Report to Orkney Renewable Energy Forum & Community Energy Scotland
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Part 2: Switching Options
The Orkney-Wide Energy Audit 2014

Part 2: Switching Options

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Executive Summary

For over 30 years Orkney has been at the forefront of the development of a variety of new renewable energy technologies. Over the last 15 years locally generated renewable energy has made a progressively greater contribution to Orkney’s electrical energy demand.

In 2013 Orkney generated renewable output equivalent to 103% its electrical demand a feat unrivalled for an area of similar scale and energy capacity in the UK.

However, the grid infrastructure has not seen the necessary investment to allow this success to continue. Whilst the UK is striving to de-carbonise the electricity system, Orkney now has to turn off renewable generation at times when, and in places where, the distribution grid has insufficient capacity to cope with energy being generated. Furthermore the lack of future connection opportunities is hindering the growth of renewable energy within Orkney.

These grid inadequacies have had a series of profound impacts upon the potential for Orkney to maximize the opportunities associated with renewable energy generation. In particular the situation is also threatening the financial viability of established community energy schemes and indeed other locally owned energy schemes. As a result Community Energy Scotland (CES) were funded to commission an energy audit for Orkney. The aim being to establish more precisely the dynamics of energy generation and demand across the Orkney Islands and then to evaluate a number of potential options to tackle energy issues identified.

The results of the ‘Energy Audit’ are presented in this document. An evaluation the possible ‘Switching Options’ are presented in a separate accompanying document. The two documents are however interdependent.

‘Switching Options’ examines a wide range of possible means to better use the abundant renewable generation in Orkney and allows a comprehensive comparison. In doing so it shows options that may be regarded as preferential. The options themselves need further discussion as they fall to different groups / companies, each of whom will have different perspectives / appetite / ability to act.

It is strongly recommended that the options found most favorable following wider discussion should be acted upon with urgency. The audit shows what is happening, the options are laid out, the opportunity to act is upon us.
The Commission

CES worked with the Orkney Renewable Energy Forum (OREF) who commissioned local consultancy Aquatera to undertake an audit and propose elements of a switching strategy. Aquatera carried out the work in conjunction with Dr. Edward Owens from Heriot–Watt University, School of the Built Environment who provided Demand Side Management expertise.

Aquatera also gratefully acknowledge the input from the companies, individuals and organisations in Orkney who willingly contributed data and other assistance to help achieve a successful outcome to this study.

Aims

The specific aims of the commission were:
- To quantify Orkney’s existing energy sources and energy uses;
- To indicate the potential suitability and value of mechanisms for energy conversion and new energy uses which could lead to an increase in local electrical energy demand; and
- To seek energy adaptation strategies with both short and medium term benefits, but to focus upon solutions that could be delivered at an appropriate scale by 2017.

Alongside these primary aims it was desired that any energy adaptation strategies should:
- decrease energy costs;
- provide grid balancing by moving electrical demand to the outlying production zones; and
- reduce CO₂ emissions.

Background

As a remote rural island community, with no gas network, Orkney has over recent decades had a high dependency on imported oil and coal as its main sources of energy. Due to the transportation costs involved in delivering such fossil fuels to Orkney they are more expensive in Orkney than in other parts of the UK. The higher costs of fuel together with the age and setting of the housing stock and the cool and windy climate means that Orkney suffers high rates of fuel poverty. Statistically Orkney is amongst the worst affected areas in the United Kingdom (UK) along with the Western Isles and Shetland.

The combination of harsh climate and high fuel costs make renewables a cost effective way of harvesting the energy needed.

Previous energy audits for Orkney have been undertaken, most recently in 2005 by the Northern and Western Isles Energy Efficiency Advice Centre a now defunct part of Orkney Islands Council (OIC). Since the last audits were undertaken the energy environment within Orkney has changed considerably due to the growth of renewables.

Orkney now boasts the highest proportion of electricity from renewables (mainly large wind), but also has the greatest number of micro-wind generators of any county in the UK. Homeowners and businesses within the county have installed renewable technologies, some with the support of government funded schemes. Orkney now has a number of community owned wind turbines, hundreds of micro-turbines and a world leading marine tidal and wave energy industry.
However, there is a limit to the amount of renewable energy that Orkney can accommodate without further grid upgrades and that limit has been reached. Therefore Orkney is faced with the need to find innovative solutions in order to continue producing, and increase the amount of, renewable energy generated within the county. Some of the problems are only limitations of capacity at particular pinch-points within the local electrical distribution network. Some limitations are due to the capacity limitations on the main cables linking Orkney to the national grid.

**Report structure**

The report seeks to provide an overview of the energy status of the islands and proposes ‘switching options’ to alleviate curtailment challenges and to minimise fuel imports. The report is split into three main sections across two documents:

In the ‘energy sources and uses’ document
- The first section analyses the current energy sources in the county.
- The second section gives an overview of the energy usage on the islands and

In the ‘switching options’ document
- The third section outlines potential switching options.

The third section outlines potential ‘Switching Options’. These options have the potential to alleviate some of the problems that are currently being faced, by: managing the existing grid; increasing electrical demand by switching from other fuels or creating new demand; storage or demand management. A number of these possible options arose from the work of the Orkney Grid Group, which was established by OIC and supported by OREF after the new connection moratorium imposed by Scottish and Southern Energy (SSE) in September 2012.

**Overview of Energy Sources**

Included in this analysis is all the energy produced on the Orkney Islands and exported, as well as the fuel imported into the islands. The energy sources are categorised as follows:
- Imported fossil fuels
- Imported biomass
- Imported and exported electricity
- Indigenous biomass
- Local electricity generation

Most of the fossil fuels described below are imported into Orkney. The exception is the gas used at the Flotta Oil Terminal which is derived from the inward flow of oil and gas from the North Sea fields. This gas is used at the terminal for heating and electrical generation.

Electricity is imported/exported to and from Orkney via two 33kV (20MVA) submarine cables. In addition over the last decade or so Orkney has seen a large increase in the amount of renewable energy generations. Renewable energy production from wind in particular has increased dramatically. Renewables are now the predominant source of electricity in Orkney.
The following pie chart (Figure 1) shows an average of annual use of electricity, fossil fuels and peat used (2009 - 2013).

![Figure 1 Average fuel use 2009 - present (GWh)](image)

The audit showed that where data is available the use of fossil fuels that their consumption looks to have stayed fairly stable over the last decade, with the exception of coal for which the use has more than halved in the last decade.

Figure 2 shows that renewable energy generation, on the other hand, has increased significantly over the last 10 years from around 17GWh in 2003 to about 140GWh in 2013. At the same time the net amount of electricity imported has fallen from around 50GWh in 2009 to almost zero in 2013.

![Figure 2 Estimated total wind generation and net import of electricity](image)

In 2009 an Active Network Management (ANM) system, which monitors the electrical network and controls the grid, was set up in Orkney to allow additional generation on the system without expensive grid upgrades. However even with this system in place the growth of the wind (and other renewables) has meant that in September 2012, Scottish and Southern Energy Power
Distribution (SSEPD) imposed a moratorium on all new generation, except the very smallest generators.

The Audit shows over 48MW of wind energy generators are currently operational in Orkney. These turbines range in size from less than a kW to several MWs. The total energy generated from wind is now estimated to be around 140GWh per year (as shown in Figure 2). Photovoltaic systems have also become increasingly common but to a lesser extent than wind generators with a total of 1.2MW of photovoltaic panels now installed.

A growing wave and tidal energy industry in Orkney is set to contribute substantially to the overall renewable energy generation picture in the future. In 2011, the Crown Estate held a leasing round for commercial and demonstration marine energy project in the Pentland Firth and Orkney waters. There are currently leases held for 550MW of wave energy projects and 530MW of tidal projects in Orkney waters. Currently these technologies are still at an early stage of development and therefore the number of GWh is small day-to-day, but this is expected to rise in the future as the testing periods increase and the industry moves towards commercial projects.
Data Gaps

In terms of data collection for these first two sections, there were limitations to the data collected for several reasons:

- The length of time to obtain data;
- Format of data;
- Confidentiality of data relating to areas such as grid; and
- Concern in the business community as to whether the overall approach to moving away from existing fuel types and behaviours would impact upon their current business.

Consequently certain assumptions were made in estimating the energy sources and uses were necessary. Where assumptions have been made they are highlighted in the body of the report.

Important data gaps to note are:

- **Modelled data** (from Department of Energy and Climate Change (DECC)) was used for most of the fossil fuel analysis due to lack of real world data. It may be important in the future to verify this modelled data.
- **Crude oil**, of which the majority of the energy embodied simply passes through Orkney's Flotta Oil Terminal and was not considered in this audit.
- Of the crude oil, passing through the Flotta Oil Terminal a small fraction is used at the oil terminal for heating and electrical generation. The oil terminal uses gas extracted from the crude oil on site for heating and to produce electricity. The total energy used in this way is equivalent to 0.49GWh but it is not clear how much energy is used for heating, electricity generation or flared as data from Talisman was unavailable.
- **Kirkwall Power Station** ceased regular operation in the late 1990's after the second cable to the mainland was commissioned. It still runs monthly for test purposes and covers faults and system outages on mainland links. This small contribution to the overall electricity supply was not considered in this audit.
- **Indigenous biomass** in the form of peat is used at Highland Park as part of the whisky making process in addition peat is still used as a fuel source in Orkney for domestic heating however it is difficult to estimate the extent of peat cutting for domestic use as no records are kept.
- **Short rotation wood crops** and fuel produced from anaerobic digesters have also been on Orkney but on a trial basis. No assessment was made of the uptake.
- **Imported biomass** comes into Orkney as logs, wood pellets, eco-logs, peat and waste wood. This was not possible to quantify but is likely to increase in the future due to the Renewable Heat Incentive (RHI), a government financial support programme, which pays participants of the scheme that generate and use renewable energy to heat their buildings.
- Marine fuel was analysed using a bottom up approach. Many of the major energy users are included in the study but it is understood that the larger fishing vessels and a number of dive boats have direct contracts with the main fuel suppliers. Therefore the data presented in this report is not a complete picture of fuel use by boats operating in Orkney.
- **Air transport** data only includes any fuel imported into Orkney. A significant portion of the fuel used on routes to and from the County will come in on planes refuelling at other airports and could not be accounted for in this report.
**Recommendation 1.** The data gaps identified should be proactively filled on a continuous basis. The necessary data flows be identified, managed, commissioned and the audit should therefore be maintained as a decision informing device.
Overview of Energy Uses

Energy use in Orkney can be broadly categorised into three main energy uses and further broken down by sector as follows:

1. Buildings and Utilities:
   - Domestic;
   - Commercial/industrial;
   - Public administration
2. Transport:
   - Road;
   - Marine;
   - Air
3. Residual fuel use, which encompasses all other terrestrial energy i.e. the use of red diesel (gas oil) for non-road transport and other static powered machinery in the following sectors:
   - Industrial;
   - Agriculture;
   - Public administration

Figure 3 shows transport is the major energy use (343GWh) followed by buildings and utilities (268GWh). Note that air transport figures included here is likely to be significantly underestimated for routes to and from Orkney due to refuelling elsewhere.

![Figure 3 Energy use by end use](image)

The following charts further break down Figure 3.

The transport section of the Figure 3 is broken down further by sector in Figure 4a and shows that the largest energy use in the transport sector is for ferry services to the mainland (184GWh) followed by domestic road transport (61GWh).

As explained above air transport is included but is likely to be significantly underestimated.
Figure 4a Energy use by sector - Breakdown of energy use in the transport sector

Figure 4b shows that the largest energy use in buildings and utilities is for domestic energy use (170GWh) and Figure 4c shows that for ‘residual fuel’ is mostly for agricultural uses (112GWh).
Figure 4c Energy use by sector - Breakdown of residual fuel use by sector
The Sankey diagram (Figure 5) below shows the different fuels in the middle and who uses them on the left and the purpose on the right. The size of each of the blocks is proportional to the total amount of energy. The width of the lines is proportional to the energy flow.

Figure 5 Sankey diagram (excluding air transport and peat)

Note: This diagram only considers present fuel uses. It does not represent imported commodities which have a high embodied energy and which could feasibly be produced in Orkney. The diagram only shows what is happening, not what could happen.
Potential Energy Strategies

Any energy strategy adopted will need to consider the options available. The ‘Switching Options’ section of the report considers a wide range of ideas and will seek to inform the strategy to be developed. Systematic examination seeks to quantify the benefits and costs of each proposal.

In the project brief it was made clear that options should aim to:
- decrease the target market’s annual spend on fuel;
- provide grid balancing by moving electrical demand to the outlying production zones; and
- reduce CO₂ emissions.

The energy switching options considered have been grouped into four broad categories: grid management, time-switching strategies, fuel switching and demand increase strategies as shown in Figure 6. The colours indicated the suitability of each option where dark green shows the most promising options and dark red the least promising.

![Figure 6 Summary of switching options](image-url)
The options that have been deemed to be most promising are those that are at an appropriate stage of development and appropriate for the nature, scale and culture of Orkney. Initial investigations show that business cases should be developed to take forward the preferred options.

The most promising options are listed below:

- Use of dynamic line ratings
- Demand side management
- Electric vehicles
- Electric ferries
- Hydrogen ferries
- Electrification of heating systems
- Heated growing spaces
- Fertiliser production

Note: This is not an order of priority.

In order for any of these options to be adopted a number of specific actions will need to be taken, these are outlined in the following table:

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Action</th>
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<tbody>
<tr>
<td>Use of dynamic line ratings</td>
<td>• Further engagement with the network operator to explore the potential to role this out further.</td>
</tr>
<tr>
<td>Demand side management</td>
<td>• Further engagement with Heriot-Watt University to maximise outcomes and opportunity for transferring outcomes from Findhorn to Orkney.</td>
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<td></td>
<td>• Further investigation, if data is available, to look at the scale of the grid balancing benefit on the individual DNO zones.</td>
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<tr>
<td>Electric vehicles</td>
<td>• The installation of ‘Rapid chargers’ at key locations to support the use of EVs.</td>
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<tr>
<td></td>
<td>• Extensive installation of ‘Fast Charge’ points throughout the county.</td>
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<tr>
<td></td>
<td>• Direct engagement with constrained turbine owners to encourage a shift to EVs.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with national grant awarding bodies to support a shift towards procurement of EVs.</td>
</tr>
<tr>
<td>Electric ferries</td>
<td>• Undertake a feasibility study into the potential of replacing existing diesel ferries which are at the end of their commissioning periods with electric ferries or hybrid electric ferries.</td>
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<tr>
<td></td>
<td>• Engagement with other relevant stakeholders that have experience with electric ferries (e.g. Caledonian Maritime Assets Ltd.) to learn from their experiences.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with battery technology developers to match the demand of the vessels for longer routes.</td>
</tr>
<tr>
<td></td>
<td>• Exploration of the potential for ‘cold ironing’ should be explored with the ferry operators.</td>
</tr>
<tr>
<td>Hydrogen ferries</td>
<td>• Undertake a feasibility study into the potential of replacing existing diesel ferries which are at the end of their commissioning periods with hydrogen ferries or hybrid hydrogen ferries.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with other relevant stakeholders that have experience with electric ferries (e.g. Caledonian Maritime Assets Ltd.) to learn from their experiences.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with fuel cell technology developers to match the demand of the vessels for longer routes.</td>
</tr>
<tr>
<td></td>
<td>• Exploration of the potential of conversion of engines to directly burn hydrogen.</td>
</tr>
<tr>
<td>Electrification of Heating Systems</td>
<td>• Analysis of EST home analytics data to look at the heating systems used in the current housing stock to give a better estimate of the market.</td>
</tr>
<tr>
<td></td>
<td>• Determine and publicise impact on customers looking at installation costs versus running costs of different heating systems including RHI payments for applicable technologies.</td>
</tr>
<tr>
<td></td>
<td>• Investigate the likely demand created by switching fuels for small turbine owners.</td>
</tr>
</tbody>
</table>
who are currently using non electrical heating for hot water and space heating.

- Economic analysis cost of wind to heat versus selling to the grid and electric heating.
- Engage with national and local grant awarding bodies to establish grant for local residents encouraging shift from fossil fuel to electric for installation costs
- Engagement with SSE or other operator to establish opportunity for Orkney specific tariff to encourage a shift from fossil fuel to electric.

| Heated growing spaces                       | Discussions with Eday and Benbecula projects to discuss opportunities and pitfalls. |
|                                          | Engagement with grant awarding organisations i.e. Rural Payments and Inspectorate Directorate in relation to agricultural land. |
|                                          | Engage with local shops to establish demand and willingness to participate and purchase locally grown produce. |
|                                          | Research cooperative style food supply business to support number of small farms supplying local shops. |

| Fertiliser production                      | Undertake a feasibility study into the cost effective production of locally produced ammonia fertilisers. |
|                                          | Identification of applicable locations to determine possible sites of operation that minimise impact. |
|                                          | Determining the seasonal demand for ammonia based fertilisers could highlight the level of production and storage that would be required. |
|                                          | Gathering data on the use of ammonia based fertilisers of neighbouring regions to Orkney. |
|                                          | Data on the variety of fertilisers used within Orkney. |

Recommendation 2. The actions above need to be allocated to specific organisations following review and agreement.
In addition to the above there is also a need to consider the following:

- How Orkney as a whole (i.e. different organisations) will approach the strategic delivery of such projects(s) in order that the Orkney communities benefit from the decisions and actions taken, by working together and supporting each other;
- Who the key organisations are within Orkney to take forward the outcomes? Will it be a number of existing organisations, is it a single organisation, is it a new organisation?
- What relationships need to be established and/or strengthened outwith Orkney to maximise opportunities within Orkney;
- How can Orkney businesses be provided with/secure the support (skills, knowledge) to maximise the opportunities for new business streams (i.e. shifting away from fossil fuels); and
- Understanding and calculating the risks associated with individual projects or the wider ambition based on different future scenarios (helping alleviate concerns or identifying previously unknown risk factors).

Conclusions

The ‘Energy Audit’ and the ‘Switching Options’ reports together provide the most comprehensive baseline of energy information for Orkney to date. They should now be used as a benchmark to help determine energy related policy and decision making within and outwith Orkney.

This study has shown what Orkney has achieved so far. Over the last 15 years Orkney has installed enough capacity to generate 103% of its electricity demand in 2013. The islands have now reached the point where further increases in generation capacity are limited by the grid.

There is however still a desire and a need to develop more renewables energy projects on Orkney in order to decrease our dependence on fossil fuels and to further increase the economic and social contribution made by renewable energy to the Orkney Islands.

The proposed options provide highlight where potential is most likely to be found as well as indicating the actions that need to be taken to deliver in these areas. The benefits to Orkney as a whole for investigating and strategically switching the way it sees and used energy can enhance its reputation as an energy laboratory as well as achieve the direct financial and environmental benefits associated with increased electrification.

Further initiatives and work is now required to turn this list of options into real 'on the ground' activities and projects. It is hoped that these documents will help focus discussions in order that the next level of decision making can take place and action to address the energy issues facing Orkney can be taken.

The Options show that delivery will be a community wide activity. It will need to be delivered by different agencies working together. Undertaking such actions in the Orkney community will take a considerable effort and need strong co-ordination to be successful.

However the potential of the options to give communities real energy security and a range of income generating projects is clear.
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1 Introduction

1.1 Purpose

Limits within the electrical distribution network both around Orkney and to the UK national grid are restricting the productive use of renewable resources, therefore limiting the potential to limit CO2 emissions and contribute to climate change targets.

