Milford Opportunities Project

Energy Assessment Recommendations

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Contents

List of tables

List of figures

List of Appendices

1. Introduction

This report consolidates the results from a number of reports forming part of the energy assessment of the Milford Opportunities Project (MOP). The purpose is to provide a recommendation on meeting the energy demands of the infrastructure and transportation system of MOP. The reports referenced are listed below:

- MOP Existing Hydropower Potential, Stantec, May 2024
- MOP Additional Hydropower Potential, Stantec, May 2024
- MOP Alternative Energy Supply Options, Stantec, May 2024
- MOP Low and Zero Transport Carbon Emission Feasibility Study, Stantec, May 2024
- MOP Infrastructure Energy Demand, Stantec, May 2024

These reports assessed the technical feasibility, operational feasibility, and constructability of each of the options. The recommendations and information from these reports were captured and were used as input to an Energy Model using HOMER to assess the various energy supply options. Any feasible options were then compared in terms of its environmental impact, any Scope 2 emissions, cost, and risks to determine a best value for money solution.

2. Transport recommendations

From the report, *MOP Low and Zero Transport Carbon Emission Feasibility Study* (Stantec, 2024), it was concluded that the following is the preferred option:

- **Battery-electric bus and boat fleets:** with the limitations being an uncertainty regarding the energy source for recharging, and battery disposal.

The following may be used as transitional options until such time as full conversion to electrical energy becomes feasible:

- Existing tour boats introduce **blended fuel** regimes into current operations.
- Tour boats be replaced with **hybrid vessels** as they reach the end of their operational life.
- Tour boats transition to use of **100% biofuels or synthetic diesel** as these fuels become available.
- **Hybrid buses** may be introduced for the hop on/hop off Te Anau – Milford service also transitioning to the use of **100% biofuels or synthetic diesel.**

3. Energy supply recommendations

From the report, *MOP Alternative Energy Supply Options* (Stantec, 2024), it was found that the supply options for energy would be a connection to the National Grid or otherwise, a combination of locally installed hydropower, solar power and batteries. These two options are briefly discussed below:

3.1 National Grid option

The National Grid option would supply power Milford Sound and to all nodes en route (supplementing existing hydropower where applicable).

As hydrogen was discounted as a feasible option for the transportation system, it was not investigated further in this report. Although it can still be used instead of batteries for the fully renewable microgrid option, it is preferred to use it as part of a complete hydrogen solution.

3.2 Fully renewable microgrid option

For energy supply from renewable microgrids, the following energy sources could be used at each node:

- Node 2 - Eglinton Reveal: Solar and batteries
- Node 3 - Te Huakaue Knobs Flat: Existing hydropower, solar and batteries
- Node 4 - Otapara Cascade Creek/Mistake Creek: Solar and batteries

- Node 5 - The Divide / Whakatipu Trails Head: New hydropower, solar and batteries
- Node 6 – Gertrude Valley: Solar and batteries
- Node 7 - Cleddau Cirque: Solar and batteries
- Milford Hub: Hydropower, solar and batteries

3.3 Reliability of supply

In providing electricity supply to the various locations, consideration must be given to ensuring the reliability of supply. The electricity industry in New Zealand generally adopts a requirement that power supply to any major load needs to have firm capacity equalling that load. To achieve firm capacity, the failure of any single item within the electricity delivery system should not affect customer supply. This level of security is usually established by duplicating key equipment items and providing route diversity of power lines.

The existing electrical infrastructure at Milford includes redundancy at a power generation level. Most power is generated from a hydroelectric power plant, with diesel generation being provided as backup. Redundancy of the transportation fleet is provided inherently due to the multiple numbers of buses and boats operating, all with their own "on board" motive power source (diesel fuelled).

Conversion of the operations at Milford Sound entirely to an electrical based energy supply will create reliability issues such as:

- Renewable energy options are limited, with no real capacity for providing redundancy/backup power sources from other local renewable sources.
- Transmission connection options are also limited to a single corridor within the National Park (along the road). Redundancy could be provided with a second power line, but as it would by necessity follow the same route supply security could not be assured.
- The bulk of the load will be at Milford Sound, and using backup power sources remote from Milford itself, will require a power line to Milford, which will also be prone to interruption.

For the above reasons it is advised that for any of the power supply options, emergency standby power generation at the critical Nodes will be required. For the purposes of this study diesel fuelled generation has been assumed, but hydrogen fuelled sets could be used so long as green hydrogen supply can be assured.

At Milford Sound, the location as indicated on Figure 3-1 has been identified as a site for the emergency backup generation. This would be far enough out of town to help prevent noise and emission complaints and would also be a suitable location for terminating any power cable from either Te Anau or a hydropower scheme from the Tūtoko.

Note that the most likely expected Tsunami will have a height of 17 m and that the proposed emergency backup generation site is located within such a Tsunami's impacted area. No other suitable sites have been identified at this stage that would not require disturbance to the natural environment. Further investigation will be required if taken forward.

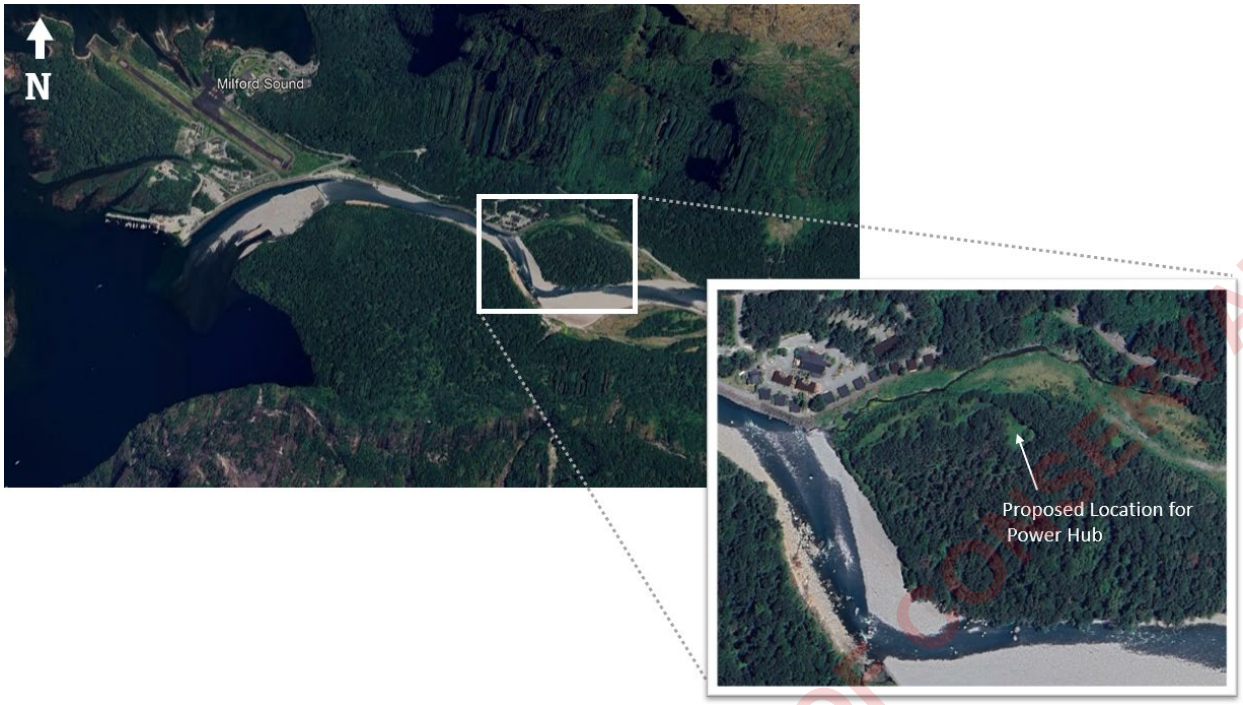

Figure 3-1: Backup generation facility location at Milford Sound

4. Energy demands

The monthly energy demands for each node and mode of transport is provided in the table below. For more information on these values, refer to the report, *MOP Infrastructure Energy Demand* (Stantec, February 2024).

Table 4-1: Monthly Energy Demand (kWh)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
Node 2	Infrastructure	1,095	1,093	1,277	1,279	1,104	1,020	1,054	1,026	1,047	1,160	1,138	1,183	13,476
Node 3	Infrastructure	69,275	68,925	80,354	80,426	69,853	64,640	66,794	65,095	66,284	73,251	71,842	74,679	851,418
Node 4	Infrastructure	2,777	2,508	2,777	2,687	2,777	2,687	2,777	2,777	2,687	2,777	2,687	2,777	32,695
Node 5	Infrastructure	7,068	6,384	7,068	6,840	7,068	6,840	7,068	7,068	6,840	7,068	6,840	7,068	83,220
Node 6	Infrastructure	60	54	60	58	60	58	60	60	58	60	58	60	706
Node 7	Infrastructure	603	544	603	583	603	583	603	603	583	603	583	603	7,097
Milford Hub	Infrastructure	436,197	431,301	499,454	517,306	489,238	469,120	484,757	482,268	485,929	534,991	488,892	475,011	5,794,464
Transport	Boats[1]	2,528,900	2,284,200	2,528,900	2,232,900	1,816,600	1,641,700	1,696,400	1,696,400	1,758,000	1,966,800	2,232,900	2,528,900	24,912,600
Transport	Buses[2]	905,300	817,700	905,300	584,100	301,800	175,300	181,100	181,100	292,100	301,800	584,100	905,300	6,135,000

[1] The following assumptions were used: Boats total battery capacity of 50,500 kWh for 100% demand; charge period: 13 hours, constantly applied across the period; allowance for charging losses.

