

IceGrid

Detailed cost estimates and data sources

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The purpose of this document is to clarify our assumptions and data sources in calculating costs and payback periods for the IceGrid project submission to the CanInfra challenge.

The written section below explains our calculations for the Iqaluit IceGrid. It is also presented in tabular form at the end of the document. In the interest of brevity, cost estimates for Cambridge Bay and Rankin Inlet are only presented in tabular form but use the same data sources as the Iqaluit IceGrid.

Procurement and installation costs

Wind

Iqaluit's diesel power plant has a 15 MW capacity. We therefore assessed the cost of constructing 15 MW of wind capacity, to match diesel capacity. The cost of onshore wind installation is highly variable. While it can be as low as \$1500/kW, installations in the far north are typically more expensive. We initially used a figure of \$7000/kW as it represents upper-bound estimates as reported in Arriaga et al (2013) and Thompson and Duggirala (2009). However, to be conservative, our final slide deck incorporates a figure of \$10,000 per kW - a figure quoted in a recently-approved wind project in Inuvik, NWT (Jefferd-Moore, 2018).

Utility-scale batteries

We assumed this project would employ Tesla Powerpack 2 utility-scale batteries, which are rated to an operating temperature of -30 and have been reported as having an all-in installation cost of USD \$400 per kWh (Lambert, 2016). Per Sullivan (2017), Iqaluit consumes 60,741,000 kWh per year of electricity, or 166,414 kWh per day. Therefore, to store 24 hours of electricity, 166,414 kWh of battery-storage is needed, at a cost of CAD \$79,878,575. This would represent approximately 830 Powerpack 2 batteries.

Battery warehousing

Tesla Powerpack 2 batteries are designed to be outdoors, but are rated to a minimum operating temperature of -30 degrees C. Since Iqaluit drops below that temperature, we estimated the cost of constructing a simple warehouse, with sufficient floorspace to house the batteries. Powerpack 2 batteries store 200 kWh each, and are often deployed in banks of 10 batteries. Powerpack dimensions were sourced from the manufacturer. Figure 1 is a schematic demonstrating an approximate layout, for how these batteries may be arranged in a warehouse. We estimated a floorspace of 50,000 square feet would be needed, assuming about 6 ft is clear on all sides of each battery bank. The Altus Group's Canadian Construction Cost Guide (2017) reports that the cost per square foot of warehouse construction in the territories can be estimated at CAD \$156 / sqft, for a total cost of CAD \$7,800,000.

