NorthwesTel Remote Station Solar/Diesel Hybrid Feasibility

Optimization and economic feasibility of using a solar photovoltaic (PV) array to meet the operational load of remote NorthwesTel communication station in the North Yukon.

Photo Credit: Engineer Creek Remote Microwave Station, B. Sudgen, 2012.

Prepared for: NorthwesTel
February 25, 2013

energy solutions centre

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Cold Climate Innovation YUKON RESEARCH CENTRE • Yukon College

Yukon Energy, Mines and Resources

Executive Summary

NorthwesTel has been actively working to reduce the costs of operating microwave stations at remote sites across Northern Canada. The cost of operating and maintaining these remote stations is significant, costing NorthwesTel up to $5.00/L to fuel and up to $2.5 million dollars per year to maintain. Given these costs NorthwesTel and the Energy Solutions Centre, in partnership with the Cold Climate Innovation Centre of Yukon College, completed this operational feasibility assessment of a solar photovoltaic (PV) array installed at Engineer Creek with an operational load of 1.8kW to 2.8kW. The study establishes an optimized installed system size based on the required materials and labour necessary to construct the PV array at a remote site and at a high evaluation. This analysis shows that the optimum system size from an economic perspective is likely in the range of 10-20 kW for a 1.8 kW load. The base cost of an installed PV at this size range is $0.28/kWh, which is significantly lower than the $1.53/kWh base cost of diesel energy load sufficient to power an operational load of 1.8kW.

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1. Introduction

NorthwesTel is a Canadian telecommunications utility that provides services to approximately 116,000 Northern Canadians residing in 96 communities within a service area of approximately 4,000,000 km^2. This service area encompasses Yukon, Northwest Territories (NWT), Nunavut, Northern British Columbia and Fort Fitzgerald, Alberta. Telecommunications across this broad region is provided through a system of 156 microwave stations. Of the 156 referenced stations, 87 are off-grid and reliant on independent sources of power. A total of 37 of these remote sites are only accessible by helicopter (NorthwesTel, 2011). Each remote site is comprised of one or two buildings and is powered by two air-cooled diesel engines providing an operational load of 2-15kW (Sugden and Drury, 2012).

The cost of operating and maintaining these remote stations is significant. For example, NorthwesTel spent $80,000 to power a single remote station in Parsons, NWT in 2010. Most of the costs associated with operating remote stations arise from the need to transport fuel by helicopter. The average cost of diesel slung by helicopter to a remote site was $2.47/L in 2010, $3.00/L in 2011, and was reported to be up to $5.00/L in 2012 (NorthwesTel, 2011, Sugden and Drury, 2012). The repair and maintenance of the remote sites is also expensive, costing NorthwesTel $2.5 million dollars in 2010 (NorthwesTel, 2011).

NorthwesTel has been actively working to reduce the costs of operating these remote sites for some time. For example, remote sites were originally powered by a single diesel engine through a prime power system model, which operated continually. NorthwesTel has since incorporated a cycle/charge system into their remote sites. In a cycle/charge scenario, a diesel engine operates at full power to supply a large station battery when required. Once the battery has been charged, the diesel engine turns itself off. Implementation of the cycle/charge mode has demonstrated fuel conservation of 50 percent when compared to the prime power mode in where the diesel engine operates continuously. However, the expense of the cycle/charge equipment has limited implementation of the system to sites where fuel costs are greater than $3.00/L (Sugden and Drury, 2012). NorthwesTel has also investigated methods for reducing the costs of managing remote stations through a partnership with the Cold Climate Innovation Centre of Yukon College (CCI). From 2009 to 2012 NorthwesTel and CCI tested the feasibility of replacing its diesel generators with diesel fired Stirling engine combined heat power unit (CHP). The preliminary findings were inconclusive, but did suggest that "solar combined with a CHP could offset approximately one-third of annual fuel consumption," with significant possible savings (Sugden and Drury, 2012: 5).

To a limited extent, the feasibility of a solar photovoltaic (PV) array to reduce the cost of power generation at remote stations has been previously explored. In 1997, a hybrid PV/diesel system, similar to that envisioned in this study, was installed at a remote site at the Nahanni Range Station, NWT (61.5°N, 2,600 metres above sea level). The hybrid PV/diesel system provided 75 percent of the power required by the station, offsetting approximately $10,000 per year in costs. At an installation cost of $50,000, the hybrid PV/diesel system was expected to pay for itself within five years (Martel, 1999). However, the station was dismantled after NorthwesTel's contract to supply services to Government of

Yukon, the only client requiring services from the site, lapsed. The station, including the hybrid PV/diesel system, was dismantled at that time. At the time, NorthwesTel concluded that the business case for a wider application of PV array was not viable due to the long payback on the time of investment. NorthwesTel was also concerned about the uncertainties associated with the life of a PV system. Such uncertainties were apparent in the Nahanni PV array case, which was dismantled after only a third of its operational life, with subsequent impacts on the cost of investment (Personal comment B. Sugden, Manager Infrastructure Planning NorthwesTel, 2013).

Figure 1: Context Map Showing the Location of the Engineer Creek Remote Station.

Given that the price of PV has been declining, NorthwesTel has decided to re-evaluate the business case for the inclusion of PV in its cycle/charge systems. This report investigates the feasibility of installing a hybrid PV/diesel system to provide power to the remote cycle/charge transfer station located at Engineer Creek (65.2°N, 1,318masl) in the north of Yukon based on a comparison of the cost per kilowatt hour ($/kW) of an installed PV array against the cost per kilowatt hour for diesel. (See Figure 1 for Context Map) The current cost of diesel energy use to meet an operational load of 1.8, 2.5 and 2.8kW is provided in Table 1. These operational load limits were selected for use in this study because NorthwesTel's cycle/charge sites currently meet a base operational load of 1.8kW and NorthwesTel is currently evaluating increasing the operational load by 700 to 1000 watts (Personal comment B. Sugden, Manager Infrastructure Planning NorthwesTel, 2013).

