5.2.3 Small Hydro

Technology description

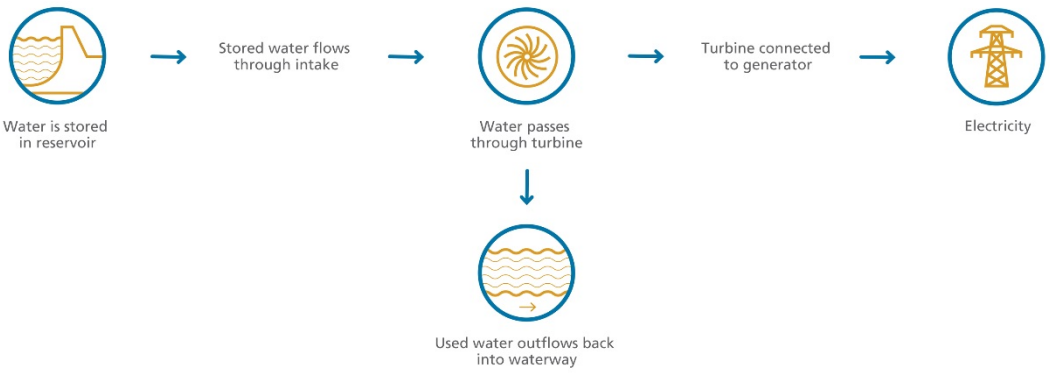
Hydroelectricity generation uses the force of falling or fast moving water to drive a turbine, which in turn drives a generator to produce electricity, as shown in Figure 5-8. Small scale hydro in Yukon could either be a conventional plant with a dam and reservoir to store water or a run-of-river plant.

Conventional hydroelectric plants with storage use an upstream reservoir to store water and control water flows to the powerhouse based on the electrical demand. This type of resource is considered dispatchable as it allows the utility to generate electricity when it is needed.

Run-of-river hydro generation has no or minimal upstream water storage, and uses the natural flow in a river at any given time to generate electricity. Water is typically diverted by a weir into a piping system that brings the water through a powerhouse and then back into the river downstream. The electricity generated varies seasonally with the flow of the river. For this reason, run-of-river hydro plants have limited dispatchability. Run of river hydropower resources typically have a seasonal generation output that depends on the runoff timing. Many rivers in Yukon have peak flows in the late summer when the snowpack melt is at its highest, and the lowest flows during the winter.

Conventional hydro provides dispatchable energy and dependable capacity while run-of-river hydro only provides small amount of dependable capacity. In addition, run-of-river hydro has limited to no dispatchability. The small hydro projects are able to provide energy in the winter, when demand for energy is highest. Some of the projects shown in Figure 5-8 would provide the same or more energy in the summer when demand for energy is lower.

Figure 5-8: Conventional Small Hydro



Studies

A screening assessment of potential small hydro sites in Yukon and northern British Columbia was completed for the 2016 Resource Plan by Knight Piesold. A pre-feasibility study completed by Morrison Hershfield for the Atlin Hydro Expansion was also included and added to the list of retained sites generated by Knight Piesold.

The first phase of this assessment involved a review of prior reports prepared on small hydro by YEC, Yukon Electrical Company, Yukon Development Corporation and other companies over the last 50 years. The

Knight Piesold screening assessment is presented in Appendix 5.7 and contains a list of the reports that were reviewed. The pre-feasibility report by Morrison Hershfield can be found in Appendix 5.8.

The screening assessment report started with 49 potential hydroelectric sites, characterized as both storage and run-of-river. These sites were first screened for redundancy and for those located in restricted areas, such as parks. The next screening was of sites that were more than 25 km away from existing or proposed transmission lines, as it was determined that connecting these sites to the grid would be cost prohibitive. These screenings left 22 sites remaining for further study. The next phase of the assessment was to review the hydrology of the sites, model energy output, review project layouts, estimate cost and finally complete a cost benefit analysis. From this analysis, a shortlist of five sites was chosen for more detailed review. The Atlin Hydro Expansion at Pine Creek in BC was also added to the list, with data coming from the Morrison Hershfield report.

Summary of studies to date and key findings

The six sites shortlisted in the reports are:

- Anvil Creek
- Drury Lake
- Finlayson River
- Tutshi Lake – Windy Arm
- Wolf River
- Pine Creek

The Wolf River and Anvil Creek projects would be considered run-of-river plants and the remaining four would have storage.

It was also noted that the Tutshi Lake – Windy Arm site could have potential synergies with the downstream Whitehorse Generating Station and potential pumped storage hydro sites between Moon Lake and Tutshi Lake that could add more winter generation.

The following Table 5-27 describes the technical and financial attributes and Table 5-28 to Table 5-33 describe the environmental, social and economic attributes of the six small hydro resource options. The average monthly energy profile is shown in Figure 5-9. The location of the small hydro projects are shown in Figure 5-10.

1 Table 5-27. Small Hydro Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	**Firm Energy** GWh/yr	**Installed Capacity** MW	**Dependable Capacity** MW	**Levelized Cost of Energy** $/kWh	**Levelized Cost of Capacity** $/kW·yr	**Project Life** Years	**Lead Time** Years	**Dispatch-able** Y/N
Drury Lake								
31.7	31.7	8.1	8.1	0.19	700	65	6	Y
Tutshi Windy Arm								
56.6	56.3	7.2	7.2	0.14	1100	65	6	Y
Wolf River								
95.6	86.9	20	2.8	0.14	700	65	6	Y
Finlayson River								
138.9	138.9	17.6	17.6	0.12	1000	65	6	Y
Atlin/Pine Creek								
36.1	22.3	8	5.5	0.13	806	30	6	Y
Anvil Creek								
41.3	31	9.8	2.5	0.17	700	65	6	Y

Figure 5-9: Average Energy Profile for Small Hydro Resource Option

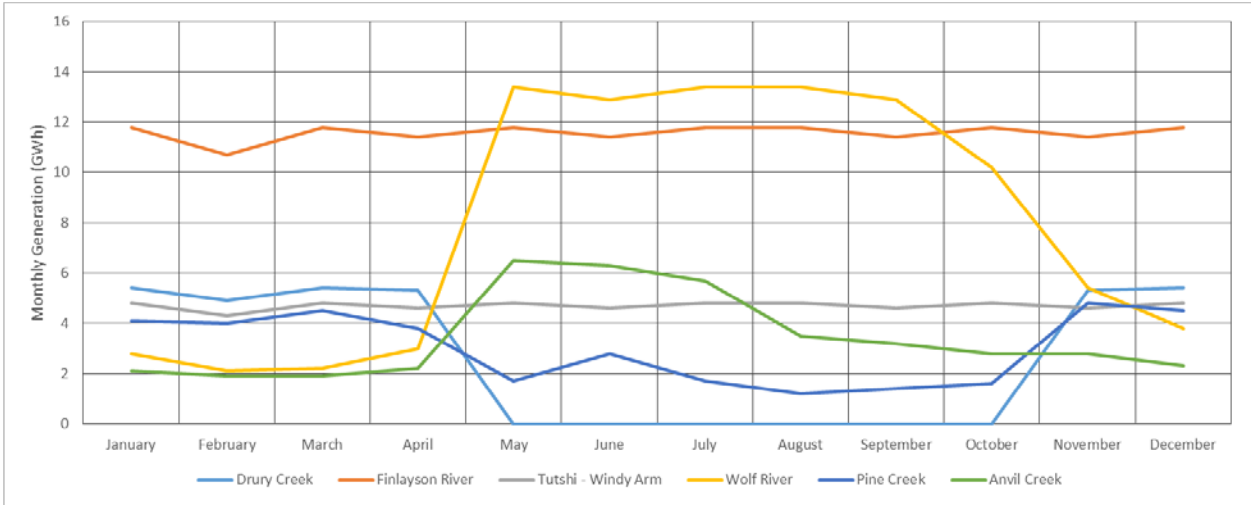


Table 5-28: Small Hydro Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Drury Lake					
Tutshi - Windy Arm					
Wolf River					
Finlayson River					
Atlin/ Pine Creek					
Anvil Creek					

Table 5-29: Small Hydro Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Drury Lake							
Tutshi - Windy Arm							
Wolf River							
Finlayson River							
Atlin/ Pine Creek							
Anvil Creek							

Table 5-30: Small Hydro Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Drury Lake		
Tutshi - Windy Arm		
Wolf River		
Finlayson River		
Atlin/ Pine Creek		
Anvil Creek		

Table 5-31: Small Hydro Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Drury Lake					
Tutshi - Windy Arm					
Wolf River					
Finlayson River					
Atlin/ Pine Creek					
Anvil Creek					

Table 5-32: Small Hydro Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		**Cultural & Community Well-being (S5)**		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Drury Lake				
Tutshi - Windy Arm				
Wolf River				
Finlayson River				
Atlin/ Pine Creek				
Anvil Creek				

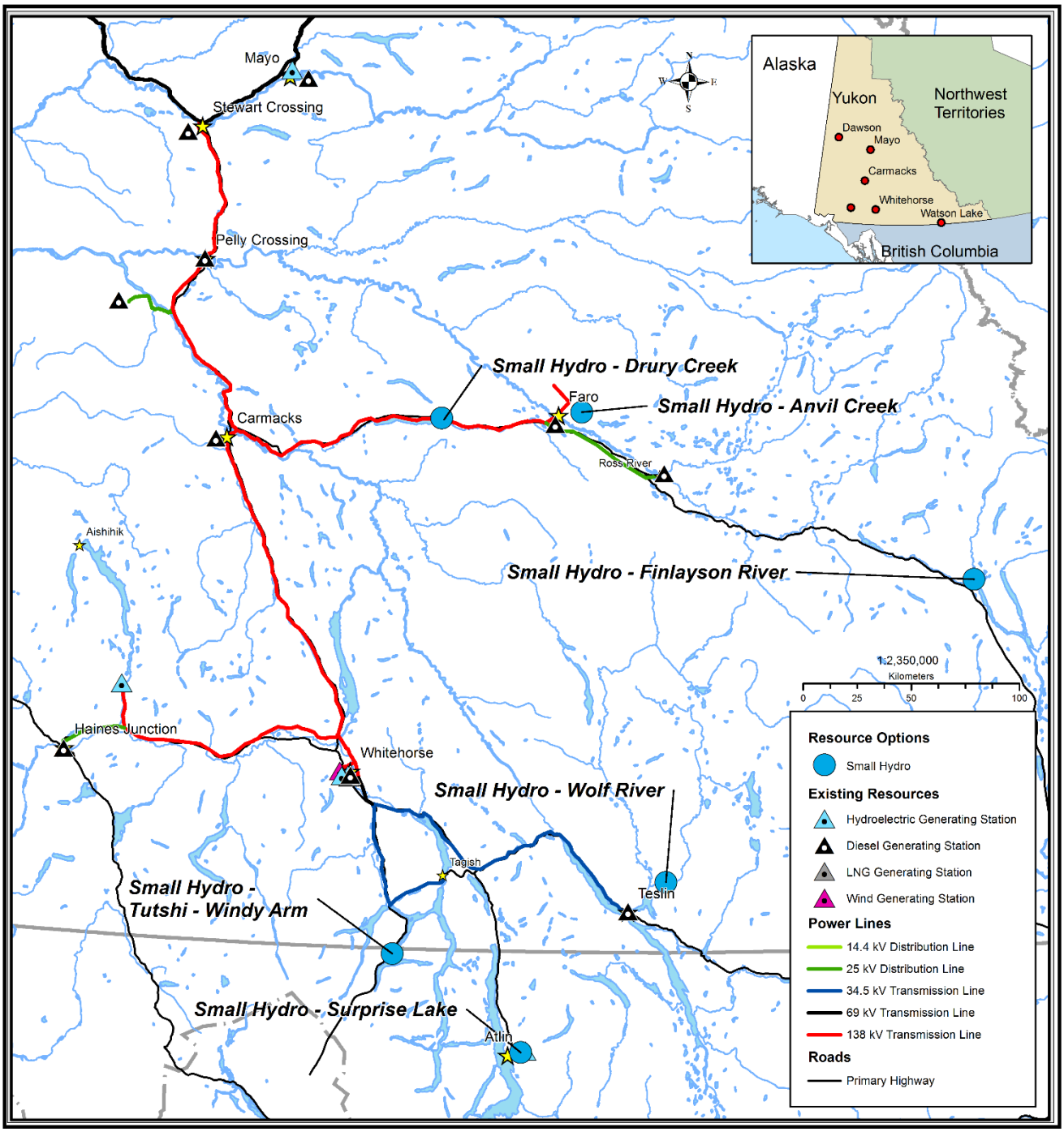
Table 5-33: Small Hydro Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	**Tourism Values (S4-2)**	**Aesthetics (S4-3)**	**Non-renewable Resources (S4-4)**	**Other Renewable Resources (S4-5)**	**Land Use & Renewable Resources Plans (S4-6)**
Drury Lake					
Tutshi - Windy Arm					
Wolf River					
Finlayson River					
Atlin/ Pine Creek					
Anvil Creek					

Table 5-34: Small Hydro Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			**Climate Change Risk affecting Resource Financial Attributes (Ec2)**				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Drury Lake							
Tutshi - Windy Arm							
Wolf River							
Finlayson River							
Atlin/ Pine Creek							
Anvil Creek							

1 *Figure 5-10: Small Hydro Resource Option Locations*



5.2.4 Wind

Technology description

Wind power uses the energy of wind to move turbine blades which drives a generator to produce electricity, as shown in Figure 5-11. Wind turbine generators range in size from very small 50 W turbines that are used in application such as charging batteries on a boat to the largest wind turbine currently produced at 6 MW. Most utility scale wind farms have wind turbine generators that range between 1 and 3 MW. These wind turbines are mounted on steel towers ranging 60 to 100 meters tall with three blades each 20 to 50 meters long. Larger wind generating stations in the Yukon may incorporate batteries to offset substantial fluctuations in generation

Wind is a variable resource and the timing of wind generation cannot be controlled by the operator. There will be times when the turbines do not produce electricity such as when wind speeds exceed the stress specifications of the turbines or towers or when wind speeds are below the start-up speed of the turbine. Because this resource is subject to the variabilities of the wind, it is not dispatchable or firm, and therefore it provides no dependable capacity.

The wind regime in the Yukon provides more energy in the winter which matches the greater demand for winter energy on the grid.

Figure 5-11: Wind



Studies

An inventory of wind energy sites was completed for the 2016 Resource Plan by CBER with sub consultants V3 Energy, LLC and Envint. A number of previous studies were reviewed for this inventory and are discussed in the report which is presented in Appendix 5.9. These studies focused on defining the wind resources on a regional level, as well as at specific known sites: Aishihik, Tehcho (Ferry Hill), Whitehorse and Mount Sumanik. The inventory completed for the 2016 Resource Plan expanded on the mesoscale (large scale) wind mapping work previously completed and identified potential wind energy sites across the Yukon. Considerations of distance to the nearest road as well as existing and planned transmission infrastructure were made when screening for the best sites. Environmental factors and land usage was also considered in the study. Seven sites were selected for conceptual design and economic analysis.

Fuel description

A wind power site requires relatively high wind speeds, which generally occur at higher elevations. Wind turbines at higher elevation sites are more susceptible to rime icing issues.

Summary of studies to date and key findings

Out of a long list of 26 sites, 7 sites were selected based on wind speed, distance to transmission infrastructure, road access and land ownership for an in-depth review and conceptual design. The sites selected include:

- Miller's Ridge (near Carmacks)
- Kluane Lake (near Destruction Bay)
- Cyprus Mine (brownfield site, near Faro Mine)
- Thulsoo Mountain (near the Aishihik Generating Station)
- Sugarloaf Mountain (near Carcross)
- Tehcho (near Stewart Crossing, formerly Ferry Hill)
- Mount Sumanik (near Whitehorse)

Yukon's northern climate means that icing can occur at high elevations during winter, making operating a wind turbine challenging. Of the seven site selected, only one site at Kluane Lake is at a low elevation. Despite energy losses due to winter icing, all seven sites show an average of three-quarters of the expected electricity production occurring in the winter months between October and April. This generation profile is complementary to the Yukon's energy needs, which are higher in the winter due to increase requirements for space heating and lighting.

The following Table 5-35 describes the technical and financial attributes and Table 5-36 to Table 5-41 describe the environmental, social and economic attributes of the seven wind resource options. The average monthly energy profile is shown in Figure 5-12. The location of the wind projects can be found in Figure 5-13.

Table 5-35. Wind Resource Option Technical and Financial Attributes

Annual Energy	**Firm Energy**	**Installed Capacity**	**Dependable Capacity**	**Levelized Cost of Energy**	**Levelized Cost of Capacity**	**Project Life**	**Lead Time**	**Dispatch-able**
GWh/yr	GWh/yr	MW	MW	$/kWh	$/kW·yr	Years	Years	Y/N
Cyprus Mine 1								
16.1	16.1	6	---	0.18	---	25	5	N
Cyprus Mine 2								
26.0	26.0	10	---	0.14	---	25	5	N

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life Years	Lead Time Years	Dispatch-able Y/N
Cyprus Mine 3								
49.6	49.6	20	---	0.12	---	25	5	N
Kluane Lake 1								
15.0	15.0	6	---	0.15	---	25	9	N
Kluane Lake 2								
24.4	24.4	10	---	0.13	---	25	9	N
Kluane Lake 3								
47.8	47.8	20	---	0.11	---	25	9	N
Miller's Ridge 1								
18.1	18.1	6	---	0.18	---	25	5	N
Miller's Ridge 2								
29.5	29.5	10	---	0.13	---	25	5	N
Miller's Ridge 3								
57.3	57.3	20	---	0.11	---	25	5	N
Mt Sumanik 1								
14.2	14.2	6	---	0.18	---	25	5	N
Mt Sumanik 2								
21.1	21.1	10	---	0.15	---	25	5	N
Mt Sumanik 3								
41.5	41.5	20	---	0.12	---	25	5	N

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life Years	Lead Time Years	Dispatch-able Y/N
Sugarloaf Mtn 1								
9.9	9.9	6	---	0.23	---	25	5	N
Sugarloaf Mtn 2								
15.9	15.9	10	---	0.19	---	25	5	N
Sugarloaf Mtn 3								
32.3	32.3	20	---	0.15	---	25	5	N
Tehcho 1								
10.3	10.3	6	---	0.22	---	25	5	N
Tehcho 2								
18.3	18.3	10	---	0.17	---	25	5	N
Tehcho 3								
33.4	33.4	20	---	0.15	---	25	5	N
Thulsoo Mtn 1								
17.3	17.3	6	---	0.17	---	25	5	N
Thulsoo Mtn 2								
27.5	27.5	10	---	0.14	---	25	5	N
Thulsoo Mtn 3								
54.4	54.4	20	---	0.11	---	25	5	N

Figure 5-12: Average Energy Profile for Wind (20 MW) Resource Option

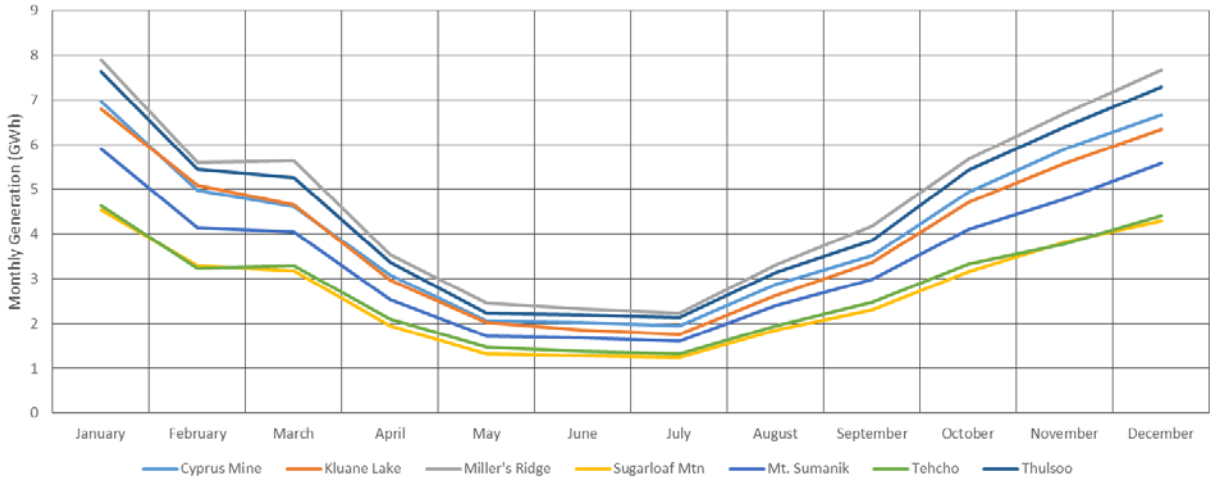


Table 5-36: Wind Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Cyprus Mine Hill, 20 MW					
Kluane Lake, 20 MW					
Millers Ridge, 20 MW					
Mt. Sumanik , 20 MW					
Sugarloaf Mountain, 20 MW					
Tehcho (Ferry Hill), 20 MW					
Thulsoo Mountain, 20 MW					

Table 5-37: Wind Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Cyprus Mine Hill, 20 MW							
Kluane Lake, 20 MW							
Millers Ridge, 20 MW							
Mt. Sumanik , 20 MW							
Sugarloaf Mountain, 20 MW							
Tehcho (Ferry Hill), 20 MW							
Thulsoo Mountain, 20 MW							

Table 5-38: Wind Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Cyprus Mine Hill, 20 MW		
Kluane Lake, 20 MW		
Millers Ridge, 20 MW		
Mt. Sumanik , 20 MW		
Sugarloaf Mountain, 20 MW		
Tehcho (Ferry Hill), 20 MW		
Thulsoo Mountain, 20 MW		

Table 5-39: Wind Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Cyprus Mine Hill, 20 MW					
Kluane Lake, 20 MW					
Millers Ridge, 20 MW					
Mt. Sumanik , 20 MW					
Sugarloaf Mountain, 20 MW					
Tehcho (Ferry Hill), 20 MW					
Thulsoo Mountain, 20 MW					

Table 5-40: Wind Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Cyprus Mine Hill, 20 MW				
Kluane Lake, 20 MW				
Millers Ridge, 20 MW				
Mt. Sumanik , 20 MW				
Sugarloaf Mountain, 20 MW				
Tehcho (Ferry Hill), 20 MW				
Thulsoo Mountain, 20 MW				

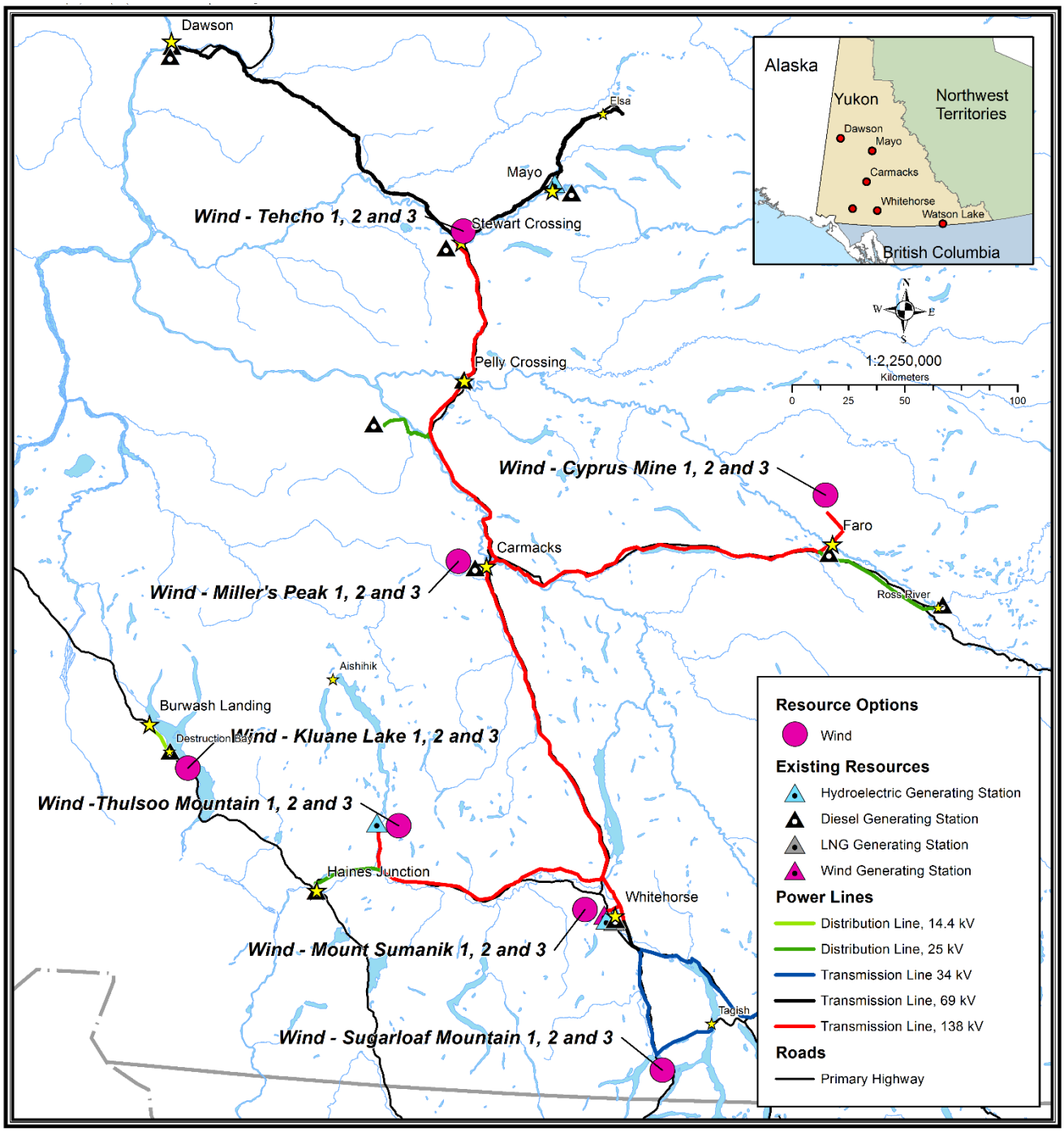
Table 5-41: Wind Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
Cyprus Mine Hill, 20 MW					
Kluane Lake, 20 MW					
Millers Ridge, 20 MW					
Mt. Sumanik , 20 MW					
Sugarloaf Mountain, 20 MW					
Tehcho (Ferry Hill), 20 MW					
Thulsoo Mountain, 20 MW					

Table 5-42: Small Hydro Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			**Climate Change Risk affecting Resource Financial Attributes (Ec2)**				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Cyprus Mine Hill, 20 MW							
Kluane Lake, 20 MW							
Millers Ridge, 20 MW							
Mt. Sumanik , 20 MW							
Sugarloaf Mountain, 20 MW							
Tehcho (Ferry Hill), 20 MW							
Thulsoo Mountain, 20 MW							

1 *Figure 5-13: Wind Resource Option Locations*



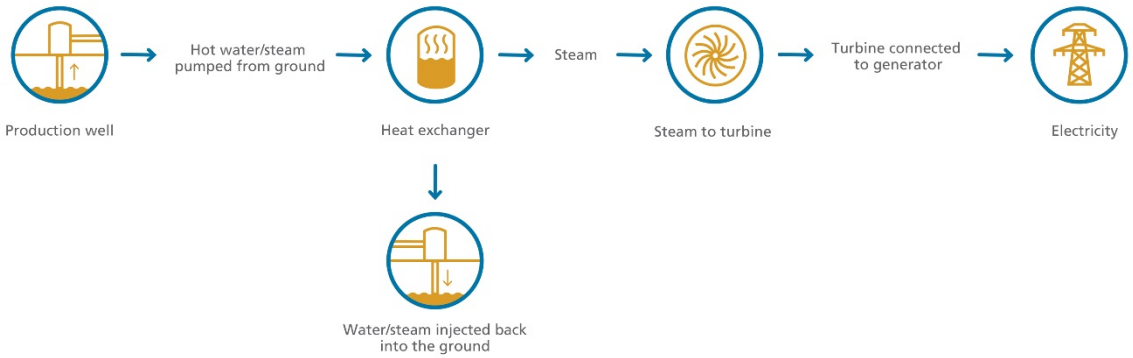
5.2.5 Geothermal

Technology description

Geothermal electricity generation uses the heat from groundwater to power a turbine and a generator, as shown in Figure 5-14. Based on survey work completed to date, geothermal resources in the Yukon provide low to medium temperature water and would require an Organic Rankine Cycle (ORC) power plant. An ORC plant uses steam and hot water from production wells to heat a binary fluid (usually a hydrocarbon) through a heat exchanger. The binary fluid has a low boiling point, and when heated, is vaporized at high pressure and then powers a turbine and a generator to produce electricity. After the vapor is used in the turbine, it is cooled, condensed to a liquid and recirculated through the system. The cooler groundwater is then reinjected back into the reservoir.

Geothermal provides dependable capacity but is not fully dispatchable. The energy provided is slightly higher in winter than summer, which complements the energy demand on the grid.

Figure 5-14: Geothermal



Studies

A review and site inventory of geothermal resources in the Yukon was completed for the 2016 Resource Plan by KGS Group, with sub consultants Mannvit hf and Intergroup. The report reviewed 26 prior studies and memos, dating back to the mid-1970s, with many completed between 2009 and 2012. These reports provided data on the basic geological setting and structure, surface spring temperature, water quality, calculations of geothermal source temperatures, isotope signatures, geothermal gradients, typical ground temperatures and climate normal data. The amount of information varies between reports. Generally the information is very high-level and additional work would be required to confirm the estimates in the report. A full bibliography of prior reports can be found in the technical report, Appendix 5.10.

Fuel description

All of the sites reviewed for this report have low to medium temperature resources, with groundwater temperatures below 150°C. Over the lifetime of a geothermal plant, it is assumed that generation output would decline by 2% per year as geothermal resource extraction slowly cools the water source at depth.

Summary of studies to date and key findings

The study reviewed both the geothermal resource and the proximity to transmission lines. Sites were ranked based on these criteria and the two highest ranking sites were selected for conceptual design development. Those two sites were Vista Mountain near Whitehorse and McArthur Spring near Stewart Crossing.

The site at Vista Mountain is close to existing transmission infrastructure and the main load centre of Whitehorse. It is located in Crown land and has a relatively high inferred resource temperature compared to other sites in the Whitehorse region. Many of the sites had a similar temperatures to the Vista Mountain site. Vista Mountain was chosen due to its location.

McArthur Springs is located in a rugged, remote area far from existing transmission infrastructure and site access would be challenging. The traditional name of McArthur Springs is Chu Tthaw Hot Springs and the site is located within the Ddhaw Ghro Habitat Protection Area on the traditional land of the Selkirk First Nation. The geothermal resource at McArthur Springs has significantly higher temperatures than the other geothermal resources studied to date, and therefore was retained as a candidate site for further analysis.

A technical and economic analysis was completed of the conceptual designs of two sizes of geothermal plants at Vista Mountain and McArthur Springs.

The following Table 5-43 describes the technical and financial attributes and Table 5-44 to Table 5-50 describe the environmental, social and economic attributes of the four geothermal options. The average monthly energy profile is shown in Figure 5-15. The location of the geothermal projects can be found in Figure 5-16.

Table 5-43. Geothermal Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	**Firm Energy** GWh/yr	**Installed Capacity** MW	**Dependable Capacity** MW	**Levelized Cost of Energy** $/kWh	**Levelized Cost of Capacity** $/kW·yr	**Project Life** Years	**Lead Time** Years	**Dispatch-able** Y/N
MacArthur Springs 1								
14.1	14.1	3.1	2.4	0.47	3,220	30	4	Y
MacArthur Springs 2								
36.5	36.5	7.7	6.2	0.23	1,388	30	4	Y
Vista Mountain 1								
6.2	6.2	1.4	1.1	0.37	2,330	30	4	Y
Vista Mountain 2								
15.9	15.9	3.6	2.8	0.19	1,094	30	4	Y

Figure 5-15: Average Energy Profile (Year 1) for Geothermal Resource Option

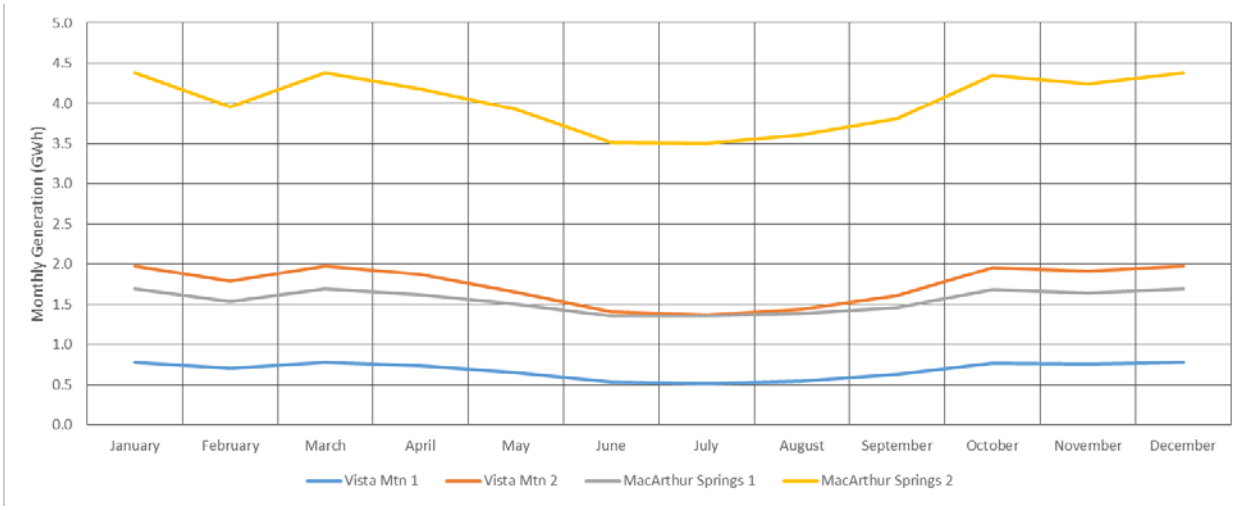


Table 5-44: Geothermal Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			**Water Quantity & Quality (En2)**		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
McArthur Springs (3.8 MW Av.)					
Vista Mountain (1.6 MW Av.)					

Table 5-45: Geothermal Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				**Terrestrial Footprint & Land Use (En4)**			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
McArthur Springs (3.8 MW Av.)							
Vista Mountain (1.6 MW Av.)							

Table 5-46: Geothermal Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
McArthur Springs (3.8 MW Av.)		
Vista Mountain (1.6 MW Av.)		

Table 5-47: Geothermal Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
McArthur Springs (3.8 MW Av.)					
Vista Mountain (1.6 MW Av.)					

Table 5-48: Geothermal Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		**Cultural & Community Well-being (S5)**		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
McArthur Springs (3.8 MW Av.)				
Vista Mountain (1.6 MW Av.)				

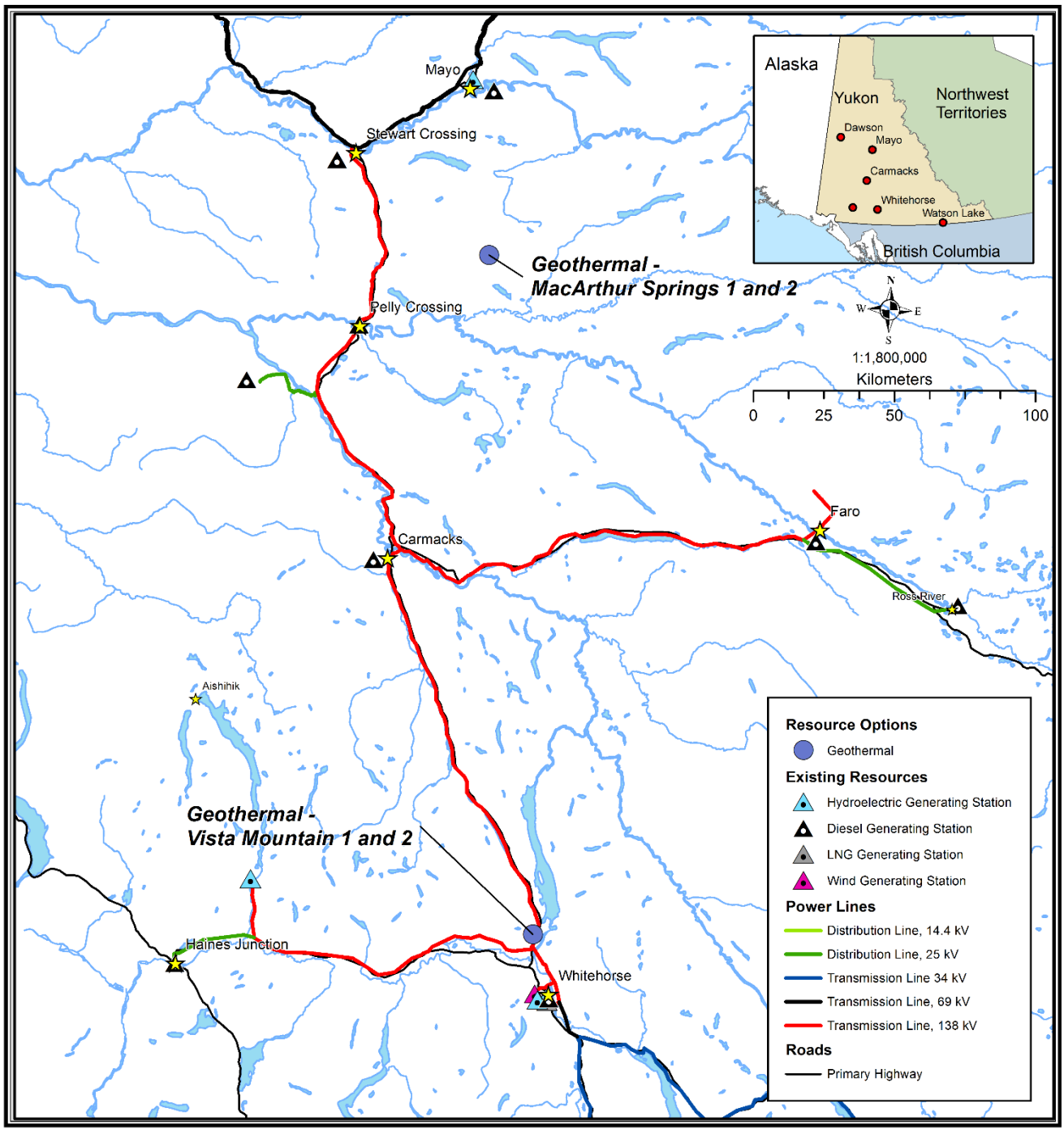
Table 5-49: Geothermal Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
McArthur Springs (3.8 MW Av.)					
Vista Mountain (1.6 MW Av.)					

Table 5-50: Geothermal Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			**Climate Change Risk affecting Resource Financial Attributes (Ec2)**				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
McArthur Springs (3.8 MW Av.)							
Vista Mountain (1.6 MW Av.)							

Figure 5-16: Geothermal Resource Option Locations



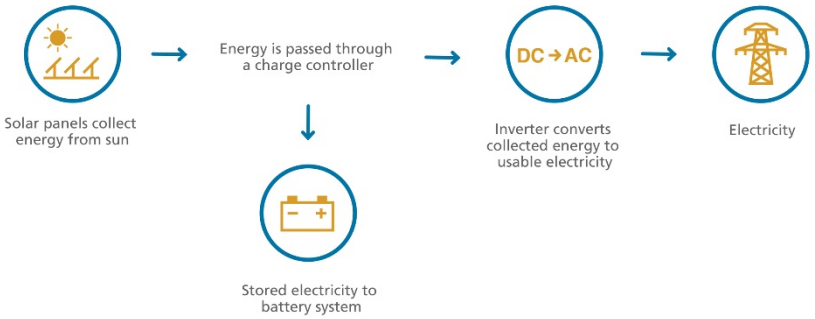
5.2.6 Solar

Technology description

Solar energy produced by photovoltaics (PV) converts sunlight to electricity using semiconductor panels. Solar PV generating sites consist of an array of solar panels mounted on a racking system and connected to inverters, as shown in Figure 5-17. A larger solar generating station may incorporate batteries to offset substantial fluctuations in generation.

Solar is an intermittent resource that is not dispatchable and does not provide dependable capacity. The majority of the energy is produced during the summer, which is opposite of the energy demand profile. Significant production occurs in April and May which is when hydro reservoirs are at the lowest levels after winter. This generation would be beneficial.

Figure 5-17: Solar



Studies

An inventory of potential solar sites was completed for the 2016 Resource Plan by Solvest, and can be found in Appendix 5.11. These sites were evaluated based on solar irradiance profiles, proximity to existing transmission infrastructure, proximity to communities, topography, land ownership and openness of land. The study also evaluated different solar panel, inverter and racking technologies.

Fuel description

The solar resource is quite consistent across the municipalities connected to the Yukon Power System, with the communities showing only a 6% annual variance relative to Whitehorse. The solar resource in Yukon is lower compared with other parts of Canada, but comparable to some countries that have implemented grid-scale solar such as Germany and Japan. A key finding is that solar irradiance in the Yukon is quite high in the late winter and spring months, when hydro generation is at its lowest.

Summary of studies to date and key findings

From an initial review of solar irradiance in the Yukon, four potential sites were identified: Haines Junction, Whitehorse Copper Mine site, Takhini and Canyon. After conducting site visits and a review of topography, it was found that the sites at Whitehorse Cooper Mine and Haines Junction the best sites overall.

The Whitehorse Cooper Mine site is located on the old tailings pile of the Whitehorse Cooper Mine. This site is 120 acres of flat, cleared land with established road access and is close to the ATCO Electric

substation at Mount Sima. The location is within Whitehorse city limits, close to the main load, which minimizes transmission losses. It is also close to the main source of construction materials and labour in the Yukon. The Haines Junction site is 1 km from the town's landfill on 65 acres of flat, semi open land close to the highway, and 3.4 km from a substation.

The price of solar panels and their related systems have dropped significantly in the recent years. There are many emerging solar panel technologies being developed that address the deficiencies in current PV technology including low efficiency, high manufacturing costs and power density. The review of PV panels recommended the Heliene Poly and Prism Bi-Facial for both sites.

Solar panels can either be mounted on a fixed racking system, which means the panels will not move, or the panels can be mounted on a racking system that can pivot so that the panels can move to track the sun. These tracking systems can pivot in one direction (single axis) or multiple directions (multi axis). For the Haines Junction location, the use of single axis trackers over fixed racking was recommended as the additional solar energy gains out-weigh the additional costs to install and maintain the single axis tracking system.

The following Table 5-51 describes the technical and financial attributes and Table 5-52 to Table 5-58 describe the environmental, social and economic attributes for three solar resource options. The average monthly energy profile is shown in Figure 5-18. The location of the solar projects can be found in Figure 5-19.