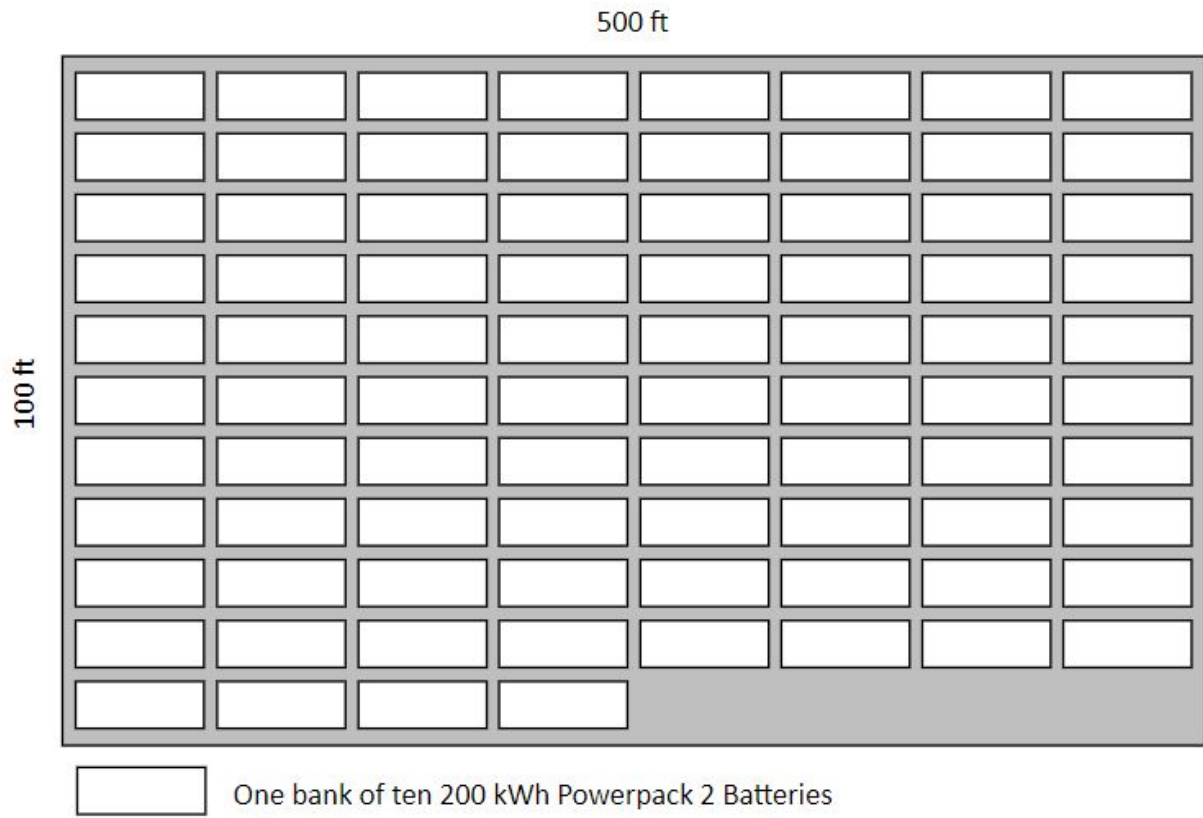


Figure 1 - Rough schematic of battery warehouse

Annual Costs

Diesel (i.e. business-as-usual)

Operation, maintenance, and fuel

Sullivan (2017) reported that combined operation and maintenance costs for Iqaluit's diesel plants operate at \$0.21 per kWh, with fuel expenses of \$0.29 per kWh. Together, these expenses total \$30,370,500 per year.

Carbon pricing

Sullivan (2017) estimated that a carbon tax at a rate of \$10/t would translate into a cost per kWh of \$0.01 at \$10/t, and \$0.05 per kWh at \$50/t. Therefore, our forecasted GHG savings assumes full elimination of diesel-derived electricity, and our forecasted carbon costs for diesel plants uses the rates per kWh as calculated in Sullivan (2017).

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Operation and Maintenance

Wind

In earlier versions of the IceGrid proposal, we used a figure of USD \$0.015 per kWh. To be extra conservative, in our final proposal, we have employed an operation and maintenance cost of USD \$0.03 per kWh, which is the reported O&M cost of onshore wind in Sweden and Norway – two northern nations with high labour costs and cold climates (International Renewable Energy Agency, 2018, page 104). The annual wind O&M cost is therefore CAD \$2,186,676.

Batteries

Few details are available in published literature for O&M costs of Tesla Powerpack batteries. We therefore calculated O&M as follows. Tesla Powerpack 1 (i.e. previous-generation, 100 kWh) batteries have been reported to be able to deliver 41,400,000 kWh over the product lifespan (Shahan, 2015). If we assume Powerpack 2 performance is equivalent (but double, because it is a 200 kWh battery) then the product lifespan will be 82,800,000 kWh. Note that “product lifespan” is defined as the batteries being capable of holding 80% of their original charge. In addition, lifespan can vary – fully depleting and fully charging the battery degrades its lifespan faster than maintaining charges in the 30-70% range.

Nevertheless, for O&M we assumed that operators would set aside money per kWh of power discharged, such that the battery could be replaced at end of life. Where batteries were estimated at USD \$80,000 per battery (i.e. USD \$400/kWh * 200 kWh per battery) O&M is calculated as USD \$0.00096 per kWh. In the interest of maintaining conservatism in our estimates, we doubled that figure, and assumed USD \$0.00192 per kWh delivered. This resulted in an O&M estimate of CAD \$139,947.26 per year owing to batteries.

Emissions

The NU Department of Environment reported that Iqaluit's electricity generation produced 38,085 t of GHGs in 2012/2013. To calculate emissions reductions, we assumed full elimination of GHGs due to diesel-electricity. Note that this is an underestimate as it incorporates only the

direct emissions as reported by the NU Department of Environment - there are additional emission associated with the production and transportation of diesel fuel itself that we do not consider. In addition, we do not consider any social or other environmental costs of diesel (see Sullivan, 2017).

Over 20 years, the cumulative emission reductions would be 761,700 t of GHGs.

The US Environmental Protection Agency estimates that a single passenger vehicle produces 4.6 t of GHGs per year (EPA, 2018). Therefore, eliminating Iqaluit's electricity-related emissions is equivalent to removing 8,279 passenger vehicles.

Cambridge Bay and Rankin Inlet

Both Cambridge Bay and Rankin Inlet have diesel power plants that have reached the end of their useful life (Senate of Canada, 2015). To estimate the cost of replacing them with new diesel plants, we examined the cost reported for building a new diesel plant in the town of Qikiqtarjuaq, which was costed at CAD \$3846 per kW (QEC, 2016). We assumed Cambridge Bay would build a 3.1 MW diesel plant, and Rankin Inlet would build a 3.55 MW plant, at costs of \$11.9 M and \$13.7 M respectively.

We assumed identical cost-per-kW and kWh respectively for wind and battery installation, operation, and maintenance. Annual energy consumption of these communities, as well as cost of carbon pricing per kWh were reported in Sullivan (2017). Annual GHG output due to electricity for these communities was taken from the 2012/2013 estimates on the NU Department of Environment website.

