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Applecross Community Hydro

Hydro Power & District Heating Analysis

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1 Introduction

Aecom was appointed by Applecross Community Company (ACC) to review the possibility of using excess electricity which could be produced by the hydro scheme currently under development by ACC. The electricity grid is limited to 90kW of export so any generation above this from the hydro scheme would need to be used locally, off the grid. ACC were interested in the possibility of using excess generation to provide heat to the buildings in the vicinity of the hydro scheme. If there was further capacity available it another idea was to consider an electric vehicle and charging point.

Prior to this study significant work had been carried out on the hydro scheme and a heat mapping exercise had been carried out. The hydro study looked at a 99kW option, based on the grid restriction, and a 230kW option, based on the flow information from the water course.

This study has built on the existing hydro study to produce an output curve for the 230kW option to show what excess generation could be available to provide heating to the village. The heat map information has been reviewed and heat loads for the possible buildings produced, on a monthly basis. These two data sets have been compared and in the simplest terms the excess generation could provide a large proportion of the annual heat required for most of the village. The actually proportion depends on the type of heating system chosen but this basic comparison shows that there is a good balance of generation and demand. The main reason that the full annual requirement cannot be met is the drop in hydro power output in the summer months.

Due to the costs associated with infrastructure the study has focussed on the Shore Street buildings and Craite Burn since these provide a suitable load and can be treated as two groups in terms of provision, requiring less infrastructure than connecting up more widely distributed buildings.

The main options considered for heat provision are:

Shore Street

- District heating system with central heat pump source and LPG boiler backup
- District heating system with central electric boiler source and LPG boiler backup
- Electric private wire connection to each building with electric boilers installed to houses with oil central heating systems, radiators retained; houses with electrical heating retain these

Craite Burn

- Electric private wire connection to each building; existing heating systems retained

There were various sub-options in some of these cases and these will be described in the report.

All the possibilities have difficulties associated as this is not a standard solution, albeit an appealing one given the circumstances. These are also described in the report for each option.

The final part of the process was to carry out a basic financial analysis to consider whether any of the options should be taken forward.

2 Hydro

2.1 Proposed Hydropower Scheme

An outline design has been carried out by Highland Eco-Design for a 99kW hydro scheme, based on the grid connection export limit of 90 kW. The proposed scheme would include the following elements:

- Intake weir with Coanda type screen on the Allt Breugaireachd and header manhole
- Buried 300mm nominal diameter nominal pipeline between intake and turbine
- Turbine house constructed of a reinforced concrete sub-structure with timber or rendered block walls, containing turbine, generator and control panel
- Tailrace channel with screened outlet returning the abstracted water to Allt Breugaireachd
- Buried cable from turbine house to grid connection point
- Pelton type turbine with a design capacity of 99kW based on a design flow of 90l/s and a gross head of 172m (net head quoted of 166.5m)

A review of the information provided, including the Preliminary Design Report by Highland Eco-Design, reveals some discrepancies in the pipe length and the pipe head loss. However, it is presumed that these matters will be dealt with at the detailed design stage.

The 230kW scheme would be very similar to the 99kW scheme, except the pipe and structures would be larger, and the turbine/generation equipment would be sized for the increased capacity.

An abstraction license has been obtained from SEPA for the 99kW scheme, based on the 90l/s maximum flow. This would require to be revised in the event that ACC proceed with the 230kW scheme as the maximum flow would increase to about 210l/s. It is also noted that the hands-off flow of 15l/s set by SEPA is not the expected Q95 or Q90 flow in accordance with standard SEPA guidelines, but a flow that is equivalent to Q85, based on the LowFlows data. If the license is modified it is suggested that this is queried with SEPA and the flow duration curve produced from the river gauging is offered as a more representative curve for this watercourse (see 2.3 below).

ACC have obtained a grid connection offer from SSE dated 15 August 2012, which includes the 90kW export limit. The offer was open for acceptance for one calendar month from the issue date.

2.2 Hydro Cost Estimate

Cost estimates for both the 99kW and 230kW schemes have been provided by Highland Eco-Design, inclusive of development (feasibility, planning and SEPA licensing), civil works, mechanical and electrical works, design, management and supervision. The respective estimates are £487,457 and £794,552.

It is considered that, following a review of the detailed breakdown provided for the 99kW scheme, the estimate may be on the low side, particularly for the mechanical and electrical works. Although the estimates provided have been used in the financial analysis for the whole scheme (hydro plus district heating), an additional analysis has been carried out incorporating a 20% uplift to the hydro cost to confirm the viability of the scheme if the cost is higher (see 4.8).

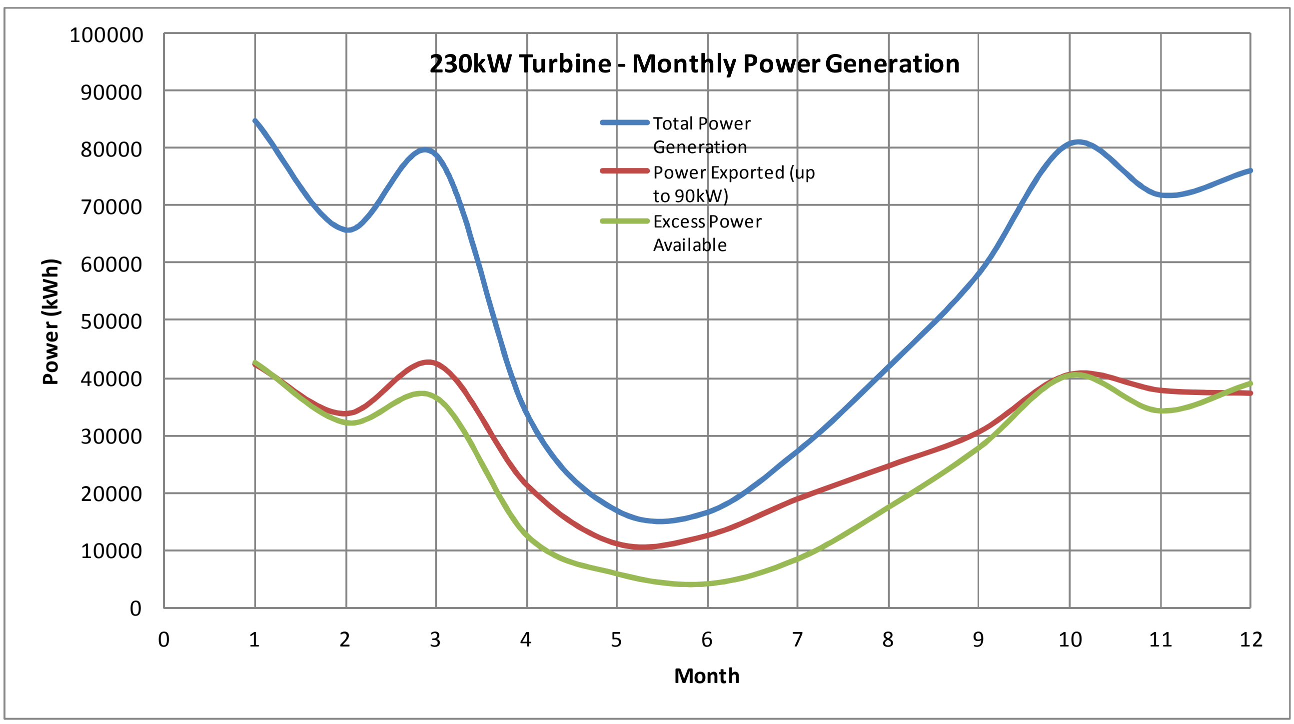
2.3 Hydrology and Flow Duration Curve

The original hydrological work undertaken for the Preliminary Design Report by Highland Eco-Design used the LowFlows 2000 software to generate monthly and the annual flow duration curves (FDC) for the Allt Breugaireachd. However, the catchment has a number of unusual features, including underground caves formed in the limestone that the watercourse enters thus allowing it to run dry prior to re-emerging further downstream. A river gauging survey was commissioned by ACC from MNV Consulting Ltd and this has produced actual flow data for the watercourse for a period of over 12 months. MNV also engaged in lengthy dialogue with SEPA and carried out extensive analysis of the data for this and other similar catchments in order to synthesise a more representative FDC than that produced by LowFlows. It is considered that this approach is the correct one and the FDC produced by MNV has been used in preference to LowFlows for this study.

Monthly FDCs have been created by modifying the LowFlows monthly FDCs that were included in the Preliminary Design Report, by using the relationship between the LowFlows and MNV annual FDCs. The resulting monthly FDCs are included in the table in Appendix A.

2.4 Power Generation and Export Revenue

From the monthly flow duration curves, estimates have been made of the total power generated by the 230kW turbine installation, the power generated up to the 90kW export limit set by the grid connection, and the excess or residual power that is available for use locally 'off grid' by ACC. A graph of the monthly power generation is shown below, and the tabulated monthly FDCs and power generation is included in Appendix A.



Assumptions:

1. 230kW turbine plant is assumed to have similar efficiencies and net head as the 90kW plant described in the Preliminary Design Report by Highland Eco-Design.
2. The operating flow range of the 230kW turbine is assumed to be between design flow and 20% of design flow (eg 210 to 42l/s for 230kW turbine).
3. The hands-off flow is 15l/s, in accordance with the CAR License.

It is estimated that the total potential annual power generation for the 230kW turbine is 653,336kWh, the annual power exported to the grid is 352,784kWh, and the potential excess power (difference between the two values) is 300,582kWh.