Table 5-51. Solar Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	**Firm Energy** GWh/yr	**Installed Capacity** MW	**Dependable Capacity** MW	**Levelized Cost of Energy** $/kWh	**Levelized Cost of Capacity** $/kW·yr	**Project Life** Years	**Lead Time** Years	**Dispatch-able** Y/N
Whitehorse Heliene Poly								
1.1	1.1	1	0	0.21	-	30	2	N
Whitehorse Prism Bi-Facial								
1.2	1.2	1	0	0.23	-	30	2	N
Whitehorse Heliene Poly								
5.6	5.6	5	0	0.16	-	30	2	N
Whitehorse Prism Bi-Facial								
5.6	5.6	5	0	0.17	-	30	2	N
Whitehorse Heliene Poly								
11.5	11.5	10	0	0.15	-	30	2	N

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life Years	Lead Time Years	Dispatch-able Y/N
Whitehorse Prism Bi-Facial								
11.5	11.5	10	0	0.16	-	30	2	N
Haines Junction Heliene Poly								
1.4	1.4	1	0	0.17	-	30	2	N
Haines Junction Prism Bi-Facial								
1.5	1.5	1	0	0.17	-	30	2	N
Haines Junction Heliene Poly								
5.8	5.8	5	0	0.17	-	30	2	N
Haines Junction Prism Bi-Facial								
5.6	5.6	5	0	0.17	-	30	2	N

Figure 5-18: Average Energy Profile for Solar Resource Option

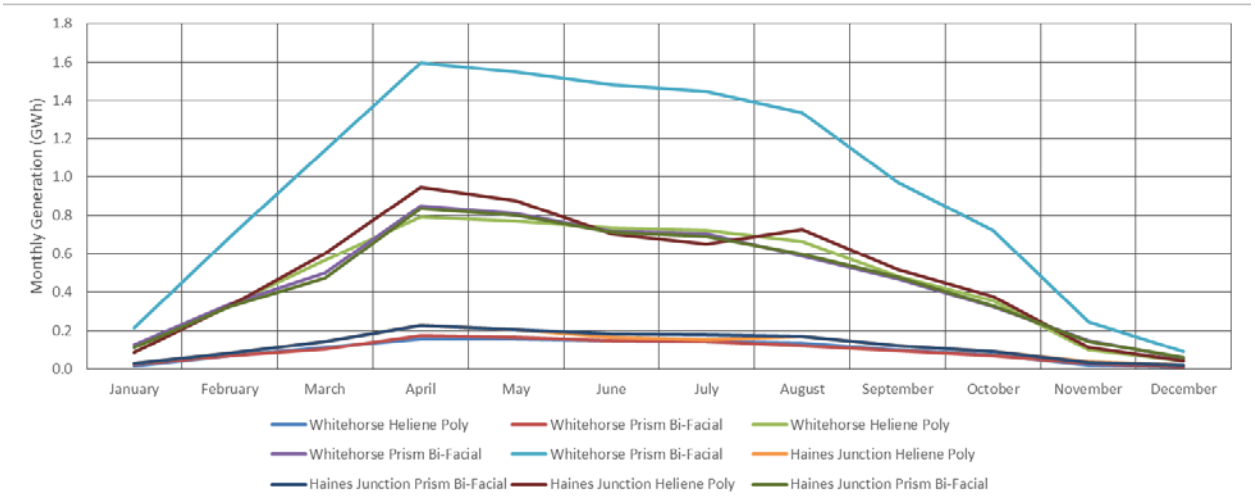


Table 5-52: Solar Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Whitehorse Fixed Tilt: 10 MW					
Haines Junction Fixed Tilt: 5 MW					

Table 5-53: Solar Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Whitehorse Fixed Tilt: 10 MW							
Haines Junction Fixed Tilt: 5 MW							

Table 5-54: Solar Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Whitehorse Fixed Tilt: 10 MW		
Haines Junction Fixed Tilt: 5 MW		

Table 5-55: Solar Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Whitehorse Fixed Tilt: 10 MW					
Haines Junction Fixed Tilt: 5 MW					

Table 5-56: Solar Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Whitehorse Fixed Tilt: 10 MW				
Haines Junction Fixed Tilt: 5 MW				

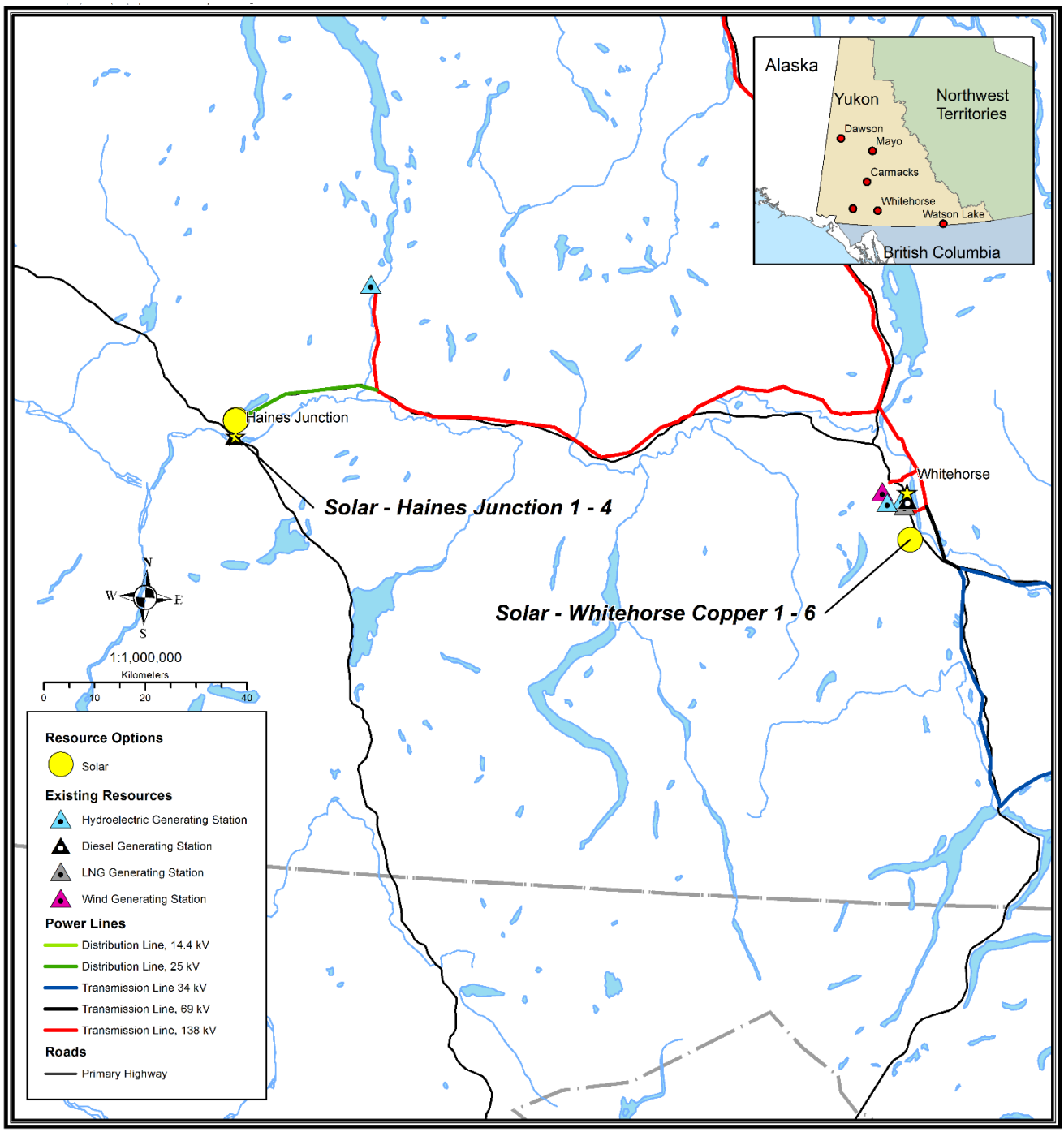
Table 5-57: Solar Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
Whitehorse Fixed Tilt: 10 MW					
Haines Junction Fixed Tilt: 5 MW					

Table 5-58: Solar Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			Climate Change Risk affecting Resource Financial Attributes (Ec2)				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Whitehorse Fixed Tilt: 10 MW							
Haines Junction Fixed Tilt: 5 MW							

1 *Figure 5-19: Solar Resource Option Locations*



5.2.7 Renewable Thermal Resources

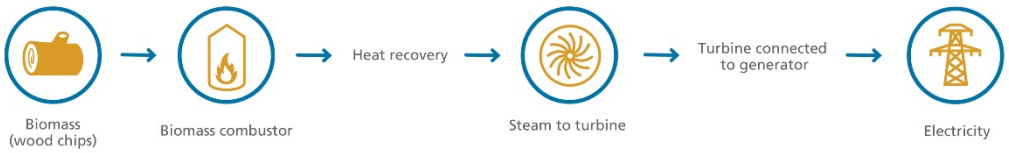
5.2.7.1 Biomass

Technology description

Wood-based biomass fuels are used in conventional, thermal oil (Organic Rankine Cycle or ORC) or gasification units to produce electricity, as shown in Figure 5-20. Conventional and ORC technologies combust biomass to heat a liquid (such as water) into a gas (steam), which is then used to drive a turbine and generator. Gasification systems convert the biomass into a synthetic gas or syngas, which is then combusted in a reciprocating engine to generate power. Conventional boilers, conventional ORC with thermal oil and gasification units were evaluated for this resource option.

Biomass provides dependable capacity and offers some dispatchability depending on fuel availability. Energy production could be matched to the energy demand on the grid.

Figure 5-20: Biomass



Studies

A Front End Engineering Design (FEED) study was completed in 2013 to assess the technical and financial feasibility of biomass electricity generation in Haines Junction. This study was updated for the 2016 Resource plan by Stantec, and presents a screening-level assessment of available technologies in the 0.5 MWe to 2.0 MWe range. This range was based on quotes from equipment vendors and information scaled from the previous FEED study. The updated study looked at three technology types in the categories of conventional biomass power generation/cogeneration and gasification. The study can be found in Appendix 5.12.

Fuel description

The study considered feedstock from sawmill residues and forest harvesting residues at the harvest block landing, including beetle killed wood. The use of beetle kill wood is beneficial because it has a lower moisture content of ~15%, whereas live trees usually have a moisture content in the range of 40-50%.

At the low end of the study range, the 0.5 MW unit would utilize feedstock with no impact to current biomass harvesting operations, and no need to supplement with green timber. There is insufficient sawmill and harvest residue material available to supply the 2.0 MWe unit, and these feedstocks would have to be

supplemented by ~68% green timber. This in turn would require new harvesting operations and policies. For this reason, the 0.5 MWe option is considered for this resource plan.

Summary of studies to date and key findings

The 2016 updated report assessed and screened available technologies which would handle 3,000 tonnes per year of biomass wastes, which would be adequate feedstock for the chosen plant size.

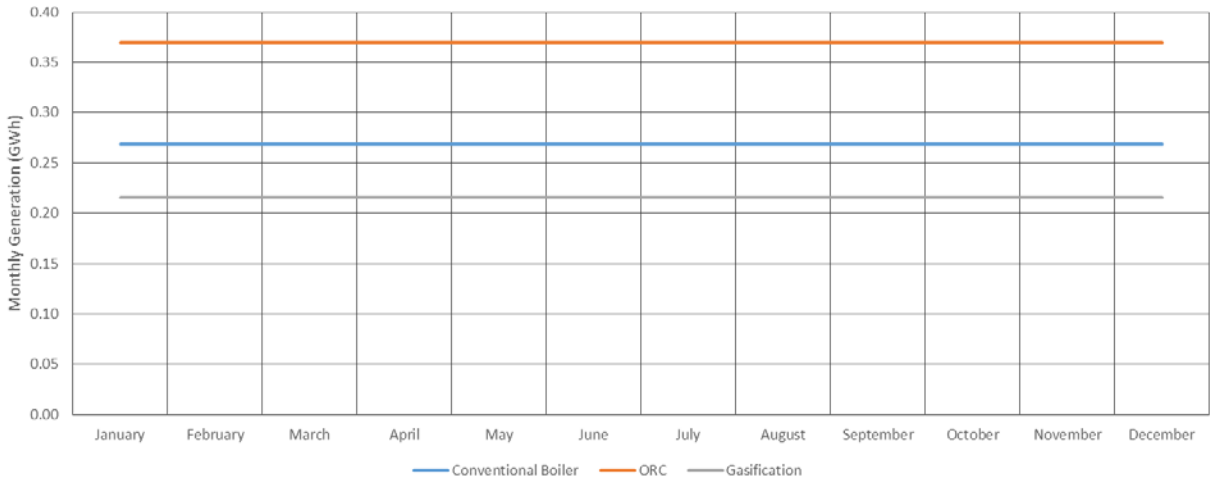
The following Table 5-59 describes the technical and economic attributes and Table 5-60 to Table 5-66 describe the environmental, social and economic attributes of the three biomass resource options. The average monthly energy profile is shown in Figure 5-21. The location of the biomass projects can be found in Figure 5-22.

Technical and financial information presented in the Stantec 2016 updated report (Appendix 5.12) were used in YEC's in-house financial model to obtain estimates of LCOE and LCOC. This approach was taken to standardize the calculation of both technical attributes, thus enabling a direct comparison between resource options.

Table 5-59: Biomass Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	**Firm Energy** GWh/yr	**Installed Capacity** MW	**Dependable Capacity** MW	**Levelized Cost of Energy** $/kWh	**Levelized Cost of Capacity** $/kW·yr	**Project Life** year	**Lead Time** years	**Dispatch-able** Y/N
Conventional Boiler								
3.2	3.2	0.5	0.4	0.44	1,969	20	3	Y
Organic Rankin Cycle								
4.4	4.4	0.6	0.6	0.35	1,715	20	3	Y
Gasification								
2.6	2.6	0.5	0.4	0.43	2,240	20	3	Y

Figure 5-21: Average Energy Profile for Biomass Resource Option



Additional Considerations

Biomass energy generation is seldom economic without the sale of heat. For example, of the energy produced in a biomass gasification plant, only around 22% is converted to electricity. The LCOE shown above does not include heat sales in order to provide consistency with the other resource options in the 2016 Resource Plan.

The economics of Biomass generation system typically rely on sales of heat in addition to energy sales, but the Yukon Utilities Board (YUB) has ruled that YEC cannot sell heat. Potentially, if the project were to be proposed by an independent power producer and if there were a viable heat market, heat produced from biomass in a combined heat and power plant would have to be sold to a nearby customer at $0.185/kWh in order to make it economic. With heat sales included as a revenue, the LCOE for the biomass options would be reduced to:

- $0.359/kWh for Steam Turbine/Boiler;
- $0.298/kWh for ORC; and
- $0.338/kWh for Gasification.

Table 5-60: Biomass Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			**Water Quantity & Quality (En2)**		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Biomass 0.5 MW Boiler / Steam Turbine					

Table 5-61: Biomass Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Biomass 0.5 MW Boiler / Steam Turbine							

Table 5-62: Biomass Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Biomass 0.5 MW Boiler / Steam Turbine		

Table 5-63: Biomass Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Biomass 0.5 MW Boiler / Steam Turbine					

Table 5-64: Biomass Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Biomass 0.5 MW Boiler / Steam Turbine				

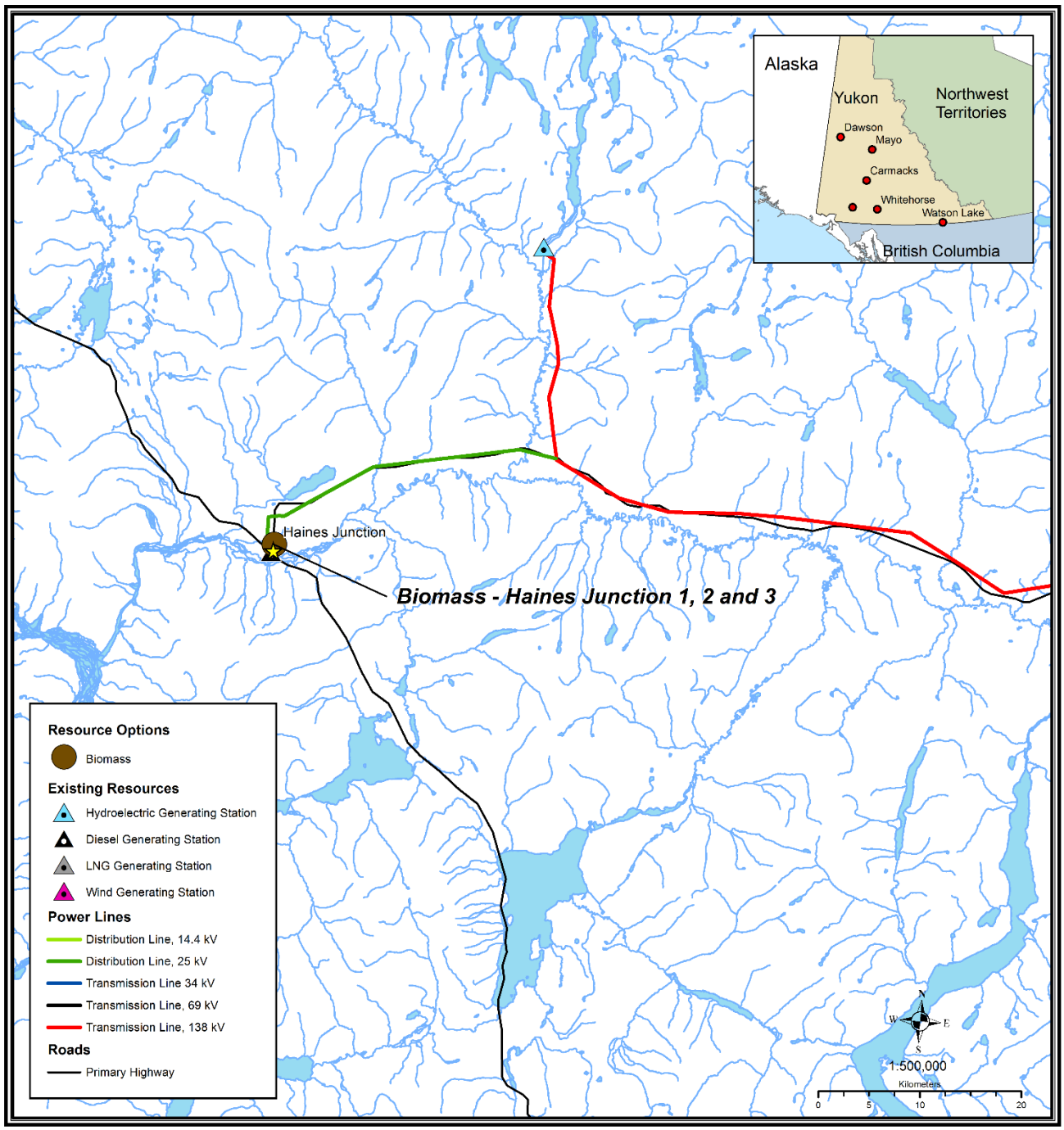
Table 5-65: Biomass Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
Biomass 0.5 MW Boiler / Steam Turbine					

Table 5-66: Biomass Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			Climate Change Risk affecting Resource Financial Attributes (Ec2)				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Biomass 0.5 MW Boiler / Steam Turbine							

Figure 5-22: Biomass Resource Option Locations



5.2.7.2 Biogas

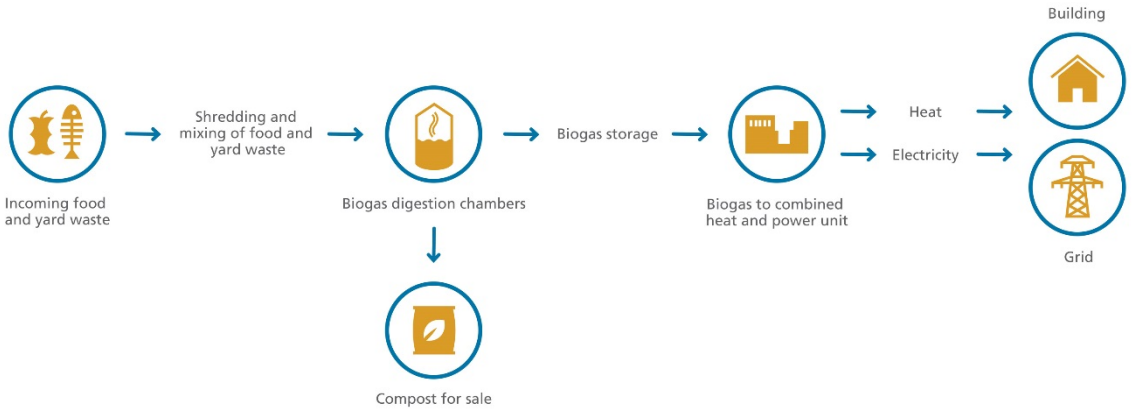
Technology description

Biogas is a methane rich gas derived from the anaerobic digestion of organic material, such as food and forestry industry wastes. The gas is combusted in a reciprocating engine to produce electricity, heat and digestate (compost) as shown in Figure 5-23. Biogas can be cleaned and upgraded to be used in place of, or to augment a natural gas supply. Biogas can be produced in either a wet system using biomass feedstocks containing ~5% solids, or dry system that uses feedstock with 25% solids. These systems can also be heated at different temperatures that encourage different bacteria to break down the organics.

For this study, dry digestion technology was chosen for the biogas system, which is heated to a temperature of about 35 degrees Celsius. This technology was chosen for its tolerance of contaminants, stability, low water requirements and lower input of electricity for heating the substrate. Heating the substrate to a thermophilic bacteria temperature range (55 degrees Celsius) requires much more input energy. The dry digestion technology also produces a high quality compost end product similar to what is currently produced at the Whitehorse compost facility. Therefore there is no loss of usable compost from this process.

Biogas projects could provide dependable capacity. Biogas offers some dispatchability if sufficient fuel is produced and adequate storage is available for handling the fuel. The current project requires the gas to be used when it is produced because of limited storage. Energy generation is higher in the summer than winter months which is the opposite of the energy demands on the grid.

Figure 5-23: Biogas



Studies

In 2015, YEC contracted WSP Canada to conduct a feasibility study for developing a Biogas facility in Whitehorse, at the compost facility at the Son of War Eagle Whitehorse landfill. The City of Whitehorse, Cold Climate Innovation and the Yukon Research Centre were partners on the project. This report can be found in Appendix 5.13. The study considered a 0.1 MW plant, which was sized for the current feedstock availability. A second 0.1 MW unit could be added in 2020 when organic diversion rates from the City of Whitehorse are expected to have increased.

Fuel Description

The study considered the volumes of feedstock available for the biogas facility. The assumed feedstock was based on material currently brought to the compost facility, as well as expected increases from the current green bin organics program run by the City of Whitehorse (Biogas Plant in Whitehorse, WSP 2016). The feedstock includes residential source sorted organics (SSO), industrial SSO, dead garden waste and fresh garden waste. In other biogas plants, sewage sludge from waste water treatment plants is often used in a wet digestion systems to produce biogas. Sewage sludge feedstock was not assessed as part of the study, as the location of the Whitehorse sewage lagoons is far from the compost facility, increasing transportation costs, and given potential concerns regarding the presence of biosolids in the compost end product.

Summary of studies to date and key findings

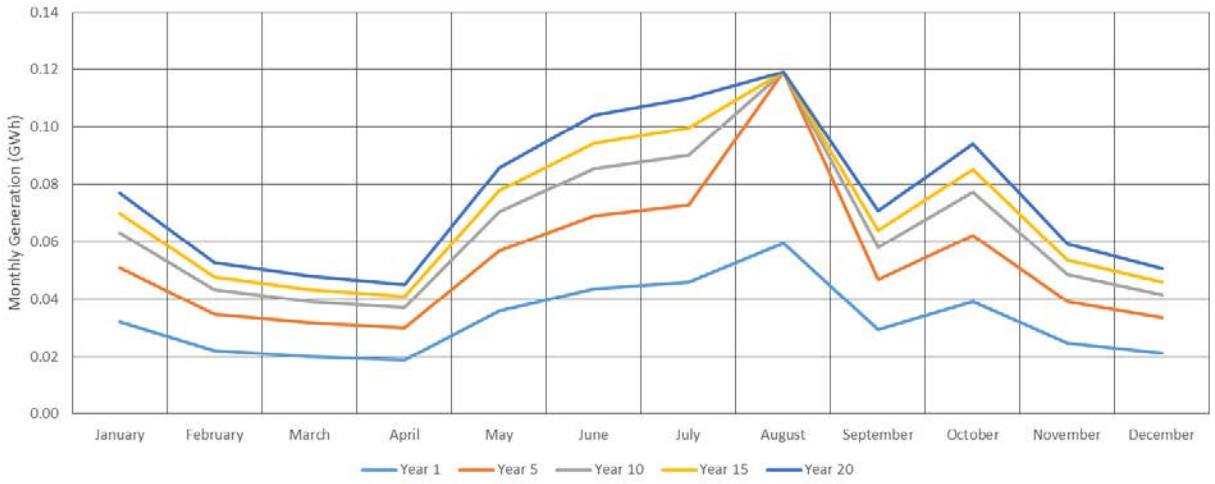
The 2016 report assessed and screened available biogas technologies which would adequately handle 3,000 tonnes per year of organic waste. In order to optimize feedstock availability a 0.1 MW unit would be installed at project start, and another 0.1 MW unit would be installed in 2020 when expected increased diversion would occur according to City of Whitehorse programs and targets.

The following Table 5-67 describes the technical and financial attributes and Table 5-68 to Table 5-74 describe the environmental, social and economic attributes of the biogas resource option. The average monthly energy profile is shown in Figure 5-24. The location of the biogas project can be found in Figure 5-25.

Table 5-67: Biogas Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	**Firm Energy** GWh/yr	**Installed Capacity** MW	**Dependable Capacity** MW	**Levelized Cost of Energy** $/kWh	**Levelized Cost of Capacity** $/kW·yr	**Project Life** year	**Lead Time** years	**Dispatch-able** Y/N
Biogas								
0.44 - 1.03	0.44 – 1.03	0.1 – 0.2	0.1 – 0.2	$0.97	$2,844	20	2	N

Figure 5-24: Average Energy Profile for Biogas Resource Option



Additional considerations

Biogas generation is seldom economic without the sale of heat. Of the energy produced in a biogas plant, only around 35% is converted to electricity. The LCOE shown above does not include heat sales or gate fees in order to provide consistency with the other resource options in the 2016 Resource Plan.

The economics of biogas generation system typically rely on sales of heat in addition to energy sales, but the Yukon Utilities Board (YUB) has ruled that YEC cannot sell heat. Potentially, if the project were to be proposed by an independent power producer and if there were a viable heat market, heat produced from biogas in a combined heat and power plant would have to be sold to a nearby customer in order to make it economic. The Biogas option could produce 750 MWh/year of heat. If the heat were sold heat at $12/GJ ($0.043/kWh) and gate fee revenues were taken into account, a lower LCOE of $0.65/kWh would be achieved.

Table 5-68: Biogas Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			**Water Quantity & Quality (En2)**		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Biogas (CHP)					

Table 5-69: Biogas Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Biogas (CHP)							

Table 5-70: Biogas Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Biogas (CHP)		

Table 5-71: Biogas Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Biogas (CHP)					

Table 5-72: Biogas Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Biogas (CHP)				

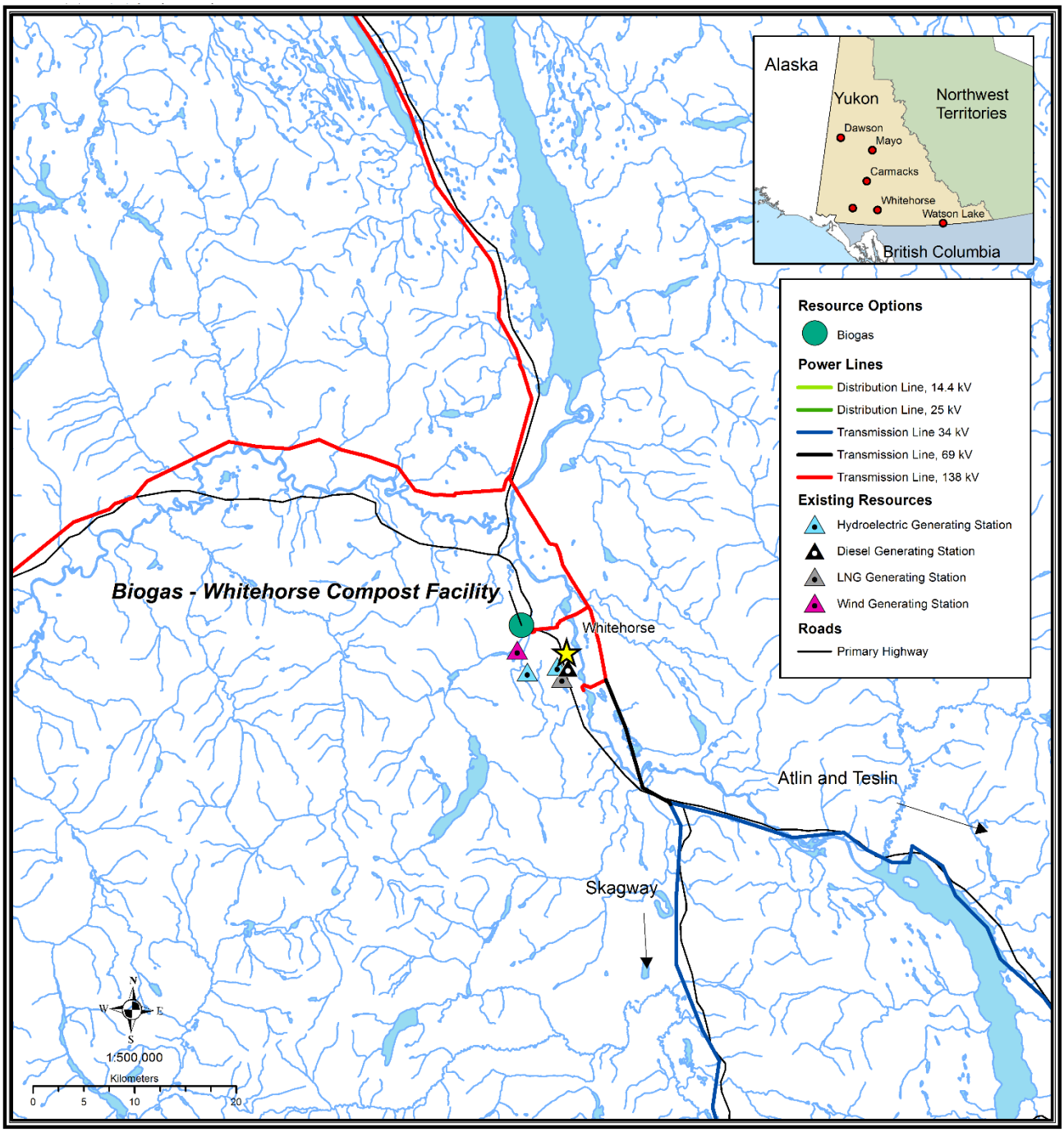
Table 5-73: Biogas Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
Biogas (CHP)					

Table 5-74: Biogas Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			Climate Change Risk affecting Resource Financial Attributes (Ec2)				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Biogas (CHP)							

1 *Figure 5-25: Biogas Resource Option Location*



5.2.7.3 Waste to Energy

Technology description

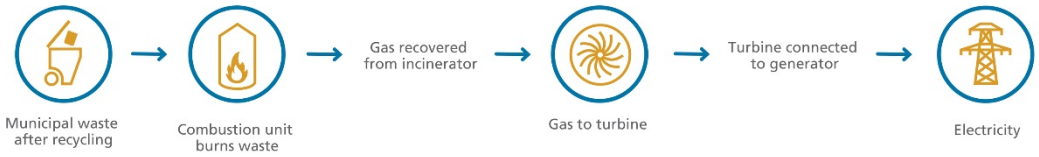
Waste to Energy (WTE) is a process that combusts Municipal Solid Waste (MSW) to produce electricity and heat. WTE technologies are generally categorized under "conventional combustion" or "advanced thermal" technologies.

Conventional combustion technologies include controlled air or small scale mass burn, which combust MSW with excess air to generate a hot flue gas as shown in Figure 5-26. The flue gas runs a conventional boiler to convert water to steam, which is then led through a steam turbine to produce electricity.

Advanced combustion, which includes gasification, pyrolysis and plasma arc gasification, combusts MSW in a reduced oxygen environment at high temperatures which creates a synthetic gas or syngas. Syngas can be combusted in a reciprocating engine which drives a generator to produce electricity. This technology is less developed and less prevalent than the conventional technologies.

Waste-to Energy projects provide dispatchable energy contingent on fuel availability and dependable capacity. Energy production could be matched to the energy demand on the grid.

Figure 5-26: Waste-to-Energy



Studies

In 2012, YEC contracted Morrison Hershfield to complete a design basis and business case analysis for of a WTE facility located in the Marwell Industrial area of Whitehorse. In 2015, Morrison Hershfield provided a letter stating that the findings of the 2012 study could be used as input information for the 2016 Resource Plan. The 2012 report can be found in Appendix 5.14.

The report looked at a 1.6 MW plant which was sized for the current feedstock availability and projected recycling targets. Both conventional combustion and advanced thermal technology were studied for this facility.

Fuel Description

The study considered the volumes of MSW feedstock available for the WTE facility, after the diversion of recycling and food waste. At the time of the report, a 16% recycling rate was being achieved, however the City of Whitehorse had plans to increase recycling rates to 50% by 2015. A financial sensitivity analysis was

completed to assess the impact of increased recycling to 50% of total waste volumes by 2015. A 1.6 MW plant was selected, which would utilize 17,300 tonnes per year of MSW assuming that the 50% recycling diversion target is achieved. This quantity of MSW feedstock is insufficient to support full utilization of the 1.6MW plant, and 7,700 tonnes of wood biomass would be initially required to supplement the MSW feedstock for optimal utilization of WTE plant. The use of wood biomass would decrease over time as MSW production is expected to increase with continued population growth in the Whitehorse area. The study assumed a projected 4% increase of MSW per year based of historic trends. Since the Waste to Energy report was completed in 2012, the latest recycling data has been updated from the City of Whitehorse. The data shows actual recycling diversion in 2015 to be 35%, but the City is still working towards the goal of 50%.

Summary of studies to date and key findings

The 2012 report assessed and screened available WTE technologies which would adequately handle 25,000 tonnes per year of MSW and biomass. Two conventional combustion technologies, namely controlled air conventional combustion and small scale mass burn, were selected in the screening study as the only available technologies which met the following criteria:

- Applicability to the MSW feedstock;
- Commercial viability;
- Appropriateness of scale;
- Compatibility to Yukon Feedstocks; and
- Supplemental input requirements.

Air pollution control equipment to treat the emissions from the WTE plan was included in the scope of the plant design. The air emissions analysis found that if energy generated by the WTE facility displaced diesel-generated electricity and furnace oil combustion in space heating, then a net reduction in particulate matter, carbon monoxide and nitrogen oxide emissions would be achieved.

As outlined above, the capacity of 1.6 MW for the facility was chosen based on available feedstock, forecast growth rates and potential recycling rates.

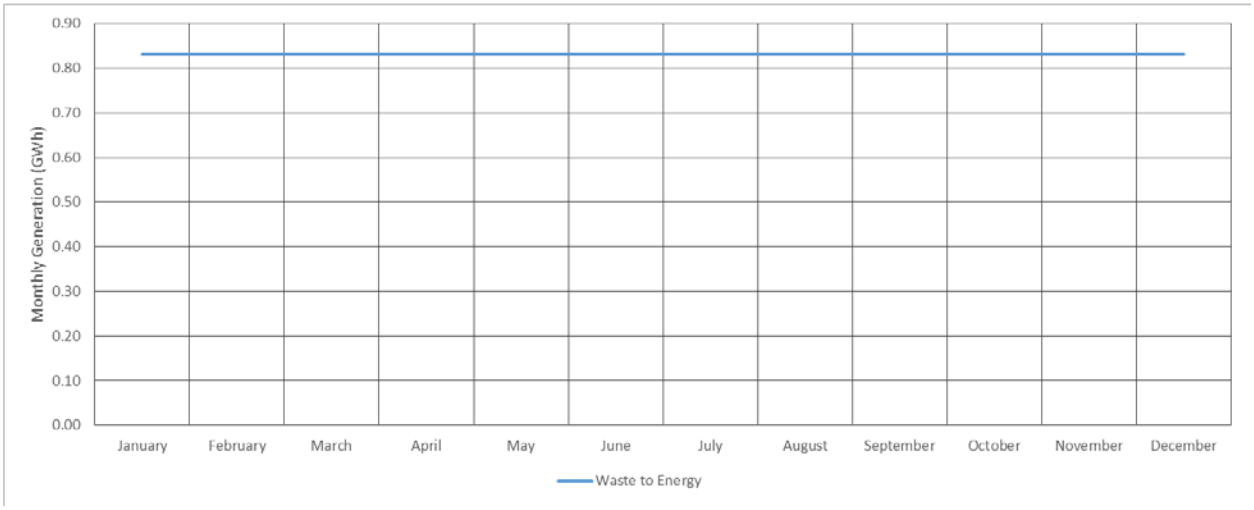
The following Table 5-75 describes the technical and financial attributes and Table 5-76 to Table 5-82 describe the environmental, social and economic attributes of the WTE resource option. The average monthly energy profile is shown in Figure 5-27. The location of the WTE project can be found in Figure 5-28 below.

Technical and financial information presented in the Morrison Hershfield study (Appendix 5.14) were used in YEC's in-house financial model to obtain estimates of LCOE and LCOC. This approach was taken to standardize the calculation of both technical attributes, thus enabling a direct comparison between resource options.

Table 5-75: Waste-to-Energy Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life year	Lead Time years	Dispatch-able Y/N
Waste to Energy (1.6 MW)								
10.0	10.0	1.6	1.6	0.45	1,301.68	25	2	Y

Figure 5-27: Average Energy Profile for Waste-to-Energy Resource Option



Additional considerations

WTE generation is seldom economic without the sale of heat (hot water or steam). Of the energy produced in a WTE plant, typically only around 10% is converted to electricity. The LCOE shown above does not include heat sales, since no firm thermal load was identified at the time this report was completed.

The economics of WTE generation typically rely on sales of heat in addition to energy sales, but the Yukon Utilities Board (YUB) has ruled that YEC cannot sell heat. Potentially, if the project were to be proposed by an independent power producer and if there were a viable heat market, heat produced from WTE generation in a combined heat and power plant would have to be sold to a nearby customer in order to make it economic. The WTE option could produce 23,700 MWh/year of heat. If a customer were sold heat at $0.81/kWh into a district energy system, then an LCOE reduction from $0.45/kWh to $0.31/kWh would be achieved.

Table 5-76: Waste-to-Energy Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Waste to Energy					

Table 5-77: Waste-to-Energy Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Waste to Energy							

Table 5-78: Waste-to-Energy Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Waste to Energy		

Table 5-79: Waste-to-Energy Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Waste to Energy					

Table 5-80: Waste-to-Energy Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Waste to Energy				

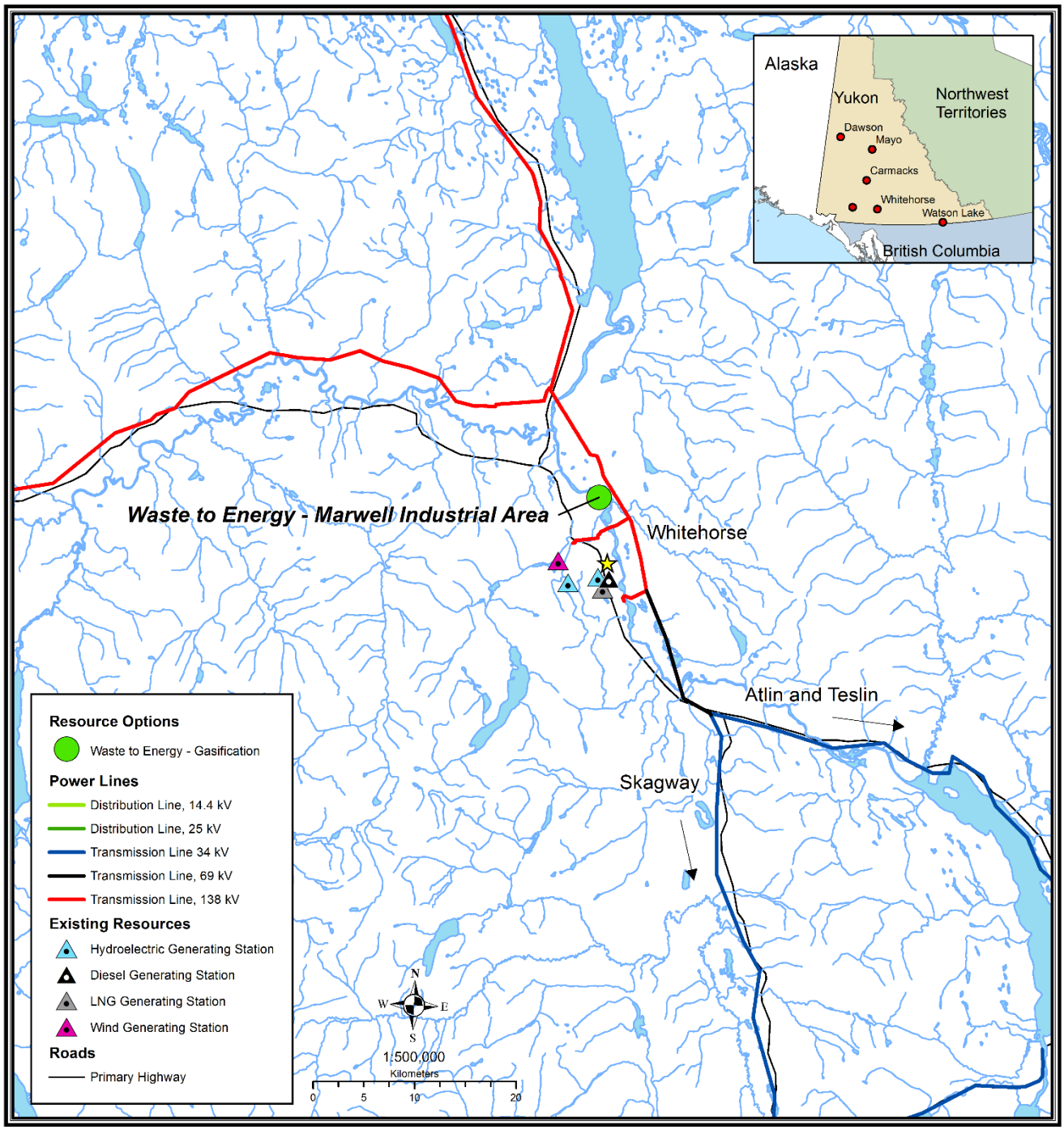
Table 5-81: Waste-to-Energy Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
Waste to Energy					

Table 5-82: Waste-to-Energy Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			**Climate Change Risk affecting Resource Financial Attributes (Ec2)**				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Waste to Energy							

Figure 5-28: Waste to Energy Resource Option Location



5.2.8 Non-renewable Thermal Resources

Technology description

Thermal electricity generation refers to the combustion of fossil fuels such as natural gas or diesel in either a reciprocating engine or gas turbine connected to a generator as shown in Figure 5-29. For the 2016 Resource Plan, YEC limited the assessment of the resource options to reciprocating engines.