Table 1: Cost per kWh ($/kWh) for Diesel Generation at Engineer Creek Station			
$/kWh Diesel	1800 watts	2500 watts	2800 watts
Wholesale Fuel Rate ($/L)	$3.06	$3.06	$3.06
Consumption (L/day)	23	30	35
Load (kW)	1.8	2.5	2.8
Load Provided per Day (kWh/day)	43.2	60	67.2
Current Plant Efficiency	19.4%	20.6%	19.8%
Daily Fuel Cost ($/day)	$70.38	$91.80	$107.10
Diesel Cost ($/kWh)	$1.63	$1.53	$1.59

2. Determining the Operational Feasibility of a Solar Array at Engineer Creek

Unlike a diesel cycle/charge site that meets a constant year-round operational load, a PV system is strongly influenced by the varying availability of solar radiation resource throughout the year (i.e., the amount of sunlight available shifts with the seasons). The following analysis was undertaken in an effort to characterise the level of useful PV energy that can be generated from a PV system for the purpose of meeting the load requirements of a cycle/charge site – currently 1800 watts - in order to demonstrate the viability of a PV array installed at a high altitude and northern latitude.

Energy Solutions Centre used the PVSyst® modelling software to model the useful PV energy generated by various capacities of solar PV systems for this application. A sample of this modelling was done for an 8 kW (Figure 2) and 12 kW sized PV system (Figure 3) where the solar PV array is mounted on a vertical surface facing due south. (The vertical array tilt angle is the reason why the PV array generates its greatest amount of energy in February, March and April.)

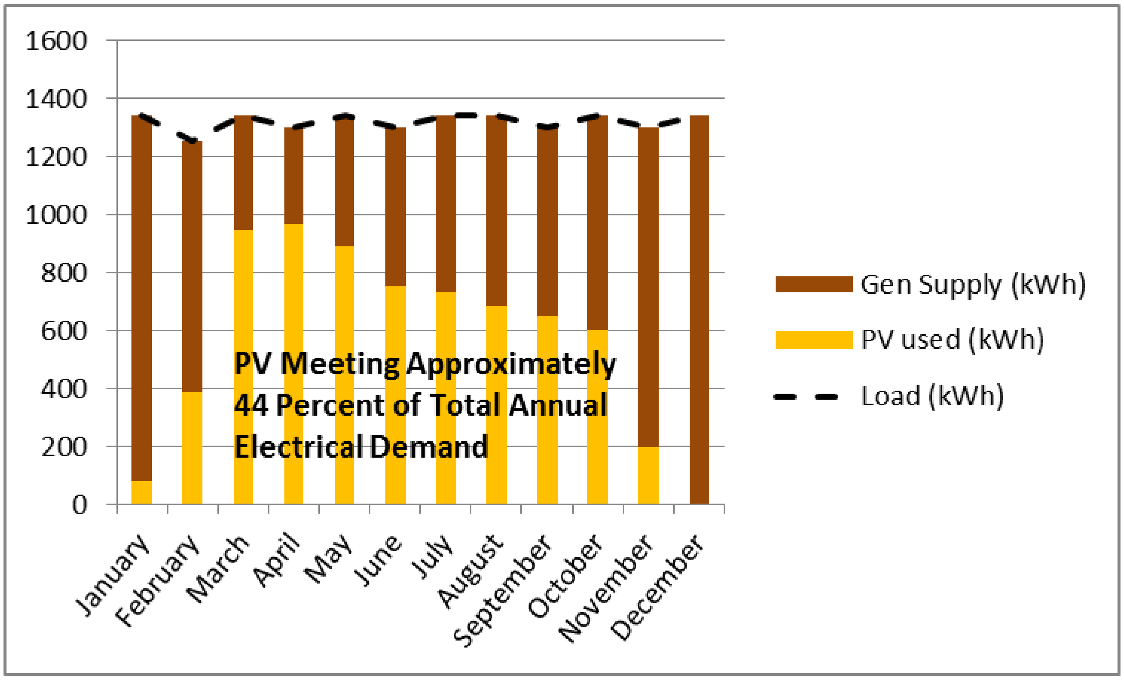

Figure 2: Simulation of an 8 kW solar PV system for a NWTel remote site with a constant 1.5 kW load.

From the analysis it is evident that an 8 kW PV system generates 44 percent of the useful energy that the system requires for the bulk of the year resulting in all the PV energy being used by the site loads. At 12 kW, the PV system begins to generate more energy than is required during the spring (March, April and May) and meets 64 percent of the useful energy that the system requires. Thus, while not all of the energy being produced is useful to the system, the array does meet a significant amount of the annual electrical demand. Waste this small amount of PV energy for these months can be acceptable since the additional PV energy from the larger PV system continues to be valuable for the balance of the year.

A PV array of between 8 and 12kW is therefore technically feasible for use in providing power to a remote cycle/charge site such as Engineer Creek at a constant operational load of 1.8kW.

It should be noted that for the proposed site the increase in useful energy will never reach 100 percent of the total system load. This is a function of the very low solar resource available during the winter months of December and January.