The purpose of this report is twofold. Firstly, to provide a baseline of information relating to energy sources and uses within Orkney in order to understand fully the currently pattern of fuel use within the islands and to help identify fuel uses that could be replaced with energy produced from renewable resources. The purpose also involves presenting strategies that could help alleviate some of the problems and maximise the socio-economic and environmental benefits for Orkney.

It is recognised that energy efficiency, in parallel with renewable energy generation and reducing the use of but switching from fossil fuels, however it was not within the remit of this report to examine energy efficiency measures.

This report is aimed at policymakers, planners, business community, entrepreneurs and community groups to help identify opportunities that would support socio-economic and environmental benefits for Orkney.

1.2 Background

Orkney has a population of around 21,530 and one which is ageing but boasts a relatively low unemployment rate in comparison to the rest of Scotland with agriculture, fishing and tourism the main sectors.

As a remote rural island community with no access to the gas network, the transportation costs imported fossil fuel prices tend to be higher than on the mainland and together with the nature of the housing stock and the northerly climate Orkney is frequently being quoted as suffering the highest rates of fuel poverty in the United Kingdom (UK) along with the Western Isles and Shetland. With the increasing costs of fossil fuels the ability to generate renewable energy within the islands and maximise its natural resources is one that Orkney has taken advantage of.

On the other hand in 2013 Orkney produced over 100% of its electricity demand from renewable energy sources exceeding Scottish Government target by seven years. Over the years homeowners and businesses have introduced other micro-renewable technologies supported through government funded schemes. Orkney has a number of community owned wind turbines, hundreds of micro-turbines and a world leading marine tidal and wave energy industry. However without further grid upgrades, the amount of renewable energy Orkney can generate is limited. Therefore Orkney is faced with opportunity of establishing innovative solutions in order to continue producing, and increase the amount of, renewable energy generated in the county.

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2 http://www.sruc.ac.uk/info/120428/rural_scotland_in_focus/1265/2014_rural_scotland_in_focus_report
1.3 Aims of the Study

The specific aims of the study were set out in the original tender document, these are described below:

- To quantify existing energy sources and energy uses; and
- To indicate the potential suitability and value of converting uses of imported energy into indigenous, electrically driven demand.

Crucial to the second aim were three priorities including:

- to decrease the target market's annual spend on fuel;
- to provide grid balancing by moving electrical demand to the outlying production zones; and
- to cause a reduction in CO\textsubscript{2} emissions.

1.4 Scope

The scope of the project involved collecting data associated with the sources and uses of energy in those islands that are populated within Orkney. It focused on key areas such as buildings and utilities, transport and commercial activity. The data collected refers largely to time periods over the last 10 years but is of a variable nature depending on what data that was available and accessible.

In relation to the second aim the geographical scope extends beyond this to consider key locations such as Shetland, Caithness and Aberdeen. These are locations from which Orkney receives imported goods and has established transport routes. Where such goods are products that could be suitable for manufacturing in Orkney and have high energy demand then these were also considered. The project sought opportunities to generate short/medium term benefits using technologies available at an appropriate scale by 2017.

1.5 Report structure

The report seeks to provide an overview of the energy status of the islands and proposes ‘switching strategies’ to alleviate curtailment challenges and to minimise fuel imports. The report is split into three main sections across two documents:

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In the ‘Switching Options’ document (this document)
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The third section outlines potential ‘Switching Options’. These options have the potential to alleviate some of the problems that are currently being faced, by: managing the existing grid; increasing electrical demand by switching from other fuels or creating new demand; storage or demand management. A number of these possible options arose from the work of the Orkney Grid Group, which was established by OIC and supported by OREF after the new connection moratorium imposed by Scottish and Southern Energy (SSE) in September 2012.

1.6 Previous Studies

The last energy audit was undertaken for Orkney by the Northern and Western Isles Energy Efficiency Advice Centre (NWEEAC) a part of the Orkney Islands Council (OIC) in 2005. Before this a further
two audits were undertaken in years 1991 and 1996. The focus of the 2004 report was on the quantification of local energy production and the balance of energy supplies imported from outwith Orkney.

Since the last audits were undertaken the energy environment within Orkney has changed considerably particularly in relation to the growth of renewables. As a result monitoring and reporting of energy performance has increased particularly for public sector and energy intensive businesses through various legislative and regulatory requirements (i.e. Climate Change Agreements, European Trading Scheme, and Carbon Reduction Commitments). As a result this report has been able to use this information. The large number of small and medium sized enterprises within Orkney do not have such stringent requirements and therefore accurate data for industry sectors as a whole is harder to establish.

Even with this in mind this report is the most comprehensive energy audit undertaken for Orkney to date.

1.7 Limiting Factors

The following were deemed to be limiting factors:

- The length of time to obtain data;
- Format of data;
- Confidentiality of data relating to areas such as grid; and
- Concern in the business community as to whether the overall approach to moving away from existing fuel types and behaviours would impact upon their current business.

Due to these limiting factors certain assumptions in estimating the energy sources and uses were necessary. These have been highlighted throughout the body of the report.

1.8 Commercially Sensitive

The data in this report has received appropriate approvals for its inclusion and dissemination. In some cases parties that were approached deemed the information that was requested to be commercially sensitive and as a result this has either not been included or the data has been presented in a way that does not directly link it to an individual or organisation. Where information is available but not accessible it has been identified as a data gap. Where data gaps have been identified further discussions to establish how these should be approached will need to be held.
2 Energy Switching Options

2.1 Overview

The main purpose of this chapter is to put forward a number of potential energy switching options that would increase the overall energy demand as well as having the potential of moving electrical demand closer to the outlying zones. Key considerations as part of this included:

- to decrease the target market’s annual spend on fuel;
- to provide grid balancing by moving electrical demand to the outlying production zones; and
- to cause a reduction in CO₂ emissions.

In order to identify key switching options to investigate in more detail a pre-screening process was undertaken. This looked at each of the above as well as considering the impact on the culture of Orkney and individual islands. Of all the options put forward within the pre-screening process only one option was screened out (community ownership of assets) on the basis that it did not provide grid balancing or operational CO₂ benefit). However this may have a role to play in engaging with the community, achieving support and buy in associated with some of the proposed options.

For the remaining options a pro-forma was completed for each of the successful options to find the best value for money while keeping in mind the criteria set out above. The analysis of these options includes the criteria set out in the tender document and laid out in the text box below (Text Box 1). In addition any intervention unlikely to be proven at the appropriate scale before December 2017 was disregarded.

The energy switching options chosen have been grouped into four broad categories: grid management, time-switching strategies, fuel switching and demand increase strategies.

A scoring system has been used in order to highlight those options that are thought to have the most potential. Each of the options have been scored against the criteria set out in Table 2.1. The scores are shown at the end of each section and collated for all the options in Section 2.6. In addition each option has an overall suitability score which reflects the potential suitability and value of converting existing imported energy into indigenous, electrically driven demand.

Table 2.1 Scoring criteria

<table>
<thead>
<tr>
<th>Suitability</th>
<th>Very low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology maturity / suitability</td>
<td>No technology solution available or not applicable to Orkney</td>
<td>Immature – not proven but a least demonstration projects exist</td>
<td>Semi-mature – Several demonstration projects but not yet widely applied</td>
<td>Mature - Widely applied</td>
<td>Standard technology solution</td>
</tr>
<tr>
<td>Costs £/MW installed</td>
<td>&gt; 100 million/MW</td>
<td>&gt; 10 million/MW</td>
<td>&gt; 1 million/MW</td>
<td>Medium &gt; 100k/MW</td>
<td>Low &gt;10k/MW</td>
</tr>
<tr>
<td>Possible timescales for deployment</td>
<td>Very long term - more than 10 years</td>
<td>Long term - more than 5 years</td>
<td>Medium-term - within 3-5 years (completed by 2017-19)</td>
<td>Short term - within 2 years completed (by 2017)</td>
<td>Very short term - within 1 year</td>
</tr>
</tbody>
</table>
**Description of the switching option, solution or technology**

- Brief description of the switching solution including any specific requirement of this solution (e.g. space required, other feedstocks, despatchability of load etc.)
- Note: Precise details of any technology involved are not necessary, beyond stating the kind of device envisaged and its typical rating/output.

**Technology maturity & possible timescales for deployment**

- Brief description of the maturity of the technology and possible timescales for deployment

**Assessment of grid balancing benefit**

- Note: one of the main priorities of this study is to provide solutions for grid balancing, moving electrical demand closer to outlying production in DNO zones 1, 2, 3 and 4.
- Size of the grid balancing benefit (MW peak demand/generation shifting)
- Size of the market and scalability to Orkney situation for this solution (what size packages does the solution come in e.g. electric cars provide packages of xkWs).
- How well does it match (temporally and geographically) with the energy generated from renewable sources (mostly wind in the case of Orkney)
- Zone of influence (An intervention may apply either Orkney-wide or at major point sources of demand/generation).
- Assessment of CO₂ benefit (Tonnes equivalent p.a.), where appropriate

**Potential local impacts**

- Brief description of environmental and socio-economic impacts (Note: Strategies must show sensitivity to the culture of Orkney and of individual islands).

**Costs**

- Estimated CAPEX, OPEX and potential revenue streams
- Impact on customers (one of the main priorities of this study is to reduce the target market’s annual spend on fuel/commodity, with requirement that such savings will be passed on to Orkney consumers/taxpayers through a functional or appropriately regulated market.)

**Examples of previous projects or case studies**

**Key stakeholders to engage for further development**

- Links with other Sectors e.g. tourism

**Next steps**

- E.g. feasibility study, more data gathering, consultation etc.
2.2 Analysis of Selected Options – Grid Management

2.2.1 Grid Upgrades

Description of the switching option, solution or technology

Regulations regarding grid are complex and although some of the capacity that is available on the second cable that crosses to the mainland is used, a large percentage is not. The main reason being the various internal pinch points within the island grid system and their location. One switching solution to this issue would be to upgrade the internal grid to feed more power to the central zone that can then be fed down through the mainland connection.

Technology maturity and possible timescales for deployment

Grid upgrades are a mature technology solution, the problem is the very high cost and the regulation that does not allow upgrades unless a customer pays to underwrite the costs. Ideally customers could cooperate and each pay a share of the upgrade, but in practice this is complicated with each developer having different timescales. Timescales for deployment are in the region of 2 to 3 years for consenting and building.

Assessment of grid balancing benefit

Any increase in grid export could also have an effect on projects further south of Orkney as the grid is close to fully contracted until the Caithness Moray link is developed.

Localised reinforcement options, which would alleviate some of these internal pinch points and have been highlighted by the Orkney Grid Steering Committee (OGSC) are:

- To build a new 33kV circuit between Scorradale/Kirkwall & Burgar Hill (The development of an engineering solution to build a new 33kV circuit between Scorradale, Kirkwall and Burgar Hill is currently underway); and
- To replace Mainland-Shapinsay and/or Shapinsay-Stronsay sub-sea cables with higher ratings to remove constraints to generators on Shapinsay, Stronsay & Sanday.

There has also been suggestions by the OGSC to look for parts of the network where private entities or community groups could build a spur circuit. SSEPD could adapt to make a ring circuit on the network. This has complications getting people to agree and how to manage any new houses within the spur.

In the long term if a significant amount of marine, onshore and offshore wind generation was to come online upgrading of the cable across the Pentland Firth would be required. This has so far been planned by SSEPD and the National Grid based on the future connections of significant amounts of wave energy in the medium term. The planning involves connection from Orkney as well as upgrades needed from Caithness through to Morayshire and beyond. There are significant constraints throughout Caithness as well as the Orkney connection and recently SSEPD announced that the company would be building a subsea HVDC connector from Caithness to Blackhillock on the Morayshire coast. There have been a number of studies\textsuperscript{3,4,5,6} that have looked into the different options to connect Orkney and Caithness with the grid further south.


\textsuperscript{4} www.hie.co.uk/subsea-cable.
The size of the benefit is difficult to quantify as the upgrades would support different areas. The problem for this solution is determining what the preferable upgrades are and who will pay for them.

This option should be analysed in conjunction with any of the options for increasing as this would mean that demand could be increased in the core zone and have a beneficially effect on generators in the north isles. Currently any increased demand in the core zone would have a minimal effect on generators in the north isles due to internal pinch points.

**Potential local impacts**

Impacts associated with this option are well understood impacts from construction and presence of grid. Significant impacts are likely to be associated with landscape and visual impacts but as these may be upgrades of existing lines then there may not be additional visual impacts depending on the engineering solution used.

**Costs**

There has been a study on the internal Orkney grid (Xero Energy, 2009) which highlights the cost for upgrading the grid to the south of the mainland. It also includes costs for connections to Thurso as a means of connecting the significant tidal generation potential in the Pentland Firth. However this study does not look at the situation in the north isles and was completed in 2009 before the implementation of the Registered Power Zone (RPZ) in Orkney, so any conclusion reached needs to be revisited in the context of the current situation.

The cost of a suggested upgrading of the line from Finstown to Burger Hill was estimated at around £3 million but was not taken forward by SSEPD as this upgrade would impact on other zones.

SSEPD has invested in the region of £500,000 in the Orkney Smart Grid, which has so far released >20MW of additional capacity in the existing grid to connect new renewable generators. Conventional investment in grid upgrades would have cost around £30 million for the same effect.

In conclusion costs associated with grid upgrades are complex matters that require detailed investigation by electrical engineering consultants in conjunction with SSEPD. An average cost was assumed for upgrading overhead lines of £100,000 per km and £1 million per km for subsea cables.

**Examples of previous projects or case studies**

See reference texts.

- Pentland Firth Tidal Energy Project Grid Options Study (Xero Energy)
- Smarter grid solutions
- Orkney grid steering group

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6 http://www.uea.ac.uk/~e680/energy/energy_links/transmission/east_coast_transmission_network_technical_feasibility_study.pdf
**Key stakeholders to engage for further development**

- ANM Group
- SSEPD
- SSE
- Developers
- Wider Orkney community
- OIC

**Next steps**

The next steps associated with grid management are as suggested by Orkney Grid Steering Committee (OGSC):

- 33kV circuit between Scorradale/Kirkwall & Burgar Hill
- Further work required on route selection to allow more accurate cost estimates to be developed & minimise delays obtaining consents, combined with detailed network modelling to ensure solution is technically valid.
- Finalise engineering solution and costs associated with the construction of a new circuit between Kirkwall/Scorradale & Burgar Hill and forward details of network reconfiguration and network model to Smarter Grid Solutions (SGS) to complete constraint analysis across network.
- Once the constraint model has been updated the effect of this network re-configuration to both new and existing generators will be quantified in order to establish the financial viability of the proposal.
- Present final proposal including costs, constraint levels, etc. to Main Orkney Steering Group prior to offering solution to developers.
- Develop engineering proposal for to replace Mainland-Shapinsay and/or Shapinsay-Stronsay sub-sea cables with higher ratings.
- Investigate further the opportunity for private and community investment into grid infrastructure (i.e. spur circuit which SSEPD could adopt creating a ring circuit).

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.2 Suitability assessment – grid upgrades**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid upgrades</td>
<td>Standard technology solution</td>
<td>Medium</td>
<td>Shapinsay upgrade (~£10 million, 10km)</td>
<td>Zones 2, 2a and 2b, Zones 1 and 1a</td>
<td>Would remove some constraints to generators on the North Isles. Costs refer to total rather than per MW costs as increased capacity is not known.</td>
<td>Medium</td>
</tr>
</tbody>
</table>
2.2.2 Use of Dynamic Line Ratings

Description of the switching option, solution or technology

The amount of power that can be distributed through overhead lines is usually limited by conductor thermal capacity defined in terms of a static line rating. This is based on a predetermined set of conditions (temperature, solar radiation, etc.). Transmission line ratings are determined using the conductor’s heat balance and are dependent on the cooling effect of wind, warming due to line current, air temperature and solar heating. Circuits are usually given two standard ratings, one for summer and another for winter. Dynamic Line Rating (DLR) seeks to maximise the amount of power that can be distributed on overhead lines by taking into account the weather conditions and rating the overhead lines in a more real time manner. By accurately monitoring these conditions, a corresponding line current limit can be determined, thereby enabling the system operator to ensure that conductor temperature does not exceed the design limit, and maximises line utilisation under all conditions. Figure 2.1 aims to illustrate the DLR could maximise the potential of transmission lines. Dynamic thermal ratings have been identified by the UK regulator, Ofgem, as a key enabling technology for the transition towards low carbon distribution networks.

For example, when the wind is blowing across the overhead lines, the cooling effect is increased and therefore the capacity of the overhead line can be increased. Importantly, wind generators are located in windy regions, which can benefit substantially from DLR.

There are several options in terms of equipment needed depending on the method employed including:

- Weather Stations
- Conductor Temperature Sensors
- Line Tension Monitors
- Sag Monitors
- Global Positioning System (GPS) Based

Technology maturity and possible timescales for deployment

This is a fairly mature technology that has been trialled elsewhere in the UK (see examples below). In addition this technology is already been trialled on Tingwall/Finstown section in Orkney. It could provide a short term solution which could be deployed in the timescale of a couple of years. The limiting factors are related to cost and regulation.

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Assessment of grid balancing benefit

Desk based studies on the Orkney grid showed that the implementation of DLR on the network could reduce the cumulative curtailment for NNFG units by 48% on average and shows that it is possible to connect an additional 4MW of generation whilst maintaining curtailment at 10% of possible energy output\(^1\). This is a scalable solution which could be trialled on a single pinch point and then rolled out across Orkney.

The zone of influence of this solution will depend on the lines on which the solution is implement and the analysis needed to quantify the effect is outwith the scope of this study.

Implementation of DLR match well with curtailment in Orkney as the majority of curtailment happens in the winter when DLR would increase the capacity of the transmission network.

Potential local impacts

Any landscape and visual impacts caused by additional equipment on the overhead lines is likely to be minimal.

Costs

There are several different methods used that have different advantages and associated costs. Costs are difficult to find but one report set the cost at \(\sim \$200K\) per 26km line section\(^12\) (£4800 per km). This would therefore be around \(\sim £0.2\) million for the 40km Burger Hill-Kirkwall line.

Examples of previous projects or case studies

A feasibility study has been carried out by SHEPD and Smarter Grid Solutions (SGS) to assess the feasibility of extending the existing ANM deployment with a DLR system. A trial of a DLR device and a real time thermal ratings application began in 2011\(^13\).

Skegness, Lincolnshire\(^14\)

Key stakeholders to engage for further development

Transmission/distribution network operator SSE.

Next steps

The next steps associated with dynamic line ratings include:

- Further engagement with the network operator to explore the potential to role this out further.

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\(^1\) Dynamic Line Ratings Deployment on The Orkney Smart Grid. 
https://www.ssepd.co.uk/WorkArea/DownloadAsset.aspx?id=995

\(^12\) https://www.smartgrid.gov/sites/default/files/doc/files/Global_Smart_Grid_Federation_Report.pdf

\(^13\) Second Generation Active Network Management on Orkney. 

