g. sustainable energy use, industrial growth, and First Nation economic development), and (2) an assessment of the feasibility of alternate project configurations to connect Watson Lake and northern BC communities/mines - in particular, an AC interconnection that allows load/supply connections without a costly HVDC converter station.</li> <li>• The biggest challenge with an AC interconnection between the Yukon and BC is keeping the two systems synchronized over such a long distance at an AC transmission voltage lower than 500 kV. A potential configuration would be: (a) extend the 287 kV BC Hydro system from Tatogga to Watson Lake Junction, (b) extend the Yukon system at 230 kV from Tahkini to Watson Lake Junction, (c) an AC/DC/AC back-to-back converter to avoid synchronisation issues, and (d) a 25 kV line from Watson Lake Junction to Watson Lake.</li> <li>• Two key technical issues would require examination and resolution in the study: (1) are the two AC systems (Tahkini to Watson Lake Junction and Iskut to Watson Lake Junction) capable of desired transfer, and (2) are the reactive power requirements met with the AC-DC-AC converter, mid-point support, an Iskut statcom, and existing Whitehorse generation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Line route updated using YK/BC data layers</li> <li>• Alternatives study showing alternatives to project</li> <li>• Summary of alternative project configurations to connect Watson Lake and northern BC communities/mines.</li> <li>• Cost estimate</li> </ul>

## Task Sheet PH2\_ENVIRO

<b>Phase</b>	Phase 2 – Conceptual	} <b>Task Code</b>	PH2_ENVIRO
<b>Silo</b>	Environmental		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>Research applicable approval processes based on Yukon (YESAB), BC (BC EAO) and federal jurisdictions (CEAA &amp; NEB). Key factors include material permits required, timelines and potential for harmonization.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>Summary of agencies and jurisdictions applicable to the project.</li> </ul>

## Task Sheet PH3\_FN

<b>Phase</b>	Phase 3 – Pre-Feasibility	} <b>Task Code</b>	PH3_FN
<b>Silo</b>	First Nations		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Continue consultation and engagement discussions with First Nations.</li> <li>• Fund and support cultural field studies that First Nations may wish to undertake to assist in their engagement.</li> <li>• Formalize agreement in a non-binding memorandum of understanding (“MOU”) with First Nations to capture form of First Nations participation in the Project (e.g. joint venture, equity participation, Impact Benefits Agreement).</li> <li>• First Nations to be funded for their participation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Cultural field studies (to include First Nations, in order to build engagement)</li> <li>• Non-binding MOU's, including form of partnership</li> </ul>

## Task Sheet PH3\_BC

<b>Phase</b>	Phase 3 – Pre-Feasibility	} <b>Task Code</b>	PH3_BC
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Building on the Alternatives Study recommendations, BC Hydro will perform a System Impact Study to confirm southern Point of Interconnection and BC Hydro system capacity taking into account BC Hydro’s current system constraints and its NW BC growth plans. BC Hydro’s System Impact Study will confirm for themselves the feasibility of YK/BC interconnection and reveal any unidentified technical issues requiring resolution.</li> <li>• Continue discussions with BC Government and/or BC Hydro regarding project support, ownership BC facilities, configuration, responsibilities (e.g. permitting lead) and power purchase terms.</li> <li>• Formalize an agreement (e.g. non-binding MOU) between YK and BC government (or BC Hydro) confirming discussion outcomes.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• BC Hydro System Impact Study</li> <li>• BC Government non-binding MOU (ownership &amp; permit lead)</li> </ul>

## Task Sheet PH3\_ECON

<b>Phase</b>	Phase 3 – Pre-Feasibility	} <b>Task Code</b>	PH3_ECON
<b>Silo</b>	Economics		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Revise project schedule and risk assessment.</li> <li>• Study successful transmission projects that integrated industrial loads to understand the characteristics of the development and commitments from each party. Examples include: Brucejack Mine connection to Long Lake and Red Chris mine connection to the Northwest Transmission Line.</li> <li>• Meet with potential industrial users identified in the Phase 1 inventory to discuss the project and their pre-requisites for connection. These parameters could serve as draft terms for future MOU(s) and include lead time, power price, capital contribution levels.</li> <li>• The financial model will be updated as needed whenever a key input is revised. Examples include: confirmation of PPA price, revision of capital cost, testing/confirming participation structure.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Revised project schedule and risk assessment</li> <li>• Assessment of market appetite for industrial offtake, including parameters for success</li> <li>• Pre-feasibility level financial model</li> </ul>

## Task Sheet PH3\_TECH

<b>Phase</b>	Phase 3 – Pre-Feasibility	} <b>Task Code</b>	PH3_TECH
<b>Silo</b>	Technical		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Based on feedback received during First Nation engagement and BC Hydro discussions, the line routing will be revised.</li> <li>• Revise the cost estimate based on project configuration and routing modifications.</li> <li>•</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Pre-feasibility level line route (based on stakeholder feedback)</li> <li>• Revised cost estimate</li> </ul>

## Task Sheet PH3\_ENVIRO

<b>Phase</b>	Phase 3 – Pre-Feasibility	} <b>Task Code</b>	PH3_ENVIRO
<b>Silo</b>	Environmental		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Confirm level of review applicable to the project segments with YESAB, BC EAO and CEAA.</li> <li>• The NEB has jurisdiction over international power lines and interprovincial power lines as designated by federal cabinet. There are no historical examples of designated interprovincial power lines and any NEB involvement would be at the federal energy ministers discretion if requested by the project.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Summary of applicable permitting processes and expected level of review (e.g. An Executive Committee or Panel of the Board for Yukon).</li> </ul>

## Task Sheet PH4\_FN

<b>Phase</b>	Phase 4 – Feasibility	} <b>Task Code</b>	PH4_FN
<b>Silo</b>	First Nations		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Work to draft, approve and execute definitive agreements with First Nations.</li> <li>• First Nations to be funded for their participation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Material agreements with First Nations</li> </ul>

## Task Sheet PH4\_BC

<b>Phase</b>	Phase 4 – Feasibility	} <b>Task Code</b>	PH4_BC
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Work to draft, approve and execute definitive agreements with BC Government (or BC Hydro). A single agreement may be developed to cover both the power purchase and interconnection or they may be separate contracts. The BC Government may have a stronger interest in the PPA while BC Hydro will be interested in capturing the technical aspects of the project into an Interconnection Agreement.</li> <li>• A third agreement may be beneficial to capture execution responsibilities including permitting of the BC segments of the project depending on the ownership structure.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• BC Hydro Power Purchase Agreement</li> <li>• BC Hydro Interconnection Agreement</li> </ul>

## Task Sheet PH4\_ECON

<b>Phase</b>	Phase 4 – Feasibility	} <b>Task Code</b>	PH4_ECON
<b>Silo</b>	Economics		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Establish a level of commercial certainty with an offtaker (i.e. mine load) to satisfy project sponsors to proceed to permitting. The form of certainty may be an MOU or more definitive agreement covering power purchase commitments.</li> <li>• Revise project schedule and risk assessment based on updated project understanding.</li> <li>• Update the financial model as required.</li> <li>• Develop project financing strategy for review with project partners.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Letters of intent with industrial offtaker(s)</li> <li>• Feasibility level capital cost estimate, schedule &amp; risk assessment</li> <li>• Revised financial model</li> <li>• Project financing strategy</li> </ul>

## Task Sheet PH4\_TECH

<b>Phase</b>	Phase 4 – Feasibility	} <b>Task Code</b>	PH4_TECH
<b>Silo</b>	Technical		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Perform a feasibility study for the preferred project configuration based on stakeholder feedback and the results of the BC Hydro System Impact Study.</li> <li>• Study will include line routes &amp; cross-sections, structure selection, substation footprints and an update of the capital cost estimate.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Feasibility Study</li> <li>• Line routes &amp; ROW cross-sections</li> <li>• Structure family selected</li> <li>• Substation footprints established</li> </ul>

## Task Sheet PH4\_ENVIRO

<b>Phase</b>	Phase 4 – Feasibility	} <b>Task Code</b>	PH4_ENVIRO
<b>Silo</b>	Environmental		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Scope and define early stage field studies in preparation for permitting and in accordance with First Nations agreements.</li> <li>• Work with permitting agencies (YESAB, EAO, CEAA) to define applicable permitting processes, submit a project description and develop consensus for a draft terms of reference to be used for permitting study work.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Project description accepted by YESAB, BC EAO and CEAA.</li> <li>• Draft EA Terms of Reference</li> </ul>

## Task Sheet PH4\_EXEC

<b>Phase</b>	Phase 4 – Feasibility	} <b>Task Code</b>	PH4_EXEC
<b>Silo</b>	Execution		
<b>Stage</b>	Combined Effort		

<b>Activities</b>	<ul style="list-style-type: none"> <li>The initial approach for contracting will be determined by presenting a set of contracting models (e.g. EPC, Design-Bid-Build etc) for review and decision by project participants. The contracting strategy will also consider timing considerations for contractor engagement. A draft contracting strategy will be developed founded on the preferred option.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>Draft contracting strategy</li> </ul>

## Task Sheet PH5\_FN\_STG1

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_FN_STG1
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Ongoing consultation in support of Yukon permitting processes. Goal is to secure letters of support from all affected First Nations either based on consultation or integration into the project team.</li> <li>• Incorporation of participating First Nations into the permitting team as project partners.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Consultation summaries for environmental assessment</li> </ul>

## Task Sheet PH5\_BC\_STG1

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_BC_STG1
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• No activities identified</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• No deliverables identified</li> </ul>

## Task Sheet PH5\_ECON\_STG1

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_ECON_STG1
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Revise and review risk assessment.</li> <li>• Monitor discussions with potential load entities to refine timing and quantity of industrial offtaker power purchase for integration into financial model.</li> <li>• Update financial model to reflect refined costing due to permitting conditions, refine risk understanding and technical/commercial advancement.</li> <li>• Refine project financing strategy into a plan and test with potential funders.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Revised project schedule and risk assessment.</li> <li>• Updated financial model</li> <li>• Project financing plan</li> </ul>

## Task Sheet PH5\_TECH\_STG1

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_TECH_STG1
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Aerial survey data (LiDAR) will be collected for the study area. This will support the permitting project application as well as progressing the line design.</li> <li>• Design will need to be advanced sufficiently to issue drawings and technical details to support the permitting process.</li> <li>• Update the cost estimate to reflect the impact of YESAB and federal permitting conditions and the Construction Environmental Management Plan (CEMP).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Aerial right-of-way survey (LiDAR)</li> <li>• Permit drawings</li> <li>• Revised cost estimate</li> </ul>

## Task Sheet PH5\_ENVIRO\_STG1

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_ENVIRO_STG1
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Stage 1 is wholly within the Yukon.</li> <li>• Complete discussions with YESAB to develop an approved terms of reference to define the contents of the project proposal.</li> <li>• Complete field studies, environmental and socio-economic impact assessments.</li> <li>• Assemble and submit the project proposal for adequacy, screening and review.</li> <li>• Recommendation and decision document issued.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Yukon socio-economic and environmental review under YESSA</li> <li>• Approved terms of reference</li> <li>• YK field studies &amp; impact reports</li> <li>• Project proposal</li> <li>• Decision document &amp; major permits issued</li> </ul>

## Task Sheet PH5\_EXEC\_STG1

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_EXEC_STG1
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• A contracting plan will be developed based on the strategy developed.</li> <li>• The plan will include securing the engineering resources for detailed design, long-lead procurement identification, division of project into construction packages (e.g. clearing and access separate from line construction).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Contracting plan</li> <li>• Secure engineer for detailed design</li> </ul>

## Task Sheet PH6\_FN\_STG1

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_FN_STG1
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• First Nations partners are integrated into project team and project benefits are delivered such as design input, training, establishment of entities to bid on project work.</li> <li>• Consultation continues to ensure commitments made in permitting process are realized.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• First Nation partners participation as project team members</li> <li>• Implementation of agreed commitments</li> </ul>

## Task Sheet PH6\_BC\_STG1

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_BC_STG1
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• No activities identified</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• No deliverables identified</li> </ul>

## Task Sheet PH6\_ECON\_STG1

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_ECON_STG1
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Revised the financial model based on bid prices from contractors, funding updates from project participants, commercial arrangements with offtakers and financing arrangements.</li> <li>• Revise the project schedule and risk assessment based on feedback from equipment vendors and contractors.</li> <li>• Assemble project financing.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Revise financial model</li> <li>• Revised project schedule and risk assessment</li> <li>• Project financing package</li> </ul>

## Task Sheet PH6\_TECH\_STG1

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_TECH_STG1
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• The design will be advanced sufficiently to support the development and issuing of tender packages for key project elements.</li> <li>• While bids are being prepared, design will continue to a state ready for construction.</li> <li>• Returned bids will be evaluated for technical compliance and recommendations made for contract award. Terms and conditions of contracts will be negotiated with suppliers.</li> <li>• The project cost estimate will be revised based on detailed design and bid results.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Tender packages issued</li> <li>• Design issued for construction</li> <li>• Evaluate bids and recommend preferred</li> <li>• Revise cost estimate</li> </ul>

## Task Sheet PH6\_ENVIRO\_STG1

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_ENVIRO_STG1
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Incorporate all permit and authorizations requirements into a construction environmental management plan (CEMP). The CEMP is a guide for the contractors on activities and actions needed to meet the commitments made during the environmental review process.</li> <li>• Secure late stage permits that follow issuance environmental assessment certificate (e.g. blasting, traffic, license to cut, NavCan notification).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction Environmental Management Plan</li> <li>• Late stage permits</li> </ul>

## Task Sheet PH6\_EXEC\_STG1

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_EXEC_STG1
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Develop tender packages for key project elements (e.g. clearing and access, line construction, stations).</li> <li>• Returned bids will be evaluated for technical compliance and recommendations made for contract award.</li> <li>• Terms and conditions of contracts will be negotiated with contractors.</li> <li>• Procurement packages will be prepared for long lead time equipment (e.g. transformers). The process will include getting technical requirements from designers, pre-qualifying suppliers, requesting quotes and selecting a preferred vendor.</li> <li>• Depending on vendor lead time, some equipment orders may be placed prior to beginning construction.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction contracts ready for award</li> <li>• Long lead-time equipment orders placed</li> </ul>

## Task Sheet PH7\_FN\_STG1

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_FN_STG1
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• First Nations partners are integrated into project team and project benefits are delivered such as work packages awarded and ongoing training &amp; support.</li> <li>• Consultation continues to ensure commitments made in permitting process are realized.</li> <li>• Delivery of additional accomodation and benefits will depend on the level of commitments made in earlier phases.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• First Nation partners participation as project team members</li> <li>• Implementation of agreed commitments</li> </ul>

## Task Sheet PH7\_BC\_STG1

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_BC_STG1
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• No activities identified</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• No deliverables identified</li> </ul>

## Task Sheet PH7\_ECON\_STG1

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_ECON_STG1
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Monitor project performance and revise financial model based on projected completion date and cost on a periodic basis.</li> <li>• Define utility regulatory filing requirements with the Yukon Utilities Board (YUB).</li> <li>• Prepare submissions and secure funding drawings to facilitate construction.</li> <li>• Facilitate communications between the Lender's Engineer and the project team to ensure lender is apprised and satisfied with project progress.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Revised financial model</li> <li>• Funding draws</li> <li>• Lender Engineer activities facilitated</li> </ul>

## Task Sheet PH7\_TECH\_STG1

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_TECH_STG1
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• During construction technical support will include design changes to meet field conditions.</li> <li>• Owner's engineer support to ensure that quality is being maintained and that construction adheres to design.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction support</li> </ul>

## Task Sheet PH7\_ENVIRO\_STG1

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_ENVIRO_STG1
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• An independent environmental monitor will be responsible to ensure the Construction Environmental Management Plan (CEMP) is followed and ensure all reporting requirements are met.</li> <li>• Prepare Operational Environmental Management Plan (OEMP) based on permit requirements, best practices and YEC policy.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction monitoring</li> <li>• Operational Environmental Management Plan (OEMP)</li> </ul>

## Task Sheet PH7\_EXEC\_STG1

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_EXEC_STG1
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Award construction contracts.</li> <li>• Clearing and access activities in preparation for large-scale construction.</li> <li>• Construction of Stage 1 components: SUB_TAK_TEMP, TX_WATJUNC_TAK_TEMP, SUB_WATJUNC_TEMP, TX_WATJUNC_WAT, SUB_WAT</li> <li>• Testing and commissioning in advance of customer acceptance.</li> <li>• During construction operational studies will be performed to establish operating limits for serving Watson Lake from the AC grid. These studies will also form the basis for the development of an internal YEC operating order.</li> <li>• Maintenance plans and schedules will be developed for the transmission lines (e.g. inspections, vegetation management). These will form the basis of an internal YEC operating order.</li> <li>• The line segment connecting Whitehorse to Watson Lake will be a DC line operated as AC. This is an uncommon configuration and some maintenance planning will need to be done to develop safe work procedures.</li> <li>• Watson Lake diesel generator to remain operational, as grid connection will not be possible until construction is complete.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction contracts awarded</li> <li>• Clearing and access complete</li> <li>• Construction complete</li> <li>• Testing &amp; commissioning certification</li> <li>• Operational planning studies</li> <li>• Operating order (YEC)</li> <li>• Maintenance plans</li> <li>• Watson Lake diesel generation maintained</li> </ul>

## Task Sheet PH8\_FN\_STG1

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_FN_STG1
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• First Nations partners receive benefits of project participation (e.g. employment, financial etc)</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Implementation of agreed commitments</li> </ul>

## Task Sheet PH8\_BC\_STG1

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_BC_STG1
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• No activities identified</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• No deliverables identified</li> </ul>

## Task Sheet PH8\_ECON\_STG1

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_ECON_STG1
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Convert project financing into operational debt.</li> <li>• File project completion reports with Yukon Utilities Board (YUB).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Operational debt secured</li> <li>• Utility regulator requirements filed</li> </ul>

## Task Sheet PH8\_TECH\_STG1

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_TECH_STG1
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Prepare drawings to adapt the construction drawings into as-built drawings showing what was actually constructed.</li> <li>• Once into operations there will be little need for engineering and technical activity unless the facilities will be modified to meet an expanded need such as the connection of additional loads (e.g. industrial or community) or generation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• As-built drawings</li> <li>• Evaluation for expansion to connect additional customers or generation.</li> </ul>

## Task Sheet PH8\_ENVIRO\_STG1

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_ENVIRO_STG1
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• During operations there will limited environmental activities compared with the construction phase. The activities will be prescribed in the Operational Environmental Management Plan (OEMP).</li> <li>• Key activities will relate to the development, approval and implementation of vegetation management plans for maintaining required clearances under the transmission lines.</li> <li>• Any environmental incidents will be reported.</li> <li>• Follow-up wildlife surveys and reporting to meet permit requirements may also be necessary.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Vegetation management plans</li> <li>• Incident reporting</li> </ul>

## Task Sheet PH8\_EXEC\_STG1

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_EXEC_STG1
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 1		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• During operation of Stage 1, maintenance on the newly constructed transmission line should be minimal. For the first few years visual inspections will likely suffice.</li> <li>• The Watson Lake diesel generation plant will be maintained as an emergency backup (during Stage 2 cutover to DC and for transmission contingencies).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Maintenance (DC line operated as AC)</li> <li>• Watson Lake back-up generation</li> </ul>

## Task Sheet PH5\_FN\_STG2

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_FN_STG2
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Ongoing consultation in support of BC and federal permitting processes. Goal is to secure letters of support from all affected First Nations either based on consultation or integration into the project team.</li> <li>• Incorporation of participating First Nations into the permitting team to demonstrate true partnership for project.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Consultation summary for environmental assessment</li> </ul>

## Task Sheet PH5\_BC\_STG2

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_BC_STG2
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>BC Hydro and BC government to support the lead entity for BC permitting at a high level with information and review agency priority setting.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>Letter of support for permitting</li> </ul>

## Task Sheet PH5\_ECON\_STG2

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_ECON_STG2
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Revise and review risk assessment.</li> <li>• Drive discussions with industrial offtaker(s) (i.e. mine) to binding agreements to purchase power based on letter(s) of intent developed during Feasibility phase.</li> <li>• Update financial model to reflect refined costing due to permitting conditions, refine risk understanding and technical/commercial advancement.</li> <li>• Refine project financing strategy into a plan and test with potential funders.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Revised project schedule and risk assessment.</li> <li>• Binding offtaker (i.e. mine) agreement(s)</li> <li>• Updated financial model</li> <li>• Project financing plan</li> </ul>

## Task Sheet PH5\_TECH\_STG2

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_TECH_STG2
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Aerial survey data (LiDAR) will be collected for the study area. This will support the permitting project application as well as progressing the line design.</li> <li>• Design will need to be advanced sufficiently to issue drawings and technical details to support the permitting process.</li> <li>• Update the cost estimate to reflect the impact of BC and federal permitting conditions and the Construction Environmental Management Plan (CEMP).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Aerial right-of-way survey (LiDAR)</li> <li>• Permit drawings</li> <li>• Revised cost estimate</li> </ul>

## Task Sheet PH5\_ENVIRO\_STG2

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_ENVIRO_STG2
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• For the Yukon project segments:</li> <li>• Complete discussions with YESAB to develop an approved terms of reference to define the contents of the project proposal.</li> <li>• Complete field studies, environmental and socio-economic impact assessments.</li> <li>• Assemble and submit the project proposal for adequacy, screening and review.</li> <li>• Recommendation and decision document issued.</li> <li>• For BC project segments:</li> <li>• Complete discussions with BC EAO to develop an approved terms of reference to define the contents of the project application.</li> <li>• Complete field studies, environmental and socio-economic impact assessments.</li> <li>• Assemble and submit the project application for completeness, referral and review.</li> <li>• EAO recommendation and EA certificate issued.</li> <li>• The federal CEAA process is expected to harmonized with the BC EAO.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• YESAB Review &amp; BC EA</li> <li>• Approved terms of reference</li> <li>• YK &amp; BC field studies &amp; impact reports</li> <li>• Project application submitted to YESAB and BC EAO</li> <li>• YESAB and BC EA certificates &amp; major permits issued</li> </ul>

## Task Sheet PH5\_EXEC\_STG2

<b>Phase</b>	Phase 5 – Permitting & Pre-Construction	} <b>Task Code</b>	PH5_EXEC_STG2
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• A contracting plan will be developed based on the strategy developed.</li> <li>• The plan will include securing the engineering resources for detailed design, long-lead procurement identification, division of project into construction packages (e.g. clearing and access separate from line construction, DC converter stations).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Contracting plan</li> <li>• Secure engineer for detailed design</li> </ul>

## Task Sheet PH6\_FN\_STG2

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_FN_STG2
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• First Nations partners are integrated into project team and project benefits are delivered such as design input, training, establishment of entities to bid on project work.</li> <li>• Consultation continues to ensure commitments made in permitting process are realized.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• First Nation partners participation as project team members</li> <li>• Implementation of agreed commitments</li> </ul>

## Task Sheet PH6\_BC\_STG2

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_BC_STG2
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• During design BC Hydro may be involved for high level input into design depending ownership of the BC project elements.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• No key deliverable</li> </ul>

## Task Sheet PH6\_ECON\_STG2

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_ECON_STG2
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Revised the financial model based on bid prices from contractors, funding updates from project participants, commercial arrangements with offtakers and financing arrangements.</li> <li>• Revise the project schedule and risk assessment based on feedback from equipment vendors and contractors.</li> <li>• Assemble project financing.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Revise financial model</li> <li>• Project financing package</li> <li>• Commercial agreement(s) with loads</li> </ul>

## Task Sheet PH6\_TECH\_STG2

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_TECH_STG2
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• The design will be advanced sufficiently to support the development and issuing of tender packages for key project elements. While bids are being prepared, design will continue to a state ready for construction.</li> <li>• Returned bids will be evaluated and recommendations made for contract award. Terms and conditions of contracts will be negotiated with suppliers.</li> <li>• Procurement packages will be prepared for long lead time equipment (e.g. transformers).</li> <li>• The project cost estimate will be revised based on detailed design and bid results.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Tender packages issued</li> <li>• Design issued for construction</li> <li>• Evaluate bids and recommend preferred</li> <li>• Revise cost estimate</li> </ul>

## Task Sheet PH6\_ENVIRO\_STG2

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_ENVIRO_STG2
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Incorporate all permit and authorizations requirements into a construction environmental management plan (CEMP). The CEMP is a guide for the contractors on activities and actions needed to meet the commitments made during the environmental review process.</li> <li>• Secure late stage permits that follow issuance environmental assessment certificate (e.g. blasting, traffic, license to cut, NavCan notification).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction Environmental Management Plan</li> <li>• Late stage permits</li> </ul>

## Task Sheet PH6\_EXEC\_STG2

<b>Phase</b>	Phase 6 – Detailed Design	} <b>Task Code</b>	PH6_EXEC_STG2
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Develop tender packages for key project elements (e.g. clearing and access, line construction, AC stations, DC converter stations).</li> <li>• Returned bids will be evaluated for technical compliance and recommendations made for contract award.</li> <li>• Terms and conditions of contracts will be negotiated with contractors.</li> <li>• Procurement packages will be prepared for long lead time equipment (e.g. transformers, DC converter station packages). The process will include getting technical requirements from designers, pre-qualifying suppliers, requesting quotes and selecting a preferred vendor.</li> <li>• Depending on vendor lead time, some equipment orders may be placed prior to beginning construction.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Long lead procurement</li> <li>• HVDC converter stations</li> </ul>

## Task Sheet PH7\_FN\_STG2

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_FN_STG2
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• First Nations partners are integrated into project team and project benefits are delivered such as work packages awarded and ongoing training &amp; support.</li> <li>• Consultation continues to ensure commitments made in permitting process are realized.</li> <li>• Delivery of additional accomodation and benefits will depend on the level of commitments made in earlier phases.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• First Nation partners participation as project team members</li> <li>• Implementation of agreed commitments</li> </ul>

## Task Sheet PH7\_BC\_STG2

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_BC_STG2
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• During construction operational studies will be performed together with BC Hydro to establish operating limits (import &amp; export) and form the basis for development of operating orders.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Operational integration study</li> </ul>

## Task Sheet PH7\_ECON\_STG2

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_ECON_STG2
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Monitor project performance and revise financial model based on projected completion date and cost on a periodic basis.</li> <li>• Define utility regulatory filing requirements with the Yukon Utilities Board (YUB) and BC Utilities Commission (BCUC).</li> <li>• Prepare submissions and secure funding drawings to facilitate construction.</li> <li>• Facilitate communications between the Lender's Engineer and the project team to ensure lender is apprised and satisfied with project progress.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Revised financial model</li> <li>• Funding draws</li> <li>• Lender Engineer activities facilitated</li> </ul>

## Task Sheet PH7\_TECH\_STG2

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_TECH_STG2
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• During construction technical support will include design changes to meet field conditions.</li> <li>• Owner's engineer support to ensure that quality is being maintained and that construction adheres to design.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction support</li> </ul>

## Task Sheet PH7\_ENVIRO\_STG2

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_ENVIRO_STG2
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• An independent environmental monitor will be responsible to ensure the Construction Environmental Management Plan (CEMP) is followed and ensure all reporting requirements are met.</li> <li>• Prepare Operational Environmental Management Plan (OEMP) based on permit requirements, best practices and YEC/BC Hydro policy.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction monitoring</li> <li>• Operational Environmental Management Plan (OEMP)</li> </ul>

## Task Sheet PH7\_EXEC\_STG2

<b>Phase</b>	Phase 7 – Construction	} <b>Task Code</b>	PH7_EXEC_STG2
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Award construction contracts.</li> <li>• Clearing and access activities in preparation for large-scale construction.</li> <li>• Construction of Stage 2 components: SUB_TAK, TX_WATJUNC_TAK, SUB_WATJUNC, TX_YK_WATJUNC, TX_TAT_YK, SUB_TAT, TX_TAK_CAR, SUB_CAR, TX_CAR_MINE, SUB_MINE</li> <li>• Testing and commissioning in advance of customer acceptance.</li> <li>• Operational studies will be performed to establish operating limits for serving the new mine load from the AC grid. These studies will also form the basis for the development of an internal YEC operating order.</li> <li>• Operational studies will also be performed together with BC Hydro to establish operating limits (import &amp; export) and form the basis for development of operating orders for YEC and BC Hydro.</li> <li>• Maintenance plans and schedules will be developed for the transmission lines (e.g. inspections, vegetation management). For DC converter station the supplier will need to be involved in the development of maintenance plans.</li> <li>• Watson Lake diesel generator to remain operational, as an interruption of grid service will be required during AC to HVDC switchover.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Construction contracts awarded</li> <li>• Clearing and access complete</li> <li>• Construction complete</li> <li>• Testing &amp; commissioning certification</li> <li>• Operational planning studies</li> <li>• Operating order (YEC and BC Hydro)</li> <li>• Maintenance plans</li> <li>• Watson Lake diesel generation maintained</li> </ul>

## Task Sheet PH8\_FN\_STG2

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_FN_STG2
<b>Silo</b>	First Nations		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• First Nations partners receive benefits of project participation (e.g. employment, financial etc)</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Implementation of agreed commitments</li> </ul>

## Task Sheet PH8\_BC\_STG2

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_BC_STG2
<b>Silo</b>	Government & BC Hydro		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• An operating agreement will be required with BC Hydro. The parameters of the agreement will be contained in an operating order detailing operational responsibility, operating limits (flow &amp; voltage), switching procedures, communications and outage scheduling.</li> <li>• An operating committee may be struck with representation from BC Hydro to meet annually to review maintenance plans and operational issues.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Operating order</li> <li>• Operating committee</li> </ul>

## Task Sheet PH8\_ECON\_STG2

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_ECON_STG2
<b>Silo</b>	Economics		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Convert project financing into operational debt.</li> <li>• File project completion reports with Yukon Utilities Board (YUB) and BC Utilities Commission (BCUC).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Operational debt secured</li> <li>• Utility regulator requirements filed</li> </ul>

## Task Sheet PH8\_TECH\_STG2

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_TECH_STG2
<b>Silo</b>	Technical		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Prepare drawings to adapt the construction drawings into as-built drawings showing what was actually constructed.</li> <li>• Once into operations there will be little need for engineering and technical activity unless the facilities will be modified to meet an expanded need such as the connection of additional loads (e.g. industrial or community) or generation.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• As-built drawings</li> <li>• Evaluation for expansion to connect additional customers or generation.</li> </ul>

## Task Sheet PH8\_ENVIRO\_STG2

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_ENVIRO_STG2
<b>Silo</b>	Environmental		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• During operations there will limited environmental activities compared with the construction phase. The activities will be prescribed in the Operational Environmental Management Plan (OEMP).</li> <li>• Key activities will relate to the development, approval and implementation of vegetation management plans for maintaining required clearances under the transmission lines.</li> <li>• Any environmental incidents will be reported.</li> <li>• Follow-up wildlife surveys and reporting to meet permit requirements may also be necessary.</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• Vegetation management plans</li> <li>• Incident reporting</li> </ul>

## Task Sheet PH8\_EXEC\_STG2

<b>Phase</b>	Phase 8 – Operations	} <b>Task Code</b>	PH8_EXEC_STG2
<b>Silo</b>	Execution		
<b>Stage</b>	Stage 2		

<b>Activities</b>	<ul style="list-style-type: none"> <li>• Stage 2 will contain a number of elements that project participants have not operated before, such as DC lines and DC converter stations.</li> <li>• Maintenance and operation will need to be according to the suppliers specifications to ensure the warranty remains in place.</li> <li>• Operational staff will require training to confidently operate the new YK/BC interconnection.</li> <li>• Operating agreements between BC Hydro, YEC and the new mine load will need to be implemented.</li> <li>• The Watson Lake diesel generation plant will be maintained as an emergency backup (for transmission contingencies).</li> </ul>
<b>Deliverables</b>	<ul style="list-style-type: none"> <li>• HVDC warranty</li> <li>• Operating agreements (BCH / YEC / Mine)</li> <li>• Operators trained for HVDC</li> <li>• Watson Lake back-up generation</li> </ul>

## Appendix C – Interconnection Study Report

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# **Yukon - BC Interconnection Study**

**Submitted By:** Midgard Consulting Incorporated

**Date:** June 7, 2018

## Document Control and Sign-off

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### DOCUMENT NUMBER

P0306-D001-RPT-R03-EXT

### REVISION CONTROL

Revision	Description	Date
0	Initial draft for client review	Mar 29, 2018
1	Second draft with additional appendices addressing O&M, Watson Lake & WECC	May 8, 2018
2	Report finalized with executive summary and updated Watson Lake appendix.	May 25, 2018
3	Removed reference to transmission north of Stewart Crossing being upgraded to 138 kV in Section 2.1	June 7, 2018

### REPORT SIGN-OFF

Prepared By:  June 7, 2018  
 Matt Good, Midgard Consulting Inc. Date

 June 7, 2018  
 Brian Mukeswe, Midgard Consulting Inc. Date

Checked By:  June 7, 2018  
 Chris Oakley, Midgard Consulting Inc. Date

Approved By:  June 7, 2018  
 Matt Good, Midgard Consulting Inc. Date

## Executive Summary

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### Introduction

The Yukon has the opportunity to host new mines such as the Casino copper-gold mine which is estimated to have an electrical power requirement of approximately 100 MW. While the Yukon does not currently have sufficient electrical generation resources to serve a new mining load of this magnitude, British Columbia Hydro (BC Hydro) expects to have surplus generation capacity upon completion of the 1100 MW Site C hydro project in 2024.