The annual revenue that might be produced by the 230kw turbine up to the 90kW limit is £70,557, based on the FiT generation rate of 15.5p/kWh and an export tariff of 4.5p/kWh which were current at the time of the study. It should be noted that Ofgem released new tariffs on 22 March 2013 which would improve the projected revenue by about 3%. Any generation output that may be produced to feed the local ‘off grid’ power supply would be eligible for the FiT generation tariff as well.

3 Electrical Infrastructure

3.1 The System

The heads and flows available suggest that an impulse turbine will be best suited for this application. As opposed to reaction turbines (Francis and Kaplan) impulse machines (Pelton and Turgo) also have a control response advantage for this type of application (this will be described later in the document.

With respect to control, the main challenge for this project is how best to limit the 90kW grid export (maximum authorised export power limit) while supplying the surplus power ‘available’ to the ‘private wire’ consumers.

During the feasibility four different options were initially assessed.

1. Two turbine/generator sets: one 90 kW machine for the grid and a larger machine (around 250kW) for the ‘private wire’ consumers. This solution effectively isolates the grid completely and hence eliminates the risk completely of exceeding the 90kW export. However, the cost of implementing this solution is excessive in terms of capital cost and will have a poor net present value (NPV) return.
2. A single large turbine/generator set: with an additional 90kW motor/generator (MG) set for supplying the grid separately. This solution also effectively isolates the grid completely and hence eliminates the risk completely of exceeding the 90kW export. However, the cost of implementing this solution is also excessive in terms of capital cost and will have a poor NPV return due to the additional energy losses across the MG set.
3. A single large turbine/generator set: with an additional 90kW electronic inverter unit for supplying the grid separately. This solution only partly isolates the grid (electronic barrier) but could be designed to eliminate the 90kW export. However, the cost of implementing this solution is also excessive in terms of capital cost and will also have a poor NPV return.
4. A single large turbine/generator set supplying both ‘private wire’ consumers and the 90kW export limit to the grid. This solution requires a robust control system to eliminate the risk of exceeding the authorised 90kW export to the grid. Although the control measures and system will require approval by the Distribution Network Operator (DNO), we do not envisage that this will be an obstacle if properly designed and demonstrated to the satisfaction of the DNO. This is by far the most cost effective and efficient solution and should provide the best NPV return. By combining an innovative control design with a high level of redundancy this should provide an effective design and hence the solution we recommend for further development.

The power allocation and control system for the last option above is illustrated in the schematic diagram included in Appendix A. The diagram identifies the main components required, as follows:

- Hydro Turbine
- LV Generator
- Load Monitor
- Certified connection to the DNO (Air Circuit Breaker (ACB) & G59 Relay)
- Import/Export control system (to be certified by the designer/contractor)
- Consumer interface switching system (Programmable Logic Controller (PLC) & Dupline communication controller)
- Consumer supplies (Western Route to 15 properties) Power and Control
- Consumer supplies (Northern Route to 8 properties) Power and Control

3.2 Consumers

It is proposed to provide two separate consumer supply routes

1. Western route consisting of a supply and control system to 15 properties (including a hotel) on Shore Street.
2. Northern route consisting of a supply and control system to 8 properties in Craite Burn.

For the western route it is proposed to make the full 230kW available. This will help maximise the potential of the available power for future expansion and during periods when the system is off-grid and/or disconnected from the northern route. The realisation that the system can provide power when off-grid requires an 'islanded' mode turbine/generator design to be implemented. The length of this route from the site of the proposed turbine is around 500m. At this distance a high voltage link will be the most economical and it can easily be sized to cater for the full 230kW available. This will be achieved by the installation of two pad mounted transformers (step-up and step down) and switch gear located at each end of the route. An HV cable (preferably buried) will link the two transformers. (It should be noted that although an LV cabling system would be uneconomical over this distance, planning constraints may require re-consideration of an LV link which would require reduction in the power made available for this section).

The secondary side of the step down transformer (located close to the hotel: the largest consumer in the string) will provide a three phase and neutral supply for the 15 properties. A suitable buried cable will run behind the rear of the properties with consumer cables 'jointed' from the main supply cable feeding each of the 15 properties. This 'private wire' arrangement will follow conventional DNO consumer low voltage installations and will be provided with a suitable independent LV earthing system. Following discussion and agreement with the DNO, the earth resistance and installation method of the 'private wire' will be suitable for connecting in parallel to the DNO earth. However, the earth must be capable of independent safe operation.

For the northern route it is proposed to make 50kW available. The length of this route from the site of the proposed turbine is around 80m. At this distance LV cables will be more economical than a costly HV supply providing the loading is restricted to around 50kW. This will be achieved by the installation of suitably sized, buried LV cables providing a split phase power supply to the 8 properties. A similar cabling arrangement as described for the western route will be installed supplying each individual property. This 'private wire' arrangement will also follow conventional DNO consumer Low voltage installations and will be provided with a suitable independent LV earthing system. Like the western route it will be suitable for connecting in parallel to the DNO earth with the capability of independent safe operation.

3.3 Communications and Switching Regime

It is proposed to install a Dupline communication system complete with central controller and individual switches at each property. The central controller will be linked to each switch by a common single pair cable (bus connected) to each switch. This is a robust and well proven industrial communication field bus system providing a reliable and low cost solution. It is envisaged that a switching programme will be developed providing each property with a 'fair share' of the power available. This will be base on 'time share' giving each property the same time slot periods averaged over distinct seasonal periods. This will require time period cycling and priority scheduling so that load shedding (during periods of low water flows) will allow consumers to be periodically switched on and off the private supply in a systematic manner. An algorithm will require to be implemented within the hydro turbine 'Programmable Logic Controller' (PLC) to deliver the agreed switching programme.

During conditions when the turbine is under-loaded or over-loaded the switching programme will be automatically adjusted by either switching in additional consumers (under-loaded generator) or switching out consumers during turbine over load conditions. The switching actions will operate automatically to keep the hydro turbine operating at the maximum power available (maximum head and flow available). When taking into account the number of properties and resulting diversity, it is envisaged that the load regulation required will be gradual during normal operation conditions and only require relatively small adjustments.

Each property will also be provided with a power changeover switch, consisting of a changeover contactor complete with mechanical and electrical interlocks. Each contactor will be operated by its associated Dupline switch, thus allowing automatic selection of either DNO supply or private supply feeding each independent storage heating system. The contractor/designer will need to undertake discussions with the DNO (as described previously) so that the system will meet the specific requirements of the DNO and hence meet all necessary approvals.

In addition to the control switches a kWh meter will be installed in each property to record the power consumed by the 'private wire' supply.

3.4 Import Export Control

It is proposed to design and install an import and export control module (see Fig 1) which will provide the following control functions.

1. Main control loop: An operating export control and limit system will be implemented by using reverse power protection relays with appropriate limits. The control will use a 'dead band' with adjustable limits (set during commissioning) between 80 – 90kW. When the export is below the dead band a signal will be sent to the turbine power control element (spear valve) so as to increase the power until the export power is again within the 'dead band'

   When the export is above the dead band a signal will be sent to the turbine power control element (spear valve) so as to decrease the power until the export power is again within the 'dead band'. As described previously, it is envisaged that the load regulation required will be gradual during normal operation conditions and only require relatively small adjustments. Hence the 90kW export limit will be controlled under normal regulation.

2. Emergency - reverse power exceeds 90kW: In the event of sudden disturbances to the consumer loads (breaker trips etc) the export will increase suddenly and will not be controlled by the normal control action as described above. Under these emergency conditions an instantaneous reverse power protection relay will detect the condition and will trip the ACB connected to the grid. With the inclusion of redundant systems for the instantaneous trip we envisage that this design will be developed further to the satisfaction of the DNO and will hence meet the required approvals.

   It should be noted that during this 'off grid' trip scenario the turbine will tend to accelerate and control safety measures will be required to eliminate any potential damage. Impulse turbines such as Pelton or Turgo machines have an inherent ability to mitigate these dangers by the fail safe action of deflector plates which rapidly divert the water jets from the impellers.

It should be further noted that the import/export control of the turbine power will work in conjunction with the Dupline load shedding/switching programme, as described previously. These two control loops will effectively act as compounds loops to ensure that maximum power is extracted from the hydro powers system at all times.

4 Heat

4.1 Heat Demand

Heat demand in Applecross village is mostly due to housing, the hotel and the campsite. This is distributed in two main groups of buildings, at Shore Street and the campsite/Craite Burn area. Heat demand is for space heating and hot water.

The heat demand for each house has been calculated from assumed benchmark data for house types developed by AECOM for heat mapping work. The original source for the data used in the calculations for the heat mapping study is the Scottish House Condition Survey. Actual consumption data was available for the hotel and this has been used to scale the benchmark figures, since the hotel is of similar age and construction to the Shore Street buildings. Floor areas were taken from the Highland Heat map data, where available, and estimated from maps and the survey, where not available.

A map of the heat demand for each house in the study is shown below.