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.3 Suitability assessment – Use of Dynamic Line Ratings**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of dynamic line ratings</td>
<td>Mature - Widely applied</td>
<td>Very short</td>
<td>~£0.2 million for the Burger Hill-Kirkwall line for an additional 4 MW of generation (~50k/MW)</td>
<td>Zones 1 and 1a (wider if deployed on other lines)</td>
<td>Understood technology and uses existing infrastructure.</td>
<td>Very high</td>
</tr>
</tbody>
</table>
2.2.3 Expansion of the Active Network Management for Sub 50kW Turbines

Description of the switching option, solution or technology

Orkney’s Active Network Management (ANM) system has been used to control output from generators whose systems are larger than 50kW since 2009. The network has now reached a point where there is little remaining capacity for further connection. In September 2012, SSEPD imposed a moratorium on all new generation, except the very smallest generators that are classed as G38 which has a limit of 3.6kW per phase.

SSEPD has initiated a research and development (R&D) project to explore the use of the ANM system to control sub 50kW generators thus facilitating generation access to maximize the use of the electricity distribution network. SSEPD project team will proceed by engaging the sub 50kW generators on Orkney to determine installation and connection requirements. SSEPD is also working with the sub 50kW developers and R&D providers to determine equipment and installation requirements.

Technology maturity and possible timescales for deployment

The technology to expand this system does not currently exist but SSEPD have an R&D underway to investigate inclusion within ANM system\textsuperscript{15}.

Assessment of grid balancing benefit

This solution would have no effect on the existing sub 50kW generators and therefore would have no immediate effect on the grid. However this should be looked at for locations where there are sub 50kW generator that have applied and not been accepted for connection until further network reinforcement is completed. It is not yet certain how much more capacity would be released.

Potential local impacts

Not applicable as it is understood that the outcome of the SSEPD project was that no suitable, cost effective equipment was found

Costs

The technology does not currently exist but it has been assumed that the costs would need to be relatively low for individual generators as it would have to be within the cost bracket of sub 50kW turbines. Furthermore, it would be assumed that additional costs would not exceed 10\% of the cost of the turbine at a maximum. Therefore maximum costs of a few thousand per unit are assumed. At this scale the average price of turbines is about £5k/kW installed\textsuperscript{16}, therefore the max cost of the equipment is assumed to be £500/kW.

Key stakeholders to engage for further development

- SSEPD
- Potential research partners

\textsuperscript{15} www.ssepd.co.uk/WorkArea/DownloadAsset.aspx?id=2562
Next steps

The next steps associated with the expansion of the ANM Network for sub 50kW turbines includes:
- Engage with SSEPD R&D project. (Note that it is understood that the outcome of this project was that no suitable, cost effective equipment was found.)
- Identify if there are opportunities for research.

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.4 Suitability assessment – Expansion of the Active Network Management for Sub 50kW Turbines

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expansion of the ANM for new sub 50kW generators</td>
<td>No technology solution available</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>SSEPD R&amp;D project did not find a suitable, cost effective, technology solution for this purpose.</td>
<td>Very Low</td>
</tr>
</tbody>
</table>
2.3 Analysis of Selected Options – Storage and Demand Management Solutions

The report identified conventional storage solutions as well as demand side management solutions. Some of the solutions can be applied behind the meter whereas others are applicable more widely as shown in the table below.

Table 2.5 Storage and demand management solutions

<table>
<thead>
<tr>
<th>Behind the meter</th>
<th>Within the curtailed DNO Zones</th>
<th>Solutions that can be applied on the Orkney mainland that would have a wider benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery storage</td>
<td>Battery storage</td>
<td>Battery storage</td>
</tr>
<tr>
<td>Hydrogen fuel cells</td>
<td>Hydrogen fuel cells</td>
<td>Hydrogen fuel cells</td>
</tr>
<tr>
<td>Compressed air storage</td>
<td>Compressed air storage</td>
<td>Compressed air storage</td>
</tr>
<tr>
<td></td>
<td>Demand side management</td>
<td>Demand side management</td>
</tr>
</tbody>
</table>

2.3.1 Electrical Battery Storage

Description of the switching option, solution or technology

The available electrical battery technologies investigated within this report are lithium ion, advanced lead acid and vanadium redox flow batteries (VRB). Lithium ion batteries are currently the battery technology most widely utilised for utility scale energy storage systems. Advanced lead acid batteries represent the modern development of the traditional lead acid chemistry coupled with technologies, such as capacitors, to greater fit modern requirements. VRB is one of the modern flow battery constructions and is predicted to make a big impact in the near future on the battery energy storage market through additional development.

Technology maturity/possible timescales for deployment

There is tried and tested potential for electrical energy storage systems (ESS) technologies to be situated throughout the transmission and distribution (T&D) network, be they sited at the turbines; among the T&D grids; or sited with the end user. Battery storage systems can either be deployed upstream of the grid, before the wind turbines generation meter, or directly to the grid as a means of balancing the grid. If deployed upstream of the grid, “behind the meter”, then this has the advantage of receiving the tariff applied to the generation type that it is connected to (FITs or ROCs for wind in this case) when the store discharges.

Table 2.6 shows the different characteristics of the three battery technologies in question\(^\text{17}\). Lead acid batteries are considered the most mature of the available technologies, but advanced lead acid are modern advancements upon this technology that utilise the cheap storage capacity alongside control mechanisms to make it more efficient and longer lasting.

Table 2.6 Battery type characteristics

<table>
<thead>
<tr>
<th>Rated Capacity (MW)</th>
<th>Energy Density (Wh/kg)</th>
<th>Efficiency</th>
<th>Life (years)</th>
<th>Life (cycles)</th>
<th>Response Time (ms)</th>
</tr>
</thead>
</table>

\(^\text{17}\) http://www.lowcarbonfutures.org/energy-storage-factsheets
Currently lithium ion batteries are the more commercially desirable battery technology due to its high energy density, efficiencies and lack of memory (the effect of reduced capacity as a result of inefficient charging). VRBs are not currently considered as mature but they, along with other flow battery technologies, are expected to make a bigger impact as the technology develops further; as all flow batteries have the advantages of negligible energy loss over time, easy scalability and longer life spans19.

Due to the commercial availability a short-term timescale is predicted for both local and Orkney wide deployment. A conservative two to three year time frame would be estimated for deployment. Examples of commercially available models of these technologies include:

- **Lithium Ion** – NEC Energy Solutions containerised units ranging from 1.2 to 4.0MW; capable of providing rated power for one hour20. These container units can again be configured to gain greater capacities as required. Samsung’s SDI division also cover Lithium Ion solutions covering residential (1 - 100h), commercial (100 - 1,000kWh) and utility users (<1MWh)21.

- **Advanced Lead Acid** – An example of a commercially available advanced lead acid battery is the UltraBattery which is manufactured by UltraBattery. It is a hybrid battery coupling the fast charging and high power capacity of an ultracapacitor with the energy storage capacity of a lead acid battery. The battery has seen multiple successful results from automotive and stationary testing. The hybrid configuration allows for significantly greater complete charging cycles, partial charging and also rapid charging22. The technology has been commercially available since 2005.

- **VRB** – Prudent Energy currently produce commercial available VRBs. These include units operating between 5 – 10kW and another operating in the range of 250kW up to 10MW; with the capacity to discharge over 10 hours.

**Assessment of grid balancing benefit**

In this situation all three technologies are applicable for distributed and centralised solutions. Lithium Ion, Advanced Lead Acid and VRBs can be scaled to purpose within the kW and MW range.

Each battery technology is capable of responding to changes in charging and discharging requirements almost instantaneously (< ¼ cycle); ramping up and down to meet the requirements associated with wind generation. All of which are appropriate for matching generation profiles of renewable turbines.

The size and specifications of the battery will vary depending on the energy requirements of the site. Multiple cells and batteries may be interconnected to form larger banks as required. Within conventional batteries, cells can be connected in configurations to meet the required capacity (i.e. 18 http://www.pdenergy.com/pdfs/Prudent_Energy_Product_Brochure_2011.pdf 19 http://www.netl.doe.gov/File%20Library/research/coal/energy%20systems/fuel%20cells/TutorialII.pdf 20 http://www.neces.com/resources-overview.htm 21 http://www.encotec.lu/files/7/1/document_id40.pdf 22 http://www.ultrabattery.com/technology/
greater power or energy capacity). Whereas, the energy capacity of VRBs can be determined by the size of the tanks containing the electrolytes, and the power by the size power conversion unit.

The size and zone of effect of implementing any storage solution is difficult to quantify as it will depend on the amount of curtailment seen at each potential deployment area and therefore the specifications of the storage solution implemented.

**Potential local impacts**

**Table 2.7 Electrical Battery Potential Impacts**

<table>
<thead>
<tr>
<th>Potential impacts</th>
<th>Lifecycle</th>
<th>GHG Emissions produced in the construction of lead acid and VRB is approximately 287.9 and 255.7 tonnes CO$_2$/MWh, respectively$^{23}$. Lithium ion batteries are listed as crating approximately 155 tonnes CO$_2$/MWh$^{24}$.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Construction</td>
<td>There are no direct GHG emissions associated with charging battery technologies from renewable electricity. In fact, a facility of this nature has the potential to displace the CO2 emissions associated with grid electricity (approximately 0.59kg/kWh). There are no indirect GHG emissions associated with use of battery technologies coupled from renewable electricity. Charging batteries from grid electricity indirectly contributes to greater GHG emissions due to inefficiencies within the technologies.</td>
</tr>
<tr>
<td></td>
<td>Operation</td>
<td>The direct use of land will be dependent upon the size of solution, and technology, required. The following are estimates for land use per battery: Lithium Ion 73.16m$^2$/MW$^{25}$; Lead Acid 77m$^2$/MW; and VRB 850m$^2$/MW$^{26}$.</td>
</tr>
<tr>
<td></td>
<td>Construction</td>
<td>It is not predicted that any requirement for land will be significantly greater during construction that operation; excluding the requirement for temporary structures (i.e. access roads, etc.). Additional land will be required to be cordoned off for health and safety reasons.</td>
</tr>
<tr>
<td></td>
<td>Operation</td>
<td>The three battery technologies do not have any direct water uses associated with their operation.</td>
</tr>
<tr>
<td>Socio-economic</td>
<td>Construction and Operation</td>
<td>An uptake of this technology would create employment and diversify Orkney’s energy industry further.</td>
</tr>
</tbody>
</table>

**Costs**

Table 2.8 details the approximate capital expenditure (CAPEX) of an electric battery solution; per kW and kWh. It also details the estimated operational expenditure (OPEX); per kW per year.

**Table 2.8 CAPEX and OPEX**

<table>
<thead>
<tr>
<th>Cost</th>
<th>Power CAPEX (£/kW)$^{27}$</th>
<th>Energy CAPEX (£/kWh)$^{28}$</th>
<th>OPEX (£/kWh/year)$^{29}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium Ion</td>
<td>945-3,800</td>
<td>630-1,500</td>
<td>6</td>
</tr>
<tr>
<td>Advanced Lead Acid</td>
<td>1,100-3,150</td>
<td>220-630</td>
<td>12.50*</td>
</tr>
<tr>
<td>VRB</td>
<td>1,890-2,500</td>
<td>440-535</td>
<td>19</td>
</tr>
</tbody>
</table>

$^{23}$ http://fti.neep.wisc.edu/pdf/fdm1261.pdf  
$^{25}$ http://www.sandia.gov/ess/docs/pr_conferences/2014/Friday/Session10/02_Gailac_Loic_SCEdison_Tehachapi.pdf  
$^{26}$ http://fas.org/sgp/crs/misc/R42455.pdf  
$^{29}$ http://theenergycollective.com/schalk-cloete/421716/seeking-consensus-internalized-costs-energy-storage-batteries
*it was not possible to obtain OPEX values for advanced lead acid batteries. This value represents that for traditional lead acid battery configurations.*

The costs associated with the batteries are due to the differing constructions and progression through development. Information available on the costs associated with operations and maintenance is not commonly available. Only one source was able to supply estimated OPEX values shown above within Table 2.8.

Potential revenue streams would be expected to be solely resulting from the capacity for further generation from currently curtailed wind turbines. There are no incentive programs aimed at energy storage technologies, however energy storage technologies situated ‘behind the meter’ would contribute towards generating further FITs and ROCs for wind and marine energy generators. There have however been calls for an incentive to be introduced for electrical storage project30.

**Examples of previous projects or case studies**

Examples of each of these technologies currently in operation around the world include:

- **Lithium-Ion** – To date there are roughly 307 lithium ion ESS projects around the world, 12 of which are located in the UK. Currently a 2MW (500kWh) unit situated in Kirkwall, Orkney, supplies grid balancing services as part of a feasibility study by Scottish and Southern Energy (SSE)31. The battery itself consists of three containers; two for the cells and one for the power electronics. In total, more than 2000 individual lithium ion cells were used to in its construction32. Among the world’s largest battery plants is the 32MW lithium ion plant located in West Virginia, used to facilitate a local 98MW wind farm33.
- **Advanced Lead Acid** – To date there are approximately 22 listed advanced lead acid ESSs around the world; according to the Department of Energy’s ‘Energy Storage Database’34. The largest of which currently operating is the 36MW Duke Energy Notrees wind storage demonstration project in western Texas35.
- **VRB** – The largest currently operating VRB is located at the 30.6MW Tomamae wind farm in Japan,36(818,790),(848,800) rated at 4MW. In the UK there is a VRB contracted for construction on the Scottish island of Gigha. At 100kW it will be able to provide rated power for 12 hours. This is the only flow battery project attached to the UK. Including all chemistries of flow battery, there are in the order of 27 operating around the world. The largest of which is a 28MW Zinc Bromide Redox Flow battery that will be constructed in Ohio, USA36.

**Key stakeholders to engage for further development**

- Local turbine owners
- Regional grid operator (SSE)
- Local Authority (Orkney Islands Council).

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Next steps

The next steps include:

- Further investigations into the comparison between distributed and centralised energy storage and how island communities and turbine operators could benefit from locally sited batteries.
- Investigations into the economics of potential solutions should also be included in order to understand the sources of funding for the capital cost of the battery and how the stakeholders will benefit.
- Discussions with national grant awarding bodies around support for installation of batteries within Orkney.

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.9 Suitability assessment – Electrical Battery Storage

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Battery Storage</td>
<td>Semi-mature at scale required</td>
<td>Short</td>
<td>£0.95-3.2 million per MW</td>
<td>All zones</td>
<td>Scalable solution which is becoming more common for large scale storage, however still fairly have a high cost per MW and low energy density (which is a problem for transport solutions).</td>
<td>Medium</td>
</tr>
</tbody>
</table>
2.3.2 Hydrogen Storage and Fuel Cells

Description of the switching option, solution or technology

Hydrogen can be produced by the electrolysis of water, indeed the method for doing this has been around since the late 1700s. Currently the most common method is by the reforming of methane. With the development of renewables and the production of hydrogen by electrolysis has again been examined as a means of storing energy.

Electrolysis of water uses electricity to break down the bonds of water molecules into its component atoms; water, hydrogen and oxygen \(2\text{H}_2\text{O} \leftrightarrow 2\text{H}_2 + \text{O}_2\). Generally there is only a market to store the hydrogen, the oxygen atoms are vented back into the atmosphere. In order to then release the stored energy, hydrogen fuel cells or special combustion engines are used to convert it into useful energy.

Hydrogen storage systems can either be deployed upstream of the grid or directly to the grid as a means of balancing the grid. If deployed upstream of the grid then this has the advantage of receiving the tariff applied to the generation type that it is connected to (FITs or ROCs for wind in this case).

Technology maturity and possible timescales for deployment

Table 2.10 details the current state of these technologies.

### Table 2.10 Hydrogen fuel cell

<table>
<thead>
<tr>
<th></th>
<th>Rated Capacity (MW)</th>
<th>Round Trip Efficiency (%)</th>
<th>Life Span (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Production</td>
<td>0.01 - 50</td>
<td>65-70</td>
<td>5 - 20</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>0.01 - 50</td>
<td>50</td>
<td>20</td>
</tr>
</tbody>
</table>

As previously mentioned electrolysers were invented in the 1700s and fuel cells in the 1840s, although the basic technology is not new there is still ongoing development to combat a number of obstacles.

Hydrogen has a greater energy content by mass (142MJ/kg) than conventional fuels such as petrol (46.4MJ/kg) but a far smaller energy content by volume. In its liquid state hydrogen has an energy density of 10.1MJ/L (stored at cryogenic temperatures since hydrogen boils at -252.8°C), compared to 4.7MJ/L for compressed at 700bar. This low energy content per unit volume, compared to conventional fossil fuels, means there are inherent difficulties in transportation and storage as a larger percentage of the weight being transported needs to be the containment for the liquid or pressurized gas, therefore it becomes advantageous to have a local demand.

Despite advancements in storage technologies energy loses due to leakages of pressurised hydrogen are still present in modern solutions. Liquid hydrogen has a higher energy density than gaseous hydrogen but must be stored at cryogenic temperatures below -253°C; and requires additional

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external cooling. This method of storage can expect loses of between 1-3% per day\textsuperscript{39}, whereas targets for leakage rate as low as 0.05 – 0.1 g/h/kgH\textsubscript{2}\textsuperscript{40} have been proposed for hydrogen powered vehicles (this equates to a loss of 0.12% - 0.24% per day). Hydrogen leakage and energy lose are both important factors for calculating feasibility of a hydrogen solution as it represents lost revenue.

It is predicted that by 2020 there will be widespread use of micro and grid scale Combined Heat and Power (CHP) units, fuelling stations and vehicles all powered by hydrogen. However, these technologies will remain more expensive than traditional alternatives. It is 2030 before it is predicted that these technologies will become financially competitive\textsuperscript{41}.

With reference to similar projects (in the paragraph below), it is estimated that a project including hydrogen production and utilisation would take two to three years to deploy. However, EMEC is working on a hydrogen project with a 500KW electrolyser and are planning on rolling it out within 15 months.

**Assessment of grid balancing benefit**

Hydrogen production through electrolysis is particularly attractive as it gives a means of storing excess energy from renewable sources, and then making it transportable without needing to use a cable. The use of electrolysers can be paired with variable generation profiles (i.e. wind) as it can easily be ramped up and down to match demand. This makes it a suitable choice for grid balancing services. Hydrogen electrolysers and fuel cells can be scaled to meet a wide range of project specifications. These can be ranged from kilowatts up to 50MW. Thus, the technology becomes applicable for small scale, commercial, utility and transport purposes. For this reason a distributed approach could be as technologically advantageous as a centralised approach.

The size and zone of effect of implementing any storage solution is difficult to quantify as it will depend on the amount of curtailment seen at each potential deployment area and therefore the specifications of the storage solution implemented.

**Potential Impacts**

**Table 2.11 Potential impacts**

<table>
<thead>
<tr>
<th>Potential impact</th>
<th>Lifecycle</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG Emissions</td>
<td>Construction</td>
<td>GHG emissions can be associated, through the use of fossil fuel powered machinery and transport, with the manufacture of the individual technologies required for this solution, as well as the construction of the facility itself. One report by the University of Birmingham put the CO\textsubscript{2} emissions associated to construction of fuel cell at approximately 700 - 950kgCO\textsubscript{2}/kW \textsuperscript{42}. The same value was not available for a hydrogen electrolyser.</td>
</tr>
<tr>
<td></td>
<td>Operation</td>
<td>There are no direct GHG emissions associated with production of hydrogen from renewable electricity, or the use of fuel cells as no fossil fuels are used within their operation. There will in fact be a displacement of power currently sourced from the</td>
</tr>
</tbody>
</table>
Potential impact  Lifecycle
---

national grid; which typically contributes approximately 0.59kg/kWh of CO2 emissions \(^{(43)}\). It is unlikely that significant fossil fuel emissions can be attached to the project as a result of transport requirements.