### Purpose of Report

In consideration of BC's anticipated generation resource surplus, this report examines the feasibility of developing a new transmission connection between the Yukon and northwestern BC to gain access to the power needed to serve new mining loads such as the Casino mine. The report includes a high level description of the proposed interconnection and the rationale behind the proposed options. In addition, the report summarizes the costs and risks associated with the proposed options for the Yukon – BC interconnection.

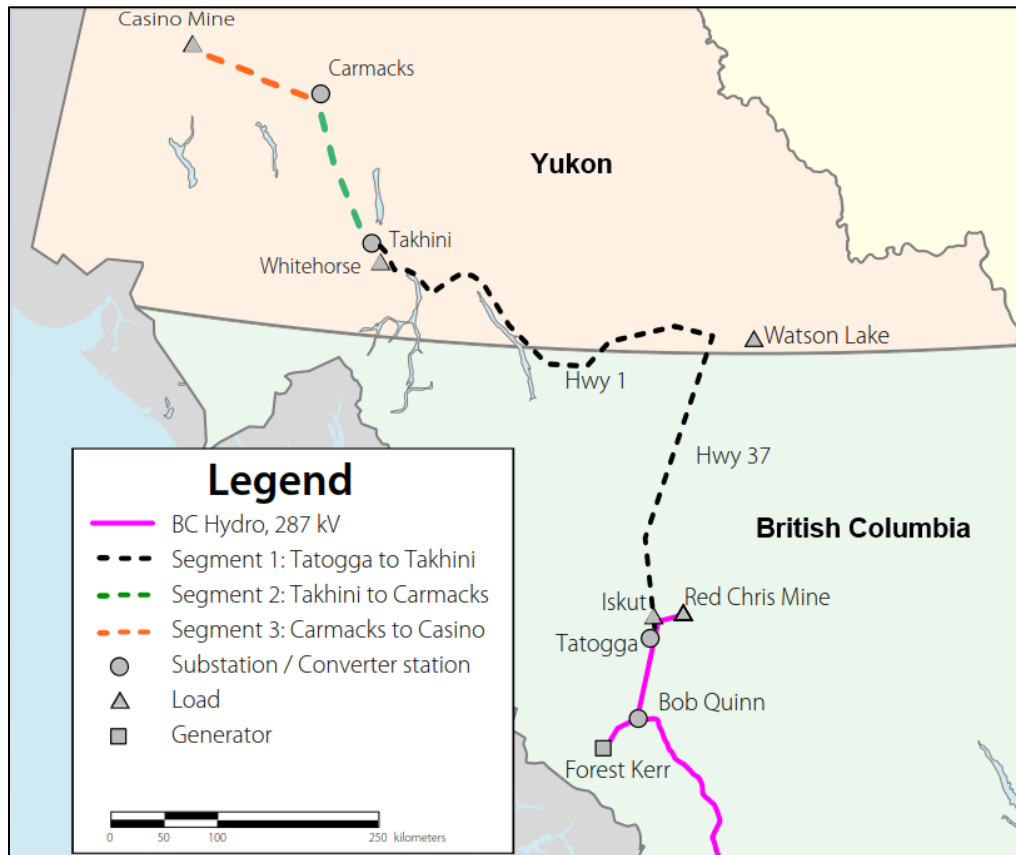
### YK/BC Option Development and Analysis

The work was divided into the following phases:

1. Transmission route divided into three segments
2. Multiple line options developed for each segment
3. Planning analysis reduced options
4. Cost analysis

Figure 1 shows the proposed transmission interconnection project between Northwest BC and a mining load represented as divided into three line segments.

**Figure 1: Proposed Interconnection Route**



The three line segments are summarized in Table 1 below.

**Table 1: Summary of Proposed Interconnection Route by Segment**

Line Segment	Description	Major Remarks
1. Tatogga to Takhini (TAK)	765 km, paralleling Yukon Highway 1 (Alaska Highway) and BC Highway 37	New transmission line Generally rough terrain (some mountain passes, multiple river crossings)
2. Takhini to Carmacks (CAR)	158 km, following the existing 138 kV corridor parallel with the Klondike Highway	Upgrade / rebuild of existing 138 kV line
3. Carmacks to Casino Mine (CAS)	180 km along the planned Casino access road from Carmacks	New transmission line

Multiple line options were developed for each segment and then planning analysis and powerflow simulation used to narrow the list down to the five (5) options in Table 2 for cost analysis.

**Table 2: Summary of Rationale Used for Developing Recommendations**

Line Segment	Description
1. Tatogga to Takhini	- AC Options ruled out due to voltage control issues - Three (3) HVDC options studied
2. Takhini to Carmacks	- 138 kV option ruled out due to transfer capacity limitations - One (1) 230 kV option studied
3. Carmacks to Casino Mine	- 138 kV option ruled out in order to maintain Voltage consistency with segment 2 - One (1) 230 kV option studied

The cost analysis revealed that the HVDC options for Segment 1 (TAK) were similar with no clear preference emerging. The costs, line and station, are tabulated in Table 3 range from \$1.6B to \$1.7B to connect from BC to Casino mine.

**Table 3: Summary of Recommended Options for Each Line Segment**

#	Segment	Option Name	Voltage	Line Type	Capital Cost (CAD 2018, \$M)
1	Tatogga to Takhini (765 km)	TAK-150DC	±150 kV	Overhead HVDC 795-Drake Conductor	\$1,040
		TAK-200DC-LIGHT	±200 kV	Overhead HVDC 477-Hawk Conductor	\$1,150
		TAK-200DC-HEAVY	±200 kV	Overhead HVDC 795-Drake Conductor	\$1,170
2.	Takhini to Carmacks (158 km)	CAR-230AC	230 kV	Overhead AC 2 x 477-Hawk Conductor	\$214
3.	Carmacks to Casino (180 km)	CAS-230AC	230 kV	Overhead AC 2 x 477-Hawk Conductor	\$336

## Watson Lake

The community of Watson Lake is currently served by diesel generation and not connected to the Yukon grid. With the proposed route for Segment 1 (TAK) of the YK/BC interconnection passing within 20 km of Watson Lake, there is an opportunity to integrate Watson Lake into the grid.

The recommended solution is an HVDC Converter station at Watson Lake with an estimated cost of \$75M. Unlike novel AC solutions with comparable costs, such as single phase AC transmission, HVDC converter technology is mature and widely adopted in industry.

## Conclusions

The Yukon needs approximately 100 MW of additional generation resources to connect the proposed Casino mine. This report has shown that it is technically feasible to supply the 100 MW load requirement via a combination of HVDC transmission line interconnecting the BC and Yukon grids, and 230 kV AC transmission line interconnecting the Casino mine to a reinforced Yukon grid.

The total capital costs range from \$1.6B to \$1.7B to connect from Tatogga near Iskut, BC to the proposed Casino mine. The total capital costs range from \$1.0B to \$1.2B to connect from Tatogga to Takhini near Whitehorse.

The similar viability of three (3) different HVDC options creates the range. The HVDC options vary in capital cost and loss performance. Evaluating the losses associated with operation did not produce a clear selection. If the project proceeds the HVDC options should be evaluated at higher resolution to select the optimal voltage level and conductor size.

The key risks identified include the level of reliability associated with 1600 km of radial transmission, the available capacity at the BC Hydro Tatogga substation at Iskut, BC, cost estimate accuracy and the long-term price of power purchased from BC Hydro.

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## 1 Introduction

---

The Yukon has the opportunity to host new mines such as the Casino copper-gold mine which is estimated to have an electrical power requirement of approximately 100 MW. While the Yukon does not currently have sufficient electrical generation resources to serve a new mining load of this magnitude, British Columbia Hydro (BC Hydro) expects to have surplus generation capacity upon completion of the 1100 MW Site C hydro project in 2024. In consideration of BC's anticipated generation resource surplus, this report examines the feasibility of developing a new transmission connection between the Yukon and northwestern BC to gain access to the power needed to serve new mining loads such as the Casino mine, and to provide the Yukon with electrical trading opportunities that would be enabled by interconnection with the Western North American power market.

The report is arranged into the following eight sections:

- Current Context – summarizes the electrical grid and available capacity of the Yukon and NW BC.
- Route Selection – proposes a transmission line route from the existing northern terminus of the BC grid to the Casino mine site via the existing Takhini substation
- Line Options – describes technical alternatives for each of the three line segments comprising the combined YK-BC interconnection and Casino supply path
- Transfer Capacity – establishes how much power can be transferred along each line segment using the evaluated options
- Cost Estimates – develops order of magnitude capital cost information for completing the YK-BC interconnection and Casino Mine supply
- Line Option Analysis – presents the economic tradeoff between cost of losses incurred during operation and carrying costs of the capital investment required to implement the different interconnection alternatives
- Risks – identification and discussion of the risks associated with undertaking a YK-BC interconnection to serve the Casino mine.
- Conclusions & Recommendations – summarizes key study findings and proposes next steps

## 2 Current Context

---

### 2.1 The Yukon Electric Grid

The Yukon electric grid has a 2018 forecast peak load of 93 MW<sup>1</sup> and 146 MW<sup>2</sup> of installed generation.

The electrical grid is configured as a set of radial transmission lines emanating out from core transmission substations located near Whitehorse, Carmacks and Stewart Crossing. South of Stewart Crossing the backbone system is energized at 138 kV as shown in Figure 2.1. Currently, north of Stewart Crossing the system is energized at 69 kV. Other lower voltage systems, energized at either 35 kV or 25 kV, connect to the 138 kV transmission system and reach out to smaller communities around the Yukon (e.g. Haines Junction, Ross River, communities south of Whitehorse etc.).

The largest proportion of annual electric energy (typically 95% and up to 99% depending upon annual hydrology) is generated by hydroelectric facilities located at Whitehorse (40 MW), Mayo (15 MW), and Aishihik (37 MW). Grid Connected Diesel generation plants are located at Whitehorse, Faro, Mayo, Dawson City, Carmacks, Haines Junction, Teslin, Ross River, Stewart Crossing and Pelly Crossing to supply local backup energy in the event of a transmission outage, or to augment hydroelectric generation when necessary during peak demand times. For example, in the winter when electricity demand is the highest, the Whitehorse hydro plant can be de-rated to 25 MW during periods of low winter flows on the Yukon River and backup diesel may be required to meet peak demands. In addition to diesel and hydroelectric generation, there is a wind generating facility (0.8 MW) at Haeckel Hill near Whitehorse, and a natural gas generation facility (8.8 MW) in Whitehorse.

An overview map showing the Yukon's current electrical grid, including key generation resources and industrial sites across the territory is provided in Figure 2.1.

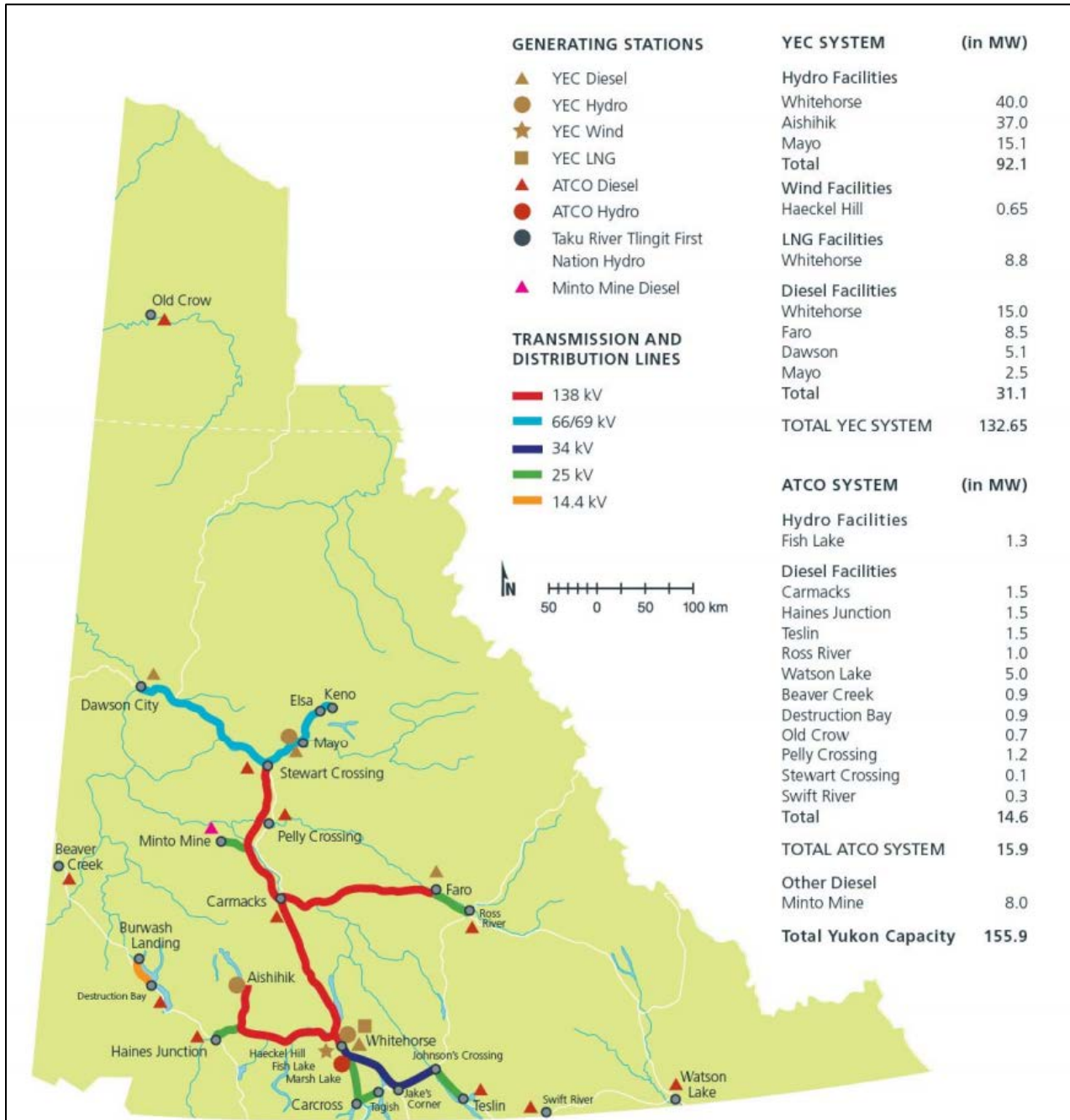
A more detailed single line diagram focusing upon the interconnected Yukon Energy electricity grid facilities is shown in Figure 2.2.

---

<sup>1</sup> Source: Load and Generation forecasts from the YEC 2016 Resource Plan

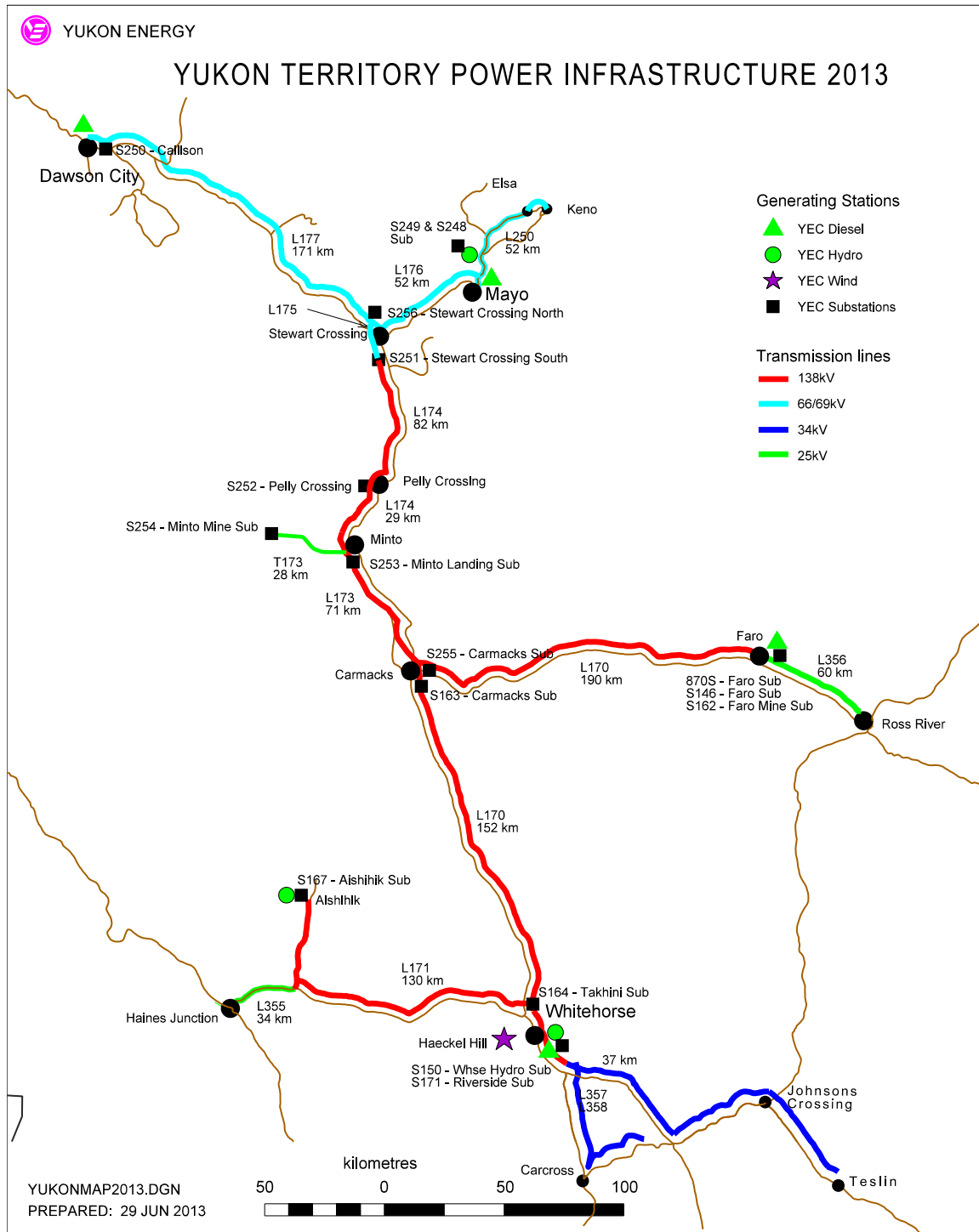
<sup>2</sup> Excess generation above the peak load is required to provide redundant sources of generation as part of contingency planning should a generator or transmission line fail.

Figure 2.1: Map of Yukon and its Existing Electrical Infrastructure <sup>3</sup>



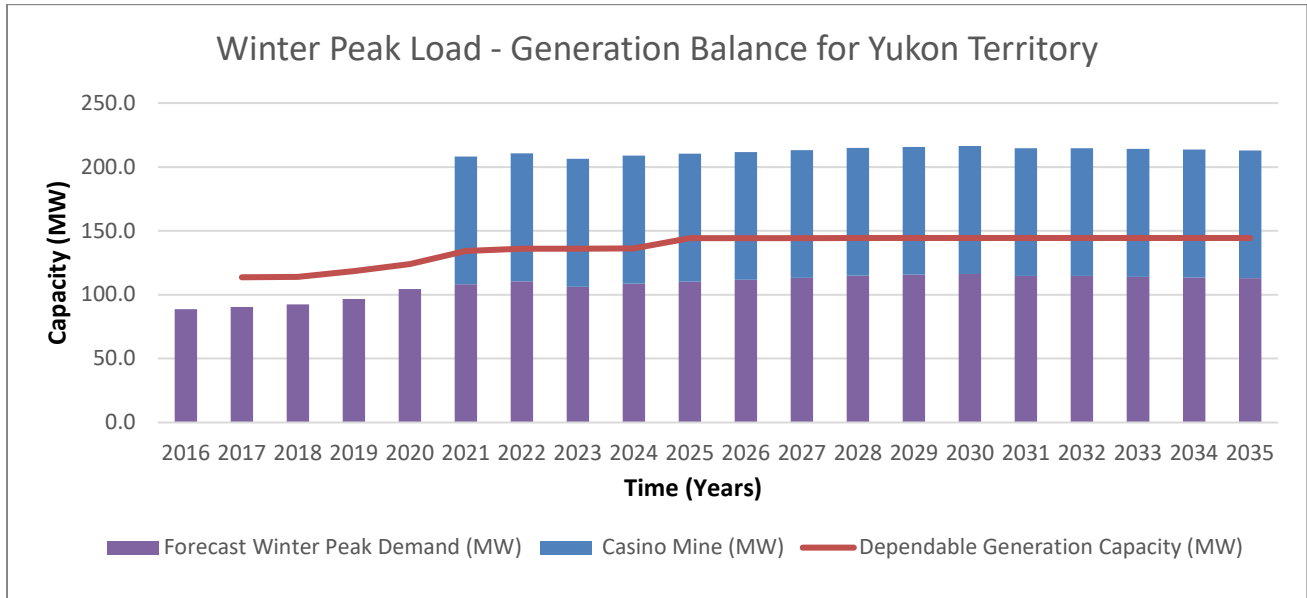
<sup>3</sup> 2016 Yukon Energy Resource Plan

Figure 2.2: Single Line Diagram of Yukon Territory Power Infrastructure

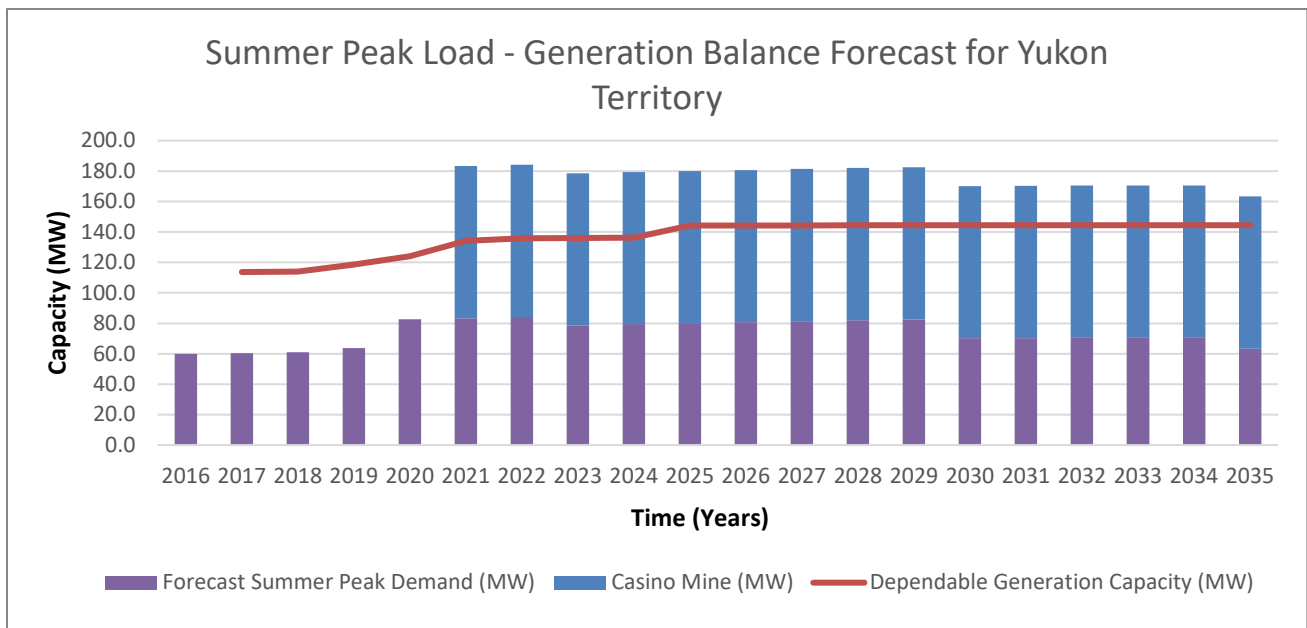


As shown in Figure 2.3 and Figure 2.4, if a 100 MW mining load is added at Casino, the Yukon Grid cannot serve the resulting load by relying only on existing Yukon generation assets<sup>4</sup> in either winter or summer. In the absence of new generation development within the Yukon, a transmission interconnection between the northwestern BC Hydro Grid and the Casino mine site could provide the power needed to serve the new load.

**Figure 2.3: Forecasted Winter Peak Load-Generation Balance for Yukon Territory<sup>5</sup>**



**Figure 2.4: Forecasted Summer Peak Load-Generation Balance for Yukon Territory<sup>6</sup>**



<sup>4</sup> As measured by Dependable Capacity of the generation assets.

<sup>5</sup> Source: Load and Generation forecasts from the YEC 2016 Resource Plan

<sup>6</sup> Source: Load and Generation forecasts from the YEC 2016 Resource Plan

## 2.2 The BC Electric Grid

As seen in Figure 2.5 below, the BC electric grid is large compared to the Yukon grid, with more than 18,000 km of transmission lines & cables ranging from 69 to 500 kV, over 300 substations, and interties to both Alberta and the United States (via the State of Washington). More than 90% of BC’s 14,000 MW of existing generation<sup>7</sup> capacity is hydro-based, and BC has significant water storage and inter-seasonal generating flexibility. Over 57,300 GWh energy was sold domestically in 2017. After the BCH 110 MW Site C hydro project is completed in 2024, BC Hydro should have adequate load/resource balance to provide Yukon mining (e.g. Casino project) with electrical supply.

**Figure 2.5: BC Transmission System**



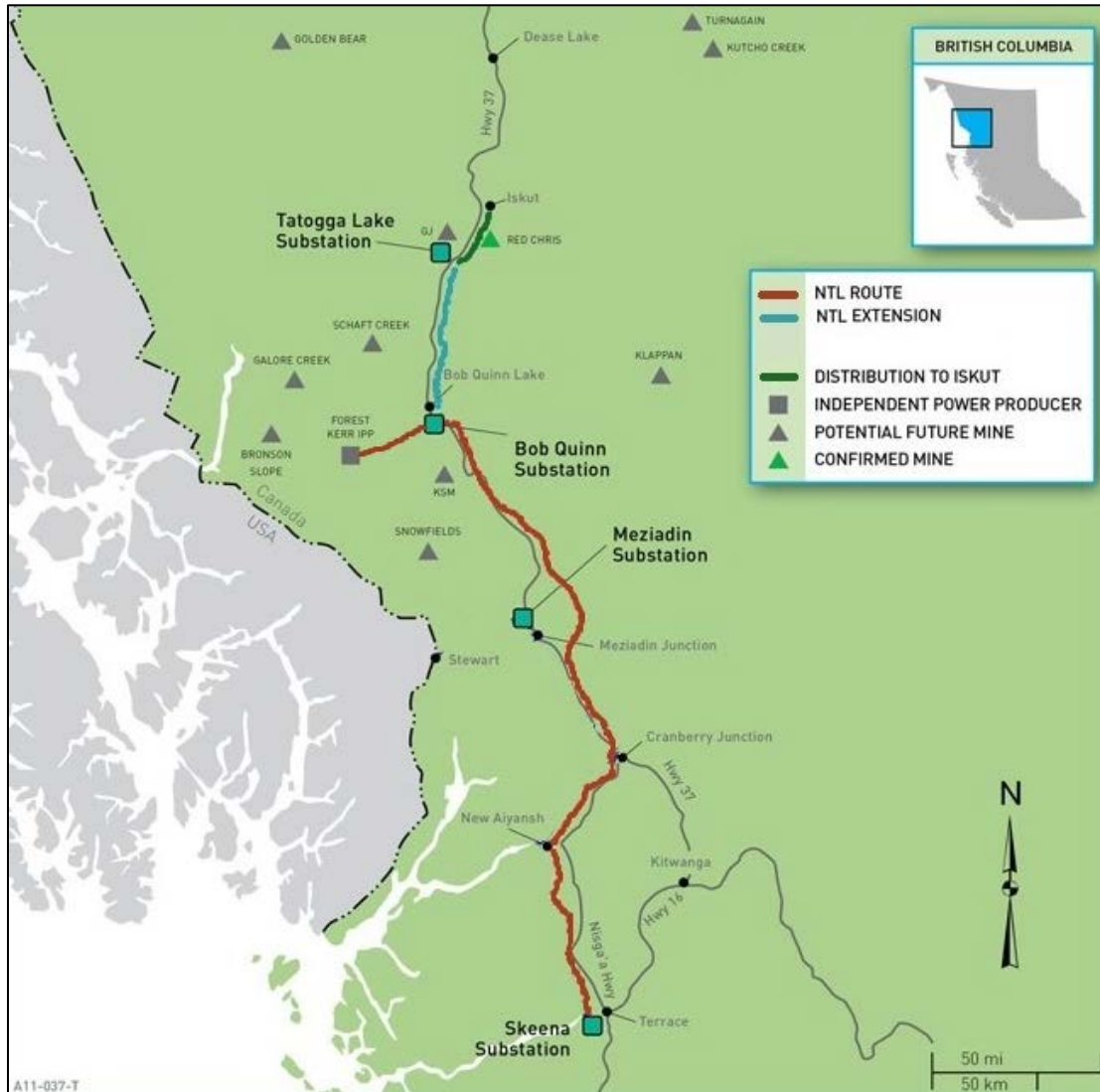
<sup>7</sup> Site C capacity is not included.