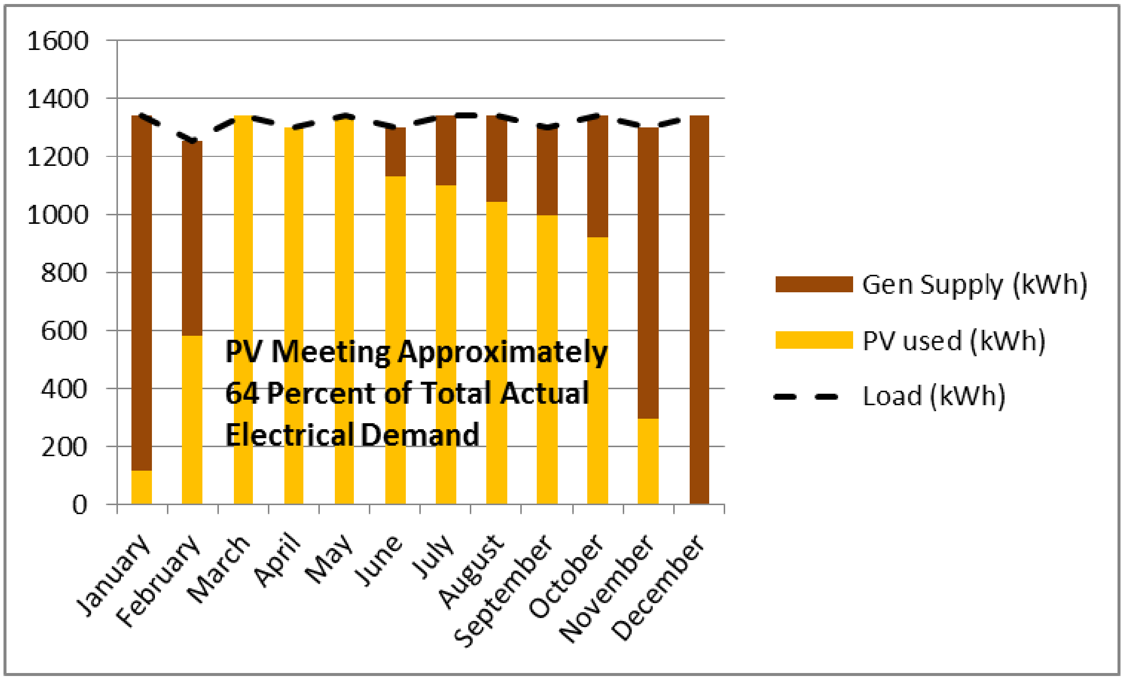

Figure 3: 12 kW PVSyst® model for a NorthwesTel remote side with a constant 1.8 kW load.

3. Establishing the Installation Cost of a PV Array at Engineer Creek Cycle/Charge Site

The economic feasibility of a PV array installed at Engineer Creek is predicated on an analysis of the material costs for two hypothetical PV arrays: a small array of 5 kW and a much larger array of 50 kW. While the 50 kW array exceeds the feasible size of the actual system installed at Engineer Creek, it was useful to compile the information on such a scenario to determine an optimal system capacity.

Installation of a PV array at the Engineer Creek station (Figure 4) would require the construction of a rock mounted framework designed by a structural engineer and installed by two journeyman electricians. Electrical drawings would also be required. The Energy Solutions Centre worked with various experienced contactors to determine the installation costs for each hypothetical PV system. Note that all PV capacity terms are referencing the direct current (DC) capacity of the solar PV array.

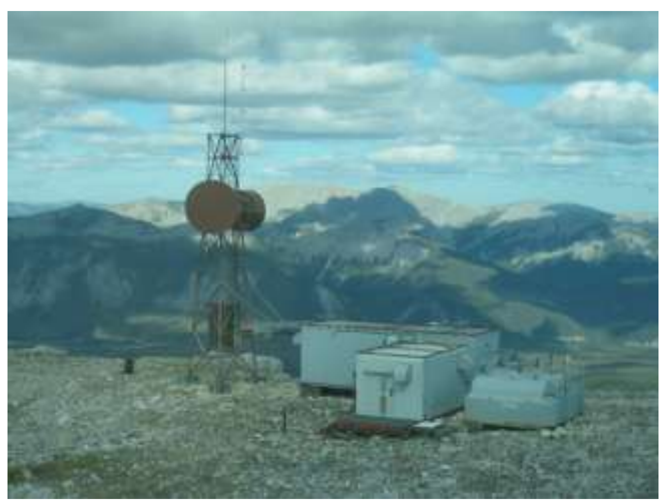

Figure 4: Engineer Creek Remote Microwave Station.

The combined material weight of the array, the electricians and the required supplies are provided in Table 2 for the small (5 kW) and the large (50 kW) array.

Table 2: Weight of Materials for Two PV Array Scenarios				
	5 kW Scenario		50 kW Scenario	
Material Weight	# of Units	Total Weight	# of Units	Total Weight
Array	1	1543.24	1	15432.36
Electricians	2	400	2	400
Supplies (1/5 kW Array)	1	50	10	500
Tools (for 2 electricians)	1	250	1	250
Total weight (lbs)		**2243.24**		**16582.36**

The material weights in Table 2 yielded a range of installed costs for the two PV array scenarios. The results of this research is summarized in Table 3 below and detailed in Appendix A.

Table 3: Costs per Array	5 kW PV Array		50 kW PV Array	
Total Costs	Total	$/kW Installed	Total	$/kW Installed
Material Costs	$10,920.00	$2,184.00	$100,100.00	$2,002.00
Design Costs	$28,067.00	$5,613.00	$48,400.00	$968.00
Labour Costs	$9,830.00	$1,966.00	$45,345.00	$907.00
Transportation Costs (low)	$7,012.50	$1,402.50	$18,505.50	$370.00
Transportation Costs (high)	$14,000.00	$2,800.00	$22,165.00	$443.00
Total Cost (low)	**$55,829.50**	**$11,165.50**	**$212,350.50**	**$4,247.00**
Total Cost (high)	**$62,817.00**	**$12,563.00**	**$216,010.00**	**$4,320.00**

Table 3 demonstrates that, while the total system costs increase as the capacity increases, the cost per kW installed decreases as the capacity increases. This is a function of the reduced unit costs associated with purchasing in bulk along with relatively large upfront cost of transportation and travel associated with this particular project (i.e., the economy of scale for purchasing materials improves with the capacity of the array).