[2] The following assumptions were used: Bus battery sizes of 400 kWh; bus peak demand: 6000 passengers per day requiring 123 buses; bus high demand: 4000 passengers per day requiring 82 buses; bus moderate demand: 2000 passengers per day requiring 41 buses; bus low demand: 1200 passengers per day requiring 24 buses; charge period: 8 hours, constantly applied across the period; allowance for charging losses.

5. Technical feasibility testing of options

Electric power supply options have been assessed for supplying loads at the various Nodes identified in the MOP Masterplan. Following the recommendations discussed in Section 3, options considered include extension of the National Electricity Grid to Milford Sound and exploitation of indigenous renewable energy sources within close proximity of the Nodes.

For the options discussed in the following section emergency standby generation has not been included as discussed in Section 3.3. Where diesel generation is included, it forms part of the primary electricity supply. Emergency standby generation will need to be sized to be able supply the peak demand of each Node.

5.1 Assumptions and limitations

- Solar at Milford was limited to 5 MW due to spatial constraints.
- Options with at least a 70% renewable fraction was considered acceptable for the purpose of this study.
- Options were disregarded if required battery capacity was over approximately 10 MWh due to cost and batteries being short duration storage solutions and not long term (a few days per cycle). Note that the largest battery presently installed in New Zealand is 30 MWh. Also note that HOMER does not consider the short duration storage of batteries well, which could lead to batteries not lasting as long as they should. Further project phases should consider this in more detail.
- Options were disregarded if the percentage contribution of an energy source is very small as this complicates the system without adding enough value.
- Costing assumptions include the values as described below. :
    - Inflation: 2%
    - Discount rate: 8%
    - Diesel fuel price: $2.50/l
    - Solar cost per installed kW: $3,000
    - Battery price per installed kWh: $350
    - Diesel generators per installed kW: $750
    - Economic lifecycle of 25 years assumed
    - Assumed batteries to be replaced every 10 years and Solar Panels every 25 years
- The Net Present Cost (or life-cycle cost) were calculated using the values above over the economic lifecycle. The Net Present Cost is the present value of the costs of installing the energy system (hydropower schemes, solar arrays, batteries, and diesel generators) as well as operating and maintenance over the project life (25 years in this case). The Capital expenditure includes the initial cost of installing the energy system.
- Costing does not allow for the upgrade of reticulation at Milford Sound, although this is expected to be required.
- Costing does not include any land purchase costs.
- Costing does not allow for emergency standby generation which would be required for all options.
- For the hydropower plants, a scheme designed for its maximum output at mean flow has been assumed for all options as a sensible modelling approach at this stage. Such a scheme can generate power for a range of flows with the highest output being at the mean flow. As detailed in the separate hydropower reports, the actual scheme's characteristics will depend on hydrological studies, civil works considerations, geotechnical conditions, energy demand, environmental and ecological factors, and resource consenting. The costings for the hydropower schemes considered are as follows[3]:
    - Milford Sound Hydro upgrade (600 kW): $3.6M
    - Milford Sound Hydro upgrade (1.9 MW): $5.5M
    - Milford Sound Hydro upgrade (5 MW): $8.5M
    - Knobs Flat Hydro upgrade (207 kW): $3.1M
    - Tūtoko Hydro new scheme (12,9 MW): $24.5M
    - Marian Creek Hydro new scheme (6.9 MW): $19.4M

[3] These costings were developed as Class 5 estimates in line with AACE's *Cost Estimate Classifications System – As Applied in Engineering, Procurement and Construction for the Hydropower Industries.* The pricing assumes a risk-based approach, assuming the Client will accept risk for example, by using local contractors and not Tier 1 contractors.

5.2 Microgrid options

To assess the technical feasibility and requirements of the microgrid options, energy modelling using HOMER (Hybrid Optimisation of Multiple Electric Renewables) software was performed. HOMER is specifically designed for the assessment of electricity microgrids and includes tools for assessing the potential of various forms of renewable energy and combining them into an overall energy supply system. HOMER is a dynamic model which simulates the energy produced by renewable sources changing continuously with time using an hourly timestep. The power output from the hydropower schemes changes with time based on the flow available in the water course (derived from regional flow seasonality and NIWA's flow duration curves). The power output from solar arrays changes with time based on the time of day and the month of the year. HOMER prioritises renewable generation, based on the seasonal data mentioned above, and whenever power from renewables is unable to meet the demand, HOMER meets this demand with power from diesel generators.

Note, power (i.e. MW) is an instantaneous value of the power produced at a specific time. Power over time provides the energy supplied by an energy source (i.e. MWh). For example, a plant generating 1 MW continuously over 2 hours produces 2 MWh.

In the tables in the following sections, the following terms are used:

- Annual Energy Demand (MWh): The total energy requirements for the node across a year including boat and bus charging where applicable.
- Renewable fraction (%): The percentage of the annual energy demand supplied by renewable sources. The remainder is supplied by diesel generators.
- Hydropower capacity (MW): This is the maximum power the installed hydropower plant can produce. In all these options, the plant capacity is based on generating at the river's mean flow. The actual power output depends on the flow availability at a specific point in time.
- Hydropower mean output (MW): This is the average power the hydropower plant produces over the year.
- Solar capacity (MW): This is the maximum power the installed solar array can produce. The actual power depends on the solar intensity at the time.
- Battery capacity (MWh): The battery capacity signifies the energy it can store and deliver.
- Diesel generator capacity (MW): The maximum power produced by a diesel generator when it is in operation.
- Fuel usage (litre): The volume of diesel required by the generators to meet the demand not supplied by renewables.
- CO_2 emission (kg): The carbon emissions in kilograms associated with the operation of the diesel generators.
- Capital expenditure (NZD): The capital expenditure includes the procurement, construction and installation of all the components of the energy supply systems.
- Net Present Cost (NZD): The Net Present Cost (or life-cycle cost) is the present value of the costs of installing the energy supply system as well as operating and maintenance over the project life (25 years in this case).

The preferred options modelled are described below. Further HOMER assessment options can be found in Appendix A.

5.2.1 Milford Sound

A HOMER model was set up considering various expansion options of the Milford Hydro and a new hydropower scheme on the Tūtoko River, supplying the difference with solar power, batteries, or a back-up power system. The back-up power system was assumed to be diesel generation due to practicality and availability but could be supplied by other sources.

5.2.1.1 Milford 1 and 2: Battery-electric boats, buses and infrastructure

As the preferred option for the transport fleet is battery-electric buses and boats, this option was modelled initially to test feasibility. Due to the very large load of electric boats, the scale of solar power required becomes unfeasibly large if a 100% renewable option is required. For this option, a solar array at least 35 MW would be required and unfeasibly large battery storage. The solar requirements are especially large due to the low solar potential in the winter months.

If, however, a back-up generation system, such as a diesel generator is considered, the system could supply these demands, whilst the majority of the energy produced would still renewable. Two feasible options are described below, one with an expansion of the Milford Hydro and one with a new hydropower plant on Tūtoko River. Hydrological and ecological assessments might favour one option over the other, therefore both are included. The Tūtoko River option (Option 2) is preferred at this stage due to its lower carbon emissions and lower Net Present Cost over the Milford Hydro option (Option 1).

Table 5-1: Milford Microgrid Options (boats, buses and infrastructure)

	Milford Option 1	Milford Option 2	Comment
Summary	• 5 MW Milford Hydro upgrade • 7.6 MW diesel generation when hydropower is not meeting the demand (about 45% of the demand)	• 12.9 MW new Tūtoko Hydro • 7.6 MW diesel generation when hydropower is not meeting the demand (about 20% of the demand)	
Annual Energy Demand	~36,800 MWh	~36,800 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**53.7%**	**78.3%**	
Hydropower	Capacity: 5.3 MW Mean output: 3.1 MW Details: • Operation at capacity (5.3 MW) achieved about 30% of the time, • Mean annual output is 3.1 MW. • 90% of the time, output of at least 500 kW is achieved.	Capacity: 12.9 MW Mean output: 6.6 MW Details: • Operation at capacity (12.9 MW) achieved about 23% of the time, • Mean annual output is 6.6 MW. • 90% of the time, output of at least 950 kW is achieved.	
Solar	Capacity: 0 MW	Capacity: 0 MW	For options that includes solar, see Appendix A. Solar was not seen as a top ranked option here as the battery requirements would be too large.
Battery	Capacity: 0 MWh	Capacity: 0 MWh	
Diesel generator	Capacity: 7.6 MW Fuel: 4,744,533 l/year	Capacity: 7.6 MW Fuel: 2,219,828 l/year	
CO_2 emission per year	12,419,413 kg	5,810,655 kg	

Capital expenditure	$14.8M	$32.0M	
Net Present Cost	$207M	$123M	

5.2.1.2 Milford 3 and 4: Battery-electric buses and infrastructure

The model again showed that a 100% renewable system would not be feasible for this option due to the scale of solar array and batteries required. Two feasible options are described below, one with an expansion of the Milford Hydro and one with a new hydropower plant on Tūtoko River. Hydrological and ecological assessments might favour one option over the other, therefore both are included. The Tūtoko River option (Option 4) is preferred at this stage due to its lower carbon emissions and similar Net Present Cost as the Milford Hydro option (Option 3).