The recent completion by BC Hydro of the 287 kV Northern Transmission Line (NTL) running 340 km north from the Skeena 500 kV substation near Terrace to Bob Quinn Lake, and the further 93 km extension of the 287 kV transmission system north from Bob Quinn Lake to Tatogga Lake substation near Iskut<sup>8</sup>, has effectively pushed the northern terminus of BC Hydro's 287 kV system to within approximately 750 km of Whitehorse. Figure 2.6 below shows an overview of the Northwest BC grid, whose northernmost point is the nearest location for Yukon to interconnect with the Western North American electricity grid. The Western North American grid is normally referred to as the Western Electricity Coordinating Council ("WECC"), and connecting to WECC will subject Yukon to North American electrical system reliability standards requirements. Appendix I discusses WECC and which reliability standards Yukon would be required to adopt after interconnecting to WECC.

---

<sup>8</sup> The 93 km extension was built as part of the Red Chris Mine electrification project

Figure 2.6: Northwest Transmission Line and Extension<sup>9</sup>



Source: BC Hydro

The key generation resources presently connected to the NTL system in NW BC are shown in Table 4.

Table 4: The Main Generation Resources Connected to the NTL System

Hydro Plant	Peak Capacity (May to October)	Low Capacity (November to April)
Forest Kerr	195 MW	55 MW <sup>10</sup>
McLymont Creek	66 MW	19 MW <sup>11</sup>

<sup>9</sup> [https://www.bchydro.com/news/press\\_centre/news\\_releases/2014/new-transmission-line-ready-to-power-northwest-bc.html](https://www.bchydro.com/news/press_centre/news_releases/2014/new-transmission-line-ready-to-power-northwest-bc.html)

<sup>10</sup> Estimated from hydrology slide in Coast Mountain Hydro presentation to Smithers city council – June 21, 2002

<sup>11</sup> Assumed to have the same seasonal shape as Forest Kerr.

Volcano Creek	16 MW	5 MW <sup>12</sup>
Totals	277 MW	79 MW

The only large load presently connected to the NTL system in Northwest BC is the Red Chris mine, which has an existing peak demand of 45 MW. The most likely identified and proposed mines in Northwest BC which may seek grid connection in the future are listed in Table 5.

**Table 5: Current and Proposed Mining Loads on the NTL System**

Mine	Electrical Demand	Status
Red Chris	45 MW	Operational to 2043
Avanti Kitsault	(remaining NTL capacity)	Substantially started per EAO
Galore Creek	90 MW	Permitting / Environmental Assessment
Schaft Creek	96 MW	Permitting / Environmental Assessment
Mount Klappan	6 MW	Permitting / Environmental Assessment

Midgard was advised in personal communications with BC Hydro that one of the mines has priority access to all the remaining load serving capacity of the existing 287 kV NTL circuit. Because the BC Environmental Assessment Office (EAO) recently declared the Avanti Kitsault mine to have substantially started, this is likely the mine BC Hydro referred to. In Midgard’s assessment, BC Hydro does not appear to be considering the system support benefits of the existing local generation resources (79 MW – 277 MW) when assessing the ability of the NTL system to serve additional loads.

On a Provincial basis, BC has sufficient resources to support year-round exports of 100 MW to the Yukon. However, the calculation of available capacity in Northwest BC grid depends on BC Hydro’s assumptions regarding the availability of local generation and the status of proposed mining loads. In any case, Midgard anticipates that the technical challenges of interconnection can be overcome if all parties to the project are aligned.

<sup>12</sup> Assumed to have the same seasonal shape as Forest Kerr.

### 3 Route Selection

The proposed transmission interconnection project between Northwest BC and a mining load represented by the Casino mine is divided into the three following major line segments:

- Segment 1: Tatogga to Takhini
- Segment 2: Takhini to Carmacks
- Segment 3: Carmacks to Casino Mine

A preliminary route was selected for the three segments based on the following guiding factors:

- Ease of access (construction and maintenance)
- Avoiding sensitive areas (parks / protected areas)
- Avoiding challenging geological features (mountain passes, avalanche areas)

Figure 3.1 shows the three segments of the proposed transmission interconnection route that generally follow existing road infrastructure. Following existing roads increases overall transmission line length but does not trigger major new access creation, which is costly compared to line construction.

**Figure 3.1: Proposed Interconnection Route**

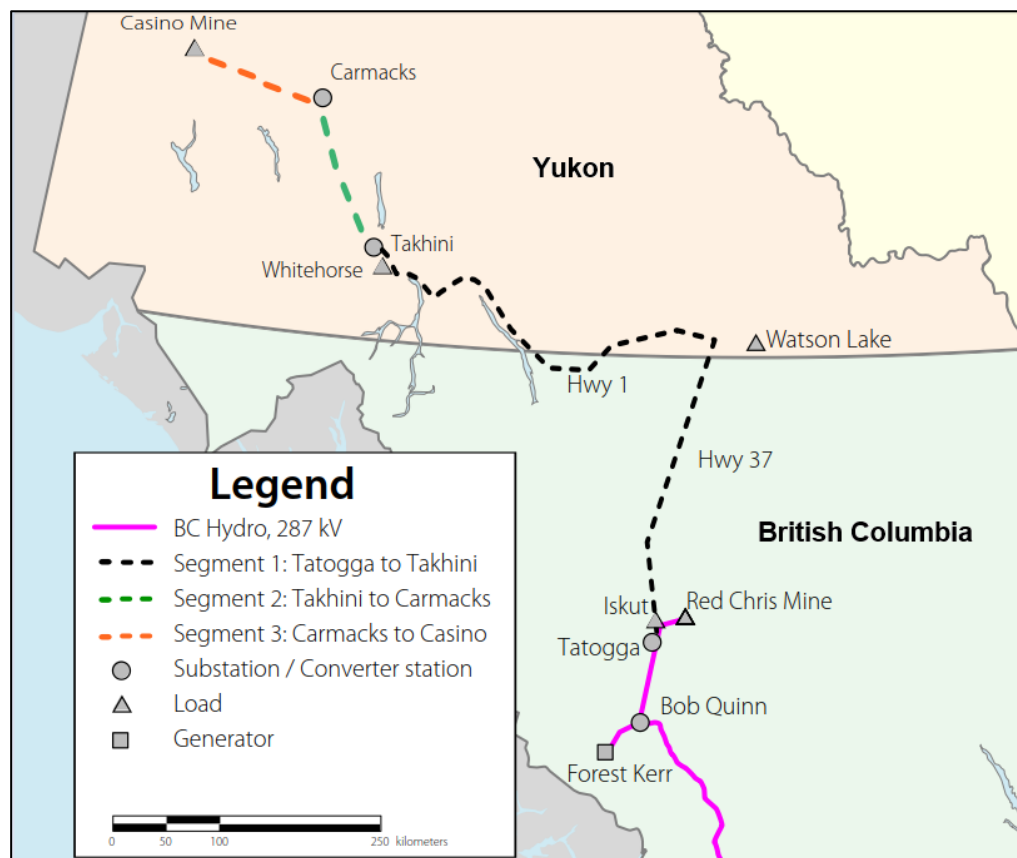


Table 6 describes the routes selected.

**Table 6: Summary of Proposed Interconnection Route**

Line Segment	Description	Major Remarks
4. Tatogga to Takhini	765 km, paralleling Yukon Highway 1 (Alaska Highway) and BC Highway 37	New transmission line Generally rough terrain (some mountain passes, multiple river crossings)
5. Takhini to Carmacks	158 km, following the existing 138 kV corridor parallel with the Klondike Highway	Upgrade / rebuild of existing 138 kV line
6. Carmacks to Casino Mine	180 km along the planned Casino access road from Carmacks	New transmission line

A more direct transmission route is possible going northwest from Tatogga to Takhini following the historical Telegraph Route to Whitehorse. While the approximately 550 km long Telegraph route saves 200 km of new transmission line construction, this route would also require the construction of at least 300 km of new access roads through challenging terrain which significantly increases overall cost of the Tatogga to Takhini Telegraph routes.

## 4 Line Options

### 4.1 Line Options Identified

Table 7 shows the line types and voltage classes that were considered for the proposed BC - Yukon Interconnection.

**Table 7: Options Considered for the BC – Yukon Interconnection**

#	Segment	Voltage	Line Type	Option Name
1.	Tatogga to Takhini (765 km)	287 kV	Overhead AC 477-Hawk Conductor	TAK-287AC
		500 kV	Overhead AC 477-Hawk Conductor	TAK-500AC
		±150 kV	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	TAK-150DC
		±200 kV	Overhead HVDC 477-Hawk Conductor Symmetrical Monopole	TAK-200DC-LIGHT
		±200 kV	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	TAK-200DC-HEAVY
2.	Takhini to Carmacks (158 km)	138 kV	Overhead AC Existing line	CAR-138AC
		230 kV	Overhead AC 2 x 477-Hawk Conductor	CAR-230AC
3.	Carmacks to Casino (180 km)	138 kV	Overhead AC 795-Drake Conductor	CAS-138AC-LIGHT
		138 kV	Overhead AC 1590-Falcon Conductor	CAS-138AC-HEAVY
		230 kV	Overhead AC 2 x 477-Hawk Conductor	CAS-230AC

Watson Lake is not currently connected to the Yukon grid, but the proposed line route for Segment 1 (TAK) will pass within 15 km. Options for connecting Watson Lake to the Yukon electric grid are presented in Appendix H:

## 4.2 Line Options Technical Viability

This section describes the rationale applied to determine the preferred line options for each segment.

### 4.2.1 Segment 1 – Tatogga to Takhini

AC transmission is technically challenging for the Tatogga to Takhini segment. The two most obvious AC options involve either extending the existing 287 kV system from Tatogga to Takhini, or alternatively, stepping-up from 287 kV to 500 kV at Tatogga, building the new line to Takhini (near Whitehorse) at 500 kV, and then stepping down to 230 kV (or 138 kV) at Takhini.

- **287 kV Option:** Powerflow analysis shows that the 287 kV option has voltage control issues (see Appendix E: Figure E-4: ) because the line is lightly loaded along its considerable length<sup>13</sup>. As a result, line end shunt reactors are required to provide acceptable voltage control on a steady state basis, and it is expected that detailed stability studies would also reveal the need for costly dynamic voltage support facilities (i.e. Static Synchronous Compensators (STATCOMs) and/or synchronous condensers) at the Tatogga and Takhini terminals, and/or intermediate substations. Additionally, series capacitors may also be required to shorten the effective electrical distance between terminals to mitigate dynamic voltage impacts resulting from changing power transfer levels.
- **500 kV Option:** A 500 kV transmission line will have even greater voltage control issues because of the higher operating voltage at the proposed relatively light loading levels<sup>14</sup>. 500 kV class construction costs involved in building the interconnection line and the terminal substations will also increase capital and operating costs when compared to 287 kV capital and operating costs.

Ultimately, the technical and economic issues associated with the AC interconnection alternatives render the use of AC effectively impractical for the proposed level of power transfer.

Fortunately, HVDC transmission options can provide technically and economically viable solutions in situations where AC systems face significant challenges due to the transmission of electrical power over long distances (i.e. distances such as those between Tatogga and Takhini). The following are reasons HVDC transmission is potentially attractive for the proposed Tatogga to Takhini transmission line segment:

- **Reduced Transmission Line Cost:** HVDC transmission line construction is less costly than AC Line construction on a per km basis for equivalent voltage classes because HVDC transmission uses two (2)

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<sup>13</sup> On long lightly load AC transmission lines, capacitive line charging results in voltage rise along the line.

<sup>14</sup> On long lightly load AC transmission lines, capacitive line charging results in voltage rise along the line. Line charging increases directly proportionally with the square of the operating voltage, therefore increasing from 287 kV to 500 kV, almost quadruples the voltage increase effects of line charging.

conductor bundles (one for each DC Pole) instead of the three (3) required<sup>15</sup> for AC transmission (one for each Phase). As a result, HVDC transmission towers are simpler in design geometry when compared to AC transmission towers due to the elimination of the third conductor bundle.

- **Dynamic Voltage Control:** Voltage Source Commutated (VSC) HVDC technology<sup>16</sup> provides dynamic voltage control capability at each of the terminal converter stations. This eliminates the need for additional facilities dedicated to providing voltage support.

The voltage level/conductor combinations evaluated in this report are potential minimum cost configurations able to deliver 100 MW at Takhini with less than 15% losses<sup>17</sup>.

Table 8 lists the transmission options that were assessed for technical viability for Segment 1 from Tatogga to Takhini, and indicates which transmission options were selected for further assessment.

**Table 8: Technical Viability of Options for Segment 1 - Tatogga to Takhini**

Segment	Line Type	Voltage	Technical Viability	Option Name
Tatogga to Takhini (765 km)	Overhead AC 477-Hawk Conductor	287 kV	Using 287 kV is challenging from a voltage control perspective at 100 MW power transfer because of the resulting capacitive line charging effects on lightly loaded long distance power lines. Powerflow results (see Appendix E: Figure E-4: ) show a need for shunt reactors. Stability studies can be expected to demonstrate the need for significant dynamic/transient voltage support.  <b>Option Status: Not selected for further assessment</b>	TAK-287AC
	Overhead AC 477-Hawk Conductor	500 kV	Using 500 kV triggers similar voltage control issues as in the 287 kV case.  <b>Option Status: Not selected for further assessment</b>	TAK-500AC

<sup>15</sup> Standard AC transmission requires three (3) phases. In special and unique circumstances, single phase transmission is used in areas where load do not warrant three (3) phase transmission and the supplying electrical system can support a load imbalance associated with a single phase transmission load. For this application, BC Hydro’s 287 kV system could only supply a balanced three (3) phase load.

<sup>16</sup> Please see Appendix C: for an introduction to HVDC.

<sup>17</sup> HVDC projects typically target achieving line losses of less than 5%, but given the total length and high capital costs of the proposed interconnection facilities and the relatively low proposed transfer levels, economic optimization drives higher than typical losses for this facility. Before selecting a final HVDC transmission configuration, voltage level and conductor sizes need further optimization to determine the lowest net present value of combined capital and operating costs.

Segment	Line Type	Voltage	Technical Viability	Option Name
	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	±150 kV	12% losses for 100 MW transfer; Converter stations required at Tatogga and Takhini <b>Option Status: Selected for further assessment</b>	TAK-150DC
	Overhead HVDC 477-Hawk Conductor Symmetrical Monopole	±200 kV	11% losses for 100 MW transfer; Converter stations required at Tatogga and Takhini <b>Option Status: Selected for further assessment</b>	TAK-200DC-LIGHT
	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	±200 kV	7% losses for 100 MW transfer; Converter stations required at Tatogga and Takhini <b>Option Status: Selected for further assessment</b>	TAK-200DC-HEAVY

#### 4.2.2 Segment 2 – Takhini to Carmacks

Segment 2 from Takhini to Carmacks is currently a 138 kV line which is approaching end of life. In consideration of the desire to supply potential Yukon mining loads such as Casino, there are two (2) options for replacing the Takhini to Carmacks transmission line segment:

- **138 kV Rebuild:** Rebuilding this segment with 138 kV would minimize YEC’s capital and operating cost, but would limit the total power transfer capacity to what it is today, and would be inadequate to serve a Casino Mine load.
- **230 kV Upgrade:** Upgrading this segment to 230 kV is necessary to serve a Casino Mine load, and also represents an opportunity provide additional transfer capacity to other loads north of Whitehorse. Increased transfer capacity ensures that the Yukon import capacity provided by a new HVDC link from BC will not be unduly constrained, and thus creates opportunities for serving additional Yukon loads beyond a Casino mine. Additionally, operating at 230 kV when compared to 138kV results in lower line losses for the same power transfer level.

Table 9 lists the transmission options that were assessed for technical viability for Segment 2 from Takhini to Carmacks, and indicates which transmission option was selected for further assessment.

**Table 9: Technical Viability of Options for Segment 2 - Takhini to Carmacks**

Segment	Line Type	Voltage	Technical Viability	Option Name
Takhini to Carmacks (158 km)	Overhead AC Re-build existing line	138 kV	Option is viable, but would limit the total transfer capability of the line to what it is today (which is inadequate to serve the new Casino Mine load). <b>Option Status: Not selected for further assessment</b>	CAR-138AC
	Overhead AC 2 x 477-Hawk Conductor	230 kV	2.3% losses Reactive voltage support required at Carmacks <b>Option Status: Selected for further assessment</b>	CAR-230AC

#### 4.2.3 Segment 3 – Carmacks to Casino

Segment 3 from Carmacks to Casino is recommended to have the same voltage and conductor configuration as was determined for Segment 2. Maintaining voltage and conductor consistency minimizes the 138 kV step-down transformer capacity required at Carmacks to serve the existing 138 kV system loads north of Carmacks, reduces transmission line losses when compared to a 138 kV line serving the Casino Mine load, and allows for better voltage control at the Casino Mine.

Table 10 lists the transmission options that were assessed for technical viability for Segment 3 from Carmacks to Casino, and indicates which transmission option was selected for further assessment.

**Table 10: Technical Viability of Options for Segment 3 - Carmacks to Casino**

Segment	Line Type	Voltage	Technical Viability	Option Name
Carmacks to Casino (180 km)	Overhead AC 795-Drake Conductor	138 kV	7.8% losses; Reactive voltage support required <b>Option Status: Not selected</b>	CAS-138AC-LIGHT
	Overhead AC 1590-Falcon Conductor	138 kV	4.4% losses; Reactive voltage support required <b>Option Status: Not selected</b>	CAS-138AC-HEAVY
	Overhead AC 2 x 477-Hawk Conductor	230 kV	2.5% losses Reactive voltage support required <b>Options Status: Selected for further assessment</b>	CAS-230AC

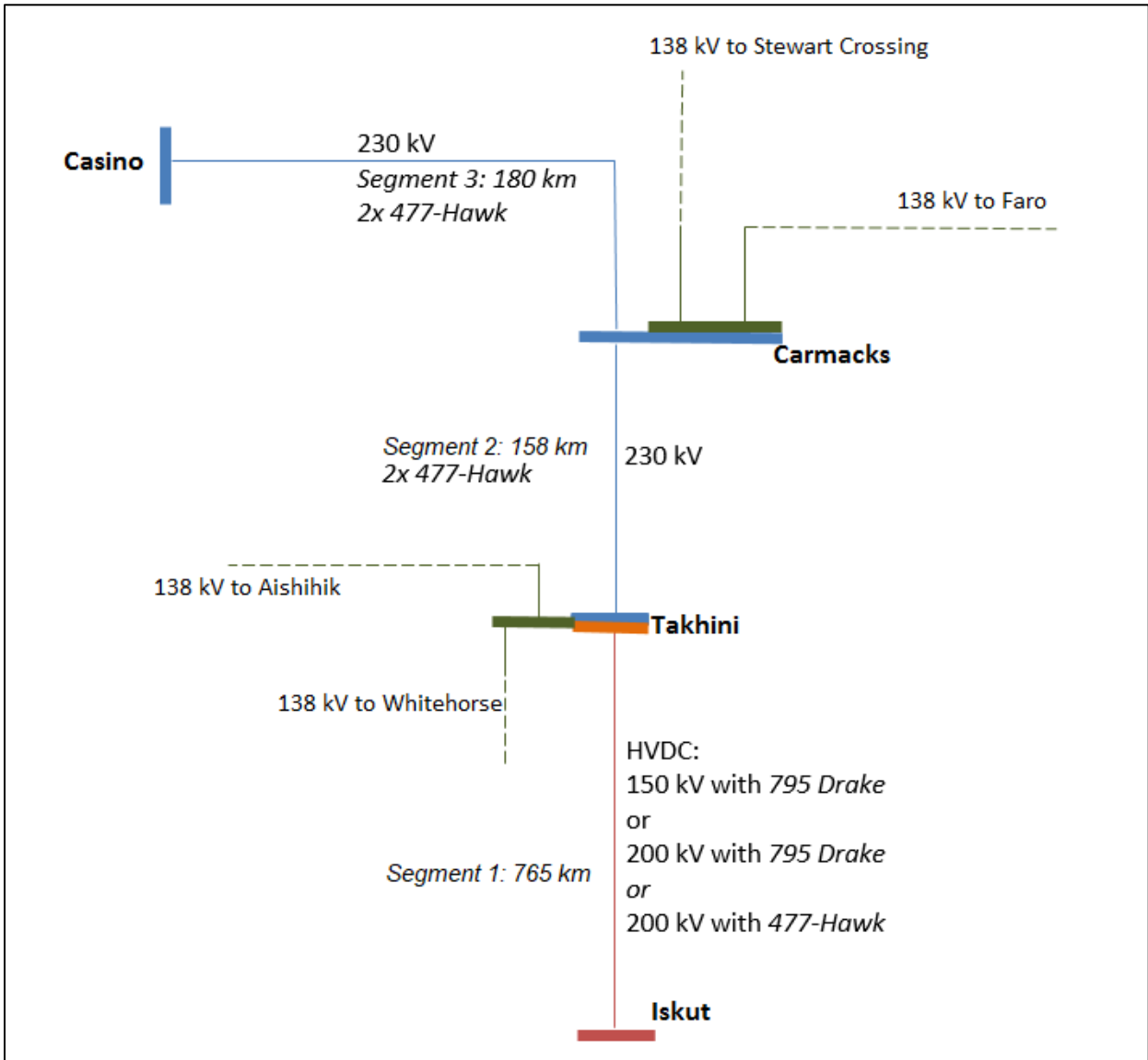
### 4.3 Line Options Selected For Further Evaluation

Based on the results of the evaluating the technical viability of options for segments one (1) through three (3), Figure 4.1 shows the preferred line options (conductor type and voltage levels) for the AC part of the interconnection project (Tahkini to Carmacks to Casino), and the different options that are to be considered for the DC part of the project (Tatogga to Takhini). The technically viable options for each segment are also summarized in Table 11.

**Table 11: Summary of Technically Viable Options for Each Segment**

#	Segment	Voltage	Line Type	Option Name
4.	Tatogga to Takhini (765 km)	±150 kV	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	TAK-150DC
		±200 kV	Overhead HVDC 477-Hawk Conductor Symmetrical Monopole	TAK-200DC-LIGHT
		±200 kV	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	TAK-200DC-HEAVY
5.	Takhini to Carmacks (158 km)	230 kV	Overhead AC 2 x 477-Hawk Conductor	CAR-230AC
6.	Carmacks to Casino (180 km)	230 kV	Overhead AC 2 x 477-Hawk Conductor	CAS-230AC

**Figure 4.1: Single Line Diagram Showing the Preferred Line Options**



## 5 Transfer Capacity

**Segment 1 (HVDC from Tatogga to Takhini):** The Transfer Capacity is determined based on the seasonal thermal constraints of the conductors under consideration.

**Segments 2 and 3 (AC from Takhini to Casino):** In addition to the thermal constraints of the conductors under consideration, the Transfer Capacity of AC lines is affected by voltage performance<sup>18</sup>. For Segments 2 and 3, voltage performance was the limiting factor for Transfer Capacity.

Table 12 shows the resulting Transfer Capacity for each segment.

**Table 12: Transfer Capacity of the Preferred Line Options**

Segment	Line Type	Voltage	Transfer Capacity Limitations
1. Tatogga to Takhini (765 km)	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	±150 kV	Max Power Transfer: Summer - <b>116 MW</b> ; Winter – <b>178 MW</b> Limiting Factor: Thermal <sup>19</sup>
	Overhead HVDC 477-Hawk Conductor Symmetrical Monopole	±200 kV	Max Power Transfer: Summer - <b>112 MW</b> ; Winter – <b>172 MW</b> Limiting Factor: Thermal <sup>20</sup>
	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	±200 kV	Max Power Transfer: Summer - <b>154 MW</b> ; Winter – <b>238 MW</b> Limiting Factor: Thermal <sup>21</sup>
2. Takhini to Carmacks (158 km)	Overhead AC 2 x 477-Hawk Conductor	230 kV	Max Power Transfer: <b>261 MW</b> <sup>22</sup> Limiting Factor: Voltage Angle at Casino <sup>23</sup> Casino – 33°; Carmacks – 16°;
3. Carmacks to Casino (180 km)	Overhead AC 2 x 477-Hawk Conductor	230 kV	Max Power Transfer: <b>230 MW</b> <sup>24</sup> Limiting Factor: Voltage Angle at Casino <sup>25</sup> Casino – 33°; Carmacks – 16°;

<sup>18</sup> Voltage criteria:

- All bus voltages are maintained between 0.9 and 1.1 per unit
- Voltage angle between Takhini and Casino is maintained below 33 degrees.

<sup>19</sup> 75 °C Maximum Operating Temperature; 35 °C Ambient Temperature; 2 ft./sec Wind Speed

<sup>20</sup> 75 °C Maximum Operating Temperature; 35 °C Ambient Temperature; 2 ft./sec Wind Speed

<sup>21</sup> 75 °C Maximum Operating Temperature; 35 °C Ambient Temperature; 2 ft./sec Wind Speed

<sup>22</sup> A higher power transfer is obtainable if the voltage angle is allowed to exceed 33°

<sup>23</sup> See details in Figure E-3: Transfer Capacity - Angle Limiting Condition on the AC Part of the Line

<sup>24</sup> A higher power transfer is obtainable if the voltage angle is allowed to exceed 33°: See Figure E-3: Transfer Capacity - Angle Limiting Condition on the AC Part of the Line

<sup>25</sup> See details in Figure E-3: Transfer Capacity - Angle Limiting Condition on the AC Part of the Line

## 6 Cost Estimates

Each line segment requires capital investment in both transmission lines and substation(s). The equipment requirements for each segment are shown below. The methodology used to determine the cost estimates is described in Appendix A: Line Cost Estimating Methodology.

The three (3) segments of the proposed BC – Yukon interconnection are composed of the following components that drive capital costs:

1. Segment 1 (TAK) – BC to Yukon HVDC
  - a. Two AC/DC convertor stations (Tatogga, Takhini;  $\pm 150$  kV or  $\pm 200$  kV)
  - b. 765 km of overhead DC line ( $\pm 150$  kV or  $\pm 200$  kV; Hawk or Drake conductor)
2. Segment 2 (CAR) – Takhini to Carmacks
  - a. Expand Takhini substation with a 230 kV ring bus and 230/138kV transformer
  - b. 158 km of 230 kV overhead transmission line (2 x Hawk)
3. Segment 3 (CAS) – Carmacks to Casino
  - a. Expand Carmacks substation with a 230 kV ring bus and 230/138kV transformer
  - b. 180 km of 230 kV overhead transmission line (2 x Hawk)

Section 4.3 narrowed the analysis down to the following options:

- Segment 1 (TAK) – three (3) technically viable options
- Segment 2 (CAR) – one (1) technically viable option
- Segment 3 (CAS) – one (1) technically viable option

Depending on the option selected for Segment 1 (TAK), there are three (3) possible scenarios as shown in Table 13.

**Table 13: Capital Cost Scenarios for BC - Yukon Interconnection**

Scenario	Scenario 1	Scenario 2	Scenario 3
Segment 1 (TAK)	<b>TAK-150DC</b> Voltage: $\pm 150$ kV Overhead HVDC Conductor: 795-Drake Conductor Substation: 2 x HVDC Converter Stations	<b>TAK-200DC-LIGHT</b> Voltage: $\pm 200$ kV Overhead HVDC Conductor: 477-Hawk Conductor Substation: 2 x HVDC Converter Stations	<b>TAK-200DC-HEAVY</b> Voltage: $\pm 200$ kV Overhead HVDC Conductor: 795-Drake Conductor Substation: 2 x HVDC Converter Stations

Scenario	Scenario 1	Scenario 2	Scenario 3
Segment 2 (CAR)	<b>CAR-230AC</b> Voltage: 230 kV Overhead AC Conductor: 2 x 477-Hawk Conductor Substation: Takhini Expansion	<b>CAR-230AC</b> Voltage: 230 kV Overhead AC Conductor: 2 x 477-Hawk Conductor Substation: Takhini Expansion	<b>CAR-230AC</b> Voltage: 230 kV Overhead AC Conductor: 2 x 477-Hawk Conductor Substation: Takhini Expansion
Segment 3 (CAS)	<b>CAS-230AC</b> Voltage: 230 kV Overhead AC Conductor: 2 x 477-Hawk Conductor Substation: Carmacks Expansion	<b>CAS-230AC</b> Voltage: 230 kV Overhead AC Conductor: 2 x 477-Hawk Conductor Substation: Carmacks Expansion	<b>CAS-230AC</b> Voltage: 230 kV Overhead AC Conductor: 2 x 477-Hawk Conductor Substation: Carmacks Expansion

Table 14, Table 15, and Table 16 show the capital costs associated with each of the three (3) scenarios.