Property	Heat Demand (kWh)
Applecross Inn	73,266
3 Shore Street	8,350
4 Shore Street	6,263
5 Shore Street	6,764
7 - 6 Shore Street	26,378
8 Shore Street	3,532
9 Shore Street	6,513
10 Shore Street	8,517
11 - 12 Shore Street	8,448
13 Shore Street	13,080
14 Shore Street	3,465
15 Shore Street	11,523
16 Shore Street	11,022
17 Shore Street	18,678
18 Shore Street	26,602
19 Shore Street	26,602
Subtotal	259,002

Property	Heat Demand (kWh)
4 Craite Burn	6,500
5 Craite Burn	6,500
6 Craite Burn	6,500
7 Craite Burn	6,500
8 Craite Burn	6,500
3 Craite Burn	6,500
2 Craite Burn	6,500
1 Craite Burn	6,500
Subtotal	52,500
Smithy Cottage	23,055
Forge End	17,940
Subtotal	40,995
Shower Block	45,000
Grieve's House	30,100
Cattleman's House	26,400
Saighdears	26,400
Subtotal	127,900

These figures were compared to the heat demand data provided by ACC from the work carried out by Highland Birchwood. The Highland Birchwood study used a different methodology, based on an algorithm calculation using high and low U values for each building and a hot water constant based on building use class. The two calculations provided a degree of verification. They can be compared using the two maps. The main differences occur where there is low occupancy as this study has added an occupancy factor to the calculation based on the survey findings.

For Craite Burn, the houses are known to be well insulated and are newer. The Highland Heat map data for the appropriate age of building was used for these houses as this should provide a good match for more modern and well insulated buildings.

The survey undertaken as part of the study allowed information regarding occupation patterns of the buildings and heating sources to be gathered. The occupation information has been used to scale the heat demand data as a home that is unoccupied for long periods will have a lower demand than one that is continually occupied. This information is shown in Tables 4.1 and 4.2.

It is important to understand there are limitations in this approach and actual consumption data should be gathered for all properties at the next stage to verify the loads. However, for the purpose of assessing whether there is merit in developing the heat option, this approach is suitable.

To give a better understanding of how variation in heat demand and hydro output over the course of a year compare, the heat loads for the buildings have been extrapolated to monthly figures, using Degree Day data for the North West Scotland region and the weather adjustment process form CIBSE TM:46 Energy Benchmarks. The degree day information gives an indication of how heat demand varies for different regions across the U.K on a monthly basis. It assumes a minimum temperature above which heating is required and then counts the number of hours each month that this condition is met. CIBSE TM:46 gives a methodology for splitting space heat demand and hot water demand from an overall figure. For the hotel it is assumed that 55% of the annual demand is for hot water and 17% for the houses, based on Department for Energy and Climate Change (DECC) Report, ‘Great Britain's Housing Energy Fact File’, 2011. The monthly heat demand information is shown in Tables 4.3 and 4.4.

Address	Building Type	Occupation	Heating Type	Supplementary Heating	Occupancy Factor	Floor Area (m²)	House Type	Assumed Heat Demand (kWh/m²)	Heat Demand (kWh)
[redacted]	Hotel		Oil			400	Hotel	183	73,266
[redacted]	Holiday Home	Moderate	Electric		0.5	100	Mid Terrace	167	8,350
[redacted]	House	Well Used	Electric.		0.75	50	Mid Terrace	167	6,263
[redacted]	House	Well Used	Electric		0.75	54	Mid Terrace	167	6,764
[redacted]	House	Full Occupation	Electric		1	121	End Terrace	218	26,378
[redacted]	Holiday Home	Not Well Used	Electric	Coal	0.3	54	End Terrace	218	3,532
[redacted]	Holiday Home	Well Used	Electric	Wood	0.75	52	Mid Terrace	167	6,513
[redacted]	House	Full Occupation	Electric	Coal	1	51	Mid Terrace	167	8,517
[redacted]	House	Light Occupation	Oil		0.25	155	End Terrace	218	8,448
[redacted]	Holiday Home	Well Used	Electric		0.75	80	End Terrace	218	13,080
[redacted]	Holiday Home	Not Well Used	Electric		0.25	83	Mid Terrace	167	3,465
[redacted]	House	Full Occupation	Electric		1	69	Mid Terrace	167	11,523
[redacted]	House	Full Occupation	Electric		1	66	Mid Terrace	167	11,022
[redacted]	House	Full Occupation	Electric		1	66	End Terrace	283	18,678
[redacted]	House	Full Occupation	Electric	Coal	1	94	Detached	283	26,602
[redacted]	House	Full Occupation	Oil		1	94	Detached	283	26,602
Total									**259,002**

Table 4.1: Heat Loads – Shore Street

Table 4.2: Heat Loads – Craite Burn / Campsite

Address	Building Type	Floor Area (m^2)	Heating Type	Heat Demand (kWh)
[redacted]	Social Housing	100	Electric	6,500
[redacted]	Social Housing	100	Electric	6,500
[redacted]	Social Housing	100	Electric	6,500
[redacted]	Social Housing	100	Electric	6,500
[redacted]	Social Housing	100	Electric	6,500
[redacted]	Social Housing	100	Electric	6,500
[redacted]	Social Housing	100	Electric	6,500
[redacted]	Social Housing	100	Electric	6,500
Total				**52,500**
Campsite				
Shower Block			LPG	45,000
[redacted]	House	100	Oil	30,100
[redacted]	House	100	Oil	26,400
[redacted]	House	100	Oil	26,400
[redacted]	House	87	Electric	23,055
[redacted]	House	65	Electric	17,940

Table 4.3: Monthly Heat Demand (kWh) – Shore Street

Address	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
[redacted]	7,135	6,619	7,061	6,445	6,504	4,956	4,760	4,820	4,905	6,037	6,860	7,164	**73,266**
[redacted]	958	782	660	459	334	308	399	623	810	1,037	1,029	952	**8,350**
[redacted]	718	586	495	344	250	231	299	467	608	778	771	714	**6,263**
[redacted]	776	633	535	371	270	250	323	505	656	840	833	771	**6,764**
[redacted]	3,025	2,470	2,085	1,449	1,055	974	1,261	1,968	2,559	3,276	3,249	3,007	**26,378**
[redacted]	405	331	279	194	141	130	169	264	343	439	435	403	**3,532**
[redacted]	747	610	515	358	260	240	311	486	632	809	802	743	**6,513**
[redacted]	977	797	673	468	340	314	407	636	826	1,058	1,049	971	**8,517**
[redacted]	969	791	668	464	338	312	404	630	820	1,049	1,041	963	**8,448**
[redacted]	1,500	1,225	1,034	718	523	483	625	976	1,269	1,625	1,611	1,491	**13,080**
[redacted]	397	324	274	190	139	128	166	259	336	430	427	395	**3,465**
[redacted]	1,322	1,079	911	633	461	425	551	860	1,118	1,431	1,419	1,314	**11,523**
[redacted]	1,264	1,032	871	605	441	407	527	822	1,069	1,369	1,358	1,257	**11,022**
[redacted]	2,142	1,749	1,476	1,026	747	690	893	1,394	1,812	2,320	2,301	2,130	**18,678**
[redacted]	3,051	2,491	2,102	1,461	1,063	982	1,271	1,985	2,581	3,304	3,277	3,033	**26,602**
[redacted]	3,051	2,491	2,102	1,461	1,063	982	1,271	1,985	2,581	3,304	3,277	3,033	**26,602**
Total	**28,437**	**24,010**	**21,740**	**16,646**	**13,929**	**11,813**	**13,636**	**18,679**	**22,927**	**29,105**	**29,739**	**28,340**	**259,002**

Table 4.4: Monthly Heat Demand (kWh) – Craite Burn

Address	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
[redacted]	745	609	514	357	260	240	311	485	631	807	801	741	**6,500**
Total	**5,964**	**4,869**	**4,110**	**2,856**	**2,079**	**1,920**	**2,485**	**3,880**	**5,046**	**6,458**	**6,405**	**5,929**	**52,000**

4.2 Options Considered – Overview

There was found to be a reasonable correlation between the loads and the excess hydro generation. In order to develop options the following factors were considered:

- Heat sources
- Distribution method
- Backup heat provision for when hydro not available
- Buildings to include

The possibilities for each of these are as follows.

4.2.1 Heat Sources

The existing buildings utilise a mixture of electrical and oil heating. Options to utilise electricity from the hydro scheme are heat pumps and electric heating. Heat pumps work on a vapour compression principle, similar to a refrigerator in reverse, and have the advantage of producing more than 1 unit of heat for each unit of electricity used. This is achieved by extracting low grade heat from the environment and upgrading it through mechanical work in the compressor. Heat pumps can be configured to extract heat from the ground, the air or water (rivers, lakes or the sea). This can be either a closed loop system with a fluid circulating in this loop and no direct contact with the environment, or an open loop system which draws water from a river, lake or the sea through the heat pump before returning it to the source. Heat pump efficiency is dependent on the difference between the environment temperature and the output temperature required. The bigger this difference the lower the efficiency.

For this study water source heat pumps, using the sea as a source, were considered as ground source options require boreholes which are expensive to drill or a large space for a ground array. Air source heat pumps typically have a lower performance in the main heating season as the air is colder than the sea/lake when demand is greatest.

Electric heating covers different types of system. The most familiar is electric panel radiators, either storage type or direct acting. Also of interest for this study is the electric boiler type. This is a similar system to an oil/LPG/gas/ biomass boiler using a wet heating system, typically with radiators, to distribute heat around the building. The heat is provided in a boiler using electricity rather than burning a fuel.

For this study both types of electrical heating have been considered, depending on the building. The main advantages and disadvantages of the two types of heat source are shown below.