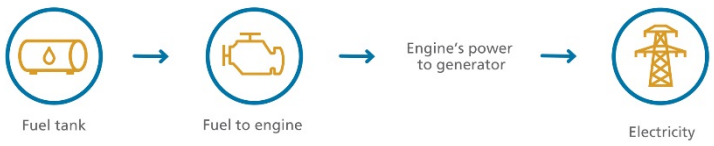
Reciprocating engines are a mature technology with several centuries of history and refinement. They are used throughout the world in a variety of applications including motorcycles, cars, ships, trucks and trains as well as power generation. Reciprocating engines can be designed use a wide variety of fuels, including conventional sources such as diesel, gasoline and natural gas, but also the liquid and gas by-products from municipal solid waste and biomass.

In Yukon, engines and generator are generally located within a building. Alternatively, the engine-generator can also be enclosed in weatherproof housing that can be moved to a different location should it be needed. This can prevent the need for a large, costly building. In addition to the engines and generators, a thermal plant would also include fuel storage, processing equipment such as vaporizers, electrical equipment such as switchgear and transformer, and ancillary systems such as fire suppression equipment, spill containment, heat recovery equipment, etc.

Diesel and natural-gas based generation technologies are the most commonly used in the world. The equipment is standardized and easy to specify and procure. It is also relatively compact, and easy to install, move or sell, if generation requirements change.

Thermal generation provide dependable capacity that can be turned on or off by the utility whenever required. Because if this dispatchability, YEC relies on thermal generation to restore power after an outage, as back-up power if one of the other plants or transmission lines goes offline, and to provide power during peak events such as cold winter evenings. Energy production could be matched to the energy demand on the grid.

Figure 5-29: Fossil Thermal



Studies

A conceptual planning and design study on a natural gas and diesel thermal generating station in the Whitehorse area was completed by Stantec for the 2016 Resource Plan. This study first considered

potential sites for the plant. For the two best sites, conceptual layouts for both diesel and natural gas plants at 5, 10 and 20 MW, and a high level cost estimate was produced. This study can be found in Appendix 5.15.

In addition to the green field thermal generation presented in the study by Stantec, YEC considered the installation of a third engine at the existing LNG facility as a separate resource option. Technical and financial attributes for this project were provided by YEC. In the Part III application for the Whitehorse Diesel - Natural Gas Conversion Project (2013), YEC estimated the cost of the third engine at $4.4 million. This number was later reviewed and updated at $5.8 million. Fixed operation and maintenance costs were estimated at $120,000 per year based on actual costs incurred at the existing natural gas plant. For the environmental, social, and economic attributes, YEC used the attributes for the greenfield LNG Whitehorse facility as a conservative approximation for the third LNG engine.

Fuel description

The reciprocating engines considered for the 2016 Resource Plan are fueled by natural gas or diesel. The diesel is purchased in Whitehorse. The natural gas is transported and stored as liquefied natural gas (LNG). YEC currently sources LNG from FortisBC's Tilbury Island plant near Delta British Columbia and from Ferus's Elmworth Alberta plant. In the medium term, YEC also expects that LNG supply points will develop closer to the Yukon in northern British Columbia. Further details on an optimized LNG supply chain and forecasted fuel costs for natural gas and diesel can be found in Section 6.1. Fuel Price Forecast.

Summary of studies to date and key findings

The study identified four sites for consideration, two within the City of Whitehorse and two just north of the city boundary. Two sites were selected for further investigation; one at the City of Whitehorse landfill and one next to the Takhini Substation on the Mayo Road. The zoning at both sites allows for public utilities infrastructure. Furthermore, both sites are directly accessible from a highway and are close to existing transmission infrastructure. The landfill site is a previously developed brownfield, while the Takhini Substation is on undisturbed land.

In addition to the green field thermal resources, YEC considered the installation of a third engine in the existing LNG facility as a resource option. In 2015 YEC constructed and commissioned a natural gas fired facility with 8.8 MW of installed capacity. The generation capability of the facility is provided by two internal combustion engines, each with installed capacity of 4.4 MW. The facility was designed, permitted and constructed for an ultimate capacity of 13.2 MW, allowing for the addition of the third engine with capacity of 4.4 MW. This retrofit would avoid the significant infrastructure associated with a new LNG facility, such as utilities, piping, control systems, foundations and the building structure.

The following Table 5-83 and Table 5-84 describe the technical and financial attributes and Table 5-85 to Table 5-98 describe the environmental, social and economic attributes for natural gas and diesel generation respectively. The average monthly energy profiles are shown in Figure 5-30 and Figure 5-31. The location of the natural gas and diesel projects can be found in Figure 5-32.

Table 5-83: Fossil Thermal (LNG) Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life Years	Lead Time Years	Dispatch-able Y/N
Takhini LNG 1								
41.6	41.6	5	5	$0.26	$812	20	4	Y
Takhini LNG 2								
83.2	83.2	10	10	$0.23	$560	20	4	Y
Takhini LNG 3								
166.4	166.4	20	20	$0.21	$409	20	4	Y
Whitehorse Landfill LNG 1								
41.6	41.6	5	5	$0.26	$814	20	4	Y
Whitehorse Landfill LNG 2								
83.2	83.2	10	10	$0.23	$561	20	4	Y
Whitehorse Landfill LNG 2								
166.4	166.4	20	20	$0.21	$409	20	4	Y
Whitehorse Rapids LNG Third Engine								
36.6	36.6	4.4	4.4	$0.18	$120	20	2	Y

Figure 5-30: Average Energy Profile for Fossil Thermal-(LNG) Resource Option

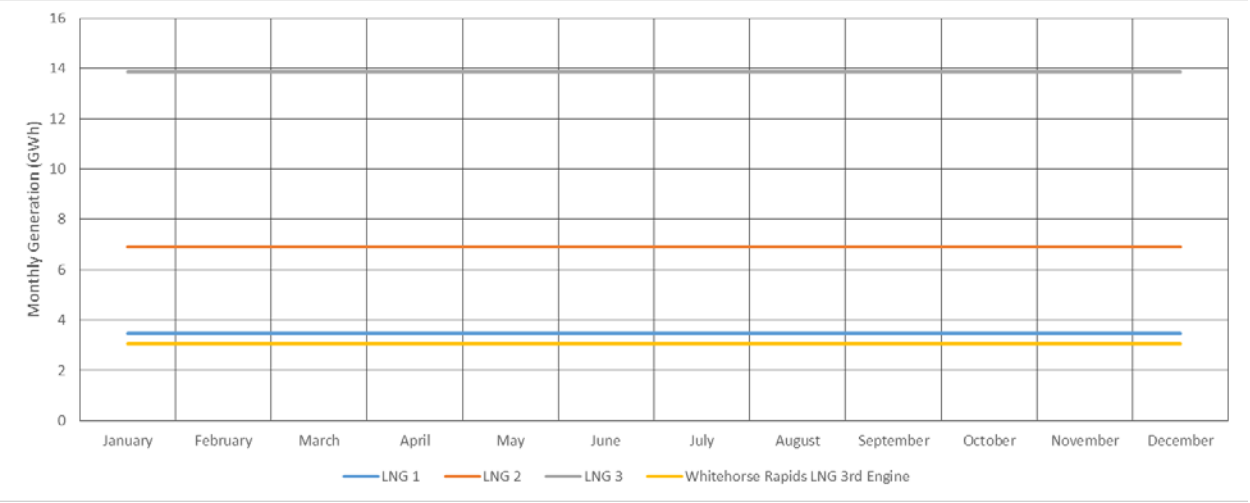


Table 5-84. Fossil Thermal (Diesel) Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	**Firm Energy** GWh/yr	**Installed Capacity** MW	**Dependable Capacity** MW	**Levelized Cost of Energy** $/kWh	**Levelized Cost of Capacity** $/kW·yr	**Project Life** Years	**Lead Time** Years	**Dispatch-able** Y/N
Takhini Diesel 1								
41.6	41.6	5	5	0.31	442	20	4	Y
Takhini Diesel 2								
83.2	83.2	10	10	0.29	292	20	4	Y
Takhini Diesel 3								
166.4	166.4	20	20	0.27	217	20	4	Y
Whitehorse Landfill Diesel 1								
41.6	41.6	5	5	0.32	447	20	4	Y
Whitehorse Landfill Diesel 2								
83.2	83.2	10	10	0.29	294	20	4	Y
Whitehorse Landfill Diesel 3								
166.4	166.4	20	20	0.27	218	20	4	Y

Figure 5-31: Average Energy Profile for Fossil Thermal-(Diesel) Resource Option

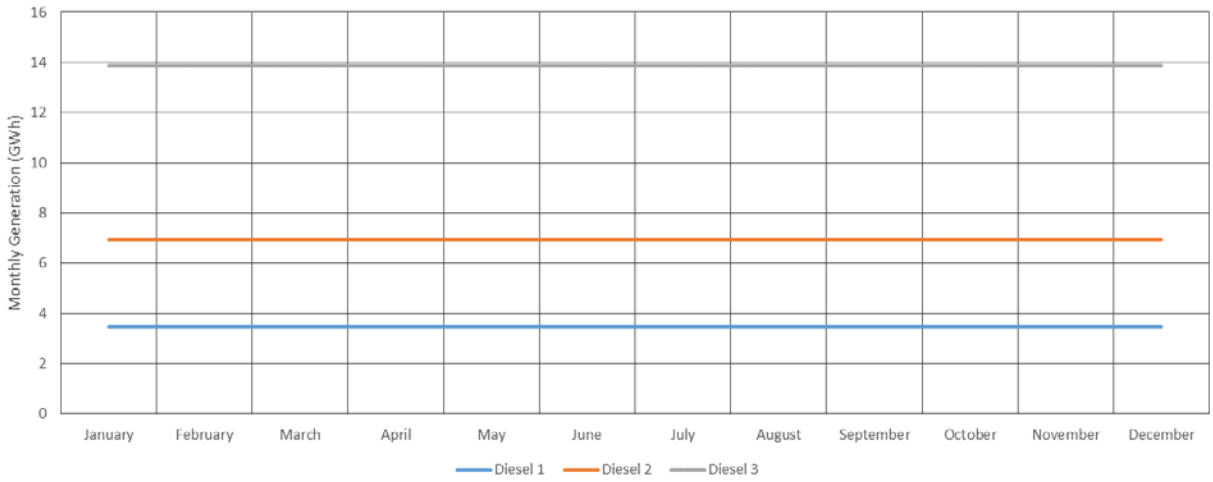


Table 5-85: Fossil Thermal (LNG) Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
LNG Whitehorse (20MW)					
LNG Takhini (20 MW)					
Whitehorse Rapids LNG Third Engine					

Table 5-86: Fossil Thermal (LNG) Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
LNG Whitehorse (20MW)							
LNG Takhini (20 MW)							
Whitehorse Rapids LNG Third Engine							

Table 5-87: Fossil Thermal (LNG) Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
LNG Whitehorse (20MW)		
LNG Takhini (20 MW)		
Whitehorse Rapids LNG Third Engine		

Table 5-88: Fossil Thermal (LNG) Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
LNG Whitehorse (20MW)					
LNG Takhini (20 MW)					
Whitehorse Rapids LNG Third Engine					

Table 5-89: Fossil Thermal (LNG) Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
LNG Whitehorse (20MW)				
LNG Takhini (20 MW)				
Whitehorse Rapids LNG Third Engine				

Table 5-90: Fossil Thermal (LNG) Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
LNG Whitehorse (20MW)					
LNG Takhini (20 MW)					
Whitehorse Rapids LNG Third Engine					

Table 5-91: Fossil Thermal (LNG) Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			Climate Change Risk affecting Resource Financial Attributes (Ec2)				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
LNG Whitehorse (20MW)							
LNG Takhini (20 MW)							
Whitehorse Rapids LNG Third Engine							

Table 5-92: Fossil Thermal (Diesel) Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Diesel Whitehorse (20 MW)					
Diesel Takhini (20 MW)					

Table 5-93: Fossil Thermal (Diesel) Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Diesel Whitehorse (20 MW)							
Diesel Takhini (20 MW)							

Table 5-94: Fossil Thermal (Diesel) Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Diesel Whitehorse (20 MW)		
Diesel Takhini (20 MW)		

Table 5-95: Fossil Thermal (Diesel) Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Diesel Whitehorse (20 MW)					
Diesel Takhini (20 MW)					

Table 5-96: Fossil Thermal (Diesel) Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Diesel Whitehorse (20 MW)				
Diesel Takhini (20 MW)				

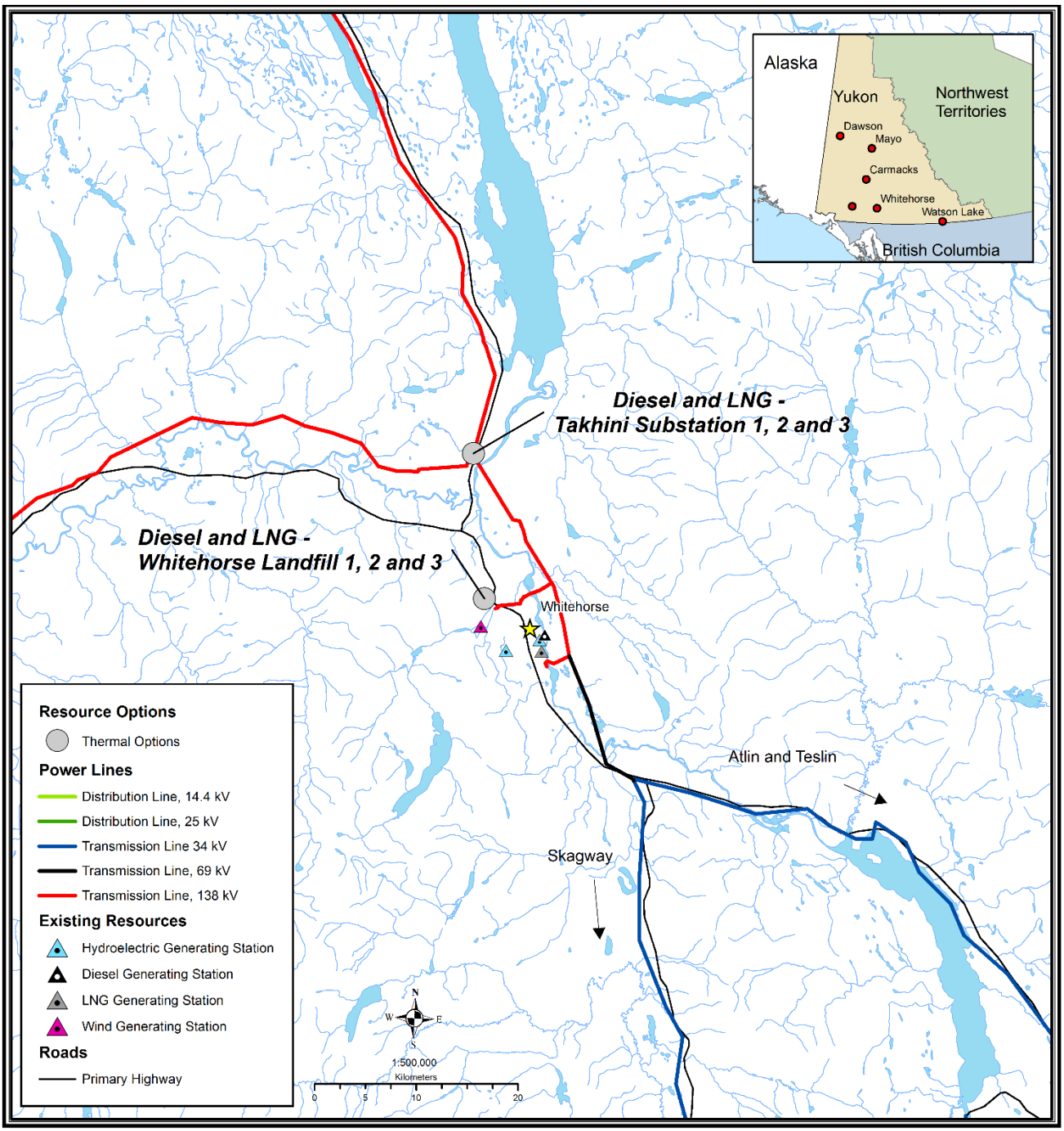
Table 5-97: Fossil Thermal (Diesel) Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
Diesel Whitehorse (20 MW)					
Diesel Takhini (20 MW)					

Table 5-98: Fossil Thermal (Diesel) Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			Climate Change Risk affecting Resource Financial Attributes (Ec2)				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Diesel Whitehorse (20 MW)							
Diesel Takhini (20 MW)							

1 *Figure 5-32 Fossil Thermal Resource Option Locations*



5.2.9 Pumped Storage

Technology description

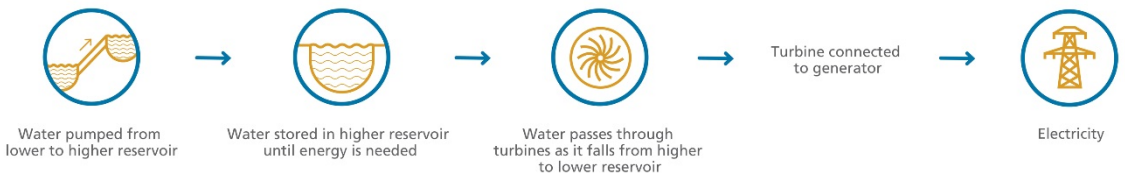
Pumped storage is a form of energy storage that uses energy to pump water from a lower reservoir into a higher reservoir as shown in Figure 5-33. When required, this water is then released back into the lower reservoir through hydro turbines that generate electricity. This allows the operator to shift excess electricity generation to a period when there is an energy shortage. Reversible pump-turbines coupled with a generator is the most common technology used, however some facilities have separated pumps and turbines. Overall round trip efficiency is around 70% to 80%. Meaning there are 20-30% energy losses in pumping the water uphill before running down through the turbines to generate electricity.

Typical pumped storage facilities provide energy storage for durations on the order of hours or days. The study completed for the 2016 Resource Plan focused on seasonal storage to move excess summer energy (spilled hydro resources at YEC's existing hydro facilities) to meet winter loads.

Pumped storage has traditionally been used to shift electricity generation to peak demand hours. More recently the technology is being used to maintain grid stability and to manage the integration of intermittent renewables resources such as wind and solar by firming their energy.

Pumped storage projects provide dispatchable energy and dependable capacity. These projects are designed and operated to provide more energy and capacity in the winter when energy requirements and demand are highest on the grid.

Figure 5-33: Pumped Storage



Studies

An assessment of pumped storage potential was completed by Knight Piesold for the 2016 Resource Plan. The assessment identified viable sites for a pumped storage project within 25 km of existing or potential transmission infrastructure. Seven sites were chosen for further analysis based on inferred construction cost, and high level cost estimate was developed for these sites. The assessment report can be found in Appendix 5.16. A 2015 report on the Moon Lake Pumped Storage Project completed by Midgard was used in completing this assessment. Picacho Associates completed a study on the pumped storage potential at the Faro Mine.

Fuel description

For this assessment, the energy used to pump the water is assumed to be surplus summer energy. As the load grows, summer surplus energy could be reduced to the point where other generating assets will needed to support the pumped storage facility.

Summary of studies to date and key findings

Energy demand in the Yukon is highest during the winter months, driven by increased loads for space heating and lighting. Currently, water is spilled at Whitehorse and Mayo hydro plants during the summer when the need for electricity is lower than the generation capability, which results in spilled water. This spilled water could generate electricity to support a pumped storage facility. The pumped storage concept being assessed for the Resource Plan would be used for seasonal storage, pumping water during the summer and generating during the winter.

The assessment identified sites based on a 15 MW and 25 MW capacity as well as 50 GWh and 100 GWh of storage for each. Using these technical constraints, the following seven sites were identified:

- Tutshi Lake – Moon Lake (BC);
- Atlin Lake – Black Mountain (BC);
- Racine Lake – Moon Lake (BC);
- Racine Lake – Mt. Brown (BC);
- Lindeman Lake – Fraser Lake (BC);
- Squanga Lake – Dalayee Lake (YK);
- Canyon Lake – Ittlemit Lake (YK); and
- Vangorda (YK).

The following Table 5-99 describes the technical and financial attributes and Table 5-100 to Table 5-106 describe the environmental, social and economic attributes for pumped storage options. The average monthly energy profile is shown in Figure 5-34. The location of the pumped storage projects can be found in Figure 5-35.

Table 5-99. Pumped Storage Resource Option Technical and Financial Attributes

Annual Energy	**Firm Energy**	**Installed Capacity**	**Dependable Capacity**	**Levelized Cost of Energy**	**Levelized Cost of Capacity**	**Project Life**	**Lead Time**	**Dispatch-able**
GWh/yr	GWh/yr	MW	MW	$/kWh	$/kW·yr	Years	Years	Y/N
Moon-Tutshi 1								
50	50	15	15	0.28	900	65	7	Y
Moon-Tutshi 2								
50	50	25	25	0.32	650	65	7	Y

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life Years	Lead Time Years	Dispatch-able Y/N
Moon-Tutshi 3								
100	100	15	15	0.19	1300	65	7	Y
Moon-Tutshi 4								
100	100	25	25	0.21	840	65	7	Y
Racine-Moon 1								
50	50	15	15	0.54	1800	65	7	Y
Racine-Moon 2								
50	50	25	25	0.61	1200	65	7	Y
Lindeman-Fraser 1								
50	50	15	15	0.56	1900	65	7	Y
Lindeman-Fraser 2								
50	50	25	25	0.64	1300	65	7	Y
Atlin-Black Mountain 1								
50	50	15	15	0.30	1000	65	7	Y
Atlin-Black Mountain 2								
50	50	25	25	0.33	660	65	7	Y
Atlin-Black Mountain 3								
100	100	25	25	0.27	1100	65	7	Y
Racine-Mt. Brown 1								
50	50	15	15	0.33	1100	65	7	Y

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life Years	Lead Time Years	Dispatch-able Y/N
Racine-Mt. Brown 2								
50	50	25	25	0.38	760	65	7	Y
Racine-Mt. Brown 3								
100	100	15	15	0.27	1800	65	7	Y
Racine-Mt. Brown 4								
100	100	25	25	0.29	1100	65	7	Y
Squanga-Dalayee 1								
100	100	15	15	0.34	2200	65	7	Y
Squanga-Dalayee 2								
100	100	25	25	0.36	1400	65	7	Y
Canyon-Ittlemit 1								
100	100	15	15	0.42	3300	65	7	Y
Canyon-Ittlemit 2								
100	100	25	25	0.53	2100	65	7	Y
Vangorda								
134	134	40	40	0.16	463	65	7	Y

Figure 5-34: Average Energy Profile for Selected Pumped Storage Projects

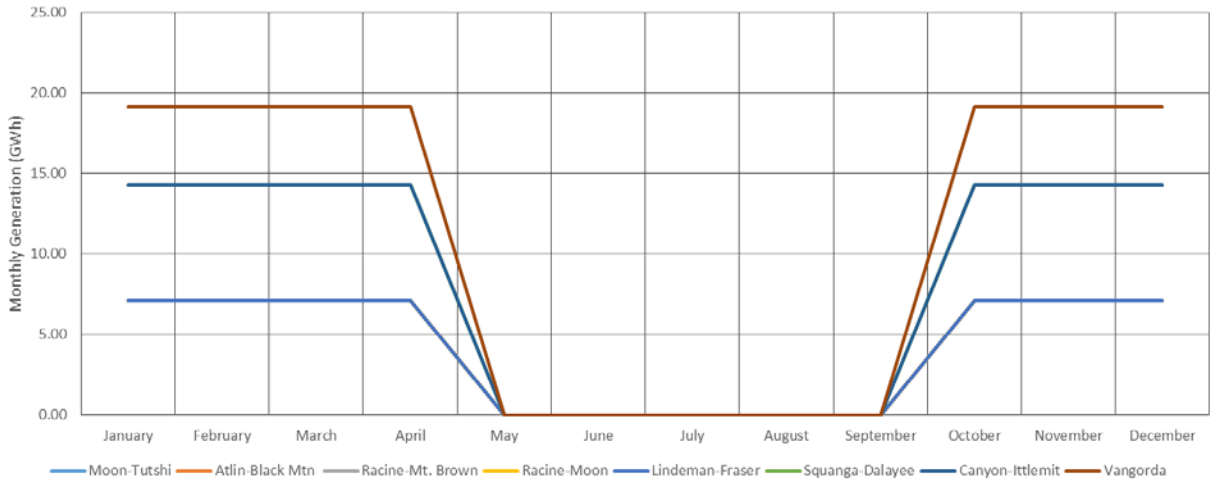


Table 5-100: Pumped Storage Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Moon Lake (Tutshi-Moon)					
Racine - Moon					
Lindeman-Fraser					
Racine - Mt. Brown					
Atlin - Black Mountain					
Squanga - Dalayee					
Canyon - Ittlemit					
Vangorda Pit					

Table 5-101: Pumped Storage Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Moon Lake (Tutshi-Moon)							
Racine - Moon							
Lindeman-Fraser							
Racine - Mt. Brown							
Atlin - Black Mountain							
Squanga - Dalayee							
Canyon - Ittlemit							
Vangorda Pit							

Table 5-102: Pumped Storage Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Moon Lake (Tutshi-Moon)		
Racine - Moon		
Lindeman-Fraser		
Racine - Mt. Brown		
Atlin - Black Mountain		
Squanga - Dalayee		
Canyon - Ittlemit		
Vangorda Pit		

Table 5-103: Pumped Storage Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Moon Lake (Tutshi-Moon)					
Racine - Moon					
Lindeman-Fraser					
Racine - Mt. Brown					
Atlin - Black Mountain					
Squanga - Dalayee					
Canyon - Ittlemit					
Vangorda Pit					

Table 5-104: Pumped Storage Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Moon Lake (Tutshi-Moon)				
Racine - Moon				
Lindeman-Fraser				
Racine - Mt. Brown				
Atlin - Black Mountain				
Squanga - Dalayee				
Canyon - Ittlemit				
Vangorda Pit				

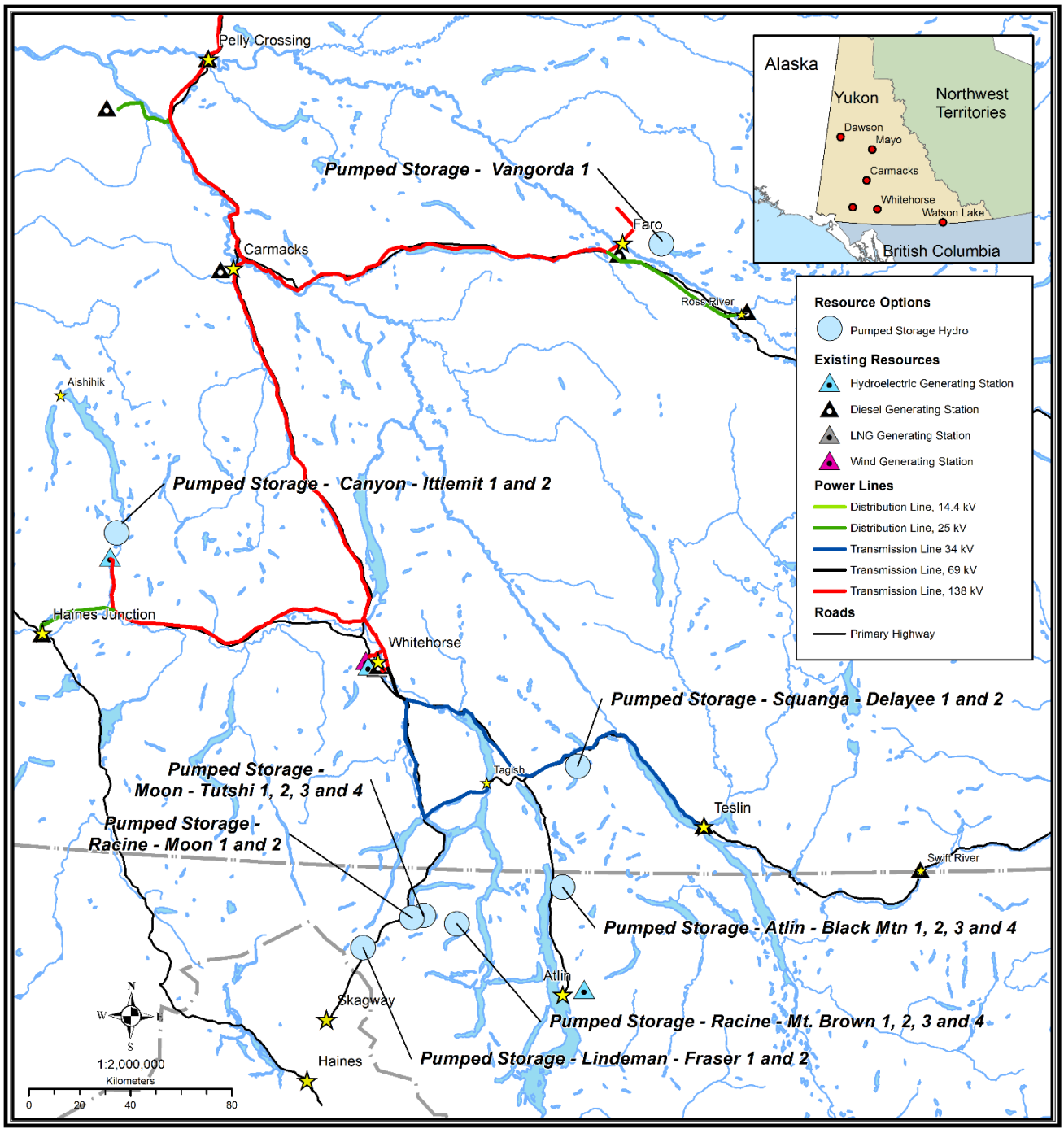
Table 5-105: Pumped Storage Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	**Tourism Values (S4-2)**	**Aesthetics (S4-3)**	**Non-renewable Resources (S4-4)**	**Other Renewable Resources (S4-5)**	**Land Use & Renewable Resources Plans (S4-6)**
Moon Lake (Tutshi-Moon)					
Racine - Moon					
Lindeman-Fraser					
Racine - Mt. Brown					
Atlin - Black Mountain					
Squanga - Dalayee					
Canyon - Ittlemit					
Vangorda Pit					

Table 5-106: Pumped Storage Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			Climate Change Risk affecting Resource Financial Attributes (Ec2)				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Moon Lake (Tutshi-Moon)							
Racine - Moon							
Lindeman-Fraser							
Racine - Mt. Brown							
Atlin - Black Mountain							
Squanga - Dalayee							
Canyon - Ittlemit							
Vangorda Pit							

Figure 5-35: Pumped Storage Resource Option Locations



5.2.10 Energy Storage

Technology description

Electricity cannot be stored, which means that electricity supply must be continuously and instantaneously balanced with demand. Storage allows for electricity generated at one time to be converted to another form of energy suitable for storage (such as chemical energy), which is then converted back to electricity at a later time as shown in Figure 5-36. Due to the necessary energy conversions, storage is a net consumer of energy. Storage provided by batteries can be valuable in smoothing out the variation between the demand and supply for electricity, as well as to maintain grid stability and to manage the integration of intermittent renewables resources such as wind and solar, by firming their energy.

The most common electrical energy storage systems are batteries, but other energy storage technologies include: pumped water storage, compressed air, flywheels, hydrogen cells, capacitors, superconducting magnetic coils and molten salt. Different energy storage technologies work on different timescales. Some can store energy for seconds, while others can store for years.

Energy storage is a net energy user that can provide dispatchable energy and dependable capacity over a limited amount of time. The operation of the energy storage system is matched to the demands on the system.

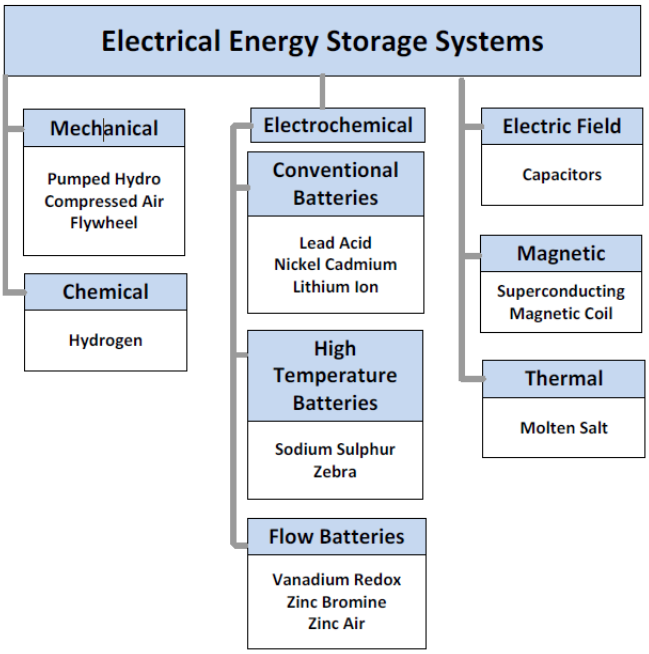
Figure 5-36: Energy Storage



Studies

TransGrid Solutions Inc. completed a review of existing energy storage technologies for the 2016 Resource Plan. This evaluation reviewed the various technologies in terms of their ability to reduce YEC's thermal generation to meet peak load requirements, and other benefits including improved power quality, grid support, load shifting and the integration of renewables. Other factors considered included safety, environmental attributes and cost. The report can be found in Appendix 5.17. The energy storage technologies considered are summarized in Figure 5-37 below.

Figure 5-37: Energy Storage Systems and Classifications (from TransGrid Solutions Report)



Fuel description

Energy storage does not produce energy, but stores energy produced by a different generating resources.

Summary of studies to date and key findings

The inventory of energy storage technologies identified four technologies to displace thermal generation, all of which featured electrochemical batteries. Only two, lead acid and lithium ion batteries, were selected based on safety, overall cost and the maturity of the technology. One advantage of batteries is that the systems are modular. This means that the system can be installed in a reasonable timeframe, and power capacity can be added in increments as the demand grows. By adding the batteries incrementally, the utility can also take advantage of future technology improvements.

The study completed a configuration design and cost estimate for lead acid batteries at 4, 6 and 8 MW, and for lithium-ion batteries at 8 MW. These storage systems were assumed to be close to the Takhini substation.

The following Table 5-107 describes the technical and financial attributes and Table 5-108 to Table 5-114 describe the environmental, social and economic attributes for the four battery configurations. The location of the energy storage systems can be found in Figure 5-38 below.

Table 5-107. Storage Resource Option Technical and Financial Attributes

Annual Energy GWh/yr	Firm Energy GWh/yr	Installed Capacity MW	Dependable Capacity MW	Levelized Cost of Energy $/kWh	Levelized Cost of Capacity $/kW·yr	Project Life Years	Lead Time Years	Dispatch-able Y/N
Lead Acid (4 MW)								
2.4	2.4	4	3.6	$0.79	$539	30	2	Y
Lead Acid (6 MW)								
2.7	2.7	6	3.6	$1.09	$811	30	2	Y
Lead Acid (8 MW)								
2.8	2.8	8	3.6	$1.31	$1,055	30	2	Y
Lithium-ion (8 MW)								
2.8	2.8	8	3.6	$0.96	$650	30	2	Y

Table 5-108: Storage Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			**Water Quantity & Quality (En2)**		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Lithium Ion Battery (8 MW/40MWh, 5 hrs)					

Table 5-109: Storage Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Lithium Ion Battery (8 MW/40MWh, 5 hrs)							

Table 5-110: Storage Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Lithium Ion Battery (8 MW/40MWh, 5 hrs)		

Table 5-111: Storage Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Lithium Ion Battery (8 MW/40MWh, 5 hrs)					

Table 5-112: Storage Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		Cultural & Community Well-being (S5)		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Lithium Ion Battery (8 MW/40MWh, 5 hrs)				

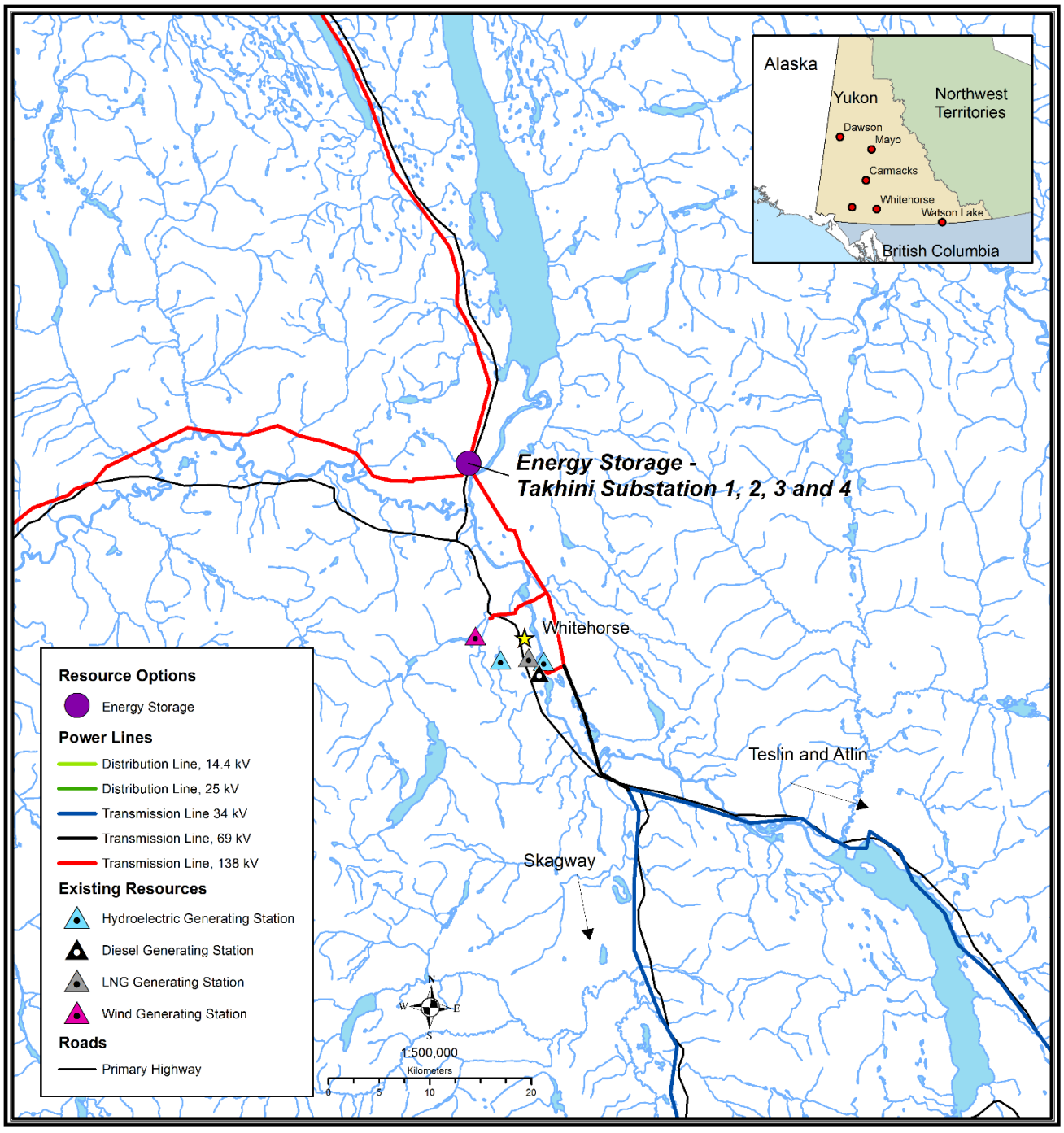
Table 5-113: Storage Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	Tourism Values (S4-2)	Aesthetics (S4-3)	Non-renewable Resources (S4-4)	Other Renewable Resources (S4-5)	Land Use & Renewable Resources Plans (S4-6)
Lithium Ion Battery (8 MW/40MWh, 5 hrs)					

Table 5-114: Storage Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			Climate Change Risk affecting Resource Financial Attributes (Ec2)				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Lithium Ion Battery (8 MW/40MWh, 5 hrs)							

1 *Figure 5-38: Energy Storage Resource Option Location*



5.2.11 Demand Side Management

Technology description

Demand side management (DSM) uses a combination of energy efficient technologies and customer behavioral changes to reduce the amount of electricity that customers demand, or shift the timing of when customers need power. This can be done by providing:

- Financial incentives to customers too help offset the cost of purchasing energy saving products;
- Financial disincentives or penalties such as taxes on high energy use products or behavior;
- Electricity rates that encourage conservation;
- Education on the benefits of conservation, both from an energy perspective as well as other factors such as comfort and safety; and
- Codes and standards such as insulation requirements for new buildings or minimum efficiency levels for appliances.

Currently YEC has used financial incentives and education in the inCharge DSM program, which is delivered to Yukon residential customers in partnership with ATCO Electric Yukon. The timing of energy-focused DSM savings cannot be controlled by the utility, but can be reasonably estimated. Demand focused DSM programs can include utility control and can be dispatched by the utility.

Studies

In 2011, a Conservation Potential Review (CPR) was completed for the Yukon by ICF International (ICFI). This study considered the level of energy savings achievable through the adoption of a range of DSM programs by Yukon homes and businesses. An update to the key exhibits in this review was completed by ICFI for the 2016 Resource Plan. This update took into consideration the change in YEC's load and population forecasts. The update also considered changes in technology and some learnings from the first few years of YEC delivering the inCharge DSM program. The updated CPR can be found in Appendix 5.18.

Fuel description

Instead of delivering electricity supply, DSM focuses on changing the demand for electricity as a way of ensuring that the utility is able to meet future load requirements.

Summary of studies to date and key findings

The 2016 CPR update indicates that there is a considerable amount of electricity conservation potential in the Yukon. The study focused on energy savings as well as the coincident peak demand savings that would result from the energy savings measures. The same rigor was applied in determining both the energy and peak demand savings. A preliminary estimate of demand reduction technologies was completed and will be investigated in more detail at a later date.

Due to the large number of energy efficiency measures considered, these were grouped from lowest to highest cost of conserved energy (CCE), which is equivalent to the LCOE of supply measures. The CCE presented is considered as the cost to both the utility and the participants for saving each kilowatt-hour of electricity. DSM has an inclining cost curve; as the cheaper DSM options are implemented, the next DSM option is more expensive. This results in the overall portfolio cost of DSM increasing as increasingly expensive measures are implemented.