**Table 14: Total Capital Costs - Scenario 1**

Scenario 1 (±150 kV Drake DC, 230 kV AC)	Length	Cost (CAD 2018, \$M)	Unit Cost
Segment 1 - Tatogga – Takhini (±150 kV DC, Drake Conductor)	765 km	\$643	\$0.84 M/km
Segment 2 - Takhini to Carmacks	158 km	\$204	\$1.29 M/km
Segment 3 - Carmacks to Casino	180 km	\$326	\$1.81 M/km
<b>Total Line</b>	<b>1103 km</b>	<b>\$1,173</b>	<b>\$1.06 M/km</b>
2 x ±150 kV HVDC Converter Stations	–	\$375	–
Takhini Substation Expansion	–	\$10	–
Carmacks Substation Expansion	–	\$10	–
<b>Total Stations</b>	–	<b>\$395</b>	–
<b>Scenario 1 Total</b>	–	<b>\$1,570</b>	–

**Table 15: Total Capital Costs - Scenario 2**

Scenario 2 (±200 kV Hawk DC, 230 kV AC)	Length	Cost (CAD 2018, \$M)	Unit Cost
Segment 1 – Tatogga - Takhini	765 km	\$735	\$0.96 M/km
Segment 2 - Takhini to Carmacks	158 km	\$204	\$1.29 M/km
Segment 3 - Carmacks to Casino	180 km	\$326	\$1.81 M/km
<b>Total Line</b>	<b>1103 km</b>	<b>\$1,270</b>	<b>\$1.15 M/km</b>
2 x ±200 kV HVDC Converter Stations	–	\$392	–
Takhini Substation Expansion	–	\$10	–
Carmacks Substation Expansion	–	\$10	–
<b>Total Stations</b>	–	<b>\$412</b>	–

<b>Scenario 2 Total</b>	–	<b>\$1,680</b>	–
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**Table 16: Total Capital Costs - Scenario 3**

<b>Scenario 3 (±200 kV Drake DC, 230 kV AC)</b>	<b>Length</b>	<b>Cost (CAD 2018, \$M)</b>	<b>Unit Cost</b>
<b>Segment 1 – Tatogga – Takhini</b>	765 km	\$758	\$0.99 M/km
<b>Segment 2 - Takhini to Carmacks</b>	158 km	\$204	\$1.29 M/km
<b>Segment 3 - Carmacks to Casino</b>	180 km	\$326	\$1.81 M/km
<b>Total Line</b>	<b>1103 km</b>	<b>\$1,290</b>	<b>\$1.17 M/km</b>
<b>2 x ±200 kV HVDC Converter Stations</b>	–	\$392	–
<b>Takhini Substation Expansion</b>	–	\$10	–
<b>Carmacks Substation Expansion</b>	–	\$10	–
<b>Total Stations</b>	–	<b>\$412</b>	–
<b>Scenario 3 Total</b>	–	<b>\$1,700</b>	–

The difference between the total capital costs for each of the three scenarios is less than the estimate accuracy. For planning purposes the capital costs are effectively equal for all scenarios to connect Casino mine at \$1.6B to \$1.7B. The capital cost to connect only to Whitehorse from BC ranges from \$1.0B to \$1.2B.

The only variation in capital costs across the scenarios is due to line options for Segment 1 (TAK). The cost variation is not large enough to select an option for Segment 1 (TAK) so line options are analyzed further in Section 7 with respect to operational costs.

## 7 Line Option Analysis for Segment 1 (TAK)

While Section 4.3 narrows Segments 2 and 3 (AC from Takhini to Casino) down to a single option each, there are still three (3) options under consideration for Segment 1 (TAK). Table 17 summarizes the three options for Segment 1 that are analyzed in this section based on capital costs and operational costs.

**Table 17: Line Options Analyzed for Segment 1 (TAK)**

#	Segment	Voltage	Line Type	Option Name
1	Tatogga to Takhini (765 km)	±150 kV	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	TAK-150DC
		±200 kV	Overhead HVDC 477-Hawk Conductor Symmetrical Monopole	TAK-200DC-LIGHT
		±200 kV	Overhead HVDC 795-Drake Conductor Symmetrical Monopole	TAK-200DC-HEAVY

The variation in the capital costs of the three options for Segment 1 (TAK) is negligible compared to the total estimated cost of the contemplated BC Yukon Interconnection. The methodology used for estimating the capital costs of the different options is summarized in Appendix A:

Operational costs can also be used as a deciding factor for selecting a preferred option for Segment 1 (TAK).

Operational costs are comprised of the following:

1. **Maintenance Costs:** These include the cost of clearing and maintaining the Right of Way and the cost of inspections and patrols. Maintenance costs are forecasted to be equal for all of the three options. A detailed breakdown of the maintenance costs is shown in Appendix G:.
2. **Line Losses Costs:** This refers to the cost of the electrical power losses associated with each line option (i.e. electrical power lost as heat along the conductor's length). Appendix B: contains a discussion on the estimation of losses and their Net Present Value (NPV) calculation over the 25 year expected life of the Casino mine.

Table 18 compares the resulting total costs of each option for Segment 1 (TAK).

**Table 18: Comparison of Line Options for Segment 1 (TAK)**

<b>Option Name</b>	<b>Capital Cost (CAD 2018, \$M)</b>	<b>Annual Energy Losses (GWh)</b>	<b>NPV of Line Losses (CAD 2018, \$M)</b>	<b>Total Cost (CAD 2018, \$M)</b>
TAK-150DC	\$1,040	85	\$76	\$1,120
TAK-200DC-LIGHT	\$1,150	79	\$71	\$1,220
TAK-200DC- HEAVY	\$1,170	48	\$42	\$1,210

All three options perform similarly in this analysis of line loss costs and so there is no basis for selecting an option. If the project proceeds the HVDC options should be evaluated at higher accuracy to select the optimal voltage level and conductor size and capture current pricing in the dynamic HVDC sector.

## 8 Risks

The major project risks identified at this time are summarized in Table 19 below.

**Table 19: Summary of Major Project Risks**

Risk Identified	Description	Mitigation
N-1 reliability	The load at Casino will be vulnerable to single element failure because it will be interconnected via a single radial system running from the Skeena substation (near Terrace BC) to the mine site, a distance of nearly 1600 km.	Further Investigation of reliability scenarios and projected outages.  Back up generation for essential loads at Casino mine.
Transmission Capacity from Northwest BC	The availability of additional capacity at Tatogga substation is subject to: a) The development status of potential mine loads in Northwest BC b) BC Hydro’s planning assumptions regarding the availability and production levels at the existing hydro plants in Northwest BC	Confirm the capacity available at Tatogga with BC Hydro.
Pricing of Power from BC	High electricity rates to import BC Hydro power decreases the projects’ competitiveness in favour of Yukon-based generation solutions.	BC Hydro contract negotiation.  Refinement of project cost estimates to minimize uncertainty.
HVDC Capital Cost	The HVDC cost converter station estimates used in this report were provided on a no-cost basis by GE and Siemens and could change under a competitive process.  The DC line costs were estimated parametrically from using baseline costs developed using a limited set of recently constructed HVDC projects.	Should the project proceed, perform a higher resolution evaluation of HVDC options to estimate costs with higher accuracy and capture current pricing in this dynamic sector.
Line / Load Coordination	Considering the Yukon’s projected load growth, <sup>26</sup> there is no viable alternative off-taker for the newly installed capacity in the event that the Casino mine does not materialize or closes earlier than forecast. The lack of long terms loads	Identification of other potential loads in the Yukon region besides the Casino mine.  Stage project development in coordination with mine

<sup>26</sup> Yukon Energy Resource Plan

Risk Identified	Description	Mitigation
	purchasing power would cause a rate increase for the current Yukon customers.	development synchronize levels of increasing financial commitment.

## 9 Conclusions & Recommendations

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The Yukon needs approximately 100 MW of additional generation resources to connect the proposed Casino mine. This report has shown that it is technically feasible to supply the 100 MW load requirement via a combination of HVDC transmission line interconnecting the BC and Yukon grids, and 230 kV AC transmission line interconnecting the Casino mine to a reinforced Yukon grid.

The total capital costs range from \$1.6B to \$1.7B to connect from Tatogga near Iskut, BC to the proposed Casino mine. The total capital costs range from \$1.0B to \$1.2B to connect from Tatogga to Takhini near Whitehorse.

The similar viability of three (3) different HVDC options creates the range. The HVDC options vary in capital cost and loss performance. Evaluating the losses associated with operation did not produce a clear selection. If the project proceeds the HVDC options should be evaluated at higher resolution to select the optimal voltage level and conductor size.

The study results are summarized below by segment.

**Segment 1 (TAK):** A HVDC interconnection between BC and the Yukon would allow the import or export of up to 238 MW during winter conditions (subject to the available capacity at BC Hydro’s Tatogga substation). The import capacity is sufficient to meet the 100 MW Casino Mine requirement and provides the flexibility to import additional power to support additional Yukon loads and export opportunities should the Yukon develop a future resource surplus and secure access to a southern market participant willing to pay for Yukon energy.

**Segment 2 (CAR):** A 230 kV AC line with double bundled Hawk conductor from Whitehorse to Carmacks would replace the existing end-of-life 138 kV line and provide a 230 kV transmission backbone sufficient to serve additional future growth of load or generation in the northern half of the Yukon grid.

**Segment 3 (CAS):** A 230 kV line with double bundled Hawk conductor from Carmacks to Casino avoids the cost of additional transformation at Carmacks and provides solid voltage control.

The key risks identified include the level of reliability associated with 1600 km of radial transmission, the available capacity at the BC Hydro Tatogga substation at Iskut, BC, cost estimate accuracy and the long-term price of power purchased from BC Hydro.

## Appendix A: Line Cost Estimating Methodology

Midgard has developed preliminary cost estimates for the Yukon - BC transmission line.

Transmission line capital costs increase with higher voltage classes (i.e.:  $\pm 150$  kV DC transmission is less costly per unit length than  $\pm 200$  kV DC transmission) and larger conductor sizes (477 MCM<sup>27</sup> ACSR<sup>28</sup> Hawk conductor is smaller and lighter than 795 MCM ACSR Drake). Increasing either the voltage class or conductor size will increase construction costs because moving to a higher voltage class requires longer insulator strings and taller structures to maintain adequate ground clearance, and using a larger conductor increases both the direct conductor costs (i.e. more metal for each unit of conductor length), and structure and foundation costs (i.e. since both the weight loads and the transverse wind loads exerted on structures increase with heavier, larger diameter conductors).

It should be noted that at this early stage of study, the cost estimate methodology used is relatively coarse. A parametric “top-down” methodology is used (in which previous cost estimates are used to determine a \$/km rate, which is then applied to this project), as opposed to a detailed “bottom-up” methodology (in which the cost of individual transmission line components would be determined from primary sources). These estimates are intended as high-level planning figures only. Optimization activities will require more detailed cost estimate development during future stages of study. It was desired to estimate the cost of four different line types:

**Table A-1: Line Types Considered for Cost Estimate**

Line Type	Voltage	Conductor
DC	$\pm 150$ kV	795 MCM Drake
DC	$\pm 200$ kV	795 MCM Drake
DC	$\pm 200$ kV	477 MCM Hawk
AC	230 kV (phase to phase)	2x 477 MCM Hawk

The methodology used to estimate each is as follows:

1. A recent estimate for a similar transmission line was used to arrive at as a baseline “\$/km” cost estimate.
  - a. For the 150 kV (DC) option, a recent 138 kV (AC) cost estimate was used.
  - b. For the 200 kV (DC) and 230 kV (AC) options, a recent 230 kV (AC) cost estimate was used.
2. In the case of the DC cost estimates, the baseline figure is modified as follows:
  - a. To account for use of a different conductor. This has implications for both conductor costs (due to the differing cost of the conductor itself) and structure costs (because larger conductors imply a stronger structure required).

<sup>27</sup> MCM = kmil = one thousand circular mils. Each circular mil is equivalent to a 0.001” diameter wire

<sup>28</sup> ACSR = Aluminum Conductor Steel Reinforced. Aluminum “conduction” wires are stranded around a steel “strength” core.

- b. To account for the differing ground clearances requirements between the baseline AC voltage and the desired DC voltage<sup>29</sup>.
  - c. To account for the cost differences between similar AC and DC transmission lines. WECC<sup>30</sup> suggests that a DC transmission line will have a cost approximately 80% of that of a similar AC transmission line.
3. In the case of the AC cost estimate, the baseline figure was used directly, as the desired AC line configuration was substantively similar to the configuration of the chosen baseline transmission line.
4. Finally, the “\$/km” cost estimate arrived at for each of the four line options was modified on a segment-by-segment basis, to account for the impact on cost of terrain factors such as:
  - a. Side-to-side steepness of the route.
  - b. Proximity to existing rights-of-way.
  - c. Land cover (treed / urban / clear).
  - d. Water crossings.
  - e. Need for new access road construction.

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<sup>29</sup> CSA 22.3 No. 1-15

<sup>30</sup> WECC’s “*Capital Costs for Transmission and Substations*” (Black & Veatch, February 2014)

## Appendix B: Estimating the Cost of Line Losses for the HVDC Segment

For HVDC, variable operating costs are primarily related to resistive line losses (i.e. electrical power lost as heat along the conductor’s length). For constant power transfer, resistive losses are directly proportional to conductor resistance (e.g. using a larger conductor that halves resistance, halves losses), directly proportional to the square of the line current, and inversely proportional to the square of voltage class (e.g. doubling the voltage class reduces losses by a factor of four). After resistive line losses have been determined for a particular transmission configuration, the net present value cost of losses can be determined by multiplying lost energy by the forecasted unit price of energy and discounting appropriately.

The Net Present Value of line losses is calculated for a future time horizon of 25 years, the anticipated lifetime of the mine at Casino. The cost of the resulting energy losses depends on the contract price at which power will be purchased from BC Hydro, and represents the operating costs of the transmission line segment.

**Table B-1: Summary of Assumptions in Net Present Value of line losses**

Factor	Assumption
Power transfer	Line losses were calculated based on a nominal power transfer of 100 MW, the peak load at Casino.
Load factor	The load factor is the ratio of the peak losses to the average annual losses.  The peak load at Casino mine is considered to have a 90% load factor to account for some down time for maintenance. The resulting annual power losses for the three DC line options are shown in Table B-2: .
Time period	25 years
Price and escalation	The current BC Hydro rates for transmission customers were used.  The future rates were based on the following considerations: <ul style="list-style-type: none"> <li>• Historical transmission rate escalation in BC has averaged 5% over the last 10 years, however, BC Hydro’s Rates Plan predicts annual escalation rate to be between 2% and 3% through to 2024.</li> <li>• The current CPI is 1.7%</li> </ul> Therefore, for each of the DC line options, the NPV of line losses was calculated under the following price escalation scenarios: <ul style="list-style-type: none"> <li>• 1.7%</li> <li>• 2.5%</li> <li>• 5%</li> </ul>

Factor	Assumption
Utility discount rate	4.92%.; the Weighted Average Cost of Capital proposed in Yukon Energy Corporation’s 2017 Rate Application was used as the discount rate for calculating NPV of line losses.

**Table B-2: Annual DC Line Energy Losses for 100 MW Power Transfer**

Conductor – Voltage	795-Drake - ±150 kV	795-Drake - ±200 kV	477-Hawk- ±200 kV
Annual energy losses (GWh)	85.1	47.5	79.4
Peak Power Losses (MW)	12	6.7	11.2
NPV (1.7% Price escalation)	\$69.7M	\$38.9M	\$65.0M
NPV (2.5% Price escalation)	\$75.9M	\$42.4M	\$70.9M
NPV (5% Price escalation)	\$101.1M	\$56.4M	\$94.3M

The NPV figures in Section 7 of this memo represent a BC Hydro rate escalation rate of 2.5%. While the last ten years have had a higher escalation rate of 5%, it likely represents the high end and is not forecast to continue over the long-term.

## Appendix C: HVDC Summary

---

Conventional power transmission systems are designed to transmit Alternating Current (AC) power. However, High Voltage Direct Current (HVDC) Transmission involves the conversion of AC power to Direct Current (DC) for transmission between two AC networks. DC power is then converted back to AC at the receiving end of the HVDC link.

### C.1 Rationale for HVDC

HVDC links are preferable over AC links for bulk power transmission over long distances because of the following advantages:

- HVDC transmission systems require fewer conductors than AC systems in the same voltage class to transmit the same amount of power; this translates into lower conductor costs. For overhead lines, this can translate into further savings in overhead structure costs.
- HVDC transmission systems have lower line losses than AC systems; in addition to resistive losses, AC systems have more losses due to cable capacitance charging.
- Unlike AC transmission systems, HVDC systems allow power transfer between asynchronous AC networks. Moreover, powerflow through an HVDC system can be controlled independently of frequency and phase angle.

An HVDC solution was considered to be a good fit for the proposed Yukon – BC interconnection because of the HVDC characteristics outlined above, and following properties of the interconnection:

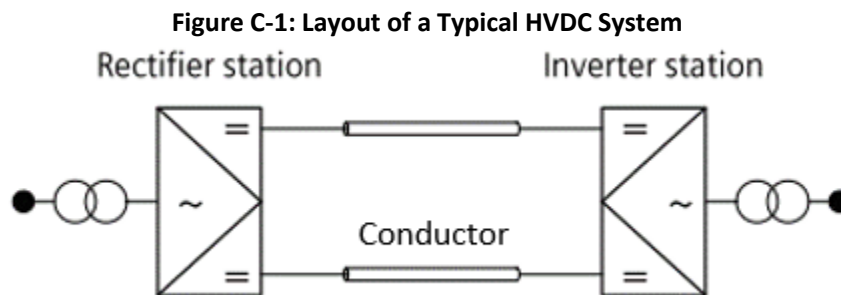
- Relatively long interconnection distance: approximately 800 km
- Relatively low power transfer requirement: 100 MW
- Relatively weak AC networks in Yukon and Northern BC
- Desire to minimize capital costs

One drawback of choosing an HVDC solution for the Yukon – BC interconnection is the cost of tapping off a load at Watson Lake. In an HVDC system, an additional converter station will be required to tap-off a load at Watson Lake, whereas only a single transformer would be required in an AC system. The incremental cost of an additional converter station exceeds that of an additional transformer in the same voltage class by approximately a factor of ten (10).

## C.2 HVDC Transmission System Description

A typical HVDC transmission system is composed of the following major components.

- Converter stations
  - Rectifier stations: Convert AC power to DC power
  - Inverter stations: Convert DC power to AC power
  - Most converter stations are capable of performing both inverter and rectifier operations, although they can be optimized for unidirectional conversion depending on the power transfer requirements of a specific system.
- Conductors
  - Overhead conductors
  - Submarine cables
  - Underground cables
  - Any combination of these conductors can be used depending on the interconnection route.



## C.3 HVDC Technologies and Capabilities

There two main HVDC technologies and they are named based on the operating mechanisms of their respective converters:

- Line Commutated Converter (LCC) Technology
  - Switching is implemented using thyristors with turn-on capability.
  - Can be implemented with Half-Bridge or Full-Bridge topology.
  - Fault clearing implemented on DC side.
- Voltage Sourced Converter (VSC) Technology
  - Switching is implemented using semiconductor switches with turn-on/turn-off capability e.g. Insulated-Gate Bipolar Transistors (IGBTs).
  - Can be implemented with Half-Bridge or Full-Bridge topology.

- Fault clearing achieved by opening AC breaker
  - i. Shorter Fault clearing times (200ms) possible with Full-Bridge topology.
  - ii. Fault clearing time with Half-Bridge is 1.5 to 2 seconds.

LCC is the more mature HVDC technology and therefore usually translates to lower capital costs, slightly lower losses, higher power transmission capability and relatively less maintenance compared to VSC technology. However, VSC offers distinct advantages that make it the preferred technology for the proposed Yukon – BC interconnection. Table C-1: summarizes the advantages of VSC technology.

**Table C-1: Advantages of VSC Technology vs LCC technology<sup>31</sup>**

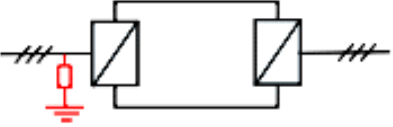


VSC Technology	LCC Technology
Operates with low short circuit power i.e. can operate in weak AC Networks	Requires a minimum short circuit power of at least 2.5 times the transmission capacity
Can supply passive networks and support Black Starts	Cannot support passive networks
Allows independent control of active and reactive power	Reactive power is dependent on the active power and is controlled in steps
Has a smaller footprint because it does not require AC harmonic filters under normal operation	Has a large footprint due to AC filters
Can provide AC fault ride through with controlled reactive injection	A commutation failure will follow an AC fault that is electrically close to the inverter
No cable type restrictions because polarity reversal is not required	Can only be connected with mass impregnated cables or certain extruded cables due to polarity reversal

<sup>31</sup> Siemens HVDC Technology

### C.4 Proposed Configuration for Yukon – BC Interconnection

VSC technology can be implemented using either Half-Bridge or Full-Bridge topologies in the following configurations:

**Table C-2: Possible HVDC System Configurations with VSC Technology**

Configuration	Illustration
<p><b>Symmetric Monopole</b></p> <ul style="list-style-type: none"> <li>- Two parallel conductors</li> <li>- Uses one conductor as a metallic return path</li> <li>- Minimal grounding requirements</li> <li>- No redundancy in case of single conductor outage</li> </ul>	
<p><b>Symmetric Bipole</b></p> <ul style="list-style-type: none"> <li>- Two parallel conductors</li> <li>- Can use either ground or metallic return path</li> <li>- Requires grounding electrodes</li> <li>- Full redundancy in case of single conductor outage</li> </ul>	
<p><b>Asymmetric Monopole</b></p> <ul style="list-style-type: none"> <li>- Single conductor</li> <li>- Uses ground as return path</li> <li>- Requires grounding electrodes</li> <li>- No redundancy in case of conductor outage</li> </ul>	



Represents a power converter

The symmetric monopole is the preferred configuration for the Yukon – BC interconnection because of the following reasons:

- The symmetrical monopole configuration requires fewer converters than the symmetric bipole, and hence lower capital costs; reliability is traded off for cost savings since the symmetric bipole offers redundancy in case of a single conductor outage. The tradeoff was judged to be acceptable because any event that permanently damages one conductor will likely damage the whole line.
- The asymmetrical monopole configuration requires fewer conductors than the symmetrical monopole because it utilizes a ground return path. However, the symmetrical monopole does not require grounding electrodes and avoids technical complexity and maintenance associated with a ground return path.

## Appendix D: Vendor Information

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There are three primary vendors in the HVDC converter space: ABB, GE and Siemens.

Midgard was able to contact and speak with technical sales representatives from all three. A summary of key findings and interactions follows:

- ABB
  - HVDC Light is the term ABB uses for their VSC technology.
  - HVDC Light was used in the first VSC HVDC system using overhead lines. The Caprivi Link connected Namibia and Zambia in 2009 to transfer 300 MW 970 km via a 350 kV overhead line. This project is the closest sample project to the BC - Yukon concept that was located.
  - An introductory phone conversation with North American representative, Fred Arnold, but further details and cost estimates were not provided.
  - Recent email correspondence with Swedish staff, Archit Singh, resulted in further information, but no cost estimates as of March 27, 2018.
- GE
  - Neil Kirby of GE was very helpful in phone conversations and quickly provided a cost estimate.
  - The cost estimate provided was approximately half Siemens' estimate, but neither was able to assist in reconciling them.
- Siemens
  - HVDC Plus is the term Siemens uses for their VSC technology.
  - In addition to answering questions and providing a cost estimate, a small team visited Midgard and gave a presentation. A copy of the presentation is attached as Appendix F:.
  - Siemens' cost estimate was approximately twice that of the one provided by GE.
  - They recommended not installing a system with a voltage below  $\pm 200$  kV, however, their concerns were about the level of losses and not technically driven.

## Appendix E: Single Line Diagrams

Figure E-1: Proposed BC - Yukon Interconnection SLD Showing the Expected 100 MW Load at Casino

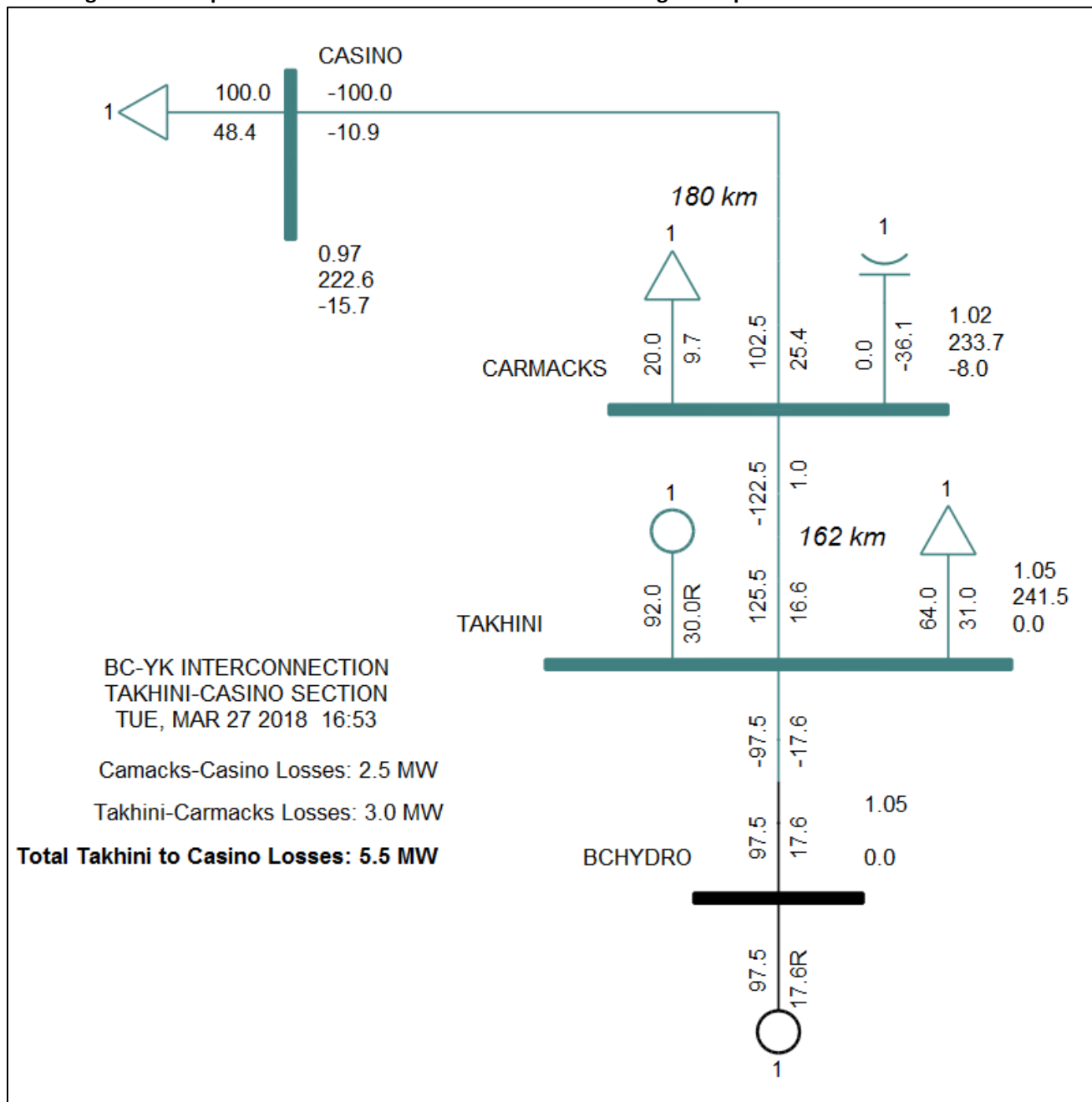


Figure E-2: Transfer Capacity - Voltage Limiting Condition on the AC Part of the Line

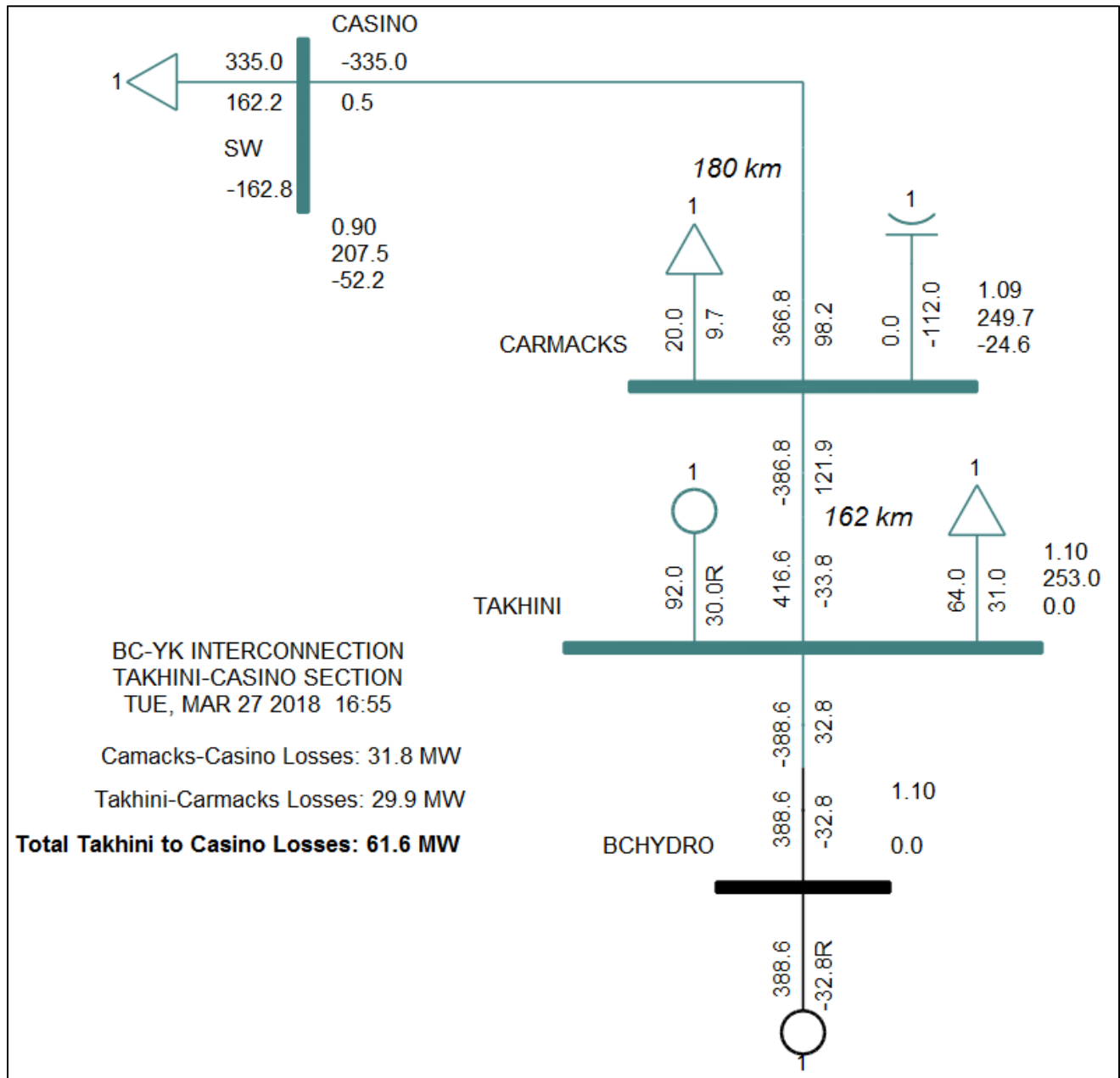


Figure E-3: Transfer Capacity - Angle Limiting Condition on the AC Part of the Line