As with all economies of scale, this decrease in unit cost will not continue in perpetuity. While reasonable to expect that the unit design costs ($/installed kW) will continue to decrease as the PV capacity is scaled up, this will eventually be offset by the material costs, labour costs, and transportation costs. These costs will remain unchanged and as the PV system scales up from 50 kW and the beneficial aspects of bulk purchasing these goods and services will decrease. This relationship is important because it allows us to isolate and eliminate the design costs of the array. This is done by scaling up the size of the PV array until it is large enough to equal the material, labour and transportation costs accounted for in the 50 kW scenario without including the design costs. The artificial data point established subsequently makes it possible to derive a relationship between PV system size and cost per kW installed, given in Figure 5.

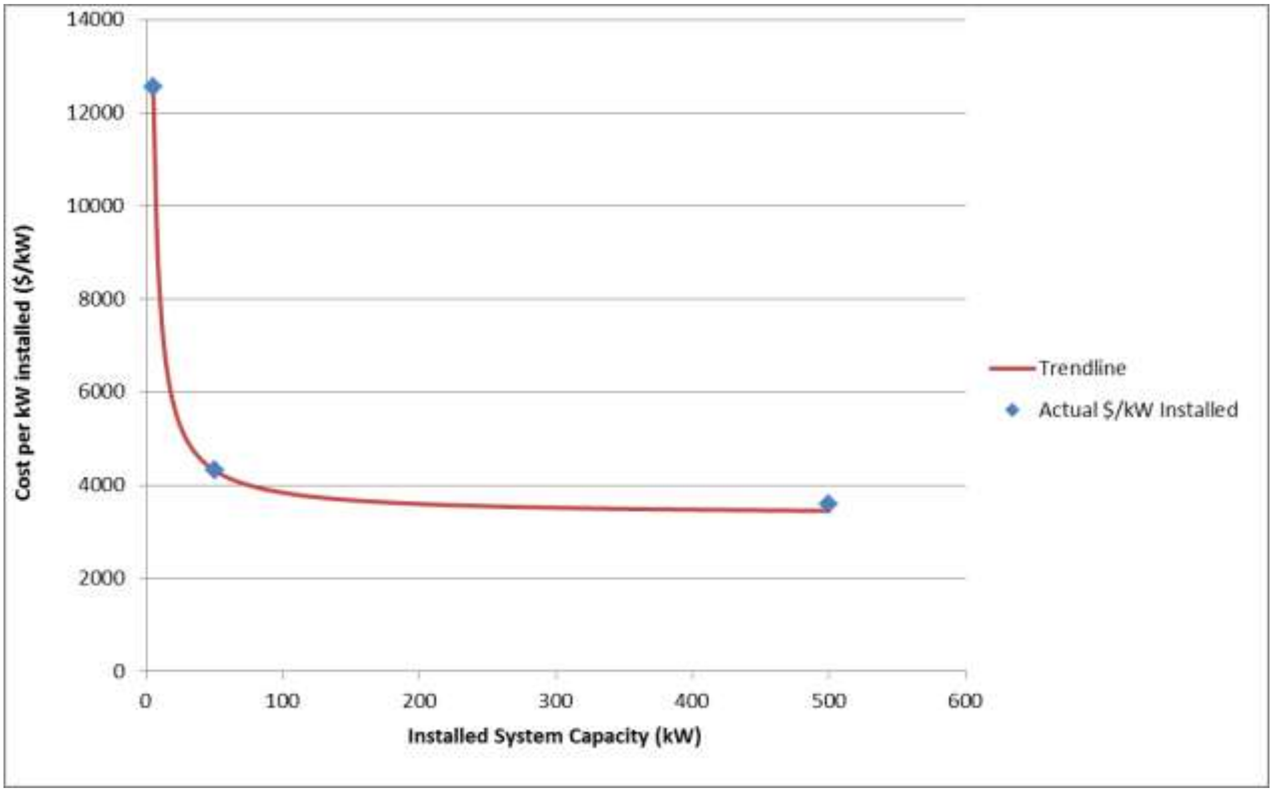

Figure 5: Relationship between installed PV system capacity-price ($/kW installed) and installed PV system capacity.

Integrating this estimated relationship across the likely PV system capacities for this project (1 kW to 50 kW) shows a nearly linear relationship between PV system capacity and final PV system costs (Figure 6).

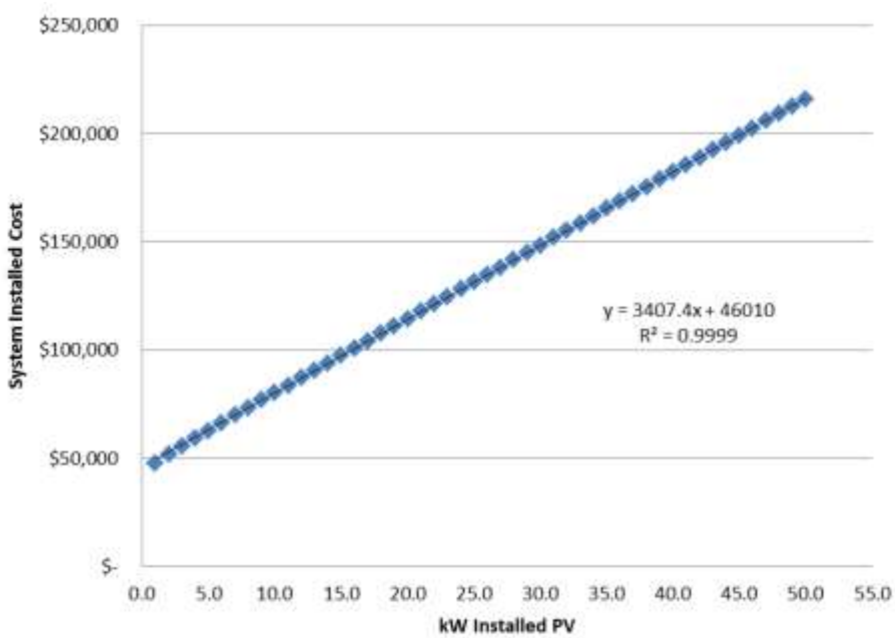

Figure 6: PV System installed Cost vs. PV System Capacity (kW).