	Advantages	Disadvantages
Heat Pump (sea water)	• Better efficiency • Lower carbon emissions	• More complex plant • Poor efficiency with traditional radiators and in poorly insulated buildings • Sea water dramatically shortens equipment life • Risk of damage from waves and tidal currents • Systems use refrigerants and anti-freeze which could cause pollution if leaks occur • More expensive
Electric Heating	• Simple technology • Relatively cheap • Few moving parts	• Lower efficiency than heat pumps • Normally higher carbon emissions (depending on source of electricity). In this case the carbon emissions will be low. • Poor control if traditional storage heaters

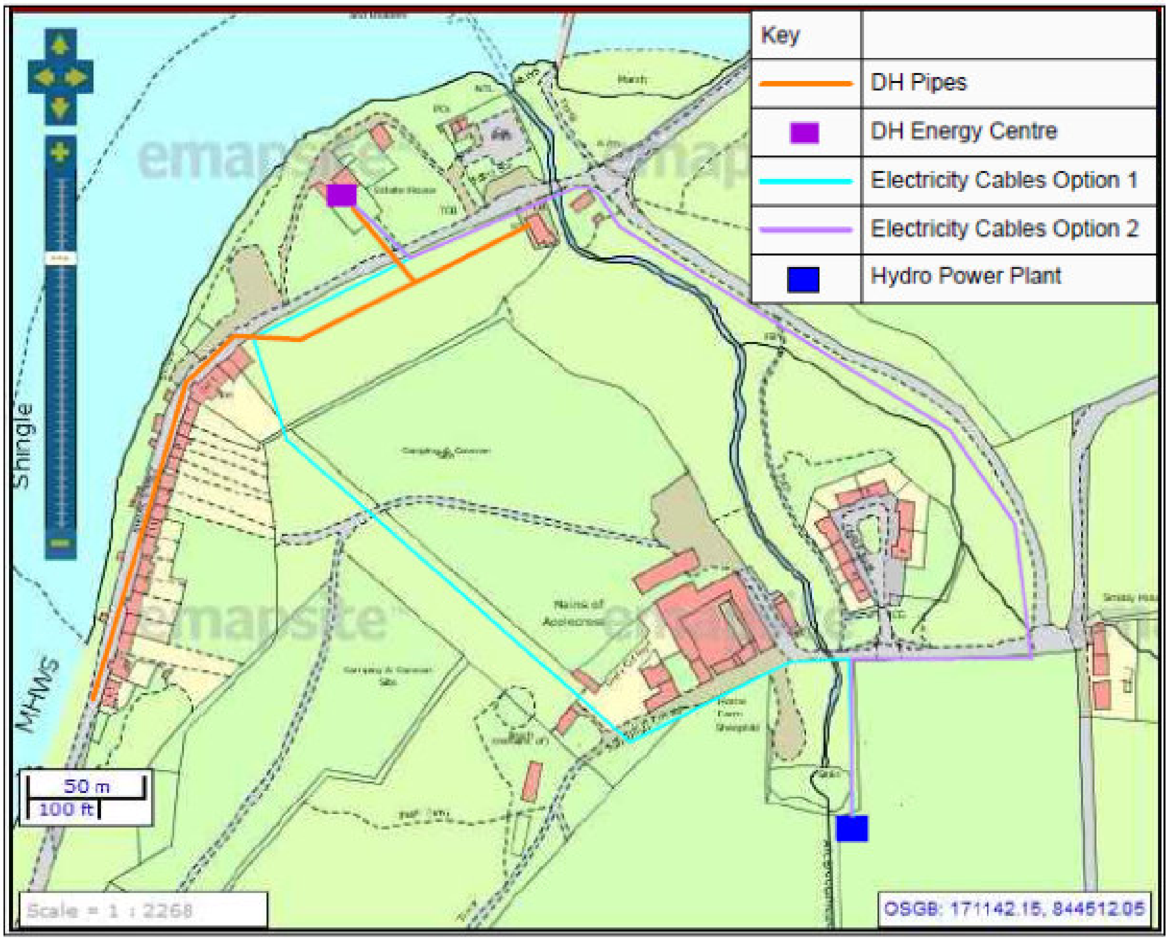
4.2.2 Distribution Method

Two main options were considered. These are district heating using a wet system, i.e. hot water piped to each building, and private wire electrical system, i.e. electrical connection from hydro scheme to each building.

4.2.2.1 District Heating

An electrical connection links the hydro scheme to an energy centre close to the buildings to be heated, in this case Shore Street. The energy centre contains the heat source, which, depending on the option, comprises of heat pumps or electrical boilers. The energy centre also contains backup boilers for when the hydro output is not sufficient. This study is based on LPG fuelled boilers as the cost information (from the hotel) would suggest that LPG is slightly cheaper than oil. In practice either could be used. Biomass could also be considered, but during the survey this was discussed and ruled out for the time being as there is not a guaranteed source of wood fuel. A large thermal storage tank is a normal part of the energy centre as it allows the heat sources to produce heat when there is energy available from the hydro scheme rather than only when there is demand from the buildings. The store also helps to meet the peak demands allowing lower capacity plant to be specified, which gives a cost benefit. A pipe network is buried in the ground (under the road would be the only option) and connects to each building. The plumbing involves a heat interface unit with meter. This can be connected directly to existing radiator based heating systems and possibly to existing hot water tanks, depending on the current plumbing. For houses with electrical heating, the existing system would need to be removed and a new wet heating system installed. The building occupier has full control of the heating system with time clock and thermostat control. The following figure gives an overview of this option.

Figure 4.1: Plan showing District Heating Option



For the study it is assumed the energy centre would be sited at the currently unoccupied Estate House. This building appears to have suitable space for this and it would reduce costs to use an existing building. Adding a new building to the sea front could also be difficult in planning terms.

4.2.2.2 Private Wire

This would involve providing an electrical connection to each building from the hydro scheme. Further details of this are given in the electrical infrastructure section. The connection in the house is restricted by what is permissible to the grid operator (District Network Operator – DNO). Connection would need to be after the electrical meter and would have to prevent any possible feedback to the grid. For the hotel the option considered is to install an electric boiler, while retaining the existing oil boiler for backup. This is to prevent an additional electrical load onto the grid when the hydro scheme is not generating. There would therefore only be a connection to the hydro scheme and not to the grid. For the housing with electrical heating which is on a separate electrical meter (white meter type), there would be a switch on the heating circuit to allow a change from hydro supply to grid supply as required. This switch would require intelligence to manage the switching and co-ordinating between the houses for when the supply is adequate for a limited number of properties only. There would be a meter on the supply from the hydro also. For the houses with oil heating, there would be the option of a similar solution to that for the hotel, i.e. an electric boiler in addition to the existing oil boiler, or removal of the existing heating system and installing electric radiators and hot water cylinder. The main issue with this will be specifying a switch that meets the approval of the DNO and is still affordable. In the case of installing an electric boiler in addition to the oil boiler the main issue would be the space required to house two boilers.

The main advantages and disadvantages of the two distribution methods are shown below.

	Advantages	Disadvantages
District Heating	• Plumbing connection to buildings avoids an issues with electricity grid interfaces • Wet heating systems can offer better control and comfort • Central plant can be more efficient and cost effective due to larger size • Central heating plant makes changing heat source in future simple, e.g. to biomass	• Pipework and installation expensive • Energy centre building required • Existing electric heating systems need to be replaced • Heat loss in pipes and distribution • Land & access to existing Estate building required
Private Wire	• Installation of infrastructure less disruptive • No central energy centre building • Less changes to existing heating systems required when considering all buildings • Less energy loss in electrical transmission than heat transmission	• Switching and controls may will require a certain degree of complexity to meet DNO approval • Connection limited to heating circuit only for buildings ad rerquires separate power meters on heating circuit • Poor control if traditional storage heaters • When output from the hydro is low, some customers will be switched back to the grid at higher cost

4.3 Implications for Applecross Community Company in becoming an energy supplier

Regardless of the arrangement of the scheme, any of the options mean that ACC would operate as a supplier of energy to part of the community. There are numerous issues that this raises that will need careful consideration to find a workable solution for Applecross.

Some of the main issues are:

1. Fairness in supply – ACC will have freedom to set the cost of energy supplied. This is likely to be lower than current utility costs or building occupiers will not participate. Only residents connected to the supply will benefit and on the private wire arrangement at low hydro output only some of the connected buildings will receive the hydro supply. This means the benefit will not be equally distributed across the Community. Finding a model acceptable to all will be a challenge.
2. Uptake – From the survey it is understood the majority of the community is supportive at this stage. To spread the infrastructure costs the highest possible uptake will be necessary and this will require promoting the benefits and countering resistance. People may fear they will lose their supply and be subject to any pricing as ACC determine with no opportunity to switch supplier. However ,in this event the consumer has the ultimate sanction, they can turn the hydro supply off from their house
3. DNO consent – The private wire option involves interfaces between grid and hydro supply in the majority of buildings. The DNO is likely to be initially resistant to this and will need to be reassured and convinced. The DNO may introduce requirements that increase the complexity and cost of the switch gear required

4.4 Modelling Results

The following options were modelled:

Option 1	District Heating – Heat Pump
Buildings served	Shore Street only
Heat Source	Two stage heat pump; closed loop; sea source
Efficiency/Co-efficient Of Performance (COP)	2.0 (COP) – This is low but is based on high output temperatures being required.
Capacity	99kW
Backup Boiler	LPG
Capacity	400kW
Thermal storage	5,000l
Network heat losses	10%

Option 2	District Heating – Electric Boiler
Buildings served	Shore Street only
Heat Source	Electric boiler
Efficiency	95%
Capacity	150kW
Backup Boiler	LPG
Capacity	400kW
Thermal storage	5,000l
Network heat losses	10%

Option 3	Private Wire – Shore Street only
Buildings served	Shore Street only
Heat Source	Electric boiler – hotel; electric radiators - houses
Efficiency	Boiler 95%; electric radiators 100%
Backup Heating	Hotel – existing oil boiler; houses – grid electricity

Option 4	Private Wire – Craite Burn only
Buildings served	Criate Burn
Heat Source	Electric radiators
Efficiency	100%
Backup Heating	Grid electricity

Option 5	Private Wire – Craite Burn and Shore Street
Buildings served	Craite Burn and Shore Street
Heat Source	Electric boiler – hotel; electric radiators - houses
Efficiency	Boiler 95%; electric radiators 100%
Backup Heating	Hotel – existing oil boiler; houses – grid electricity

4.5 Costs

Table 4.5 below includes the information used in the financial analysis.