Table 5-2: Milford Microgrid Options (buses and infrastructure)

	Milford Option 3	Milford Option 4	Comment
Summary	• 5 MW Milford Hydro upgrade • 5.2 MW diesel generation when hydropower is not meeting the demand (about 25% of the demand)	• 12.9 MW new Tūtoko Hydro • 5.2 MW diesel generation when hydropower is not meeting the demand (about 10% of the demand)	Due to smaller energy demand, the capacity of the diesel generators can be less than for Milford Options 1 and 2.
Annual Energy Demand	~11,900 MWh	~11,900 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**74.8%**	**87.9%**	
Hydropower	Capacity: 5.3 MW Mean output: 3.1 MW	Capacity: 12.9 MW Mean output: 6.6MW	
Solar	Capacity: 0 MW	Capacity: 0 MW	For options that includes solar, see Appendix A. Solar was not seen as a top ranked option here as the battery requirements would be too large. Or its contribution made a negligible contribution to the renewable fraction but would add complexity to the system.
Battery	Capacity: 0 MWh	Capacity: 0 MWh	

Diesel generator	Capacity: 5.2 MW Fuel: 866,851 l/year	Capacity: 5.2 MW Fuel: 420,601 l/year	
CO_2 emission per year	2,269,083 kg	1,100,972 kg	
Capital expenditure	$13.0M	$30.2M	
Net Present Cost	$49.3M	$49.8M	

5.2.1.3 Milford 5 and 6: Battery-electric boats and infrastructure

The model again showed that a 100% renewable system would not be feasible for this option due to the scale of solar array and batteries required. As for the previous sections, two feasible options are described below, one with an expansion of the Milford Hydro and one with a new hydropower plant on Tūtoko River. The Tūtoko River option (Option 6) is preferred at this stage due to its lower carbon emissions and similar Net Present Cost as the Milford Hydro option (Option 5).

Table 5-3: Milford Microgrid Options (boats and infrastructure)

	Milford Option 5	Milford Option 6	Comment
Summary	• 5 MW Milford Hydro upgrade • 7.6 MW diesel generation when hydropower is not meeting the demand (about 45% of the demand)	• 12.9 MW new Tūtoko Hydro • 7.6 MW diesel generation when hydropower is not meeting the demand (about 25% of the demand)	The same infrastructure requirements as for Milford Options 1 and 2, however, diesel generators will be operating less due to the smaller energy demand.
Annual Energy Demand	30,700 MWh	30,700 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**53.4%**	**76.6%**	
Hydropower	Capacity: 5.3 MW Mean output: 3.1 MW	Capacity: 12.9 MW Mean output: 6.6 MW	
Solar	Capacity: 0 MW	Capacity: 0 MW	For options that includes solar, see Appendix A. Solar was not seen as a top ranked option here as the battery requirements would be too large. Or its contribution made a negligible contribution to the renewable fraction but

			would add complexity to the system.
Battery	Capacity: 0 MWh	Capacity: 0 MWh	
Diesel generator	Capacity: 7.6 MW Fuel: 3,939,046 l/year	Capacity: 7.6 MW Fuel: 1,974,136 l/year	
CO_2 emission per year	10,310,904 kg	5,167,529 kg	
Capital expenditure	$14.8M	$32.0M	
Net Present Cost	$173M	$112M	

5.2.1.4 Milford 7 and 8: Only infrastructure

If boats and buses are not charged at Milford, the infrastructure can be powered by 100% renewable sources, however this would require a battery of at least 32 MWh which is too large to be considered practically. Therefore, two possible options of powering the infrastructure are described below. These two options were chosen as the most cost-effective near-100% renewable options (as 100% renewable was not practical). Although Option 7 is more expensive and has higher emissions than Option 8, it requires less extensive upgrades to the hydropower plant which might be more feasible once further hydrological and ecological assessments are done. Option 8 is preferred due to its higher renewable fraction and lower cost.

Table 5-4: Milford Microgrid Options (infrastructure)

	Milford Option 7	Milford Option 8	Comment
Summary	• 600 kW Milford Hydro upgrade • ~1,300 kW solar array • ~2,800 kWh battery • 1.2 MW diesel generation when renewables not meeting the demand (about 5% of the demand)	• 1.9 MW Milford Hydro upgrade • ~350 kWh battery • 1.2 MW diesel generation when renewables not meeting the demand (about 3% of the demand)	
Annual Energy Demand	~5,800 MWh	~5,800 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**94.6%**	**96.7%**	
Hydropower	Capacity: 0.600 MW Mean output: 0.5 MW	Capacity: 1.9 MW Mean output: 1.6 MW	
Solar	Capacity: 1.2 MW	Capacity: 0 MW	For Option 8, options including solar had too

	(~6,130 m^2 solar array)		large battery requirements, or a negligible effect on renewable fraction. See Appendix A for more details.
Battery	Capacity: 2.84 MWh	Capacity: 0.4 MWh	
Diesel generator	Capacity: 1.2 MW Fuel: 91,976 l/year	Capacity: 1.2 MW Fuel: 55,036 l/year	
CO_2 emission per year	240,757 kg	144,064 kg	
Capital expenditure	$9.7M	$6.9M	
Net Present Cost	$15.4M	$9.7M	

5.2.2 Node 5 Lake Marian

5.2.2.1 Node 5 Lake Marian: Only infrastructure

If buses are not charged at Node 5, a hydropower scheme will not be developed. Unfortunately, solar capacity is the lowest of all sites at Node 5. Two options for powering the Wananga and other infrastructure at Node 5 is shown below. The second option has a much smaller renewable contribution but is significantly more cost-effective and could therefore be considered in further stages. However, for the purposes of this study, the 100% renewable option is recommended.

Table 5-5: Lake Marian Microgrid Options (infrastructure)

	Lake Marian -1	Lake Marian - 2	Comment
Summary	• 0.644 MW solar array • ~1.1 MWh battery	• 0.068 MW solar array • ~0.080 MWh battery • 0.022 MW diesel generation when renewables not meeting the demand (about 60% of the demand)	
Annual Energy Demand	~83.2 MWh	~83.2 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**100%**	**37.6%**	
Hydropower	Capacity: 0 MW	Capacity: 0 MW	

	Mean output: 0 MW	Mean output: 0 MW	
Solar	Capacity: 0.644 MW (~3,220 m^2 solar array)	Capacity: 0.068 MW (~432 m^2 solar array)	
Battery	Capacity: 1.1 MWh	Capacity: 0.0791 MWh	
Diesel generator	Capacity: 0 MW Fuel: 0 l/year	Capacity: 0.022 MW Fuel: 15,575 l/year	
CO_2 emission per year	0 kg	40,770 kg	
Capital expenditure	$2.3M	$260,000	
Net Present Cost	$3.0M	$890,000	

5.2.2.2 Node 5 Lake Marian: Battery-electric buses and infrastructure

As an alternative to bus charging at Milford Sound, bus charging at Node 5 was also assessed. It was found that to enable bus charging at Node 5 from 100% renewable sources, battery storage of about 50 MWh would be required. Such a battery is estimated to cost more than the hydropower scheme and is larger than any battery currently used in New Zealand. A more practical option relying on diesel generation as back-up power supply is described below:

Table 5-6: Lake Marian Microgrid Options (buses and infrastructure)

	Lake Marian - 3	Comment
Summary	• 6.9 MW new Lake Marian Hydro (Marian Creek option) • ~2.9 MWh battery • 4.1 MW diesel generation when renewables not meeting the demand (about 10% of the demand)	
Annual Energy Demand	~6,200 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**90.4%**	
Hydropower	Capacity: 6.9 MW	Marian Creek option

	Mean output: 3.5 MW	
Solar	Capacity: 0 MW	For options that includes solar, see Appendix A. Solar was not seen as a top ranked option here as the battery requirements would be too large.
Battery	Capacity: 2.9 MWh	
Diesel generator	Capacity: 4.1 MW Fuel: 166,891 l/year	
CO_2 emission per year	436,857 kg	
Capital expenditure	$25.1M	
Net Present Cost	$34.5M	

5.2.3 Node 3 Knobs Flat

A 100% renewable option is possible to provide power at Knobs Flat. However, as adding a back-up power supply will have a much lower cost, options for both 100% renewable and 84% renewable are shown below. Due to the carbon reduction objective, the 100% renewable option is recommended. However, if cost becomes a constraint, the 84% renewable option should be considered as it reduces both Net Present Cost and capital expenditure by 50% and still achieves a reasonable renewable fraction.