Land Use  Construction

The direct use of land will depend upon the scale of intervention required and whether deployment is within a centralised or distributed manner. The production of hydrogen typically requires roughly 75m\(^2\)/MW; but can be as low as 16.7m\(^2\)/MW \(^{(44)}\). It is not expected that land use during construction will be any greater than the final facility; with exception to any temporary constructions (i.e. access roads, etc.).

Operation

The use on land during operation will be dependent upon the scale of intervention deployed. There should be minimal indirect use of land as water and grid electricity are the only feedstock. However, additional land will need to be cordoned off for health and safety reasons.

Water Use  Construction

No significant impacts on water use should be expected during construction.

Operation

The production of hydrogen by electrolysis requires significant quantities of water in the electrolysis stage. This can be sourced from sea water and does not need to draw from fresh water sources. In order to produce 1kg or hydrogen 2.4 gallons of water is required \(^{(45)}\). Another source details that between 250 and 560 litres of water is needed to produce one megawatt hour of hydrogen \(^{(46)}\). Significant quantities of water are required in order to act as a cooling medium for the electrolyser. Exact figures of water requirements for this purpose were not available.

Socio-economic Impacts:

Construction and operation

The utilisation of hydrogen based fuels in Orkney would create a job market that does not currently exist in Orkney; diversifying Orkney’s energy industry further as well. There is a perceived risk associated with the use of hydrogen that would undoubtedly need to be addressed in order to achieve confidence among the population within Orkney and maximise uptake.

Costs

Capital Cost: The current CAPEX rule of thumb for hydrogen production through electrolysis is a 1MW unit will cost approximately £1 million. Utility scale fuel cell units can be expected to add an addition £2 - 3 million per MW. Technology developers, such as AFC Energy, are developing fuel cell units that drop this down to a predicted £1 million per megawatt \(^{(47)}\). Hydrogen storage is estimated to be approximately £386/kg (or £10.16/kWh) \(^{(48)}\).

The biggest electrolysers currently on the market can produce about 3.6kg of hydrogen per hour for a 230kW system (therefore 15.4kg/h/MW). Therefore the cost of storing a days’ worth of hydrogen production would cost £~142,666.

If the hydrogen is going to be used locally then one set of storage tanks would suffice but if it is transported multiple storage tanks would be needed. For example, if the hydrogen was transported to Aberdeen then it will take a day to get there and a day to get back and a day to fill, so you'll need three trailers in rotation to make that work. So the storage costs are three time the cost given in the paragraph above (£428,000).

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\(^{(43)}\) http://www.lowenergybuildings.org.uk/leb/technical-information/fuel-usage-coefficients/


\(^{(45)}\) http://phys.org/news111926048.html


\(^{(47)}\) Personal correspondence with Nigel Homes, Scottish Hydrogen and Fuel Cell Association

Operations and Maintenance: Operational expenditure (OPEX) is not readily available, but are estimated at between 2 - 5% of the capital expenditure per year\(^49\). This does not include the cost of the electricity. The operational costs are also generally not directly scalable. For example, the number of staff required will increase incrementally at certain scales. Another source places OPEX values of £26/kW/annum (equivalent of 1% of the CAPEX based on 1 million/MW) for electrolysers and £217/kW/annum for stationary fuel cells\(^50\) (equivalent of 7% of the CAPEX based on 3 million/MW).

Revenue: The revenue streams available after deploying a hydrogen storage and fuel cell solution will, as like other energy storage mediums, in the ability for currently curtailed turbines to generate for a greater portion of the time. Additional potential to generate revenue comes from the possibility to sell on the manufactured hydrogen. But as previously mentioned, there is not currently a demand for hydrogen within Orkney.

Examples of previous projects or case studies

- H2Herten – the H2Herten Energy Complementary System (ECS), located in Germany, installed wind turbines to provide power to 80kW of lithium Ion battery capacity as well as a hydrogen electrolyser. The system took three years to roll out\(^51\).
- H2 Aberdeen – the H2 Aberdeen project was launched in 2014, deploying 10 hydrogen fuel cell buses, a hydrogen production facility and refuelling station. This project is set to run until 2017 where if the project is deemed successful another refuelling station will be constructed and further buses deployed\(^52\).
- Wind2H2 – the wind-to-hydrogen (Wind2H2) project in Colorado, USA, is a demonstration project investigating the use of variable speed wind turbines and solar panels providing power a number of different electrolysers. The hydrogen is then stored in pressurised tanks to feed a combustion engine and a fuel cell at times of peak demand\(^53\).

Key stakeholders to engage for further development

- Local turbine operators
- Local grid operator (SSE)
- Local Authority (Orkney Islands Council)
- EMEC in relation to their proposed project

Next steps

Next steps for hydrogen storage and fuel cells include:

- Further studies that will help move this work forward would include possible demand for hydrogen; whether a distributed or centralised approach is more advantageous; where funding would be sourced from; and how stakeholders on the islands would benefit from particular scenarios.

\(^{49}\) http://www.fch-ju.eu/sites/default/files/study%20electrolyser_0-Logos_0.pdf
\(^{50}\) http://energy.gov/sites/prod/files/2014/08/f18/fcto_webinarslides_h2_storage_fc_technologies_081914.pdf
\(^{51}\) http://www.iea.org/media/topics/roadmaps/annex_a_technical_annex_fin.pdf
\(^{52}\) http://www.aberdeeninvestlivevisit.co.uk/Invest/Aberdeens-Economy/City-Projects/H2-Aberdeen
Consultation should be conducted with parties within the industry to determine viability. This could include PURE Energy Centre, Scottish Hydrogen and Fuel Cell Association and members of the H2 Aberdeen board.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.12 Suitability assessment – Hydrogen Storage and Fuel Cells**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Storage and Fuel Cells</td>
<td>Semi-mature</td>
<td>Short</td>
<td>£1-2 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Scalable solution which is becoming more common for large scale storage, however still fairly have a high cost per MW and low energy density (which is a problem for transport solutions).</td>
<td>Medium</td>
</tr>
</tbody>
</table>
2.3.3 Pumped Hydroelectric

*Description of the switching option, solution or technology*

Pumped hydroelectric energy storage relies on two bodies of water being situated at different altitudes. By using an electric pump it is possible to pump water from the lower body to the higher body so converting the electrical energy into potential energy. Traditionally this was done through utilising or creating two reservoirs connected by a bidirectional pump. When demand is low and electricity at off-peak rates, the water is pumped up. When the power is required again the water is allowed to flow down again through the electric generator and supply the power grid. Pumped seawater systems operate with a natural body of seawater acting as the lower source and a reservoir as the upper. Pumped seawater energy storage systems have the advantage of only requiring the use, or production, of one reservoir, which can theoretically cut down on land use.

*Technology maturity and possible timescales for deployment*

Pumped hydroelectric energy storage is a very mature technology. It has been in use within the UK since the 1960s. However, pumped seawater energy storage plants are certainly not as mature. To date there is only one operating plant; located in Japan. This facility is a demonstration project that has been investigating methods of navigating around potential hazards. These include biofouling by vegetation and marine organisms, and also corrosion due to interaction with seawater. Biofouling of vegetation on land is protected against by using a rubber lining and salt water detectors under the reservoir. Fiberglass reinforced plastic and austenite stainless steel, one of the most anticorrosive metals tested, are used to limit the corrosion due to saltwater. Additional plants are also being planned for Hawaii and Ireland.

Constructing new pumped hydro station is very time consuming, taking in the order of 6 – 10 years to complete a new project.

*Assessment of grid balancing benefit*

Given the right location and suitable head of water, pumped hydro is certainly a good option for storing energy and has been used for bulk storage on the grid in the UK (e.g. Cruachan and Foyers). Examples of this are the 1.7GW Dinorwig and 3GW Foyers pumped hydroelectric plants in Scotland. However, the topography of Orkney does not lend itself to this large scale storage. There are very

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few places in where land height is greater than >100m high and topographically there are no valleys of the right shape for hydro in Orkney.

Pumped storage plants in the megawatt range are located internationally. Examples of this include a 2MW plant in China; a 2.6MW plant in Spain; and a 4.6MW plant in Croatia58.

Pumped hydro stations do not boast instantaneous response to charging and discharging. It is in the range of seconds to minutes. This means this technology is not as quick as many other energy storage systems, such as

The island of Hoy has underground oil tanks within the hills of Wee Fea dating back to the Second World War. There are six tanks built with a combined capacity for 100,000 tonnes (13 million litres) of oil. The tanks are situated roughly 90 meters above sea level close to Lyness Pier.

Calculations on these tanks, to be used as an upper reservoir, were done in order to illustrate the initial potential of Orkney’s topography for a pumped seawater energy storage plant. It is understood these tanks are not currently fit for this purpose since they present too great of a befouling risk as a result of residual oil from its original use. But the specifications of these tanks help to highlight the potential use of this type of energy storage in Orkney. Several assumptions were made in order to complete these calculations:

1) Efficiency of a hydroelectric plant is 60%;
2) Rated power was taken to be 5MW;
3) The effective head is taken as 80m; and
4) The density of seawater is 1025kg/m³.

In order to calculate the energy potential of these tanks, it is first necessary to calculate the required flow rate of this hypothetical facility:

\[
\text{Rated Power} = \text{Flow Rate} \times \text{Effective Head} \times \text{Gravity} \times \text{Efficiency} \times \text{Water Density}
\]

Thus, the required flow rate under these conditions is 10,359 litres per second. At a storage capacity of 13 million litres within the six tanks, this translates to energy capacity of 1.47MWh. There are a number of locations among the Orkney Islands that have at least the same elevation above sea level and relative proximity to the shore.

Costs

Pumped hydroelectric energy storage can be expected to cost in the range of £500-2,000/kW59 (£0.5 - 2 million /MW).

Operations and maintenance costs have been estimated to be range of 1 - 4% annually of the installed cost; depending on the scale of the installation. A range of 1 - 6% of the installed cost is estimated for refurbishment and upgrade costs60.

58 http://www.energystorageexchange.org
59 http://www.scotland.gov.uk/Publications/2010/10/28091356/0
60 http://www.irena.org/documentdownloads/publications/re_technologies_cost_analysis-hydropower.pdf
Examples of previous projects or case studies

The US Department of Energy’s Energy Storage Database lists 292 currently operating pumped hydroelectric plants around the world. Four of these are in the UK: two in Wales, Dinorwig (1,728GW) and Ffestiniog (360GW); and two within Scotland, Cruachan (440GW) and Foyers (300GW). All of these plants provide grid balancing services when required. It also lists 28 plants in construction around the world with a combined rated power capacity of 19.23GW.61

Japan constructed the first seawater pumped energy storage power station. A man made reservoir acts as the upper body of water while the Philippine Sea acts as the lower. The station itself is rated at a power capacity of 30MW and an energy capacity 13,025MWh.62

Ireland is currently developing a 1500MW seawater pumped energy storage plant that will be located in Glinsk. The project has been in development since circa 2007.

Key stakeholders to engage for further development

Key stakeholders would include:

- Local engineering firms
- residence in the vicinity of any proposed development
- turbine operators
- regional grid operator (SSE)
- Orkney Islands Council and Scottish Parliament.

Next Steps

As this project would most probably be deemed too expensive and too time intensive to make it viable there would likely be no further steps to its development. But future investigations could focus on the other potential locations among the islands to utilise pumped seawater hydroelectric energy storage; where only one reservoir is required.

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.13 Suitability assessment –Pumped Hydroelectric

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped hydro</td>
<td>Mature but not applicable to Orkney due to topology</td>
<td>Long</td>
<td>£0.5-2 million per MW</td>
<td>NA</td>
<td>The topography of Orkney does not lend itself to this large scale storage. There are very few places in where land height is greater than &gt;100m high and topographically there are no valleys of the right shape for hydro in Orkney.</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

61 http://www.energystorageexchange.org/
2.3.4 Compressed Air Energy Storage

*Description of the switching option, solution or technology*

Compressed Air Energy Storage (CAES) is a means of converting electrical energy into a storable medium. In this case an air pump is used to compress air into a fixed space; commonly an underground cavern. During the compression stage the air temperature rises. Traditionally the excess temperature is vented back into the atmosphere, as it is possible to store greater quantities of cooler air than warmer air. When the stored energy is required the air is heated up again in order to cause it to expand. It is this expansion that will drive a turbine in order to generate electrical energy\(^63\).

Advanced Adiabatic - Compressed Air Energy Storage (AA-CAES) is a progression on the traditional CAES method. The concept centres on the idea of storing the heat that is created during compression, which would normally be vented back into the atmosphere, in order to utilise it once the energy within the compressed air is required again. By recycling this heat instead of generating more during the expansion stage it is possible to achieve a greater round-trip efficiency. This approach can also cost less and result in significant emission savings.

Isothermal Compressed Air Energy Storage (ICAES) utilises heat exchangers to maintain similar internal and external temperatures. The mentioned heat created during compression is vented in the atmosphere, then during the expansion stage heat is extracted from the atmosphere again. This expansion again drives an electrical generator\(^64\).

*Technology maturity and possible timescales for deployment*

Traditional CAES is a mature technology. It does not require the need for any new technology. To date there are three CAES plants in operation; a 290MW plant in Huntorf, Germany (operational since 1978); a 110MW plant in Alabama, USA (1991); and a 2MW plant in Texas, USA (2012). AA-CAES and ICAES are beginning to emerge, but are still being developed in order to reach their potential.

CAES technologies can expect efficiencies of roughly 55 - 60% for traditional CAES; 70% for AA-CAES and 70 - 80% for ICAES. Life spans for each can be expected be greater than 20 years, and greater than 10,000 charge-discharge cycles.

Developments are being made in order to produce above ground CAES that utilise tanks instead of underground caverns. This will allow the technology to be much more versatile and accommodate smaller power requirements\(^65\). Figure 2.6 demonstrates the concept of a CAES plant designed by a company called SustainX, in the USA. The company currently has a 1.5MW demonstration plant currently

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\(^{63}\) [http://www.thegreenage.co.uk/tech/compressed-air-energy-storage/](http://www.thegreenage.co.uk/tech/compressed-air-energy-storage/)

\(^{64}\) [http://www.thegreenage.co.uk/tech/compressed-air-energy-storage/](http://www.thegreenage.co.uk/tech/compressed-air-energy-storage/)

connected to the grid; however designed to draw power from wind and solar energy and store it for later use. The above ground air storage Figure 2.6, demonstrate the ability to locate the facility practically anywhere. The company details this demonstration project as a means to “entice” project developers to the technology. It is technology that can be sited anywhere; can be used to provide balancing services for renewable generators; it is environmentally friendly; and is financially competitive over a predicted 20 year life span.

Assessment of grid balancing benefit

Typical minimum capacities of conventional CAES solutions, that utilise underground caverns, are roughly 50MW. This is currently beyond the requirements of Orkney. The scales of the technology typically restricts it to a centralised approach. It would be required to accommodate Orkney as a whole; rather than a distributed approach accommodating each turbine or wind farm. However, smaller solutions will become commercially proven in the next few years and could certainly prove to be viable.

CAES does not boast as fast a reaction time as some other energy storage technologies (electrochemical batteries). Sources report the response time of the SustainX CAES unit is between 10ms and 1sec, but the SustainX states their patented system has been designed to accommodate the variable nature of wind and solar power generation.

The size and zone of effect of implementing any storage solution is difficult to quantify as it will depend on the amount of curtailment seen at each potential deployment area and therefore the specifications of the storage solution implemented.

Costs

The price range that can be expected for CAES is within the range of £250 - 950/kW for power capacity, and £80 - 250/kWh for energy capacity. It is unclear at this time if this applies to smaller scale modular technologies, but CAES is among the most financially competitive among the energy storage options.

Examples of previous projects or case studies

Examples of existing projects include the previously mentioned CAES power plants in Germany and USA. Future examples of this technology being rolled out include a 300MW plant in California, USA; a 150MW plant in New York State, USA; a 317MW plant in Texas, USA; and a second plant in Germany rated at 200MW.

66 http://www.sustainx.com/index.htm
67 http://www.sustainx.com/index.htm
69 http://www.sustainx.com/applications-renewables.htm
70 http://www.iea.org/media/topics/roadmaps/annex_a_technical_annex_fin.pdf
71 http://www.energystorageexchange.org/
**Key stakeholders to engage for further development**

Key stakeholders would include:
- technology manufacturers
- local engineering firms
- turbine operators
- the regional grid operator (SSE)
- local council (OIC)

**Next steps**

As current traditional underground CAES technology requires a scale much greater than which is required for Orkney, it is unlikely that further efforts should be made in determining its viability. However, monitoring the development of smaller scale CAES technologies, which provide realistic possibilities for future solutions, should be considered.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.14 Suitability assessment –Compressed Air Energy Storage**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed air storage</td>
<td>Immature</td>
<td>Short</td>
<td>£0.25-0.9 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Above ground compressed air storage would be possible on Orkney but is still at the demonstration stage, so should be highlighted as an option for future investigation.</td>
<td>Low</td>
</tr>
</tbody>
</table>
2.3.5 Demand Side Management

**Summary - Application of the ORIGIN Demand Response System to the Orkney Islands**

It is expected that deployment of an informational Demand Side Management (DSM) system using ORIGIN renewable energy forecasts would be able to create a response of between 0.7 and 2.8MW additional demand during periods when generation is curtailed and a corresponding reduction in total consumed energy at other times.

An informational system would require clear messages to be relayed to the end users concerning price and availability of energy via the ORIGIN user interface. Informational systems require little upfront investment in hardware other than that required for the user interface and can be in the form of a smart phone application and/or a webpage. The system would be entirely voluntary however participation would be encouraged by use of a low cost electricity tariff during periods forecast to correspond with excess generation or curtailment. The ORIGIN system would produce 24 hour ahead renewable energy forecasts several times each day and include tariff levels for the day ahead.

Deployment of an actuated demand management system based on ORIGIN cloud based energy orchestration would enable energy loads in Orkney to be controlled remotely and would further increase the potential for reductions in curtailment. However deployment would be relatively expensive in terms of hardware, communications and labour.

Installation of an informational ORIGIN based DSM System across Orkney would require approximately 18 months to point of deployment.

Adoption of a high impact ORIGIN DSM system for Orkney would require a new electricity retail business model to be developed with the key stakeholders in the industry. Integrating variable tariffs into the business model would greatly increase the impact of DSM.

Deployment of an informational ORIGIN system in a 1000 house pilot trial in Orkney is estimated to cost around £150,000 to £200,000 however this pilot trial would need to be preceded by a planning phase to develop an appropriate business model and accurate costings.

**Origin Concept**

**Introduction**

The ORIGIN project is demonstrating improved uptake of locally generated renewable energy via DSM in three European communities, namely: Findhorn in Morayshire; Tamera in Portugal and Damanhur in Italy.

**Figure 2.7 Origin participating communities**
It has two operational modes:

- **Actuated properties** - which are retrofitted with energy monitoring and control systems that can be remotely monitored and controlled from a cloud based optimisation system.
- **Informational properties** - where occupiers are given regular highly localised renewable energy availability forecasts and encouraged to participate in demand response via a variable tariff for electricity.

While the actuated properties can provide definite responses to control messages from the ORIGIN system they require the installation of relatively expensive hardware for monitoring each property and controlling the major dispatchable loads in the properties such as the hot water immersion heaters. The informational properties rely upon the buildings’ occupants responding positively to messages provided to them via a dedicated web or hardware based user interface concerning the forecast availability of low cost renewable energy. Typically the variable tariff would have two rates, perhaps 4p per kWh when there is an excess of locally generated renewables forecast and 15p when energy is being imported from the grid. This price differential and an accurate forecast enable the community to plan their domestic energy consumption and reduce the need to import expensive high carbon energy from the grid.