Item	£	Source
Fuels	p/kWh	
Oil	7.5	Estimated from hotel data
LPG	7.0	Estimated from hotel data
Grid Electricity (assumed economy 7 night tariff)	9.0	Estimated from Scottish Hydro
Incentives		
Feed in Tariff (hydro; 100 – 500kW)	15.5	OFGEM
Renewable Heat Incentive (Heat Pump <100kW)	4.7	OFGEM
District Heating costs	£/metre	
Pipe Costs (including install)	150	Estimate/Rehau (depends on size)
Civils work (trenching, re-instatement)	350	PPSL district heating
Branch cost – hotel	6,600	Poyry Report
Branch cost – house	2,177	Poyry Report
HIU / meter	2,300	Poyry Report
Heat Source – Heat Pumps	£	
3no 30kW heat pumps	45,000	Kensa Heat Pumps
Closed loop 'pond mats'	23,000	Kensa Heat Pumps
Sea bed install	23,000	Estimate (100% uplift)
Heat Source – Electric Boiler		
Electric boilers 3no 50kW	21,000	Atlantic Boilers
LPG Boiler (400kW)	20,000	SPONS
Thermal Store (5,000 litre)	25,000	SPONS
Commissioning	3,000	AECOM
Delivery	2,500	
	100	
Retrofit Wet Heating System		
4 / 5 radiators	2,200	Kensa heat pumps
Private Wire Option		
Electric boiler – 50kW (hotel)	7,000	Atlantic Boilers
Electric boiler – 15kW (oil heated houses)	1,000	Elnur
Meter (1 per building)	1,000	AECOM
Automatic Transfer Switch (ATS) - 1 per building	150	AECOM

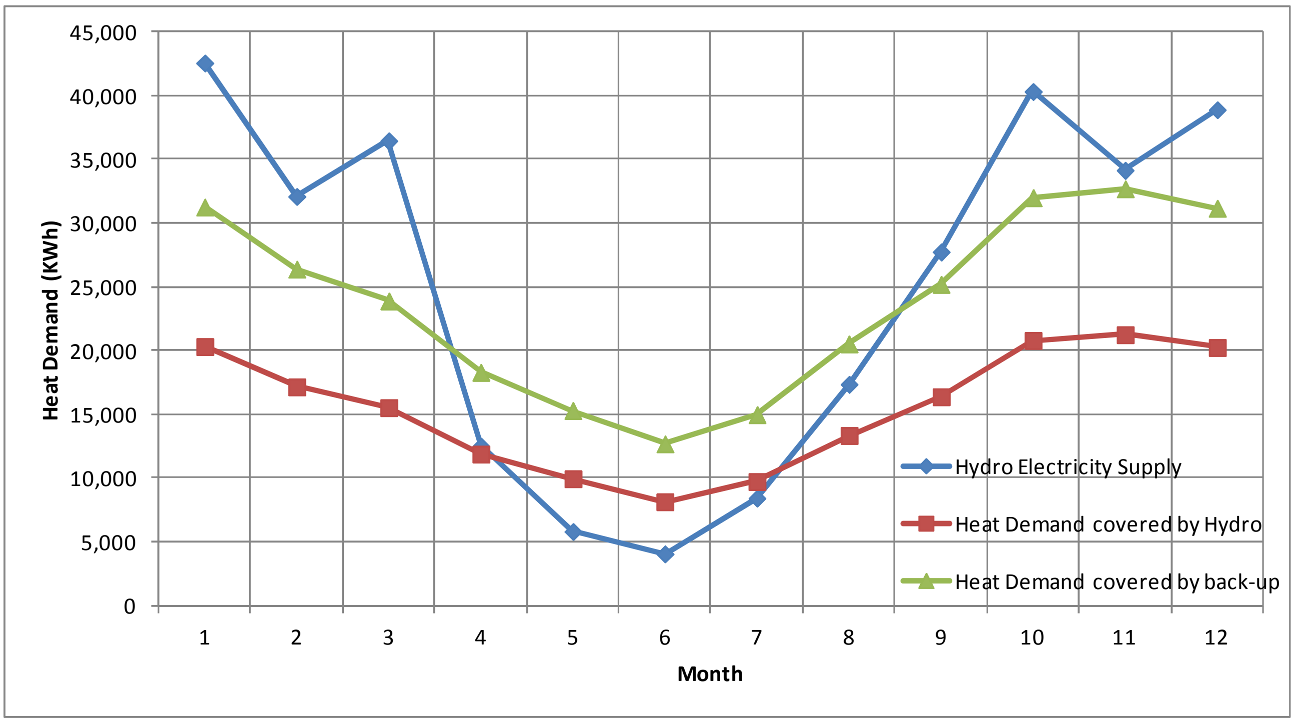
4.6 Results - Loads

The following section provides details of the results of the modelling work. The graphs show the heat loads for the buildings plotted against the available output from the hydro. It should be remembered that the hydro output is electricity not heat and conversion efficiencies between energy types vary so it is not an exact comparison, but the proportion of the overall heat load from hydro is accurate in heat delivered terms.

4.6.1 Shore Street Only

4.6.1.1 Option 1

This option uses heat pumps with LPG back up to supply a district heating network.

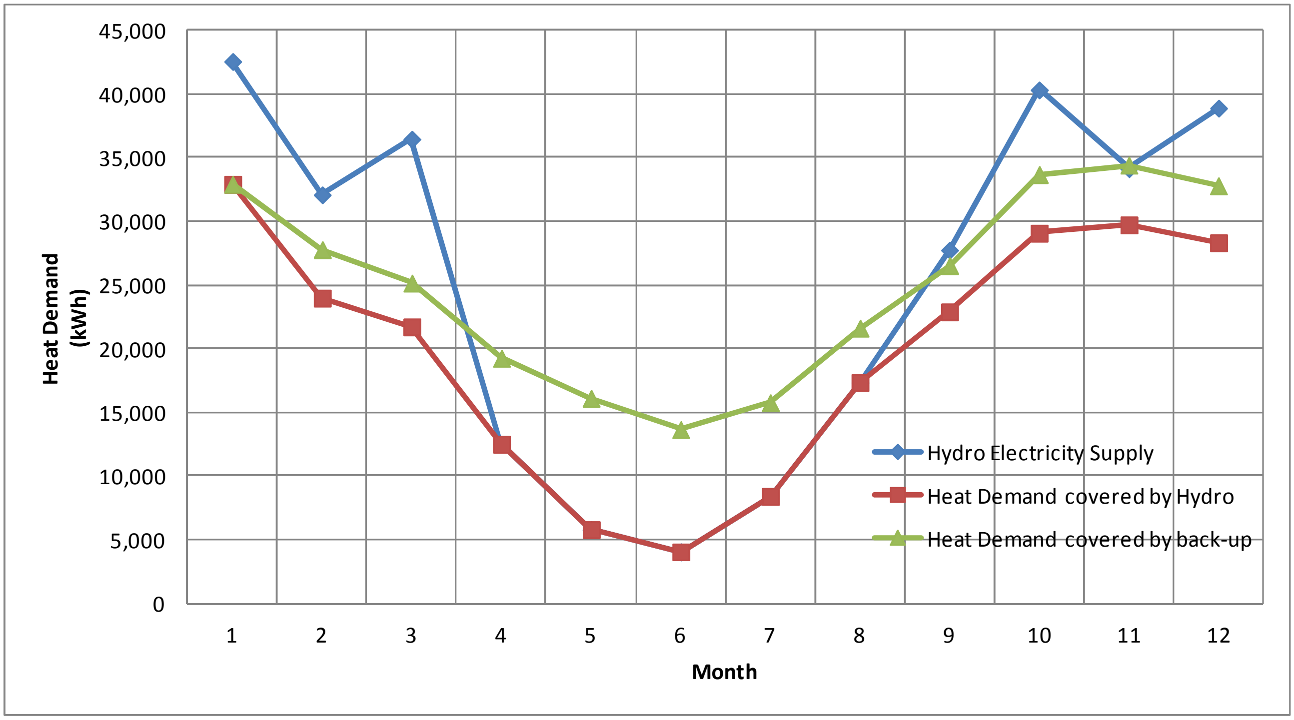


The graph shows a large proportion of the heat is provided by the hydro scheme. It is assumed that the LPG provides top up and backup equivalent to 35% of the heat required annually. This is a fairly high proportion and this is due to the higher temperatures than are expected to be needed in the district heating scheme given the age and insulation levels of the buildings. The 35% from LPG is split evenly across the year but in reality it would vary from month to month.