Table 5-7: Knobs Flat Microgrid Options (infrastructure)

	Knobs Flat 1	Knobs Flat 2	Comment
Summary	• 0.207 MW Knobs Flat Hydro upgrade • ~1.05 MW solar array • ~6.7 MWh battery	• 0.207 MW Knobs Flat Hydro upgrade • ~0.080 MW solar array • ~0.270 MWh battery • 0.140 MW diesel generation when renewables not meeting the demand (about 15% of the demand)	

Annual Energy Demand	~850 MWh	~850 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**100%**	**83.6%**	
Hydropower	Capacity: 0.207 MW Mean output: 0.114 MW	Capacity: 0.207 MW Mean output: 0.114 MW	
Solar	Capacity: 1.045 MW (~5,225 m^2 solar array)	Capacity: 0.0817 MW (~409 m^2 solar array)	
Battery	Capacity: 6.7 MWh	Capacity: 0.3 MWh	
Diesel generator	Capacity: 0 MW Fuel: 0 l/year	Capacity: 140 MW Fuel: 41,406 l/year	
CO_2 emission per year	0 kg	108,385 kg	
Capital expenditure	$8.9M	$3.5M	
Net Present Cost	$12.1M	$5.8M	

5.2.4 All other nodes

For all the nodes with smaller loads (Node 2, Node 4, Node 6 and The Chasm), two options are described. One option shows the details of a 100% renewable system and the second shows a more economical option that still has a renewable component.

For these nodes, the 100% renewable option is recommended due to the objective of carbon reduction. However, the more economical options should be considered as viable alternatives. At Nodes 2 and 4, the more economical options still have a high renewable contribution. At Node 6 and The Chasm the renewable component is very low or even negligible, however, the cost is significantly less than for the 100% renewable options. Furthermore, as these nodes have very small loads, the emissions are low compared to nodes such as Milford, Knobs Flat and Lake Marian (if buses are charged).

Table 5-8: Node 2 Microgrid Options

	Node 2 - 1	Node 2 - 2	Comment
Summary	• ~0.030 MW solar array • ~0.165 MWh battery	• ~0.012 MW solar array • ~0.050 MWh battery • 0.002 MW diesel generation when renewables not meeting the demand (about	

		25% of the demand)	
Annual Energy Demand	~13.5 MWh	~13.5 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**100%**	**75.3%**	
Hydropower	Capacity: 0 MW	Capacity: 0 MW	
Solar	Capacity: 0.0294 MW (~147 m^2 solar array)	Capacity: 0.012 MW (~60 m^2 solar array)	
Battery	Capacity: 0.165 MWh	Capacity: 0.047 MWh	
Diesel generator	Capacity: 0 MW Fuel: 0 l/year	Capacity: 0.002 MW Fuel: 1,199 l/year	
CO_2 emission per year	0 kg	3,137 kg	
Capital expenditure	$150,000	$50,000	
Net Present Cost	$220,000	$130,000	

Table 5-9: Node 4 Microgrid Options

	Node 4 - 1	Node 4 - 2	Comment
Summary	• ~0.09 MW solar array • ~0.42 MWh battery	• ~0.03 MW solar array • ~0.12 MWh battery • 8.6 MW diesel generation when renewables not meeting the demand (about 25% of the demand)	
Annual Energy Demand	~32.7 MWh	~32.7 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**100%**	**73.7%**	
Hydropower	Capacity: 0 MW	Capacity: 0 MW	
Solar	Capacity: 0.087 MW (~437 m^2 solar array)	Capacity: 0.031 MW (~156 m^2 solar array)	

Battery	Capacity: 0.42 MWh	Capacity: 0.123 MWh	
Diesel generator	Capacity: 0 MW Fuel: 0 l/year	Capacity: 8.6 MW Fuel: 3,275 l/year	
CO_2 emission per year	0 kg	8,572 kg	
Capital expenditure	$410,000	$140,000	
Net Present Cost	$590,000	$340,000	

Table 5-10: Node 6 Microgrid Options

	Node 6- 1	Node 6 - 2	Comment
Summary	• ~0.005 MW solar array • ~0.008 MWh battery	• ~0.00034 MW solar array • ~0.001 MWh battery • ~0.001 MW diesel generation when renewables not meeting the demand (about 65% of the demand)	
Annual Energy Demand	~0.7 MWh	~0.7 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**100%**	**36.5%**	
Hydropower	Capacity: 0 MW	Capacity: 0 MW	
Solar	Capacity: 0.005 MW (~24 m^2 solar array)	Capacity: 0.341 kW (~2 m^2 solar array)	
Battery	Capacity: 0.008 MWh	Capacity: 0.001 MWh	
Diesel generator	Capacity: 0 MW Fuel: 0 l/year	Capacity: 0.088 MW Fuel: 138 l/year	
CO_2 emission per year	0 kg	362 kg	
Capital expenditure	$17,000	$1,000	
Net Present Cost	$21,000	$7,000	

Table 5-11: The Chasm Microgrid Options

	The Chasm 1	The Chasm 2	Comment
Summary	• ~0.060 MW solar array • ~0.090 MWh battery	• ~0.0002 MW solar array • ~0.002 MWh battery • ~3.4 kW diesel generation when renewables not meeting the demand (about 99% of the demand)	
Annual Energy Demand	~7.1 MWh	~7.1 MWh	See Table 4-1 for monthly breakdown
Renewable fraction	**100%**	**1.1%**	
Hydropower	Capacity: 0 MW	Capacity: 0 MW	
Solar	Capacity: 0.058 kW (~289 m^2 solar array)	Capacity: 0.002 MW (~1 m^2 solar array)	
Battery	Capacity: 0.091 MWh	Capacity: 0.002 MWh	
Diesel generator	Capacity: 0 MW Fuel: 0 l/year	Capacity: 0.0034 MW Fuel: 2,281 l/year	
CO_2 emission per year	0 kg	5,970 kg	
Capital expenditure	$210,000	$4,000	
Net Present Cost	$260,000	$40,000	

5.2.5 Microgrid recommendation

Table 5-12: Microgrid summary and recommendations

	Renewable fraction	CO_2 emissions (kg)	Capital Expenditure (NZD)	Net Present Cost (NZD)	Details	Recommendation
Milford - 2	78.3%	5,810,655 kg	$32.0M	$123.0M	Buses, boats and infrastructure	NO
Milford - 4	87.9%	1,100,972 kg	$30.2M	$49.8M	Buses and infrastructure	MAYBE (in conjunction with Lake Marian - 1, this can be considered instead of Milford – 6 and Lake Marian -3)
Milford - 6	76.6%	5,167,529 kg	$32.0M	$112.0M	Boats and infrastructure	NO
Milford - 8	96.7%	144,064 kg	$6.9M	$9.7M	Only infrastructure	YES
Lake Marian - 1	100%	0 kg	$2.3M	$3.0M	Only infrastructure	MAYBE (see note for Milford – 4)
Lake Marian - 3	90.4%	436,857 kg	$25.1M	$34.5M	Buses and infrastructure	YES
Knobs Flat - 1	100%	0 kg	$8.9M	$12.1M		YES
Knobs Flat - 2	83.6%	108,385 kg	$3.5M	$5.8M		MAYBE (due to much lower cost)
Node 2 - 1	100%	0 kg	$150,000	$220,000		YES
Node 2 - 2	75.3%	3,137 kg	$50,000	$130,000		MAYBE (due to much lower cost)
Node 4 – 1	100%	0 kg	$410,000	$590,000		YES
Node 4 -2	73.7%	8,572 kg	$140,000	$340,000		MAYBE (due to much lower cost)
Node 6 – 1	100%	0 kg	$17,000	$21,000		YES
Node 6 -2	36.5%	362 kg	$1,000	$7,000		MAYBE (due to much lower cost)
The Chasm - 1	100%	0 kg	$210,000	$260,000		YES
The Chasm - 2	1.1%	5,970 kg	$4,000	$40,000		MAYBE (due to much lower cost)

The recommendations for the Milford Hub and Node 5 Lake Marian had to be made collectively. The energy required for charging the boats is considered too much to make charging at Milford Sound feasible from microgrids. Charging the buses at Lake Marian (i.e. the combination of Lake Marian -3 and Milford – 8), will have a lower Net Present Cost and carbon emissions than charging the buses at Milford Sound (i.e. the combination of Lake Marian – 1 and Milford - 4). The capital expenditure of the two options is very similar. A limitation of this option is that Milford Sound is the preferred option for charging from a transport perspective. Furthermore, hydrological and ecological assessments might prove the Tūtoko Hydro to be preferable to the Marian Creek Hydro. Therefore, charging buses at Milford Sound should not be disregarded completely.

For all other options, where 100% renewable options were technically feasible, these options were recommended. However, it should be noted that the alternatives listed have advantages, most notably cost.

It is assumed that if buses are not charged at Milford Sound, it will be charged at Node 5 (Lake Marian) and vice versa. However, if boats are not charged at Milford Sound, battery-electric boats will not be used.

5.3 Connection to the National Grid

The existing network in Te Anau is a 66 kV connection to the PowerNet subtransmission system, and 11 kV reticulation for Te Anau. The existing line at Retford is a 2 phase 11 kV and although detailed information is not available to assess, it is expected from observation that it would not be able to carry the load required to service Piopiotahi.