Figure 6 estimates an initial project capacity, independent of cost, of approximately $46,000. The cost of installation increases linearly at a rate of approximately $3,400/kW installed.

4. Optimizing the Size of a PV System Installed at the Engineer Creek Cycle/Charge Site

By carrying this modeling process forward for multiple capacity PV systems providing the operational loads provided by diesel generation, 1.8 kW to 2.8 kW, the following relationship between system capacity and useful energy was determined (Figure 7).

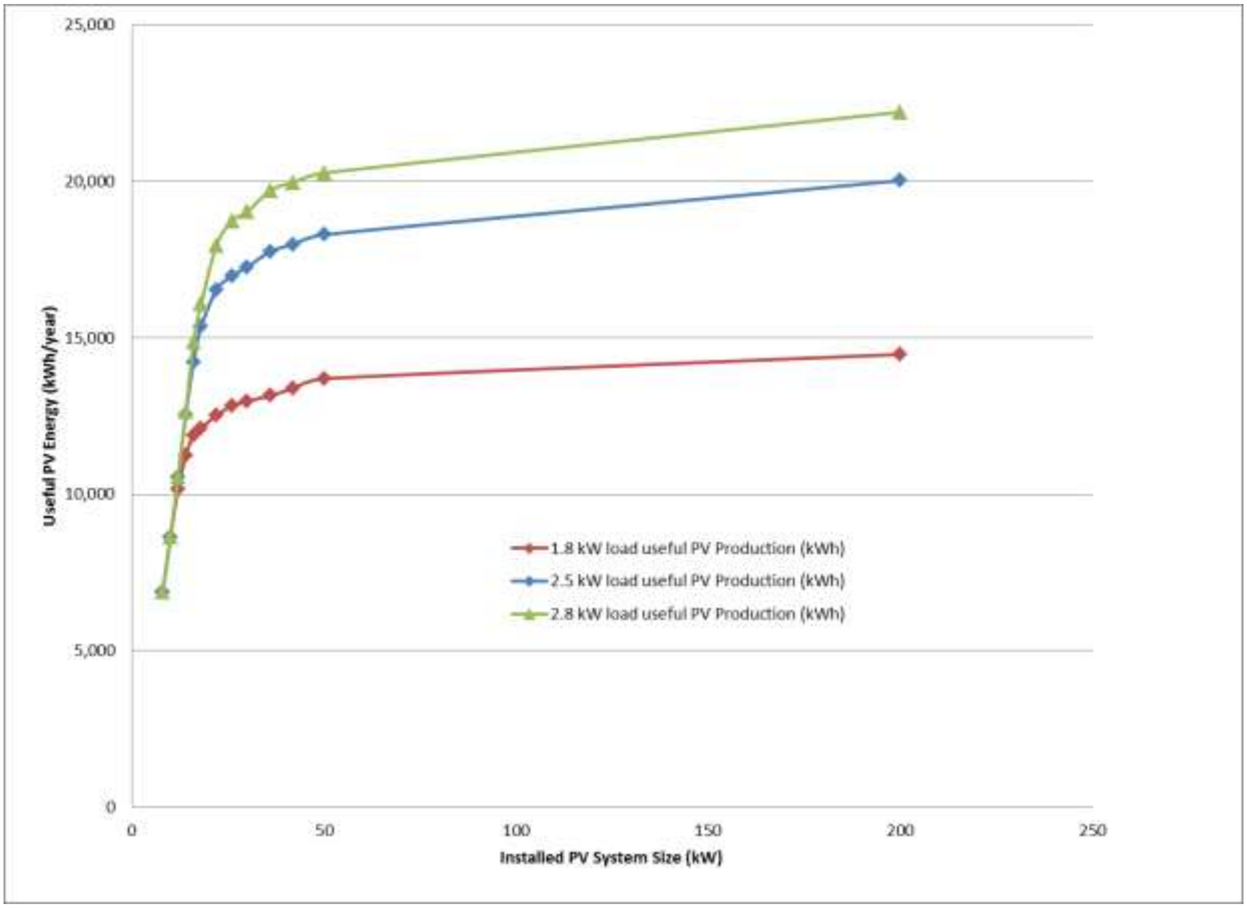

Figure 7: Useful energy from PV system vs. installed PV system capacity.

It is evident from the relationship between useful energy and installed PV system capacity that, as the PV system capacity increases, the useful energy generated increases. However, the rate of increase begins to drop sharply as the system capacity approaches 50 kW because the installed PV system is providing more energy that is not useful to the cycle/charge system (as illustrated in Figure 2).

Essentially smaller and smaller gains are made by the system in early spring and fall while more and more energy is being generated in the spring and summer that the system is unable to use. This relationship suggests that the optimal systems capacity to provide the required operational loads is below 50 kW regardless of the operational load.

Building on the relationship between the useful energy of the system and the system cost allows a simple cost of energy in relation to system size to be derived. A cost-optimised PV system capacity was therefore derived (Figure 8) by comparing the useful PV energy and PV system cost relationships with PV system capacity.