The following Table 5-115 to Table 5-118 describes the technical and financial parameters of the various DSM options. An environmental, social and economic assessment was not undertaken. DSM is considered the most environmentally friendly option as it does not require the construction of generation and

transmission assets. Measures greater than $0.38/kWh for commercial customers and $0.45/kWh for residential customers were not included as costs greater than this were not considered cost effective in the 2011 CPR.

Table 5-115. Energy DSM Technical and Financial Attributes – Commercial Customer Class

Annual and Firm Energy Conserved (GWh/yr)					**Cost of Conserved Energy**	**Project Life**	**In-service Lead Time**
2015	2020	2025	2030	2035	($/kWh)	years	years
Cost of Conserved Energy up to 10 ¢/kWh							
2.4	6.7	10.2	14.5	14.5	0.07	20	2
Cost of Conserved Energy between 10 -20 ¢/kWh							
1.2	3.3	5.5	7.9	7.9	0.13	20	2
Cost of Conserved Energy between 20 -30 ¢/kWh							
0.2	0.8	2.4	4.7	4.3	0.27	20	2
Cost of Conserved Energy greater than 30 ¢/kWh							
0.1	0.3	0.50	0.7	0.7	0.38	20	2

Table 5-116: Capacity DSM Technical Attributes – Commercial Customer Class

Coincident Peak Reduction (*) (MW)				
2015	2020	2025	2030	2035
Cost of Conserved Energy up to 10 ¢/kWh				
0.3	1.0	1.5	2.2	2.1
Cost of Conserved Energy between 10 -20 ¢/kWh				
0.2	0.6	0.9	1.3	1.3
Cost of Conserved Energy between 20 -30 ¢/kWh				
0.0	0.2	0.5	1.0	0.9
Cost of Conserved Energy greater than 30 ¢/kWh				
0.0	0.0	0.1	0.1	0.1

(*) The Coincident Peak Reductions are by-products of DSM Energy Efficiency measures presented in Table 4-115. Table 4-116 is presented separately from Table 4-115 because there was not enough space on the page to present a combined table.

Table 5-117. Energy DSM Technical and Financial Attributes – Residential Customer Class

Annual and Firm Energy Conserved (GWh/yr)					Cost of Conserved Energy	Project Life	In-service Lead Time
2015	2020	2025	2030	2035	($/kWh)	years	Years
Cost of Conserved Energy up to 10 ¢/kWh							
1.0	2.1	2.8	3.3	2.8	0.04	20	2
Cost of Conserved Energy between 10-20 ¢/kWh							
0.4	1.9	5.3	10.1	10.0	0.17	20	2
Cost of Conserved Energy between 20-30 ¢/kWh							
0.2	0.9	2.3	4.2	4.4	0.26	20	2
Cost of Conserved Energy between 30-40 ¢/kWh							
0.2	1.4	2.8	3.4	3.3	0.32	20	2
Cost of Conserved Energy greater than 40 ¢/kWh							
0.0	0.1	0.4	0.5	0.5	0.45	20	2

Table 5-118: Capacity DSM Technical Attributes – Residential Customer Class

Coincident Peak Reduction (**) (MW)				
2015	2020	2025	2030	2035
Cost of Conserved Energy up to 10 ¢/kWh				
0.0	0.1	0.1	0.2	0.2
Cost of Conserved Energy between 10-20 ¢/kWh				
0.1	0.2	0.1	0.1	0.1
Cost of Conserved Energy between 20-30 ¢/kWh				
0.1	0.2	0.1	0.1	0.1
Cost of Conserved Energy between 30-40 ¢/kWh				
0.0	0.0	0.1	0.1	0.1
Cost of Conserved Energy greater than 40 ¢/kWh				
0.0	0.0	0.1	0.1	0.1

(**) The Coincident Peak Reductions are by-products of DSM Energy Efficiency measures presented in Table 4-117. Table 4-118 is presented separately from Table 4-117 because there was not enough space on the page to present a combined table.

5.2.12 Transmission

Technology description

Power transmission allows the bulk movement of electricity through high voltage systems. The YIS consists of high voltage alternating current infrastructure conveying electricity at a voltage of 69 kV (Mayo-Dawson line and Stewart-Keno lines) or 138 kV (Whitehorse-Aishihik-Faro and Carmacks-Stewart lines).

Transmission infrastructure includes the conductors and the supporting poles and the transmission lines that allow the flow of electricity from the generating stations to the load centers as shown in Figure 5-39. Closer to the customer meters, lower voltage (25 kV or 34.5 kV) distribution wiring transmits electricity from the substations to individual customers. Although transmission can also be underground, all transmission infrastructure in Yukon is overhead.

Figure 5-39: Transmission



Studies

An evaluation of the options for eleven transmission routes of interest was conducted by Midgard Consulting for the 2016 Resource Plan. The routes were identified through an iterative process that evaluated the connection between major load centers and current or potential future generation resources. This evaluation considered transmission corridor optimization (adjacent to roadways, avoiding challenging terrain, avoiding private land and avoiding sharp bends in the line), capital and operating expenditures, power transfer capacities, development schedules and risks. The results of this technical evaluation are intended to be combined with the resource options requiring new transmission infrastructure. The routes evaluated were:

- Faro to Finlayson;
- Faro to Watson Lake;
- Aishihik to Destruction Bay;
- Whitehorse to Skagway;
- Whitehorse to Atlin;
- Whitehorse to Teslin;
- Whitehorse to Squanga - Dalayee Pumped Storage Site;
- Whitehorse to Atlin – Mount Black Pumped Storage Site;
- Whitehorse to Tutshi Windy Arm; and

- Whitehorse to Racine – Mount Brown Pumped Storage Site, Racine – Moon Pumped Storage Site, and Tutshi – Moon Lake Pumped Storage Site

The evaluation report can be found in Appendix 5.19.

Summary of studies to date and key findings

The risks that affect the development of transmission corridors were broken down into meteorological, geotechnical, social, logistical and political. The meteorological risks included extended extreme cold, extreme snow and extreme wind. The geotechnical risks included permafrost, exposed bedrock, steep side slopes and floodplains. The social risks were related to permitting in First Nations settlement land, urban or populated areas, parks and recreational areas. Logistics risks were related to planning a very large project in a remote area with little local capacity. The political risks are related to the transmission lines that cross the Yukon border into British Columbia and Alaska. Safety risks were also identified pertaining to proposed transmission line route passing near existing airport runways.

The following Table 5-119 describes the technical and financial attributes and Table 5-120 to Table 5-126 describe the environmental, social and economic attributes for the transmission lines. As the Whitehorse-Atlin 69kV line was introduced after the environmental, social and economic attributes report had been finished, no formal evaluation of the 69kV Whitehorse-Atlin transmission line was conducted. Considering the similarities between the 138kV and 69kV lines, it is a conservative assumption that the environmental, social and economic attributes determined for the Whitehorse-Atlin 138kV line can be applied to the Whitehorse-Atlin 69kV line. The location of the transmission lines can be found in Figure 5-40 and Figure 5-41.

Table 5-119. Transmission Lines Resource Option Technical and Financial Attributes

Voltage	Transmission Line Length	Reliable Transfer Capacity	CAPEX	OPEX	Lead Time	Line Losses
kV	km	MW	$Million	$000/yr	Years	%
Whitehorse → Atlin (69 kV)						
69 kV	172	21	$104	$236k/yr	4.8	7.5%
Whitehorse → Atlin (138 kV)						
138 kV	172	97	$158	$236k/yr	4.1	4.6%
Whitehorse → Atlin- Mt. Black Pumped Storage Hydro						
138 kV	127	131	$119	$174k/yr	3.7	3.5%
Jake's Corner → Atlin						
69 kV	93	38	$54	$129k/yr	4.1	5.0%

Voltage kV	Transmission Line Length km	Reliable Transfer Capacity MW	CAPEX $Million	OPEX $000/yr	Lead Time Years	Line Losses %
Whitehorse → Skagway (138 kV)						
138 kV	170	114	$166	$285k/yr	4.1	4.6%
Whitehorse → Skagway (230 kV)						
230 kV	170	443	$251	$285k/yr	4.1	0.4%
Whitehorse → Squanga- Dalayee Pumped Storage Hydro						
138 kV	105	134	$100	$143k/yr	3.3	2.7%
Whitehorse → Tutshi Windy Arm						
138 kV	96	135	$94	$143k/yr	3.2	2.7%
Whitehorse → Racine-Mt. Brown, Racine-Moon Lake, and Tutshi-Moon Lake Pumped Storage Hydro						
138 kV	112	132	$108	$168k/yr	3.3	3.5%
Whitehorse → Lindeman- Fraser Pumped Storage Hydro						
138 kV	129	129	$125	$200k/yr	3.8	3.5%
Whitehorse → Teslin (138 kV)						
138 kV	174	95	$165	$239k/yr	4.1	4.6%
Faro → Watson Lake (230 kV)						
230 kV	414	190	$597	$613k/yr	6.0	1.6%
Faro → Finlayson (138 kV)						
138 kV	233	84	$221	$351k/yr	4.3	5.7%
Aishihik → Destruction Bay (138 kV)						
138 kV	157	122	$167	$217k/yr	3.8	3.8%

Voltage kV	Transmission Line Length km	Reliable Transfer Capacity MW	CAPEX $Million	OPEX $000/yr	Lead Time Years	Line Losses %
Aishihik → Destruction Bay (230 kV)						
230 kV	157	484	$241	$217k/yr	3.8	0.4%

Table 5-120: Transmission Lines Resource Option Environmental Attributes – Aquatic Environment

Fish & Fish Habitat (En1)			Water Quantity & Quality (En2)		
Salmon & Habitat (En1-1)	Species at Risk & Habitat (En1-2)	Commercial, Recreational & Aboriginal Fisheries Species & Habitat (En1-3)	Consumptive Water Use (En2-1)	Relative Scale of New Impoundment/ Flooding (En2-2)	Flow Changes (En2-3)
Whitehorse - Atlin (138 kV)					
Whitehorse - Skagway (230 kV)					
Whitehorse - Teslin (138 kV)					
Faro - Watson Lake (230 kV)					
Aishihik - Destruction Bay (230 kV)					
Stewart-Keno City (138 kV & substations)					

Table 5-121: Transmission Lines Resource Option Environmental Attributes - Terrestrial Environment

Terrestrial Species & Habitat (En3)				Terrestrial Footprint & Land Use (En4)			
Species at Risk & Habitat (En3-1)	Protected & Conservation Areas (En3-2)	Wildlife Key Areas (En3-3)	Caribou Ranges (En3-4)	Footprint Terrestrial Area (En4-1)	Linear Dev for Roads/ Transmission (En4-2)	Permafrost En4-3)	Wetlands (En4-4)
Whitehorse - Atlin (138 kV)							
Whitehorse - Skagway (230 kV)							
Whitehorse - Teslin (138 kV)							
Faro - Watson Lake (230 kV)							
Aishihik - Destruction Bay (230 kV)							
Stewart-Keno City (138 kV & substations)							

Table 5-122: Transmission Lines Resource Option Environmental Attributes – Air

Air Quality (En5)		
GHG Emissions (En5-1)		Other Air Pollutants (En5-2)
with Biogenic CO2	without Biogenic CO2	
Whitehorse - Atlin (138 kV)		
Whitehorse - Skagway (230 kV)		
Whitehorse - Teslin (138 kV)		
Faro - Watson Lake (230 kV)		
Aishihik - Destruction Bay (230 kV)		
Stewart-Keno City (138 kV & substations)		

Table 5-123: Transmission Lines Resource Option Social Attributes – First Nations Land and Traditional Lifestyle

First Nation Lands (S1)	Traditional Lifestyle (S2)				
First Nation Settlement Lands/ Interim Protected Lands (S1-1)	Footprint Land Area Impact (S2-1)	Land Area Loss Re: Traditional Lifestyle (S2-2)	Land Quality Effects on Traditional Lifestyle (S2-3)	Cabins, Camps & Structures (S2-4)	Country Foods (S2-4)
Whitehorse - Atlin (138 kV)					
Whitehorse - Skagway (230 kV)					
Whitehorse - Teslin (138 kV)					
Faro - Watson Lake (230 kV)					
Aishihik - Destruction Bay (230 kV)					
Stewart-Keno City (138 kV & substations)					

Table 5-124: Transmission Lines Resource Option Social Attributes – Heritage Resources and Cultural & Community Well-being

Heritage Resources (S3)		**Cultural & Community Well-being (S5)**		
Density of Heritage Resources (S3-1)	Importance/ Cultural Value of Heritage Resources (S3-2)	Infrastructure & Services (S5-1)	Public Safety, Worker Interaction, Human & Community Health (S5-2)	Community, First Nation & Personal Development (S5-3)
Whitehorse - Atlin (138 kV)				
Whitehorse - Skagway (230 kV)				
Whitehorse - Teslin (138 kV)				
Faro - Watson Lake (230 kV)				
Aishihik - Destruction Bay (230 kV)				
Stewart-Keno City (138 kV & substations)				

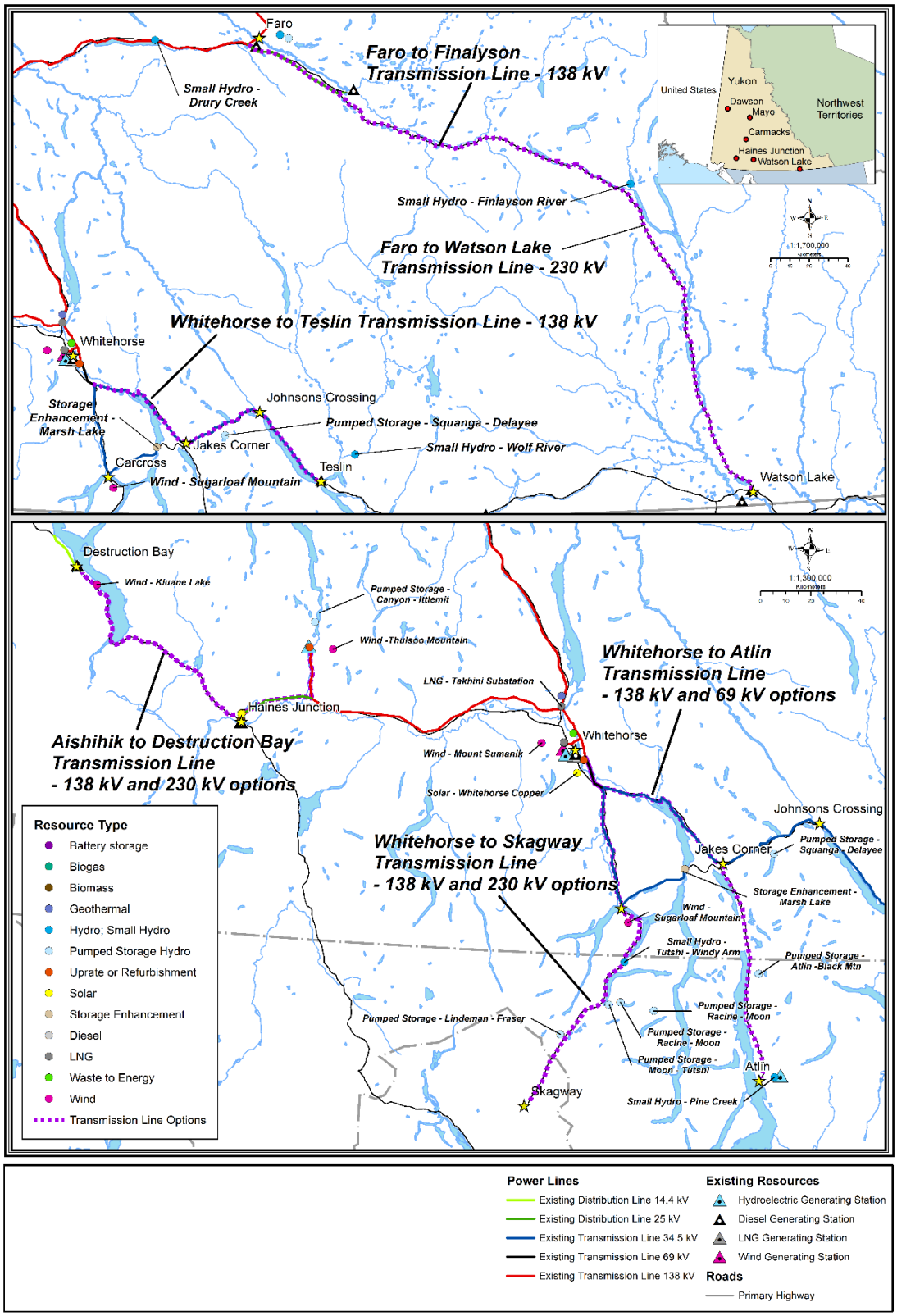
Table 5-125: Transmission Lines Resource Option Social Attributes – Tourism, Recreation, Other Resources and Land Use

Tourism, Recreation & Other Resources and Land Use (S4)					
Recreational Values (S4-1)	**Tourism Values (S4-2)**	**Aesthetics (S4-3)**	**Non-renewable Resources (S4-4)**	**Other Renewable Resources (S4-5)**	**Land Use & Renewable Resources Plans (S4-6)**
Whitehorse - Atlin (138 kV)					
Whitehorse - Skagway (230 kV)					
Whitehorse - Teslin (138 kV)					
Faro - Watson Lake (230 kV)					
Aishihik - Destruction Bay (230 kV)					
Stewart-Keno City (138 kV & substations)					

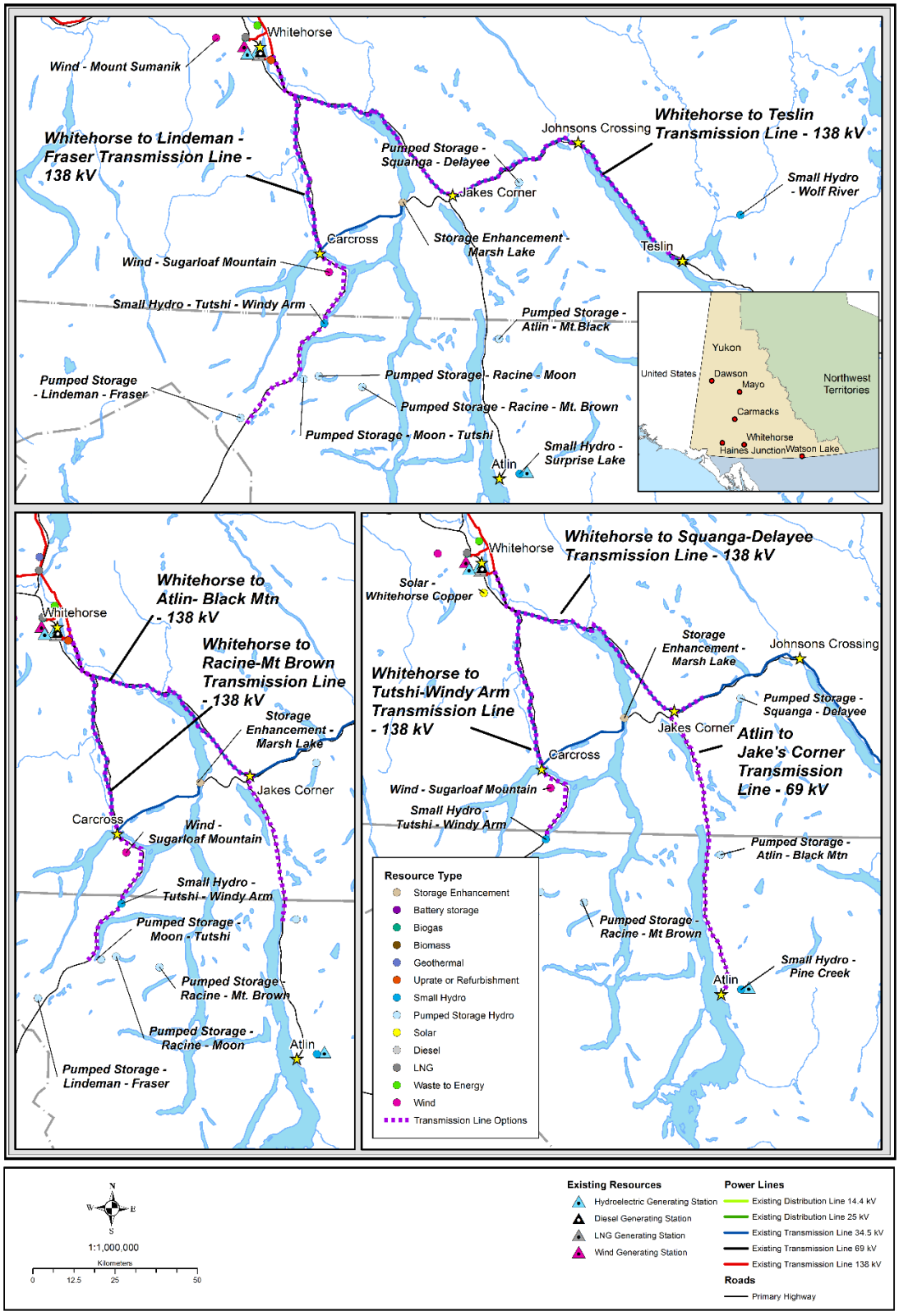
Table 5-126: Transmission Lines Resource Option Economic Attributes – Local Economic Impacts and Climate Change Risk

Local Economic Impacts (Ec1) (Positive Effects)			**Climate Change Risk affecting Resource Financial Attributes (Ec2)**				
Yukon Opportunities During Construction (Ec1-1) Positive Effects	Yukon Opportunities during Operation (Ec1-2) Positive Effects	Community & Other Development Opportunity (Ec1-3) Positive Effects	Susceptible to Extreme Heat/Drought (Ec2-1)	Susceptible to Extreme Precipitation - flood/snow (Ec2-2)	Susceptible to Extreme Wind Events (Ec2-3)	Susceptible to Ice Related Processes/ Events (Ec2-4)	Conditions Susceptible to Climate Change (Ec2-5)
Whitehorse - Atlin (138 kV)							
Whitehorse - Skagway (230 kV)							
Whitehorse - Teslin (138 kV)							
Faro - Watson Lake (230 kV)							
Aishihik - Destruction Bay (230 kV)							
Stewart-Keno City (138 kV & substations)							

1 *Figure 5-40: Transmission Line Options Locations (Map 1)*



1 *Figure 5-41: Transmission Line Options Locations (Map 2)*



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6 Market Assessment

6.1 Fuel Price Forecasts

6.1.1 Background

The cost of hydrocarbon fuels, diesel and liquefied natural gas (LNG), is a major component in the cost of electricity delivered from thermal-based generation and therefore, this is a key factor in electricity generation resource decisions. This chapter summarizes the diesel and LNG price forecasts undertaken by Yukon Energy (YEC) for the purposes of long-term resource planning.

6.1.2 Forecast Approach

There are several ways to create forecasts. The simplest approach involves a trend analysis, in which recent historical prices are escalated using an inflation-based index. This was the approach used in YEC's 2011 Resource Plan. A forecast of future diesel prices was constructed by anchoring current diesel prices, and applying escalation at inflation.

YEC's 2016 Resource Plan takes a more detailed approach, in that the key components of diesel and LNG fuel price were analyzed, and specific escalation factors were applied separately to each of the cost components. These separate cost forecasts were then aggregated to generate a total diesel and LNG price forecast.

The prices of diesel and LNG delivered to YEC's thermal generation facilities are comprised of a few key components. For example, the price of delivered diesel includes the following:

- Fuel cost (crude oil)
- Refining costs (crude oil converted to diesel)
- Marketing
- Shipping
- Taxes

All the price forecasts presented in this Chapter exclude effects associated with carbon pricing. An assessment of a social cost of carbon, which has been applied to thermal generation resources in the YEC's portfolio analysis, is presented in Section 6.2. The results of the portfolio analysis are presented in Chapter 8.

In undertaking the forecast, the above costs have been grouped into two categories. The forecast costs in each category are separately created and then added together, as follows:

1. Fuel costs: The feedstocks for diesel and LNG are crude oil and gas, respectively. Therefore price forecasts for oil and gas are key forecast inputs. As oil and gas prices are denominated in US dollars (US$), a Canadian dollar (C$)-US$ exchange rate forecast was created and applied. Oil prices are largely driven by global forces of supply and demand, with some degree of producer market power. Natural gas prices are set on a continental basis, as imports and exports of natural gas (as LNG) are relatively small. Processing and shipping costs for both fuels are largely cost-based, and generally track inflation; and

2. Other non-fuel costs: this grouping includes all other costs such as shipping, liquefaction for natural gas, refining for diesel, and taxes. In the forecasts, these are escalated at a rate consistent with the supplier cost of providing the service (i.e., equivalent to the inflation rate). These costs are largely local and therefore, are denominated in C$.

The key inputs to the diesel and LNG price forecast are:

- Recent diesel and LNG prices paid by YEC: These are the actual delivered prices of the fuel, and include all other charges such as shipping and liquefaction;
- Recent market prices for oil (Brent and West Texas Intermediate) and natural gas (Sumas Hub and Henry Hub);
- Historical Exchange rates (C$/US$);
- A base C$/US$ exchange rate of 0.82, which was the exchange rate at the time this forecast was completed in June 2016, and high and low sensitivities around the base; and
- Long-term market price forecasts and scenarios for oil and natural gas, from a recent study by the National Energy Board of Canada (NEB)[1].

6.1.3 Scenarios

Energy prices are among the most uncertain and volatile of all commodities, and are subject to the future events such as technology developments, changes in taxation and energy policies, customer demand, and substitution by other fuels. A scenario-based forecasting approach was used to account for these uncertainties.

The key uncertainty in the diesel and LNG forecasts relates to the fuel costs and the exchange rates. Consequently, three exchange rate scenarios (High, Base and Low) and three long-term oil and gas price scenarios (High, Base and Low), and were considered.

6.1.3.1 Exchange Rate Scenarios

The Base Exchange rate forecast of 0.82 US$/CA$ was used, with low and high scenarios of 0.70 and 0.90 US$/C$ respectively. These scenarios fall reasonably within the historical range from the past 30 years. Exchange rates of as low as 0.60 and over 1.00 US$/C$ have occurred over this period, but these were unusual short-term events.

YEC undertook a regression analysis of the historical relationship between the Canadian dollar (relative to the US$) and the market price of oil. The results of this regression analysis is clear and consistent with previous studies. When oil prices are low, the Canadian dollar has historically been low, which supports the price of oil denominated in C$. Therefore, only certain combinations of oil prices and foreign exchange rates are sensibly aligned. This reduces the number of scenarios to be analyzed.

[1] Canada's Energy Future 2016: Energy Supply and Demand Projections to 2040 – An Energy Market Assessment – January 2016: https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/index-eng.html

6.1.3.2 Fuel Cost Scenarios

Two consistent fuel price forecasts were developed based on the NEB high and low scenarios. The low oil price case was matched with the low US$/C$ exchange rate (0.70 US$/C$), and the high oil price case was matched with the high exchange rate (0.90 US$/C$).

A correlation between Henry Hub natural gas prices and the Canadian dollar was also tested, and it did not show a strong relationship. However, for consistency, the NEB high and low gas price scenarios were matched with the same exchange-rate cases as were used with oil prices. The high natural gas price case was matched with the high exchange rate (0.90 US$/C$) and the low natural gas case was matched with the low exchange rate (0.70 US$/C$).

The forecast prices of the fuel feedstock were escalated at rates consistent with the NEB's long-term forecasts, relative to a 2016 base year. The escalation rates were applied to actual diesel and LNG prices paid by YEC in late 2015 and early 2016 to generate the fuel feedstock price forecasts[2]. High and Low fuel cost forecasts were created by escalating the fuel feedstock components by the High and Low escalators, respectively, from the NEB cases.

The potential for future local sources of natural gas supply from either local resources (e.g., through development of Eagle Plains resources), or delivered from outside the Yukon Territory by pipeline, was not considered. This forecast for diesel and LNG considers existing sourcing and modes of transportation.

6.1.3.3 Non-Fuel Costs

For the Base and Low cases, the actual non-fuel cost components of the diesel and LNG fuel costs paid by YEC were analyzed and consequently escalated at inflation, or zero escalation when expressed in Real dollars. Non-fuel costs under the High case were inflated at 1% over inflation when expressed in Real dollars. The summary of the inputs and assumptions in the scenarios is shown in Table 6.1.

[2] The absolute values in the NEB oil and natural gas price forecasts are not used directly. They were used to construct future oil and gas price escalators that were applied to current diesel and LNG prices paid by YEC.

Table 6-1: Summary of the inputs and assumptions in the scenarios

Price Scenario	Fuel Price Assumptions	Non-Fuel Price Assumptions	Exchange Rate Assumption
Base (Reference)	Oil and natural gas prices escalated as per NEB mid-price forecast.	Starting price is based on recent diesel and LNG prices paid by YEC delivered to Whitehorse. Escalation at 0% Real.	Mid- C$/US$ exchange rate assumption.
High	Oil and natural gas prices escalated as per NEB high price forecast.	Starting price is based on recent diesel and LNG prices paid by YEC delivered to Whitehorse. Escalation at 1% Real.	High C$/US$ exchange rate assumption.
Low	Oil and natural gas prices escalated as per NEB low price forecast.	Starting price is based on recent diesel and LNG prices paid by YEC delivered to Whitehorse. Escalation at 0% Real.	Low C$/US$ exchange rate assumption.

6.1.4 Results

Based on the analysis of actual prices of diesel and LNG fuel delivered to YEC, it was determined that the majority of the delivered costs were comprised of shipping, liquefaction and taxes. The fuel (oil) feedstock made up approximately 50% of delivered diesel price, while the natural gas feedstock made up less than 20% of the delivered price of LNG.

Figure 6-1 and Figure 6-2 show the forecast delivered diesel and LNG costs to Whitehorse for the Base, High and Low scenarios. Since the majority of delivered LNG and diesel prices are made up of non-fuel components (shipping and liquefaction), and since these non-fuel cost factors are assumed to escalate at inflation in the Base and Low scenarios, the observed increase in total delivered LNG and diesel price forecasts is relatively suppressed. Table 6-2 shows the diesel and LNG price forecasts as numerical values. The forecast increase in diesel prices between 2015 and 2016 is based on the NEB's assumption (in late 2015) of increases in near-term global crude oil prices, particularly in the High scenario. Oil prices have subsequently increased, but not to the extent predicted by the NEB.

Figure 6-1: Delivered LNG costs to Whitehorse (2016 C$)

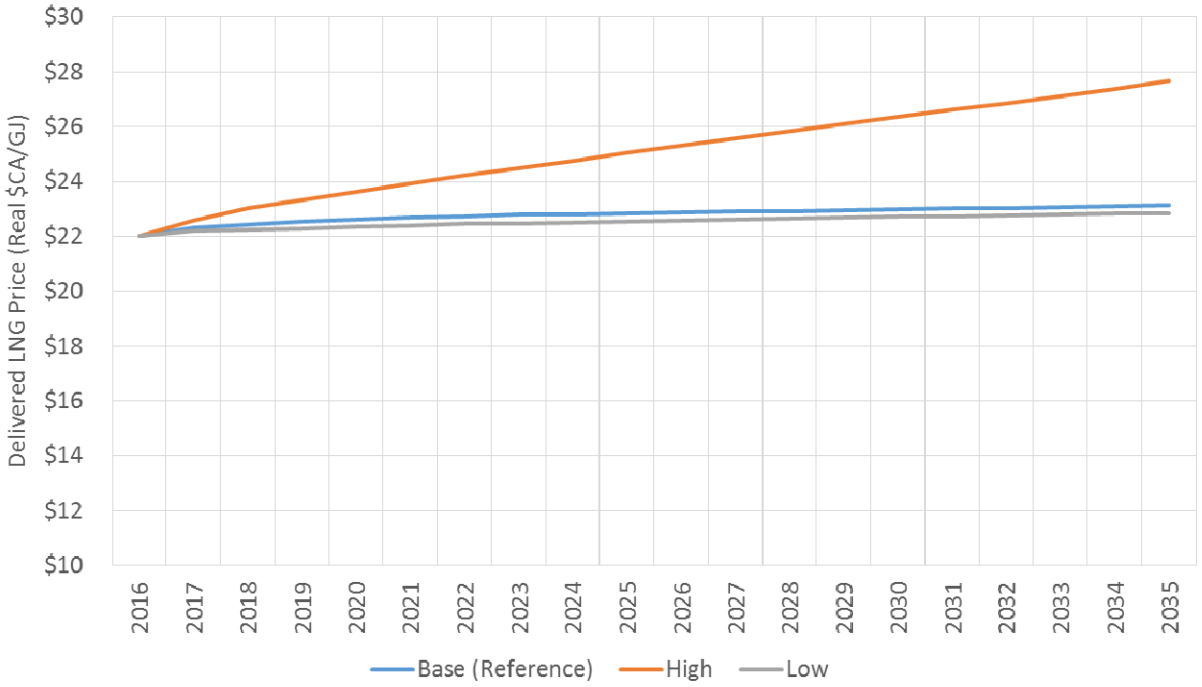


Figure 6-2: Delivered Diesel costs to Whitehorse (2016 C$)

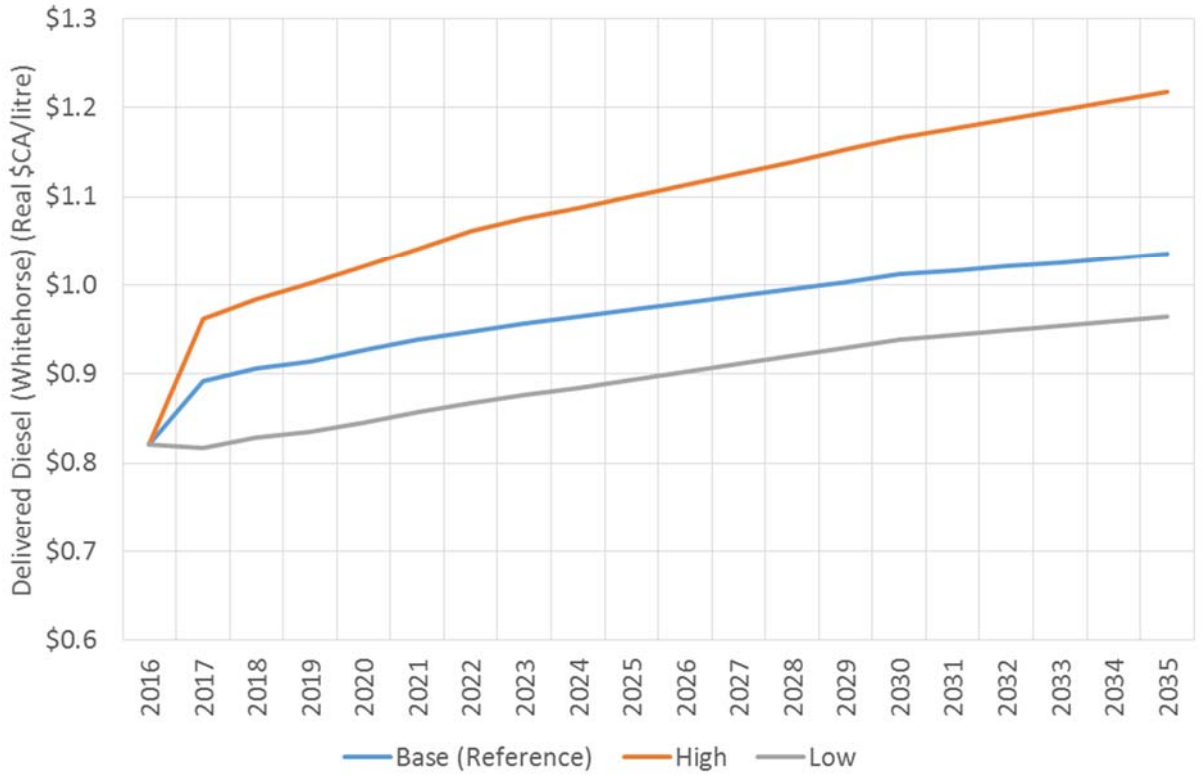


Table 6-2: Delivered Diesel and LNG costs to Whitehorse (2016 Real C$) – Base (Reference) Forecast

Year	LNG Delivered to Whitehorse C$/GJ			Diesel Delivered to Whitehorse C$/litre		
	Fuel Cost	Non Fuel Cost	Total	Fuel Cost	Non Fuel Cost	Total
2016	**3.00**	**19.00**	**22.00**	**0.32**	**0.50**	**0.82**
2017	3.33	19.00	22.33	0.39	0.50	0.89
2018	3.44	19.00	22.44	0.41	0.50	0.91
2019	3.53	19.00	22.53	0.41	0.50	0.91
2020	3.61	19.00	22.61	0.43	0.50	0.93
2021	3.68	19.00	22.68	0.44	0.50	0.94
2022	3.74	19.00	22.74	0.45	0.50	0.95
2023	3.79	19.00	22.79	0.46	0.50	0.96
2024	3.82	19.00	22.82	0.46	0.50	0.96
2025	3.84	19.00	22.84	0.47	0.50	0.97
2026	3.87	19.00	22.87	0.48	0.50	0.98
2027	3.90	19.00	22.90	0.49	0.50	0.99
2028	3.93	19.00	22.93	0.50	0.50	1.00
2029	3.96	19.00	22.96	0.50	0.50	1.00
2030	3.98	19.00	22.98	0.51	0.50	1.01
2031	4.01	19.00	23.01	0.52	0.50	1.02
2032	4.04	19.00	23.04	0.52	0.50	1.02
2033	4.07	19.00	23.07	0.53	0.50	1.03
2034	4.10	19.00	23.10	0.53	0.50	1.03
2035	4.13	19.00	23.13	0.54	0.50	1.04
2036	4.15	19.00	23.15	0.5	0.50	1.04

Year	LNG Delivered to Whitehorse C$/GJ			Diesel Delivered to Whitehorse C$/litre		
	Fuel Cost	Non Fuel Cost	Total	Fuel Cost	Non Fuel Cost	Total
20-year compounded growth	1.6%	0.0%	0.3%	2.6%	0.0%	1.2%

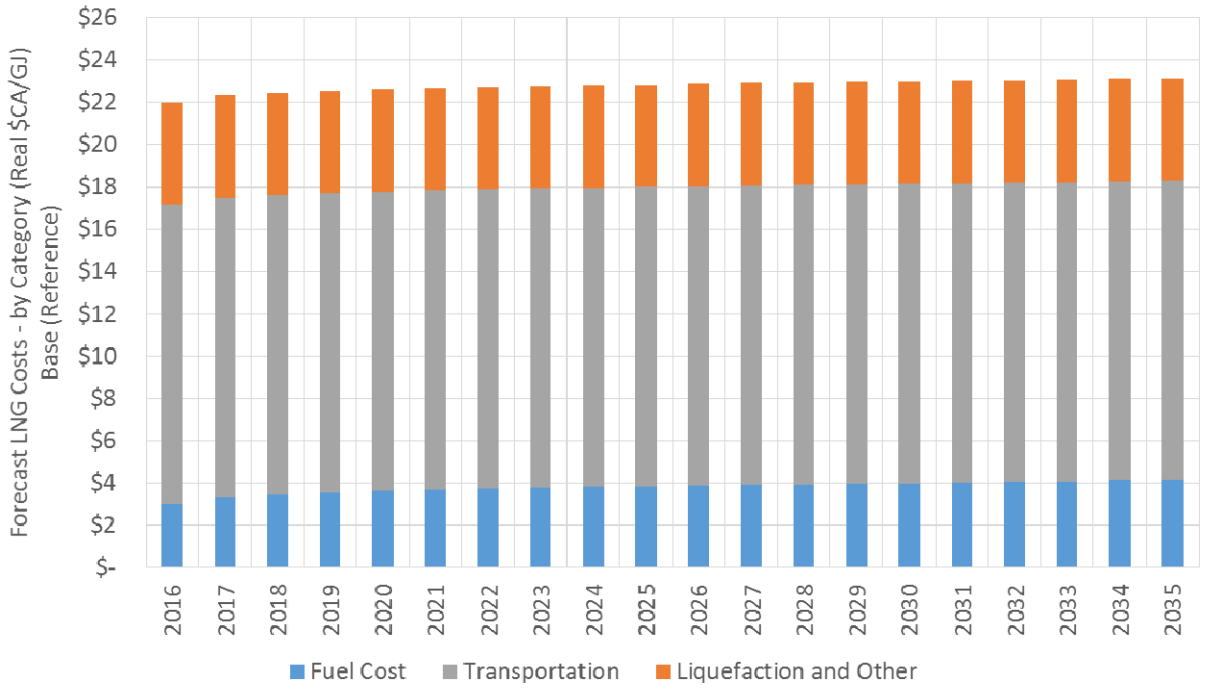
6.1.5 Potential LNG Supply Options

To augment the LNG forecast analysis, YEC recently reviewed other potential LNG delivery options, which may achieve cost savings relative to current supply. A summary of these findings is presented in this section, while details on this investigation are presented in Appendix 6.1.

YEC's current sources of LNG are from Delta (Tilbury Island), in the Lower Mainland of British Columbia (BC), approximately a 2,390 km one way trip to Whitehorse, and Elmworth, Alberta (AB), approximately a 1,524 km trip. Other potential sources of LNG supply include Dawson Creek, BC (approximately a 1,460 km trip) and Fort Nelson, BC (approximately a 988 km trip). As the largest cost component of LNG delivered to YEC is associated with transportation and because these transportation costs are highly correlated with distance, a closer LNG supply source should result in significant savings in the delivered LNG price.

Figure 6-3 shows a breakdown of forecast LNG cost components, assuming the source of LNG is Tilbury Island.

Figure 6-3: Breakdown of forecast LNG cost components – Delta, BC (Tilbury Island) Supply



Further reductions in the delivered price of LNG price could be driven by an increase in the volume of LNG per shipment, above the current volume of 60 m^3 per delivery. Design work has been completed on an optimized B-train configuration with a shipping volume in the range of 80 to 90 m^3 per load. This would represent an increase of up to 50% over current shipping volumes. The trailer design is currently under review by Provincial and Federal authorities for commercial use on the road network in Yukon, British Columbia and Alberta.

Overall, The LNG transportation charge represents the greatest opportunity for future cost savings, due to the economies of scale in larger delivery volumes, and shorter delivery distances. YEC is conservative with respect to estimating cost savings due to the availability of the optimized B-train trailer, as the trailer design has not yet received regulatory approval and has not yet been manufactured for commercial service. Therefore, availability of the optimized B-train trailer is not assumed in the Base (Reference) case LNG price forecasts.

Based on information available at the time the forecast was generated, YEC estimates an initial cost reduction of approximately $8/GJ by sourcing LNG from Dawson Creek with larger shipping volumes realized with the new B-train configuration. This saving assumption is largely based on reduced trucking distances, but it also the benefits of larger (i.e., 80 m^3) LNG loads. This savings assumption is current as of November, 2016.

Table 6-3 presents the four LNG price scenarios analyzed: medium, high, low and optimized.