A 33 kV distribution line is envisaged from PowerNet's existing 66/11kV substation at Te Anau. Two 66/33 kV transformers would be provided for redundancy, each of nominal 7.5 MVA capacity. 33 kV is currently selected to keep losses at a reasonable level, but even so, the losses are over 10% of the line capacity, which would not be tolerable in normal grid connections owing to the energy cost. Later optimisation could establish that using 66kV is more economic.

From the Te Anau substation to the National Park boundary (approximately 50 km) the 33 kV line would be overhead, with underground cable (approximately 70 km) from the National Park boundary to Milford Sound.

Owing to the very long cable length voltage control of the line will be challenging, with reactive compensation equipment required at the Milford end. In addition, any tee off supplies will require transformers with voltage regulation capability. Tee offs are presently envisaged for Nodes 3 and 5 only as these nodes represent the largest loads outside of Milford itself.

The 33 kV cable would terminate at a new energy hub just outside Milford township, adjacent to the State Highway. The hub would provide interconnection to the local power reticulation facilities, by means of two transformers in redundant configuration. The emergency generation plant, as described in Section 3.3, would also be located at the energy hub.

As mentioned above, the selection of the 33 kV cable size will require optimisation between required transfer capacity (7.5 MVA presently assumed), cable capital cost (increases with size) and cable losses. The cable losses will be significant, with losses to the order of 700 kW to be expected. Over the course of a year losses of around 6.1 MWh should be anticipated. This would represent about 15% of the total energy consumption of Milford (facilities and transportation loads)

A cost estimate for the capital expenditure associated with this option totals to $53.4M. Note, this costing needs to be investigated more thoroughly in future project phases as the project area is very remote and has unique challenges such as inaccessibility and weather. This price includes:

- Transformers and switchgear at Te Anau ($3M)
- Overhead Line from Hillside Sub to the National Park boundary ($11M)
- Cable from the National Park boundary to Milford Sound ($10.5M for trenching, $15.4M for cable supply and installation)
- Transformers and switchgear at Milford Sound ($3M)
- Tee offs at Knobs Flat and Lake Marian ($1M)
- 10% for Design, Project Management, and Consenting
- 10% contingency

6. Options comparison

As discussed previously, it is assumed that if buses are not charged at Milford Sound, it will be charged at Node 5 (Lake Marian) and vice versa. Therefore, buses (in terms of capital cost and battery replacement) are excluded from the comparison as it is the same for both cases as discussed below. However, if boats are not charged at Milford Sound, battery-electric boats will not be used. The final micro-grid recommendation concluded that battery-electric boats are not recommended if reliant on a micro-grid and will therefore only be used with the National Grid Option. This difference in boat type (battery-electric vs bio-diesel-powered boats) needs to be taken into account in the option comparison. For the boats, the capital cost of initial procurement is excluded (assumed to be similar at this stage), however fuel cost for bio-diesel-powered boats and battery replacement for battery-electric boats are included.

Table 6-1: Microgrids versus National Electricity Grid

	Microgrids	National Electricity Grid
Description of energy demands supplied	Infrastructure from microgrids (combination of hydropower, solar, battery storage and back-up power from diesel generators). Battery-electric buses. Boats originally with blended fuel regimes and then replaced by hybrid vessels as they reach the end of their operational life using of 100% biofuels.	Infrastructure powered by National Electricity Grid. Battery-electric buses. Battery-electric boats.
Estimated renewable energy fraction[4]	>90%	100%
Environmental impact	The construction of new hydropower schemes can have a significant impact on the environment. Solar arrays can have a significant physical footprint.	The overhead transmission line and buried cable with have a minimal environmental impact. Transformers and switchgear will have a physical footprint, but these will also be required for the renewable options, depending on the chosen option.
Capital cost (NZD)[5]	$41.8M	$53.4M

[4] Only considering electricity supply.
[5] The capital cost of procuring buses and boats is not included as it is assumed to be similar for both cases.

Net Present Cost (NZD	$136.3M This includes $78.9M for biodiesel for boat operations not included in the options tables in Section 5[6]	$144.2M This includes $18.2M for the boats' battery replacement every 10 years not included in the options tables in Section 5[7] and assumes all energy needs are supplied by the grid or the existing hydropower schemes at Milford Sound and Knobs Flat[8]
Operation and Maintenance	The hydropower station and each microgrid would require knowledgeable operators. There are many components to be maintained across the microgrids.	Minimal operational requirements.
Carbon (kg/year)	985,751 • 580,921 kg from electricity supply as per Table 5-12. • 404,830 kg from boat emissions assumed to be powered by biodiesel.	0[9]
Risks	Dependent on streamflow/rainfall and sunshine. Varies significantly seasonally.	More reliable than microgrids, but as there is only one line, the entire corridor can be disconnected if a fault occurs.
Resource Consenting	Resource consenting is expected to be more challenging.	Resource consenting is expected to be less challenging.
Emergency power supply	Would require emergency generation equal to peak power demand.	Would require emergency generation equal to peak power demand, however, less likely to be required.
Other	The microgrid option would require much more rigorous further studies and design than the National Energy Grid option, which could make up the difference in cost between the two options.	Can power boats as well, this is not possible with the microgrid options.

[6] Bio-diesel cost assumed as 3.18 per litre. Bio-diesel consumption assumed as 0.13 l/kWh (plus 2% annual inflation).
[7] Battery cost per kWh assumed 25% more than the cost of a battery used as part of the power supply systems, i.e. $350/kWh + 25% = $440/kWh (plus 2% annual inflation).
[8] Energy cost from the National Grid is assumed to be 18c per kWh (plus 2% annual inflation).
[9] It has been assumed that electricity will be purchased through a purchasing arrangement involving 100% renewable electricity.

7. Overall recommendations

Even though the capital expenditure of the National Grid Option is about 25% more, this option has much less risk and many advantages above the microgrids option as discussed in Table 6-1. Also note that the Net Present Cost of two options over a 25 year period is estimated to be comparable. Most notably, this option would be the only way to achieve the recommended transportation solution of both battery-electric boats and buses. Furthermore, it would be easier to maintain, more reliable, easier to develop, and have a smaller environmental impact.

Note that both options (Microgrids or connection to the National Grid) would require back-up, emergency power supply at critical Nodes as discussed in more detail in Section 3.3. Although diesel-fuelled generation has been assumed as the most likely solution, hydrogen fuelled sets could be considered if green hydrogen supply can be assured. The emergency power supply has not been included in the costing, but would be the same for both options and would therefore not change the options comparison.

7.1 Next steps

To fully understand the feasibility of these recommendations, further data and assessment will be required. The most critical further work is discussed below:

- *Hydrology* – If any hydropower (new or expansion or existing) is considered, it is critical to conduct hydrological assessments in the concerning catchments due to the unreliability of the data currently available. This should be the first step to be actioned as soon as possible as the longer the flow records available, the more reliable the data will be. Furthermore, if the flow records show much differing results than NIWA Rivermaps, it might have an impact on the feasibility of the scheme(s).
- *Ecological assessment* – Ecological assessment will also need to be actioned soon, as this could also impact the feasibility of the scheme. For example, if it is found that a rare species is found close to the intake location or if the scheme will critically impact the migration of certain types of fish. It should be noted that ecological assessments can be rigorous studies and expensive. Engaging fish passage experts early would also be a good idea to understand the physical requirements/constraints of designing fish passages for the required species.
- *Survey/ Lidar* – Completion of topographical surveys / Lidar to confirm scheme gross heads and assist in design development.
- *Design development and cost models* – Further development of concepts to understand physical size/ impacts and developing cost estimates better.
- *Geotechnical investigation* – Geotechnical investigations will need to be performed at any proposed infrastructure locations, especially for the weirs/intake works, powerhouses, and any steep slopes proposed as part of the conveyance routes.
- *Demand assessment* – A more detailed assessment of the energy demand for infrastructure is required. To enable a more detailed assessment, a better understanding of the planned infrastructure and operational profiles will be required.
- *Solar* – Site specific assessments to confirm the solar potential should be conducted.