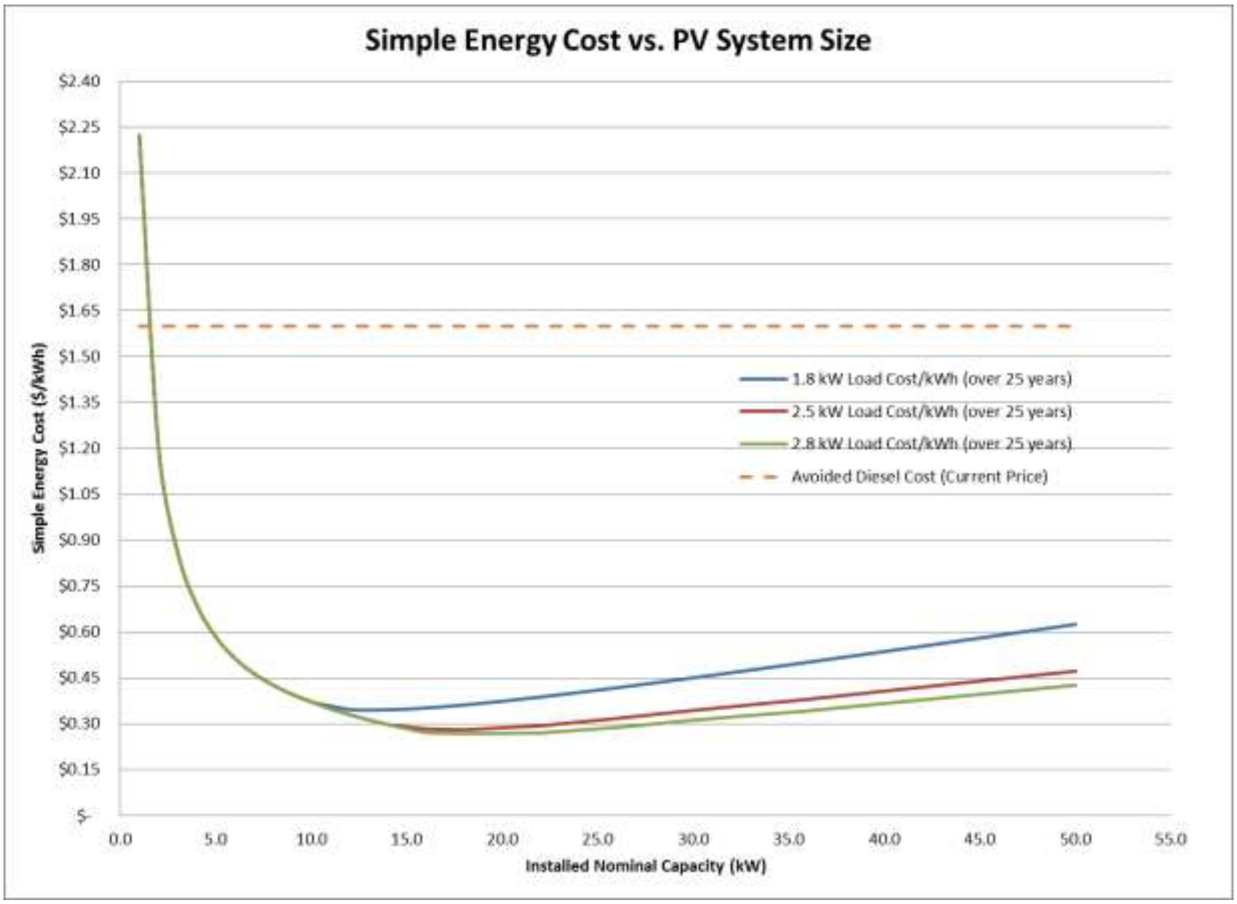

Figure 8: Simple PV Energy Price vs. Installed PV system Capacity (kW).

This analysis shows that a cost-optimised PV system capacity is likely in the range of 10 to 20 kW for a 1.8 kW load and 15 to 25 kW for the 2.5 kW and 2.8 kW load scenarios. It should be noted, however, that the simple PV energy price for the three PV system scenarios are all significantly lower than the current price of diesel generation at these sites (shown by the orange dashed line).

The optimized relationship between PV arrays and diesel systems essentially means that, while the optimized cost of energy supply for PV arrays will equal the price of diesel at much larger PV system capacities, much larger PV arrays are economically feasible. Where PV arrays will only become more expensive than diesel systems at very large capacities, such as up to where the site loads are 100% PV supplied for all but winter months, or where the price of PV electricity equals the price of diesel electricity.

5. Determining the Economic Feasibility of a Solar Array at Engineer Creek

Based on a relatively simple[1] assessment of the economic feasibility of a solar array installed at Engineer Creek, calculated using the current cost of diesel generation at these sites, a 10 kW array will require a base cost of $0.37/kW to meet an operational load of 1.8 kW to 2.8 kW. A larger 25 kW system will require a base cost of $0.41/kW to meet a 1.8 kW load. This cost drops to $0.28 kW to meet a 2.8 kW load.

The base cost of both scenarios is significantly lower than the $1.53 to $1.63/kW base cost of diesel energy load sufficient to power an operational load of 1.8 to 2.8 kW.

The complete assessment of operational PV energy costs compared to the base cost of diesel for PV array between 10 kW and 25 kW, and including the total cost of each array, is provided in Table 4. Table 4 also provides a simple assessment of the payback period for the array size by operational load. This simple assessment, which does not include the costs of operations, maintenance, inflation or depreciation, suggests that the payback period for a solar array would be approximately five to eight years.

[1] Note that the term "simple" is used to reference the economic analysis conducted in this report as an extensive economic analysis was not performed on the PV system costs and benefits, such as could include estimated discount rates, cost of financing, diesel fuel escalation rates, the environmental and social value of reduced greenhouse gas emissions, the effect of reduced depth of battery discharge on the costs of maintenance and lifetime of the battery bank, and the effect of reduced generator run-time on the costs of maintenance and lifetime of the diesel generator.