Table 6-3: Delivered LNG costs with optimized supply to Whitehorse (2016 C$)

Year	LNG Base (Reference) C$/GJ	LNG High C$/GJ	LNG Low C$/GJ	Optimized LNG C$/GJ
2016	22.00	22.00	22.00	22.00
2017	22.33	22.56	22.18	22.33
2018	22.44	23.01	22.24	22.44
2019	22.53	23.32	22.29	14.64
2020	22.61	23.64	22.35	14.71
2021	22.68	23.92	22.40	14.79
2022	22.74	24.21	22.45	14.84
2023	22.79	24.49	22.48	14.89
2024	22.82	24.77	22.51	14.92
2025	22.84	25.04	22.55	14.95

Year	LNG Base (Reference) C$/GJ	LNG High C$/GJ	LNG Low C$/GJ	Optimized LNG C$/GJ
2026	22.87	25.31	22.58	14.98
2027	22.90	25.57	22.61	15.00
2028	22.93	25.83	22.65	15.03
2029	22.96	26.10	22.68	15.06
2030	22.98	26.36	22.71	15.09
2031	23.01	26.61	22.74	15.12
2032	23.04	26.87	22.78	15.14
2033	23.07	27.12	22.80	15.17
2034	23.10	27.39	22.82	15.20
2035	23.13	27.66	22.83	15.23
2036	23.15	27.93	22.84	15.26

6.1.6 Diesel and LNG price forecasts selected for portfolio analysis

The YEC portfolio analysis used three of the four LNG price scenarios, specifically:

- Base;
- High; and
- Optimized.

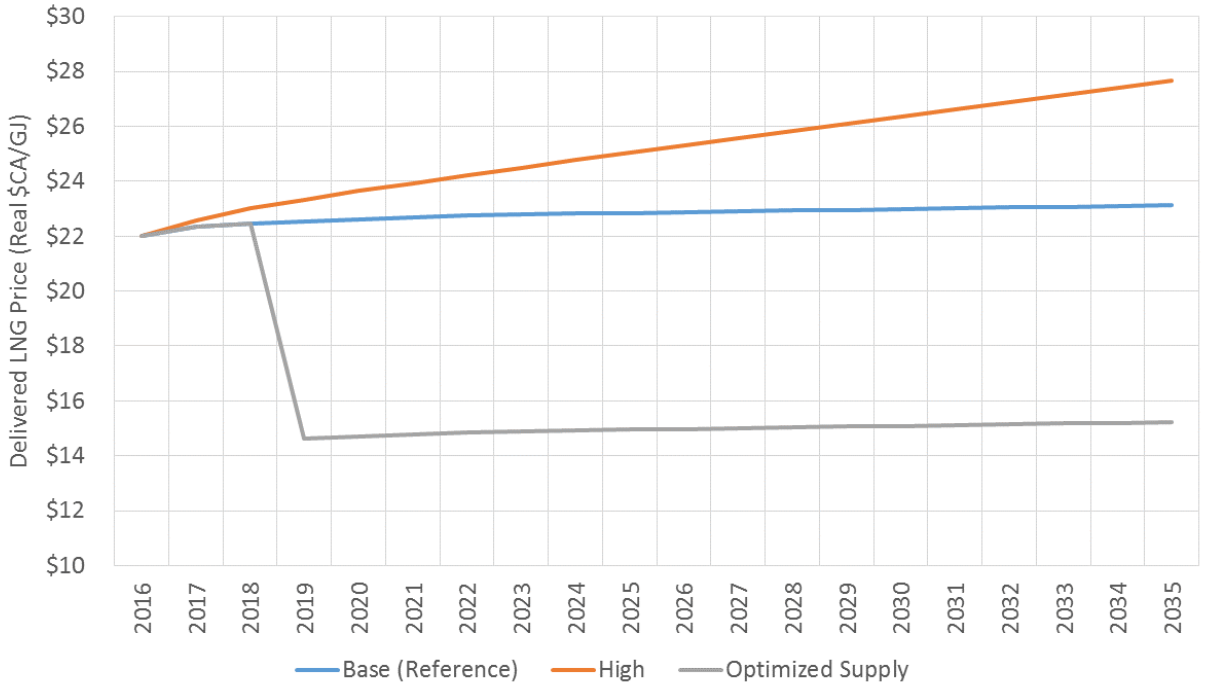
The Low LNG scenario presented in Figure 6-1 and Table 6-3 was not selected for the portfolio analysis, as it is very close to the Base scenario.

The Base scenario assumes current LNG shipment volumes and the current LNG source as Tilbury Island. The High scenario assumes same assumptions as the Base scenario, but with the high gas fuel price forecast. The Optimized Supply scenario assumes the Base case fuel price forecast, but with 80 m^3 shipping volumes and LNG sourced from Dawson Creek. The B-train configuration with larger shipping volumes is assumed to be commercially available to serve the Dawson Creek to Whitehorse route starting in 2019.

Figure 6-4 shows the three scenarios selected as input for the portfolio analysis. The case with the potential cost reduction is labeled “Optimized Supply”. The numerical values for those three scenarios

are presented in Table 6-3. Note the significant price drop in 2019; this is due to reduced transportation costs, and lower natural gas prices possible due to the alternative supply arrangements discussed above.

Figure 6-4: Delivered LNG costs to Whitehorse for selected scenarios (Real 2016 C$)



6.2 Social Cost of Carbon

On December 9, 2016, Yukon signed onto the Pan-Canadian Framework on Clean Growth and Climate Change (the Framework). The Framework is both a concrete plan with key commitments and also a launching point for further collaboration across Canada in addressing and adapting to the impacts of climate change and shifting to a clean, renewable economy. The Framework introduces carbon pricing across Canada. Application of a cost of carbon is one of the key policy instruments used by many governments to reduce greenhouse gas (GHG) emissions.

Given the eventual application of carbon pricing across Canada, YEC chose to assess the impact of a social cost of carbon (SCC) within the 2016 Resource Plan, specifically on the economics of the resource options studied and in the portfolio analysis. The SCC represents an assigned monetary value of the *net* harm of human caused by GHG emissions from burning coal, oil and natural gas (fossil fuels). The SCC is expressed in dollars per tonne of CO_2 equivalent ($/t$CO_2$e).

The SCC considers possible effects to the Earth's managed and unmanaged systems such as reduced output from agriculture, forestry, fisheries, the extinction of non-commercial species, and the destruction of major ecosystems.

The effects of human-caused GHG emissions are difficult to quantify, due to uncertainties such as:

- Accurate estimating of the global harm of GHG emissions. Climate change is a global problem and needs to be observed at global level, which introduces highly complex causes and effects.

- Accurate estimating of harms of low probability high impact events. Some SCC estimates place little value on low probability catastrophic outcomes, such as the possibility of runaway methane release in the Arctic, the collapse of the West Antarctic Ice Sheet, or the reversal of the Gulf Stream. Recent SCC estimates attempt to quantify and then incorporate these potential costs, but there is considerable uncertainty about what values to use.
- Selection of the discount rate used in the economic analysis on the SCC. A higher discount rate favours near-term actions, placing less emphasis on future harm. The SCC generally considers long-term impacts on the economy and the environment, so that relatively low discount rates are applied to the SCC.

Due to these uncertainties, the range of SCC estimates is necessarily broad. A review of current estimates deemed credible, and a benchmarking of policy-driven GHG reduction measures by Canadian jurisdiction is presented in Appendix 6.2.

A key consideration in the adoption of a SCC for YEC's Resource Plan is ratepayer, regulatory and political acceptability. The Yukon Utilities Board is primarily an economic regulator, with the mandate of approving low-cost solutions for ratepayers. The Framework adoption now makes it clear that the cost of carbon must be considered in subsequent regulatory proceedings. In addition, the Framework considerably narrows the potential range of carbon prices applicable to thermal resources in the Yukon. However, Yukon-specific legislation regarding a carbon price is still forthcoming. Therefore, YEC has adopted a conservative approach in its SCC forecast, by adopting a reputable third-party forecast.

YEC used the most recent forecast from the US Environmental Protection Agency[3] (EPA) to investigate the impact of the SCC on the selection of future generation and transmission resources. The range of SCC as provided by the EPA is shown in Table 6-4.

Table 6-4: Social Cost of Carbon ranges by EPA (2016 Canadian Dollars)

US EPA (2016 C$)	2015	2035
Lowest estimate	$60	$90
Highest estimate	$174	$279

The EPA has assessed a wide range of outlooks for the SCC by assessing proposed regulations, such as vehicle or generation plant emissions standards. However, the EPA outlook does not include the effects of low probability catastrophic outcomes listed above.

Given this consideration, together with the wide uncertainty in SCC outlooks, for its SCC, YEC has accepted the low range of the EPA outlook. That is, a SCC of $60/tCO$_2$e in 2016 and $90/tCO$_2$e in 2035 (in 2016 C$), with equal increase for each year from 2016 to 2035.

[3] US EPA, Social Cost of Carbon, 2016. https://www.epa.gov/climatechange/social-cost-carbon

The effects of the recommended SCC values on the cost of LNG and diesel at YEC's generating facilities are presented in Table 6-5.

Table 6-5: Effects of Social Cost of Carbon on the proxy cost of LNG and diesel generation

Proxy Cost of SCC (2016 C$/kWh)	2015	2035
LNG	0.026	0.040
Diesel	0.040	0.062

If the portfolio scenarios with applied SCC were accepted, the actual cost to YEC or its ratepayers would not increase by these amounts, but future decisions made by YEC on the selection of resources would handicap GHG-emitting generating assets by these amounts, relative to non-emitting generating resources such as hydro, wind and solar power.

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7 Risks and Uncertainties

7.1 Introduction

Reliable electricity is crucial for the safety of Yukon citizens and the success of local communities and businesses. Yukon's electricity system is islanded and therefore must be self-sufficient. That is, the electricity generation in the Yukon must meet local requirements at all times. Unlike most systems in North America and around the world, the Yukon system has no interconnections to neighbors, which most electricity utilities occasionally rely on to share resources and meet peak electricity demand. The Yukon system must be totally reliant on internal resources to meet demands during periods of extreme need, which typically occurs during cold winter days. Reliability metrics and standards developed in other parts of North America need to be reviewed and applied very carefully to the Yukon, as the consequences of sustained electricity outages in the north can be severe. A long-duration power outage in most of the world carries the discomfort of heat and humidity. In contrast, a sustained power outage in a Yukon winter can be life-threatening. Such an outage could also result in significant costs such as frozen and burst water pipes leading to the flooding of residences and businesses. YEC must provide a supply solution that can deliver reliable electricity on cold and dark winter days.

To recap the steps in developing YECs Resource Plan, they are repeated from Chapter 1:

1. Forecast future electricity load (demand);
2. Create an inventory of existing energy supplies;
3. Determine potential shortfalls;
4. Create an inventory of potential energy supplies and conservation options;
5. Forecast future fuel and carbon prices;
6. Assess risks and uncertainties relevant to the Resource Plan;
7. Analyze the portfolio of options;
8. Draft an action plan; and
9. Finalize the Plan.

This Chapter, corresponding to Step 6 above, details the process undertaken for the Resource Plan risk assessment, and how this assessment informed subsequent steps 7, 8 and 9.

Step 6 is the critical process of assessing uncertainties and risks. This includes an assessment of current and future risks to the Plan, including but not limited to resources, regulatory and policy issues, the load forecast, fuel price forecast, and climate change

To provide clarity, the following definitions are provided:

- **Consequence** is an outcome or impact of relevance to the planning process. Consequences are usually tied to business of planning objectives and can be positive or negative, easily measurable or difficult to quantify;
- **Uncertainty** is the state of not knowing which one of several potential future consequences could occur, i.e. the state where there is the potential for more than one future outcome;
- **Risk** is the potential of losing something of value if a consequence occurs. The key risks to utilities are usually thought of as negative impacts such as: financial losses, damage to infrastructure, reduced reliability, or loss of reputation.

In planning to meet customer demands, it is important to separate risks from uncertainties. Some consequences may be negative, but could be excluded from in depth consideration if their likelihood is

small enough. Some uncertainties may be large and complex, but can be passed over if they don't lead to large consequences. Ultimately, the focus of analysis needs to be on risk. In the planning context, risk has to be understood, quantified, and appropriately managed.

The fundamental risks to be addressed by the YEC Resource Plan are:

- Inadequate electricity supply in terms of insufficient generation and transmission capabilities, which reduces YEC's ability to 'keep the lights on', and leads to reduced reliability; and
- Over-building or over-procuring electricity supply, which could lead to higher rates. Capital intensive projects pose major risks to ratepayers if the future load projections used to justify these projects do not materialize.

The major uncertainties identified in the 2016 Resource Plan are related to the following four broad categories:

- Resources,
- Regulatory and Policy,
- Load Forecast, and
- Climate Change.

The uncertainties and associated risks are discussed in detail in the following section.

7.2 Uncertainties and Risks

7.2.1 Resource Uncertainties and Risks

The following uncertainties are related to resources:

- **Generation fuel price volatility and escalation uncertainty, both short and long-term.** The resulting risk is a rate increase caused by increased portfolio cost;
- **Hydrology uncertainty.** The potential for a multi-year drought could result in lower hydro generation than expected. The resulting risk is insufficient supply of energy and/or capacity;
- **Project feasibility uncertainty.** The potential for technical, financial or regulatory problems during project planning or construction, which could result in abandoning specific lower cost resources in favor of more expensive resources and/or delays. The resulting risk is a rate increase caused by increased portfolio cost and/or insufficient energy and/or capacity supply;
- **Equipment reliability uncertainty.** The possible failure of generation and transmission assets which can lead to outages. The resulting risk is insufficient energy and/or capacity supply;
- C**onservation delivery uncertainties.** YEC enabled conservation activities may not produce expected savings. The resulting risk a rate increase caused by increased portfolio cost and/or insufficient energy and/or capacity supply;
- **IPP supply uncertainty.** The possibility of bankruptcy or failure of contracted generation assets, or the failure of contracted IPPs to reach commercial operation (multiple causes) can result is some projects not being completed or delayed. The resulting risk a rate increase caused by increased portfolio cost and/or insufficient energy and/or capacity supply;
- **Labour and resource uncertainty.** Future periods of high economic activity could cause labour and resource constraints. The high economic activity could be caused by a coincident boom in mining, oil & gas and YEC's own projects. As a consequence the projects could be delayed and

their costs increased. The resulting risk a rate increase caused by increased portfolio cost and/or insufficient energy and/or capacity supply; and

- **Capital availability uncertainty.** The capital required to execute the action plan proposed by the Resource Plan could be unavailable. This is particularly possible in financing for very large capital projects which could involve multiple levels of government and/or private sector interests. The resulting risk is a rate increase caused by increased portfolio cost and/or insufficient energy and/or capacity supply.

7.2.2 Regulatory and Policy Uncertainties and Risks

The following are uncertainties related to regulation and policy:

- **Regulatory uncertainties.** These uncertainties could lead to proposed electricity supply projects being disallowed by the regulator or to protracted legal and regulatory processes delaying project approvals or relicensing. The resulting risk is a rate increase caused by increased portfolio cost and/or insufficient energy and/or capacity supply due to introducing more expensive replacement projects and delaying project in-service date;

- **Policy uncertainties related to specific generation types.** These uncertainties could cause specific generation types become significantly disadvantaged, such as a carbon tax disadvantaging the operations of diesel and LNG, after those assets are operational. The resulting risk is a rate increase caused by increased portfolio cost.

7.2.3 Load Forecast Uncertainties and Risks

Uncertainty is inherent in forecasting. Actual electricity demand will invariably differ from forecasts. Nevertheless, electricity providers including YEC must forecast future demand requirements, and responsibly plan to meet these needs. To mitigate the uncertainty in forecasting, a plan with flexibility needs to be prepared to avoid unnecessarily over-building of supply, or avoid consequences of not building sufficient supply to meet the demand.

There are several substantial uncertainties in the load forecast:

- **Economic development uncertainties.** Federal transfer payments and mining are the major economic drivers in the Territory and a change in either of these can affect the load. Mining load can develop relatively quickly, potentially in a shorter timeframe than it takes to serve these customers with electricity generation or transmission grid upgrades. For example, a single new connected metal mine could increase YEC's load by 25% or more. The development and subsequent operation of mines is a relatively risky venture due to cyclical and volatile global commodity prices, and due to financing and permitting risks. Based on the data provided by mining companies operating in the Yukon, the average expected mine life is 10 years. Attrition in a large electricity load, such as a mine, served by YEC can result in stranded assets (investments). Also, a future reduction in federal transfer payments can reduce economic activity and consequently reduce forecast load. If the load forecast does not capture the discussed developments, the resulting risk is insufficient energy and/or capacity supply and/or increased rates caused by reduced load and, consequently, reduced sales.

- **Electrification uncertainties, as driven by policy or technological change.** This includes the potential for increased numbers of electric vehicles and the changeover of space heating in buildings. The resulting risk is the resulting risk is insufficient energy and/or capacity supply;

- **Technological uncertainties,** either due to policy changes (such as the introducing more stringent local building codes), or as-yet unanticipated developments in technology such as what

has already occurred with LED lighting. The resulting risk is increased rates caused by reduced load and, consequently, reduced sales; and

- **Uncertainties over distributed electrical generation technologies** such as solar panels, which could lead to the risk of lower electricity demand to be serviced by YEC, or a significant change in the annual pattern of demand. The resulting risk is increased rates caused by reduced load and, consequently, reduced sales.

7.2.4 Climate Change Uncertainties and Risks

The following are uncertainties related to climate change[1]:

- **Hydrology uncertainty.** Climate change could result in seasonal hydrology patterns outside of historical variability. Although the early indications of the effects of climate change in the Yukon are a net increase in precipitation, the impacts would be particularly problematic if overall flows into YEC's hydro generation assets were to decrease. Another consequence is if the seasonal or yearly precipitation variability was accentuated, leading to floods or extended periods of drought. The resulting risk is oversupply of energy and/or capacity, or insufficient energy and/or capacity supply. YEC is in the process of developing the hydrological models that will incorporate the impact of climate change into the future inflow forecasts for all the existing hydropower plants. The climate change affected inflow forecasts will be used in the future updates of the technical attributes of the affected resources;

- **Temperature uncertainty.** Overall warming could decrease winter demand due to reduced space heating. The resulting risk is reduced load and consequently increased rates increased rates caused by reduced loads and, consequently, reduced sales; and

- **Climate change uncertainties.** Long-term climate changes could result in changes in net migration to the Yukon, with the associated impact on Yukon electricity demand. For example, an influx of climate change refugees from other parts of the world, or an influx of people from other parts of Canada due to increasingly temperate Yukon winter conditions. Climate changes could also introduce economic opportunities to the Yukon economy and industry. For example, a longer growing season in the Territory could increase electricity demand in the agricultural sector. Decreased sea ice could cause increased Arctic Ocean shipping. The resulting risk is increased load and consequently insufficient energy or/capacity supply.

7.3 Incorporating Uncertainty

The previous section laid out key uncertainties and risks that could potentially influence the comparison of resource options with respect to the Resource Plan's key questions. Where possible, YEC quantified these uncertainties in the analysis, results and conclusions of the Resource Plan. This section describes the approaches to incorporating uncertainty in the Resource Plan analysis. These approaches are addressed in more detail in the Chapter 8: Portfolio Analysis.

As presented in Table 7-1, the Resource Plan analysis uses a mix of approaches to explore how uncertainty impacts the comparison of options and the strategies to manage the residual risks of the

[1] In compiling this risk summary, the following report was referenced: Streicker, J., 2016. Yukon Climate Change Indicators and Key Findings 2015. Northern Climate ExChange, Yukon Research Centre, Yukon College, 84 p. The report presents indicators of temperature, precipitation, fire history, sea ice melt, ocean oscillation patterns, and greenhouse gas emissions. Sources of information contained in the report include both scientific and traditional knowledge.

Action Plan. Professional judgment informed by quantitative analysis and qualitative information is required when interpreting data, balancing objectives, and making decisions.

Table 7-1: Approach to Incorporating Uncertainty

Approach	Brief Description	Example of Application
Scenario Analysis	Using a few, select combinations of uncertain variables.	- Mining development scenarios within the load forecast. - Fuel price scenarios for thermal resources. - Social cost of carbon to accommodate regulatory uncertainty related to greenhouse gas emissions costing
Conservative Point Estimates	Incorporating uncertainty in a key parameter by adopting a 'conservative' value.	Adopting a conservative (historically low) value for firm energy and dependable capacity from YEC's existing hydro assets.
Subjective Probability Elicitation	In cases where good historical data does not exist, uses knowledgeable specialists to construct a description of the range of uncertainty.	Savings from demand side management (DSM).
Parameterization of Historical Observations	Uses historical data to derive a statistical description of the range of uncertainty.	Water inflows into the YEC hydro system.
Best Estimates	Does not take into account uncertainty in any fashion; usually reserved for variables where uncertainty is assumed to have a small or manageable impact.	Energy from wind projects.

Further details of these approaches and the modeling involved can be found in Chapter 4: Load Resource Balance and Chapter 8: Portfolio Analysis.

7.4 Risk Mitigation

The goal of the Resource Plan with respect to risk is to recommend measures that will efficiently allocate capital and other resources to bring risks to appropriate levels. This wording is selected deliberately, in

that the risks inherent in providing electricity service cannot be completely eliminated. That is, there will always be residual risks, regardless of the systems, practices, and backup infrastructure that is put in place to manage risk. The measures taken to decrease risks often involve exponentially increasing expenditures for increasingly marginal gains. Providing electricity service is a complex tradeoff between rate impacts, supply reliability, environmental and social requirements. YEC has attempted to strike the appropriate balance between these factors, through the use of utility best practices, and through the solicitation and review of stakeholder and customer feedback.

The following is a high-level overview of mitigation measures proposed by YEC to manage risks. Key specific measures, such as recommended new resources needed to meet future reliability requirements, are presented in the Action Plan Chapter (Chapter 9).

Some active risk mitigation measures that YEC has undertaken in the preparation of the Resource Plan include:

- **Scenarios.** Development and analysis of scenarios. Faced with the uncertainties inherent in the industrial load forecasts, the forecast approach focuses on assessing a range of industrial-related scenarios. The fourteen scenarios reviewed cover a wide but plausible range of industrial sector outcomes. To address uncertainties in the diesel and LNG price forecast, three scenarios were developed for each of the diesel and LNG price forecasts. Similarly, two scenarios were analyzed to address uncertainty of the carbon pricing by comparing portfolios with the social cost of carbon and without it. Resource plans tested and developed for these scenarios allow YEC to balance the tradeoff between risk and cost with respect to future possible outcomes;
- **Prudent planning criteria**, for example, the N-1 criteria. When applied by YEC throughout the planning period, this criteria allows for customer reliability despite major generation and transmission equipment failures;
- **Regulatory participation.** Active participation in and support of regulatory and legal processes.
- **Load Monitoring.** YEC is constantly monitoring developments with respect to new large potential loads. This includes ongoing communications with potential industrial development proponents and government departments, particularly with respect to potential mining projects;
- **Updates.** YEC will update elements of the Resource Plan in the event of a significant and material change to the external environment. This could include major changes to government policy, transformative new technologies, climate change, or major new customer loads;
- **Plan Flexibility and Replacement Resources.** YEC's Resource Plan will incorporate the need for flexibility to deal with risks such as major and sudden changes in grid loads, and the inability to develop a preferred resource proposed in the Action Plan. In light of ongoing uncertainties, the Action Plan needs to be resilient and robust under various potential load scenarios and regulatory, financial and development outcomes. For example, a portfolio of relatively small, scalable and modular assets presents a lower risk than a single large asset, in terms of regulatory approvals, financing, fuel diversity, policy changes and resourcing. YEC will continuously consider the scalability of proposed generation and transmission assets planned to meet electricity demand growth. As an example of scalability, YEC's LNG facility completed in 2015 was built with the expansion potential for a third unit, which is now

recommended in the Action Plan as an attractive capacity option. YEC will consider the balance between potential lower costs due to economies of scale for larger solutions, versus the ability of smaller, incremental supply solutions to more closely match growth; and

- **Rate Risk Mitigation.** The servicing of new large industrial electricity demand will require project-specific negotiations and joint planning to determine if mutually acceptable arrangements and opportunities can be found, including appropriate risk management and mitigation measures to protect all other grid-served customers from unacceptable rate risks. In the case of the larger off-grid mine projects, initial operation could commence using fossil fuels and on-site power generation (as was the case with the Minto Mine prior to connecting to the grid in 2008), with any grid connected generation commitments being linked to the completion of new infrastructure with appropriate third-party contributions towards planning and construction costs. Such an approach was followed with Carmacks Stewart Transmission Project[2] and Mayo B. A sufficiently large and stable load extending over 20 or more years would also likely be needed to ensure that the energy generated by new bulk power assets is fully utilized over a reasonable period of years.

Table 7-2 summarizes uncertainties, risks and mitigation measures.

Table 7-2: Summary of Uncertainties, Risks and Mitigation Measures

Resources			
Uncertainty Category	**Uncertainty**	**Risk**	**Proposed Mitigation within the Resource Plan**
1	Generation fuel price	Increased rates due to Increased portfolio cost	Scenario Analysis. Test the portfolios under different fuel price scenarios.
2	Hydrology	Insufficient supply of energy and/or capacity	Prudent Planning Criteria. Implement prudent planning criteria to provide reasonable reserve margins (backup) to account for reduced water inflows.
3	Project Feasibility	Increased rates due to Increased portfolio cost and/or insufficient energy and/or capacity supply	Plan Flexibility and Replacement Resources. Recommend replacement resources with similar attributes, in the event that one resource becomes infeasible and follow stagegate process to reduce risk.
4	Equipment reliability	Insufficient energy and/or capacity supply	Prudent Planning Criteria. Implement prudent planning criteria to provide reasonable reserve margins, such as single contingency (N-1) criterion.

[2] Carmacks Stewart Transmission Project would not have proceeded absent YEC securing a material contribution towards the Carmacks Stewart Main Line from Minto mine through a Power Purchase Agreement.

Resources			
Uncertainty Category	**Uncertainty**	**Risk**	**Proposed Mitigation within the Resource Plan**
5	Conservation delivery	Increased rates due to increased portfolio cost and/or insufficient energy and/or capacity supply	Plan Flexibility and Replacement Resources. Recommend replacement resources with similar attributes, in the event that one resource becomes infeasible.
6	IPP Supply	Increased rates due to increased portfolio cost and/or insufficient energy and/or capacity supply	Plan Flexibility and Replacement Resources. Recommend replacement resources with similar attributes, in the event that one resource becomes infeasible.
7	Labour and resources	Increased rates due to increased portfolio cost and/or insufficient energy and/or capacity supply	Plan Flexibility. A portfolio of relatively small, scalable and modular assets presents a lower risk than a single large asset in terms of resourcing.
8	Capital availability	Increased rates due to increased portfolio cost and/or insufficient energy and/or capacity supply	Plan Flexibility. A portfolio of relatively small, scalable and modular assets presents a lower risk than a single large asset in terms of financing.

Regulatory & Policy			
Uncertainty Category	**Uncertainty**	**Risk**	**Proposed Mitigation within the Resource Plan**
1	Regulatory	Increased rates due to increased portfolio cost and/or insufficient energy and/or capacity supply	Regulatory Participation. Active participation in and support for regulatory and legal processes. Plan Flexibility and Replacement Resources. Recommend replacement resources with similar attributes, in the event that one resource becomes infeasible.
2	Policy	Increased rates due to Increased portfolio cost	Plan Flexibility. A portfolio of relatively small, scalable and modular assets presents a lower risk than a single large asset, in terms of policy.

Regulatory & Policy			
Uncertainty Category	**Uncertainty**	**Risk**	**Proposed Mitigation within the Resource Plan**
			Rate Risk Mitigation. Outside funding to be provided to offset rate increase.

Load Forecast			
Uncertainty Category	**Uncertainty**	**Risk**	**Proposed Mitigation within the Resource Plan**
1	Economic development	Insufficient energy and/or capacity supply and/or increased rates due to reduced loads and, consequently, reduced sales	Load monitoring. Regular monitoring of the Yukon economy and industrial developments and load forecast updates. Plan Flexibility. A portfolio of relatively small, scalable and modular assets presents a lower risk than a single large asset, in terms of policy.
2	Electrification	Insufficient energy and/or capacity supply	Scenarios. Develop Resource Plan under different load scenarios.
3	Technology	Increased rates due to reduced loads and, consequently, reduced sales	Scenarios. Develop Resource Plan under different load scenarios.
4	Distributed generation	Increased rates due to reduced loads and, consequently, reduced sales	Scenarios. Develop Resource Plan under different load scenarios.

Climate Change			
Uncertainty Category	**Uncertainty**	**Risk**	**Proposed Mitigation within the Resource Plan**
1	Hydrology (water inflows)	Insufficient energy and/or capacity supply or oversupply of energy and/or capacity	Updates. Update technical attributes of affected resources to reflect the change. Update Resource Plan to incorporate climate-change induced effects.
2	Temperature	Increased rates due to reduced loads and, consequently, sales	Updates. Update load forecast to reflect the temperature caused change. Update Resource Plan to incorporate climate-change induced effects.
3	Climate change	Insufficient energy and/or capacity supply	Updates. Update load forecast to reflect the climate caused change. Update Resource Plan to incorporate climate-change induced effects.

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8 Portfolio Analysis

8.1 Portfolio Analysis Methodology

The goal of portfolio analysis is to select an optimum set of resources that best meet YEC's future energy and capacity needs at the minimum cost while meeting environmental, social and economic objectives. A portfolio is a combination of resource options, such as energy conservation, wind power, hydroelectricity and thermal generation, and the associated transmission lines required to bring electricity to customers. Each portfolio contains a unique mix of conservation and generation assets, with each asset being developed at the appropriate time to meet YEC's future needs over the planning horizon. Each portfolio needs to meet the technical, financial, environmental, social and economic objectives of YEC and its customers.

Energy planning is an exercise in tradeoffs between cost, reliability, environmental, social and economic considerations. Some of these factors are easier to quantify, such as the strict costs arising from the procurement and ongoing operation of generation assets. Some environmental impacts, such as the cost of GHG emissions can also be quantified. However, many remaining factors cannot be easily quantified.

The future is far from certain, and responsible planning requires YEC to consider and address future uncertainties, such as electricity demand, fuel prices, government policies, and/or capital availability. Therefore, a scenario-based approach was used in which scenarios were developed, and then portfolios were assembled and tested for each scenario.

The portfolio analysis was performed in two sequential steps. First, a quantitative technical and financial evaluation was completed to identify portfolios which meet future energy and capacity needs, while minimizing total capital and operating costs. In the second step, a primarily qualitative environmental, social and economic evaluation was completed on each portfolio. The goal was to create portfolios that meet technical, environmental, social and economic requirements, while minimizing total capital and operations & maintenance costs.

The following sections outline the methodology used for both the steps of the portfolio analysis and scenario development, as well as present the results of the portfolio analysis.

8.1.1 Technical and Financial Evaluation Methodology

The technical and financial evaluation is aimed to identify a set of resource options that meets the energy and capacity planning criteria at the lowest cost. The cost is expressed as the present value of all annualized capital and operating & maintenance (O&M) expenditures over the planning period.

Portfolio optimization is an exercise similar to filling in a series of puzzles (the portfolio) with the puzzle pieces representing different resource options. The size of the puzzle grows with time as forecast load changes. Filling the portfolio in every year is mandatory in order to meet expected load growth. There is nearly an infinite number of possible solutions, given the range of different resource options available, the ability to scale up or down the size of these resources, the timing of resources construction, and their locations. The goal of the exercise is to financially evaluate each portfolio that meets the energy and capacity planning criteria and select one with the minimal present value of all the expenditures.

Given the complexity of the exercise, a sophisticated, industry-accepted, capacity expansion optimization model, the System Optimizer, was used for the portfolio analysis. This is the first time YEC has used this

type of a rigorous analytical optimization approach to identify the optimum portfolios, consistent with large-utility best-practices. This approach is more sophisticated than that used by YEC in the 2011 Resource Plan. The 2011 Resource Plan portfolio analysis methodology was similar, with the objective of minimizing the present value of all the expenditures, while meeting energy and capacity planning criteria. Instead of using an optimization model to financially evaluate a large number of portfolios meeting the planning criteria and select the optimal one, the analysis in the 2011 Resource Plan was focused on evaluating only a limited number of portfolios satisfying a plausible range of resource combinations. The portfolios were developed using professional judgement, with the selection of the generation resources within each portfolio and determination of portfolio costs undertaken manually. The present value of all the expenditures was calculated for each portfolio and the portfolio with the minimal present value was selected as the optimal portfolio. The 2016 Resource Plan provided a more cost effective solution as a consequence of evaluating a significantly larger number of portfolios, while the methodology used in the 2011 Resource Plan did not guarantee the most cost effective solution due to a limited number of portfolios evaluated.

Considering the high cost of the System Optimizer model and the low expected frequency of its use by YEC, the purchase of the model could not be justified. Consequently, the System Optimizer model owned by BC Hydro was used for portfolio analysis. The model simulations were performed by BC Hydro staff with YEC staff providing the input data and analyzing the output data.

The System Optimizer Model is a mixed integer programming optimization model developed by Ventyx /ABB (formerly Global Energy Decisions, Henwood) and has been adopted by several utilities in North America to aid in the development of resource plans. The model selects an optimal generation and transmission resource expansion sequence given a set of input assumptions (e.g. load forecast, fossil fuel prices, available resource options including DSM, Social Cost of Carbon, energy and capacity planning criteria, resource generation profiles) and constraints (e.g. transmission line limits, installed and dependable capacity of resources). The objective of the model is to minimize the present value of costs, including the capital and operating costs for new resources, as well as operating costs of existing resources to meet a given load forecast and planning criteria.

The model takes into account characteristics of resources beyond the LCOE and LCOC rankings, such as firm energy, dependable capacity, average energy and monthly energy profiles of resources. The model also takes into account the transmission system, which allows a selection of resources that are located favorably in terms of transmission losses and constraints. As a consequence, the model provides the optimal selection of the resource options that best complement the existing system and its constraints.

To ensure that the model generated meaningful outputs, all the model outputs were quality controlled.

The major portfolio analysis inputs were:

- Energy and peak demand forecast (20 year horizon);
- Resource financial attributes (capital and operating & maintenance expenditures);
- Resource technical attributes (annual energy, firm energy, installed capacity, dependable capacity, project life, construction lead time, dispatchability, transmission line transfer capabilities and losses);
- Discount rate. In converting future to present costs, a real discount rate of 3.38% was used, consistent with YEC's cost of capital; and
- Social cost of carbon.

The major portfolio analysis outputs are:

- A set of resource options (generation, transmission, DSM) that meets the energy and capacity planning criteria, while minimizing the present value of both the capital and O&M expenditures; and
- Monthly energy generated by each resource in the portfolio.

The major portfolio analysis constraints were:

- Firm energy of all the existing and future resources needed to meet or exceed the energy load. Hydro energy generation was modelled under lowest water conditions;
- Dependable capacity of all the existing and future resources needed to meet or exceed the peak demand. Dependable capacity planning criterion was assessed under single contingency (N-1) criterion;
- Minimum and maximum capacities of generating stations;
- Transfer capability of transmission lines; and
- Sequential stations investment constraints (e.g., all units of resource A must be built before the first unit of resource B is built).

To mimic decision making that would take place in real world, the following assumptions were made in the portfolio analysis:

- Operational expenditures were expressed as the present value of the entire portfolio over the 20 year planning horizon, under average conditions for each resource. For example, to determine the operational expenditures, hydro energy generation was modelled under average water inflow conditions.
- If the firm energy and/or dependable gap could not be closed due to resource unavailability caused by long lead time to introduce the resource, another resource with a shorter lead time was recommended, even though it could potentially have less preferred financial attributes.
- If a decision needed to be made between: a) overbuilding significantly and b) not meeting planning constraints marginally, a decision was made not to overbuild. As a consequence, it was preferred to have a minimal deficiency in not meeting planning criteria within few years in the planning period, rather than significant overbuilding. For example, if a capacity gap under the single contingency (N-1) criterion of 1MW could be closed only by using a resource with capacity of 10 MW, a decision was made to keep the marginal gap in a year, rather than overbuild. As the portfolio analysis presented in the following sections demonstrated, the only instance the dependable capacity criterion was not met under conditions described above was for the Low Industrial Activity Scenario in 2025.
- The resources' life would continue after the end of the planning period unless resources' end of life was within the planning period. As a consequence, the salvage value of the resources at the end of the planning period was not deducted from the present value of the expenditures. The present value was determined as the sum of annualized capital and O&M expenditures over the planning period. This was consistent with the expectation that the long life resources would be used after the end of the planning period in 2035 since YEC would need to meet load after 2035.

The technical and financial attributes of each resource options used as inputs to the System Optimizer model are presented in Chapter 5.

8.1.2 Environmental, Social and Economic Evaluation Methodology

The environmental, social and economic evaluation was based on the environmental, social and economic attributes presented in Chapter 5. The selection of the environmental, social and economic attributes for each resource option was based on an understanding of stakeholder interests, including those commonly included in project impact assessments and permitting processes. Attributes were also selected based on industry best practices and knowledge gained from previous resource planning exercises and from the public interests identified in the Electricity Values Survey. Figure 8-1 presents the environmental, social and economic evaluations of all of the resource options considered in the Resource Plan.

Each resource portfolio generated by the System Optimizer model was examined with respect to environmental, social, and economic characteristics. The first test was to examine a portfolio for adverse effects that could not be mitigated. If this test was passed, each resource option included in the portfolio would be examined in detail to understand the overall benefits, challenges and potential effects of the portfolio.

In addition, an analysis was conducted to determine whether there were environmentally, socially, or economically comparable options available that were not strictly output from the technical and financial modelling. By doing so, those resources options excluded for technical or financial reasons could be reconsidered for inclusion if the options selected in the technical and financial evaluation could not be pursued for various reasons, such as for example geotechnical problems for a small hydro project discovered in the next, more detailed, project stage.

Figure 8-1: Environmental, Social and Economic Attribute Analysis – All Resource Options

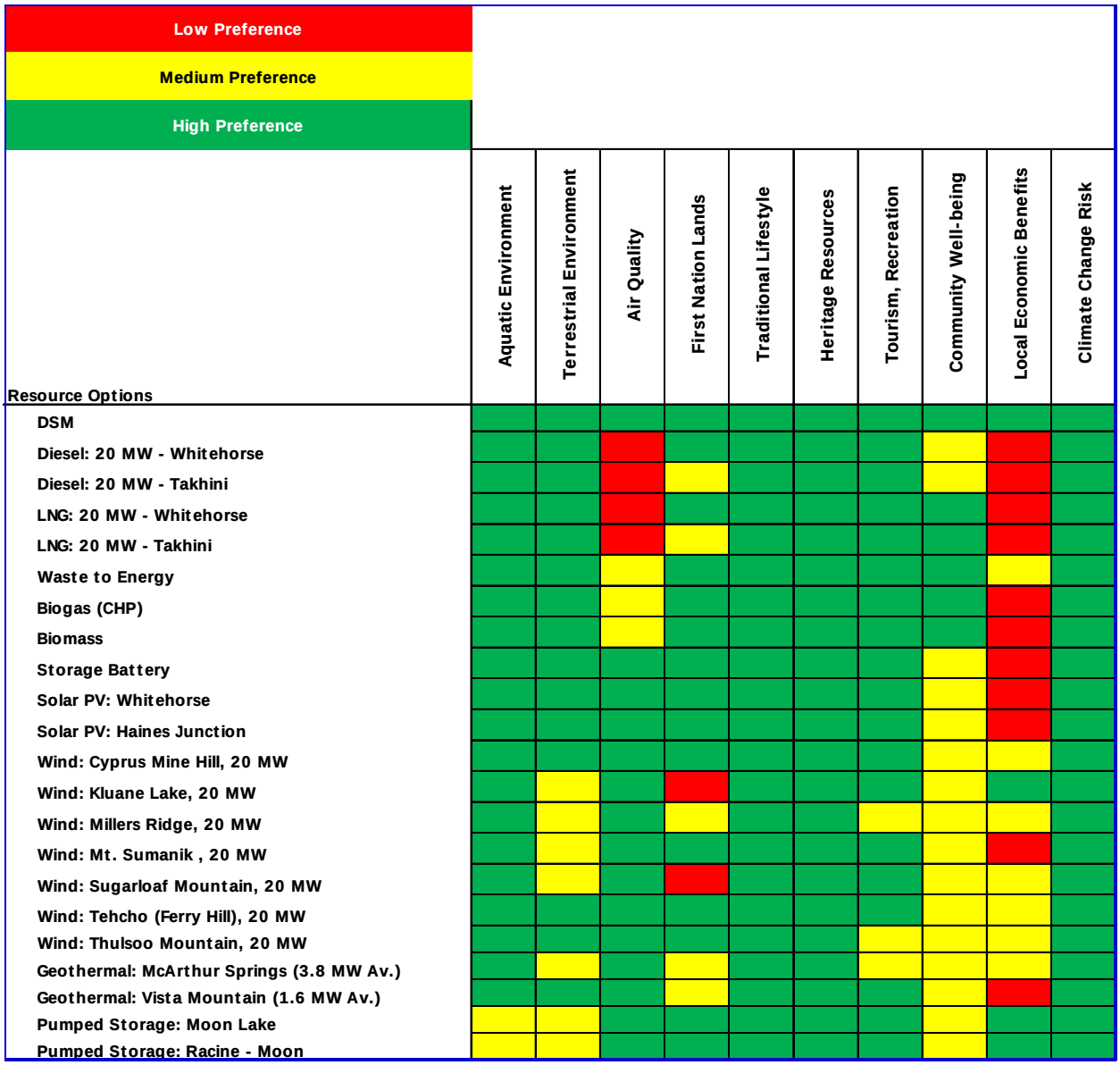
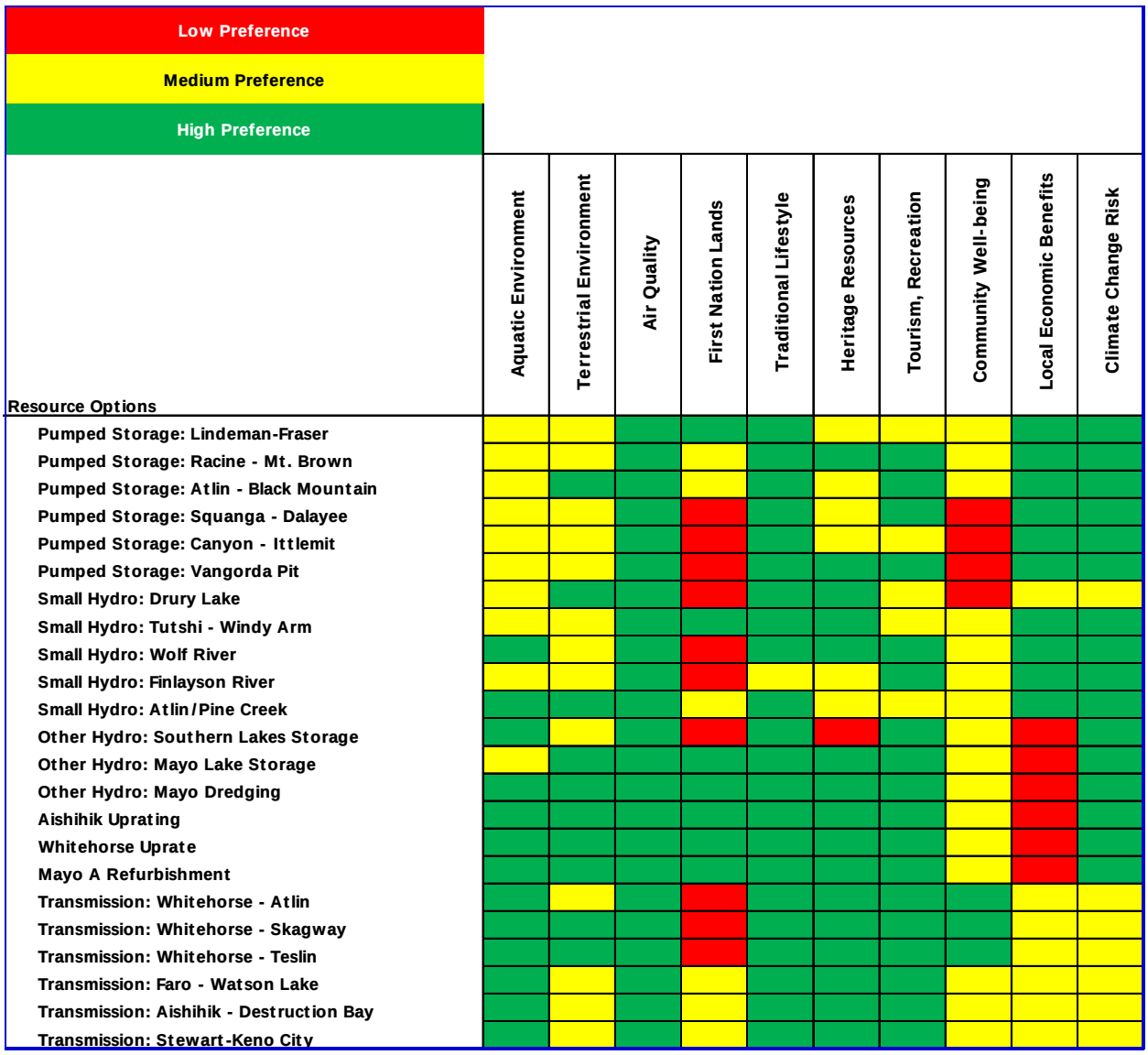


Figure 8-1 is continued on the next page.