Appendices

Appendix A HOMER results

Architecture						Cost				System			Diesel Generator					PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$319M	$31.9M	$18.2M	$1.88M	25.1	36,841,016	19,016,240	7,600	6,756	27,594,132	7,264,720	5,000	5,602,112	17,089	600	532
⚠						$352M	$26.7M	$21.0M	$1.96M	13.0	36,841,016	21,971,216	7,600	7,440	32,054,878	8,393,602	5,000	5,602,112	13,814		
⚠						$343M	$12.1M	$21.5M	$1.97M	11.8	36,841,016	22,459,440	7,600	8,220	32,476,776	8,580,116			5,783	600	532
⚠						$352M	$12.0M	$22.1M	$2.05M	9.44	36,841,016	23,165,604	7,600	8,760	33,364,890	8,849,890	729	816,975		600	532
⚠						$352M	$9.60M	$22.3M	$2.04M	8.43	36,841,016	23,394,130	7,600	8,760	33,734,856	8,937,193				600	532
⚠						$374M	$12.6M	$23.8M	$2.05M	1.74	36,841,016	24,916,072	7,600	8,760	36,198,768	9,518,616	2,148	2,406,604			
						$376M	$5.70M	$24.6M	$2.00M	0	36,841,016	25,710,006	7,600	8,760	37,484,088	9,821,921					
						$376M	$6.02M	$24.5M	$2.01M	0	36,841,016	25,682,204	7,600	8,760	37,439,080	9,811,299			876		

Figure A- 1: Milford 600kW Hydro HOMER output - boats, buses and infrastructure

Architecture						Cost				System			Diesel Generator					PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$246M	$33.0M	$13.0M	$1.54M	47.1	36,841,016	13,574,395	7,600	5,266	19,488,110	5,185,788	5,000	5,602,112	15,344	1,900	1,559
⚠						$269M	$14.5M	$15.9M	$1.69M	35.7	36,841,016	16,630,548	7,600	6,863	23,681,322	6,353,321			6,834	1,900	1,559
⚠						$295M	$16.4M	$17.7M	$1.94M	28.9	36,841,016	18,535,888	7,600	8,100	26,181,526	7,081,212	1,510	1,692,305		1,900	1,559
⚠						$297M	$11.6M	$18.2M	$1.94M	26.9	36,841,016	19,053,240	7,600	8,263	26,942,072	7,278,855				1,900	1,559
⚠						$352M	$26.7M	$21.0M	$1.96M	13.0	36,841,016	21,971,216	7,600	7,440	32,054,878	8,393,602	5,000	5,602,112	13,814		
⚠						$374M	$12.6M	$23.8M	$2.05M	1.74	36,841,016	24,916,072	7,600	8,760	36,198,768	9,518,616	2,148	2,406,604			
						$376M	$5.70M	$24.6M	$2.00M	0	36,841,016	25,710,006	7,600	8,760	37,484,088	9,821,921					
						$376M	$6.02M	$24.5M	$2.01M	0	36,841,016	25,682,204	7,600	8,760	37,439,080	9,811,299			876		

Figure A- 2: Milford 1900kW Hydro HOMER output - boats, buses and infrasructure

Architecture						Cost				System			Diesel Generator					PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$163M	$40.8M	$6.22M	$1.21M	75.2	36,841,016	6,510,568	7,600	2,936	9,153,065	2,487,214	4,059	4,548,294	34,444	5,266	3,112
						$172M	$24.6M	$8.29M	$1.29M	67.2	36,841,016	8,681,435	7,600	4,194	12,073,217	3,316,544			23,959	5,266	3,112
⚠						$207M	$14.8M	$11.9M	$1.56M	53.7	36,841,016	12,419,413	7,600	6,439	17,064,114	4,744,553				5,266	3,112
⚠						$207M	$14.9M	$11.9M	$1.56M	53.7	36,841,016	12,416,384	7,600	6,438	17,059,684	4,743,396	26.0	29,178		5,266	3,112
⚠						$352M	$26.7M	$21.0M	$1.96M	13.0	36,841,016	21,971,216	7,600	7,440	32,054,878	8,393,602	5,000	5,602,112	13,814		
⚠						$374M	$12.6M	$23.8M	$2.05M	1.74	36,841,016	24,916,072	7,600	8,760	36,198,768	9,518,616	2,148	2,406,604			
						$376M	$5.70M	$24.6M	$2.00M	0	36,841,016	25,710,006	7,600	8,760	37,484,088	9,821,921					
						$376M	$6.02M	$24.5M	$2.01M	0	36,841,016	25,682,204	7,600	8,760	37,439,080	9,811,299			876		

Figure A- 3: Milford 5MW Hydro HOMER output - boats, buses and infrasructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
⚠						$105M	$37.4M	$3.80M	$819,695	84.9	36,841,016	3,979,629	7,600	1,890	5,549,826	1,520,326	42.2	47,264	12,482	12,855	6,639
⚠						$105M	$37.3M	$3.81M	$822,954	84.9	36,841,016	3,987,544	7,600	1,903	5,556,499	1,523,350			12,617	12,855	6,639
⚠						$123M	$32.0M	$5.55M	$937,196	78.3	36,841,016	5,810,655	7,600	2,957	8,010,036	2,219,828				12,855	6,639
⚠						$123M	$32.1M	$5.55M	$937,391	78.3	36,841,016	5,807,248	7,600	2,955	8,005,465	2,218,526	26.0	29,178		12,855	6,639
⚠						$352M	$26.7M	$21.0M	$1.96M	13.0	36,841,016	21,971,216	7,600	7,440	32,054,878	8,393,602	5,000	5,602,112	13,814		
⚠						$374M	$12.6M	$23.8M	$2.05M	1.74	36,841,016	24,916,072	7,600	8,760	36,198,768	9,518,616	2,148	2,406,604			
						$376M	$5.70M	$24.6M	$2.00M	0	36,841,016	25,710,006	7,600	8,760	37,484,088	9,821,921					
						$376M	$6.02M	$24.5M	$2.01M	0	36,841,016	25,682,204	7,600	8,760	37,439,080	9,811,299			876		

Figure A- 4: Milford 12.9MW Hydro at Tutoko HOMER output - boats, buses and infrasructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$68.8M	$27.7M	$2.16M	$557,310	74.2	11,928,792	2,262,063	5,200	1,800	3,080,274	864,170	5,000	5,602,112	11,260	600	532
						$124M	$24.9M	$5.25M	$977,230	37.6	11,928,792	5,495,744	5,200	4,509	7,439,698	2,099,524	4,999	5,601,016	14,897		
⚠						$92.3M	$9.44M	$5.10M	$632,340	37.1	11,928,792	5,341,257	5,200	3,555	7,497,969	2,040,505			3,879	600	532
⚠						$155M	$17.0M	$8.13M	$1.28M	4.82	11,928,792	8,514,216	5,200	7,519	11,353,417	3,252,662	2,858	3,202,249		600	532
						$150M	$5.39M	$8.57M	$1.01M	0	11,928,792	8,973,206	5,200	6,234	12,511,856	3,428,008			3,575		
⚠						$159M	$7.80M	$9.22M	$1.24M	0	11,928,792	9,658,776	5,200	7,708	13,145,282	3,689,915				600	532
⚠						$178M	$15.1M	$9.73M	$1.45M	0	11,928,792	10,184,480	5,200	8,760	13,656,305	3,890,748	3,464	3,880,630			
						$184M	$3.90M	$11.1M	$1.37M	0	11,928,792	11,638,550	5,200	8,760	16,010,337	4,446,242					

Figure A- 5: Milford 600kW Hydro HOMER output - buses and infrastructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$91.4M	$54.4M	$0.00	$1.12M	100	11,921,206	0					4,236	4,745,942	95,708	1,900	1,559
						$42.3M	$26.5M	$552,064	$368,851	93.5	11,928,792	578,037	5,200	497	775,146	220,826	3,571	4,000,778	14,316	1,900	1,559
						$50.0M	$19.6M	$1.03M	$440,738	87.7	11,928,792	1,077,328	5,200	848	1,470,004	411,569			24,965	1,900	1,559
⚠						$73.7M	$14.7M	$3.52M	$598,593	58.8	11,928,792	3,680,866	5,200	3,215	4,919,820	1,406,191	1,522	1,705,435		1,900	1,559
⚠						$75.0M	$9.80M	$3.99M	$586,280	52.4	11,928,792	4,179,454	5,200	3,380	5,673,664	1,596,665				1,900	1,559
						$124M	$24.9M	$5.25M	$977,230	37.6	11,928,792	5,495,744	5,200	4,509	7,439,698	2,099,524	4,999	5,601,016	14,897		
						$150M	$5.39M	$8.57M	$1.01M	0	11,928,792	8,973,206	5,200	6,234	12,511,856	3,428,008			3,575		
⚠						$178M	$15.1M	$9.73M	$1.45M	0	11,928,792	10,184,480	5,200	8,760	13,656,305	3,890,748	3,464	3,880,630			
						$184M	$3.90M	$11.1M	$1.37M	0	11,928,792	11,638,550	5,200	8,760	16,010,337	4,446,242					

Figure A- 6: Milford 1900kW Hydro HOMER output - buses and infrastructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$110M	$64.9M	$0.00	$1.38M	100	11,919,959	0					4,503	5,045,624	117,817	5,266	3,112
						$33.3M	$16.8M	$832,001	$288,837	90.2	11,928,792	871,144	5,200	763	1,163,682	332,801	233	261,235	7,304	5,266	3,112
						$33.4M	$16.2M	$875,159	$289,258	89.7	11,928,792	916,332	5,200	793	1,227,141	350,064			7,461	5,266	3,112
⚠						$49.4M	$13.1M	$2.16M	$413,323	74.8	11,928,792	2,265,715	5,200	2,062	3,001,496	865,565	26.0	29,178		5,266	3,112
⚠						$49.3M	$13.0M	$2.17M	$412,828	74.8	11,928,792	2,269,083	5,200	2,063	3,006,626	866,851				5,266	3,112
						$124M	$24.9M	$5.25M	$977,230	37.6	11,928,792	5,495,744	5,200	4,509	7,439,698	2,099,524	4,999	5,601,016	14,897		
						$150M	$5.39M	$8.57M	$1.01M	0	11,928,792	8,973,206	5,200	6,234	12,511,856	3,428,008			3,575		
⚠						$178M	$15.1M	$9.73M	$1.45M	0	11,928,792	10,184,480	5,200	8,760	13,656,305	3,890,748	3,464	3,880,630			
						$184M	$3.90M	$11.1M	$1.37M	0	11,928,792	11,638,550	5,200	8,760	16,010,337	4,446,242					