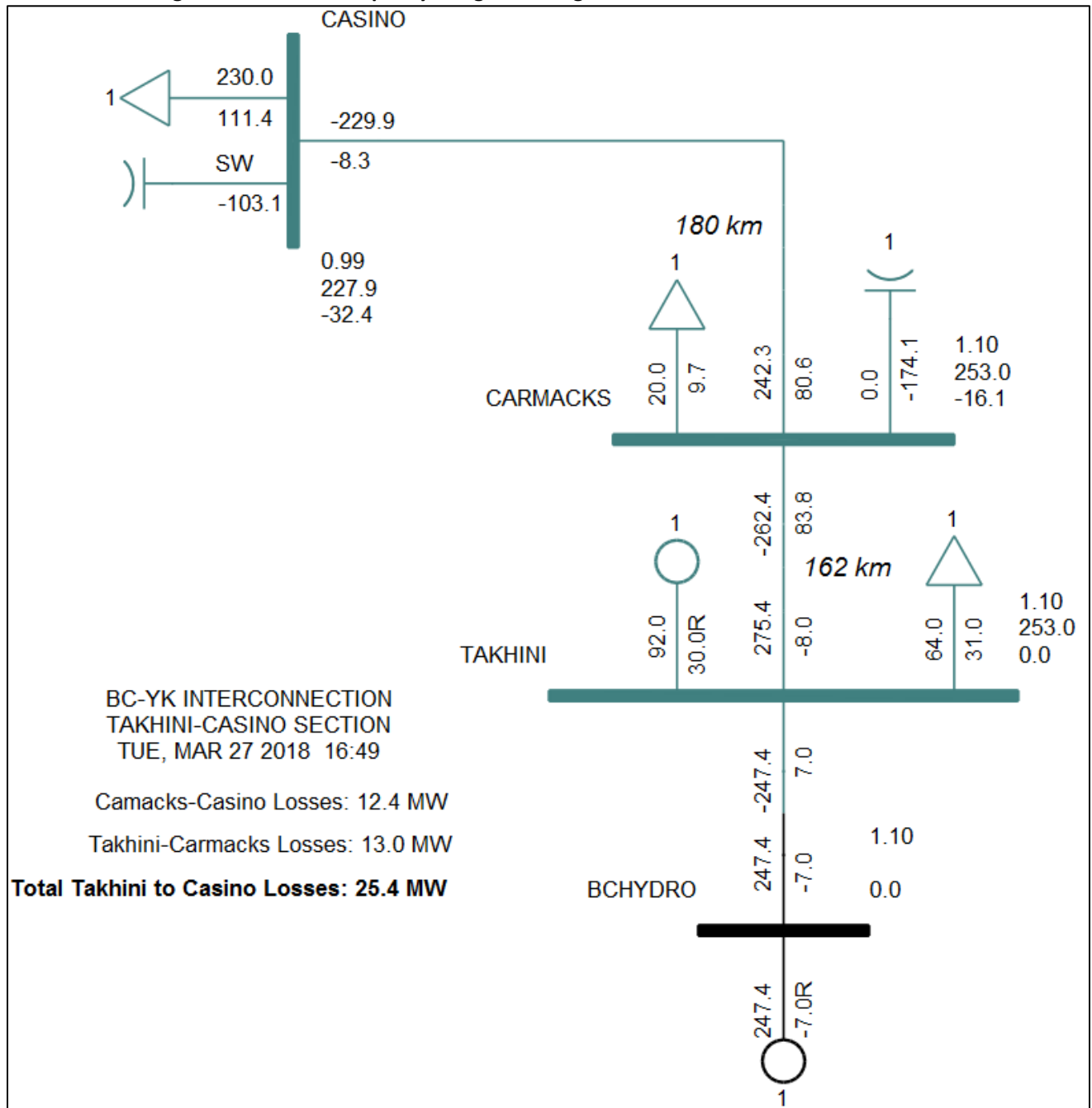
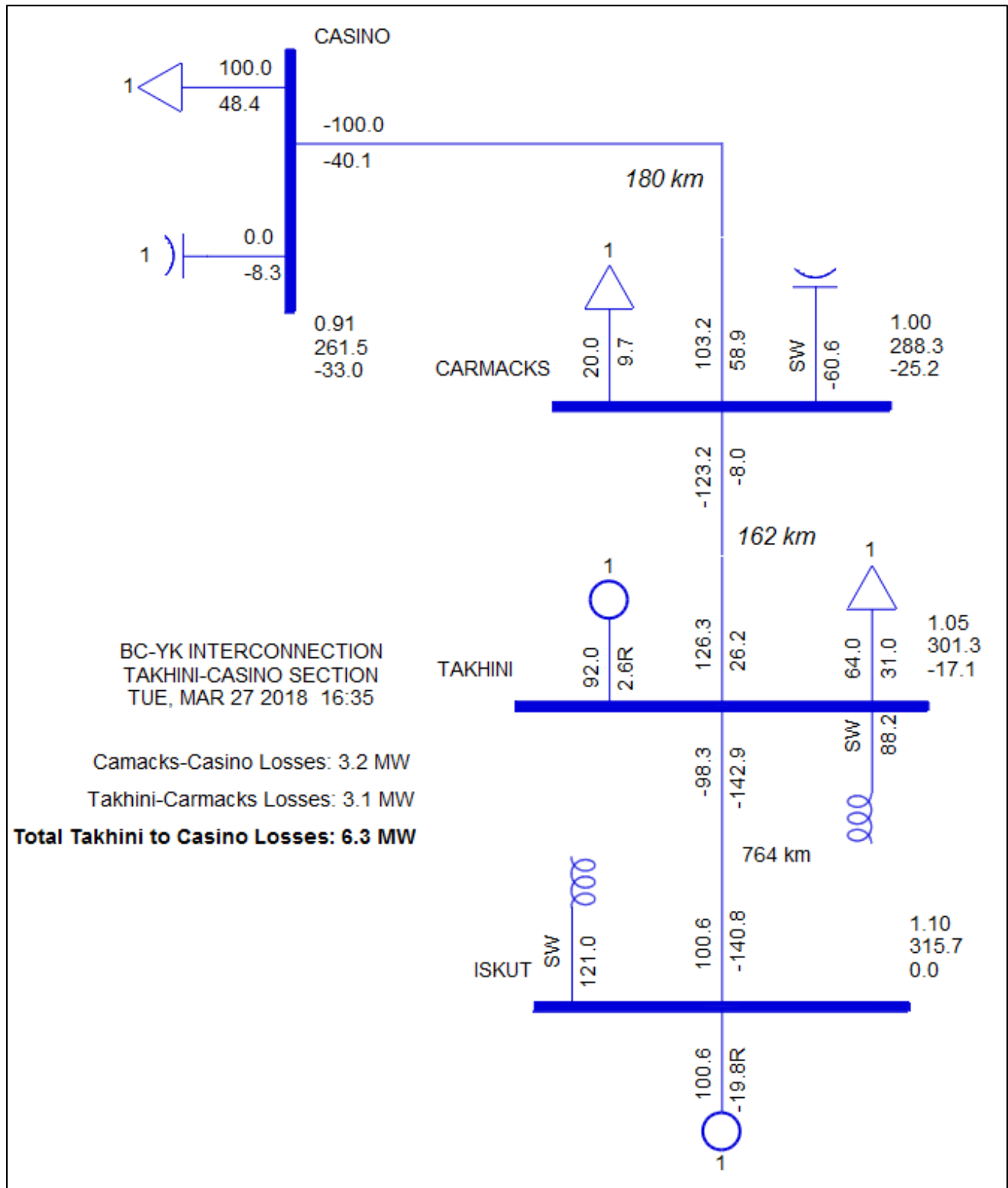


Figure E-4: 287 kV Option for Iskut (Tatogga) to Casino



## Appendix F: Siemens Presentation Material

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# Siemens HVDC Technology

British Columbia – Yukon HVDC Transmission Solutions,  
Midgard Consulting, Vancouver, W. Pender Street  
14<sup>th</sup> March 2018, Vancouver, Canada

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[siemens.com/energy/power-transmission](http://siemens.com/energy/power-transmission)

# Siemens HVDC Technology

## What is HVDC?



# Siemens HVDC Technology

## What is HVDC?

### High Voltage Direct Current Transmission is ...

the **Conversion of Alternating Current (AC) in Direct Current (DC)** and **vice versa** for the bulk transmission of electrical power between two AC grid connection points

It is used for the following reasons

- ❑ For long distance transmission, HVDC systems are **more economical** due to lower **overhead line cost** and **lower losses**.
- ❑ AC cables have charging currents which are proportional to their length.  
For **AC cables** starting at a length of approximately 80km – 100km the losses due to cable capacitance charging **exceed the critical threshold for economical operation**  
**The Solution** is using HVDC cables, MI or XLPE, for submarine and underground
- ❑ HVDC is necessary for power transmission between:
  - ❑ **asynchronous** AC transmission systems
  - ❑ Synchronous parts of an AC transmission where **fast and flexible power control** is required
- ❑ The active power flow through an HVDC link can be **controlled independently** of frequency, and phase angle

# Siemens HVDC Technology

## LCC and VSC – Two powerful HVDC technologies

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### LCC - HVDC Classic

Line Commutated Converter  
(Current-sourced)

Thyristors with turn-on  
capability



- Direct light-triggered thyristor (LTT)
- Up to 10,000 MW
- MI/PPL cable up to 600 kV
- OHL up to 800 kV

### VSC - HVDC PLUS

Voltage Sourced Converter  
(Self-commutated)

Semiconductor Switches  
With turn-on/ turn-off  
capability, e.g. IGBTs



- XPLE cable up to 500 kV DC
- Half bridge up to 2 kA
- Full bridge up to 2 kA

# Technology Selection Criteria

## HVDC “Classic” vs. HVDC “PLUS”

### Line Commutated Converters

vs.

### Voltage Sourced Converters

#### Line Commutated Converters

- Lower CAPEX
- Lower Losses
- Higher Power Transmission Capability
- Less Maintenance
- Requires a minimum short circuit power of at least 2,5 times the transmission capacity
- Can not supply passive networks
- Reactive power is mainly given by the active power and is controlled in steps
- Have a large footprint due to the AC filters
- Can only be connected with mass impregnated cables or certain extruded cables due to the polarity reversal
- Switched shunt filters are required to mitigate harmonic currents
- A commutation failure will follow an AC fault electrically close to an inverter.



#### Voltage Sourced Converters

- Higher CAPEX
- Higher Losses
- Limited Power Transmission Capacity
- Somewhat More Maintenance
- Operates with low short circuit power i.e. can operate in weak AC Networks
- Can supply passive networks and have **SRAS\*** (Black Start)
- Have independent control of Active and Reactive power
- Have a smaller footprint and lower profile
- Can be connected with all extruded DC cables because polarity reversal is not required
- A **Modular Multilevel Converter (MMC)** will normally not require AC harmonic filters
- Can provide AC fault ride through with controlled reactive current injection.



**Best solution depends on required transmission capacity and other general requirements**

# Siemens HVDC Technology

## Decisive Design Criteria for an HVDC converter station

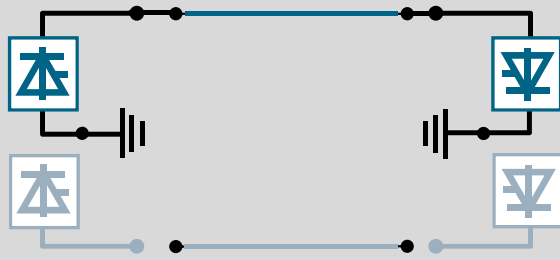
- Transmission Capacity including Overload
- Transport limitation for heavy loads impacts transformer design.
- Minimum Short Circuit Power.  
Minimum SCR  $\approx 2.5$  for LCC.  $SCR = S_{k \min} / P_d \implies$  Minimum ESCR  $\approx 2.0$
- Normal and Extreme Ranges for Voltage, Frequency and Negative Sequence
- Maximum and Minimum Reactive Power Exchange with the grid and maximum Voltage Step at sub-bank switching determines the size and thus total number of sub-banks.
- Harmonic impedance, harmonic distortion limits, and pre-existing harmonic distortion determines AC filter design.
- Power Line Carrier noise limits determine PLC noise filter design.
- DC line parameters and DC Harmonic Current Limits have impact on Smoothing Reactor and DC Filter design.
- Site coordinates and topographic survey data
- Site conditions can have major impact on design.  
(Electrical and thermal design, mechanical design, civil design e.g. seismic design)

# Siemens HVDC Technology

## LCC - Typical Bipolar HVDC Converter Station

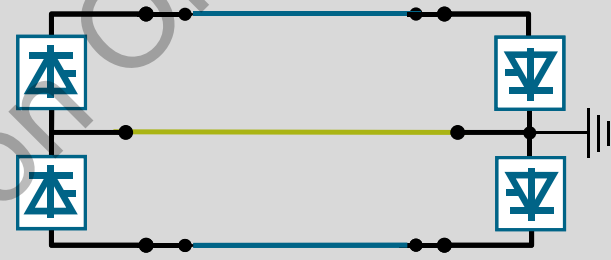
### Basic Bipole – Alternative Operation Modes

Monopolar, ground return one DC line pole

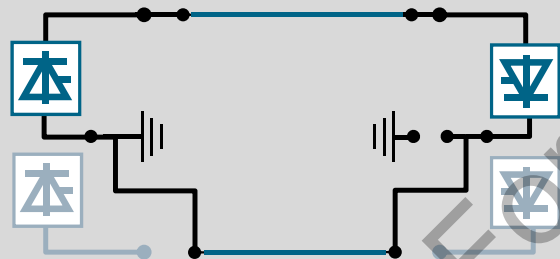


### Bipole – Alternatives

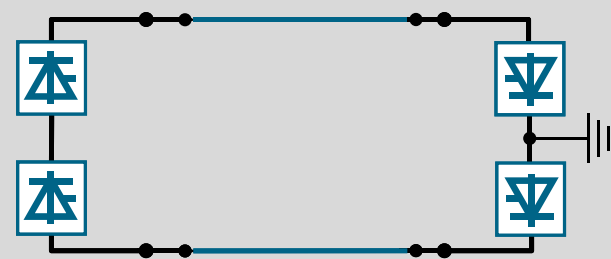
Bipole, Dedicated Metallic Return (DMR)



Monopolar, metallic return



Rigid Bipole w. Bypass, No LV Return



# Siemens HVDC Technology LCC Thyristor Valves (4), Valve Hall

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8

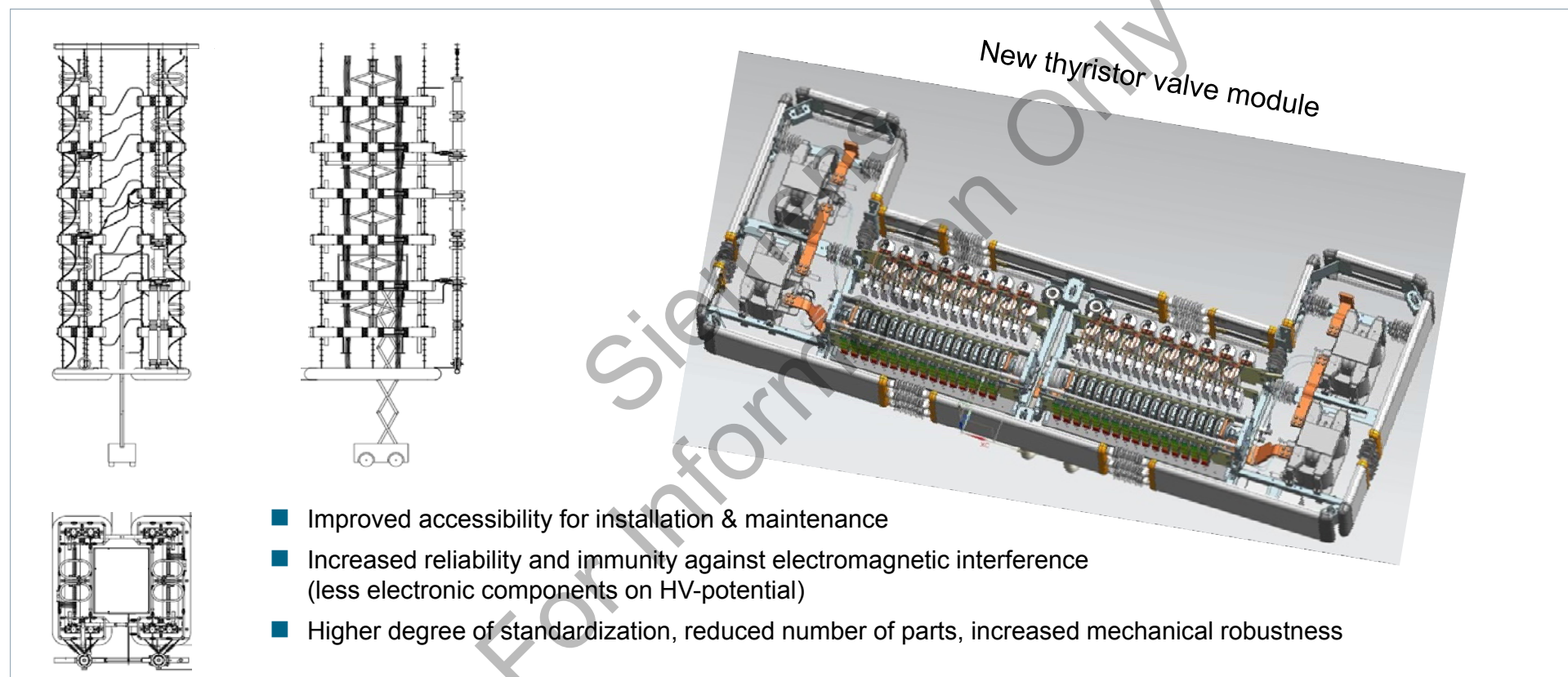
March 2018

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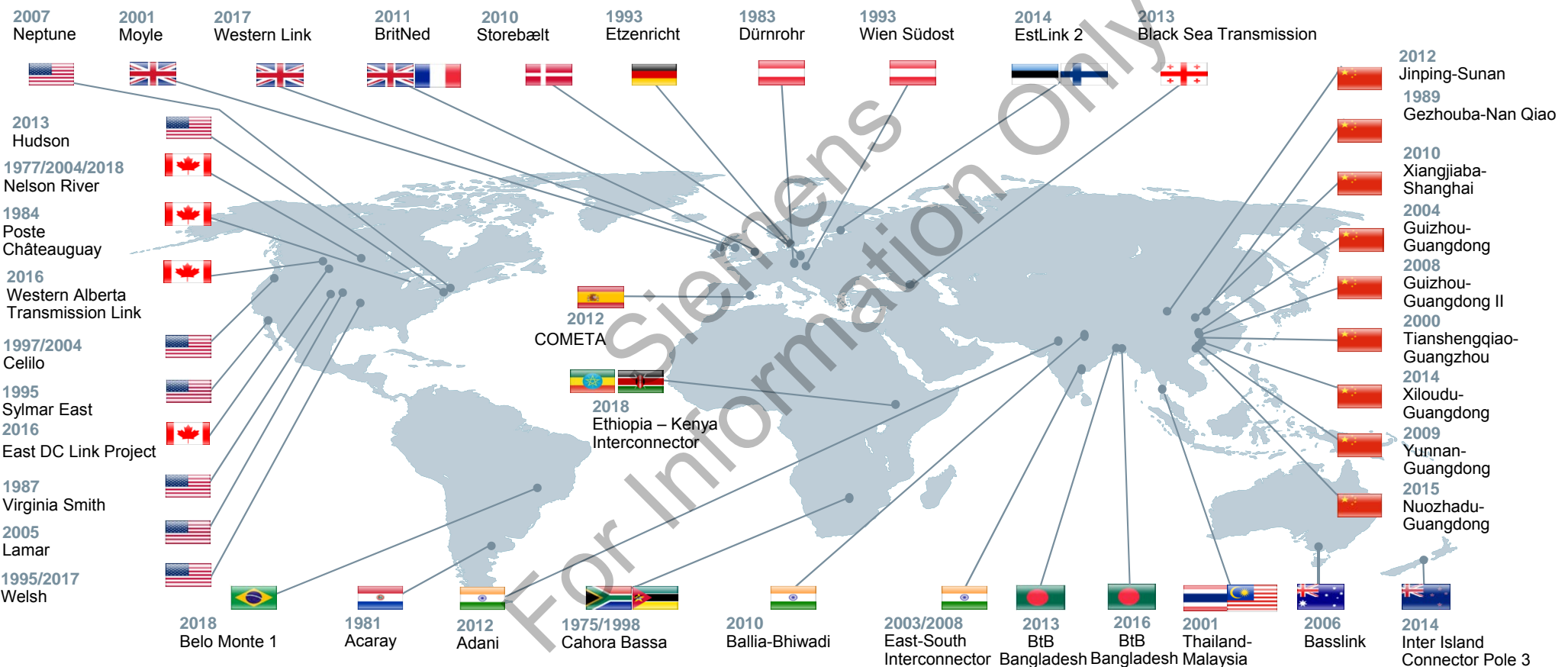
EM TS LTS

# Siemens HVDC Technology

## LCC - Thyristor Valves (4), Module Design



# Siemens HVDC Technology References Classic HVDC



# Siemens HVDC Technology

## Western Alberta Transmission Link, Alberta, Canada, 2016



**Western Alberta Transmission Link (WATL), Alberta, Canada**

**Customer:**  
AltaLink

**Project Name:**  
WATL-Western Alberta Transmission Link

**Location:**  
Sunnybrook – Crossings, Alberta, Canada

**Power Rating:**  
1000 MW, monopolar with LTT Thyristors (8kV)

**Type of Plant:**  
HVDC Classic, 400 km OHL

**Voltage Levels:**  
500 kV DC  
500/230 kV AC, 60 Hz

# Canada References

## East DC Link Project, Alberta, Canada, 2015

**East DC Link (EATL), Alberta, Canada**

<p><b>Customer:</b> ATCO</p> <p><b>Project Name:</b> East DC Link Project Procurement (FNTP)</p> <p><b>Location:</b> Heathfield – Newell Canada</p> <p><b>Power Rating:</b> 1000 MW , monopolar with LTT Thyristors (8kV)</p> <p><b>Type of Plant:</b> HVDC Classic, 500 km OHL</p> <p><b>Voltage Levels:</b> 500 kV DC 500/230 kV AC, 60 Hz</p>	
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# Canada References References

## Nelson River, Bipole 3, Canada, 2018

**Increased Availability with series 12-pulse group Arrangement**

**Customer:**  
Manitoba Hydro (Winnipeg)



**Project Name:**  
Nelson River Bipole 3

**Location:**  
Keewatinohk (Northern Station), Riel (Southern Station),  
Canada

**Power Rating:**  
2000 MW with LTT Thyristors (8kV) , bipolar, plus 15%  
continuous overload

**Type of Plant:**  
Long-distance transmission, 1.340 km

**Voltage Levels:**  
 $\pm$  500 kV DC; AC 230 kV / 60 Hz



EM TS LTS

# HVDC PLUS - Voltage Sourced Converters (VSC) Half Bridge and Full Bridge Design



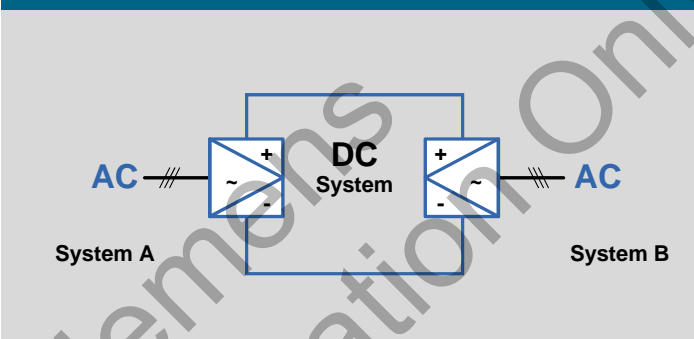
# Siemens HVDC Technology

## VSC - Converter Principles – DC Circuit

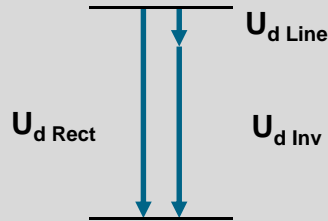
### Characteristics

- $I_d$  can only flow in both directions
- The Magnitude and the direction of  $P / I_d$  is controlled by the converter DC voltages  
 $\Rightarrow I_d = (U_{d \text{ Rect}} - U_{d \text{ Inv}}) / R$
- The polarity of the DC voltage is always the same.

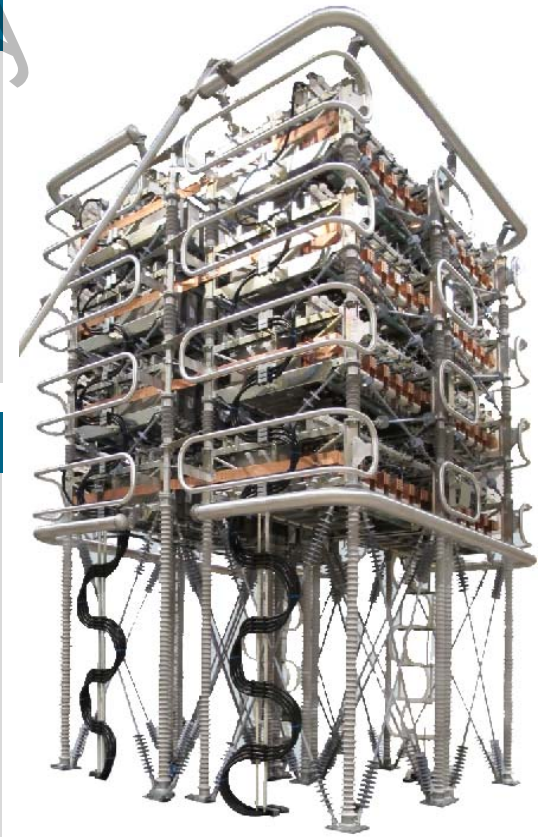
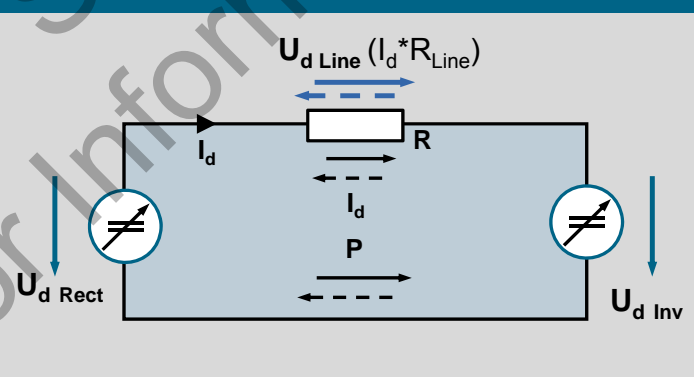
### Simplified Block Diagram