If two portfolios were compared, such as for example Medium Industrial Activity Scenario including thermal portfolio vs. Medium Industrial Activity Scenario – Renewable, the attributes that were ranked predominately equally across all resource options in both portfolios were removed from further consideration and therefore had no additional influence on the comparison. Attributes that scored relatively consistently for both portfolios, were no longer considered in the comparison, thereby simplifying the remaining analysis. To proceed to the next stage of the comparison, trade-off analysis, the remaining environmental, social and economic attributes had to be assigned a qualitative weighting. The results of the Electricity Values Survey were used for this purpose, as the Electricity Values Survey focused on the same environmental, social and economic attributes used to evaluate resource options. The values (attributes) most favoured in the Electricity Values Survey were assigned the most weight in the comparison of portfolios. Following the results of the Electricity Values Survey, the goal was to create balanced portfolios that were environmentally friendly, cost effective, reliable and socially responsible. At the end of the process, a judgement call was made to decide on the preferred portfolio. For example,

if one portfolio was marginally environmentally preferred (eg. generating higher percentage of renewable energy), but significantly more expensive (eg. being double the cost) than the other portfolio, all other attributes being equal, it could not be favoured, even though it was environmentally preferred. Or, for example, if one portfolio was environmentally preferred and slightly more expensive than the other portfolio, all other attributes being equal, the decision could be made in its favour.

The results of this analysis are presented in Section 8.3.

8.1.3 Economic Scenarios and Resource Option Sensitivities

When forecasting future energy and capacity needs over the planning horizon, fourteen economic scenarios were developed and modelled to account for key uncertainties, such as future economic growth. Energy and peak demand forecasts related to different economic scenarios were developed, and are presented and discussed in Section 4.1 of Chapter 4.

Prior to the portfolio analysis, the load forecast scenarios were compared for similarities in order to eliminate redundant/similar scenarios, thereby minimizing the number of analyzed cases. Five load scenarios were down-selected for the portfolio analysis: Very Low, Low, Low with Early Minto Closure, Medium and High Industrial Activity. These selected scenarios were expected to cover a plausible range of future energy and capacity requirements. The discarded scenarios were judged redundant, and not needed to provide additional information to inform the portfolio analysis and the Action Plan. Subsequent to the completion of the Load Forecast in mid-2016, Capstone Mining have confirmed that the Minto mine will cease operations at the end of 2017. Therefore, the Low with Early Minto Mine Closure scenario was analyzed to provide additional insights into the portfolio that would result from the early closure of the Minto mine.

In addition to analyzing portfolios for selected future load scenarios, additional uncertainties were reviewed through sensitivities on the following parameters:

- Social Cost of Carbon (SCC): To account for a potential future government policy with respect to the cost of greenhouse gas emissions, a long term social cost of carbon forecast was developed and applied. The SCC forecast is presented in Chapter 6. Portfolios were analyzed with and without the inclusion of the SCC to determine the impact of carbon pricing on the selection of future resources. The details on the portfolios included in the SCC sensitivity analysis are presented in Section 8.2.2.
- Global Warming Potential (GWP): To account for a potential future changes in the accounting of the impacts of greenhouse gas emissions, a sensitivity analysis was conducted on two different GWPs. One analysis considered the GWP limited to 20 years, and a second extended to 100 years (the assumed base assumption). The details on the GWP analysis are presented in Appendix 5.1. The details on the portfolios included in the GWP sensitivity analysis are presented in Section 8.2.2.
- Diesel Fuel Price: To account for the uncertainty in future fossil fuel prices, three long term diesel price forecast scenarios were developed and reviewed. The scenarios are presented in Chapter 6. The diesel price forecast scenarios were combined with LNG price forecast scenarios to cover a broad but plausible range of future outcomes. The details of the diesel price scenarios are presented in Section 8.2.3.
- LNG Fuel Price: to account for the uncertainty in future fossil fuel prices, three long term LNG price forecast scenarios were developed and reviewed. These scenarios are presented in

Chapter 6. The LNG price forecast scenarios were combined with diesel price forecast scenarios to cover a broad but plausible range of future outcomes. The details of the LNG price scenarios are presented in Section 8.2.3.

- Renewable portfolios: to account for potential future government policy mandating the development of only renewable future resource options, an analysis was conducted to analyze future portfolios which excluded all new thermal resources. The portfolios introducing exclusively renewable resources in the future are referred in the entire 2016 Resource Plan document as "renewable portfolios" even though they are, strictly speaking, mixed portfolios consisting of future renewable resources, existing renewable resources and existing thermal resources. The details of the renewable portfolios included in this sensitivity analysis are presented in Section 8.2.4.
- Zero cost of specific transmission lines: to account for potential future government funding to support the construction of future transmission infrastructure, an analysis was conducted to determine the impact of the make-up of the portfolios if specific transmission lines were assumed to have a zero cost (i.e. fully funded by Government). These specific cases were considered - a potential transmission line connecting the Moon Lake pump storage project to the existing Yukon grid, and a line connecting the potential Pine Creek small hydro project to the existing grid. The details of the transmission lines included in this sensitivity analysis are presented in 8.2.5.

8.2 Portfolio Analysis – Financial and Technical Evaluation

Fourteen energy and peak demand forecast scenarios were generated for the 20-year planning period. Industrial activity and government spending were determined to be the major economic drivers influencing future energy and capacity demand growth. As discussed in Section 8.1.3, of the fourteen scenarios, five were selected to cover the range of load uncertainties: Very Low, Low, Low with early Minto closure, Medium and High industrial Activity. These five scenarios formed the foundation of the portfolio analysis modelling.

Additional analysis was performed to explore portfolio sensitivities based on the uncertainties of fuel prices, the introduction of social carbon pricing, the GWP of greenhouse gas emissions, the absence of transmission costs for specific new transmission lines, and the introduction of portfolios consisting of all renewable future resources. To analyze all of these combinations would have required 1,440 System Optimizer model runs, requiring at least a full year. Given the similarities among the many of the cases, most of the computer simulations would not provide any additional information. To reduce the workload to a manageable level, sensitivity runs were eliminated in two phases. First, the runs deemed to be of marginal importance were eliminated up front, before any computer modeling was conducted. Once the five basic runs related to the load forecast were completed and their outputs analysed, additional sensitivity runs which were not expected to provide any usable information were eliminated.

Given the inherent constraints of renewable resources related to the electricity grid stability, a 20 MW limit on the penetration of intermittent resources was invoked in all the portfolio optimization runs to reflect reasonable operational system stability constraints related to the maximum penetration of intermittent resources to the YEC system. In isolation, most intermittent renewable resources do not provide the voltage and frequency support attributes required to keep the electricity grid stable. They are not firm, not dispatchable in the event of undersupply, and not curtailable in the event of

oversupply. Storage technologies such as batteries can effectively augment renewable resources in order to provide the above attributes, and such an approach is taken in the portfolio analysis, with storage correctly treated as separate resource option.

To deliver on the Standing Offer Program (SOP), which is a key element of Yukon Government's IPP Policy, an allowance for IPP-sourced firm energy for future supply options was made at 10 GWh/year starting in 2022 for all the major scenarios and sensitivity analysis scenarios. Consequently, this resource was a part of all the resulting portfolios starting in 2022.

The list of industrial scenarios and sensitivity analysis scenarios run in the portfolio analysis are presented in Table 8-1. The columns in Table 8-1 list the loads, the SCC, GWP, diesel price, LNG price, renewable portfolio, absence of transmission cost for the Atlin to Whitehorse transmission line, and absence of the Whitehorse to Skagway transmission line. Each row in Table 8-1 presents a portfolio analyzed. The parameters modified in the sensitivity scenarios are highlighted and italicized.

Table 8-1: Summary of Parameters in Industrial and Sensitivity Scenario

Scenario and Load	Social Cost of Carbon (SCC)	Global Warming Potential (GWP)	Diesel Price	LNG Price	Renewable Portfolio	Atlin Zero Cost Transmission	Skagway Zero Cost Transmission
Industrial Activity Scenarios							
Very Low	Yes	100-Year	Medium	Medium	No	No	No
Low	Yes	100-Year	Medium	Medium	No	No	No
Low with Early Minto Closure	Yes	100-Year	Medium	Medium	No	No	No
Medium	Yes	100-Year	Medium	Medium	No	No	No
High	Yes	100-Year	Medium	Medium	No	No	No
Social Cost of Carbon Scenarios							
Low	*No*	100-Year	Medium	Medium	No	No	No
Medium	*No*	100-Year	Medium	Medium	No	No	No
Global Warming Potential Scenarios							
Medium	Yes	*20-Year*	Medium	Medium	No	No	No
Fuel Price Scenarios							
Low	Yes	100-Year	*High*	*High*	No	No	No
Medium	Yes	100-Year	*High*	*High*	No	No	No
Low	Yes	100-Year	Medium	*Low*	No	No	No
Medium	Yes	100-Year	Medium	*Low*	No	No	No
Zero Cost Transmission Scenarios							
Medium	Yes	100-Year	Medium	Medium	No	*Yes*	No
Medium	Yes	100-Year	Medium	Medium	No	No	*Yes*
New Renewable Only Scenarios							
Medium	Yes	100-Year	Medium	Medium	*Yes*	No	No
High	Yes	100-Year	Medium	Medium	*Yes*	No	No

The following parameters were assumed as the base case for the sensitivity and a single parameter adjusted for each sensitivity model run.

- SCC included,
- GWP of 100 years,
- Medium diesel Price,
- Medium LNG Price,
- Future Thermal resources allowed, and
- Transmission resources with costs included.

The five industrial activity portfolios noted above were used as the foundation for the sensitivity analysis. The sensitivity analysis was completed by varying one parameter at a time, with the other parameters remaining unchanged, as presented in Table 8-2.

The sensitivity on the SCC was tested with two different industrial activity scenarios: Low and Medium. As discussed in the following sections, given the similarities among the portfolios generated for the Low, Medium and High Industrial Activity scenarios, it was not deemed necessary to run the SCC sensitivity on the High Industrial Activity scenario.

The sensitivity on a GWP was tested on the Medium Industrial Activity scenario only. Given the similarities between the portfolio contents of the Low, Medium and High Industrial Activity scenarios, it was not deemed necessary to run the GWP sensitivity on the Low and High Industrial Activity scenarios.

The sensitivity on diesel and LNG prices was tested in combination with different loads. The combinations of loads, and diesel and LNG pricing presented in Table 8-1 were deemed to cover likely outcomes that would potentially affect the portfolios. Consequently, the following potential future states were investigated in the fuel price sensitivity analysis: a) the price of LNG decreases compared to diesel, and b) the price of both diesel and LNG increase. As discussed in the following sections, given the similarities among the portfolio content of the Low, Medium and High Industrial Activity scenarios, it was not deemed necessary to run the diesel and LNG price sensitivities on the High Industrial Activity scenario, or additional combinations of diesel vs. LNG pricing. For example, if the LNG thermal options were not selected for the portfolio even if the price of LNG was lower than that of diesel, the LNG thermal options would not be selected if the price of LNG were higher than that of diesel.

The sensitivity on a renewable portfolio was tested with two Industrial Activity scenarios: Medium and High. Considering that additional firm energy was not required under the Very Low and Low Industrial Activity scenarios, and the similarity between the Medium and Low with Early Minto Closure Industrial Activity scenarios, those three load scenarios were not considered for the sensitivity analysis.

The sensitivity on the zero cost of transmission lines for the Atlin to Whitehorse transmission line was tested with Medium Industrial Activity scenario.

The sensitivity on the zero cost of transmission lines for the Whitehorse to Skagway transmission line was tested the Medium Industrial Activity scenario. This transmission line is considered important as it would connect Moon Lake pumped storage, one of the promising capacity resources, to the existing grid.

The resource portfolios for the five industrial activity energy and peak demand scenarios are presented in Section 8.2.1, followed by the sensitivity analysis portfolios in Sections 8.2.2 to 8.2.5.

All the portfolios were generated by the System Optimizer model, with quality control and quality assurance completed on each portfolio to ensure that the model generated meaningful results. The System Optimizer model identified specific sites for each project, as site-specific information was presented to the model. The development of the selected specific sites is not binding, and as many projects presented in the portfolio analysis are at an early stage of development, the final decisions on any project development have not been made.

The portfolios are presented in the following format:

- Energy graphs: These graphs show the energy requirement as a line, existing energy capability under average water conditions as bars in the shades of gray and future energy of new resources

shown in different colored bars. Note that the portfolio analysis considered firm energy production requirements to meet the energy planning criterion as discussed in Section 4.3, while it considered energy under average water conditions to calculate operating costs. The firm energy planning criterion was met for each portfolio. The firm energy graphs were not shown since it was judged that the average energy graphs would be more informative as they show how much each resource would be used under average operational conditions. By doing so, it is possible to check how much thermal generation is used in real operations, as opposed to how much thermal energy is available.

- Peak demand graphs: These graphs show the peak demand requirement under N-1 conditions as a line, existing dependable capacity as bars in the shades of gray and future dependable capacity of new resources shown in different colours.
- Summary table with the list of new resources accompanied by the in-service date and installed capacity. For sensitivity scenarios, the resources selected for the base scenarios were presented along with the resources selected for the sensitivity scenarios for easier comparison. For example, for the case of examining the impact of SCC on the Low Industrial Activity scenario, resources selected for both the base scenario (Low Industrial Activity without SSC) and sensitivity scenario (Low Industrial Activity with SCC) were presented.
- Portfolio cost table showing the following:
    1. Portfolio capital cost: this is the simple (undiscounted) value of all capital expenditures over the 20-year planning period. This cost was presented for illustration purposes only to demonstrate the magnitude of undiscounted capital investment over the planning period. It is useful information for capital constrained conditions.
    2. The present value: this represents the sum of annualized: a) fixed and b) operational & maintenance portfolio costs discounted over the planning period of 20 years.
    3. Total cost: this is the sum of the fixed and operational & maintenance portfolio costs presented in 2 above.

  The portfolio capital cost represents the simple (undiscounted) dollar value of all capital expenditures over the 20-year Plan horizon, while the total cost presents the discounted cost of fixed and operational & maintenance costs over the planning period of 20 years.

  Although the resources usually have a useful life beyond the planning horizon of 20 years, the calculation of portfolio present value both for fixed and variable costs is limited to the 20 years planning horizon of the Plan.

- The average percentage of renewable energy generated by each portfolio for the 20 year planning period, calculated under average water conditions. Depending on the load from one year to another and resource availability, the annual renewable generation percentage can be less or greater than the average renewable generation percentage listed in the table.
- The data generated from the portfolio analysis can be found in Appendix 8.1.

8.2.1 Industrial Activity Portfolio Analysis

These resource portfolios were generated using the energy and peak demand forecasts presented in Section 4.1. The analysis of these portfolios also assumed the SCC as presented in Chapter 6, a 100-year GWP for greenhouse gas emissions, a medium price forecast for diesel and a medium price forecast for

LNG, both as presented in Chapter 6, thermal resources allowed in the portfolio, and actual costs for transmission options. The details on the portfolio analysis inputs are presented in Table 8-2 to Table 8-6.

In the following sections, Figure 8-2 to Figure 8-11 show the five selected scenarios of Very Low, Low, Low with early Minto closure, Medium and High industrial Activity for both capacity and energy.

8.2.1.1 Very Low Industrial Activity

Figure 8-2: Very Low Industrial Activity Portfolio, Energy

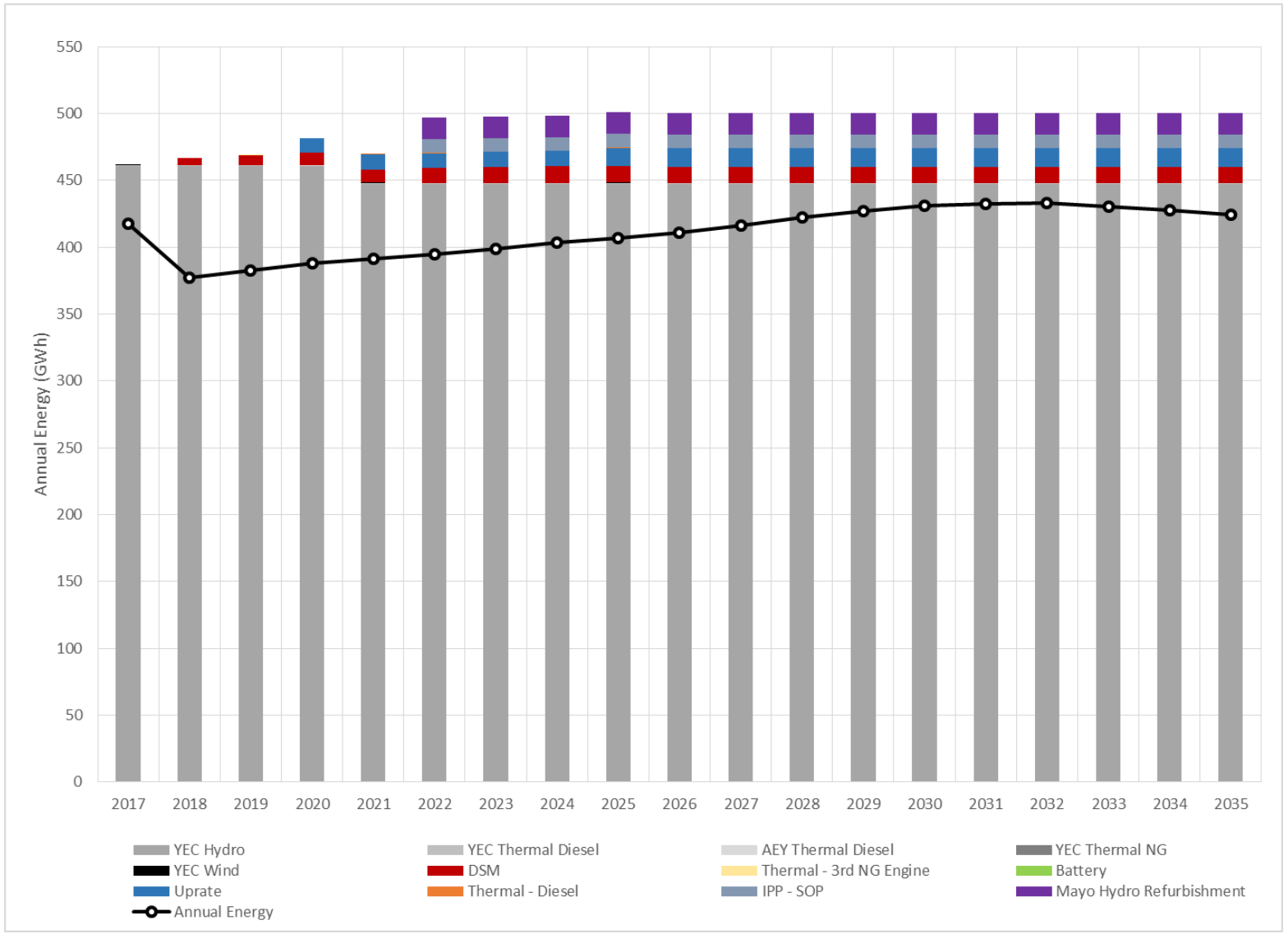


Figure 8-3: Very Low Industrial Activity Portfolio, Capacity

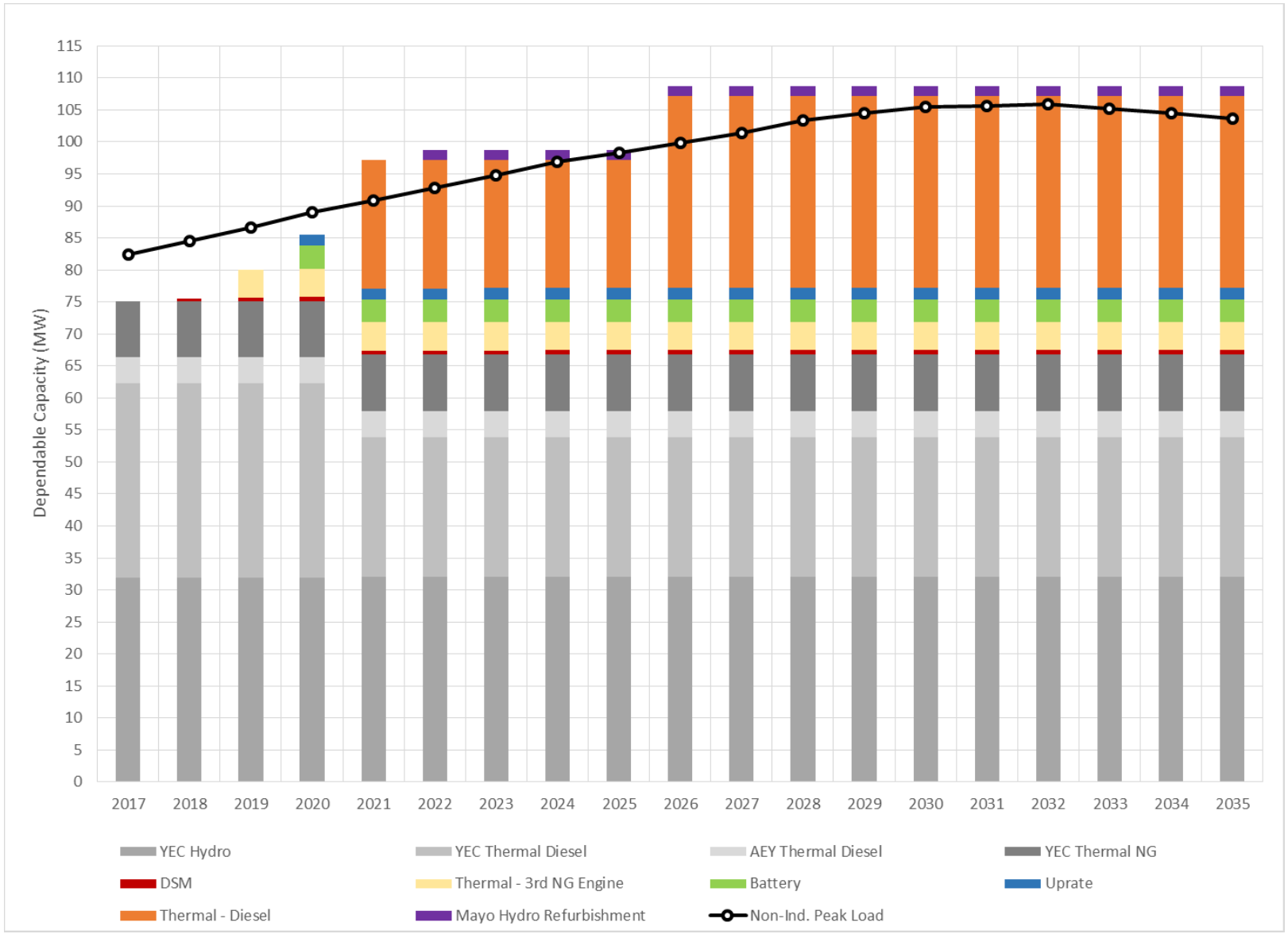


Table 8-2: Very Low Industrial Activity Portfolio Summary

Resource Option	Installed Capacity [MW]
2018	
Demand Side Management	1.3
2019	
Thermal - 3rd NG Engine at Whitehorse	4.4
2020	
4 MW Battery - Takhini Substation	4.0
Whitehorse Uprate	1.7
2021	
Thermal Diesel - Takhini Substation	20.0
2022	
Mayo Hydro Refurbishment	2.3
2025	
Aishihik Uprate	1.3
2026	
Thermal Diesel - Takhini Substation	10.0
Grand Total	45.0

Cost Components	Cost [2016 $Millions]	Comment
Portfolio Capital Cost:	$ 207.4	
Present Value:		
Fixed Costs	$ 97.6	[A]
Variable Costs	$ 37.0	[B]
Total Costs	$ 134.5	[C] = [A] + [B]

This portfolio generates an average of 99.8% renewable energy over the 20 year planning period, under average water assumptions.

8.2.1.2 Low Industrial Activity

Figure 8-4: Low Industrial Activity Portfolio, Energy

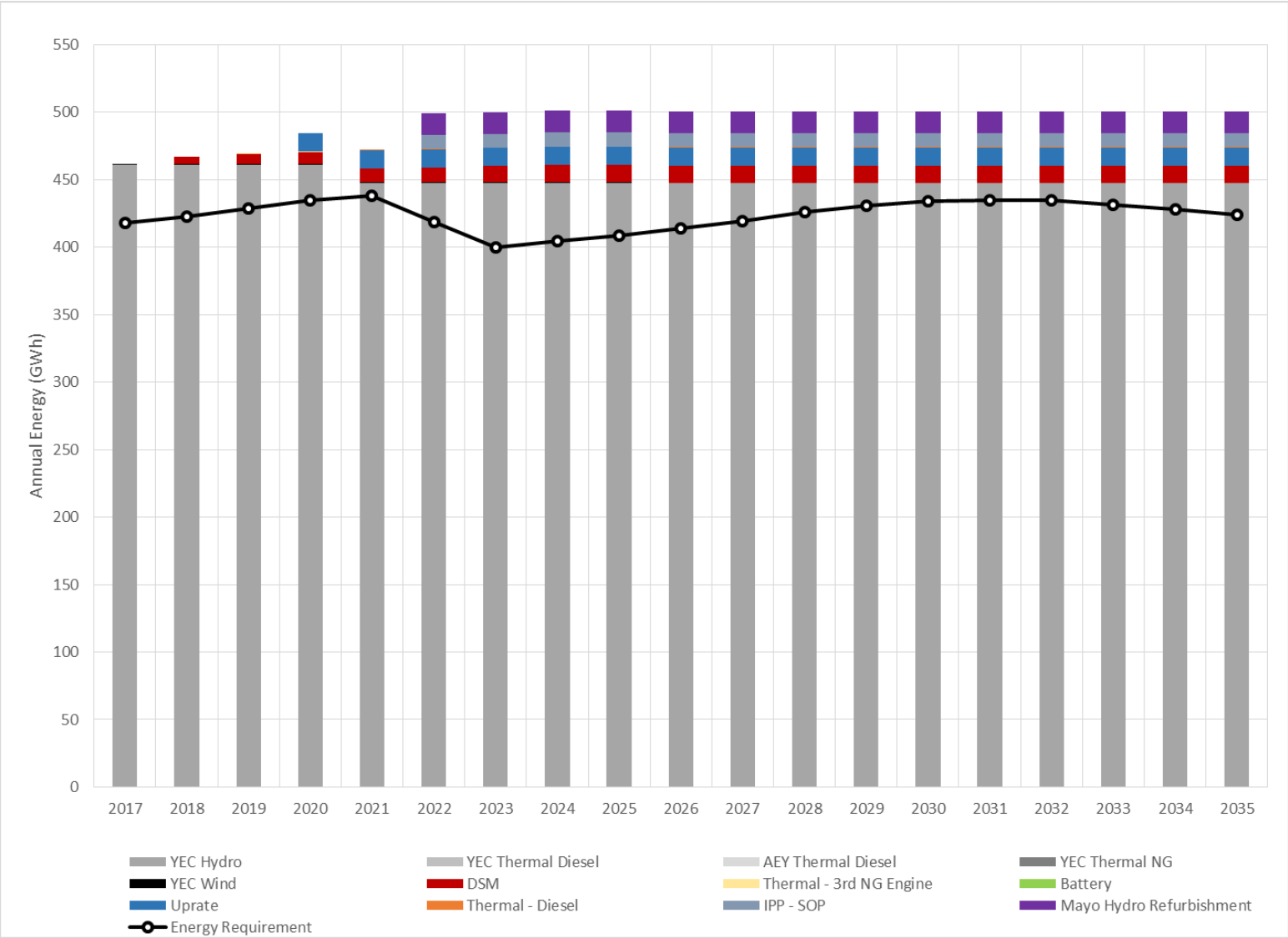


Figure 8-5: Low Industrial Activity Portfolio, Capacity

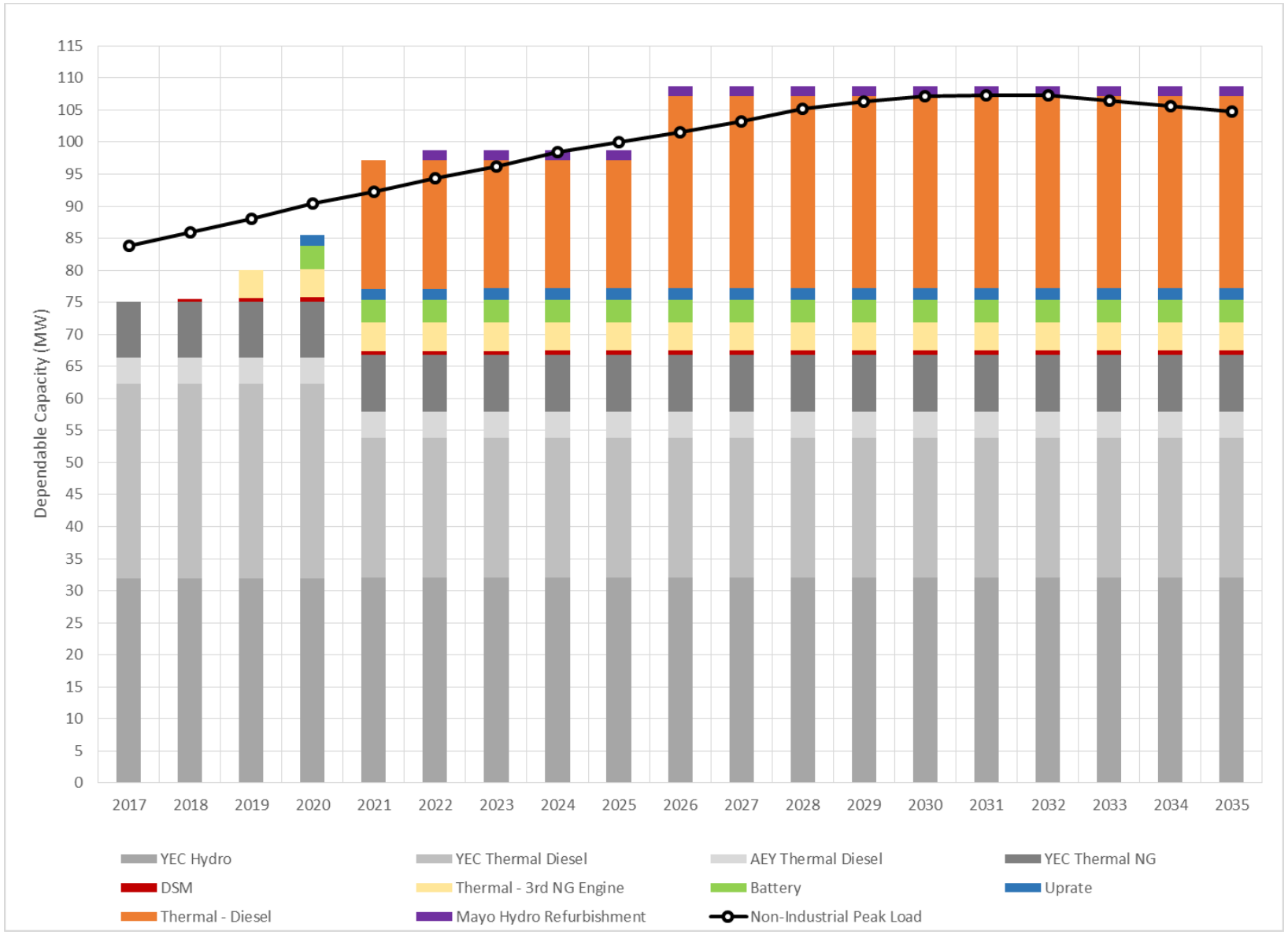


Table 8-3: Low Industrial Activity Portfolio Summary

Resource Option	Installed Capacity [MW]
2018	
Demand Side Management	1.3
2019	
Thermal - 3rd NG Engine at Whitehorse	4.4
2020	
4 MW Battery - Takhini Substation	4.0
Aishihik Uprate	1.3
Whitehorse Uprate	1.7
2021	
Thermal Diesel - Takhini Substation	20.0
2022	
Mayo Hydro Refurbishment	2.3
2026	
Thermal Diesel - Takhini Substation	10.0
Grand Total	45.0

Cost Components	Cost [2016 $Millions]	Comment
Portfolio Capital Cost	$ 207.4	
Present Value		
Fixed Costs	$ 97.6	[A]
Variable Costs	$ 37.8	[B]
Total Costs	$ 135.4	[C] = [A] + [B]

This portfolio generates an average of 99.8% renewable energy over the 20 year planning period, under average water assumptions.

8.2.1.3 Low Industrial Activity with Minto Mine Closing Early and Eagle Gold Project

Figure 8-6: Low Industrial Activity with Minto Closing Early and Eagle Gold Project Portfolio, Energy

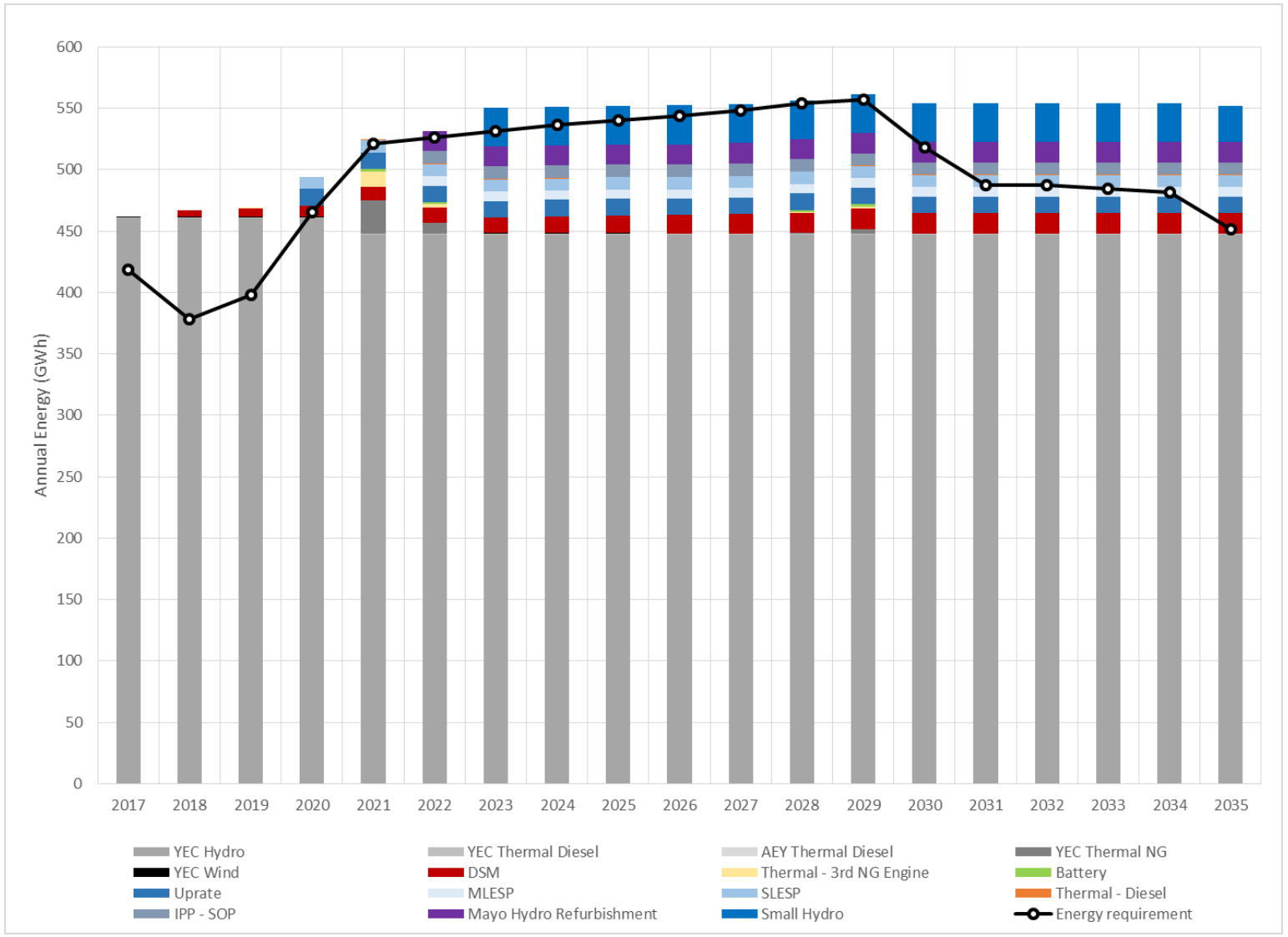


Figure 8-7: Low Industrial Activity with Minto Closing Early and Eagle Gold Project Portfolio, Capacity

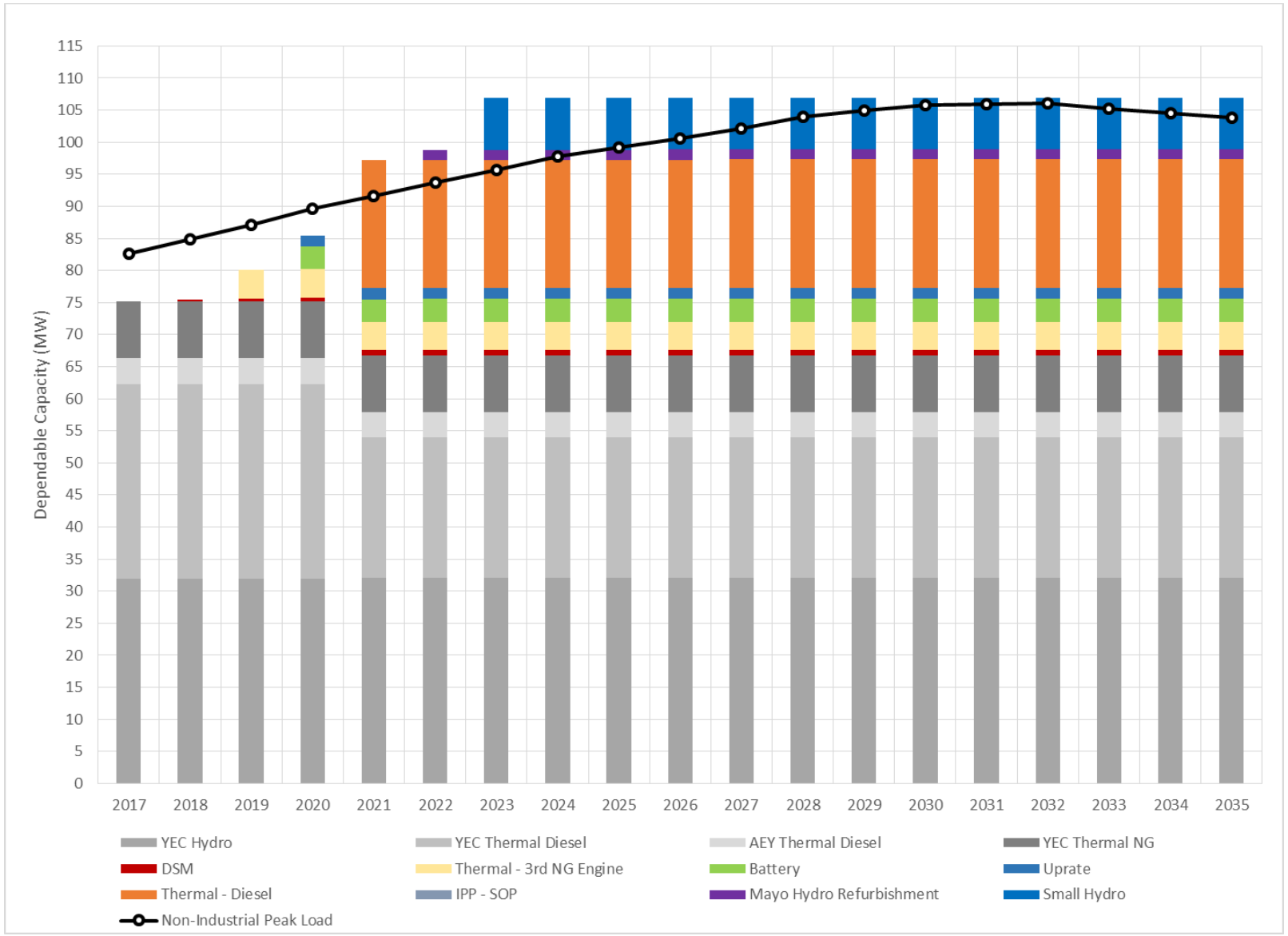


Table 8-4: Low Industrial Activity with Minto Closing Early and Eagle Gold Project Portfolio Summary

Resource Option	Installed Capacity [MW]
2018	
Demand Side Management	1.5
2019	
Thermal - 3rd NG Engine at Whitehorse	4.4
2020	
4 MW Battery - Takhini Substation	4.0
Aishihik Uprate	1.3
Whitehorse Uprate	1.7
Southern Lake Enhancement Storage Project	0.0
2021	
Thermal Diesel - Takhini Substation	20.0
2022	
Mayo Hydro Refurbishment	2.3
Mayo Lake Enhancement Storage Project	0.0
2023	
Drury Lake Small Hydro	8.1
Grand Total	43.3

Cost Components	Cost [2016 $Millions]	Comment
Portfolio Capital Cost	$ 298.6	
Optimization Results (Present Value)		
Fixed Costs	$ 130.2	[A]
Variable Costs	$ 49.1	[B]
Total Costs	$ 179.4	[C] = [A] + [B]

This portfolio generates an average of 99.3% renewable energy over the 20 year planning period, under average water assumptions.