Figure A- 7: Milford 5MW Hydro HOMER output - buses and infrastructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$137M	$84.5M	$0.00	$1.69M	100	11,918,906	0					3,495	3,916,420	134,115	12,855	6,639
						$45.2M	$31.9M	$598,228	$393,297	93.1	11,928,792	626,373	5,200	582	825,923	239,291	0.593	664	3,952	12,855	6,639
						$45.2M	$31.9M	$598,228	$393,332	93.1	11,928,792	626,373	5,200	582	825,923	239,291			3,957	12,855	6,639
						$49.8M	$30.3M	$1.05M	$423,863	87.9	11,928,792	1,095,713	5,200	1,027	1,441,908	418,592	26.0	29,178		12,855	6,639
						$49.8M	$30.2M	$1.05M	$423,836	87.9	11,928,792	1,100,972	5,200	1,031	1,449,127	420,601				12,855	6,639
						$124M	$24.9M	$5.25M	$977,230	37.6	11,928,792	5,495,744	5,200	4,509	7,439,698	2,099,524	4,999	5,601,016	14,897		
						$150M	$5.39M	$8.57M	$1.01M	0	11,928,792	8,973,206	5,200	6,234	12,511,856	3,428,008			3,575		
						$178M	$15.1M	$9.73M	$1.45M	0	11,928,792	10,184,480	5,200	8,760	13,656,305	3,890,748	3,464	3,880,630			
						$184M	$3.90M	$11.1M	$1.37M	0	11,928,792	11,638,550	5,200	8,760	16,010,337	4,446,242					

Figure A- 8: Milford 12.9MW Hydro at Tutoko HOMER output - buses and infrasructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$267M	$20.7M	$15.9M	$1.43M	20.5	30,706,712	16,663,950	7,600	5,416	24,419,008	6,366,082	2,379	2,665,002	9,285	600	532
						$281M	$13.0M	$17.4M	$1.52M	13.7	30,706,712	18,174,596	7,600	6,160	26,513,144	6,943,190			8,106	600	532
						$300M	$19.8M	$18.3M	$1.51M	8.17	30,706,712	19,139,760	7,600	5,904	28,196,616	7,311,908	3,732	4,181,475	7,150		
						$326M	$24.8M	$19.6M	$1.91M	3.79	30,706,712	20,490,676	7,600	7,681	29,544,134	7,827,995	4,974	5,572,934		600	532
						$327M	$7.70M	$20.6M	$1.71M	0	30,706,712	21,546,996	7,600	7,300	31,434,236	8,231,538			4,717		
						$337M	$9.60M	$21.2M	$2.04M	0	30,706,712	22,194,422	7,600	8,760	31,792,618	8,478,872				600	532
						$353M	$5.70M	$22.8M	$2.00M	0	30,706,712	23,873,406	7,600	8,760	34,510,768	9,120,290					
						$354M	$5.79M	$22.8M	$2.00M	0	30,706,712	23,872,756	7,600	8,760	34,509,716	9,120,041	26.0	29,178			

Figure A- 9: Milford 600kW Hydro HOMER output - boats and infrastructure

Architecture						Cost				System			Diesel Generator					PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)		Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$209M	$18.2M	$11.7M	$1.24M	42.3	30,706,712	12,247,475	7,600	4,486	17,708,422	4,678,868		206	230,562	14,951	1,900	1,559
						$209M	$17.1M	$11.8M	$1.23M	41.7	30,706,712	12,394,162	7,600	4,549	17,916,136	4,734,906				13,583	1,900	1,559
⚠						$224M	$11.6M	$13.9M	$1.30M	31.8	30,706,712	14,525,744	7,600	5,461	20,936,150	5,549,229		13.0	14,589		1,900	1,559
⚠						$224M	$11.6M	$13.9M	$1.30M	31.8	30,706,712	14,526,065	7,600	5,461	20,936,670	5,549,352					1,900	1,559
⚠						$300M	$19.8M	$18.3M	$1.51M	8.17	30,706,712	19,139,760	7,600	5,904	28,196,616	7,311,908		3,732	4,181,475	7,150		
						$327M	$7.70M	$20.6M	$1.71M	0	30,706,712	21,546,996	7,600	7,300	31,434,236	8,231,538				4,717		
						$353M	$5.70M	$22.8M	$2.00M	0	30,706,712	23,873,406	7,600	8,760	34,510,768	9,120,290						
						$354M	$5.79M	$22.8M	$2.00M	0	30,706,712	23,872,756	7,600	8,760	34,509,716	9,120,041	26.0	29,178				

Figure A- 10: Milford 1900kW Hydro HOMER output - boats and infrastructure

Architecture						Cost				System			Diesel Generator					PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	O&M Cost ($/yr)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$142M	$35.5M	$4.98M	$1.09M	75.9	30,706,712	5,211,328	7,600	2,184	7,404,960	1,990,869	497,952	635	711,748	48,552	5,266	3,112
						$142M	$31.9M	$5.37M	$1.08M	74.1	30,706,712	5,622,380	7,600	2,416	7,960,818	2,147,902	550,848			43,817	5,266	3,112
⚠						$173M	$14.8M	$9.85M	$1.24M	53.4	30,706,712	10,310,904	7,600	5,055	14,304,443	3,939,046	1,152,540				5,266	3,112
⚠						$173M	$14.9M	$9.84M	$1.24M	53.4	30,706,712	10,307,624	7,600	5,053	14,300,077	3,937,792	1,152,084	26.0	29,178		5,266	3,112
⚠						$300M	$19.8M	$18.3M	$1.51M	8.17	30,706,712	19,139,760	7,600	5,904	28,196,616	7,311,908	1,346,112	3,732	4,181,475	7,150		
						$327M	$7.70M	$20.6M	$1.71M	0	30,706,712	21,546,996	7,600	7,300	31,434,236	8,231,538	1,664,400			4,717		
						$353M	$5.70M	$22.8M	$2.00M	0	30,706,712	23,873,406	7,600	8,760	34,510,768	9,120,290	1,997,280					
						$354M	$5.79M	$22.8M	$2.00M	0	30,706,712	23,872,756	7,600	8,760	34,509,716	9,120,041	1,997,280	26.0	29,178			

Figure A- 11: Milford 5MW Hydro HOMER output - boats and infrastructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$97.3M	$40.5M	$2.95M	$776,864	85.8	30,706,712	3,092,636	7,600	1,363	4,362,823	1,181,471			20,326	12,855	6,639
						$97.3M	$40.4M	$2.96M	$780,246	85.8	30,706,712	3,096,194	7,600	1,377	4,361,969	1,182,830	5.59	6,266	20,331	12,855	6,639
⚠						$112M	$32.0M	$4.94M	$838,928	76.6	30,706,712	5,167,529	7,600	2,526	7,172,482	1,974,136				12,855	6,639
⚠						$113M	$32.1M	$4.94M	$839,579	76.6	30,706,712	5,167,390	7,600	2,526	7,172,258	1,974,084	26.0	29,178		12,855	6,639
⚠						$300M	$19.8M	$18.3M	$1.51M	8.17	30,706,712	19,139,760	7,600	5,904	28,196,616	7,311,908	3,732	4,181,475	7,150		
						$327M	$7.70M	$20.6M	$1.71M	0	30,706,712	21,546,996	7,600	7,300	31,434,236	8,231,538			4,717		
						$353M	$5.70M	$22.8M	$2.00M	0	30,706,712	23,873,406	7,600	8,760	34,510,768	9,120,290					
						$354M	$5.79M	$22.8M	$2.00M	0	30,706,712	23,872,756	7,600	8,760	34,509,716	9,120,041	26.0	29,178			

Figure A- 12: Milford 12.9MW Hydro at Tutoko HOMER output - boats and infrasructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$41.7M	$28.3M	$0.00	$466,708	100	5,790,198	0					4,290	4,806,518	32,072	600	532
						$15.4M	$9.65M	$229,939	$132,866	94.6	5,794,464	240,757	1,200	972	311,020	91,976	1,226	1,373,810	2,824	600	532
⚠						$21.5M	$5.39M	$891,202	$178,808	78.8	5,794,464	933,130	1,200	3,498	1,227,276	356,481			1,389	600	532
						$51.1M	$17.6M	$1.64M	$411,515	59.1	5,794,464	1,716,117	1,200	5,013	2,372,136	655,603	3,909	4,379,379	13,344		
⚠						$36.5M	$5.46M	$1.80M	$319,968	58.1	5,794,464	1,882,596	1,200	7,660	2,427,206	719,203	208	233,421		600	532
⚠						$36.9M	$4.80M	$1.88M	$316,488	55.7	5,794,464	1,971,268	1,200	7,708	2,566,870	753,078				600	532
⚠						$54.4M	$5.35M	$3.11M	$350,736	21.4	5,794,464	3,252,112	1,200	8,760	4,555,234	1,242,395	1,415	1,585,442			
						$59.0M	$950,694	$3.84M	$316,740	0.00122	5,794,464	4,017,532	1,200	8,760	5,794,394	1,534,806			138		
						$58.9M	$900,000	$3.84M	$315,360	0	5,794,464	4,017,576	1,200	8,760	5,794,464	1,534,823					