As highlighted earlier in the report this option has some major risk factors associated with it and on balance is not considered to be the best option.

4.6.1.2 Option 2

This option uses electric boilers with LPG back up to supply a district heating network.

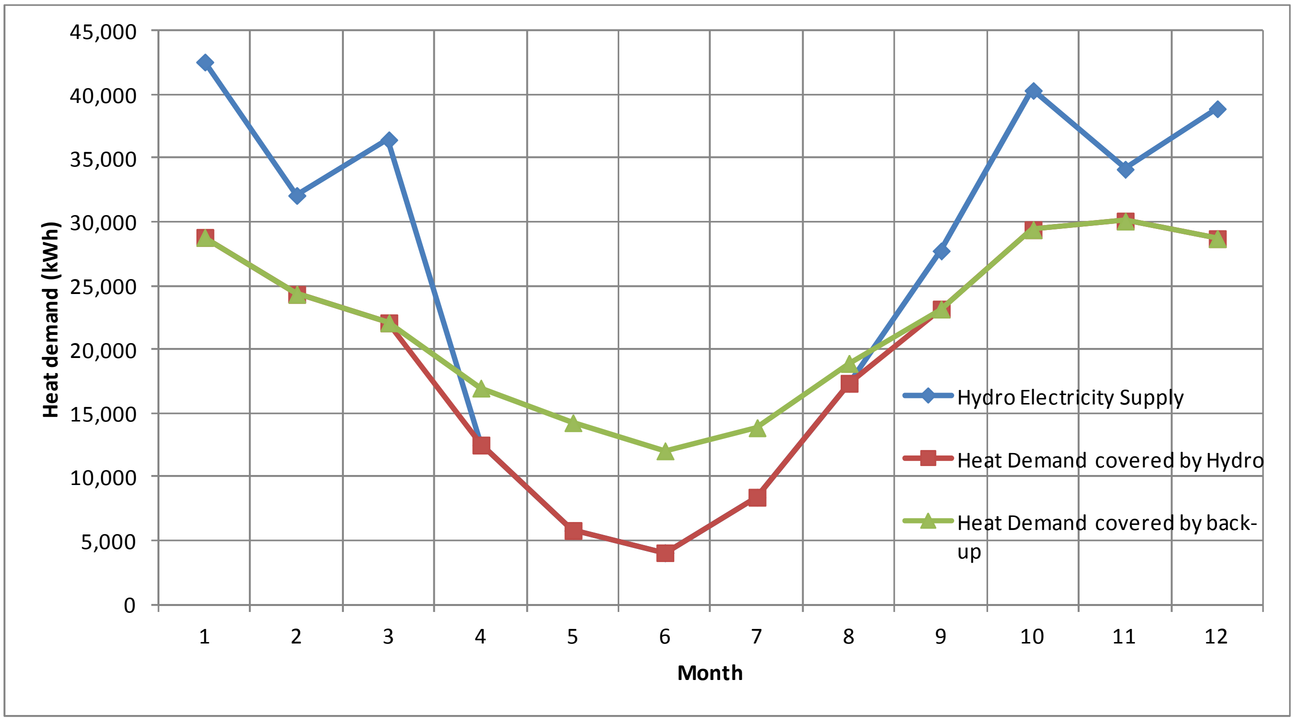


The graph shows that more of the heat is provided by the hydro output in this option. This is due to the boilers being able to achieve higher temperatures than the heat pumps so the LPG is used only for backup when the hydro is not producing excess electricity.

This option looks more promising than option 1 but the costs are high so financially it is not the best option.

4.6.1.3 Option 3

This option uses a private wire network to supply electricity to all buildings and uses existing electric heaters and electric boilers in buildings with oil heating currently.



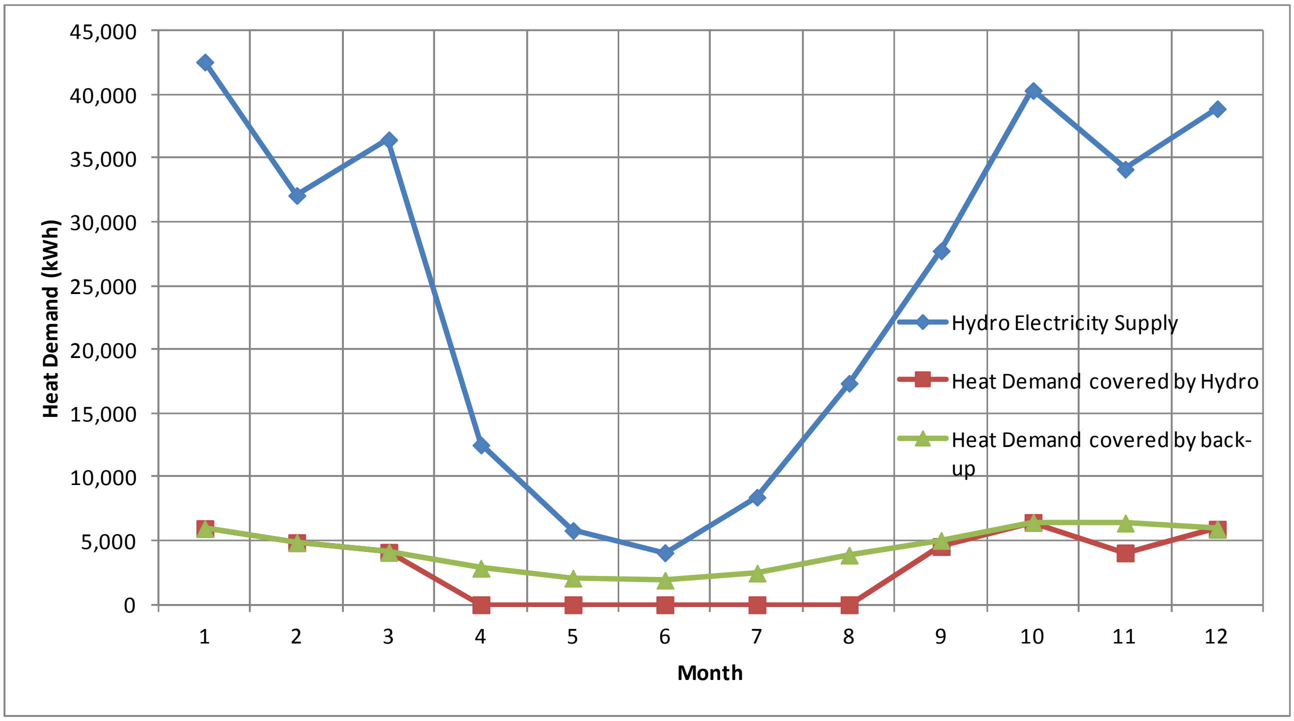
This option achieves the highest proportion of the heat load provided from the hydro scheme. This is due to the reduced losses in electrical distribution as opposed to district heating. This appears to be the most favourable option for Shore Street only.

4.6.2 Shore Street and Craite Burn

Options 4 and 5 are based on including Craite Burn. During the modelling work it was found that there was some additional capacity from the hydro scheme outside of the summer months. The best method for using this spare capacity would appear to be the connection of the social housing at Craite Burn as the housing is close to the hydro scheme and already has electrical heating in place, thus minimising the internal disruption required. There may also be a further benefit in being able to reduce heating costs for those in social housing.

4.6.2.1 Option 4

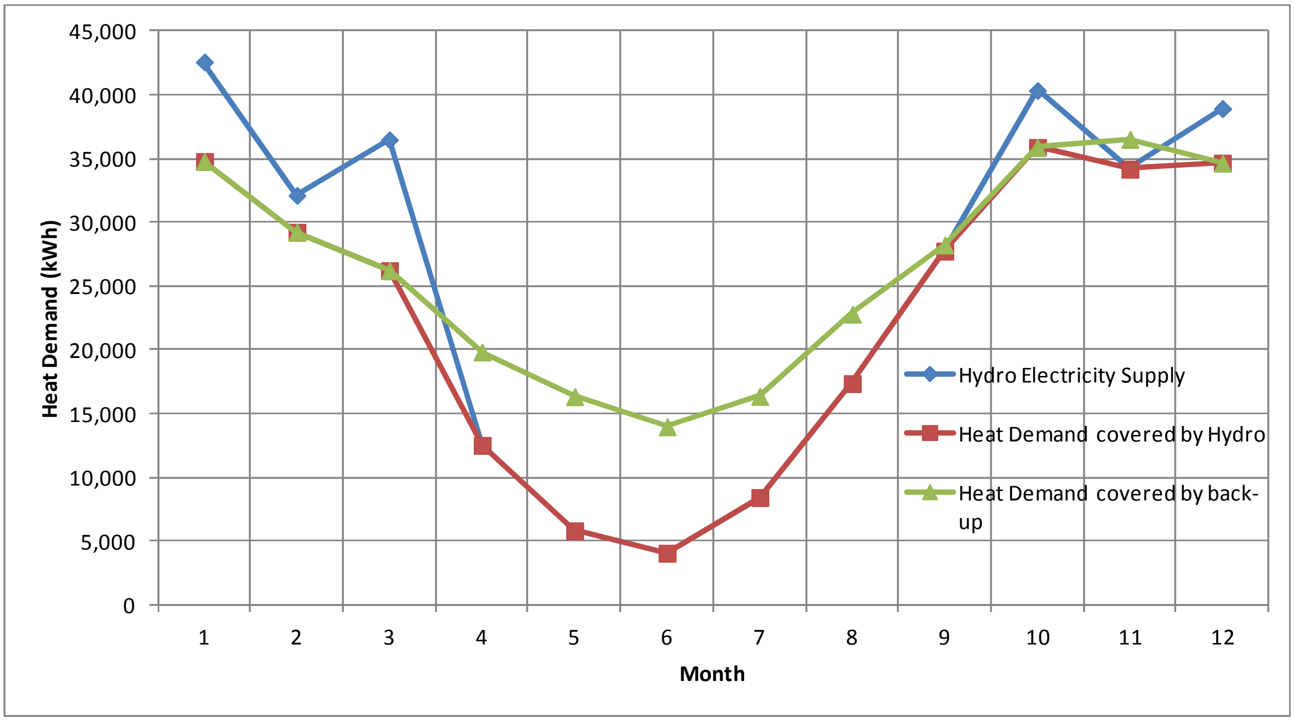
Option 4 considers Craite Burn only as an addition to option 3. This was to allow an assessment of the financial impact of this as a standalone addition. There is no remaining capacity during the summer after Option 3 so the supply is limited to the rest of the year in this option.