**Forecasting**

The ORIGIN control algorithm is informed by its own site specific weather forecast that can be replicated for any location on the globe. It then combines the highly local weather forecast with generation curves for locally installed renewable energy systems, usually wind and solar generation, to produce a renewable generation forecast. The algorithm also predicts the demand for energy in the community over the same period and identifies occasions when a surplus of locally generated energy will be available. In the actuated buildings the energy loads are scheduled via remote control to utilise the forecast energy surplus without compromising the environmental comfort of the occupants. In the informational properties the occupants are sent a user friendly renewables forecast via the end user interface, which can be web or hardware based.

The ORIGIN weather forecasting has been found to be highly accurate due to the neural network methods it deploys and its use of highly localised forecasting. This increased accuracy is of particular use to wind generation where differences of one or two metres per second in wind speed can make a significant contribution to errors in generation forecasts.
Figure 2.8 Findhorn 7 day ahead forecast for April 2014. (Comparison with Met Office Forecasts and Actual Weather Experienced.)
Figure 2.9 Mean absolute error between forecast and actual weather for Findhorn in m/s from 1 to 24 hours ahead
End User Interface

The ORIGIN project requires a clear user interface for communicating energy forecasts to the participants. This is the subject of a continuing research effort and a screen shot of the current energy interface home screen is shown below. The 24 hour energy forecast is in the bottom right hand box which will be morphing into a 24 hour ahead “clock style” renewables forecast during November 2014. The user interface will be finalised and available for deployment for other communities, such as Orkney, before October 2015.

![Screenshot of the web based ORIGIN end user interface](image)

In this screenshot information related to The Findhorn Community is presented. The boxes in the interface communicate information concerning the energy flow into and out of the community, the highly localised weather forecast, the proportion of renewables in the current energy generation mix, the ongoing CO₂ savings the present availability of excess renewable generation and the renewable energy availability 24 hour ahead forecast.

Demand Response

A review of dynamic tariff level indicated that peak demand reduction has some degree of elasticity to price with significantly larger peak demand reduction achieved in critical peak pricing trials for instance. In a recent pilot trial conducted in London in 2013 a dynamic time of use tariff with a peak to off-peak price ratio of circa 2.8 involving circa 1,100 households secured an average demand
response (i.e. increase in load) of circa 100W per household during low tariff periods. Approximately 70% of participants were still responding at the end of the 12 month trial (Carmichael et al 201472).

![Figure 2.11 Relationship between peak demand reduction and in the TOU and CPP pilot trials](image)

Figure 2.11 Relationship between peak demand reduction and in the TOU and CPP pilot trials

From these studies it seemed plausible to explore the impact of demand response of 100W and 400W per household during periods where curtailment was occurring.

**Orkney Domestic Demand**

The total number of households in Orkney in 2013 was 9945. Domestic demand for a January weekday was estimated using a bottom up model (Figure 2.12) (Richardson et al., 200873). Assuming that space heating for the Orkney housing stock was provided by fossil fuel fired boilers (or coal in open fires) and electric storage heaters in the ratio 71:29. The simulated domestic demand results in domestic sector demand with an after diversity maximum demand (ADMD) of 1.6kW which is plausible (Peacock and Newborough, 200674).

---


Reduced curtailment of wind energy

The issue of curtailment of wind output has been estimated by:

- Applying an hourly 2013 weather file for Kirkwall (Weather Analytics, 2013)
- Height correcting to 56m hub height for a WinWinD 1MW wind turbine (http://www.ecosource-energy.bg/uploads/Technical_Specification_WWD1.pdf)
- Computing output from a WinWinD 1MW wind turbine and scaling for a total installed Orkney capacity of 47.4MW
- The output estimated using this simple assessment is then compared to the output data provided by Aquatera for the month of January 2013 (Figure 2.13)
- Curtailment would appear to be occurring frequently at around 30MW generation as illustrated by the flat “peaks” in the estimated and actual wind output
- The output data would suggest that curtailment is occurring when the output exceeds circa 27MW. Using the procedure described above this occurs when the observed wind speed (not height corrected) exceeds 7.15m/s. In 2013 this occurred for 3120 hours or 36% of the year
- The Origin demand response system is able to forecast the instances of wind speeds that exceed the point at which curtailment is required
- At the same time it can monitor demand in each participating load centre (household or business) and provide contextualised information informing occupants of the curtailment event and suggesting ways in which load might be shifted
- Over time the probability of response can be determined for each participating load centre and used to optimise the scale of demand response to match the event.
Figure 2.13 Actual wind generation, wind speed and modelled potential generation for Orkney. The gap between the blue and the red line represents the curtailed generation.
The bespoke systems designed for the ORIGIN communities create a 48 hour forecast twice a day (06h00 and 18h00) which is communicated to the residents via the end user interface either on dedicated hand held tablets or via the internet.

The ORIGIN demand response system could be applied to the domestic sector in Orkney to inform participants of instances where the forecasted wind speed would be greater than 7.15 m/s, i.e. curtailment would be occurring.

If this were applied to the month of January 2013 then the frequency of event would be as shown in Figure 2.14 with the longest curtailment period lasting 56 hours from the 17th at 02h00 to the 19th at 10h00.

This could be communicated to the participants via the ORIGIN user interface or via a dynamic tariff whereby participants could be incentivised to modify their energy consumption behaviour using tariff signals.

The impact of load growth during curtailment periods, where a curtailment period is triggered by the met office wind speed exceeding 7.5m/s is shown using the 26th January (Figure 2.14). For participation rates of 70%, a total domestic sector response of 0.7 and 2.8MW for the 100W and 400W response respectively.
Figure 2.14 Instances when curtailment of Orkney generation occurred during January 2013
Figure 2.15 Potential of load growth via the ORIGIN system during 26th of January 2013.

The red and green areas highlight the potential reduction in curtailed energy generation available through variable tariff voluntary demand side management in the domestic sector. Although not shown in this figure there would also be a corresponding reduction in the load profile during periods below the curtailment threshold of 7.5 m/s.
Domestic scale demand response in Orkney

Reduced export of wind energy
Figure 2.16 shows the import and export data from SSEPD (which is summarised in Section 2.5.4 of the ‘Orkney-wide energy audit 2014 - Energy Sources and Uses’ Report) from the mainland through the Pentland Firth interconnector. Considering only January 2013 in the first instance, 10,495 and 10,042MWh of electricity was imported to and exported from the mainland respectively. As shown, export/import during this period was highly correlated with local Orkney electricity generation (Pearson’s correlation – 0.953).

It was possible therefore to determine a value of generation output that would correlate with periods where export was high and use this as a trigger point that would determine when a signal would be sent to the participating households to indicate that a change in demand was desirable.
Figure 2.16 Import and export of electricity to the mainland in January 2013
**Strategy**

The strategy required to achieve wide spread participation in the ORIGIN system would be the following:

- Provision of a user interface to all participants via either: a) a dedicated tablet based device or b) an Orkney dedicated ORIGIN website.
- Production of an Orkney specific weather and renewable generation forecast several times each day.
- Provision of easy to understand 24 hour ahead variable tariff price information via the user interface.
- Access to smart meter readings in all participating properties or installation of ORIGIN hardware for reporting energy use during high and low tariff periods.

**Costs**

Informational Systems – Pilot Trials of 1 to 2 years duration: Total cost circa £150,000- £200,000 for a 1000 property informational system. This cost is approximate and it is recommended that the pilot trials be preceded by a detailed planning phase costing around £15,000.

It is envisaged that householders who participate will access a dedicated web based resource via smart phone, tablet or PC.

It is further envisaged that these will be incentivised to participate in load shifting behaviour through a dynamic time of use tariff that is linked to periods of high wind output (i.e. curtailment).

The business model would involve the use of a DNO/trusted third party who would administer the tariff – for instance through a direct billing or rebate scheme. The DNO/trusted third party would then negotiate with wind generation companies a fee for reducing curtailment exposure to offset the cost of administering the dynamic tariff.

Upfront capital cost for this project would be:

- developing the bespoke ORIGIN systems for Orkney (to include the Orkney specific use interface) – discussion with HWU regarding the scope of the project
- deploying monitoring equipment in each participating dwelling – circa £50 per participating dwelling/building
- developing the business model with the wind generation companies

**Actuated systems**

This approach uses the ORIGIN outputs to directly switch or modulate electrical loads. This would require that each participating load is equipped with monitoring and actuating equipment, for instance in the form of a smart plug.

The cost per participating load is likely to be approximately £50-100 for simple electrical loads (e.g. dishwasher) and £500 – 1000 for thermal loads (e.g. an air source heat pump). The latter require the installation of heat meters.

Both systems would require that some form of secure, accessible cloud server be set up. The cost of set up, maintenance and access to a data server would be circa £1,200 per annum plus £6 per participating dwelling.
To extend either or both of these pilot trials to secure, robust and stable systems that had longevity would require that metering issues be solved, i.e. through the deployment of smart metering.

**Conclusions**

Voluntary participation DSM in Orkney via the ORIGIN informational system is capable of providing a response of between 0.7 and 2.8MW. Achieving a response nearer to the higher end of this range would be achievable by selling electricity at a very low price during curtailed periods. For example a price difference of 2p/kWh during curtailed periods and 14p/KWh during non-curtailed periods may achieve a response rate of 2.5MW. Effectively this would allow the maximum generation across Orkney to grow by 2.5MW thus reducing curtailment. From the generation data provided, and weather records for Orkney, it is apparent that curtailment currently occurs at a total generation of approximately 30MW and a wind speed of around 7.15 m/s and so ORIGIN deployment could increase maximum generation by approximately 8 – 9% if a high level of participation is achieved.

Assuming that the total amount of energy used in the domestic sector remained the same, there would be a corresponding reduction in energy use during non-curtailed periods when generation is currently imported to the islands or generated by non-renewable means.

Although some people are motivated by a will to reduce their carbon footprint, ensuring maximum uptake of the technology will require a financial incentive to the participants. The low price tariff during curtailed periods would provide a direct financial benefit to the participants. However varying the retail price of electricity will have economic consequences beyond those of the participants and an electricity retailer will have to be involved in negotiation of the variable tariff structure. There would be a potential business opportunity for a new or existing retailer to become involved in the Orkney electricity market, specialising in provision of renewable electricity.

Variable time of use tariffs will require smart meters or equivalent technology in all participating properties so that electricity use in reduced tariff periods can be recorded. This can be achieved via the widespread use of induction clamps and cloud based energy monitoring in properties with internet access or via smart meters with appropriate functionality.

Deployment of an ORIGIN system in Orkney would require a two year lead in time so that an appropriate customised technical and business plan could be developed. Much of the technology would be derived directly from the system currently installed in Findhorn which will be launched in November 2014 and gradually activated over the following three months.

The conclusions here have used data on the import and export from Orkney as a whole to analyse the effect of demand side management on the system. In order to look more closely at individual DNO zones it would be necessary to obtain data from SSEPD for these areas. This data was not made available to the study.

**Next steps**

The next steps associated with Demand Side Management include:

- Further engagement with Heriot-Watt University to maximise outcomes and opportunity for transferring outcomes from Findhorn to Orkney.
Further investigation, if data is available, to look at the scale of the grid balancing benefit on the individual DNO zones.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.15 Suitability assessment –Compressed Air Energy Storage**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand side management</td>
<td>Mature</td>
<td>Short</td>
<td>£0.5-2.9 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>DSM is a solution that could be deployed in the short term with a significant impact on the electrical demand on the grid at times when there is high wind energy generation (0.7 - 2.8MW response for a 1000 property informational system.). There are also benefits to customers if a system is set up in which the price of energy can be reduced during curtailed periods.</td>
<td>Very high</td>
</tr>
</tbody>
</table>
2.4 Analysis of Selected Options – Fuel Switching

The fuel solutions identified for the Orkney scenario include electric vehicles, electric monorails, electric ferries, hydrogen ferries, electrification of heating systems and district heating. These can be applied behind the meter, within the curtailed DNO zones or on the wider Orkney mainland as classified in the table below.

Table 2.16 Fuel switching solutions

<table>
<thead>
<tr>
<th>Behind the meter</th>
<th>Within the curtailed DNO Zones</th>
<th>Solutions that can be applied on the Orkney mainland that would have a wider benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicles</td>
<td>Electric vehicles</td>
<td>Electric vehicles</td>
</tr>
<tr>
<td>Electrification</td>
<td>Hydrogen vehicles</td>
<td>Hydrogen vehicles</td>
</tr>
<tr>
<td>of Heating</td>
<td>Electric ferries</td>
<td>Electric ferries</td>
</tr>
<tr>
<td>Systems</td>
<td>Hydrogen ferries</td>
<td>Hydrogen ferries</td>
</tr>
<tr>
<td></td>
<td>Electrification of Heating</td>
<td>Electrification of Heating Systems</td>
</tr>
<tr>
<td></td>
<td>Systems</td>
<td></td>
</tr>
</tbody>
</table>

2.4.1 Electric vehicles

*Description of the switching option, solution or technology*

An electric vehicle (EV) relies on an electric motor for propulsion using electrical energy stored in an energy storage device rather than being propelled by a petroleum based combustion motor.

The solution analysed in this section entails demand side design of grid infrastructure to take up electricity which has been created by renewables energy resources, particularly currently grid constrained wind, to replace the current consumption of road transport based on petrol and diesel.

There are broadly two categories of electric vehicles. These are battery operated electric vehicles (BEVs) plug-in hybrid electric vehicle (PHEV) and hydrogen operated electric vehicles also known as fuel cell vehicle (FCV). Plug-in electric vehicles (PEVs) including all-electric vehicles and PHEVs, provide a new opportunity to reduce the net oil consumption of Orkney by using energy that would otherwise be curtailed.

*Technology maturity and possible timescales for deployment*

The technology of EVs is relatively new at a commercial scale and the industry is still dealing with issues of production cost, range and charging speed. In Orkney, the development of EVs is semi mature with the first electric car being installed fairly recently in 2011. However there has been a recent surge in uptake of EVs with ownership of more than 40 cars as of October 2014

EVs require short term timescales for deployment. This involves purchase orders that may typically take six weeks for delivery. Network installation of rapid charging points takes about six months allowing all procedures, whereas home charging depots take up to two months for installation.

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Implementation of electric vehicles in Orkney will fall into two broad categories:

- Personal vehicles
- Public and industrial vehicles

**Assessment of grid balancing benefit**

The implementation of EVs which recharge using renewable electricity offers significant opportunities to achieve carbon reduction benefits as well as provide an optimal solution to the grid issues. The strategy gives consideration to the energy created in Orkney through renewables and the current issues related to curtailment.

By implementing a smart grid connected charging solution, surplus electricity from renewable energy resources can be utilised for charging vehicles.

A new and novel idea is to use electric cars as a means of storing energy in what is termed as 'Vehicle to Grid' scenarios. This will involve communication with the power grid to sell demand response services by either delivering electricity into the grid from the cars’ battery or by using electricity from the grid to charge the battery while throttling their charging rate. Studies are underway to assess this solution for two-way energy transfer between the vehicles and the grid.\(^\text{76}\)

**Size of the grid balancing benefit**

The current consumption of personal vehicles road transport diesel per annum ranges between 60 - 70GWh for the whole of Orkney. The study chose the Nissan LEAF 2012 as a case study model EV which typically consists of 24kWh battery with a range of 175km (0.22kWh/mile), at full charge.\(^\text{77}\) Comparing the energy usage of the model EV with a diesel powered vehicle, it was found that the ratio of electric fuel equivalent to diesel fuel for transport is approximately 1:4.67.

The increase in demand of electricity for charging vehicles will be at night. This will be suitable for the nature of the grid which typically gets curtailed at night when the usage is the least. A smart charging network can effect peak charging times to ensure all generated electricity is utilised.

**Size of the market**

The Scottish Government reports that as at 31 December 2010, there were 15,200 vehicles licensed in Orkney, with a car ownership level of 0.48 per head of population. The table below shows the summary of the types of vehicles registered at 31 December 2010.\(^\text{78}\)

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>9,600</td>
</tr>
<tr>
<td>Other vehicles</td>
<td>2,300</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>600</td>
</tr>
<tr>
<td>Public transport</td>
<td>0</td>
</tr>
<tr>
<td>Goods vehicles</td>
<td>200</td>
</tr>
<tr>
<td>Crown &amp; exempt</td>
<td>2,300</td>
</tr>
<tr>
<td>Other vehicles</td>
<td>200</td>
</tr>
</tbody>
</table>

---

\(^{76}\) [http://www.udel.edu/V2G/](http://www.udel.edu/V2G/)

\(^{77}\) [http://www.nissanusa.com/electric-cars/leaf/charging-range/](http://www.nissanusa.com/electric-cars/leaf/charging-range/)

\(^{78}\) [http://www.scotland.gov.uk/Topics/Statistics/Browse/Transport-Travel/TablesPublications/STS29-Upd-Ch1](http://www.scotland.gov.uk/Topics/Statistics/Browse/Transport-Travel/TablesPublications/STS29-Upd-Ch1)
The current number of EVs in Orkney is 40. There is a potential of reaching 1,000 EVs in Orkney by 2020\textsuperscript{79}. It must be assumed that the data here is not exhaustive as there are many public transport vehicles currently located in Orkney which would need energy to be provided by a potential electric vehicle scheme. The implementation of a council supported county wide electrification of road transport scheme is likely to comprise a mix of police vehicles, health service vehicles and other public service council owned vehicles. There is also an estimated possibility for all vehicles on the island to be electric by 2050 given a compounded annual growth estimate of 12%. From the above, assuming the net replacement of all oil based road transport fuel sources by EVs, the demand for electric energy will go up by 15GWh per annum\textsuperscript{80}.

**Scale of solution relative to Orkney situation**
Standard EV chargers recharge the vehicles battery at 3.3kW. In order to produce a demand of around 5MW this would require around 1500 vehicles to be charging simultaneously. Using the progression scale stated earlier, this number of vehicles is estimated to be reached by 2023.

If we look at the energy consumption for a Nissan Leaf of 0.22kWh/mile and take an average annual mileage for vehicles on Orkney of 5000 miles per year this gives us an annual electrical demand as shown in the table below.

**Table 2.17 Estimate energy requirement based on average annual mileage and market penetration**

<table>
<thead>
<tr>
<th>No of electric cars</th>
<th>Estimated Year achieved</th>
<th>KWh</th>
<th>MWh</th>
<th>GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>2014</td>
<td>44000</td>
<td>44</td>
<td>0.0</td>
</tr>
<tr>
<td>100</td>
<td>2017</td>
<td>110000</td>
<td>110</td>
<td>0.1</td>
</tr>
<tr>
<td>1000</td>
<td>2020</td>
<td>1100000</td>
<td>1100</td>
<td>1.1</td>
</tr>
<tr>
<td>1700</td>
<td>2023</td>
<td>1870000</td>
<td>1870</td>
<td>1.9</td>
</tr>
<tr>
<td>15,200</td>
<td>2050</td>
<td>16720000</td>
<td>16720</td>
<td>16.7</td>
</tr>
</tbody>
</table>

**Scale of solution relative to local constraint situation or household**
EVs are a solution which could be implemented across Orkney, including the north isles which are currently affected by curtailment. This solution of EVs is also suitable for off-grid wind turbines where private owners can charge their vehicles from their own wind turbines.