8.2.1.4 Medium Industrial Activity

Figure 8-8: Medium Industrial Activity Portfolio, Energy

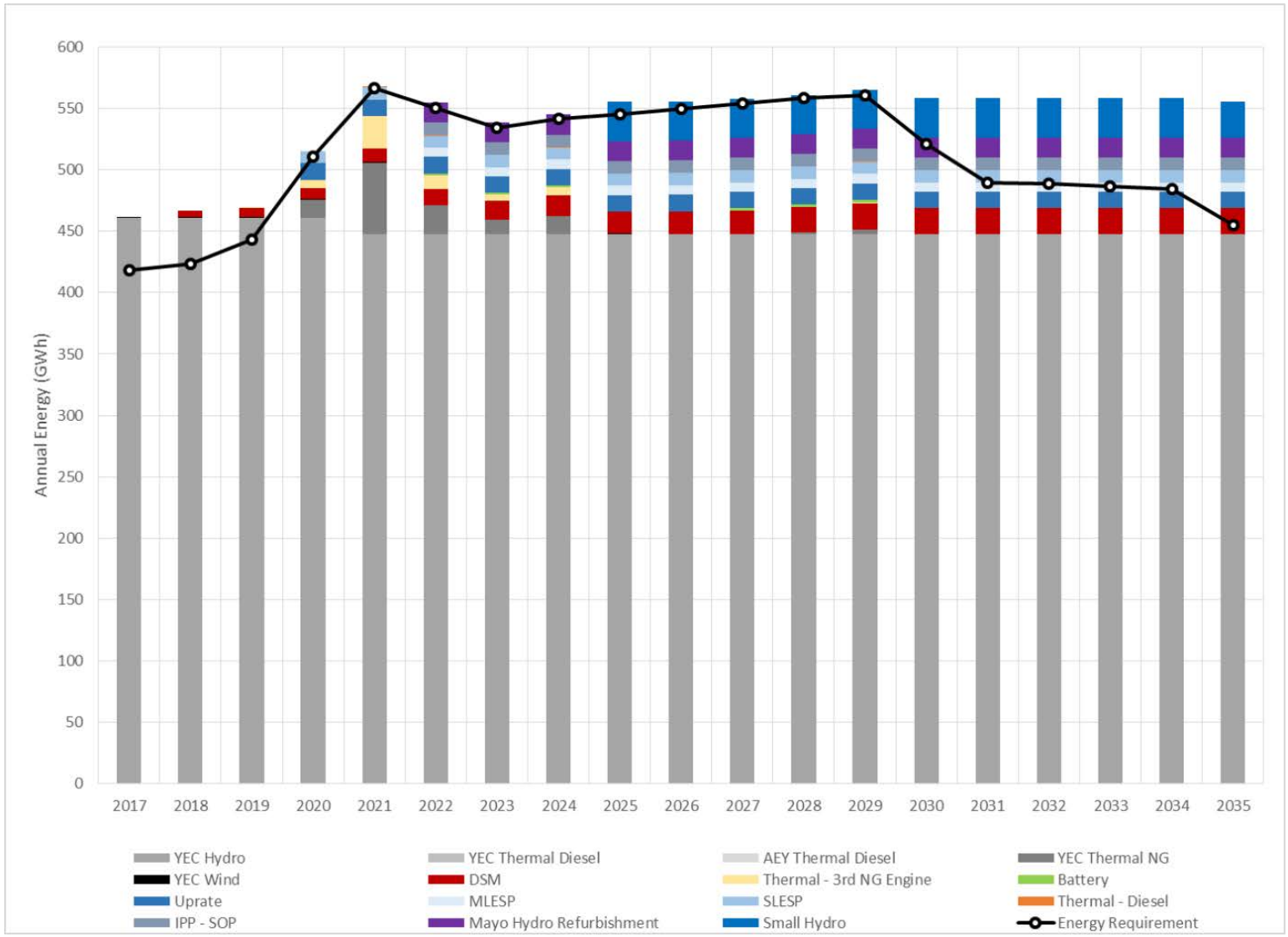


Figure 8-9: Medium Industrial Activity Portfolio, Capacity

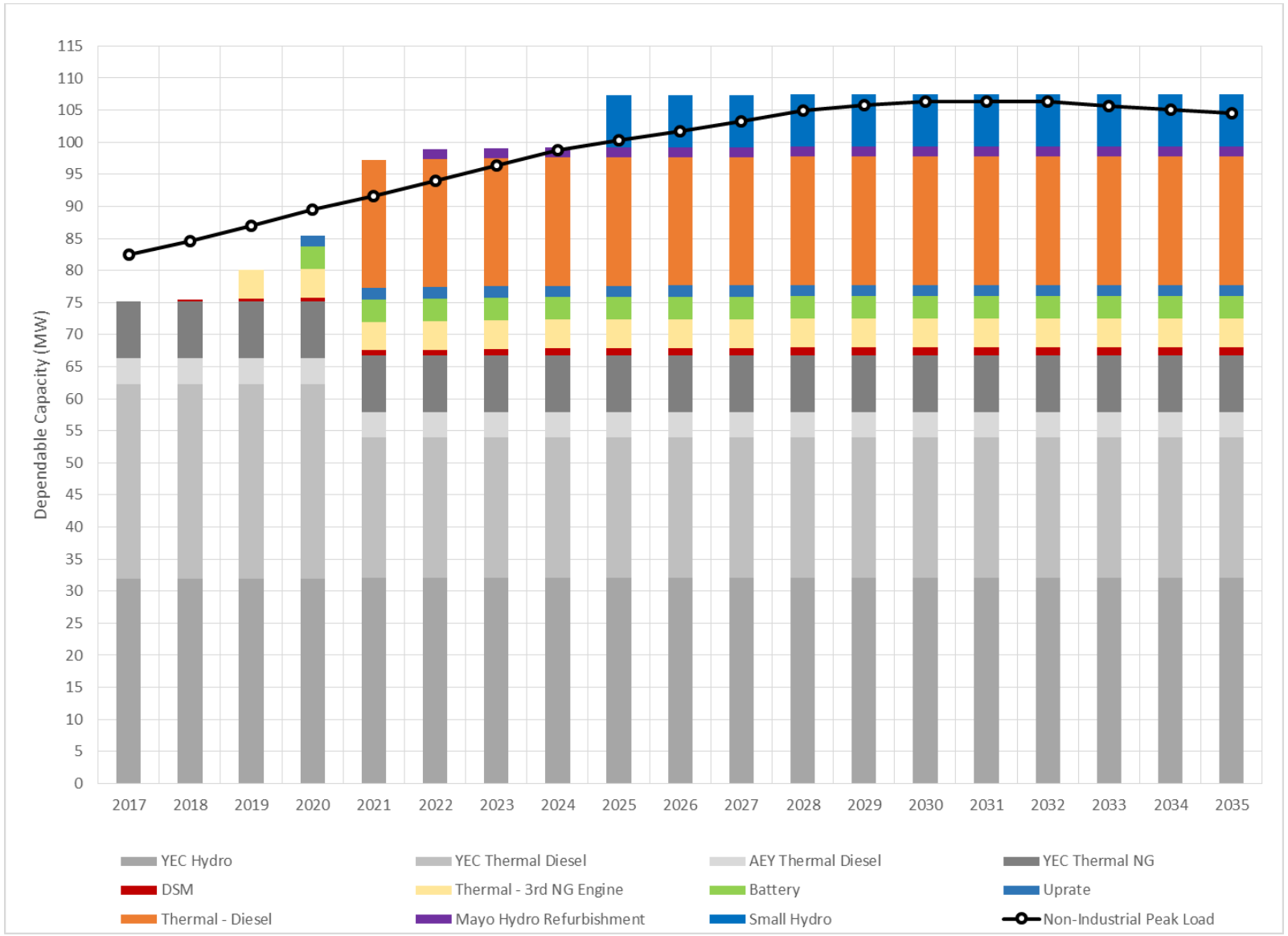


Table 8-5: Medium Industrial Activity Portfolio Summary

Resource Option	Installed Capacity [MW]
2018	
Demand Side Management	1.9
2019	
Thermal - 3rd NG Engine at Whitehorse	4.4
2020	
4 MW Battery - Takhini Substation	4.0
Aishihik Uprate	1.3
Whitehorse Uprate	1.7
Southern Lake Enhancement Storage Project	0.0
2021	
Thermal Diesel - Takhini Substation	20.0
2022	
Mayo Hydro Refurbishment	2.3
Mayo Lake Enhancement Storage Project	0.0
2025	
Drury Lake Small Hydro	8.1
Grand Total	43.7

Cost Components	Cost [2016 $Millions]	Comment
Portfolio Capital Cost	$ 298.6	
Present Value		
Fixed Costs	$ 122.7	[A]
Variable Costs	$ 74.4	[B]
Total Costs	$ 197.1	[C] = [A] + [B]

This portfolio generates an average of 98.1% renewable energy over the 20 year planning period, under average water assumptions.

8.2.1.5 High Industrial Activity Scenario

Considering a need to create a realistic Action Plan that can be executed sequentially under each load scenario, new resources suggested in the Low Industrial Activity portfolio were considered as committed when modelling the High Industrial Activity scenario. As a consequence, the High Industrial Activity scenario was modelled with selected Low Industrial Activity scenario resources assumed to be already committed. This approach allows the Action Plan to be staged to respond to a potential future increases in load.

Figure 8-10: High Industrial Activity with Capped Intermittent and Committed Resources Portfolio, Energy

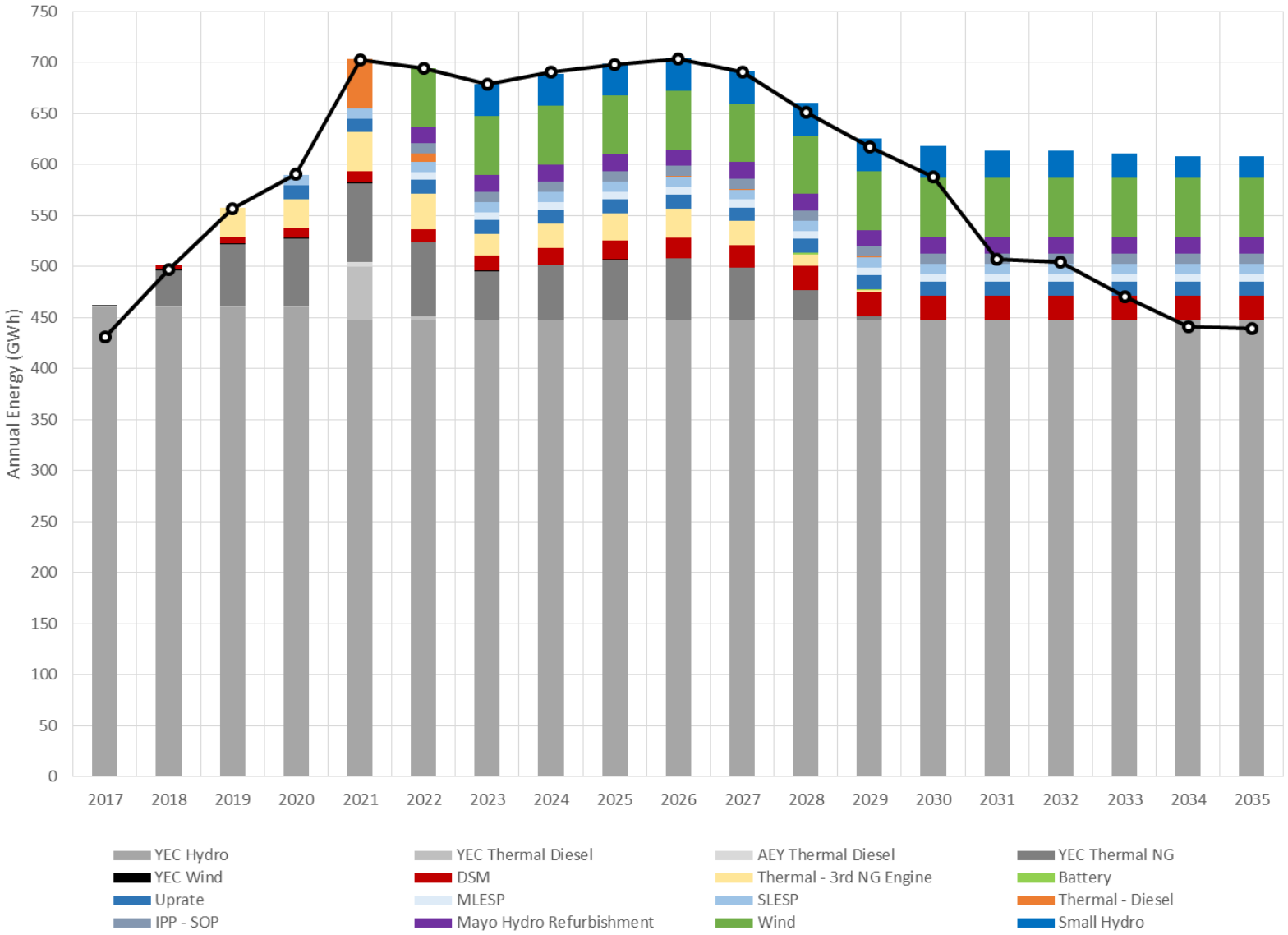


Figure 8-11: High Industrial Activity with Capped Intermittent and Committed Resources Portfolio, Capacity

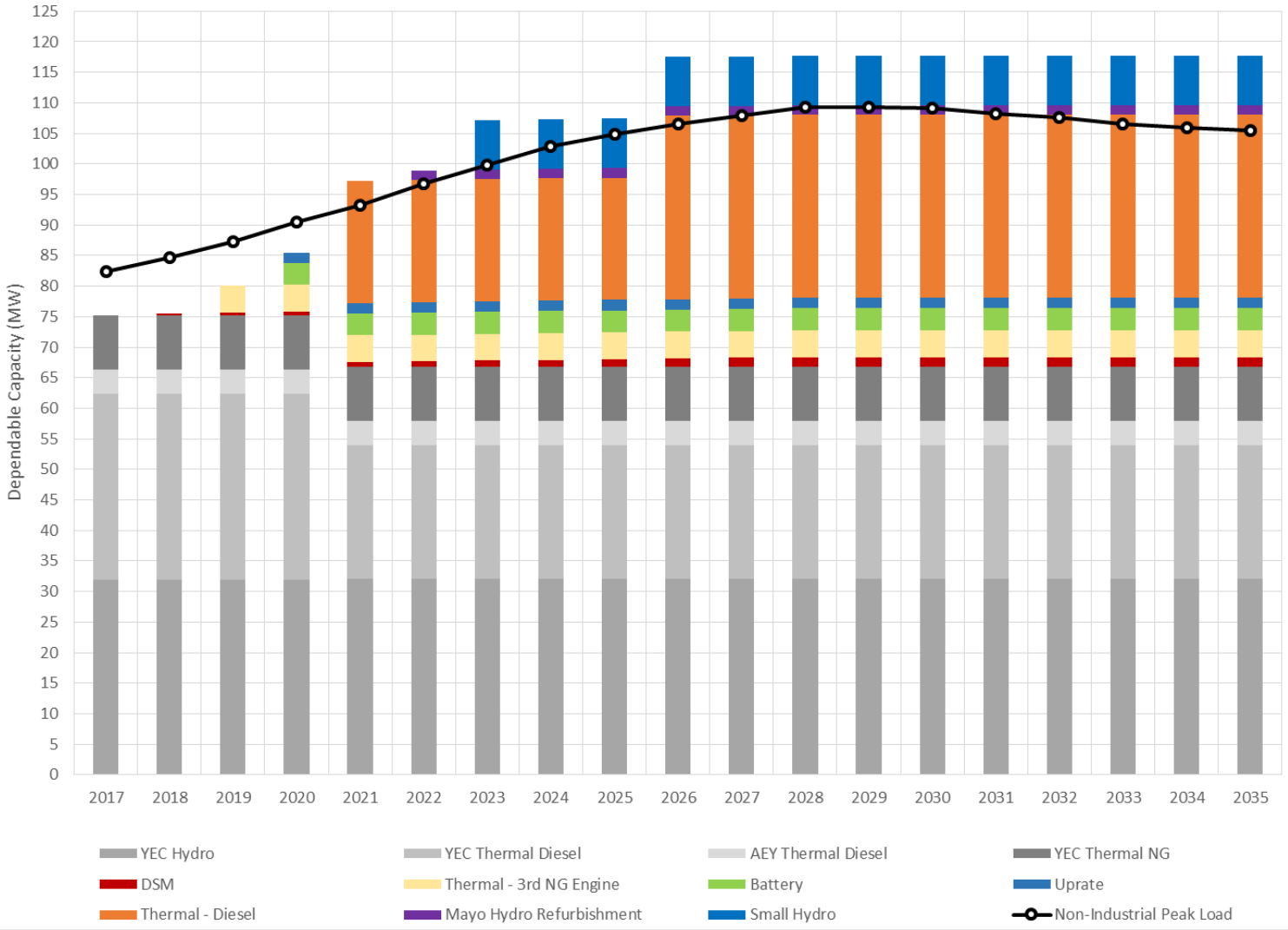


Table 8-6: High Industrial Activity with Capped Intermittent and Committed Resources Portfolio Summary

Resource Option	Installed Capacity [MW]
2018	
Demand Side Management	2.2
2019	
Thermal - 3rd NG Engine at Whitehorse	4.4
2020	
4 MW Battery - Takhini Substation	4.0
Aishihik Uprate	1.3
Whitehorse Uprate	1.7
Southern Lake Enhancement Storage Project	0.0
2021	
Thermal Diesel - Takhini Substation	20.0
2022	
Mayo Hydro Refurbishment	2.3
Mayo Lake Enhancement Storage Project	0.0
Wind - Miller's Ridge	20.0
2023	
Drury Lake Small Hydro	8.1
2026	
Thermal Diesel - Takhini Substation	10.0
Grand Total	74.0

Cost Components	Cost [2016 $Millions]	Comment
Portfolio Capital Cost	$ 414.0	
Optimization Results (Present Value)		
Fixed Costs	$ 150.9	[A]
Variable Costs	$ 294.8	[B]
Total Costs	$ 445.7	[C] = [A] + [B]

This portfolio generates an average of 91.9% renewable energy over the 20 year planning period, under average water assumptions.

8.2.1.6 Industrial Activity Portfolio Analysis Discussion

The summary of the five major industrial activity portfolios is presented in Table 8-7. A common set of resources are included in the portfolios for all the scenarios from 2018 until 2022. These common resources include DSM, a third LNG engine at the Whitehorse generating facility, battery-based storage, hydro uprating at Whitehorse, new diesel generators and refurbishment of Mayo A. This commonality helps streamline the execution of the Action Plan as discussed in Chapter 9.

An uprate of Aishihik Hydro is also required for all of the scenarios in the first five years, except in the Very Low Industrial Activity scenario, where it could be deferred until 2025.

The Southern Lakes and Mayo Lake Enhanced Storage Projects were also included in the first five years, except under the Very Low and Low Industrial Activity scenarios.

As a consequence of long lead times for all the available resources, all the portfolios show a shortfall in dependable capacity until 2021, when new diesel capacity is introduced.

After the first five years, the portfolios diverge in their composition. The Very Low and Low Industrial Activity scenarios require a second diesel unit in 2026. The Low with Early Minto Mine Closure, and Medium Industrial Activity scenarios require a future small hydro project, while the High Industrial Activity scenario requires small hydro, wind and diesel resources.

A more detailed analysis of the commonalities in the portfolios and their consequences to the Action Plan is presented in Chapter 9.

Table 8-7: Resources selected for the Five Major Industrial Scenario

Scenario	Very Low	Low	Early Minto Closure	Medium	High
2018	DSM	DSM	DSM	DSM	DSM
2019	3rd NG Engine	3rd NG Engine	3rd NG Engine	3rd NG Engine	3rd NG Engine
2020	Battery (Takhini) Whitehorse uprate	Battery (Takhini) Aishihik uprate Whitehorse uprate	Battery (Takhini) Aishihik uprate Whitehorse uprate SLESP	Battery (Takhini) Aishihik uprate Whitehorse uprate SLESP	Battery (Takhini) Aishihik uprate Whitehorse uprate SLESP
2021	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)
2022	Mayo Refurbishment Standing Offer Program	Mayo Refurbishment Standing Offer Program	Mayo Refurbishment Standing Offer Program MLESP	Mayo Refurbishment Standing Offer Program MLESP	Mayo Refurbishment Standing Offer Program MLESP Wind 20 MW (Thulsoo Mt.)
2023			Small Hydro (Drury Lake)		Small Hydro (Drury Lake)
2025	Aishihik re-runnering			Small Hydro (Drury Lake)	
2026	Diesel 10 MW (Takhini)	Diesel 10 MW (Takhini)			Diesel 10 MW (Takhini)
Renewable Energy (%)	99.8	99.8	99.3	98.1	91.9
Total Cost $M	$134.5	$135.4	$179.4	$197.1	$445.7
Fixed Cost $M	$97.6	$97.6	$130.2	$122.7	$150.9
Variable Cost $M	$37.0	$37.8	$49.1	$74.4	$294.8
Portfolio Capital Cost $M	$207.4	$207.4	$298.6	$298.6	$414.0

8.2.2 Social Cost of Carbon and GWP Sensitivity Analysis

All of industrial activity scenarios discussed in Section 8.2.1 were modelled assuming the inclusion of a SCC and 100 year GWP of greenhouse gases.

To estimate the impact of removal of the SCC on the preferred portfolio content, the Low and Medium Industrial Activity scenarios were modelled without the SCC. Given the similarities between the Medium and Low with Early Minto Closure Industrial Activity scenarios in terms of load and portfolio content, it was reasoned that the Medium Industrial Activity scenario would provide a reasonable representation for both the Medium Industrial Activity and Early Minto closure scenarios. Given that the High Industrial Activity scenario portfolio is built based on the Low Industrial Activity scenario, it was reasoned that the Low Industrial Activity scenario would provide a plausible representation for the High Industrial Activity scenario.

To estimate the impact of different GWP values on the portfolio content the Medium Industrial Activity scenarios was modelled with a shorter (20-year) GWP. Given that the impact of 20-year GWP would be negative with respect to the selection of LNG compared to diesel, and as new LNG was not dominant in any scenario, the Medium Industrial Activity scenario was considered sufficient to provide insight into the impact of GWP.

The results for the portfolio analysis for the sensitivities to the SCC and GWP are presented below in Table 8-8 to Table 8-10. The data generated from the portfolio analysis can be found in Appendix 8.1.

8.2.2.1 Low Industrial Activity without Social Cost of Carbon

Table 8-8: Low Industrial Activity with No Price on Carbon Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Low Industrial Activity without SCC	**Low Industrial Activity**
2018		
Demand Side Management	1.3	1.3
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	-	1.3
Whitehorse Uprate	1.7	1.7
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Mayo Hydro Refurbishment	2.3	2.3
2023		
Aishihik Uprate	1.3	-
2026		
Thermal Diesel - Takhini Substation	10.0	10.0
Grand Total	45.0	45.0

Cost Components	Cost [2016 $Millions]	
	Low Industrial Activity without SCC	**Low Industrial Activity**
Portfolio Upfront Capital	$207.4	$207.4
Optimization Results (Present Value)		
Fixed Costs	$97.6	$97.6
Variable Costs	$36.7	$37.8
Total Costs	$134.2	$135.4

This portfolio generates 99.8% energy under average water assumptions.

8.2.2.2 *Medium Industrial Activity without Social Cost of Carbon*

Table 8-9: Medium Industrial Activity with No Price on Carbon Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Medium Industrial Activity without SCC	Medium Industrial Activity
2018		
Demand Side Management	1.8	1.9
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0.0	0.0
2025		
Drury Lake Small Hydro	8.1	8.1
Grand Total	43.6	43.7

Cost Components	Cost [2016 $Millions]	
	Medium Industrial Activity without SCC	Medium Industrial Activity
Portfolio Upfront Capital	$298.6	$298.6
Optimization Results (Present Value)		
Fixed Costs	$122.5	$122.7
Variable Costs	$66.4	$74.4
Total Costs	$188.9	$197.1

This portfolio generates 98.1% energy under average water assumptions.

8.2.2.3 Medium Industrial Activity with 20-Year GWP

Table 8-10: Medium Industrial Activity with 20-Year GWP Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Medium Industrial Activity with GWP 20	**Medium Industrial Activity**
2018		
Demand Side Management	1.9	1.9
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0.0	0.0
2025		
Drury Lake Small Hydro	8.1	8.1
Grand Total	43.7	43.7

Cost Components	Cost [2016 $Millions]	
	Medium Industrial Activity with GWP 20	**Medium Industrial Activity**
Portfolio Upfront Capital	$298.6	$298.6
Optimization Results (Present Value)		
Fixed Costs	$122.7	$122.7
Variable Costs	$74.6	$74.4
Total Costs	$197.3	$197.1

This portfolio generates 98.1% energy under average water assumptions.

8.2.2.4 Social Cost of Carbon and GWP Sensitivity Analysis Discussion

The sensitivity of adopting a GWP of 20 years versus the default of 100 years also did not impact the makeup of the portfolio. Such a result was expected considering that the diesel was selected even for GWP 100, which theoretically should favour LNG because of the higher GHG emissions of methane at a GWP of 20 years than at a GWP of 100 years.

8.2.3 Fuel Price Sensitivity Analysis

All of the industrial activity scenarios discussed in Section 8.2.1 previously were modelled assuming the medium (base) price forecasts for both diesel and LNG.

To estimate the impact of different diesel and LNG prices on the portfolio content, a sensitivity on fuel prices was tested in combination with the Low and Medium Industrial Activity scenarios. Four combinations of loads, and diesel and LNG prices were modeled. These are outlined in Table 8-1. The rationale of this approach was to test the following potential future states: a) that the price of LNG decreases compared to diesel, and b) that the price of both diesel and LNG increase. Given the similarities among the portfolio content of the Low, Medium and High Industrial Activity scenarios, it was not deemed necessary to run the diesel and LNG price sensitivities on the High Industrial Activity scenario, or additional combinations of diesel vs. LNG prices, such the case of a LNG price increase compared to diesel. If the LNG thermal options are not favoured if the price of LNG is lower than the price of diesel, it will not be favoured if the price of LNG increases relative to the price of diesel.

The results for the portfolio analysis for the sensitivities to the fuel prices are presented in Table 8-11 to Table 8-14 in the following sections. The data generated from the portfolio analysis can be found in Appendix 8.1.

8.2.3.1 Low Industrial Activity with High Diesel and High LNG Price

Table 8-11: Low Industrial Activity with High Diesel and LNG Price Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Low Industrial Activity with High Diesel and LNG Price	Low Industrial Activity
2018		
Demand Side Management	1.2	1.3
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	-	1.3
Whitehorse Uprate	1.7	1.7
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Aishihik Uprate	1.3	-
Mayo Hydro Refurbishment	2.3	2.3
2026		
Thermal Diesel - Takhini Substation	10.0	10.0
Grand Total	44.9	45.0

Cost Components	Cost [2016 $Millions]	
	Low Industrial Activity with High Diesel and LNG Price	Low Industrial Activity
Portfolio Upfront Capital	$207.4	$207.4
Optimization Results (Present Value)		
Fixed Costs	$96.9	$97.6
Variable Costs	$37.7	$37.8
Total Costs	$134.6	$135.4

This portfolio generates 99.8% energy under average water assumptions.

8.2.3.2 *Medium Industrial Activity with High Diesel and High LNG Price*

Table 8-12: Medium Industrial Activity with High Diesel and High LNG Price Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Medium Industrial Activity with High Diesel and LNG Cost	**Medium Industrial Activity**
2018		
Demand Side Management	1.9	1.9
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0.0	0.0
2024		
Drury Lake Small Hydro	8.1	8.1
Grand Total	43.7	43.7

Cost Components	Cost [2016 $Millions]	
	Medium Industrial Activity with GWP 20	**Medium Industrial Activity**
Portfolio Upfront Capital	$298.6	$298.60
Optimization Results (Present Value)		
Fixed Costs	$127.1	$122.70
Variable Costs	$72.3	$74.40
Total Cost	$199.4	$197.1

This portfolio generates 98.3% energy under average water assumptions.

8.2.3.3 Low Industrial Activity with Medium Diesel and Low LNG Price

Table 8-13: Low Industrial Activity with Medium Diesel and Low LNG Price Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Low Industrial Activity with Medium Diesel and Low LNG Price	**Low Industrial Activity**
2018		
Demand Side Management	1.3	1.3
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	-	1.3
Whitehorse Uprate	1.7	1.7
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Aishihik Uprate	1.3	-
Mayo Hydro Refurbishment	2.3	2.3
2026		
Thermal Diesel - Takhini Substation	10.0	10.0
Grand Total	45.0	45.0

Cost Components	Cost [2016 $Millions]	
	Low Industrial Activity with Medium Diesel and Low LNG Price	**Low Industrial Activity**
Portfolio Upfront Capital	$207.4	$207.4
Optimization Results (Present Value)		
Fixed Costs	$97.6	$97.6
Variable Costs	$37.4	$37.8
Total Costs	$135.0	$135.4

This portfolio generates 99.8% energy under average water assumptions.

8.2.3.4 *Medium Industrial Activity with Medium Diesel and Low LNG Price*

Table 8-14: Medium Industrial Activity with Medium Diesel and Low LNG Price Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Medium Industrial Activity with Medium Diesel and Low LNG Price	**Medium Industrial Activity**
2018		
Demand Side Management	1.8	1.9
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0.0	0.0
2025		
Drury Lake Small Hydro	8.1	8.1
Grand Total	43.6	43.7

Cost Components	Cost [2016 $Millions]	
	Medium Industrial Activity with Medium Diesel and Low LNG Price	**Medium Industrial Activity**
Portfolio Upfront Capital	$298.6	$289.6
Optimization Results (Present Value)		
Fixed Costs	$122.5	$122.7
Variable Costs	$64.3	$74.4
Total Costs	$186.8	$197.1

This portfolio generates 98.1% energy under average water assumptions.

8.2.3.5 Fuel Price Sensitivity Analysis Discussion

Lower LNG prices did not affect the content of the modeled portfolios. As the new diesel resource is used mostly for meeting capacity requirements and not for energy generation, it is still the preferred choice due to a lower LCOC than that of LNG. The capital investment for diesel is lower than that of LNG and using a resource to meet capacity requirements favours the resource with the lower capital investment. If thermal is needed for energy, the existing LNG units would be operated instead of diesel units because of LNG's lower operating costs.

Raising the price of both diesel and LNG did not result in a change in resources selected for the portfolios. The sensitivity in which the LNG price alone is increased results in the same outcome, as diesel was favoured even at the lower LNG price.

8.2.4 Renewable Portfolio Sensitivity Analysis

All of the industrial activity scenarios discussed in Section 8.2.1 were modelled assuming that thermal resources could be included in future portfolios.

To investigate the impact of potential future government policy prohibiting the construction of new thermal resources, a sensitivity analysis was completed excluding all new thermal resources from the portfolio. Portfolios were generated for the Medium and High Industrial Activity scenarios. Existing thermal resources (diesel and LNG) were assumed to continue to be available.

The results for the portfolio analysis of a sensitivities to the renewable portfolio are presented Table 8-15 and Table 8-16 in the following sections. The data generated from the portfolio analysis can be found in Appendix 8.1.

8.2.4.1 Medium Industrial Activity – Renewable Portfolio

Table 8-15: Medium Industrial Activity – Renewable Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Medium Industrial Activity with only New Renewable	**Medium Industrial Activity**
2018		
Demand Side Management	2.4	1.9
2019		
Thermal - 3rd NG Engine at Whitehorse	-	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
2021		
Thermal - Diesel at Takhini Substation	-	20.0
Geothermal - MacArthur	7.7	-
Geothermal - Vista Mountain	3.6	-
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0.0	0.0
2023		
Drury Lake Small Hydro	8.1	8.1
2024		
Pumped Storage - Moon Lake	20.2	-
2035		
Biomass (ORC) - Haines Junction	0.6	-
Waste-to-Energy - Whitehorse	1.6	-
Grand Total	53.6	43.7

Table 8-15 continues on the next page.

Cost Components	Cost [2016 $Millions]	
	Medium Industrial Activity with only New Renewable	Medium Industrial Activity
Portfolio Upfront Capital	$784.6	$298.6
Optimization Results (Present Value)		
Fixed Costs	$155.8	$122.7
Variable Costs	$163.8	$74.4
Total Costs	$319.6	$197.1

This portfolio generates an average of 99.4 % renewable energy over the 20 year planning period, under average water assumptions.

8.2.4.2 *High Industrial Activity – Renewable Portfolio*

Table 8-16: High Industrial Activity – Renewable Portfolio Summary

Resource Option	Installed Capacity [MW]	
	High Industrial Activity with only New Renewable	**High Industrial Activity**
2018		
Demand Side Management	2.0	2.2
2019		
Thermal - 3rd NG Engine at Whitehorse	-	4.4
Solar - Whitehorse	5.0	-
Waste-to-Energy - Whitehorse	1.6	-
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
Biomass (Gasification) - Haines Junction	0.5	-
Biomass (ORC) - Haines Junction	0.6	-
2021		
Thermal Diesel - Takhini Substation	-	20.0
Geothermal - MacArthur	7.7	-
Geothermal - Vista Mountain	3.6	-
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0	0.0
Wind - Miller's Ridge	20	20
2023		
Drury Lake Small Hydro	8.1	8.1
2024		
Pumped Storage - Moon Lake	20.2	-
2026		
Thermal Diesel - Takhini Substation	-	10.0
Grand Total	78.67	74.0

Table 8-15 continues on the next page.

Cost Components	Cost [2016 $Millions]	
	High Industrial Activity with only New Renewable	High Industrial Activity
Portfolio Upfront Capital	$909.6	$414
Optimization Results (Present Value)		
Fixed Costs	$156.3	$150.9
Variable Costs	$382.2	$294.8
Total Costs	$538.5	$445.7

This portfolio generates an average of 96.6 % renewable energy over the 20 year planning period, under average water assumptions.

8.2.4.3 Renewable Portfolio Sensitivity Analysis Discussion

The resulting portfolios with only new renewables were characterized by:

- Significantly higher costs compared to mixed (some thermal) portfolios;
- The inability to close the capacity gap until 2024;
- Penetration of intermittent resources of 25MW raising concerns over the operability of the electricity system; and
- Only marginal increase in the overall percentage of renewable generation, when compared to the portfolios with mixed resources.

8.2.5 Transmission Line Cost Sensitivity Analysis

All of the industrial activity scenarios discussed in Section 8.2.1 were modelled assuming that the costs of future transmission resources would be borne by YEC.

To estimate the impact of potential capital funding from an entity outside YEC, sensitivity analyses were conducted assuming the absence of costs for two potential future transmission lines: Atlin to Whitehorse, and Whitehorse to Skagway. These sensitivities were run under the Medium Industrial Activity scenario.

The portfolio analysis results for the sensitivities related to zero cost transmission lines are presented below in Table 8-17 and Table 8-18. The data generated from the portfolio analysis can be found in Appendix 8.1.

8.2.5.1 Medium Industrial Activity with No Transmission Cost to Moon Lake

Table 8-17: Medium Industrial Activity with No Transmission Cost to Moon Lake Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Medium Industrial Activity with no Transmission Cost to Moon Lake	**Medium Industrial Activity**
2018		
Demand Side Management	2.0	1.9
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0.0	0.0
2025		
Drury Lake Small Hydro	8.1	8.1
Grand Total	43.8	43.7

Cost Components	Cost [2016 $Millions]	
	Medium Industrial Activity with no Transmission Cost to Moon Lake	**Medium Industrial Activity**
Portfolio Upfront Capital	$298.6	$298.6
Optimization Results (Present Value)		
Fixed Costs	$123.0	$122.7
Variable Costs	$74.1	$74.4
Total Costs	$197.1	$197.1

This portfolio generates an average of 98.1% renewable energy over the 20 year planning period, under average water assumptions.

8.2.5.2 Medium Industrial Activity with No Transmission Cost to Atlin

Table 8-18: Medium Industrial Activity with No Transmission Cost to Atlin Portfolio Summary

Resource Option	Installed Capacity [MW]	
	Medium Industrial Activity with no Transmission Cost to Atlin	**Medium Industrial Activity**
2018		
Demand Side Management	1.9	1.9
2019		
Thermal - 3rd NG Engine at Whitehorse	4.4	4.4
2020		
4 MW Battery - Takhini Substation	4.0	4.0
Aishihik Uprate	1.3	1.3
Whitehorse Uprate	1.7	1.7
Southern Lake Enhancement Storage Project	0.0	0.0
2021		
Thermal Diesel - Takhini Substation	20.0	20.0
2022		
Mayo Hydro Refurbishment	2.3	2.3
Mayo Lake Enhancement Storage Project	0.0	0.0
2025		
Drury Lake Small Hydro	8.1	8.1
Grand Total	43.7	43.7

Cost Components	Cost [2016 $Millions]	
	Medium Industrial Activity with no Transmission Cost to Moon Lake	**Medium Industrial Activity**
Portfolio Upfront Capital	$298.6	$298.6
Optimization Results (Present Value)		
Fixed Costs	$122.7	$122.7
Variable Costs	$74.4	$74.4
Total Costs	$197.1	$197.1

This portfolio generates an average of 98.1% renewable energy over the 20 year planning period, under average water assumptions.

8.2.5.3 Transmission Line Cost Sensitivity Analysis Discussion

Removing the costs associated with either of these transmission projects did not change the resources selected. Given the low load flows expected through the transmission lines, and the power losses due to the long distances, these lines were not material to the portfolio selection process.

8.2.6 Existing Transmission Grid Adequacy Assessment

A load flow analysis was completed to assess the adequacy of the existing YEC transmission grid to accommodate the development of all of the new resource options suggested in the High Industrial Activity scenario portfolio, with the peak load including the industrial loads. The High Industrial Activity scenario with industrial loads was selected as the worst case scenario for the assessment of the existing transmission grid adequacy. If the existing YEC transmission grid is capable of accommodating the highest load scenario, it would be capable of accommodating all the remaining, less demanding loads.

The simulation assumed the system peak demand of 136.5 MW, including 107.8 MW of non-industrial peak demand and 28.7 MW of industrial peak demand. The non-industrial peak demand was spatially distributed according to historical peak information with all the forecast increases applied to Whitehorse, which is the main load centre. The location of the new industrial peak demand was selected based on publicly available information. The analysis was completed in-house using ETAP, the widely used commercially available model for the electrical power system analysis

The analysis demonstrated that the existing YEC transmission grid could accommodate the increased generation under the High Industrial Activity scenario to meet the forecasted peak demand.

8.2.7 Financial and Technical Evaluation - Conclusions

The key conclusions of the technical and financial evaluation are:

- YEC is in imminent need for new capacity to meet requirements under N-1 contingency conditions. Given the lead time in constructing new resources, the expected electricity demand under all load cases is expected to exceed YECs generating capacity until the year 2021.
- For the Very Low, Low, Low with Early Minto Closure and Medium Industrial Activity scenarios, YEC is expected to have sufficient firm energy without introducing new resources, as long as it is acceptable to run YECs existing thermal resources. Despite the fact that there is sufficient firm energy for those scenarios, new renewable resources that are cheaper to operate than thermal resources are proposed to provide lower cost energy when needed. The increased load of the High Industrial Activity scenario would require incremental new energy resources.
- Thermal assets are included in most portfolios to meet capacity requirements. However, these thermal assets are not operated often for energy production over the 20 year planning period. Therefore, all of the portfolios contain a high percentage of renewable energy, most in excess of 95% on the average over the 20 year planning period.
- All the base portfolios have common resources for the first five years, which makes developing a consistent and sequential action plan possible, reducing the implementation risk of stranded investments if the future unfolds somewhat differently than under the base assumptions.
- The LNG third engine is common for all the base scenarios - it is the cheapest source of incremental capacity as it is an addition to an existing plant. For additional capacity beyond this, diesel was preferred over LNG because of its lower LCOC.

- Grid-scale battery storage is included in most portfolios as a near-term solution to address the capacity gap under N-1 conditions. While the battery has a higher LCOC than diesel, it is included in all portfolios as it has a shorter construction lead time that diesel and can be brought into service earlier to meet capacity requirements.
- Intermittent renewables such as wind provide energy but not capacity. Wind was included in the portfolio for the High Industrial Activity scenario, as there is a significant energy deficit under this scenario.
- Small hydro is a part of the Low with Early Minto Closure, Medium and High Industrial Activity scenarios even though its use for energy generation is low during late last several years of the planning period. Regardless of its low energy use at the end of the planning period, it is a lower cost solution for meeting both energy and capacity needs than a combination of thermal resources and intermittent renewable resources.
- In several of the portfolios, there is a drop-off in energy load near the end of the 20-year planning period as grid-connected mines reach end-of-life. In portfolio planning, there always exists the risks and associated cost that capital expenditures required to service customer demand growth may ultimately be 'stranded' if load disappears. The Yukon economy is cyclical, with the potential for a resurgence of load growth after the end of the 20-year Plan horizon. Thus, the selected Action Plan needs to be robust to respond to a surge in future electricity demands. The System Optimizer model took this reduction in energy demand into consideration, which is reflected in the cost implications to YEC and its customers.
- The preferred portfolios were not materially sensitive to the social cost of carbon, the global warming potential, fuel prices, or low-cost new transmission lines.
- The portfolio containing only new renewables was significantly more expensive than the corresponding mixed (including thermal) portfolios. In addition, the renewable portfolio did not meet YECs capacity needs until 2024. Finally the renewable portfolio provided only marginally more renewable energy generation overall than the mixed (including thermal) portfolios.