### DC Voltages

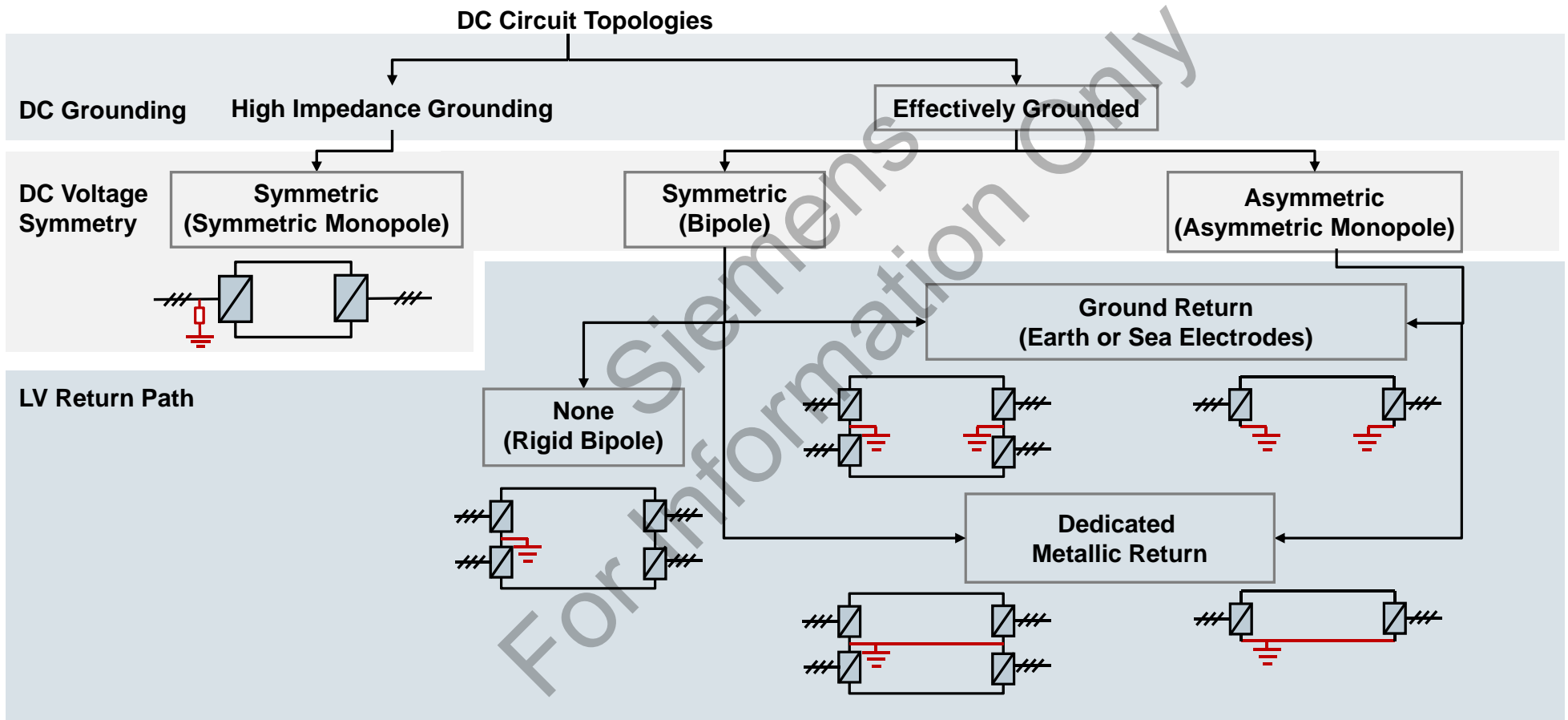


### Equivalent DC Circuit



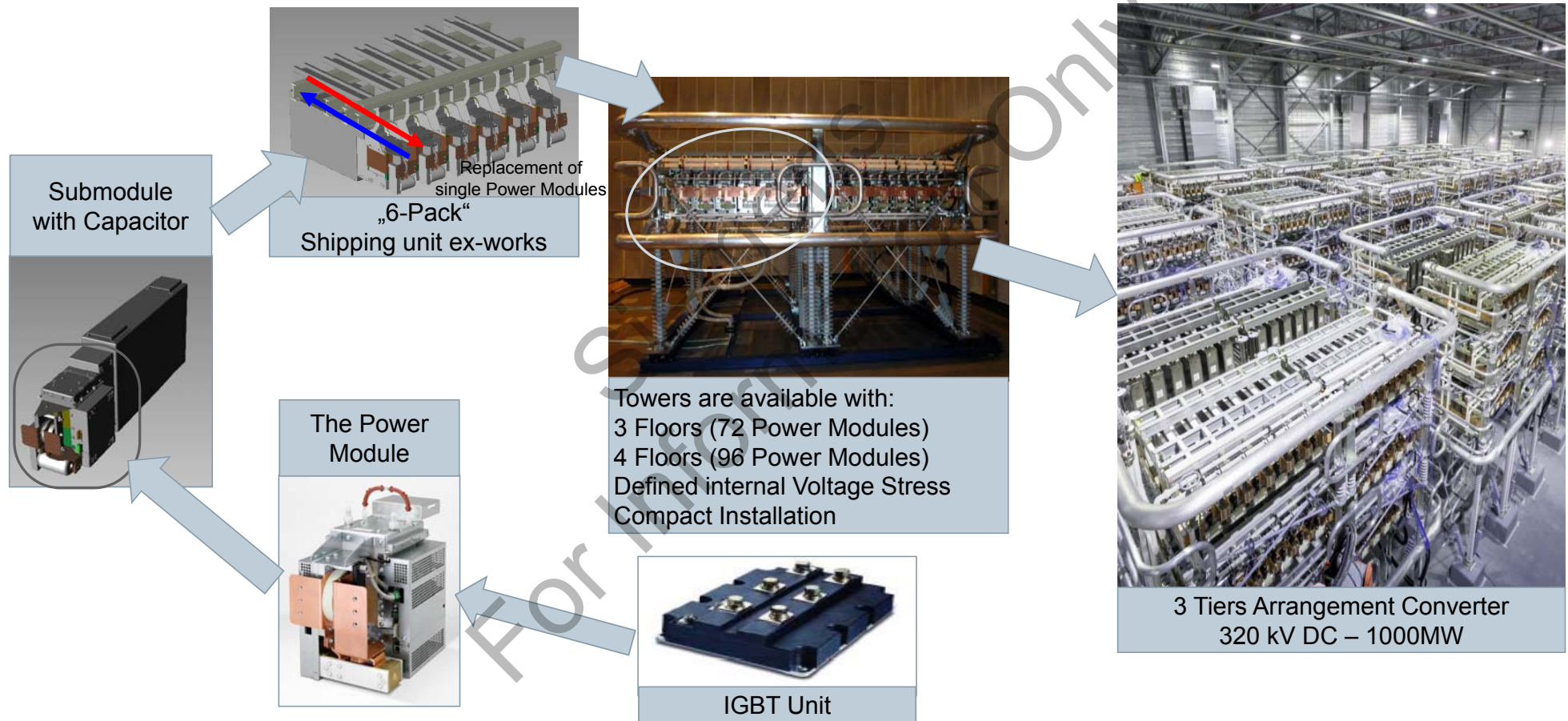
# Siemens HVDC Technology

## VSC – Topologies



# Siemens HVDC Technology

## VSC - Key Components from IGBT to Converter



# Siemens HVDC Technology

## 1000 MW HVDC PLUS Converter Hall

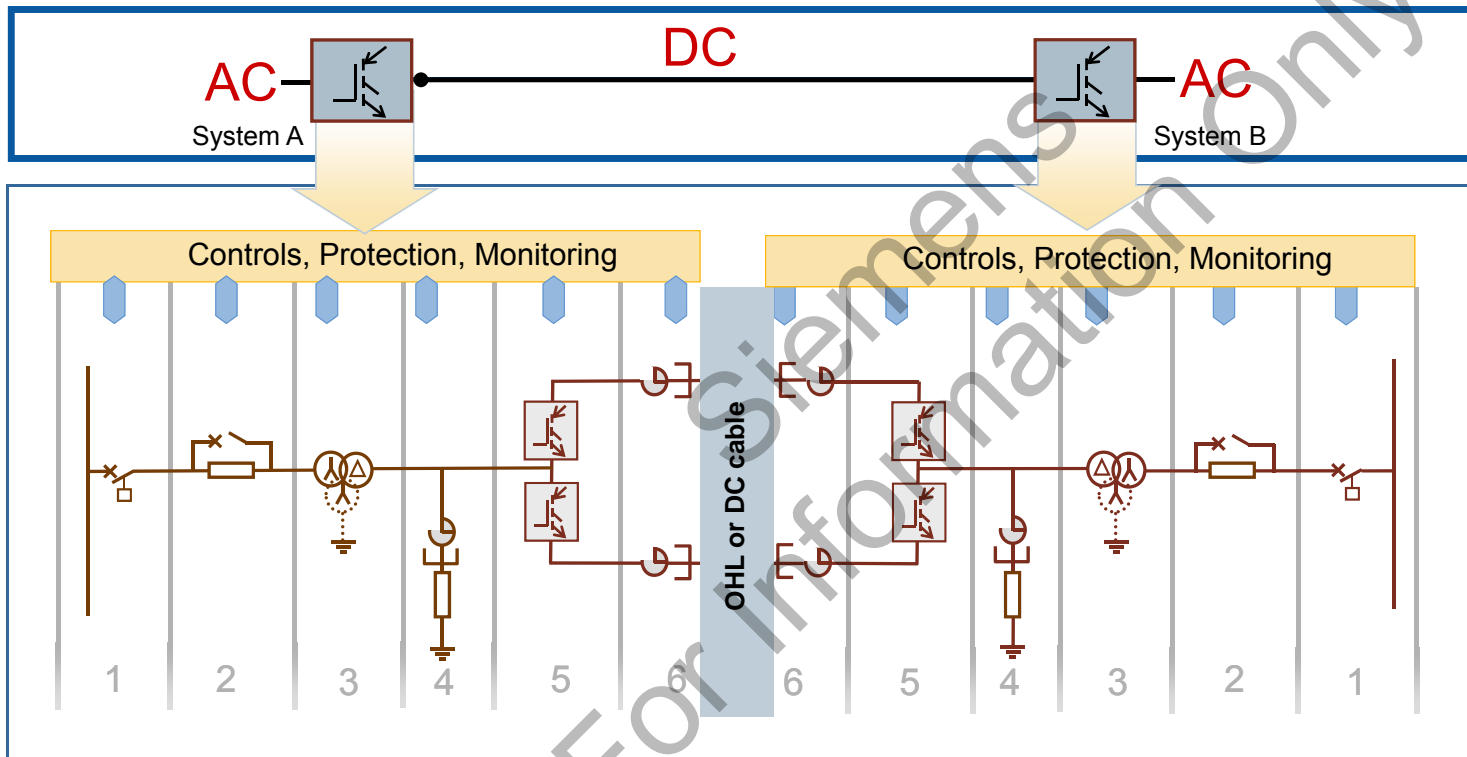
**SIEMENS**  
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Up to four tiers size of a converter tower



# Siemens HVDC Technology

## HVDC PLUS Technology – Key Components VSC

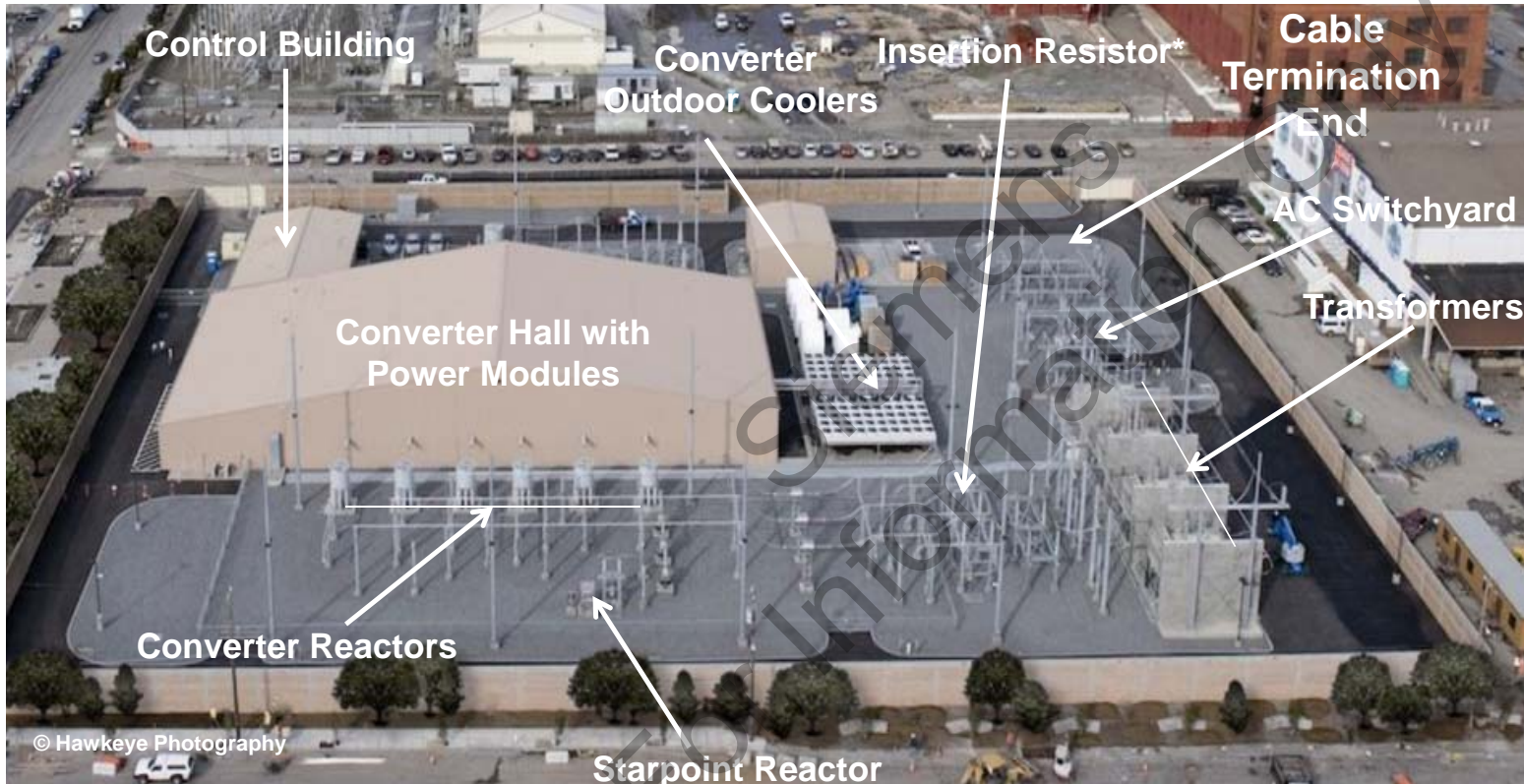


1. AC Switchyard
2. Insertion Resistor
3. Transformer
4. Star point Reactor
5. Power Modules
6. Converter Reactor

**Example: Symmetrical Configuration**

# Siemens HVDC Technology

## HVDC PLUS Technology – Key Components VSC



**Customer:**

Trans Bay Cable, LLC

**Project Name:**

Trans Bay Cable Project

**Location:**

Pittsburg, CA and San Francisco, CA

**Power Rating:**

400 MW

**Type of Plant:**

HVDC PLUS;  
85 km submarine cable transmission

**Voltage Levels:**

± 200 kV DC  
230 kV/138 kV, 60 Hz

**Semiconductors:**

IGBT

\* - Location depends on design requirements

**Example: Symmetrical Configuration**

## Pacifico Link Transmission Project HVDC Seminar

### Key Components VSC - AC Switchyard

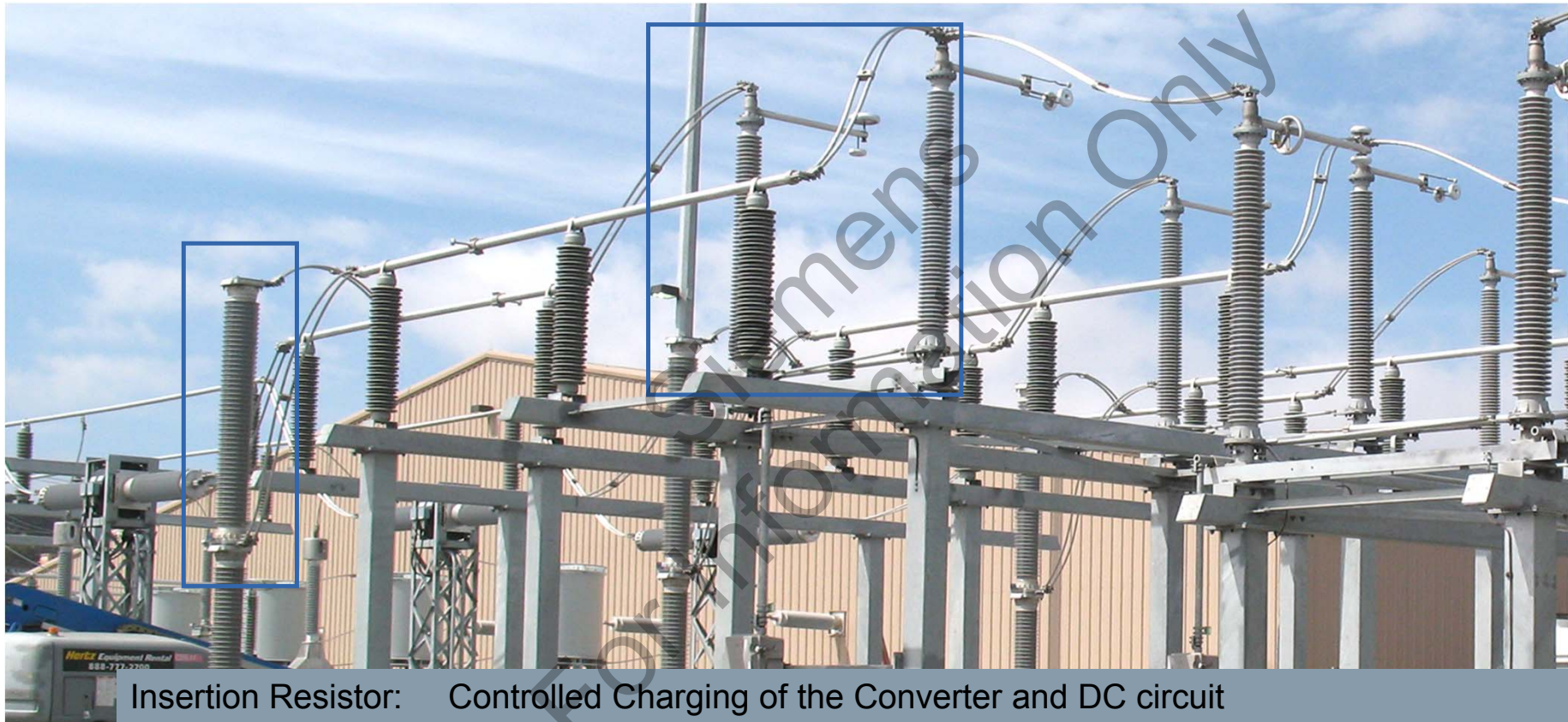
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## Pacifico Link Transmission Project HVDC Seminar

### Key Components VSC - Insertion Resistor

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Insertion Resistor: Controlled Charging of the Converter and DC circuit

## Pacifico Link Transmission Project HVDC Seminar

### Key Components VSC - Transformers

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Converter Transformer: Adapt the AC voltage to the DC voltage  
Provide galvanic separation  
Optional 3rd winding for auxiliary voltage

## Pacifico Link Transmission Project HVDC Seminar

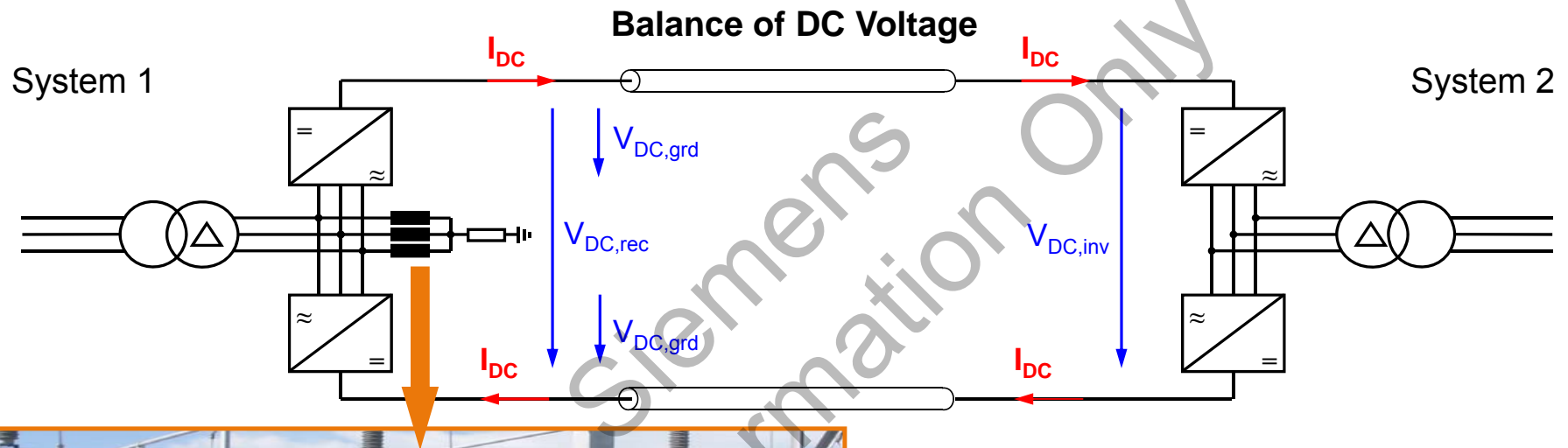
### Key Components VSC - Star Point Reactor

The Star Point Reactor keeps DC voltages symmetrical



# Pacifico Link Transmission Project HVDC Seminar

## Key Components VSC - Star Point Reactor

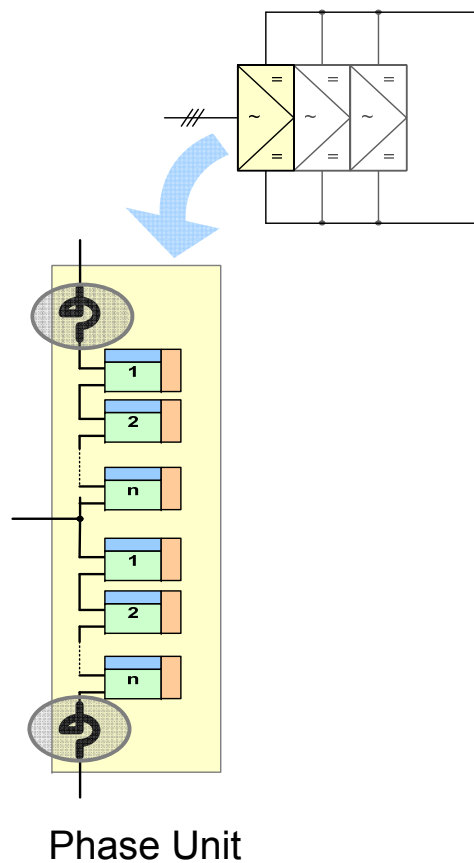


→ The DC Circuit cannot be allowed to float.

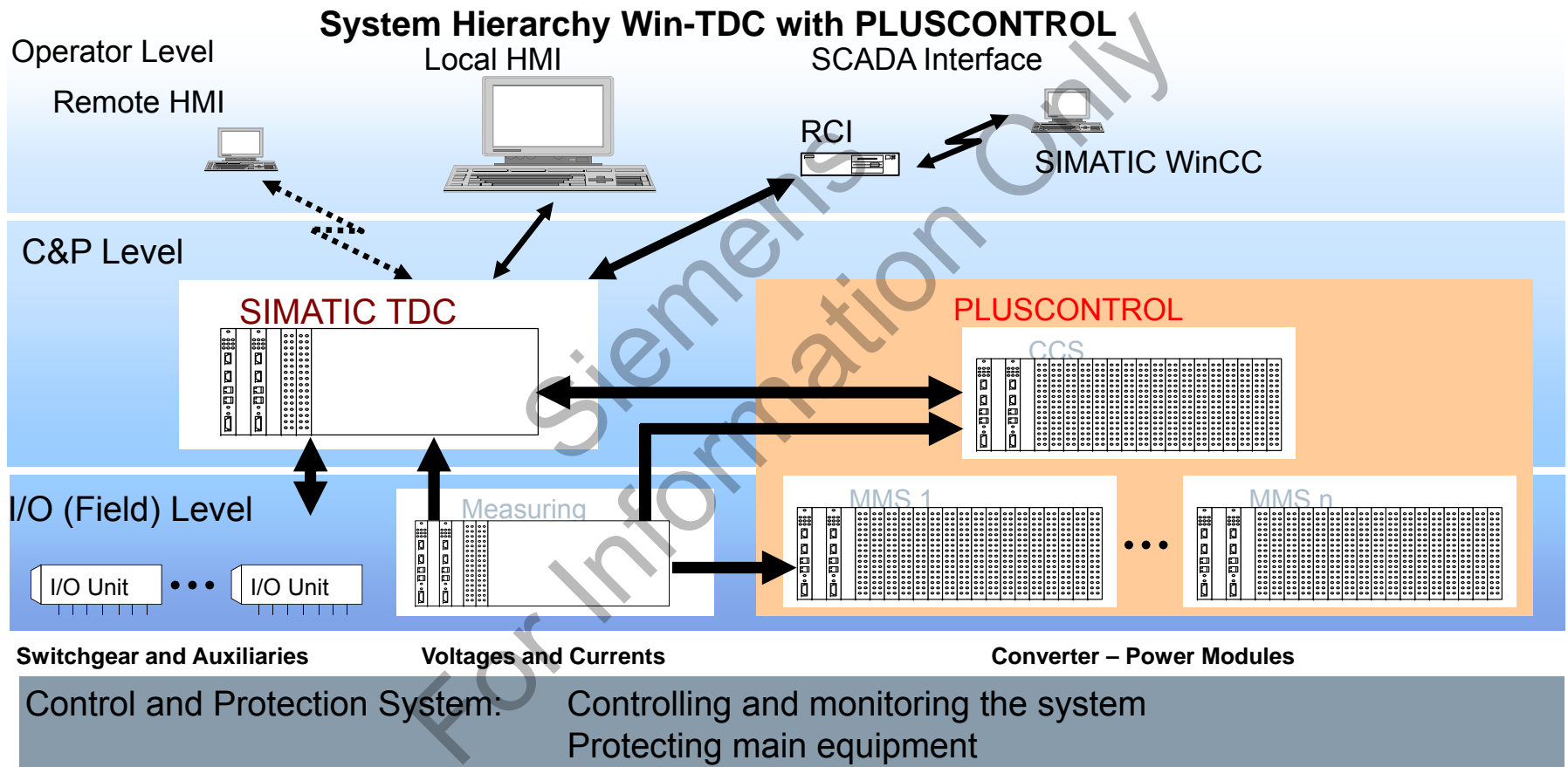


# Pacifico Link Transmission Project HVDC Seminar

## Key Components VSC - Converter Reactors



**Pacifico Link Transmission Project HVDC Seminar**  
 Key Components VSC - Control and Protection





# Siemens HVDC Technology

## Proven Technology for Stable Grids Full Bridge Film



# Siemens HVDC Technology

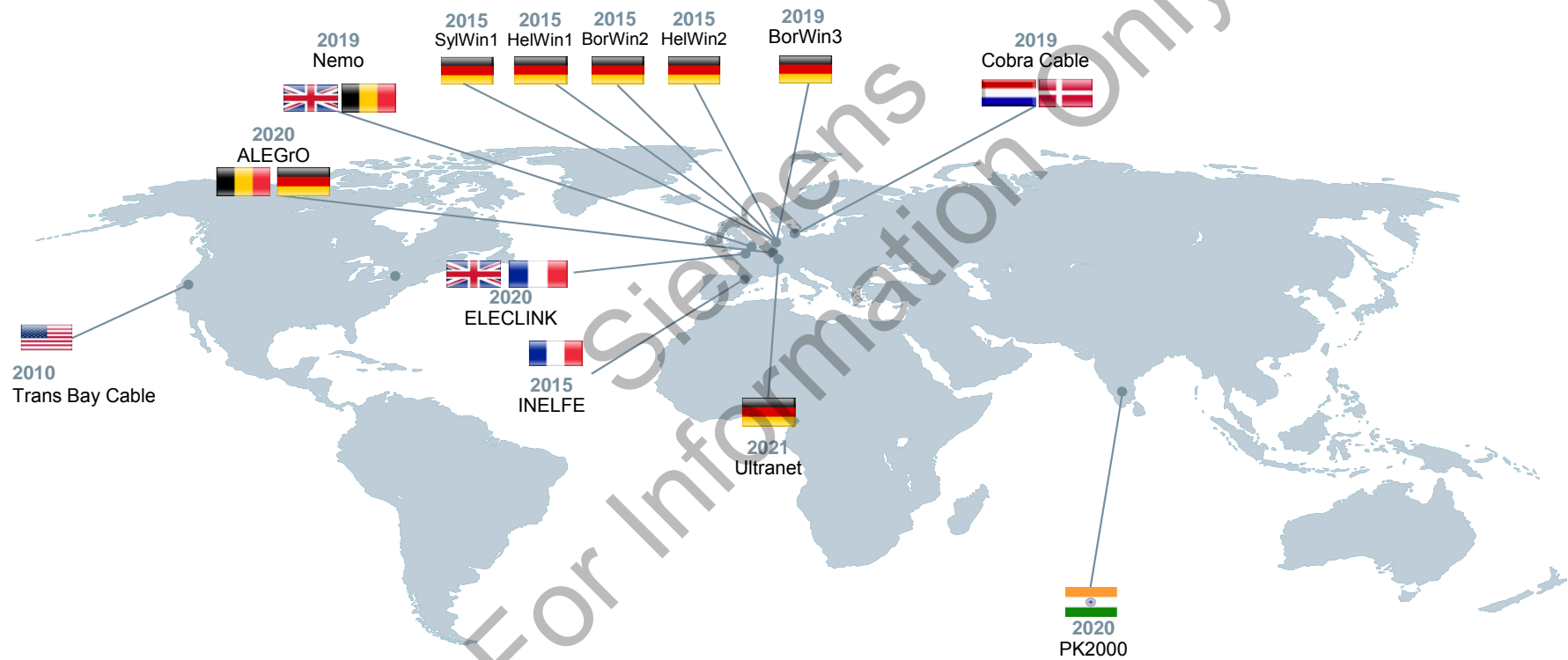
## Half Bridge & Full Bridge Technologies

Half Bridge	vs.	Full Bridge
<p><b>Half Bridge</b></p> <ul style="list-style-type: none"> <li>Lower CAPEX</li> <li>Less Components</li> <li>Lower Losses</li> </ul>		<p><b>Full Bridge</b></p> <ul style="list-style-type: none"> <li>Higher CAPEX</li> <li>More Components</li> <li>Higher Losses</li> </ul>
<ul style="list-style-type: none"> <li>Applicable when the 1.5 to 2 s DC line fault recovery time is acceptable</li> <li>In case of fault the AC Circuit Breaker must be opened</li> <li>The DC voltage must be higher than the AC ph. to ph. peak voltage</li> </ul>	 <ul style="list-style-type: none"> <li>Applicable when the DC line fault recovery time must be as fast as with LCC, e.g. 160 ms.</li> <li>In case of fault there is no need to open the AC Circuit Breaker, so reactive power can be continued during the fault clearance time.</li> <li>The DC voltage control is independent from the AC voltage. Reduced DC voltage operation is easily available.</li> <li>Converter AC terminal faults can be controlled in bipolar configuration with low impedance grounding of the DC circuit..</li> </ul>	

**Best solution depends on required transmission requirements. Full Bridge Converter, with its high degree of flexibility is the right solution for complex transmission systems.**