The graph shows that the hydro power output covers all the heat requirements with a considerable amount left over.

4.6.2.2 Option 5

Option 5 combines Shore Street and Craite Burn housing. For the modelling exercise Option 3 for Shore Street was chosen since this was considered to be the best option.



The graph shows that the hydro generation can cover the majority of the heat requirements (83%). There is a limited amount of excess hydro with this option, around 30,000kWh or 10% of output. This is not considered sufficient to merit investigation of further end uses and furthermore should be considered to be less than the range of error contained in the overall study compared to the actual demands and hydro generation in any given year.

4.7 Results – Costs

This section covers the financial aspects of each option. All options are based on a sale price of a unit of heat or a unit of electricity at 6p/kWh.

4.7.1 Shore Street Only

4.7.1.1 Option 1

		kWh	Income	Expenditure
Capital Cost				£513,976
Heat sales		259,002	£15,540	
	RHI (Heat Pump output)	185,186	£8,704	
	FIT (additional Hydro generation)	92,449	£14,330	
Costs				
	LPG top up / back up			£8,725
	Servicing / maintenance			£3,000
Total			£26,848	
Simple Payback				19.1

4.7.1.2 Option 2

		kWh	Income	Expenditure
Capital Cost				£522,151
Heat sales		259,002	£15,540	
	FIT (additional Hydro generation)	237,036	£36,741	
Costs				
	LPG top up / back up			£5,500
	Servicing / maintenance			£3,000
Total			£43,780	
Simple Payback				11.9

4.7.1.3 Option 3

		kWh	Income	Expenditure
Capital Cost				£194,340
Heat sales		234,955	£14,097	
	FIT (additional Hydro generation)	234,955	£36,418	
Costs				
	Grid Import (top up)			£3,348
	Servicing / maintenance			£3,000
Total			£44,167	
Simple Payback				4.3

4.7.2 Shore Street and Craite Burn

4.7.2.1 Option 4

		kWh	Income	Expenditure
Capital Cost				£33,920
Heat sales		35,963	£2,158	
	FIT (additional Hydro generation)	35,963	£5,574	
Costs				
	Grid Import (top up)			£1,924
	Servicing / maintenance			£0
Total			£7,732	
Simple Payback				4.4

There is no servicing cost as there is only electrical equipment and existing storage radiators.

4.7.2.2 Option 5

		kWh	Income	Expenditure
Capital Cost				£230,100
Heat sales		270,918	£16,255	
	FIT (additional Hydro generation)	270,918	£41,992	
Costs				
	Grid Import (top up)			£5,273
	Servicing / maintenance			£3,000
Total			£49,975	
Simple Payback				4.5

4.7.3 Building Owner Costs

The costs to the building owner are limited in this study to conversion works required to change heating systems. It may be considered more appropriate to pass on more of the costs to the building owners, including meters, switchgear and heat exchanger units depending on the option.

4.7.3.1 Options 1 and 2 District Heating

For these options the electrically heated houses would need to convert to wet systems. For a 4/5 radiator system the cost to the house owner is likely to be around £2,200. The cost saving of switching to the district heating scheme is estimated to be around £330, giving a simple payback period of around seven years.

Additional costs that could be passed on to the building owner are the Heat Interface Unit and meter, which would cost around £2,300.

4.7.3.2 Options 3, 4 and 5 Private Wire

For these options buildings with wet heating systems would have the choice of installing an electric boiler in addition to the oil boiler which would be retained as a backup. A cost of around £1,000 plus installation is assumed for this. For the hotel the electric boiler would cost around £7,000, which is currently included in the overall scheme cost.

The cost saving of switching to the private wire scheme is estimated to be about £200.

Additional costs that could be passed on to the building owner are the switchgear and meter, which would cost around £1,150. The simple payback period for this element of costs would be about six years.

4.7.3.3 Sale Price Issues

The sale price for a unit of heat or electricity is a key consideration and has a significant impact on the attractiveness of the scheme for ACC and the building occupiers. For building occupiers to benefit, the sale price needs to be lower than the cost of their existing supply, which is likely to be a minimum of 7.5p/kWh for oil heating systems. The lower the cost however, the longer it will take to break even for ACC. We have used a cost of 6p/kWh for this study.

4.8 Whole Life Cost Analysis

A whole life cost analysis was undertaken for the five options over a 25 year period and was based on the total costs and benefits for the scheme options. In other words, the costs included the hydropower civil, mechanical and electrical works, the grid connection, heating works, planning, licensing design, construction supervision, etc. The results are shown in Table 4.6, below.

Table 4.6: Summary of Whole Life Cost Analysis (25 period)

Option	Description	Total Capital Cost (1)	NPV over 25 year period (2)	IRR (%)	Discounted Payback (yrs)	Ranking
Shore Street only						
1	District heating with heat pumps + LPG back-up	£1,329,730	£539,394	6.6	16	5
2	District heating with electric boilers + LPG back-up	£1,337,905	£659,624	8.4	14	4
3	Private wire network with electric heaters & boilers	£1,010,094	£1,051,399	12.0	10	2
Craite Burn only						
4	Private wire network with electric heaters	£849,674	£866,061	10.7	11	3
Shore Street and Craite Burn						
5	Private wire network with electric heaters & boilers	£1,045,854	£1,076,666	12.3	10	**1**

Notes: 1. Total capital cost includes hydro, heating, design, planning, etc. Hydro costs provided by Highland eco-Design.

2. Discount rate used in net present value (NPV) analysis is 4.2%, based on Treasury discount rate for schemes up to a 30 year period; FiT indexation and inflation rate assumed to be 2.5% over the period.

3. FiT export tariff assumed to be 4.5%, based on DECC review, from December 2012.

4. Estimated generation tariff, post 20 year FiT period, assumed to be 4.5%.

The analysis has shown that the private wire network options (3, 4 & 5) are more economically viable than the district heating ones (1 & 2), and has confirmed the ranking noted in section 4.6, which did not include the costs of the 230kW hydropower works. Option 5, the private wire network covering both Shore Street and Craite Burn, is ranked first for all parameters analysed. However, Options 3 and 5 are very close together suggesting that an improved benefit to the community can be obtained for the small increased capital outlay required to include Craite Burn in the proposed network.

A sensitivity check was also undertaken to determine the impact of a 20% increase in the hydropower installation cost. This does not alter the fundamental results or ranking of the options which are shown below.

Table 4.7: Revised WLC Summary with 20% increase in Hydropower Costs

Option	Description	Total Capital Cost (1)	NPV over 25 year period (2)	IRR (%)	Discounted Payback (yrs)	Ranking
Shore Street only						
1	District heating with heat pumps + LPG back-up	£1,488,640	£380,483	5.5	18	5
2	District heating with electric boilers + LPG back-up	£1,496,815	£500,714	7.1	16	4
3	Private wire network with electric heaters & boilers	£1,169,004	£892,489	10.0	12	2
Craite Burn only						
4	Private wire network with electric heaters	£1,008,584	£707,151	8.6	13	3
Shore Street and Craite Burn						
5	Private wire network with electric heaters & boilers	£1,204,764	£917,756	10.4	12	**1**

5 Recommendations

Option 5 is the best overall option, within the limits of the study. There is a good correlation between hydro production and heat demand, particularly when looking at Shore Street and Craite Burn in conjunction. The costs for this option, which are based on a private wire electricity supply to each house, give a reasonable NPV, IRR and payback period while allowing the sale of the electricity at a price that is better than the current costs paid by the building occupiers, regardless of the main heating fuel.