Figure A- 13: Milford 600kW Hydro HOMER output - infrastructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$47.8M	$33.3M	$0.00	$525,660	100	5,789,998	0					5,000	5,602,112	34,193	1,900	1,559
⚠						$9.65M	$6.94M	$137,591	$81,024	96.7	5,794,464	144,064	1,200	514	191,588	55,036			352	1,900	1,559
⚠						$9.68M	$6.84M	$152,789	$80,349	96.3	5,794,464	159,978	1,200	575	212,408	61,116	8.35	9,354	44.0	1,900	1,559
⚠						$9.63M	$6.80M	$153,735	$79,808	96.3	5,794,464	160,967	1,200	578	213,767	61,494				1,900	1,559
⚠						$9.64M	$6.80M	$153,735	$79,808	96.3	5,794,464	160,967	1,200	578	213,767	61,494	0.00413	4.63		1,900	1,559
						$51.1M	$17.6M	$1.64M	$411,515	59.1	5,794,464	1,716,117	1,200	5,013	2,372,136	655,603	3,909	4,379,379	13,344		
⚠						$54.4M	$5.35M	$3.11M	$350,736	21.4	5,794,464	3,252,112	1,200	8,760	4,555,234	1,242,395	1,415	1,585,442			
						$59.0M	$950,694	$3.84M	$316,740	0.00122	5,794,464	4,017,532	1,200	8,760	5,794,394	1,534,806			138		
						$58.9M	$900,000	$3.84M	$315,360	0	5,794,464	4,017,576	1,200	8,760	5,794,464	1,534,823					

Figure A- 14: Milford 1900kW Hydro HOMER output - infrastructure

Architecture					Cost				System			Diesel Generator				Battery	Hydro Generator	
					NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
					$60.1M	$39.4M	$0.00	$715,300	100	6,128,984	0					50,771	6,978	3,533
					$34.5M	$25.1M	$417,228	$295,339	90.4	6,134,328	436,857	4,100	473	586,688	166,891	2,918	6,978	3,533
⚠					$36.9M	$23.9M	$700,278	$308,860	84.1	6,134,328	733,224	4,100	820	978,046	280,111		6,978	3,533
					$69.1M	$4.46M	$4.17M	$414,338	0	6,134,328	4,371,402	4,100	3,096	6,287,915	1,669,994	3,356		
					$72.4M	$3.08M	$4.50M	$448,950	0	6,134,328	4,709,147	4,100	3,650	6,693,504	1,799,022			

Figure A- 15 Lake Marian 6,900kW Hydro HOMER output - buses and infrastructure

Architecture					Cost				System			Diesel Generator				PV		Battery
					NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)
					$2.95M	$2.34M	$0.00	$27,096	100	83,202	0					644	402,396	1,100
					$886,273	$256,047	$38,938	$4,280	37.6	83,220	40,770	22.0	2,700	51,934	15,575	68.3	42,679	79.1
					$987,890	$45,251	$63,580	$3,340	0	83,220	66,571	22.0	4,015	86,851	25,432			69.1
					$1.29M	$16,500	$86,576	$5,782	0	83,220	90,649	22.0	8,760	101,105	34,630			
					$1.29M	$20,127	$86,361	$5,811	0	83,220	90,424	22.0	8,760	100,741	34,544	1.19	745	

Figure A- 16: Lake Marian HOMER output - infrastructure

Architecture						Cost				System			Diesel Generator				PV		Battery	Hydro Generator	
						NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)	Capacity	Mean Output (kW)
						$12.1M	$8.93M	$0.00	$126,195	100	850,705	0					1,045	1,282,672	6,713	207	114
						$13.2M	$9.08M	$0.00	$143,637	100	850,842	0					1,887	2,316,690	9,655		
						$5.80M	$3.77M	$103,515	$45,964	83.6	851,418	108,385	140	1,955	139,285	41,406	81.7	100,331	271	207	114
						$5.85M	$3.48M	$129,998	$46,256	80.1	851,418	136,114	140	2,730	169,832	51,999			179	207	114
						$6.20M	$3.44M	$156,421	$49,264	77.1	851,418	163,780	140	3,800	194,818	62,569	12.2	14,921		207	114
						$6.17M	$3.41M	$156,977	$48,964	77.0	851,418	164,363	140	3,801	195,742	62,791				207	114
						$7.65M	$2.32M	$277,757	$51,677	55.5	851,418	290,824	140	4,969	378,857	111,103	514	631,495	1,796		
						$8.83M	$141,738	$595,839	$37,096	0.416	851,418	623,871	140	8,760	847,872	238,336	12.2	14,921			
						$8.83M	$112,284	$597,925	$36,992	0.00120	851,418	626,055	140	8,760	851,408	239,170			20.0		
						$8.81M	$105,000	$597,931	$36,792	0	851,418	626,062	140	8,760	851,418	239,173					

Figure A- 17: Knobs Flat 200kW Hydro HOMER output - infrastructure

Architecture					Cost				System			Diesel Generator				PV		Battery
					NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Prod (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)
					$215,918	$146,936	$0.00	$2,385	100	35,319	0					29.4	35,319	165
					$126,002	$54,726	$2,996	$989.04	75.3	17,660	3,137	2.40	3,070	3,334	1,199	11.9	14,326	47.0
					$159,394	$2,384	$10,845	$635.54	0.542	13,635	11,355	2.40	8,760	13,404	4,338	0.193	232	
					$160,024	$2,163	$10,888	$640.72	0.00379	13,476	11,400	2.40	8,760	13,476	4,355			1.00
					$159,303	$1,800	$10,888	$630.72	0	13,477	11,401	2.40	8,760	13,477	4,355			

Figure A- 18: Node 2 HOMER output - infrastructure

Architecture					Cost				System				Diesel Generator					PV		Battery
⚠					NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Prod (kWh/yr)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($/yr)	Fuel Cost ($/yr)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)
					$593,683	$413,436	$0.00	$6,384	100	99,059	32,673	0						87.4	99,059	420
					$337,204	$144,161	$8,187	$2,676	73.7	43,931	32,697	8,572	3,045	8,612	3,275	667	8,187	31.1	35,319	123
					$421,506	$6,897	$28,120	$1,930	0.544	33,050	32,697	29,443	8,760	32,519	11,248	1,918	28,120	0.469	531	
					$422,009	$5,841	$28,225	$1,928	0.00156	32,696	32,697	29,552	8,760	32,696	11,290	1,918	28,225			1.00
					$421,283	$5,475	$28,225	$1,918	0	32,697	32,697	29,553	8,760	32,697	11,290	1,918	28,225			

Figure A- 19: Node 4 HOMER output - infrastructure

Architecture					Cost				System			Diesel Generator				PV		Battery
⚠					NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Prod (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)
					$21,342	$16,943	$0.00	$197.59	100	4,474	0					4.70	4,474	8.01
					$6,903	$1,466	$345.70	$36.37	36.5	770	362	0.0880	6,759	445	138	0.341	324	1.00
⚠					$7,094	$510.82	$457.68	$26.69	15.4	729	479	0.0880	8,760	593	183	0.142	135	
					$8,130	$422.25	$520.85	$33.13	0.0728	700	545	0.0880	8,760	700	208			1.00
					$7,417	$66.00	$521.15	$23.13	0	701	546	0.0880	8,760	701	208			

Figure A- 20: Node 6 HOMER output - infrastructure

Architecture					Cost				System			Diesel Generator				PV		Battery
⚠					NPC ($)	Initial capital ($)	Fuel cost ($/yr)	O&M ($/yr)	Ren Frac (%)	Elec Cons (kWh/yr)	CO_2 (kg/yr)	Capacity	Hours	Production (kWh)	Fuel (L)	Capacity (kW)	Production (kWh/yr)	Nominal Capacity (kWh)
					$258,258	$206,507	$0.00	$2,354	100	7,090	0					57.8	53,217	91.1
⚠					$43,271	$3,910	$2,281	$360.12	1.08	7,096	5,970	3.40	3,285	7,019	2,281	0.202	186	2.00
					$43,516	$3,301	$2,328	$355.07	0	7,096	6,095	3.40	3,285	7,222	2,328			2.00
⚠					$80,913	$6,831	$3,982	$868.42	0	7,096	10,424	3.40	8,182	10,286	3,982	1.35	1,248	
					$82,632	$2,550	$4,360	$893.52	0	7,096	11,412	3.40	8,760	11,421	4,360			

Figure A- 21: The Chasm HOMER output - infrastructure

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