# Siemens HVDC Technology

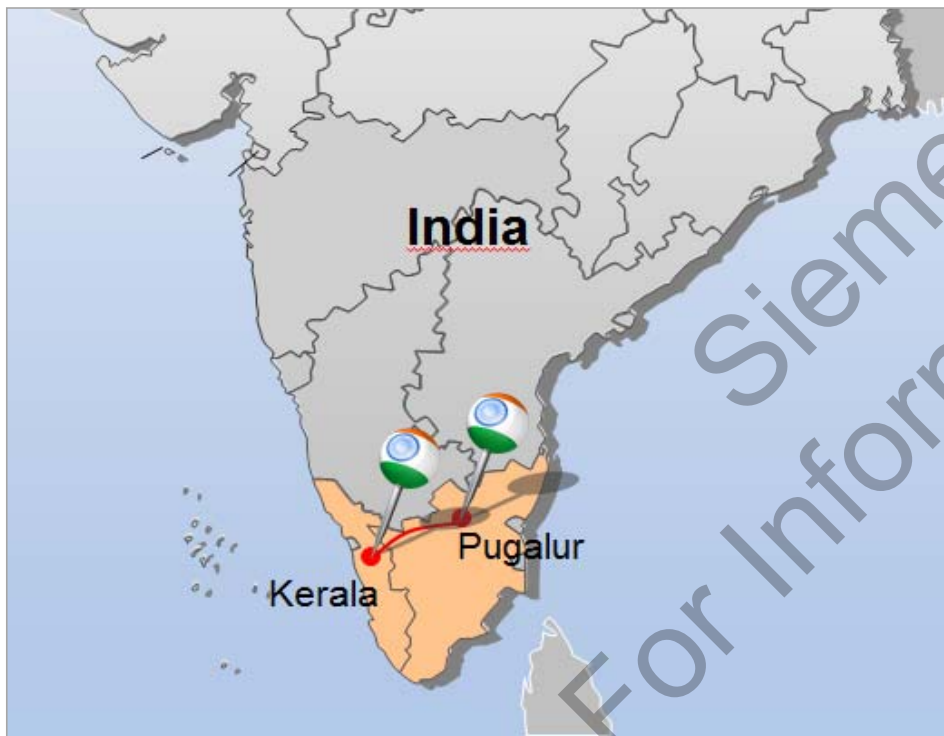
## Siemens References HVDC PLUS (VSC)



# Siemens HVDC Technology

## References HVDC PLUS - Pugalur - Kerala, India

### Location



### Key Data

Customer	Power Grid Corporation of India
Project Name	Pugalur - Kerala
Location	Pugalur - Kerala, India
Power Rating	2 x 1000 MW, Symmetrical Monopole
Type of Plant	HVDC PLUS in half-bridge topology
Voltage Levels	± 320 kV DC 400 k V AC, 50 Hz
Distance	<b>142 km OHL</b> 32 km land cable
Semiconductors	IGBT
RfQ	December 2015
Bid Due	January 2016
Award	April 2017
COD	July 2020
Remarks	Consortium with Sumitomo Corp. Japan

# Siemens HVDC Technology

## References HVDC PLUS - Ultranet, Germany

Location



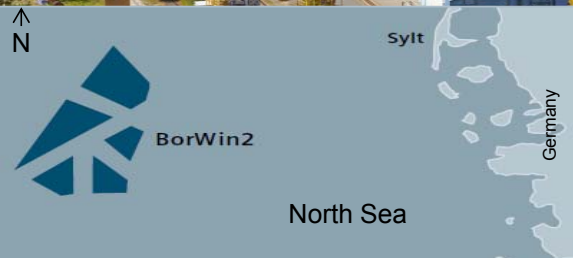
Key Data

Customer	Amprion / TransnetBW
Project Name	Ultranet
Location	Osterath – Philippsburg, Germany
Type of Plant	2000 MW (3000 MW installed) OHL + Cable Bipolar
Voltage Levels	± 420 kV DC
Distance	330 km
Power Module	Full Bridge
RfQ	January 2014
Bid Due	July 2014
Awarded	October 2015
COD	2022
Contract signed	November 2015

# Siemens HVDC Technology

## References HVDC PLUS - Onshore/ Offshore HVDC Converter

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BorWin2, Germany

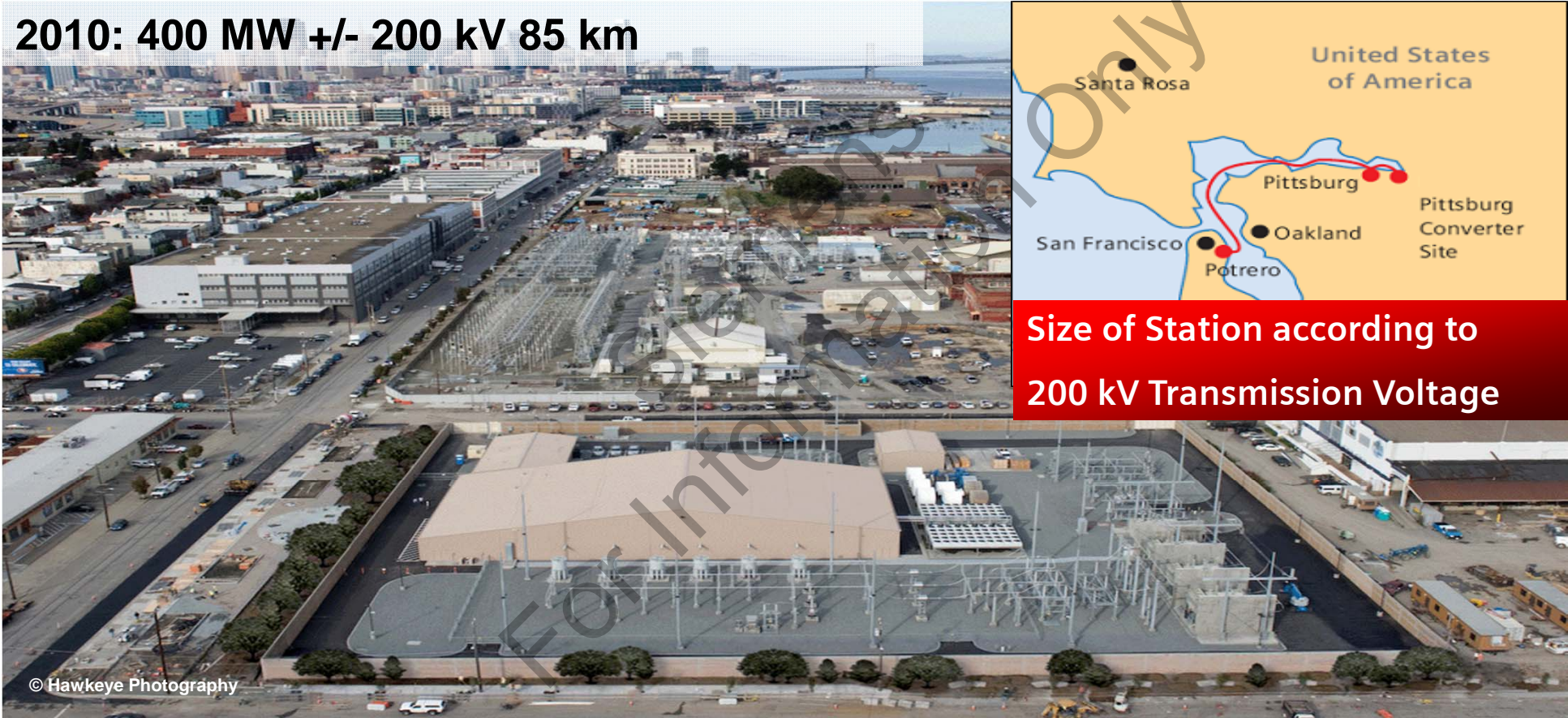
Customer	TenneT
Project Name	BorWin2
Location	Diele, Germany
Power Rating	800 MW
Type of Plant	200 km HVDC PLUS On-/Offshore Cable
Voltage Levels	± 300 kV DC AC 400 kV/155 kV, 50 Hz

# Siemens HVDC Technology

## References HVDC PLUS – TransBay Cable USA, California



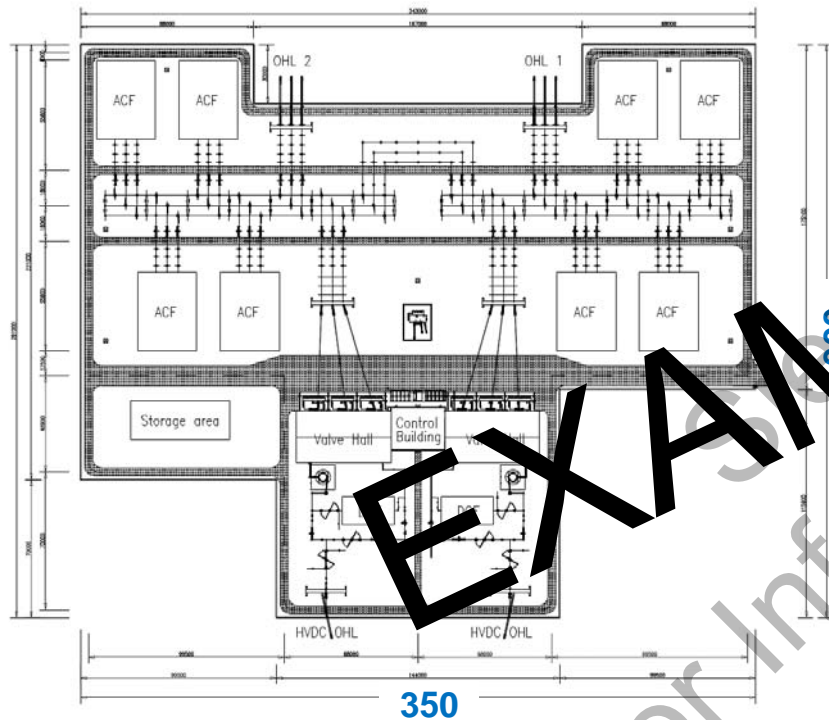
**2010: 400 MW +/- 200 kV 85 km**



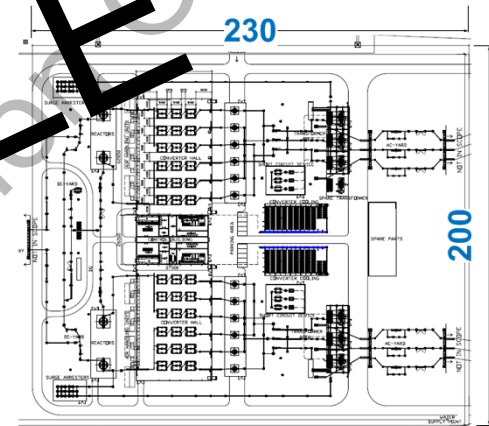
© Hawkeye Photography

# Siemens HVDC Technology

## Footprints 1000 MW HVDC Classic and HVDC PLUS



Footprint – 2 x 700 MW Siemens HVDC Classic Converter Station  
Bipolar Scheme, DC = 500 kV, AC = 500 kV



HVDC PLUS (VSC) Bipole 2 x 700 MW  $\pm$  500 kV with OHL (AC and DC)

# Siemens HVDC Technology

## Yukon – BC (Extract from Mail 27<sup>th</sup> February 2018)



Line distance: ~800 km, Transfer capacity: 150 MW (unidirectional North to South), Sending end voltage: 100kV, 150kV or 200 kV, Technology: Voltage Source Converter

Siemens would consider a VSC (HVDC PLUS) on Fullbridge Basis for the project. This is caused by several OHL Fault Scenarios as well recovery. A symmetric monopolar configuration is considered. Furthermore as basis for consideration a voltage drop (or associated OHL losses) of max. 5% / 10% shall not exceed. The considered conductor types are reflecting a rough estimate, it is not reflecting any detailed design,

OHL length = 800 km, POI of interest receiving end of the link.

Converter losses per station usually (under rated power transmission conditions) ~ 1%. The converter will be operated far below its capability. Therefore the percentual value of the losses in this operating range will be appr. 1,2% per station (rated power 150 MW).

### +/-200 kV DC Transmission Voltage (recommended):

**Conductor Type: 2 x ASTM Pheasant, max. Current Capability for 50° C = ~ 2000A, A Bundle with 2 Conductors, each 645 mm<sup>2</sup> (Diameter of each conductor ~ 29 mm) ACSR, Line losses <= 5% (voltage drop same range).**

**Conductor Type: 1 x ASTM Parrot, max. Current Capability for 50° C = ~ 1300A, Single Conductor, each 766 mm<sup>2</sup> (Diameter of each conductor ~ 29 mm) ACSR, Line losses <= 8,1% (voltage drop same range).**

### +/-150 kV DC Transmission Voltage:

**Conductor Type: 3 x ASTM Parrot, max. Current Capability for 50° C = ~ 3000A, A Bundles with 3 conductors each 766 mm<sup>2</sup> (Diameter of each conductor ~ 31 mm) ACSR, Line losses <= 5% (voltage drop same range).**

**Conductor Type: 2 x ASTM Martin, max. Current Capability for 50° C = ~ 2500A, A Bundles with 2 conductors each 685 mm<sup>2</sup> (Diameter of each conductor ~ 36 mm) ACSR, Line losses <= 8,2 % (voltage drop same range).**

**+/-100 kV DC Transmission Voltage:** not considered OHL line as not viable

For a 800 km OHL DC Transmission line for both considered solutions +/-150 kV DC and +/-200 kV DC the OHL Transmission Line are thermally oversized. We consider – if – only a +/-200kV Transmission system as borderline viable.

We would like to get Siemens's insights about HVDC factors we need to consider as we move forward with this project. Specifically we would like to set up a discussion about the questions below:

1. What are the technical limitation or concerns regarding line protection in a VSC scenario? – **with Fullbridge HVDC PLUS technology no limitations. Fault Recovery time in a range up to 200ms.**
2. What are the unit costs of converter stations in the 100 kV, 150 kV and 200 kV voltage classes?

**We have considered for a erection time of appr. 36 – 40 month a budgetary price indication of 310 – 320 Mio (+/-15%) Euro for both converter stations with a DC voltage of +/- 200 kV, OHL not included.**

**We have considered for a erection time of appr. 36 – 40 month a budgetary price indication of 290 – 310 Mio (+/-15%) Euro for both converter stations with a DC voltage of +/- 150 kV, OHL not included.**

Special requirements like rock blasting, seismic, seasonal limitations (installation/ civil), labor, transport restrictions etc. are not considered. All budgetary prices are indicative and not binding.

3. What factors may impact the technical feasibility of such a link? **We do see mainly constraints for the OHL erection. Furthermore transport limitations may exist.**

**For lower dc transmission voltages higher system losses as above described must be considered. It has to be evaluated if acceptable.**

**Space Requirements (Footprint) for a 200 kV symmetrical Monopole : 75 x 80 m, for Bipole slightly more, appr. 100 x 120 m**

# Siemens HVDC Technology

## Yukon – BC (Extract from Mail 27<sup>th</sup> February 2018)



Some thoughts as discussed during the meeting on 14th March in Midgard Consultings office:

A third station (Tap) would have nearly the same size of a converter station – and costs

- **The dc transmission voltage is determining the size of the converter (and therefore the associated hall)**
- **The Transmission Power influences the size of the Transformer (windings, conductors) except the insulation requirements driven by the primary and secondary (and dc voltage)**
- **Capacity and size of the cooling system, converter reactors are mainly driven by the transmission power.**
- **To balance the costs in association with the requirements for having „taps“ it is recommend to consider the location of the tap in order to optimize the supply the load centers by appropriate AC transmission (more cost effective than further „taps“ in the dc transmission system)**

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# Siemens HVDC Technology

## Transmission System Solution Topologies (Examples)

### Symmetrical Monopole

- No redundancy in case of converter outage or line fault (no N-1)
- Possible in Half Bridge or Fullbridge technology (depends on requirements for fault clearing)
- Transmission will be off until fault clearing with AC breaker
- High Overvoltages for cable in case of pole to ground faults (Hybrid Transmission Cable/ OHL) → higher stress of cable insulation
- Preferred solution for applications with **either all cable or all OHL**
- For one link no staged investment and construction approach possible

**For smaller applications (DC Voltages) valid too. The described values describe possible configurations and common size of applications and technologies**

# Siemens HVDC Technology

## Project HVDC Transmission Topology (EXAMPLES)

### Bipolar system with Dedicated Metallic return (Ultrahigh Voltage – Germany):

- N-1 redundancy in case of converter outage or line fault without any delay
- Operation with 50% of rated power rating in case of outage of converter or one dc line path (cable/ OHL)
- Half Bridge or Fullbridge design
- Advantage Bipolar System → staged erection approach according project requirements (first Pole 1, later Pole 2)
- With HB complex and difficult fault clearing, **therefore FB solution preferred for application with OHL**
- OHL line fault will cause → AC breaker trip (only with HB)

### Rigid Bipolar system (Viking Link (DK/UK) – in Tender Phase):

- In case of converter fault – short outage (appr. 2s) until reconfiguration of the system
- Operation with 50% of rated power rating in case of outage of one converter
- Outage of Line causes total outage of the system until fault rectification
- Preferred solution for application with only cable transmission
- OHL line fault will cause → AC breaker trip (only with HB)

**For smaller applications (DC Voltages) valid too. The described values describe possible configurations and common size of applications and technologies**

- Advantage Bipolar Systems → Staged approach/ investment and construction approach (converter stations - First Pole 1, later Pole 2)
- Transmission line → construction in one stage recommended
- For rigid Bipolar system: One HV conductor can be saved

**Decisive Criteria for selection of HVDC solution:**  
**What are the availability requirements?**

# Siemens HVDC Technology

## Example: The Ultranet Project / Germany



**TRANSNET BW**

### Key Data for the Ultranet Project

Technology:	Bipole in VSC Full Bridge Technology
Stage 1, South:	Point to Point Connection
Stage 2, North:	Future extension to Multiterminal
Transmission Power:	2.000 MW Nominal
Nominal DC Voltage	$\pm 380$ kV, ( $U_m = 420$ kV)
Nominal DC Current	2,63 kA
Owner:	Amprion (NRW), TransnetBW (BW)
Locations	
Stage 1:	Kaarst (NRW), Philippsburg (BW)
Stage 2, Future:	Not determined, close to Emden
Transmission Path	
Stage 1:	<b>340</b> km existing AC OHTL => AC / DC
Stage 2, Future:	<b>350</b> km new DC Underground Cable with possible Overhead Line sections
Contract Date :	20.10.2015
Execution Time:	Approx. 7 years project execution time for the first stage due to the long permitting processes in Germany

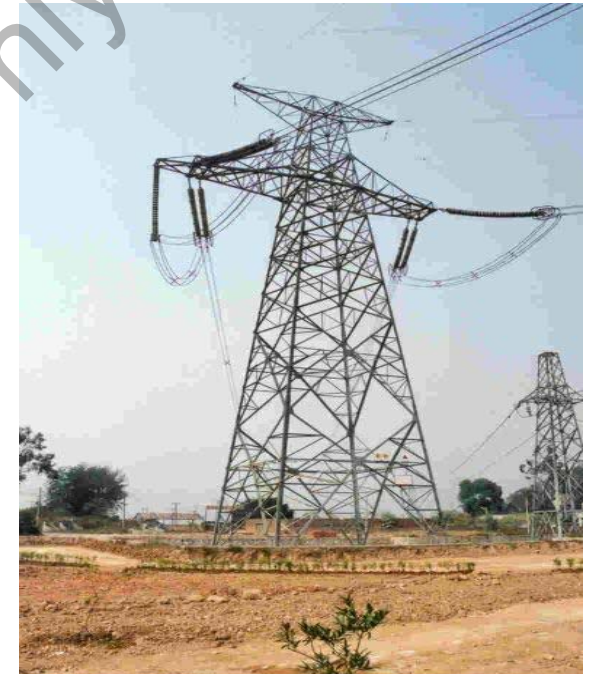
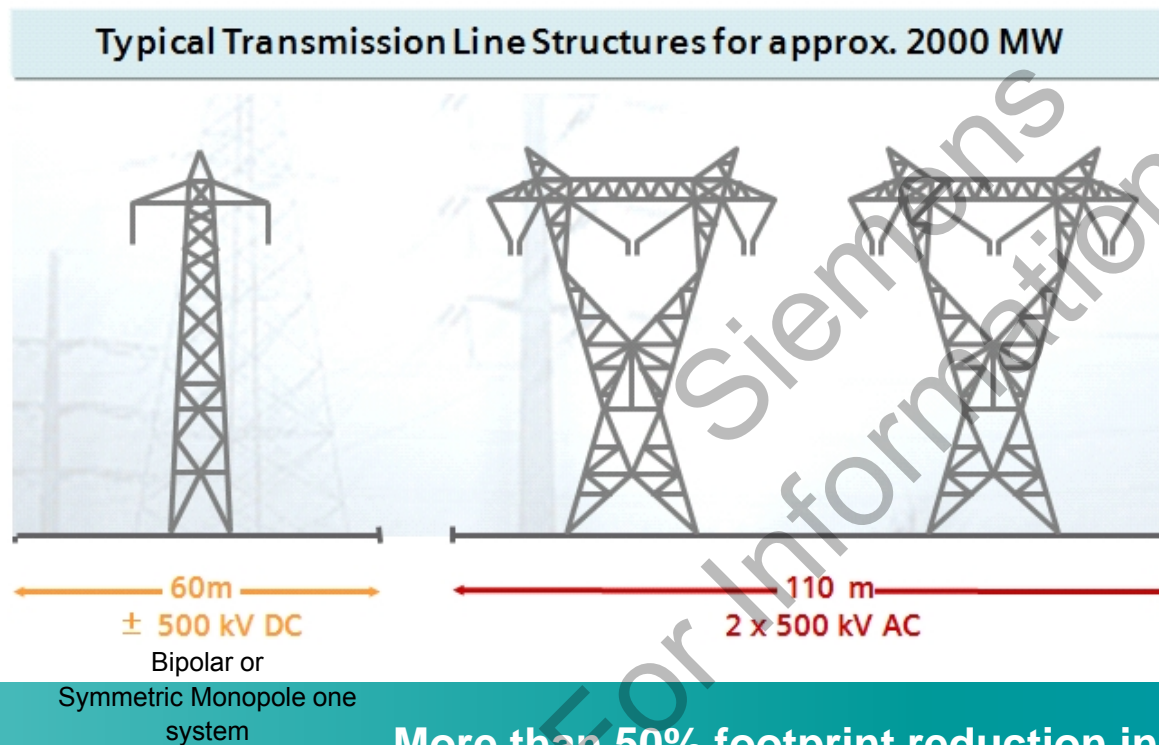
# Siemens HVDC Technology

## Symmetric Monopole Example



# Siemens HVDC Technology

## DC vs. AC → Economical Considerations

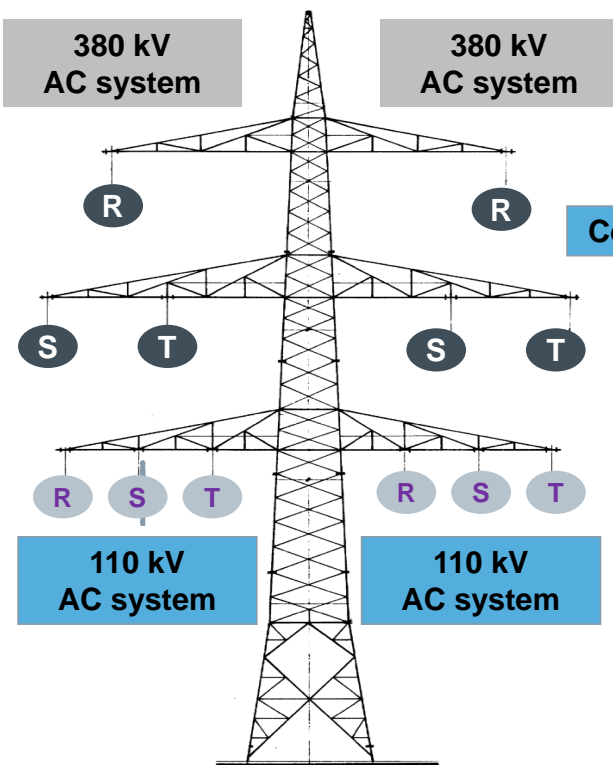


**More than 50% footprint reduction in Right-of-Way**

# Utilization of existing AC OHL Corridors with an additional DC line

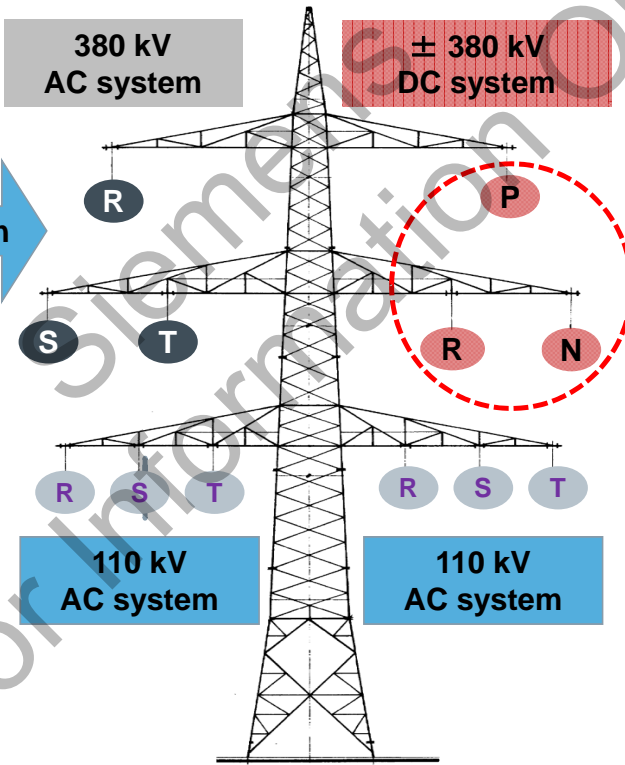
## Example: German Corridor Project

AC tower

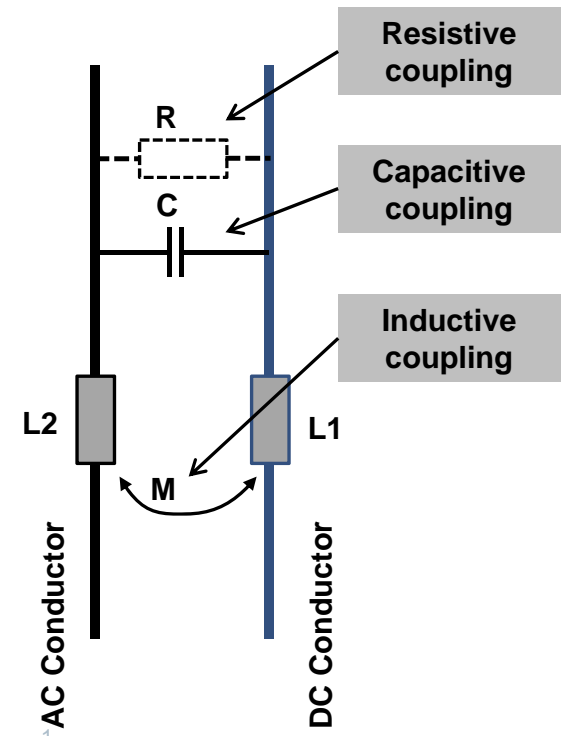


Conversion

AC/DC tower / Hybrid tower



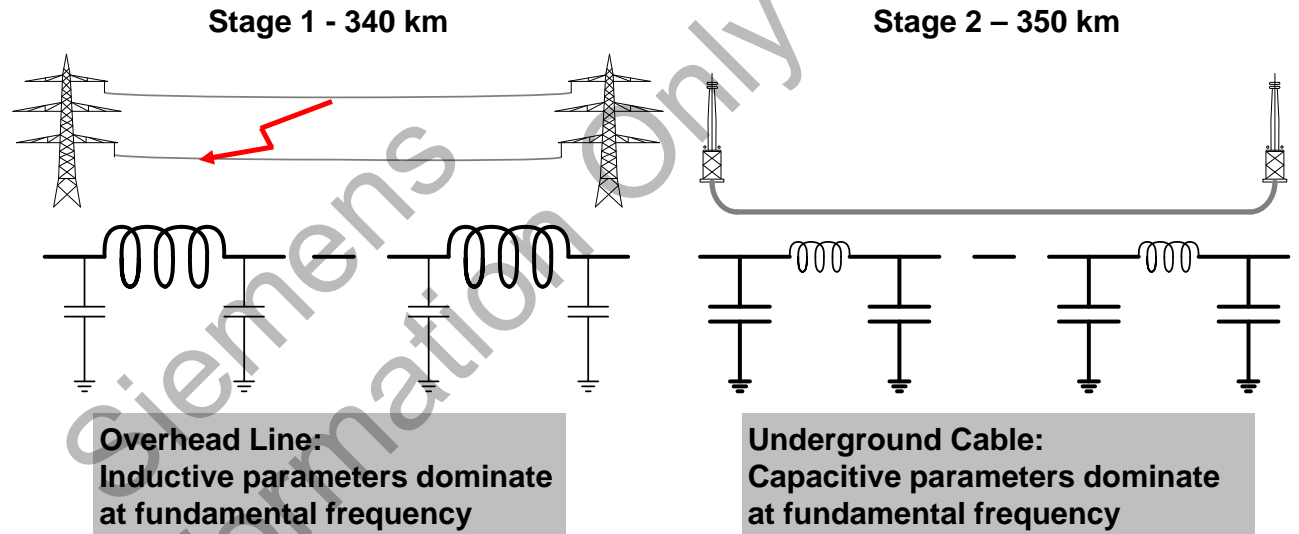
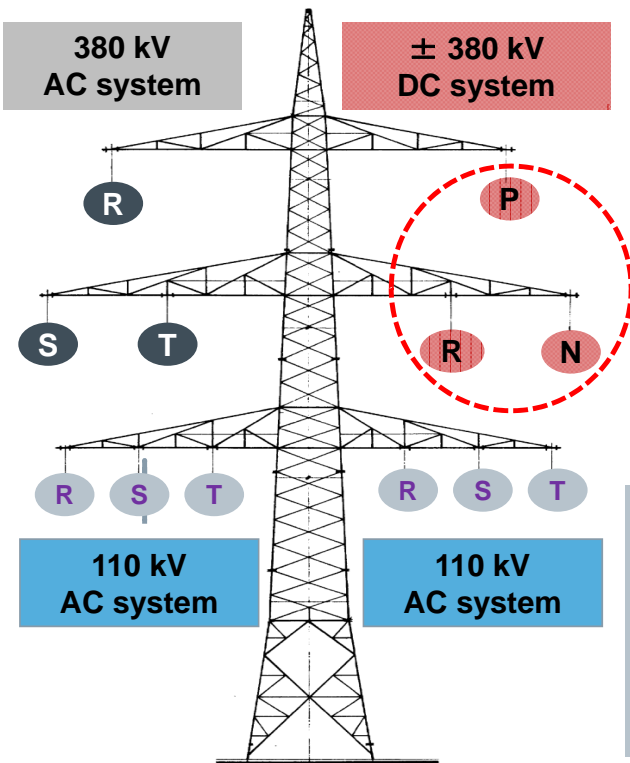
Inter-System Coupling