Table 4: Cost of Energy and Payback Period for a 10kW to 25kW Solar Array			1.8 kW Site Load			2.5 kW Site Load			2.8 kW Site Load		
PV System Size (kW installed)	PV System Cost	Avoided Diesel Cost (Current Price $/kWh)	PV Energy Cost* ($/kWh)	Savings ($/year)	Simple Payback	PV Energy Cost* ($/kWh)	Savings ($/year)	Simple Payback	PV Energy Cost* ($/kWh)	Savings ($/year)	Simple Payback
10.0	$ 80,275.12	$ 1.60	$ 0.37	$ 10,598.60	7.57	$ 0.37	$ 10,598.60	7.57	$ 0.37	$ 10,598.60	7.57
11.0	$ 83,723.31	$ 1.60	$ 0.36	$ 11,602.79	7.22	$ 0.35	$ 12,004.67	6.97	$ 0.35	$ 12,004.67	6.97
12.0	$ 87,163.12	$ 1.60	$ 0.35	$ 12,607.31	6.91	$ 0.33	$ 13,411.08	6.50	$ 0.33	$ 13,411.08	6.50
13.0	$ 90,595.89	$ 1.60	$ 0.34	$ 13,187.22	6.87	$ 0.31	$ 14,928.16	6.07	$ 0.31	$ 14,928.16	6.07
14.0	$ 94,022.66	$ 1.60	$ 0.35	$ 13,649.07	6.89	$ 0.30	$ 16,445.49	5.72	$ 0.30	$ 16,445.49	5.72
15.0	$ 97,444.24	$ 1.60	$ 0.35	$ 14,018.86	6.95	$ 0.29	$ 17,591.03	5.54	$ 0.28	$ 18,083.19	5.39
16.0	$ 100,861.29	$ 1.60	$ 0.35	$ 14,315.59	7.05	$ 0.28	$ 18,736.75	5.38	$ 0.27	$ 19,721.07	5.11
17.0	$ 104,274.37	$ 1.60	$ 0.36	$ 14,553.48	7.16	$ 0.28	$ 19,501.03	5.35	$ 0.27	$ 20,568.71	5.07
18.0	$ 107,683.92	$ 1.60	$ 0.36	$ 14,743.34	7.30	$ 0.28	$ 20,265.44	5.31	$ 0.27	$ 21,416.48	5.03
19.0	$ 111,090.31	$ 1.60	$ 0.37	$ 14,893.55	7.46	$ 0.28	$ 20,599.99	5.39	$ 0.27	$ 22,028.31	5.04
20.0	$ 114,493.88	$ 1.60	$ 0.37	$ 15,010.67	7.63	$ 0.29	$ 20,934.64	5.47	$ 0.27	$ 22,640.24	5.06
21.0	$ 117,894.88	$ 1.60	$ 0.38	$ 15,099.92	7.81	$ 0.29	$ 21,269.40	5.54	$ 0.27	$ 23,252.28	5.07
22.0	$ 121,293.57	$ 1.60	$ 0.39	$ 15,165.51	8.00	$ 0.29	$ 21,604.26	5.61	$ 0.27	$ 23,864.42	5.08
23.0	$ 124,690.13	$ 1.60	$ 0.40	$ 15,210.86	8.20	$ 0.30	$ 21,645.19	5.76	$ 0.27	$ 24,045.91	5.19
24.0	$ 128,084.76	$ 1.60	$ 0.40	$ 15,238.75	8.41	$ 0.31	$ 21,686.21	5.91	$ 0.28	$ 24,227.49	5.29
25.0	$ 131,477.60	$ 1.60	$ 0.41	$ 15,251.51	8.62	$ 0.31	$ 21,727.30	6.05	$ 0.28	$ 24,409.14	5.39

*PV energy costs are aggregated over a predicted 25 year project lifespan.

It should be noted that the reference to a 25-year project lifespan is not to indicate that the solar PV modules only last for 25 years, but rather that 25 years was used to establish a reasonable economic analysis period.

6. Preliminary Conclusions and Next Steps

This analysis shows that an optimum system size from an economic perspective is likely in the range of 10 to 20 kW for a 1.8 kW load and 15 to 25 kW for the 2.5 kW and 2.8 kW load scenarios.

The base cost of both scenarios, ranging from $0.28/kWh to $0.41/kWh, is significantly lower than the $1.53 to $1.63/kWh base cost of a diesel energy load sufficient to power an operational load of 1.8 to2.8 kW.

In the spring of 2013, NorthwesTel determined that the installation of a PV array at Engineer Creek was feasible based on the base cost estimates in this report and determined that it would proceed to the construction phase of a 15 kW array in partnership with the Cold Climate Innovation Centre of Yukon College and the Energy Solutions Centre. At that time, construction was scheduled for the summer of 2013. The collection of performance data from the installed PV array is a planned component of work going forward.

With this in mind, it is recommended that this report be updated after a minimum of one year of data collection to determine how the actual cost and performance of a PV array at a remote site match up with the performance and costs estimated in this report.