Tables - Iqaluit, Cambridge Bay, Rankin Inlet

EXAMPLE CALCULATIONS - IQALUIT

Electricity Consumption - Iqaluit (kWh)

Annual:	60,741,000
Daily:	166414

IceGrid Procurement Costs (\$)

	Cost (CAD \$)	Units Required	Cost
Tesla Powerpack	\$480 / kWh	166413.7	\$79,878,576
Wind Turbines	\$10,000 / kW	15000	\$150,000,000
Warehouse Facility	\$156 / sqft	46080	\$7,188,480
TOTAL Construction (One-Time)			\$237,067,056

IceGrid Operation and Maintenance Costs (\$)

	\$ per kWh (CAD \$)	Cost (Annual)
Fuel	\$0.0000	
Battery O&M	\$0.0023	\$139,947
Wind O&M	\$0.0360	\$2,186,676
TOTAL O&M (Annual):		\$2,326,623

Existing Diesel Plan Operation and Maintenance Costs (\$)

* Note: No procurement costs since plant already exists

	\$ per kWh (CAD \$)	Cost (Annual)
Fuel	\$0.29	\$17,614,890
Diesel Plant	\$0.21	\$12,755,610
TOTAL O&M (Annual):		\$30,370,500

Future Cost of Federal Carbon Tax (\$)

	\$ per kWh (CAD \$)	Carbon Tax Cost	Tax + O&M
2018	0.01	\$607,410	\$30,977,910
2019	0.02	\$1,214,820	\$31,585,320
2020	0.03	\$1,822,230	\$32,192,730
2021	0.04	\$2,429,640	\$32,800,140
2022 +	0.05	\$3,037,050	\$33,407,550

EXAMPLE CALCULATIONS - CAMBRIDGE BAY

Electricity Consumption - Iqaluit (kWh)

Annual:	10,267,000
Daily:	28129

IceGrid Procurement Costs (\$)

	Cost (CAD \$)	Units Required	Cost
Tesla Powerpack	\$480 / kWh	28128.767	\$13,501,808
Wind Turbines	\$10,000 / kW	3100	\$31,000,000
Warehouse Facility	\$179 / sqft	9000	\$1,608,750
TOTAL Construction (One-Time)			\$46,110,558

IceGrid Operation and Maintenance Costs (\$)

	\$ per kWh (CAD \$)	Cost (Annual)
Fuel	\$0.0000	
Battery O&M	\$0.0023	\$23,655
Wind O&M	\$0.0360	\$369,612
TOTAL O&M (Annual):		\$393,267

New Diesel Plan Operation and Maintenance Costs (\$)

* Note: Cambridge Bay identified as area where new plant is required

	\$ per kWh (CAD \$)	Cost (One-Time)	Cost (Annual)
Construction	\$3,846	\$39,486,882,000	
Fuel	\$0.29		\$2,977,430
Diesel Plant	\$0.21		\$2,156,070
TOTAL O&M (Annual):			\$5,133,500

Future Cost of Federal Carbon Tax (\$)

	\$ per kWh (CAD \$)	Carbon Tax Cost	Tax + O&M
2018	0.01	\$102,670	\$5,236,170
2019	0.02	\$205,340	\$5,338,840
2020	0.03	\$308,010	\$5,441,510
2021	0.04	\$410,680	\$5,544,180
2022 +	0.05	\$513,350	\$5,646,850

EXAMPLE CALCULATIONS - RANKIN INLET

Electricity Consumption - Iqaluit (kWh)

Annual:	17,625,000
Daily:	48288

IceGrid Procurement Costs (\$)

	Cost (CAD \$)	Units Required	Cost
Tesla Powerpack	\$480 / kWh	28128.767	\$13,501,808
Wind Turbines	\$10,000 / kW	3100	\$31,000,000
Warehouse Facility	\$179 / sqft	9000	\$1,608,750
TOTAL Construction (One-Time)			\$46,110,558

IceGrid Operation and Maintenance Costs (\$)

	\$ per kWh (CAD \$)	Cost (Annual)
Fuel	\$0.0000	
Battery O&M	\$0.0023	\$40,608
Wind O&M	\$0.0360	\$634,500
TOTAL O&M (Annual):		\$675,108

New Diesel Plan Operation and Maintenance Costs (\$)

* Note: Cambridge Bay identified as area where new plant is required

	\$ per kWh (CAD \$)	Cost (One-Time)	Cost (Annual)
Construction	\$3,846	\$67,785,750,000	
Fuel	\$0.29		\$5,111,250
Diesel Plant	\$0.21		\$3,701,250
TOTAL O&M (Annual):			\$8,812,500

Future Cost of Federal Carbon Tax (\$)

	\$ per kWh (CAD \$)	Carbon Tax Cost	Tax + O&M
2018	0.01	\$176,250	\$8,988,750
2019	0.02	\$352,500	\$9,165,000
2020	0.03	\$528,750	\$9,341,250
2021	0.04	\$705,000	\$9,517,500
2022 +	0.05	\$881,250	\$9,693,750

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