# Utilization of existing AC OHL Corridors with an additional DC line

## Example: German Corridor Project

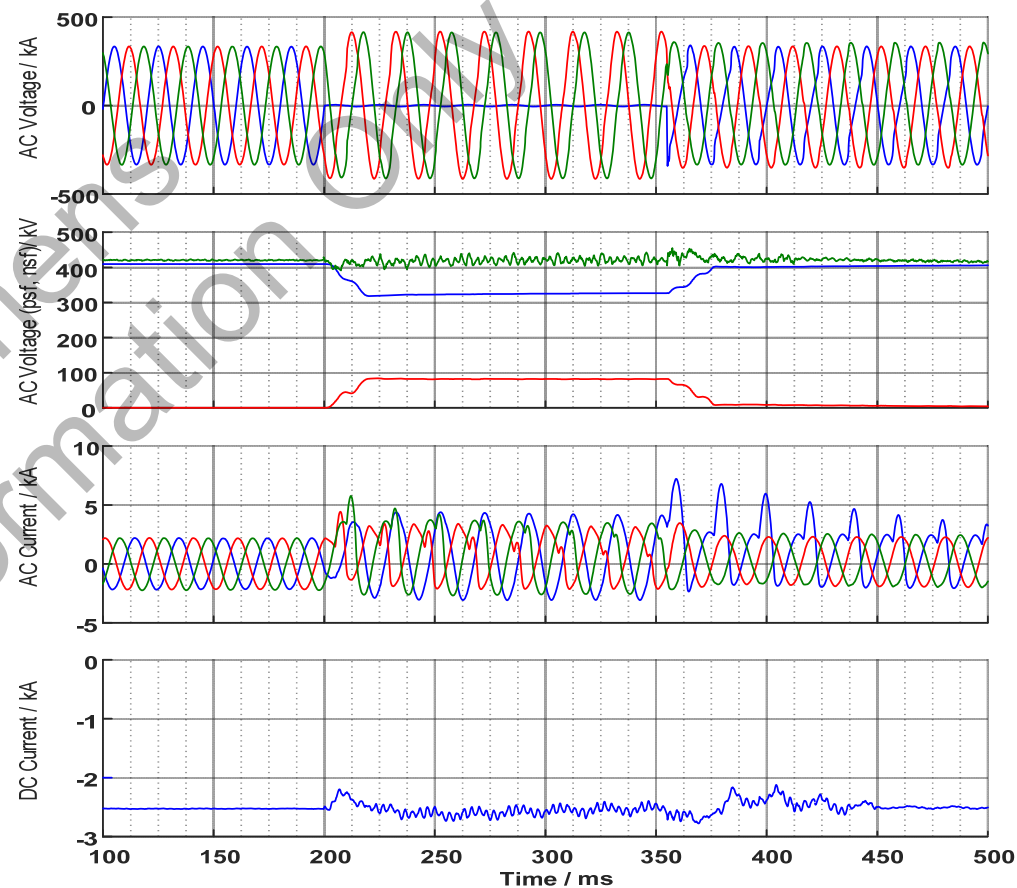
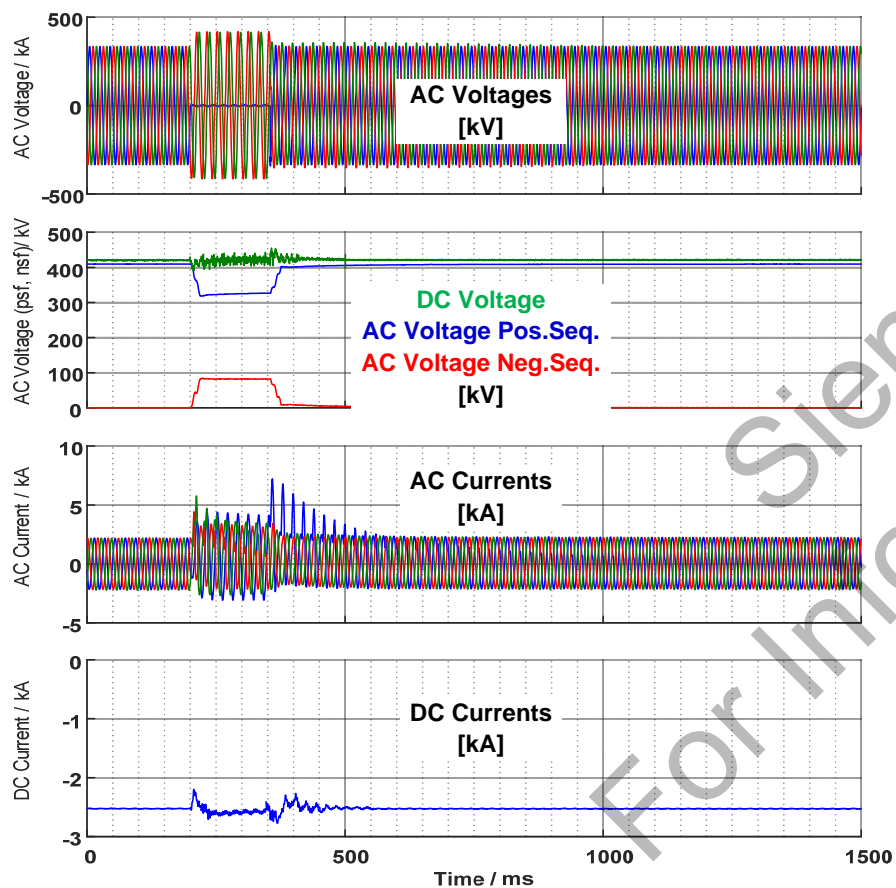
### AC/DC tower / Hybrid tower



### Managing inter-system faults is a challenge:

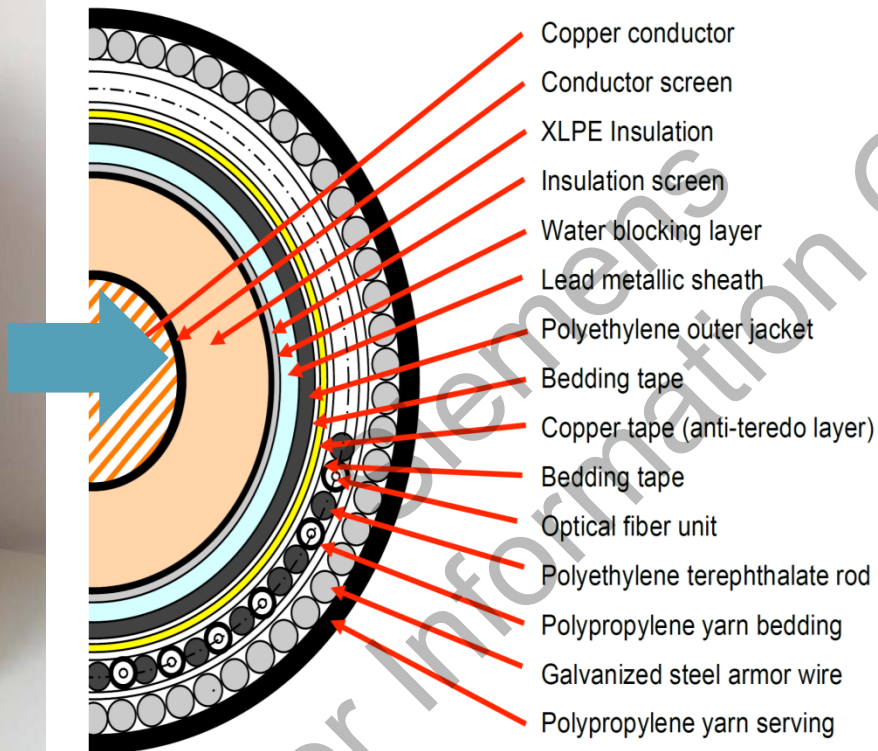
- 80 kA short circuit current level in 380 kV AC system
  - Extreme design of overvoltage protection to avoid damage of cables
  - The DMR cable is the most exposed due to its lower insulation level
- System Grounding in the middle station**

# Utilization of existing AC OHL Corridors with an additional DC line, Example: German Corridor Project – Fault Scenario 1ph to Ground



# Siemens HVDC Technology

## HVDC Transmission Path: HVDC XLPE Cable



**Typ\*:**  
400kV / 500 kV DC OHL w/wo  
Dedicated Metallic Return (DMR)

\*Designed, manufactured and delivered by Sumitomo Corp. Japan

# Siemens HVDC Technology

## HVDC Onshore Cable Installation & Jointing (DC Cable)

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**Michael Schmidt**

Siemens AG  
Energy Management Division  
Transmission Solutions  
Sales & Marketing HVDC  
Freyeslebenstr. 1  
91058 Erlangen, Germany  
Tel.: +49 9131 7-24228  
Mobile: +49 152 22598684  
[michael.schmidtms@siemens.com](mailto:michael.schmidtms@siemens.com)

## Appendix G: Operations and Maintenance (O&M)

This appendix estimates the O&M Costs associated with a new YK/BC Interconnection.

### G.1 Line Maintenance Costs

The YK/BC Interconnection would add three new line segments triggering incremental maintenance costs.

- Segment 1 – Tatogga to Takhini  $\pm$ 200 kV DC – 765km
- Segment 2 – Takhini to Carmacks 230 kV AC – 158 km

Segment 3 – Carmacks to Casino 230 kV AC – 180 km

Typically utility line maintenance is comprised of:

- Right of way – brushing and spraying to keep vegetation from growing up into the conductors. Initial construction will clear the right of way and subsequent maintenance will rely on herbicide application and hazard tree removal.
- Inspections & Patrols – Twice annually a general helicopter patrol of the line will be performed. Periodic inspections will be performed from the ground (“walk-up” including infrared cameras) and by climbing the structures.

The estimated annual maintenance costs below are based on recent utility estimates for similar classed transmission lines in Northern BC and Ontario and then increased 25% for the increased remoteness and harsh climate of the proposed line routes.

**Table G-1: Annual Maintenance Costs – DC Lines**

Segment	Distance	Unit Maintenance Cost (\$/yr/km)	Annual Maintenance (\$/yr)
Segment 1 (TAK) - Tatogga to Takhini	765 km	3,285	2,513,000
Segment 2 (CAR) - Takhini to Carmacks	158 km	3,285	519,000
Segment 3 (CAS) - Carmacks to Casino	180 km	3,285	591,000
<b>Totals</b>	1103 km	–	3,623,000

### G.2 Station Operation & Maintenance Costs

The YK/BC Interconnection would add two new DC converter stations and expand the existing stations at Carmacks and Takhini. The new/expanded stations requiring maintenance are:

- 2 – ±200 kV DC Converter stations
- 1 – Takhini Expansion (2 – 230 kV breakers, 1 – 138 kV breaker, 230/138kV Transformer)
- 1 – Carmacks Expansion (2 – 230 kV breakers, 1 – 138 kV breaker, 230/138kV Transformer)

The DC converter stations are designed with built-in redundancy and required a few routine maintenance activities to care for the system components that include moving parts:

- Valve cooling plant (filter checking, make-up tank level checking)
- Converter transformer tapchangers
- AC circuit breakers

Typical maintenance activities for conventional AC substations comprises:

- Fall / spring inspections,
- Relay, transformer, breaker & battery maintenance,
- ground grid testing,
- annual heat scan,
- oil sampling and replacement

The estimated annual maintenance costs below are based on retaining the HVDC vendor for non-routine maintenance and trouble callouts, and are informed by recent utility estimates for AC station maintenance in Northern BC, increased by 25% for remoteness and harsh climate.

**Table G-2: Annual Maintenance Costs – Substations**

<b>Station</b>	<b>Annual Maintenance (\$/yr)</b>
<b>±200 kV DC Converter stations (2)</b>	2,450,000
<b>Takhini Expansion</b>	106,000
<b>Carmacks Expansion</b>	106,000
<b>Totals</b>	2,662,000

## Appendix H: Watson Lake Connection Options

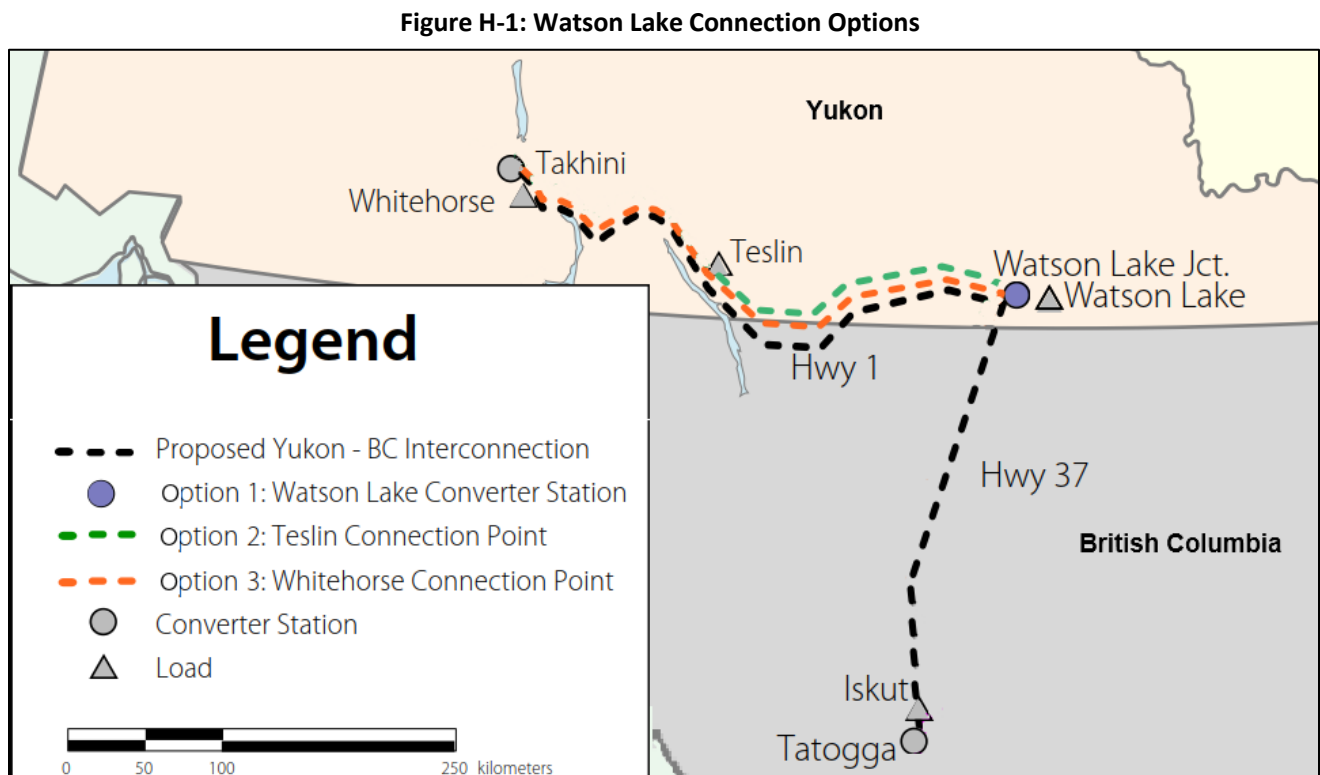
### H.1 Watson Lake

Watson Lake is currently fully served by diesel generation and not connected to the Yukon grid. Since the HVDC segment (TAK) of the proposed Yukon - BC interconnection will pass within 20 km of Watson Lake (Watson Lake Junction), there is an option to connect Watson Lake via a new converter station. However, the cost of a converter station to connect only 5 MW (Watson Lake peak load) is significant so additional (potentially less costly) AC connection options were considered. Teslin and Whitehorse are the two most plausible points on the Yukon grid for connecting Watson Lake via an AC transmission line; Teslin is the closest point of the Yukon grid to Watson Lake and Whitehorse is the closest major substation of the Yukon grid to Watson Lake.

Consequently, the following three options were considered for connecting the Watson Lake load to the Yukon grid:

1. An HVDC converter station at Watson Lake to tap power from the proposed Yukon - BC Interconnection.
2. An AC line from Teslin to Watson Lake
3. An AC line from Whitehorse to Watson Lake

Figure H-1 illustrates the options considered for connecting Watson Lake to the Yukon grid.



Options 2 and 3 are analyzed further in Section H.2 to determine the least cost, technically feasible AC connection option for connecting Watson Lake to the Yukon grid.

## H.2 AC Connection Options Analysis

The AC options were developed based on the factors summarized in Table H-1.

**Table H-1: AC Option Development Factors for Watson Lake Connection**

Factor	Options Considered	Rationale
Connection Point	Teslin	Closest point of the Yukon grid to Watson Lake
	Whitehorse	Closest major substation of the Yukon grid to Watson Lake
Voltage Class	34.5 kV	Would be a continuation of the existing 34.5 kV line between Whitehorse and Watson Lake
	69 kV	The next standard voltage class above 34.5 kV
	138 kV	Would be an extension of the existing 138 kV system in Whitehorse
Conductor	3/0 Pigeon	Two common ACSR conductors that are capable of handling the required line current to provide 5 MW at Watson Lake
	266 Partridge	
Number of Phases	3 phase	Lower power losses since power is delivered via three parallel conductors
	Single phase	Lower conductor costs since only one conductor is required to deliver power

Combining the factors in Table H-1 results in the connection permutations summarized in Table H-2 below. Considering the 415 km distance between Whitehorse and Watson Lake and the load profile of Watson Lake, 69 kV was determined to be the lowest practical AC voltage for connecting directly to Whitehorse. The 3/0 Pigeon conductor was not considered at 138 kV because of the associated corona discharge levels.

**Table H-2: Summary of AC Connection Options Considered**

Connection Point	Voltage	Conductor	# phases
Teslin	34.5 kV	266 Partridge	1
			3
		3/0 Pigeon	1
			3

Connection Point	Voltage	Conductor	# phases
	69 kV	266 Partridge	1
			3
		3/0 Pigeon	1
			3
Whitehorse	69 kV	266 Partridge	1
			3
		3/0 Pigeon	1
			3
	138 kV	266 Partridge	1
			3

### H.2.1 Connection Point Selection

Teslin is currently connected to Whitehorse via a 34.5 kV AC line via Johnsons Crossing. Connecting at Teslin would reduce the length of the incremental AC line requirement by 176 km. However, as shown in Table H-3. A Teslin connection point is not viable because the existing 175 km 34.5 kV Whitehorse-Teslin section would be a bottleneck. An additional 5 MW power transfer over the existing Whitehorse-Teslin section results in voltage collapse at Teslin.

**Table H-3: Selection of Preferred AC Connection Point**

Connection Point	Voltage	Conductor	# phases	Viability
Teslin	34.5 kV	266 Partridge	1	<b>Option Status: Not selected</b> An additional 5 MW power transfer over the existing Whitehorse-Teslin section results in voltage collapse.
			3	
		3/0 Pigeon	1	
			3	
	69 kV	266 Partridge	1	
			3	
		3/0 Pigeon	1	
			3	
Whitehorse	69 kV	266 Partridge	1	<b>Option Status: Selected for further analysis</b>
			3	
		3/0 Pigeon	1	
			3	
	138kV	266 Partridge	1	
			3	

### H.2.2 Whitehorse – Watson Lake Connection Options – Powerflow Analysis

Table H-4 shows analysis results for the different Whitehorse to Watson Lake options that were evaluated. Based on powerflow analysis of voltage and losses, one 69 kV option and two 138 kV options were selected for cost analysis.

**Table H-4: Voltage Class Selection**

Connection Point	Voltage	Conductor	# phases	Viability
Whitehorse	69 kV	266 Partridge	1	<b>Option Status: Not selected</b> The single phase option results in voltage collapse
			3	<b>Option Status: Selected for further analysis</b>
		3/0 Pigeon	1	<b>Option Status: Not selected</b> The 3/0 Pigeon option results in high losses (>30%) at 69 kV
			3	
	138 kV	266 Partridge	1	<b>Option Status: Selected for further analysis</b>
			3	

### H.2.3 Summary of Technically Feasible AC Connection Options

Table H-5 presents a summary of the technically feasible AC options for connecting to Watson Lake to Whitehorse. The feasible AC connection options are moved forward for cost comparison.

**Table H-5: Summary of Feasible AC Connection Options**

Connection Point	Voltage	Conductor	# Phases
Whitehorse	69 kV	266 Partridge	3
	138 kV	266 Partridge	1
			3

### H.2.4 Summary of Costs for Technically Feasible AC Connection Options

The total cost of each feasible AC option is determined by estimating the initial capital cost and adding the net present value of the resulting line losses. The cost estimates for the viable AC options are developed assuming two possible configurations:

- 1) An over-build on the section of the proposed BC-Yukon HVDC line that runs between Whitehorse and Watson Lake Junction (3 phase and 1 phase).
- 2) A stand-alone transmission line (3 phase only) running parallel to the section of the proposed BC-Yukon HVDC line that runs between Whitehorse and Watson Lake Junction. This configuration is included only for comparison and is not considered economically viable.

Table H-6 summarizes the capital costs for each feasible AC connection option.

**Table H-6: Capital Costs of Feasible AC Connection Options**

Connection Point (Configuration)	Voltage	Conductor	# Phases	Capital Costs (\$M)
Whitehorse (over-build)	69 kV	266 Partridge	3	100
	138 kV		1	60
			3	140
Whitehorse (stand-alone)	69 kV	266 Partridge	3	180
	138 kV		3	290

Table H-7 summarizes the Net Present Value of the line losses for each feasible AC connection option.

**Table H-7: NPV of Losses of Feasible AC Connection Options**

Connection Point	Voltage	Conductor	# Phases	NPV of Losses (\$M)
Whitehorse	69 kV	266 Partridge	3	3.3
	138 kV	266 Partridge	1	2.4
			3	0.9

### H.3 Summary of Total Costs for Feasible Connection Options

Table H-8 summarizes the total costs for each viable AC option and includes the cost of building an HVDC converter station at Watson Lake. The least cost AC connection option consists of a 138 kV single phase over-build on the proposed Yukon – BC interconnection with a 266-Patridge conductor.

**Table H-8: Summary of Total Costs for Feasible Connection Options**

Connection Point (Configuration)	Voltage	Conductor	# Phases	Capital Costs (\$M)	NPV of Losses (\$M)	Total Costs (\$M)
Whitehorse (over-build)	69 kV	266 Partridge	3	100	3.3	103
	138 kV		1	60	2.4	62
			3	140	0.9	141
Whitehorse (stand-alone)	69 kV	266 Partridge	3	180	3.3	183
	138 kV		3	290	0.9	291
HVDC converter station at Watson Lake				75	negligible	75

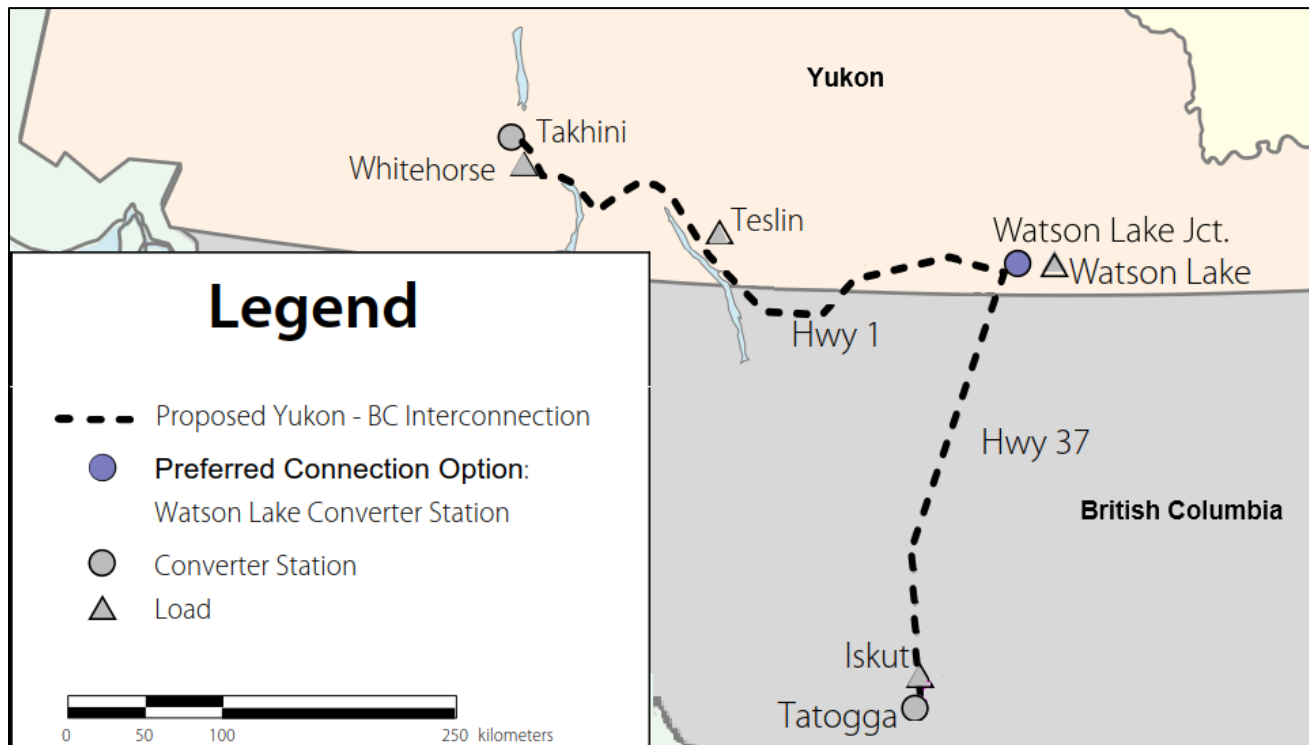
### H.4 Preferred Connection Option for Watson Lake

Table H-9 shows the final comparison of the two least cost connection options and the rationale for selecting the preferred option. Figure H-2 illustrates the preferred connection option for Watson Lake.

**Table H-9: Selection of Preferred Connection Option for Watson Lake**

Connection Option	Verdict
Least cost feasible AC connection option <ul style="list-style-type: none"> <li>○ 138 kV single phase over-build on the proposed Yukon – BC HVDC interconnection with a 266-Patridge conductor</li> </ul>	<p><b>Option Status: Not preferred</b></p> <p>Although this is the least cost option overall and technically feasible, single phase AC transmission is not widely adopted in the utility industry as compared to HVDC. This means there would be little technical support for troubleshooting operational issues should they arise.</p>
HVDC Converter station at Watson Lake	<p><b>Option Status: Preferred</b></p> <p>HVDC converter technology is mature and widely adopted in and the cost of this option is within the accuracy range of the 138 kV single phase option.</p>

Figure H-2: Preferred Connection Option for Watson Lake



### H.5 Assumptions

Table H-10: summarizes the assumptions made while developing the cost estimates for the Whitehorse to Watson Lake connection

Table H-10: Cost Estimate Assumptions for Watson Lake Connection

Factor	Assumption
Power transfer	5 MW
Load factor	90%
Time period	25 years
Price and escalation	2.5%
Utility discount rate	4.92%
Existing Whitehorse – Teslin Conductor	1/0

## Appendix I: WECC and Reliability Standards

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This appendix deals with Western Electricity Coordinating Council (WECC) membership and North American Electricity Reliability Corporation (NERC) Reliability Standards as they may apply to the Yukon with an interconnection to BC.

Entities connected to the North American Bulk Electric System (BES) are subject to reliability standards as a condition of connection. The applicable standards and incremental cost for a radial asynchronous connection such as the YK/BC Interconnection will likely be minimal, however a future connection through to Alaska could trigger additional requirements. Provinces have typically undergone a review process to determine the extent and applicability of the reliability standards. The Yukon would need to undergo a similar process to determine which reliability standards would be adopted as mandatory by the regulator (YUB).

WECC membership and NERC Reliability Standards requirements are often commingled because WECC administers the Reliability Standards program for BC. WECC and the NERC Reliability Standards are described in the following two sections.

### I.1 WECC

WECC is a reliability organization that provides a coordination role for the Western US, BC & Alberta.

- Membership is voluntary and free and members can participate in WECC committee activities and access the technical expertise within the organization.
- Members are obligated to abide by WECC rules and contribute system data to aid in coordinated operations and planning.
- WECC also administers the reliability standards program for BC.

Becoming a WECC member would not trigger a material change for YEC and could likely be accommodated within the existing processes for planning and operation.

### I.2 NERC Reliability Standards

NERC is the electricity reliability organization for North America and develops reliability standards.

- In response to major blackouts in the early 2000's, the current set of reliability standards were developed to ensure adequate reliability across North America
- Each jurisdiction connected to the North American BES has adopted them and new interconnectors adopt them as a condition of connection.
- Alberta and BC each went through a process of reviewing the standards for applicability to their systems. Applicable standards were recommended for adoption and made mandatory through legislation and regulatory approval.

The level of effort and expense associated with adopting the NERC RS would depend on the scope of the standards adopted but is expected to be minimal because of the radial and asynchronous nature of the contemplated YK/BC HVDC interconnection.

There are more than 100 NERC Reliability Standards organized under the 13 categories below:

- 1) Resource And Demand Balancing (BAL) — real power balancing, contingency reserve, frequency response and AGC
- 2) Communications (COM) — communications and operating personnel communications protocols
- 3) Critical Infrastructure Protection (CIP) — cyber security categorization, personnel & training, electronic and physical security, incident reporting & recovery plans
- 4) Emergency Preparedness And Operations (EOP) — event reporting, system restoration, loss of control center, emergency operations
- 5) Facilities Design, Connections, And Maintenance (FAC) — facility interconnection requirements & studies; vegetation management, ratings, system operating limits for planning & operation
- 6) Interchange Scheduling And Coordination (INT) — evaluation and implementation of interchange transactions
- 7) Interconnection Reliability Operations and Coordination (IRO) — reliability coordination – responsibilities, monitoring and analysis, operations analysis and coordination.
- 8) Modeling, Data, And Analysis (MOD) — ATC and reliability margins, load management, verification and validation of machine models, area interchange and path ratings, data for power system modeling
- 9) Personnel Performance, Training, And Qualifications (PER) — operating personnel credentials, staffing & training
- 10) Protection & Control (PRC) — system protection coordination, disturbance monitoring and reporting requirements, protection misoperation & correction, protection maintenance and testing, underfrequency and undervoltage load shedding, remedial action schemes (RAS), disturbance monitoring equipment, transmission and machine protection settings for loadability and power swings
- 11) Transmission Operations (TOP) — transmission operations, operations planning, operational reliability data, real-time reliability monitoring
- 12) Transmission Planning (TPL) — transmission system planning performance requirements
- 13) Voltage And Reactive (VAR) — voltage and reactive control, generator operation for maintaining network voltage schedules, automatic voltage regulators (AVR), power system stabilizer (PSS)