The conclusions above are specific to the technical and financial attributes of the selected portfolios. Conclusions related to the environmental, social and economic evaluations are presented in Section 8.3.2. The overall portfolio analysis and action plan conclusions are provided in Chapter 9.

8.3 Portfolio Analysis - Environmental, Social and Economic Evaluation

As discussed in in Section 8.1.2, after passing through the various technical and financial filters of the optimization modelling, each resource option was further characterized according to its unique environmental, social and economic attributes. These evaluations were conducted using five environmental, five social, and two economic criteria to address different aspects of each important resource attribute. Each criteria consisted of multiple indicators resulting in sixteen environmental indicators, seventeen social indicators and eight economic indicators. Each resource option was evaluated separately for each indicator. The attribute and indicator analyses for all resource options are presented in detail in Chapter 5 and Appendix 5.2.

8.3.1 Industrial Activity Portfolio Analysis

The resource options contained within the five industrial activity portfolios and the renewable portfolio were assembled into tables summarizing their respective environmental, social, and economic

characteristics (refer from Figure 8-12 to Figure 8-16). The analysis showed that all portfolios contain resources that have some degree of adverse environmental, social or economic impacts. No portfolio contains resources that will not cause some impact on the human and/or biophysical environment, or without challenges to be managed.

The data in Figure 8-12 to Figure 8-16 illustrate that there are consistent outcomes for some of the key indicators for each scenario. These include:

- Air Quality: The air quality indicator for thermal generation portfolios clearly distinguished them from the portfolio containing only new renewables. Thermal resources are needed to meet near-term capacity requirements in every scenario. While not ideal, the human health issues associated with thermal generation are manageable, and not likely to result in significant adverse health effects. In addition, given that the thermal resource options are included to meet capacity requirements, these resources are not expected to be run consistently for energy generation. Therefore, GHG emissions from these thermal assets will not be significant, as demonstrated by the high renewable content of the energy generated from all portfolios over the 20 year planning period. In addition, by including the social cost of carbon into the financial analysis, the damage caused by GHG emissions from thermal resources is accounted for. Contemporary engineering standards, assessment and permitting/enforcement processes will ensure appropriate environmental and human health considerations are a part of developing thermal resources.
- Community Well-Being: The presence of mostly medium preferences for the Community Well-Being attribute is also common across all portfolios, which is associated with effects on community infrastructure and services (e.g., will the construction project strain local municipal resources), effects on community wellness (e.g., influx of temporary transient workers for construction), and community development opportunities (e.g., opportunities for training and transfer of knowledge).
- Local Economic Benefits: Finally, the presence of predominantly low preference results for the Local Economic Benefits attribute is common for almost all resource options except those that offer significant benefits for local labour and suppliers, such as with local small hydro and pumped storage options. This indicator does not imply that the other resource options are completely deficient in local benefits, but rather that the opportunities for local labour and ability to direct project capital dollars to local businesses are fewer with these smaller sized projects. This will simply challenge Yukon Energy to be more creative and to work harder to maximize local economic benefits.

Individually and taken together, the attribute profiles of the core portfolios are not significantly negative from an environmental, social and/or economic perspective. Overall, the portfolios are mostly in the environmentally friendly or otherwise characterized by challenges to attributes that can be mitigated.

Figure 8-12: Environmental, Social and Economic Characteristics of the Very Low Industrial Activity Scenario

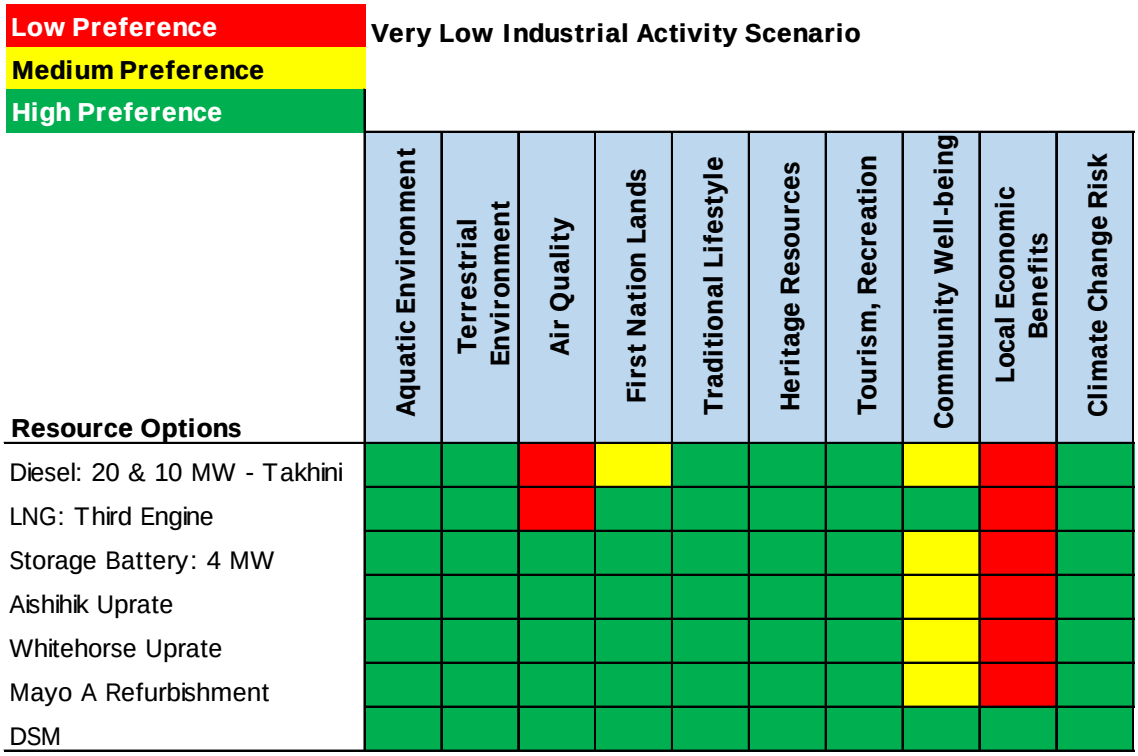
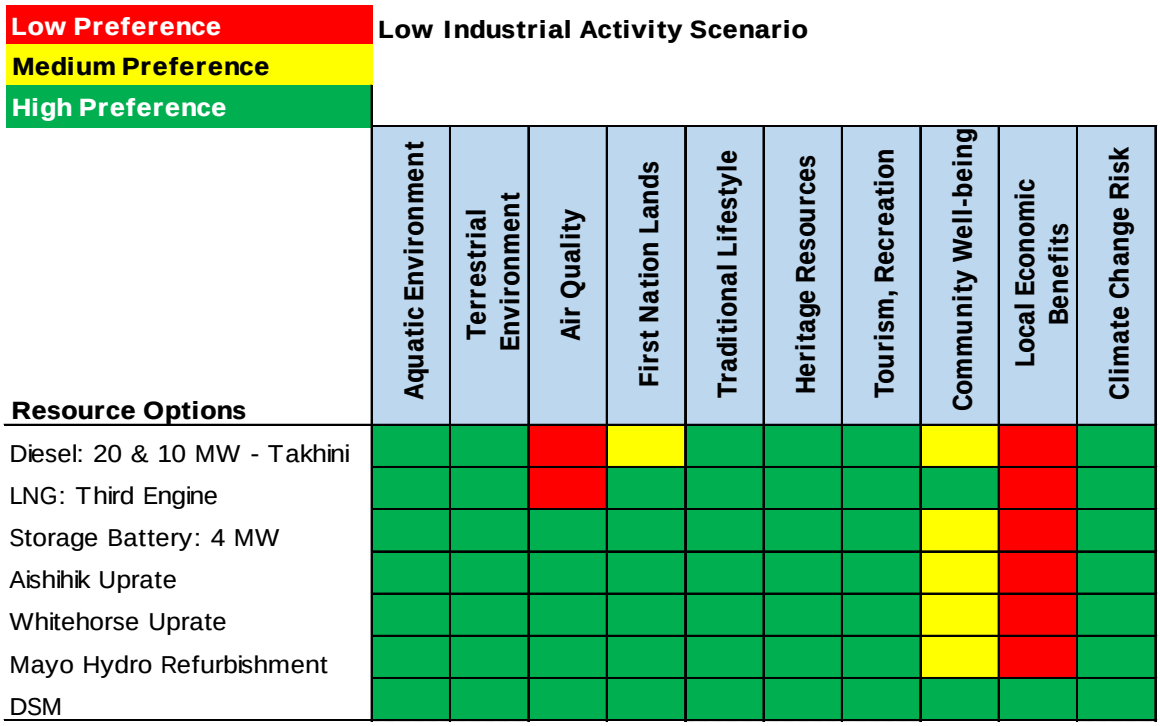
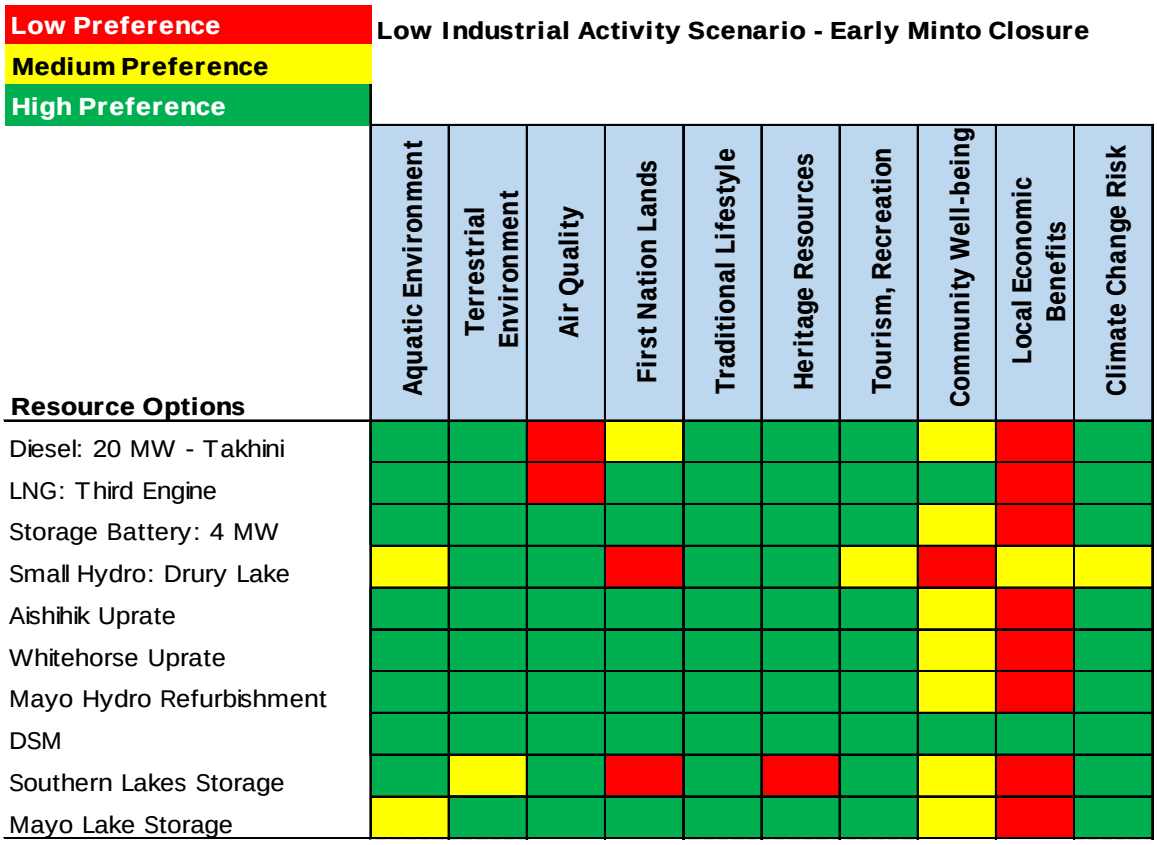


Figure 8-13: Environmental, Social and Economic Characteristics of the Low Industrial Activity Scenario



The Early Minto Closure scenario shown in Figure 8-14 introduces three additional hydro-related resource options. These clean energy sources from an air emissions standpoint, have associated environmental effects on land and water, as well as challenges associated with potential effects to first nations settlement lands and heritage resources requiring special attention. The presence of permafrost in the location of the Drury Lake Small Hydro introduces additional engineering challenges that drive a lower preference score under the *Climate Change Risk* criteria.

Figure 8-14: Environmental, Social and Economic Characteristics of the Low Economic Activity Scenario – Early Minto Closure



The Medium Industrial Activity scenario shown in Figure 8-15 contains the same resource options as the Low Industrial Activity scenario with Early Minto Closure, but includes more diesel capacity. As such, the environmental and socio-economic characterizations are similar.

The High Industrial Activity scenario as shown in Figure 8-16 includes wind to the resource mix, which introduces additional potential effects related to the terrestrial environment, such as migratory birds and bats, as well as and socio-economic impacts related to aesthetics.

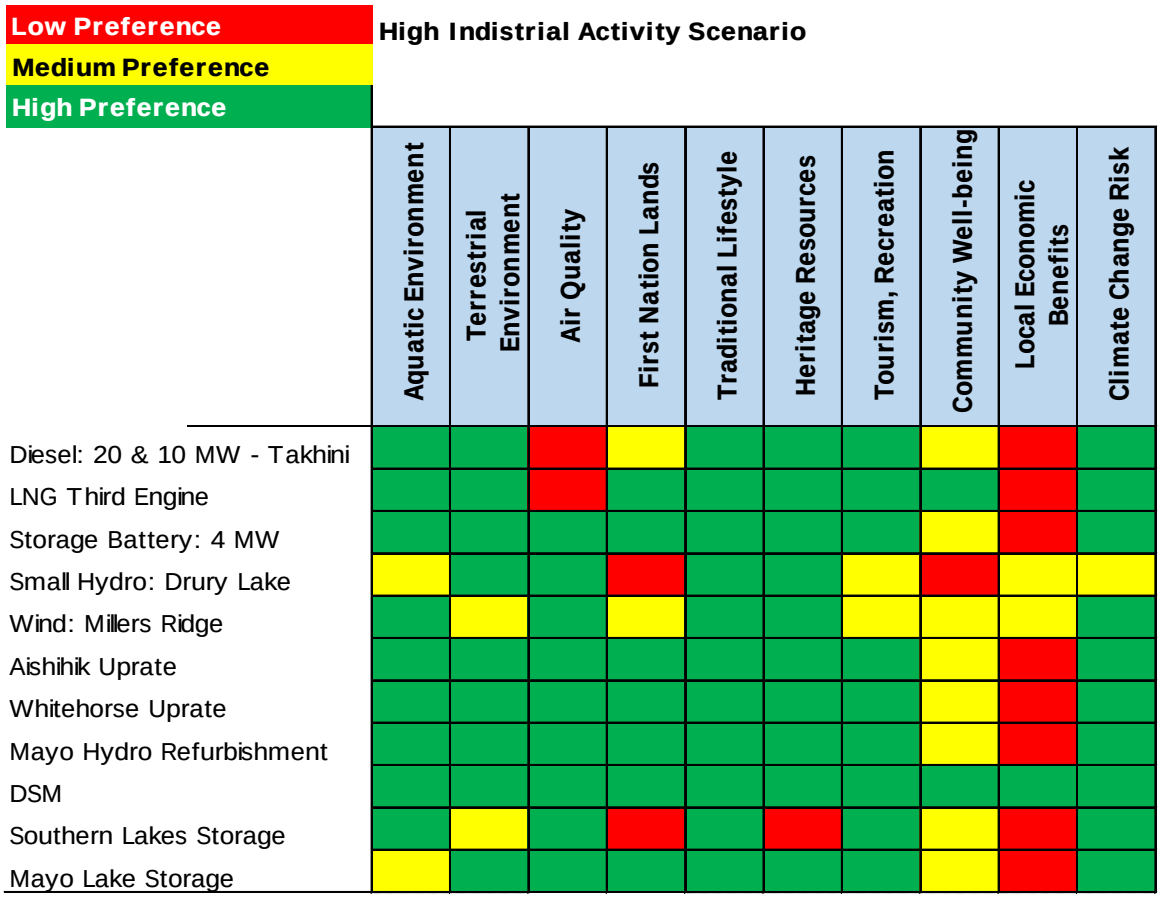
Figure 8-15: Environmental, Social and Economic Characteristics of the Medium Economic Activity Scenario

Low Preference
Medium Preference
High Preference

Medium Industrial Activity Scenario

Resource Options	Aquatic Environment	Terrestrial Environment	Air Quality	First Nation Lands	Traditional Lifestyle	Heritage Resources	Tourism, Recreation	Community Well-being	Local Economic Benefits	Climate Change Risk
Diesel: 20 MW - Takhini	High	High	Low	Medium	High	High	High	Medium	Low	High
LNG Third Engine	High	High	Low	High	High	High	High	High	Low	High
Storage Battery: 4 MW	High	High	High	High	High	High	High	Medium	Low	High
Small Hydro: Drury Lake	Medium	High	High	Low	High	High	Medium	Low	Medium	Medium
Aishihik Uprate	High	High	High	High	High	High	High	Medium	Low	High
Whitehorse Uprate	High	High	High	High	High	High	High	Medium	Low	High
Mayo Hydro Refurbishment	High	High	High	High	High	High	High	Medium	Low	High
DSM	High	High	High	High	High	High	High	High	High	High
Southern Lakes Storage	High	Medium	High	Low	High	Low	High	Medium	Low	High
Mayo Lake Storage	Medium	High	High	High	High	High	High	Medium	Low	High

Figure 8-16: Environmental, Social and Economic of the High Economic Activity Scenario



8.3.2 Renewable Portfolio Analysis

The renewable portfolio was assembled to examine the costs and benefits of constructing only new renewable resource options. The analysis was undertaken for both the Medium and High Industrial Activity scenarios, but is only presented for the Medium Industrial Activity scenario, because of the prohibitive costs of the portfolio under High Industrial Activity scenario. As shown in Figure 8-17, the renewable portfolio is not without potential effects. It has similar characteristics to the other portfolios that include thermal resources with respect to the social and economic attributes, but introduces some previously unseen challenges with some environmental and social criteria, such as greater impacts on aquatic and terrestrial ecosystems and distinct tourism and/or recreational effects.

As the scenario attribute analysis demonstrates, no portfolio offers a perfect solution from an environmental, social and economic perspective. The portfolios generated by the System Optimizer include a mix of resource options, which on balance represent what could be considered a reasonable or acceptable mix of resource options to meet forecasted demand at the lowest cost. The identified portfolios provide more than 98% of renewable generation for all the scenarios except for the High Industrial Activity scenario which has 92% of renewable generation. Even if the renewable portfolio were considered as an alternative to the mixed portfolio for the Medium Industrial Activity scenario, it would not offer material benefits.

Figure 8-17: Environmental, Social and Economic Characteristics of the Medium Economic Activity Scenario – Renewable Portfolio

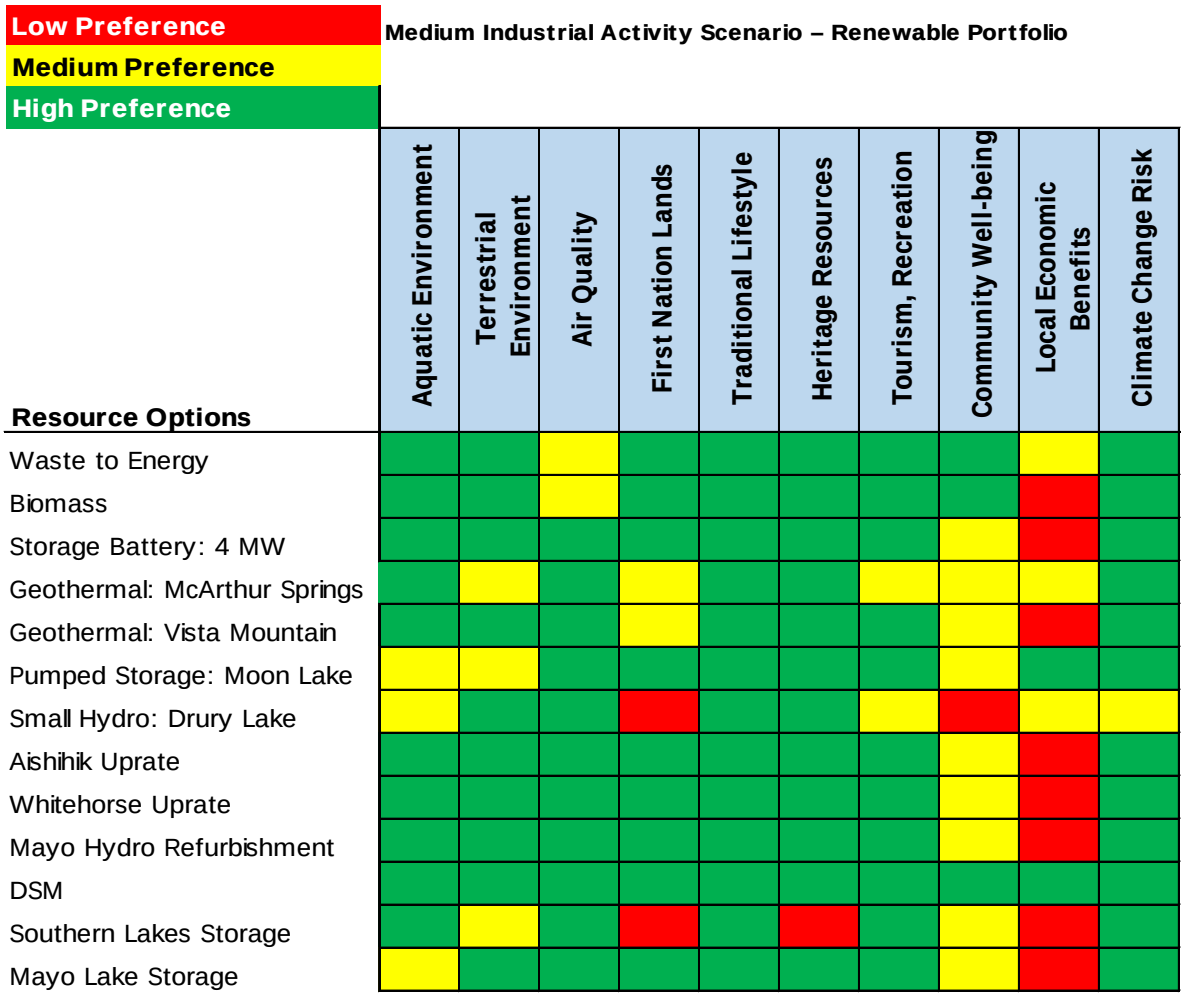
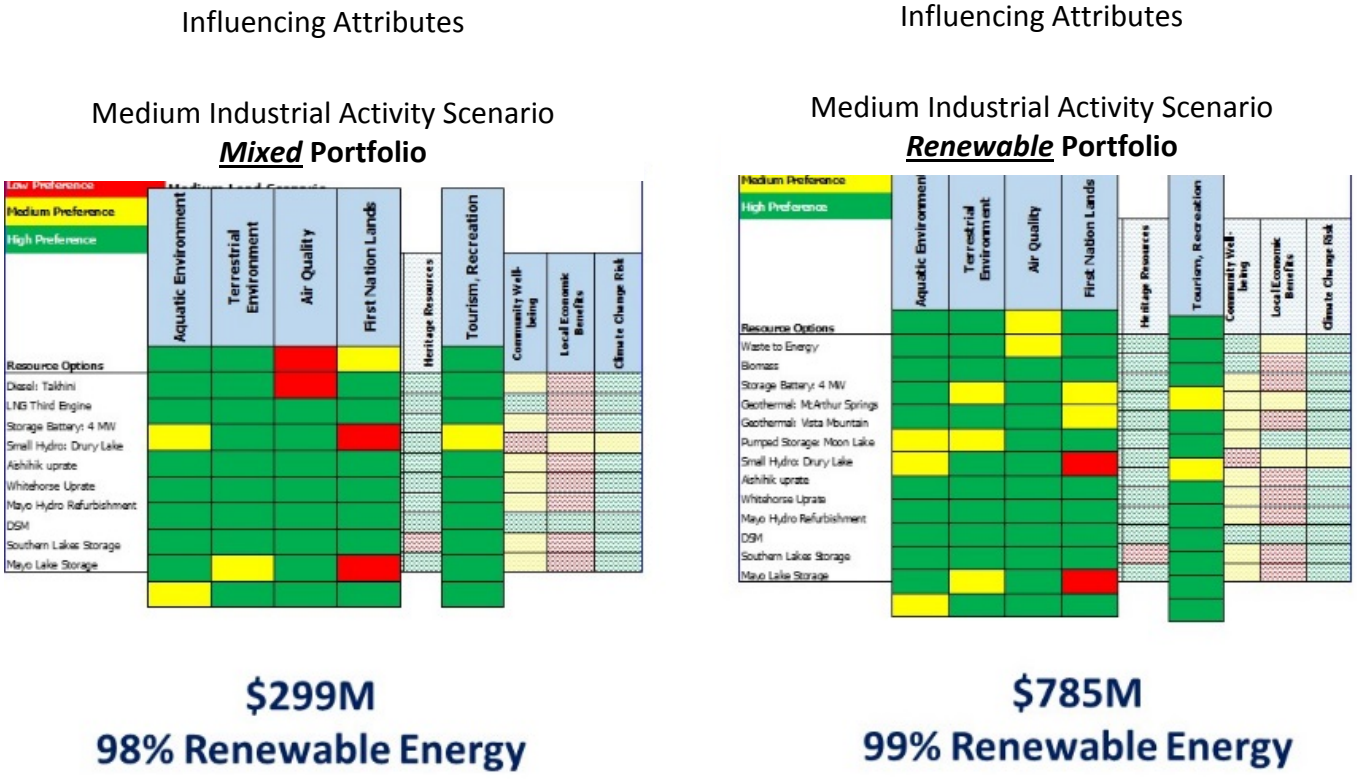


Figure 8-18 further illustrated that there are few clear environmental, social, or economic drivers for selecting the renewable portfolio over the mixed portfolio, which contains some thermal resources. For example, while the mixed portfolio has a less preferable profile with regard to air emissions, the renewable portfolio has a less preferable profile with regards to aquatic, terrestrial, and tourism/recreation attributes. When considering the relative importance of the various environmental and socio-economic attributes (as revealed by the Electricity Values Survey, see Chapter 3) there is no strong direction indicating either portfolio over the other. Figure 8-18 also presents the portfolio capital cost and percentage renewable energy generation of each portfolio. The renewable portfolio is considerably more expensive than the mixed portfolio, while delivering only a modest increase in the overall renewable energy content of the portfolio. Overall, the cost advantage of the mixed portfolio presents a strong case for pursuing this portfolio over the renewable portfolio.

Figure 8-18: Example Environmental & Socio-Economic Attribute Trade-Off Analysis – Medium Industrial Scenario mixed portfolio vs. Medium Industrial Scenarios renewable portfolio



8.3.3 Environmental, Social and Economic Evaluation - Conclusions

These key conclusions of the Environmental, Social and Economic evaluations are:

- All resource options, and all portfolios represent trade-offs with respect to the potential for environmental, social and economic impacts. Consistent with the compromises inherent in resource planning, there was no portfolio without some negative attributes.
- The least-cost portfolios selected by the System Optimizer model were relatively balanced and positive from an environmental, social and economic perspective. This outcome made the environmental, social and economic attribute trade-off screening less challenging. The least cost portfolios identified did not contain onerous negative attributes that would cause them to be disqualified early.
- Most portfolios generated a high percentage of (92% to 98%) energy from renewable sources over the 20 year planning period. This indicates that the portfolios were aligned with the findings of the Electricity Values survey, which showed that Yukoners have a strong preference for renewable sources of energy.
- The portfolio containing only new renewables was reviewed. The resources contained in that portfolio featured some degree of environmental, social and economic impacts and on balance the overall attribute scorings of the renewable portfolio were relatively close to those of the mixed portfolio that contained some thermal resources. The renewable portfolio substitutes any future potential thermal resources with all renewables, for an overall increase of 1% renewable

energy. Despite a modest change in the environmental, social and economic attributes, the renewable portfolio requires an additional capital investment of $486 million, which is 2.5 times greater than that of the mixed portfolio. This significant cost difference is too great to recommend the all-renewables option in the Action Plan.

- The Action Plan does not preclude the option to substitute additional renewable resources in the future, but this substitution could incur potentially significant additional costs with potentially little gain in the net renewable energy percentage.

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9 Action Plan

This chapter presents the key considerations in developing the Action Plan, and the proposed steps to be undertaken towards the implementation of the 2016 YEC Resource Plan.

9.1 Key Action Plan Considerations

The assessment of the environmental, socio-economic and financial attributes of each of the portfolios presented in Chapter 8 illustrated that all portfolio choices inevitably involve tradeoffs, as each resource option has challenges or potentially less desirable effects. Notwithstanding, portfolios were selected to meet expected load growth at the lowest cost, and the portfolio analysis subsequently demonstrated that these portfolios were well aligned with Yukoners values as laid out in the Electricity Values Survey, Appendix 3.1. The Electricity Values survey found that Yukoners valued environmental protection first, then minimizing the cost of energy, followed by reliability and finally social responsibility.

Given the current high percentage of renewable energy within the proposed portfolios, the renewable portfolio resulted in a marginal increase from 98% to 99% renewable energy generation overall, when compared to the mixed portfolio including thermal resources under the medium industrial activity scenario. However, the capital cost of the renewable portfolio was 2.5 times higher than that of the mixed portfolio. In addition, the renewable portfolio presented its own set of environmental challenges, and if implemented would be not be able to meet YEC's peak demand requirements under the single contingency criterion (N-1) until 2024. It was felt that the additional cost did not warrant such a marginal increase in renewable generation.

YEC's Action Plan has incorporated the need for flexibility to deal with risks such as major and sudden changes in grid loads, and the potential inability to develop a preferred resource proposed in the Action Plan. In light of ongoing uncertainties, the Action Plan needs to be resilient and robust under various potential load scenarios and regulatory, financial and development outcomes. A portfolio of relatively small, scalable and modular assets to meet load growth, as proposed in YECs Action Plan, presents a lower risk than a single large asset, in terms of regulatory approvals, financing, fuel diversity and resourcing. Such an approach is also aligned with public values. As an example of scalability, YEC's LNG facility completed in 2015 was built with the expansion potential for a third unit, which is now recommended in the Action Plan as an attractive option to provide additional capacity. YEC will consider the balance between potential lower costs due to economies of scale for larger solutions, versus the ability of smaller, incremental supply solutions to more closely match growth.

The portfolio analysis sensitivity on social cost of carbon, transmission cost and fuel prices discussed in Chapter 8 did not result in significant changes to the resource options selected.

The recommended Action Plan is based on the resource portfolios generated for the five major industrial activity scenarios: Very Low, Low, Low with Early Minto Closure, Medium and High. The Low with Early Minto Closure and Medium industrial activity scenarios are considered more likely to occur than the remaining three scenarios.

The portfolio analysis integrated the research and analysis presented in the previous chapters, while the Action Plan describes how YEC proposes to implement the results of the portfolio analysis. Professional judgment and stakeholder input were used to translate the portfolio analysis into the Action Plan.

The methodology followed in the portfolio analysis identified specific projects, as presented in Table 9.1, such as, the Drury Lake small hydro project and the Thulsoo Mountain wind project. Considering that many projects presented in the portfolio analysis are in an early stage of development, the final decisions on any project development have not been made. Projects with comparable technical, financial, environmental, social and economic attributes may be considered before the final project selections are made. For example, the Pine Creek small hydro project has similar technical, environmental, social and economic attributes to the Drury Lake project, and, as such, both projects may be considered during the early stages of planning of the identified small hydro project. YEC will follow the rigorous stagegate process discussed in Section 9.5 to make the final decision on resources that will be built.

The content of the five portfolios presented in Table 9.1 indicated that there were commonalities among the portfolios. The common resources for each portfolio at the beginning of the planning period helped develop the recommended Action Plan in two stages. Those two stages are:

1) Short Term Action Plan (present to 2022): The Short Term Action Plan is a recommendation based on common resources. In addition to the common resources, a) resources that were not a part of the lower probability scenarios (Very Low and Low industrial activity scenarios), but deemed essential for the remaining scenarios and b) resources that were part of all the portfolios but whose timing was not identical for all the portfolios, were included in the Short Term Action Plan recommendations. The details are presented in Section 9.2.
2) Long Term Action Plan (2022 to 2035): The Long Term Action Plan is a recommendation of additional resources to be developed over the longer term, contingent on the specific future industrial activity scenario that develops over time. Unlike the Short Term Action Plan recommendations that are common for all the scenarios, the Long Term Action Plan recommendations depend on the specific industrial activity scenario that unfolds in the future. The Long Term Action Plan consists of four different paths depending on the future industrial activity scenario. The details are presented in Section 9.3.

Table 9-1: Portfolios for five major industrial activity scenarios

Scenario	Very Low	Low	Early Minto Closure	Medium	High
2018	DSM	DSM	DSM	DSM	DSM
2019	3rd NG Engine	3rd NG Engine	3rd NG Engine	3rd NG Engine	3rd NG Engine
2020	Battery (Takhini) Whitehorse uprate	Battery (Takhini) Aishihik uprate Whitehorse uprate	Battery (Takhini) Aishihik uprate Whitehorse uprate SLESP	Battery (Takhini) Aishihik uprate Whitehorse uprate SLESP	Battery (Takhini) Aishihik uprate Whitehorse uprate SLESP
2021	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)	Diesel 20 MW (Takhini)
2022	Mayo Refurbishment Standing Offer Program	Mayo Refurbishment Standing Offer Program	Mayo Refurbishment Standing Offer Program MLESP	Mayo Refurbishment Standing Offer Program MLESP	Mayo Refurbishment Standing Offer Program MLESP Wind 20 MW (Thulsoo Mt.)
2023			Small Hydro (Drury Lake)		Small Hydro (Drury Lake)
2025	Aishihik re-runnering			Small Hydro (Drury Lake)	
2026	Diesel 10 MW (Takhini)	Diesel 10 MW (Takhini)			Diesel 10 MW (Takhini)

9.2 Short Term Action Plan

The portfolio analysis results presented in Table 9.1 identified the following resources which are common to all the portfolios until 2022: DSM (conservation), LNG Third Engine, Battery, Diesel Plant, Whitehorse Hydro Plant uprate, Mayo Hydro Plant refurbishment, and the Independent Power Producer (IPP) Standing Offer Program (SOP). Consequently, those resources are included as key elements of the Short Term Action Plan. The IPP SOP is a part of the Yukon Territorial Government IPP Policy that sets a target of 10 GWh/year of energy to be supplied by independent power producers. YEC included this energy source in all portfolios starting in 2022.

In addition to the common resources listed above, three additional resources are included in the Short Term Action Plan: the Southern Lakes Enhanced Storage Project (SLESP), Mayo Lake Enhanced Storage Project (MLESP), and Aishihik hydro plant uprate.

Despite the fact that the SLESP and MLESP developments are not required for the Very Low and Low industrial activity scenarios, they are included from 2020 onwards in the Medium, Early Minto Closure and High portfolios. The Very Low and Low industrial activity scenarios are considered less ikely to occur than the Early Minto Closure and Medium scenarios. Therefore, it was considered prudent to include the SLESP and MLESP projects in recommended Short Term Action Plan, recognizing that timing for any related physcial works can be optimized subsequent to securing all necessary approvals.

The Aishihik Hydro Plant uprate is included in all the portfolios, but the project timing depends on the scenario. This project is included from 2025 onwards in the Very Low Industrial Activity scenario, while it is included from 2020 onwards in all the remaining portfolios. Considering that the lower likelihood of the very low scenario than the remaining scenarios and the need for this resource for the remaining, it was considered prudent to include work on the Aishihik hydro plant uprate in the recommended Short Term Action Plan.

The new diesel plant will be designed to be scalable, so that additional diesel engines can be added if required, for example if the Low Industrial Activity scenario develops and an additional 10MW capacity of diesel is required. Such an approach was undertaken with the design of the existing LNG plant, which was designed for three engines, but only two engines were installed in the initial plant construction.

The resources recommended in the Short Term Action Plan and their in service years are presented in Table 9-2. Those resources are common for all the industrial activity scenarios.

Table 9-2: Resource Options in the recommended Short Term Action Plan

Year	Resource Option
2018	DSM
2019	LNG Third Engine (4.4 MW)
2020	Aishihik Hydro Plant Uprate
2020	Whitehorse Hydro Plant Uprate
2020	Batteries (4 MW)
2020	SLESP
2021	Diesel (20 MW)
2022	Mayo A Refurbishment
2022	MLESP
2022	Standing Offer Program

9.3 Long Term Action Plan

The recommended Long Term Action Plan consists of two components:

- Continued implementation of the resource options included in the Short Term Action Plan, and
- Development of additional resource options which are dependent on the specific industrial activity scenario that develops over time.

Therefore, specific additional resources included in the recommended Long Term Action Plan have been identified for each scenario. Growth in energy use and peak demand will be closely monitored to help guide the utility on which long term actions are required. An updated load forecast scheduled for 2018

should provide better insights into the load scenario unfolding in the future in sufficient time to develop the resources to meet the load.

Table 9-3 presents the resource options included in the recommended Long Term Action Plan, and the projected in-service years.

Table 9-3: Resource Options in the recommended Long Term Action Plan

Scenario	Very Low and Low	Early Minto Closure	Medium	High
2022				Wind 20 MW (Thulsoo Mt)
2023		Small Hydro (Drury Lake)		Small Hydro (Drury Lake)
2025			Small Hydro (Drury Lake)	
2026	Diesel 10 MW			Diesel 10 MW

There are commonalities among the additional resource options included in recommended Long Term Action Plan. For example the Small Hydro is included in the Medium, Early Minto Closure and High industrial activity scenarios, while the 10 MW Diesel project is common to the Very Low, Low and High industrial scenarios. Considering the likelihood of Early Minto Closure and Medium industrial activity scenarios, and the long lead time for development of a hydro project, YEC plans to start planning work on the small hydro project in the short term.

Table 9-4 summarizes the Short and Long Term Action Plan recommendations. The first column in the table presents resource options that will be developed in the Short Term Action Plan; the second column distinguishes among the industrial activity scenarios that would lead to different recommended Long Term Action Plans, while the third column presents additional resources that are targeted for development in the recommended Long Term Action Plans, for different industrial activity scenarios.

Table 9-4: Short and Long Term Action Plan Recommendations

Short Term Action Plan	Industrial Activity Scenario	Long Term Action Plan
	Very Low, Low	Diesel 10 MW (2026)
DSM (2018) **3rd Engine (2019)** **Whitehorse, Aishihik uprates (2020)** **Battery (2020)** **SLESP (2020)** **Diesel 20 MW (2021)** **MLESP (2022)** **Mayo A (2022)** **Standing Offer Program (2022)**	Early Minto Closure	Small Hydro 8MW (2023)
	Medium	Small Hydro 8MW (2025)
	High	Wind 20 MW (2022) Small Hydro 8MW (2023) Diesel 10 MW (2026)

9.4 Constraints

It should be noted that there are a number of practical constraints that could potentially impact the execution of both the recommended Short and Long Term Action Plans. These constraints are currently unknown, and without undue speculation could not be addressed formally in the portfolio analysis or the development of the recommended Action Plans. These constraints are:

- Access to Capital: an assumption was made in the development of the recommended Short and Long Term Action Plans that YEC will have access to the required debt and equity to finance the assets included in the plan. Any constraints in the availability of capital may impact the scope and timing of project execution, and the recommended Action Plans will be adjusted in response to any capital constraints that materialize.
- New Government Policy: existing government policies over the planning period were considered in the development of the Action Plans, including for example the application of a social cost of carbon in the determination of the economics resources. The recommended Short and Long Term Action Plans do not take future government policies into account. The Action Plans will be reassessed through YEC's annual business planning process and the formal Resource Plan update process, and adjustments will be made in response to potential new Government Policies that directly impact the Action Plan.
- Internal Resource Constraints: as a small utility, YEC has finite resources available to both plan and manage the construction of new resources. YEC leverages these internal resource through the use of external consultants to enhance the company's project development capacity. The finite availability of internal and external resources could limit the number of new projects that can be developed in any given year. The timing of projects included in the Action Plan may be adjusted in response to potential internal and external resource constraints.

9.5 Next Steps

In accordance with precedence established in the 2006 Resource Plan proceedings before the YUB, YEC has continued to update the resource plan every five years. Following the completion of the 2016 Resource Plan and submission to the YUB, detailed planning will begin for the studies, design, and permitting required to implement the resource options presented in the recommended Short Term Action Plan.

YEC will follow the stagegate project framework to define and develop resource options (new projects). The framework covers the full set of activities from project conception to construction and commissioning. The framework is a consistent industry standard approach in which large projects are divided into stages, with appropriate authorization gates between the stages. The stages in the YEC framework are: prefeasibility, feasibility, preliminary engineering, regulatory, detailed engineering, and construction. The activities associated with each stage are: engineering, socio-economic and environmental assessment, contracting and procurement, First Nation engagement and public engagement. Decision gates, positioned at the end of project stages, ensure the appropriate oversight and control by YEC management and the YEC Board. Each gate is a formal approval point (proceed to the next stage of the project, conditionally proceed to the next stage of the project, or close the further development of the project), involving a review of key project information including costs, resources, schedule, scope and residual risks. The specific evaluation approach and criteria applied at each gate

may vary depending on the preceding stage, and the purpose of the gate, but in general it aims to provide answers to the following questions:

- Quality of execution: Was the previous step executed adequately.
- Viability of project: Is the continuation of the project still desirable. i.e. is the project still the best choice from technical, financial, environmental, social and economic perspectives. As a consequence, a project substitution can potentially be pursued.
- Action plan: Are the proposed action plan and the requested resources reasonable and sound.

The end of the preliminary engineering stage is followed by the major project approval gate, requiring Board of Directors approval. Projects passing this gate will typically be advanced for regulatory review and approval. The regulatory approval stage typically consists of a review by the Yukon Environmental and Socio-economic Assessment Board (YESAB) and, depending on the type of the project, Yukon Water Board. In some instances a review by the Yukon Utilities Board may also be required.

As collaboration with First Nations and stakeholders will be critical to the success of these projects, YEC will continue to work on different aspects of planning and execution of new energy projects with:

- First Nations,
- Yukon Territorial Government,
- ATCO Electric Yukon,
- Municipal governments,
- Potential IPP proponents, and
- Consumer, business, community and environmental advocacy groups.

As work on satisfying YEC customer demands is ongoing, economic activity and consequent growth of energy and peak demand will be monitored as an indication of which Long Term Action Plan is most probable to be implemented. The Resource Plan is a living process and is updated every five years with the energy and peak demand forecasts scheduled for updating in 2018.

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