7. References

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Appendix A: Detailed Cost Analysis

SITE DESCRIPTION: ENGINEER CREEK REMOTE MICROWAVE STATION			
Factors		Travel time/hour (one way)	Distance
Location	Dempster Region		
Distance Traversed	Travel to km 159 Dempster Highway (sling site)		
Mode of transportation recommended (to sling site)	5-ton Picker truck with 18' deck	N/A	1,500 km
Mode of transportation recommended (from sling site)	Helicopter from sling site to remote station	0.25	
Other travel (helicopter from Dawson to sling site)		1	
Helicopter contractor	Fireweed	Trans North	

MICROWAVE STATION FUEL CONSUMPTION AND COST DATA			
$/kWhDiesel	1800 watts	2500 watts	2800 watts
Wholesale fuel rate ($/L)	$3.06	$3.06	$3.06
Consumption (L/day)	23	30	35
Load (kW)	1.8	2.5	2.8
Load provided per day (kWh/day)	43.2	60	67.2
Current plant efficiency	19.4 percent	20.6 percent	19.8 percent
Daily fuel cost ($/day)	$70.38	$91.80	$107.10
Diesel cost ($/kWh)	$1.63	$1.53	$1.59

PRODUCTION CAPACITY SCENARIOS		
kWh PV	5 kW Scenario	50 kW Scenario
Production capacity (kW)	5	50

MATERIAL WEIGHT	5 kW Scenario				50 kW Scenario			
	Weight	Unit	# of Units	Total Weight	Weight	Unit	# of Units	Total Weight
Array	1,543.24	lbs	1	1,543.24	1,5432.36	lbs	1	1,5432.36
Electricians	200	lbs	2	400	200	lbs	2	400
Supplies (1/5 kW array)	50	lbs	1	50	50	lbs	10	500
Tools (two electricians)	250	lbs	1	250	250	lbs	1	250
Total weight (lbs)				**2,243.24**				**16,582.36**

MATERIAL COST	Unit	5 kW Scenario	Unit	50 kW Scenario
Modular price (80c/w)		$4,000.00		$40,000.00
Racking (10c/w)		$3,500.00		$35,000.00
Rock bolts	10	$1,000.00	100	$10,000.00
Charge controller	1	$600.00	10	$6,000.00
Estimated retail markup	20 percent	$1,820.00	10 percent	$9,100.00
Total Material Cost		**$10,920.00**		**$100,100.00**
Total Material Cost per kWh		**$2,184.00**		**$2,002.00**

		5 kW Scenario			**50 kW Scenario**		
DESIGN COST	Unit	Cost/Unit	# of Units	Total $	Cost/Unit	# of Units	Total $
Electrical design	Drawing	$4,000	1	$4,000	$10,000	1	$10,000
Structural design	Drawing	$2,666.67	1	$2,667	$15,000	1	$15,000
PV system commissioning	Travel + six hours on site	$7,000	1	$7,000	$7,000	1	$7,000
Intial site visit				$5,000			$5,000
Structural assessment	Travel + six hours on site	$7,400	1	$7,400	$7,400	1	$7,400
Additional design charges	Listed			$2,000			$4,000
Total Design Cost				**$28,067**			**$48,400**
Total Design Cost per kWh				**$5,613.33**			**$968**

LABOUR COST: 5 kW SCENARIO					
Expenditure	Unit	Cost/ Unit	# of Units	Total $ (per day)	$/kW Installed
Electrician	Hourly	95/hr	12/day	$3,420.00	$8.50
Electrician	Hourly	95/hr	12/day	$3,420.00	$8.50
Food costs	day	$87.65	3	$262.95	$2.19
Site visit (to scout location)				$2,727.65	
Total Cost				**$9,830.60**	
Total Labour Cost per kWh					**$59.19**

LABOUR COST: 50 kW SCENARIO					
Expenditure	Unit	Cost/ Unit	# of Units	Total $	$/kW installed
Electrician	Hourly	95/hr	12/day	$20,520.00	$17.10
Electrician	Hourly	95/hr	12/day	$20,520.00	$17.10
Food costs	day	$87.65	18	$1,577.70	$1.31
Site visit (to scout location)				$2,727.65	
Total Cost				**$45,345.35**	
Total Labour Cost per kWh					**$35.51**

TRANSPORTATION COSTS: 5 kW SCENARIO					
	Unit	Cost/Unit	# of Units	Total $	$/kW installed
Light helicopter (weight limit is 800-1,000 lbs)	Hour	$1,500.00	0.7	$1,051.52	$210.30
			0.6	$841.22	$168.24
Heavy helicopter (weight limit is 2,500 lbs)	Hour	$3,000.00	1	$3,000.00	$600.00
		$4,000.00		$4,000.00	$800.00
Ground freight	Trip (from Whitehorse - three to four days)	$6,000.00	1	$6,000.00	$1,200.00
	Shipping (Edmonton/ Whitehorse)	$2,000.00	1	$2,000.00	
Total Transportation Costs (low)				**$8,841.22**	**$1,768.24**
Total Transportation Cost (high)				**$12,000.00**	**$2,400.00**

TRANSPORTATION COSTS: 50 kW SCENARIO					
	Unit	Cost/Unit	# of Units	Total $	$/kW installed
Light helicopter (weight limit is 800-1,000 lbs)	Hour	$1,500.00	5.2	$7,772.98	$155.46
			4.1	$6,218.39	$124.37
Heavy helicopter (weight limit is 2,500 lbs)	Hour	$3,000.00	1.7	$4,974.71	$99.49
		$4,000.00		$6,632.94	$132.66
Ground freight	Trip (from Whitehorse - three to four days)	$6,000.00	2	$12,000.00	$240.00
	Shipping (Edmonton/ Whitehorse)	$20,000	1	$20,000	
Total Transportation Costs (low)				**$36,974.71**	**$739.49**
Total Transportation Cost (high)				**$39,772.98**	**$795.46**

TOTAL COST PER INTALLED kW BY SCENARIO		
Total Costs ($/kWh)	5 kW PV Array	50 kW PV Array
Material costs	$2,184.00	$2,002.00
Design costs	$5,613.33	$968.00
Labour costs	$59.19	$35.51
Transportation costs (low)	$1,768.24	$739.49
Transportation costs (high)	$2,400.00	$795.46
Total Cost per kW Installed (low)	**$9,624.77**	**$3,745.01**
Total Cost per kW Installed (high)	**$10,256.52**	**$3,800.97**