**How well does it match (temporally and geographically) with the energy generated from renewable sources**
The technology matches the general needs for Orkney’s generation portfolio. Smart grids may further be utilised in conjunction with smart vehicles to charge vehicles in periods of surplus supply as well as studies which are further investigating the possibility of vehicles as grid storage options.

Orkney’s island status makes fuel costs relatively high and the solution of electricity as a replacement are highly favourable and especially for the remote communities.

\textsuperscript{79} Jonathan Porterfield, Eco-Cars Ltd.

\textsuperscript{80} Assumption: All vehicles will be electric by 2050. (30 year plus timespan)
Zone of influence

The implementation of electric vehicles is suitable for both the Orkney mainland as well as for the outer zones as shown in the distribution table below (Table 2.18):

Table 2.18 EV potential impact per zone

<table>
<thead>
<tr>
<th>Zones</th>
<th>Orkney Address Points (Households)</th>
<th>Short term - 2017</th>
<th>Long term - 2035</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Potential Cars</td>
<td>Increase in Demand (kW)</td>
</tr>
<tr>
<td>Core zone - Mainland</td>
<td>7365</td>
<td>66</td>
<td>217</td>
</tr>
<tr>
<td>DNO Zone 1 (Westray, Eday, Rousay, Eglisy, Wyre &amp; Rendall)</td>
<td>916</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>DNO Zone 1a (Costa Birsay, Marwick)</td>
<td>399</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>DNO Zone 2 (Shapinsay)</td>
<td>164</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>DNO Zone 2a (Stronsay)</td>
<td>193</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>DNO Zone 2b (Sanday)</td>
<td>329</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>DNO Zone 3 (Hoy)</td>
<td>358</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>DNO Zone 4</td>
<td>1493</td>
<td>13</td>
<td>44</td>
</tr>
<tr>
<td>Total</td>
<td>100 cars</td>
<td>330kW</td>
<td>111217 cars</td>
</tr>
</tbody>
</table>

Assessment of CO₂ benefit

Electric cars, as well as plug-in hybrids operating in all-electric mode, emit no harmful tailpipe pollutants from the on-board source of power, such as particulates, volatile organic compounds, hydrocarbons, carbon monoxide, ozone, lead, and various oxides of nitrogen. However, it is important to note that there are emissions in the production of electricity used to charge electric vehicles and these vary greatly depending on the source of the electricity based on its long tailpipe composition. In the Orkney scenario, emissions will be based on the premise that in conjunction with DSM implementation, 100% of the electricity used for charging EVs can be obtained directly from renewable energy resources.

Lifecycle carbon emissions from onshore wind energy contribute about 9 - 1 gCO₂/kWh compared to the current UK electricity mix which has an average emissions factor of around 500gCO₂/kWh. Given lifecycle carbon emissions of 9 - 12gCO₂/kWh for wind energy and energy consumption for the Nissan Leaf of 0.212kWh/km this will result in carbon emission of 1.9 - 2.5gCO₂/km. In addition manufacturing of electric vehicles accounts for carbon emissions of between 50 and 90gCO₂/km. Therefore the total lifecycle carbon emissions from an electric vehicle power by wind energy are between 51.9 - 92.5gCO₂/km.

Comparing EVs in Orkney with the emissions for a small new car of 130gCO₂/km, we have a savings of between 37.5 and 78.1gCO₂/km.

81 http://www.fueleconomy.gov/feg/evtech.shtml

82 http://www.nissanusa.com/electric-cars/leaf/

**Potential local impacts**

There are a range of positive impacts for switching to EVs which include the climate change benefits, reduction in noise pollution, and a reduction in use of fossil fuels. Socio-economic impacts include the reduction in fuel despite the initial elevated cost of vehicle expenditure.

**Costs**

The major capital cost is the EV itself. However the prices are coming down with costs starting at as little as £13,000. There are also government subsidies ranging from £2,000 to £5,000 per vehicle offered to offset the upfront premium. Servicing is cheap and available locally and there is presently no road tax. During the lifespan of the vehicle considerable savings could therefore be passed back to the user.

Another cost which is reasonably minimal includes the installation of charging points across the grid which ranges from £3000 - £5000 for a rapid chargers and £500 - £1000 for slow chargers. It is important to note that currently EV owners and leasers are eligible for grant towards the cost of installing home charge points; 75% of the total cost, and capped at £900\(^{84}\).

**Impact on customers**

The implementation of a fully EV transport economy has a generally positive impact to consumers especially considering that for a standard EV (which does around 4miles/kWh), £1.50 - £2.00 (based on economy 7 tariff at 10p/kWh)\(^{85}\) an overnight charge may achieve a mileage of 128km - 160km (80-100 miles) as compared to 130p/litre of fuel with average mileage of 6 - 10 litres per 100km which results in approximately £10 - £16 per 128km - 160km (80 - 100 miles)\(^{86}\).

In addition to that the consumers will be able to:

- Reduce monthly road transport fuel costs by up to 85%
- No road tax charges, tailpipe emissions charges or diesel or petrol costs.
- Improve noiseless driving experience.

**Examples of previous projects or case studies**

- Warwickshire Rural Electric Vehicle Project\(^ {87}\)
- Stratford upon Von Electric Vehicle Project\(^ {88}\)

**Key stakeholders to engage for further development**

Implementation of EVs is a significant opportunity for Orkney to be a model town in the implementation of the project across the UK and Europe. This will lead to tourism opportunities. It is also necessary to engage the local community on the benefits of EVs.

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\(^{85}\) [http://www.ukpower.co.uk/home_energy/economy-7](http://www.ukpower.co.uk/home_energy/economy-7)


\(^{87}\) [http://www.greenwatt.co.uk/downloads/GreenwattWREVlaunchevent.pdf](http://www.greenwatt.co.uk/downloads/GreenwattWREVlaunchevent.pdf)

**Next steps**

Currently, the most critical aspect of EVs in Orkney is the provision of suitable infrastructure in the county to support the use of EVs. This will include the installation of ‘Rapid chargers’ that can recharge an EV to 80% in 25 minutes in the main centres. There is already a rapid charging unit which is ready to go live (Shearers’ garage in Kirkwall)\(^99\).

Successful implementation of EVs will also involve extensive installation of the plug in points throughout the county, including but not limited to homes, public parking lots and public areas of tourist attractions where visitors may occasionally park their vehicles. This should be implemented throughout the mainland and the outer isles.

Further research on newer battery technologies is necessary in ensuring the growth of the industry and practical implementation in communities such as Orkney where the distances between charging points may be relatively high compared to the range currently offered by EVs (40 - 90 miles). Despite this EVs offer enormous hope for managing the surplus curtailed electricity from renewable energy reducing carbon emissions, improving local air quality and limiting noise pollution\(^90\).

The next steps associated with fuel switching include:

- The installation of ‘Rapid chargers’ at key locations to support the use of EVs.
  - extensive installation of the plug in points throughout the county, including but not limited to homes, public parking lots and public areas of tourist attractions where visitors may occasionally park their vehicles. This should be implemented throughout the mainland and the outer isles.
- Extensive installation of ‘Fast Charge’ points throughout the county.
  - the installation of ‘Rapid chargers’ that can recharge an EV to 80% in 25 minutes in the main centres. There is already a rapid charging unit which is ready to go live (Shearers’ garage in Kirkwall)\(^91\). Currently, the most critical aspect of EVs in Orkney is the provision of suitable infrastructure in the county to support the use of EVs.
- Direct engagement with turbine owners to encourage a shift to EVs
- Engagement with national grant awarding bodies to support a shift towards procurement of EVs.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

### Table 2.19 Suitability assessment – Electric vehicles

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
</table>

\(^89\) Jonathan Porterfield, Eco-Cars Ltd.

\(^90\) http://shrinkthatfootprint.com/electric-cars-green#GOxG6VlfJhTphAAv.99

\(^91\) Jonathan Porterfield, Eco-Cars Ltd.
<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicles</td>
<td>Mature</td>
<td>Very short</td>
<td>£5.7 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Electric vehicles are becoming more commonplace in Orkney and with continuing investment in charging infrastructure will continue to increase in numbers. There are also benefits to customers in reducing spend on fuel but CAPEX costs are still high compared to conventional vehicles.</td>
<td>High</td>
</tr>
</tbody>
</table>
2.4.2 Electric Monorails

**Description of the switching option, solution or technology**

Monorails are rail transport systems typically fuelled by grid electricity. The monorails currently in service worldwide are powered by approximately 750 volt electrical motors, which draw electrical energy from electrical distribution equipment attached to their guide way rails.

**Technology maturity and possible timescales for deployment**

The technology of monorails is widely applied around the globe, however it is still limited in use with a lot of challenges in routing logistics as well as competition from cheaper rail systems. This makes it a semi-mature technology. Monorails are typically used in areas of high commuter numbers as well as in transport for tourism. Orkney has a low population and the use of monorails is unlikely to be economically feasible.

Implementation of monorails requires long timescales for deployment owing to extensive planning permissions related to significant increase in land use. This may take more than five years.

**Assessment of grid balancing benefit**

**Size of the grid balancing benefit**

Typical electric monorails consume 1.85kWh per train mile powered by a 750V DC link. At tourist speeds of 10mph this translates to a consumption of 18.5kW and at 50mph this translates to 92.5kW. Demand for high speed transport would peak at 185kW for speeds of 100mph.

**Size of the market**

The market in Orkney is unsuitable for monorail transport given the low population and variable tourism numbers which peak only in the summer months and on specific days.

**How well does it match (temporally and geographically) with the energy generated from renewable sources.**

As the monorail transport requires a direct grid connection for a continuous power supply, this technology does not match well with the variability of renewable energy generation that is characteristic of Orkney’s grid.

**Zone of influence**

A monorail intervention for Orkney would be applied on the mainland alone owing to the increase in costs for routing between islands, as well as the uneconomic cost of isolated location on the islands. The intervention is unlikely to be suitable for specific points of surplus generation.

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93 [http://www.monorails.org/pdfs/ScomiSutra.pdf](http://www.monorails.org/pdfs/ScomiSutra.pdf)
Potential local impacts

Positive impacts include the climate change benefits of reduction in fossil fuel usage as well as carbon emissions reduction. There is also a reduction in noise pollution when compared to conventional transport.

However, the monorail will lead to a significant increase in land use that may lead to disruption of neighbourhoods as well as loss of arable land. There is also extensive infrastructure that would go into construction for monorails that may cause a significant visual impact.

Costs

The CAPEX of monorails typically range from $36.2M to $138.7M per km (average of $83.9M)\textsuperscript{94}, which is equivalent to £22.8M to £87.5M per km (average of £52.9M per km).

As an example a track from Kirkwall to Stromness (~25.3km) would cost between £580 – 2200 million. The average cost from the examples in the reference above would result in a cost of 1300 million per km in order to create a demand that is only a maximum of 185kW.

Impact on customers

The installation of a monorail may lead to lower transport costs for local residents. Various other benefits include a smooth ride quality, as well as higher passenger capacity per trip.

Examples of previous projects or case studies

Chester Zoo Monorail, Chester, UK
UK Safari Skyway, Chessington, UK

Key stakeholders to engage for further development

The tourism authority may be interested in implementation of monorails from the ferry terminals to tourist locations on the islands for peak day operations. Industrial transport may also be deployed on monorails but this is unlikely to be required to any great extent on Orkney.

Next steps

This technology can be ruled out as an option as the costs are extremely high compared to the potential impact it would have on the existing grid. The installation of the monorails is unsuitable for the short distance journeys that are particular for Orkney. This technology is unsuitable for further assessment for now given the population of Orkney and the scattered island geography of the zone.

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

---

### Table 2.20 Suitability assessment – Electric Monorails

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Monorails</td>
<td>Mature</td>
<td>Long</td>
<td>Kirkwall to Stromness (~25.3km) would cost between £580 – 2200 million and consume around 92.5 kW (£6270-23784 million per MW).</td>
<td>Core zone only</td>
<td>This is a high cost long term infrastructure project that would have a minimal impact on the electrical energy demand.</td>
<td>Very Low</td>
</tr>
</tbody>
</table>
2.4.3 Electric Ferries

**Description of the switching option, solution or technology**

Electric ferries rely on an electric motor for propulsion using electrical energy stored in an energy storage device rather than being propelled by a petroleum based combustion motor. There are also hybrid electric ferries which combine traditional diesel power with electric battery power, resulting in reductions in fossil fuel consumption, carbon emissions and other pollutants. By switching from standard diesel powered engines to grid fed electric ferries, Orkney has a great potential in reducing generation lost due to curtailment as well as meeting carbon reduction targets.

In addition to electric engines, there is potential for ‘cold ironing’ which is the process of providing shore-side electrical power to a ship at berth while its main and auxiliary engines are turned off. This is currently in practice with the vessels operating in the inter-isle routes and many of the newer smaller guest vessels which visit the harbours.

**Technology maturity and possible timescales for deployment**

Electric vessels are very new on the market with the earliest commercial scale implementations only being tested within five years. The emergence of better battery technology is however accelerating the potential for this implementation and relatively wide scale adoption should be expected in the next 15 - 20 years for shorter routes.

Once mature, deployment of commissioned electric ferries will take typically short timescales ranging from 0.5 - 2 years owing to the relatively simple infrastructure required for implementation which is mostly charging points for the already existing docks.

**Assessment of grid balancing benefit**

**Size of the grid balancing benefit (MW peak demand/generation shifting)**

The implementation of electric and hybrid electric ferries would be paired with the variable generation profiles of Orkney’s renewable energy resources by implementing night time charging solutions where there is little vessel operation. This will be a critical solution in uptake of surplus power from the grid that would typically be curtailed as well as making it a suitable choice for grid balancing services when there is low demand for electricity in Orkney.

By analysing a short - medium term implementation of the shorter routes of Shapinsay and Rousay, typical ferries which consume an average of 0.5MWh to 1MWh of fuel depending on the engine size and type\textsuperscript{95}. The short routes and low mileage of the battery operated vessels make the technology suitable for both centralised and decentralised application on Orkney’s grid.

\textsuperscript{95} Aquatera, 2014. *Shapinsay Low carbon Transport Study.*
Table 2.21 Alternative Ferry Engines

<table>
<thead>
<tr>
<th>Type</th>
<th>Input</th>
<th>Weight</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Electric Engine</td>
<td>Li-ion Battery 537.04kWh</td>
<td>4882.15 kg</td>
<td>1.79 m³</td>
</tr>
<tr>
<td>Hybrid Electric Diesel Engine (assuming 50% diesel + 50% electric)</td>
<td>Diesel + Li-ion Battery 268.52kWh</td>
<td>PM 200 880 kg + 2441 kg</td>
<td>Diesel Engine + 0.9 m³</td>
</tr>
</tbody>
</table>

Size of the market
The market size is greater than ranges between 0.2MW per terminal and 5MW in total depending on the location of the charging point (the Mainland or outer isles). For a 100% electricity powered vessel, the overall energy demand per one way trip for a typical vessel in Orkney will range from 0.5MWh - 1MWh per trip. The design of the battery bank will be customised for a full charge to be in the range above. A typical charger will be customised to utilise 50-150kW per vessel based on design by rapid charging estimates done by the study.

With regards to cold ironing, there is a potential for plugging in the MV Hamnavoe which berths at Stromness. This may range in demand of power from 5MW - 10MW. Studies are underway by the Orkney Maritime to investigate the possibilities of this implementation. This study also considered a potential of plugging in cruise ships which tour Orkney in summer. This was however found to be a challenge with regards to the varying electrical infrastructure on ships, as well as the large fluctuations of demand that would be placed on the grid considering an increase of 10MW - 15MW per cruise ship. In addition to that, there is the need to synchronise frequencies and voltages with incoming ships which would require further installations of rectifiers and inverters on the shoreside.

How well does it match (temporally and geographically) with the energy generated from renewable sources
Electric ferries can be plugged in for overnight charge. Implementation of fast charging can also be used to minimize charging periods for the ferries which can be done in the return sections. Charging points at ferry terminals can be used in conjunction with storage banks. Electric ferries may also be ideal for providing portable power banks which can be plugged back into the grid to supply energy during low generation.

Zone of influence
An intervention of electric ferries matches well with both Orkney wide generation as well as with generation in the outer zones. The implementation of charging points at various ferry terminals across the isles would be critical for the round trips involved in the transportation of passengers and cargo. These would subsequently assist in moving electrical demand closer to outlying production in DNO zones 1, 2, 3 and 4.

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The zonal influence of electric ferries was investigated in the Table 2.22 below. The assumptions were that diesel engines have an efficiency of 0.3, whereas electric engines have efficiency of 0.9. It was also assumed that the amount of time available for charging was at night which would range from 10-12 hours per vessel depending on the scheduling information. Vessels operating both zone 1 and 2 were distributed equally between the two. We have assumed that the vessels are charged overnight in the North Isles although some of the vessels currently spend the overnight period in Kirkwall.

Table 2.22 Potential zonal distribution of energy required for electric ferries

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Service Route 1</th>
<th>Service Route 2</th>
<th>Zone</th>
<th>Average Current Fuel Usage litres</th>
<th>Electric Equivalent Required (kWh)</th>
<th>Average Uptake Electric Vessels (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV Earl Sigurd</td>
<td>North Isles</td>
<td></td>
<td></td>
<td>657486</td>
<td>2191621</td>
<td>0.50</td>
</tr>
<tr>
<td>MV Earl Thorfinn</td>
<td>North Isles</td>
<td>1,2</td>
<td></td>
<td>692903</td>
<td>2309677</td>
<td>0.53</td>
</tr>
<tr>
<td>MV Eynhallow</td>
<td>Rousay</td>
<td>Egilsay, Wyre</td>
<td>1</td>
<td>156527</td>
<td>521757</td>
<td>0.12</td>
</tr>
<tr>
<td>MV Golden Mariana</td>
<td>Westray</td>
<td>Papa Westray</td>
<td>1</td>
<td>16489</td>
<td>54963</td>
<td>0.01</td>
</tr>
<tr>
<td>MV Graemsay</td>
<td>Graemsay</td>
<td>North Hoy</td>
<td>5</td>
<td>75634</td>
<td>252113</td>
<td>0.06</td>
</tr>
<tr>
<td>MV Hoy Head</td>
<td>South Isles</td>
<td>3</td>
<td></td>
<td>306796</td>
<td>1022653</td>
<td>0.23</td>
</tr>
<tr>
<td>MV Shapinsay</td>
<td>Shapinsay</td>
<td>2</td>
<td></td>
<td>148680</td>
<td>495600</td>
<td>0.11</td>
</tr>
<tr>
<td>MV Thorsoe</td>
<td>Shapinsay</td>
<td>South Isles</td>
<td>2</td>
<td>115151</td>
<td>383838</td>
<td>0.09</td>
</tr>
<tr>
<td>MV Varagen</td>
<td>North Isles</td>
<td>1,2</td>
<td></td>
<td>627420</td>
<td>2091401</td>
<td>0.48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>27970867</td>
<td>9323622</td>
<td><strong>2.13</strong></td>
</tr>
</tbody>
</table>

Based on the above data, the study found the zonal average potential power uptake from the Orkney grid by switching to electric vessels would be as shown Figure 2.20 below.