Aspects that require further investigation and thought are:

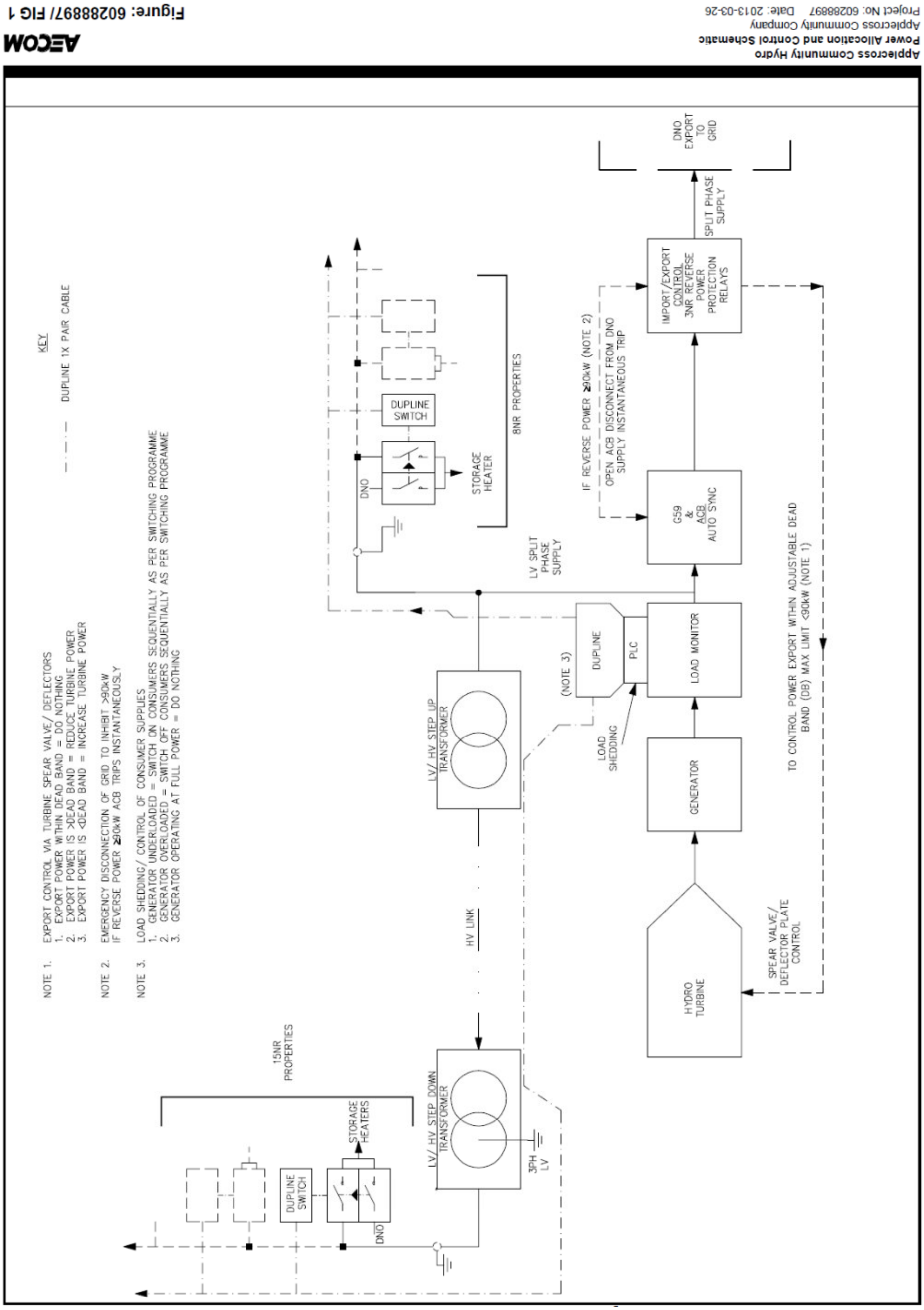
- Some details of the design will need careful attention as the proposed works are considered to be probably unique in Scotland and the DNO, in particular ,will require reassurance that there will be no impact on the grid.
- More detailed analysis of actual power consumption and electricity costs for the individual properties should be undertaken if the scheme is taken forward.
- How Applecross Community Company could fairly manage the scheme to the benefit of the community..

Appendix A: Monthly FDCs, Power Generation and Export Revenue

Measured monthly FDC - based on river gauging results

% Exceedance	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
0	0.515	0.428	0.448	0.261	0.226	0.191	0.227	0.333	0.361	0.441	0.420	0.511		
5	0.401	0.348	0.352	0.219	0.184	0.159	0.194	0.265	0.305	0.359	0.344	0.398		
10	0.310	0.280	0.274	0.176	0.130	0.119	0.156	0.201	0.255	0.290	0.278	0.307		
15	0.272	0.248	0.240	0.152	0.103	0.099	0.133	0.176	0.222	0.258	0.245	0.271		
20	0.237	0.215	0.206	0.123	0.069	0.073	0.103	0.146	0.189	0.226	0.214	0.237		
25	0.217	0.196	0.189	0.107	0.054	0.059	0.086	0.127	0.172	0.208	0.196	0.213		
30	0.194	0.174	0.172	0.087	0.038	0.044	0.068	0.103	0.152	0.189	0.176	0.187		
35	0.180	0.157	0.159	0.076	0.030	0.035	0.055	0.088	0.135	0.172	0.158	0.171		
40	0.165	0.139	0.145	0.063	0.020	0.025	0.044	0.071	0.115	0.155	0.138	0.153		
45	0.149	0.125	0.133	0.054	0.016	0.017	0.035	0.057	0.100	0.141	0.123	0.135		
50	0.132	0.110	0.119	0.044	0.012	0.012	0.025	0.043	0.082	0.126	0.107	0.115		
55	0.117	0.096	0.108	0.038	0.008	0.008	0.019	0.031	0.069	0.111	0.095	0.099		
60	0.101	0.080	0.095	0.031	0.006	0.006	0.013	0.020	0.054	0.096	0.080	0.079		
65	0.086	0.066	0.083	0.025	0.004	0.004	0.008	0.013	0.041	0.083	0.069	0.066		
70	0.071	0.051	0.072	0.019	0.004	0.003	0.005	0.008	0.030	0.069	0.055	0.051		
75	0.055	0.036	0.060	0.016	0.002	0.000	0.004	0.005	0.020	0.054	0.044	0.038		
80	0.038	0.023	0.049	0.012	0.001	0.001	0.002	0.003	0.013	0.039	0.031	0.025		
85	0.025	0.015	0.035	0.008	0.001	0.000	0.001	0.002	0.007	0.025	0.022	0.016		
90	0.013	0.008	0.022	0.005	0.000	0.000	0.000	0.000	0.004	0.012	0.013	0.007		
95	0.005	0.004	0.009	0.002	0.000	0.000	0.000	0.000	0.002	0.004	0.007	0.003		
100	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000		
													Annual	
Monthly Power Production	84837	65804	78866	33869	16885	16612	27339	41969	58271	80836	71918	76162	**653366**	**kWh**
Monthly Power Production for Export (up to 90kW)	42261	33690	42396	21335	11055	12533	18903	24599	30512	40496	37759	37245	**352784**	**kWh**
Monthly Excess Power Production	42576	32114	36470	12534	5830	4079	8436	17369	27759	40339	34160	38917	**300582**	**kWh**
Export Revenue	£8,452	£6,738	£8,479	£4,267	£2,211	£2,507	£3,781	£4,920	£6,102	£8,099	£7,552	£7,449	**£70,557**	

Appendix B: Power Allocation and Control Schematic Diagram



Applecross Community Hydro
Power Allocation and Control Schematic
Applecross Community Company
Project No: 60288897 Date: 2013-03-26
Figure: 60288897/ FIG 1
AECOM
NOTE 1. EXPORT CONTROL VIA TURBINE SPEAR VALVE/ DEFLECTORS
1. EXPORT POWER WITHIN DEAD BAND = DO NOTHING
2. EXPORT POWER IS >DEAD BAND = REDUCE TURBINE POWER
3. EXPORT POWER IS <DEAD BAND = INCREASE TURBINE POWER
NOTE 2. EMERGENCY DISCONNECTION OF GRID TO INHIBIT >90kW
IF REVERSE POWER ≥90kW ACB TRIPS INSTANTANEOUSLY
NOTE 3. LOAD SHEDDING/ CONTROL OF CONSUMER SUPPLIES
1. GENERATOR UNDERLOADED = SWITCH ON CONSUMERS SEQUENTIALLY AS PER SWITCHING PROGRAMME
2. GENERATOR OVERLOADED = SWITCH OFF CONSUMERS SEQUENTIALLY AS PER SWITCHING PROGRAMME
3. GENERATOR OPERATING AT FULL POWER = DO NOTHING
KEY
DUPLINE 1X PAIR CABLE
15NR PROPERTIES
8NR PROPERTIES
STORAGE HEATERS
STORAGE HEATER
DUPLINE SWITCH
DNO
LV/ HV STEP DOWN TRANSFORMER
LV/ HV STEP UP TRANSFORMER
3PH LV
HV LINK
LV SPLIT PHASE SUPPLY
(NOTE 3)
DUPLINE
PLC
LOAD MONITOR
LOAD SHEDDING
GENERATOR
HYDRO TURBINE
SPEAR VALVE/ DEFLECTOR PLATE CONTROL
G59 & ACB AUTO SYNC
IF REVERSE POWER ≥90kW (NOTE 2)
OPEN ACB DISCONNECT FROM DNO SUPPLY INSTANTANEOUS TRIP
IMPORT/EXPORT CONTROL 3NR REVERSE POWER PROTECTION RELAYS
SPLIT PHASE SUPPLY
DNO EXPORT TO GRID
TO CONTROL POWER EXPORT WITHIN ADJUSTABLE DEAD BAND (DB) MAX LIMIT <90kW (NOTE 1)