Figure 2.20 Zonal influence of Fuel Switching – Electric Vessels

Assessment of CO2 benefit
A typical electric vessel installation for the Shapinsay and Rousay routes will reduce about 26.8 tonnes of carbon emissions per annum (based on the diesel displaced by existing ferries which
use approximately 10,000 litres of diesel per annum\(^{99}\). This is given that the electric batteries on the vessels are charged using only renewable energy from the Orkney grid.

**Potential local impacts**

Potential for air quality improvement due to reduced levels of CO\(_2\), NO\(_x\) and SO\(_x\) emissions from fossil fuels.

**Costs**

Based on a purchase cost of £10 - 15 million for a standard ferry and a typical standard retrofit of £1.5 million, the incremental cost of replacing a standard ferry with an electric ferry suitable for the shorter routes within the Orkney Isles is estimated to be £4 - 6 million\(^{100}\). Overall CAPEX will include the cost of shoreline infrastructure such as rapid charging points at the ferry terminals which are relatively inexpensive. This brings the minimum overall cost per MW installed to be estimated at £3 million/MW (for a retrofit) and 8-12 million/MW (for a replacement electric ferry) based on a 0.5MW demand.

**Impact on customers**

The annual spend by customers on ferry costs is likely to decrease significantly due to a reduction in energy costs by operators. Typical fuel savings being gained by ship operators will range between 20% - 30% with the elimination of approximately 10,000 litres of diesel fuel per annum per vessel as compared to the electric conversion.

**Examples of previous projects or case studies**

- Caledonian Maritime Assets (CMAL), hybrid ferries powered by a combination of two lithium-ion battery banks and diesel generators\(^{101}\).
- Sweden’s Green City Ferries “supercharged” electric passenger ferry. 2014 \(^{102}\).

**Key stakeholders to engage for further development**

- Scottish Enterprise & Highlands and Islands Enterprise
- Northlink Ferries
- Orkney Ferries
- Pentland Ferries
- Scottish and Southern Energy
- Orkney Islands Council

**Next steps**

The next steps associated with electric ferries include:

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\(^{99}\) http://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation\%20of\%20CO\(_2\)\%20emissions\%20from\%20fuels.html

\(^{100}\) http://www.scotland.gov.uk/News/Releases/2011/03/18112954

\(^{101}\) http://forargyll.com/2014/06/major-international-award-for-cmals-mv-hallaig/

- Undertake a feasibility study into the potential of replacing existing diesel ferries which are at the end of their commissioning periods with electric ferries or hybrid electric ferries.
- Engagement with other relevant stakeholders that have experience with electric ferries (e.g. Caledonian Maritime Assets Ltd.) to learn from their experiences.
- Engagement with battery technology developers to match the demand of the vessels for longer routes.
- Exploration of the potential for ‘cold ironing’ should be explored with the ferry operators.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.23 Suitability assessment – Electric ferries**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric ferries</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£3-12 million per MW</td>
<td>Zones 1, 1a, 2, 2a and 2b if implement on the north isles ferries, also other zones</td>
<td>Potential to have a beneficial impact on the constrained zones on the North Isles. There is already an OIC aspiration to replace ferries with a number coming to the end of their useful life. They are also one of the highest users of fossil fuels in the county</td>
<td>High</td>
</tr>
</tbody>
</table>
2.4.4 Hydrogen Ferries

*Description of the switching option, solution or technology.*

Hydrogen is a potentially emissions-free alternative fuel that can be produced from the electrolysis of water using electricity from renewable energy resources in Orkney. This hydrogen can subsequently be used for fuelling the ferries joining the islands of Orkney as well as ferries linking the isles to the mainland.

There are three major technologies for implementation of hydrogen fuels for ferries: direct burning, fuel cells and co-fuelling.

Most of the prototype systems in use today are hybrids, using the fuel cell with batteries or super capacitors. Applications are from across the marine section and include Auxiliary Power Units (APUs) for luxury yachts and merchant vessels, powertrains for passenger ferries and tourist boats and powertrains for unmanned underwater vehicles. Direct-burn hydrogen is being considered as an option for smaller seagoing vessels.

Research is under way to make hydrogen vessels practical for widespread use. The implementation of hydrogen fuel for Orkney marine vessels and inter-island linkage routes would be a direct solution to the curtailed generation challenges of the Orkney grid by creating a surplus demand for power for electrolysis at surplus supply.

*Technology maturity and possible timescales for deployment*

Hydrogen vessels are new on the market and as such there are limited off the shelf products. There are a few vessels under operation across Europe and these are still in experimental and testing phases with assessments as to the most efficient technology for either short distance or long distance use. A few vessels that have gone through experimental phases in the last five years are in the early stages of viability and lifetime assessment of operations such as the Zemship (Zero Emissions Ship) FCS Alsterwasser developed by Alster-Toursistik GmbH and launched in 2009\(^\text{103}\). This was the world’s first hydrogen-powered ship. The technology is immature at the moment. However, great strides are being taken in the industry to make it a viable option and widespread commercial vessels are expected in the next 10 - 15 years.

Once mature, deployment of commissioned hydrogen ferries will take typically short timescales ranging from 1 - 3 years. This will involve the design of vessels as well as and supporting hydrogen production infrastructure.

*Assessment of grid balancing benefit*

*Size of the grid balancing benefit (MW peak demand/generation shifting)*

Hydrogen electrolyser and fuel cells can be scaled to meet the marine vessel demand in Orkney to provide sufficient power for the ferries scheduled route. Depending on the routes

between the isles, this can range between 1MW to 5MW that should generate enough hydrogen for a typical refill during peak power production. With the possibility of hydrogen refuelling stations located on both the outer isles and the mainland this technology becomes applicable for both centralised as well as decentralised application on the Orkney grid.

Size of the market

Given a short-medium term implementation, this study will look at options for shorter ferry routes such as the Kirkwall-Shapinsay and Tingwall-Rousay which both average five miles for a single one-way trip. The overall energy demand per one way trip for a typical vessel on these routes in Orkney will range from 0.5MWh to 1MWh depending on the engine and hydrogen technology implementation selected as well as route selected\(^\text{104}\).

The study noted that these crossings take about half an hour to complete leading to a total energy consumption ranging from 1 - 2MWh. The hydrogen energy equivalent that would be suitable for this is trip would be 27.88kg of hydrogen (H\(_2\)) for a fuel cell and 18.6kg for a direct-burn hydrogen engine. For a single trip, the electrolyser would require 1.08 - 1.67MWh to produce enough hydrogen for the vessels above. Typical electrolysers produce 1kg of hydrogen from 60kWh of electricity supply.

<table>
<thead>
<tr>
<th>Type</th>
<th>Input</th>
<th>Weight</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Fuel Cells Engine</td>
<td>27.88kg H(_2)/h</td>
<td>3262.50kg</td>
<td>7.40m(^3)</td>
</tr>
<tr>
<td>Direct Burn Hydrogen</td>
<td>18.64kg H(_2)/trip</td>
<td>1100kg</td>
<td>2.38m(^3)</td>
</tr>
</tbody>
</table>

Scale of solution relative to local constraint situation or household

The energy requirement will vary between the island routes. The study estimated an average energy requirement of 0.2 - 0.4MWh/mile for an hour’s journey. The process of electrolysis offers an efficiency of 41%, the plants can produce 2.05MWh per hour of hydrogen for peak surplus power from the grid. Hydrogen ferries energy efficiency may vary from 20% - 50%. This translates to about 1MWh transport from hydrogen from 5MWh curtailed electricity, which is equivalent to a ratio of 5:1MW of power which should be sufficient for the shorter routes of Shapinsay and Rousay.

How well does it match (temporally and geographically) with the energy generated from renewable sources

The island status of Orkney makes fuel costs relatively high. The solution of renewable electricity for hydrogen production for powering vessels as a replacement for relatively costly diesel is favourable to the outer isles where the most power is curtailed.

Hydrogen ferries are suitable for relatively short ferry routes in Orkney whereas the flexible intermittent production of hydrogen matches the grid constraint issues. This is particularly possible with the customising production of hydrogen from electrolysers to the instances of peak generation and storing this until a ferry docks onto the harbour. The operation of these electrolysers will be paired with the variable generation profiles of Orkney’s renewable resources.

\(^{104}\) Aquatera, 2014. Shapinsay Low carbon Transport Study.

\(^{105}\) Aquatera, 2014. Shapinsay Low carbon Transport Study.
as this technology can easily be ramped up and down to match demand. This will be suitable in mitigating the waste of surplus generation due to curtailment as well as using stored hydrogen without transporting it to further distances which usually results in further losses.

**Zone of influence**

An intervention of hydrogen fuelled ferries matches well with both Orkney wide generation as well as with generation in the outer zones. The implementation of hydrogen production at various ferry terminals across the isles would be critical for the round trips involved in the transportation of passengers and cargo. These would subsequently assist in moving electrical demand closer to outlying production in DNO zones 1, 2, 3 and 4.

The study investigated the distribution of hydrogen ferries based on the data in Table 2.25. The assumptions made in the calculations are: hydrogen fuel cell engines have an efficiency of 0.6; direct-burn engines have an efficiency of 0.4; and the overall efficiency from the grid to the hydrogen vessel would be 0.25. It was also assumed that majority of the hydrogen production would be carried out in the outerlying zones.

**Table 2.25 Potential zonal distribution of energy required for hydrogen ferries**

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Zone</th>
<th>Average Current Fuel Usage litres</th>
<th>Hydrogen Equivalent Required (Fuel Cell) (kWh)</th>
<th>Hydrogen Direct (kWh)</th>
<th>Well to vessel electricity to hydrogen general (kWh)</th>
<th>Average Power Uptake Hydrogen Vessels (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV Earl Sigurd</td>
<td>1,2</td>
<td>657486</td>
<td>3287432</td>
<td>4931148</td>
<td>7889836</td>
<td>0.90</td>
</tr>
<tr>
<td>MV Earl Thorfinn</td>
<td>1,2</td>
<td>692903</td>
<td>3464515</td>
<td>5196772</td>
<td>8314836</td>
<td>0.95</td>
</tr>
<tr>
<td>MV Eynhallow</td>
<td>1</td>
<td>156527</td>
<td>782635</td>
<td>1173952</td>
<td>1878324</td>
<td>0.21</td>
</tr>
<tr>
<td>MV Golden Mariana</td>
<td>1</td>
<td>16489</td>
<td>82445</td>
<td>123667</td>
<td>197868</td>
<td>0.02</td>
</tr>
<tr>
<td>MV Graemsay</td>
<td>5</td>
<td>75634</td>
<td>378170</td>
<td>567255</td>
<td>907608</td>
<td>0.10</td>
</tr>
<tr>
<td>MV Hoy Head</td>
<td>3</td>
<td>306795</td>
<td>1533979</td>
<td>2300968</td>
<td>3681549</td>
<td>0.42</td>
</tr>
<tr>
<td>MV Shapinsay</td>
<td>2</td>
<td>148680</td>
<td>743400</td>
<td>1115100</td>
<td>1784160</td>
<td>0.20</td>
</tr>
<tr>
<td>MV Thorsvoe</td>
<td>2</td>
<td>115151</td>
<td>575756</td>
<td>863634</td>
<td>1381815</td>
<td>0.16</td>
</tr>
<tr>
<td>MV Varagen</td>
<td>1,2</td>
<td>627420</td>
<td>3137101</td>
<td>4705651</td>
<td>7529042</td>
<td>0.86</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>2797086</td>
<td>13985433</td>
<td>20978150</td>
<td>33565040</td>
<td>3.83</td>
</tr>
</tbody>
</table>

The subsequent potential distribution of electricity used in hydrogen production for the Orkney zones was as shown in Figure 2.22 below.
Assessment of CO₂ benefit
According to a report from Det Norske Veritas (DNV), the world’s shipping fleet accounts for 2% of global CO₂ emissions, 4-6% of SOx emissions and 10-15% of NOx emissions. A typical Orkney isles ferry, such as on the Kirkwall-Shapinsay route, emits 28.6 tonnes of CO₂ per annum based on 10,000 litres of diesel fuel consumed. A hydrogen ferry would eliminate 50 - 100% of the CO₂ emissions based on whether it is a hybrid or a pure hydrogen ferry. Hydrogen fuelled vessel technologies are a feasible solution to the challenge of reducing local and regional emissions caused by marine vessels.

Potential local impacts
Air quality improvement due to reduced levels of CO₂, NOx and SOx emissions from fossil fuels.

Costs
New ferry - The estimated cost of a 150 passenger hydrogen ferry for inter-island links will range from £15 - 20 million. Overall CAPEX for hydrogen production and supply for hydrogen ferries will include the cost of shoreline infrastructure such as electrolysers ranging from £1m to £1.4m for a 1MW installation. This brings the minimum overall cost installed to be estimated at £16 million/MW.

Incremental cost - A typical diesel operated ferry (100 - 200 passengers’ capacity) for the short inter-island links would cost from a range of £10 million – £15 million. Similar sized hydrogen ferries (assuming 1MW installation) will range from £15 - £20 million giving an incremental cost of £5 million per ferry. This brings the minimum overall cost installed to be estimated at £5 million/MW.

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106http://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm
107http://www.ika.rwth-aachen.de/r2h/index.php/Main_Page
108http://www.shfca.org.uk/news_article/376/
109http://www.academia.edu/7918824/Feasibility_Study_on_Nuclear_Propulsion_Ship_according_to_Economic_Evaluati
Conversion of an old ferry - Implementations of a smaller scale as well as for hybrid technologies may incur far lesser costs such as the detailed costs for a 200kW power conversion & conditioning system would cost approximately £270,000. Such a system is scalable at approximately £1350/kW, either as one system or modularly, leading to a cost of £1.35 million per MW\textsuperscript{110}.

It is important to note that most of the ferries in Orkney are at the end of their lifespan as shown in Table 2.26 below:

Table 2.26 Orkney Ferries - Year of manufacture

<table>
<thead>
<tr>
<th>Ship</th>
<th>Year of Manufacture</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVs Earl Sigurd</td>
<td>1990</td>
</tr>
<tr>
<td>MV Varagen</td>
<td>1988</td>
</tr>
<tr>
<td>MV Shapinsay</td>
<td>1989</td>
</tr>
<tr>
<td>MV Thorsoe</td>
<td>1991</td>
</tr>
<tr>
<td>MV Golden Mariana</td>
<td>1973</td>
</tr>
<tr>
<td>MV Graemsay</td>
<td>1996</td>
</tr>
<tr>
<td>MV Eynhallow</td>
<td>1987</td>
</tr>
<tr>
<td>MV Hoy Head</td>
<td>1994</td>
</tr>
</tbody>
</table>

Impact on customers
The annual spend by customers on ferry costs is likely to decrease significantly owing to the current high cost of operations based on fuel consumption. This will initially be under subsidies. However, widespread implementation will lead to eventual lower costs of operations. Typical fuel savings being gained by ship operators range between 5% and 12%.

Examples of previous projects or case studies
- Smart H\textsubscript{2} boat - Whale watching boat equipped with fuel cell technology\textsuperscript{111}.
- Zemship (Zero Emissions Ship) FCS Alsterwasser\textsuperscript{112}
- Cheetah marine direct combustion vessel\textsuperscript{113}

Key stakeholders to engage for further development
- Visit Orkney
- Orkney Tourism Group
- Scottish Enterprise and Highlands and Islands Enterprise
- Orkney Ferries
- Pentland Ferries
- Orkney Islands Council
- Nature and wildlife interest groups

\textsuperscript{110} Aquatera, 2014. Shapinsay Low carbon Transport Study.
\textsuperscript{111} http://www.ika.rwth-aachen.de/r2h/index.php/Cost_Scenarios_for_Hydrogen_and_Fuel_Cells
\textsuperscript{112} http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=Zemships_Brochure_EN.pdf
\textsuperscript{113} Aquatera, 2014. Shapinsay Low carbon Transport Study.
**Next steps**

The next steps associated with hydrogen ferries include:

- Undertake a feasibility study into the potential of replacing existing diesel ferries which are at the end of their commissioning periods with hydrogen ferries or hybrid hydrogen ferries.
- Engagement with other relevant stakeholders that have experience with electric ferries (e.g. Caledonian Maritime Assets Ltd.) to learn from their experiences.
- Engagement with fuel cell technology developers to match the demand of the vessels for longer routes.
- Exploration of the potential of conversion of engines to directly burn hydrogen.
**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.27 Suitability assessment – Hydrogen ferries**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen ferries</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£1.4 - 5 million per MW (based on incremental cost on a new ferry or conversion of an old ferry)</td>
<td>Zones 1, 1a, 2, 2a and 2b if implement on the north isles ferries, also other zones</td>
<td>Potential to have a beneficial impact on the constrained zones on the North Isles. There is already an OIC aspiration to replace ferries with a number coming to the end of their useful life. They are also one of the highest users of fossil fuels in the county. Also gives the option to develop a hydrogen economy.</td>
<td>High</td>
</tr>
</tbody>
</table>
2.4.5 Electrification of Heating Systems

Description of the switching option, solution or technology

Orkney has no access to the mains gas grid and it relies on electricity, kerosene or coal to meet electrical and thermal demand. The latter two fuels and significant amounts of the electrical demand come from imported sources.

Approximately 4,800 houses (approximately 46% of total dwellings) in Orkney are in fuel poverty, being defined as those who are forced to spend more than 10% of their income on domestic fuel. Furthermore, 20% of these are also declared as extreme fuel poor; those who spend more than 20% of their income on domestic fuel. Commercial and public buildings rely on these imported fuels and thus subject to increasing prices.

The challenge is to design a fuel switching strategy which lowers the running costs for customers and at the same time increases electrical demand from local sources; minimising the requirement for imported fuels. Fuel switching strategies include:

- Storage heaters and electrification of hot water systems, and
- Heat pump technology (air-to-air, air-to-water and ground source heat pumps).

There are additional benefits to the issue of curtailment if these technologies are implemented as part of a demand side management approach. This is covered in Section 2.3.5.

Technology maturity and possible timescales for deployment

Electric storage heaters are a mature technology with a short-term deployment timescale. Heat pumps may be described as semi-mature. Their uptake in Orkney has been quite rapid over the last few years so the expertise built up is fairly mature in the county although the technology is fairly new. Additional switching control mechanisms and storage heating would be required for the wind to heat solution. This is a fairly low tech solution that could be deployed in a fairly short timescale.

Assessment of grid balancing benefit

Table 2.28 breaks down the use of fuels across the whole of Orkney in 2011; as this represented the year with the most recent complete data set. This has been taken as a good approximation for current fuel consumptions. The table also demonstrates the consumption per year and per sector (domestic, commercial and public).

Table 2.28 Orkney’s Fuel Demand Breakdown

<table>
<thead>
<tr>
<th>Year</th>
<th>Kerosene and gas oil</th>
<th>Coal</th>
<th>Electricity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
<td>GWh</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Domestic</td>
<td>69.23</td>
<td>77.7%</td>
<td>8.39</td>
<td>95%</td>
</tr>
<tr>
<td>Commercial</td>
<td>2.25</td>
<td>2.5%</td>
<td>0.44</td>
<td>5%</td>
</tr>
<tr>
<td>Public</td>
<td>17.65</td>
<td>19.8%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>89.13</td>
<td>35.2%</td>
<td>8.83</td>
<td>3.49%</td>
</tr>
</tbody>
</table>

Domestic and Commercial

Approximately 9.14 tonnes of coal was imported into Orkney in 2013; the majority of which (equivalent to 7.19GWh) is assumed to be for domestic purposes (see Section 3.2.1 of the ‘Orkney-wide energy audit 2014 - Energy Sources and Uses’ Report). The remainder being consumed by the industrial sector (approximately 0.38GWh). Assuming this is used exclusively for space heating, at 70% efficiency for closed coal fires, this is equivalent to 5.03GWh and 0.27GWh, respectively, of electrical heating. Therefore, an additional demand of 5.3GWh could be added to the grid.

Domestic kerosene imports accounted for approximately 69.23GWh per annum in 2011, and in the same year commercial premises accounted for 2.2GWh (Section 2.2.2 of the ‘Orkney-wide energy audit 2014 - Energy Sources and Uses’ Report). Presuming this is again primarily used for space and water heating, at 80% efficiency, this would equate to 55.36GWh and 1.76GWh, respectively, of electric heating. A total of 57.12GWh.

In total, the potential electrical demand produced from fuel switching, from coal and kerosene, in domestic and commercial buildings would equate to approximately 62.42GWh. Averaged over the year this would be 7.16MW across Orkney. If in the short term 10% of these dwellings could be switched to electricity then that would be 0.716MW.

Public

NHS Orkney’s annual electricity consumption is estimated at 1.42GWh. The oil consumption is approximately 4.69GWh, and 0.27GWh for kerosene consumption per year; therefore approximately 4.96GWh in total. Assuming an efficiency of 80% for boilers this is equivalent to 3.97GWh (0.45MW average). For bigger single organisations, which are under the control of the public service, a switching strategy that changes 20% of current fossil fuel use to electric could be envisaged 0.79GWh (0.09MW average over the year).

For the Orkney Islands Council (OIC) the potential available energy for the switching strategy comes from the LPG consumption, which accounts for 1.37GWh/annum and kerosene consumption equates to 13.13GWh/annum. Therefore, approximately 14.5GWh could potentially be converter to electrical use. Assuming an efficiency of 80% this is equivalent to 11.6GWh (1.32MW average over a year). For bigger single organisations that are under the control of the public service a switching strategy that changes 20% of current fossil fuel use to electric could be envisaged 2.32GWh (0.26MW average over the year).

Wind to Heat

In addition where ‘behind the meter’ solutions are appropriate there are additional benefits to the generator if they are replacing energy that they would otherwise have to source from the grid with lower cost energy produced from their own turbine. This option will either be on small household demand scales or larger community buildings (such as schools, care homes, swimming pools etc.). Within the zones that are currently affected by curtailment the housing is fairly sparse, however there are some larger energy users like schools etc. The scale of the turbine needs to be matched to the size of the demand. Larger turbines require bigger transformers to reduce the voltage down to a useable voltage. Therefore this solution will be

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116 http://www.confusedaboutenergy.co.uk/index.php/heating-and-hot-water/heating-units#.VD5O6PldU6w
117 Actual efficiencies may range from ~70% for old boilers to 90% for new ones
118 Actual efficiencies may range from ~70% for old boilers to 90% for new ones
mostly relevant to small turbines supplying energy to individual dwellings. Most generators with small turbines will already be using the energy from their turbines to heat storage heaters and exporting the excess. The additional demand created is therefore likely to be low.

**Zone of Influence**

The zone of influence will generally be restricted to the individual premises that switch to electrical fuel over fossil based fuels. However, with a substantial uptake the collective impacts have the potential to add significant power demand to the grid, and partially alleviate congestion. Figure 2.23 demonstrates the approximate breakdown of the fuels used within Orkney; subdivided into domestic, commercial and public buildings and the significant use of electrical power Orkney already uses. It also aims to illustrate the remaining significant use of kerosene, oil and coal used for heating. This equates to a non-electrical demand of approximately 97.96GWh annually; or an average power demand of 11.18MW across Orkney as a whole.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Number of address points</th>
<th>% of address points</th>
<th>Percentage uptake of non-electrical fuel usage to electrical</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Zone</td>
<td>7,365</td>
<td>66%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>12.86</td>
<td>25.73</td>
<td>38.59</td>
<td>51.46</td>
<td>64.32</td>
</tr>
<tr>
<td>Zone 1</td>
<td>916</td>
<td>8%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>1.60</td>
<td>3.20</td>
<td>4.80</td>
<td>6.40</td>
<td>8.00</td>
</tr>
<tr>
<td>Zone 1a</td>
<td>399</td>
<td>4%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>0.70</td>
<td>1.39</td>
<td>2.09</td>
<td>2.79</td>
<td>3.48</td>
</tr>
<tr>
<td>Zone 2</td>
<td>164</td>
<td>1%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>0.29</td>
<td>0.57</td>
<td>0.86</td>
<td>1.15</td>
<td>1.43</td>
</tr>
<tr>
<td>Zone 2a</td>
<td>193</td>
<td>2%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>0.34</td>
<td>0.67</td>
<td>1.01</td>
<td>1.35</td>
<td>1.69</td>
</tr>
<tr>
<td>Zone 2b</td>
<td>329</td>
<td>3%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>0.57</td>
<td>1.15</td>
<td>1.72</td>
<td>2.30</td>
<td>2.87</td>
</tr>
<tr>
<td>Zone 3</td>
<td>358</td>
<td>3%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>0.63</td>
<td>1.25</td>
<td>1.88</td>
<td>2.50</td>
<td>3.13</td>
</tr>
<tr>
<td>Zone 4</td>
<td>1,493</td>
<td>13%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>2.61</td>
<td>5.22</td>
<td>7.82</td>
<td>10.43</td>
<td>13.04</td>
</tr>
<tr>
<td>Total</td>
<td>11,217</td>
<td>100%</td>
<td>Percentage uptake of non-electrical fuel usage to electrical</td>
<td>19.59</td>
<td>39.18</td>
<td>58.78</td>
<td>78.37</td>
<td>97.96</td>
</tr>
</tbody>
</table>

Table 2.29 Fuel Switching Uptake Scenarios per Zone (GWh)

Table 2.29 represents the increasing power demand on Orkney’s grid under the scenario of replacing current demands of fossil fuels with that of electrical. The percentage breakdown of fuel for all sectors, demonstrated in Figure 2.23 Orkney’s Fuel Demand was applied across each the ANM zones. Without more detailed data, this provided the most accurate available model.

Switching from these fuels to electric heating and power from local wind power will displace the current GHG emissions. This excludes production of GHG during construction. The level of displaced emissions will be directly proportional to the uptake of these fuel switching strategies. An example of this emission displacement is a removal of the CO₂ from Orkney’s coal demand.
Coal imports currently account for approximately 1000 tonnes. At 2479kg\(\text{CO}_2/\text{tonne}\)\textsuperscript{119}, this would mean the removal of the annual production of 2,479 tonnes of \(\text{CO}_2\).

**Potential local impacts**

As highlighted previously, one of the main aims of developing fuel switching strategies is to help reduce fuel poverty in Orkney. It is not necessarily cheaper to source heat from electrical boiler systems, but heat pumps do have the potential to reduce unit costs for heating especially those eligible for the RHI. In addition installation costs are a significant factor for those that are categorised as fuel poor. As previously stated, the challenge is to design a fuel switching strategy which lowers the running costs for customers and at the same time increases electrical demand from local sources; minimising the requirement for imported fuels.

**Costs**

Switching fuel types for premises that are currently heated by fossil fuel will involve either:

- Installing storage heaters which cost in the region of £600 for a 3kW heater (£0.2 million per MW)\textsuperscript{120}.
- Installing a conventional electric heater which cost in the region of £20 - 80 for a 3kW heater (£0.0067 - 0.026 million per MW)
- Installing a heat pump system which costs around £11,000 to £15,000 for a ground source heat pump\textsuperscript{121} and £7,000 to £14,000 for an air source heat pump\textsuperscript{122}. The cost will vary depending on the size but units are approximately £1100-2500 per kW (1.1-2.5 million per MW)\textsuperscript{123}.

Capital costs for wind to heat system are estimated to be low as the only additional equipment are the switching control mechanisms and storage heating. A transformer will also be needed in most situations.

**Examples of previous projects or case studies**

Some examples for 5kW-14kW heat pump installations can be found here:
http://www.geowarmth.co.uk/domestic-case-studies/domestic-air-source-heat-pump-case-studies

Detailed case study for a 14kW air source heat pump (ASHP) installation:
http://www.severnwyre.org.uk/renewables/CaseStudy_CheltASHP.pdf

Commercial ground source heat pump case study:
http://www.heatpumps.danfoss.co.uk/Content/b8048034-f647-41c1-acb6-bc0559bdf61_MNU17542255_SIT459.html

Three case studies for commercial air source heat pump installations:

\textsuperscript{120} http://www.confusedaboutenergy.co.uk/index.php/heating-and-hot-water/heating-units#VD5O6PldU6w
\textsuperscript{121} http://www.energysavingtrust.org.uk/scotland/Generating-energy/Choosing-a-renewable-technology/Ground-source-heat-pumps
\textsuperscript{122} http://www.energysavingtrust.org.uk/scotland/Generating-energy/Choosing-a-renewable-technology/Air-source-heat-pumps
\textsuperscript{123} http://www.yougen.co.uk/renewable-energy/Heat+Pumps/
The Orkney Schools Investment Programme has installed 13 heat pumps in four locations: Kirkwall Grammar School, Stromness Primary School, Pickaquoy Leisure Centre and Papdale Hall of Residence. More details can be found here: http://higheduexpo2013.mmsite.co.uk/wp-content/uploads/2013/08/Orkney-Schools-GI-Case-Study.pdf

Wind to heat system have been trialled in Orkney previously:
http://westraydevelopmenttrust.co.uk/hofn/

**Key stakeholders to engage for further development**

- Home owners and privately rented accommodation owners
- Orkney Housing Association Limited (OHAL)
- Local businesses
- Orkney Islands Council
- NHS
- Regional rid operator (Scottish and Southern Energy)
- Small turbine operators (<50kW)
- Energy Savings Trust
- Carbon Trust

**Next steps**

The next steps associated with hydrogen ferries include:

- Analysis of EST home analytics data to look at the heating systems used in the current housing stock to give a better estimate of the market.
- Determine and publicise impact on customers looking at installation costs versus running costs of different heating systems including RHI payments for applicable technologies.
- Investigate the likely demand created by switching fuels for small turbine owners who are currently using non electrical heating for hot water and space heating.
- Economic analysis cost of wind to heat versus selling to the grid and electric heating.
- Engage with national and local grant awarding bodies to establish grant for local residents encouraging shift from fossil fuel to electric for installation costs
- Engagement with SSEPD or other operator to establish opportunity for Orkney specific tariff to encourage a shift from fossil fuel to electric.
Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.30 Suitability assessment – Electrification of Heating Systems

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrification of heating systems</td>
<td>Standard technology solution</td>
<td>Short</td>
<td>£0.2 million per MW for storage heaters</td>
<td>All zones depending on uptake.</td>
<td>Mature technology and short term solution but should be complement with demand side management in order to maximise the impact on local energy generation and potentially also benefit customers.</td>
<td>Very high</td>
</tr>
<tr>
<td>Mature</td>
<td>Short</td>
<td>£1.1-2.5 million per MW for heat pumps</td>
<td></td>
<td></td>
<td></td>
<td>High</td>
</tr>
</tbody>
</table>
2.4.6 District Heating

*Description of the switching option, solution or technology*

A district heating scheme comprises a network of insulated pipes used to deliver heat, in the form of hot water or steam, from the point of generation to an end user. The system is used for distributing heat generated in a centralised location for residential and commercial heating requirements such as space heating and water heating. District heating plants can provide higher efficiencies and better pollution control than distributed boilers.

The strategy in Orkney involves the implementation of a large scale wind-to-district heat scheme where the surplus energy generated from the wind turbines in respective zones is used to electrically heat water which then supplies the heating needs for the respective zone.

District heating has the potential to play a significant role in reducing fuel poverty levels in Orkney while providing hot water for domestic and commercial/industrial demands as well as providing an increase in electrical demand that would prevent the curtailment of generation.

*Technology maturity and possible timescales for deployment*

District heating is a mature technology which is currently being implemented in many developed countries, most notably Norway, Finland and Iceland. Electric steam and hot water boilers are a safe and mature technology that produce low or high pressure steam or hot water for commercial and industrial processes.

The timescales for deployment of a district heating scheme is over five years and in Orkney will only be assessed for long term solutions owing to the extensive infrastructure layout and planning prerequisites that come with implementation of such a network.

*Assessment of grid balancing benefit*

The implementation of the district heating from wind will be viable across the core zone owing to the slightly larger population and in more concentrated areas like Kirkwall and Stromness. A 2.5 - 5MW peak district heating scheme can effectively take up a portion of the excess electricity that would normally be curtailed off the network.

District heating is particularly attractive as it gives a means of temporarily storing excess energy from renewable sources, and then making it available for distribution through the network at peak demands.

The operation of the district heating scheme can be paired with variable generation profiles such as wind, as it can easily be ramped up and down to match demand. This makes it a suitable choice for grid balancing services.

Due to energy losses to the environment, the energy in a district heating scheme may not be stored for a long time. However, it may provide the possibility of short term hour to hour demand matching and smoothing of demand profile in line with generation spikes.
The inherent scale of the scheme may make it unsuitable as a solution for curtailment issues among the outer island communities.

Currently, this is not directly applicable to Orkney, which operates without a district heating grid. A possible implementation will involve wide-scale infrastructure layout that would cost more than the electricity usage itself.

**Size of the grid balancing benefit**

The district heating schemes may be designed for smaller developments which can effectively take up the higher demand ranging from 1MW to 5MW in Orkney’s new housing schemes slated for the next five years. This can be effective in providing a grid balance when the generation exceeds the export outlay from the grid.

**Size of the market and Scale of solution relative to Orkney situation**

Currently the core zone is likely to be the only zone which has a feasible potential of the implementation of a district heating scheme. This is owing largely to the fact that the development of a district heating scheme would only be suited to the relatively more densely populated towns in Orkney which are Kirkwall, Stromness and any other possible new housing developments.

Taking the above into consideration, for about 1600 residential and 100 commercial consumers, estimates of providing heated water for a scheme for the two locations may result in an annual uptake of 100 - 180GWh of electricity to be generated and subsequently 22,000 tonnes CO₂ savings.

**How well does it match (temporally and geographically) with the energy generated from renewable sources**

Typically, electricity from wind generation rises when the wind simultaneously causes a chill factor causing an increase in heating demand. The use of a district heating scheme allows for the matching of variable renewable energy generation profiles from the wind and wave resources available in Orkney.

There is also a high level of fuel poverty on the islands which can be partly mitigated by the use of a district heating scheme for the more densely populated regions. This matches well with the needs of the island.

District heating is less attractive for areas with low population densities, as the investment per household is considerably higher. Also it is less attractive in areas of many small buildings (e.g. detached houses) than in areas with larger buildings (e.g. blocks of flats), because each connection to a single family house is quite expensive.

Essentially the implementation of district heating schemes should be considered for all new large scale housing developments to maximise on economies of scale.
Potential zone of influence

District heating is only economically applicable for regions with closely packed high population. For this reason, a potential district heating scheme in Orkney would potentially be for only Stromness and Kirkwall and any new large-scale housing developments planned by the Council.

The zones 1 - 4 may will be better served by individual wind to heat boilers rather than a district wide implementation. The following table illustrates the potential energy usage by domestic heating for the zones and the district heating intervention that may be applied with the assumption of the delivery of heating for 2000 residential consumers and 200 commercial consumers in a potential five year analysis.

Table 2.31 District Heating by Zone

<table>
<thead>
<tr>
<th>Zone</th>
<th>Address points</th>
<th>Current Estimated Annual Household Heating Energy Usage (MWh based on oil and coal)</th>
<th>Medium-term District Heating Implementation supply MWh (2000 address points)</th>
<th>Estimated average peak power demand (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>1315</td>
<td>468.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 2</td>
<td>686</td>
<td>244.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 3</td>
<td>358</td>
<td>127.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 4</td>
<td>1493</td>
<td>532.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Zone</td>
<td>7365</td>
<td>2,626.37</td>
<td>468.28</td>
<td>4.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>11217</td>
<td>4,000.00</td>
<td>713.20</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Potential local impacts

If implemented as part of a new build development any impacts associated the installation of the distribution network will not be significantly more than the construction impacts of the buildings themselves. Retrofit of existing buildings is likely be more disruptive depending on the where the distribution network needs to be installed, especially if roads need to be dug up.

Costs

CAPEX

Previous studies on district heating schemes in Orkney put costs for a 2MW district heating scheme in Stromness at £2.2-2.7 million (£1.1-1.35 million/MW) depending on the technology used. Distribution networks make up the main costs associated to district heating projects and are estimated at £8,625 per detached/semi-detached dwelling and 19 - 24m pipe lengths. Orkney Islands Council and Orkney Housing Association Limited (OHAL) could consider this strategy for new buildings application planning since the distribution network installation costs could be considerably reduced.

It is imperative that district heating is considered a long-term investment owing to the high initial investment on infrastructure.

OPEX and revenue streams:

- The Non-Domestic Renewable Heat Incentive pays for renewable heat units that supplies large-scale industrial heating to small community heating projects (including district heating

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schemes). The non-domestic RHI will pay 7.2p/kWh for ground source heat pumps (GSHPs).

Impact on customers

Benefits to the Orkney community include avoided costs of energy, through the use of surplus and curtailed wind energy, and reduced investment in individual household or building heating equipment. This may reach savings of up to £100 - £200 per annum. District heating will help to alleviate the local fuel poverty crisis in Orkney.

Consumers will initially have to pay a large amount of capital for new installations but their heating costs will significantly reduce in the long run with an estimated payback period of 7 - 10 years.

Potential environmental and socio-economic impacts

Potential environmental impact are negligible where a district heating scheme is implemented alongside new build housing schemes as the groundworks for the distribution system can be installed at the same time the houses are being built. Retrofit of existing buildings is more difficult for this reason.

Assessment of CO2 benefit

Energy losses are typically low for district heating schemes (80 - 95% distribution network efficient) owing to technical interventions on leakages and monitoring systems. The study found that by switching to a wind powered district heating scheme, the carbon emissions from Orkney Islands would reduce by 0.294kg/CO2/kWh, as shown in the table below. This will include the emissions saved from the transportation of fuel from the mainland as well as the actual use of fuel within the households.

<table>
<thead>
<tr>
<th>Heat Supply Options</th>
<th>kg/CO2/kWh per unit of energy</th>
<th>Energy average loss %</th>
<th>CO2 Average loss kg</th>
<th>kg/CO2/kWh Energy delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity from Renewables Wind</td>
<td>0.010</td>
<td>10</td>
<td>0.001</td>
<td>0.007</td>
</tr>
<tr>
<td>Coal heat</td>
<td>0.301</td>
<td>NA</td>
<td>NA</td>
<td>0.301</td>
</tr>
</tbody>
</table>

Currently most households in Orkney use a mix of individually powered coal, gas and oil heaters with a top up of convectional heaters. A district heating scheme will eliminate an average emissions factor of around 500gCO2/kWh.

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**Examples of previous projects or case studies**

- Lerwick District Heating Scheme:  
  http://www.sheap-ltd.co.uk/
- Wick District Heating Scheme:  

**Key stakeholders to engage for further development**

- Orkney Islands Council in planning for new households
- Orkney Housing Association Limited (OHAL)
- Installers

**Next steps**

The next steps associated with district heating include:

- Data gathering and consultation with key stakeholders
- Feasibility studies for potential new developments.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.33 Suitability assessment – District heating**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>District heating</td>
<td>Medium</td>
<td>Long</td>
<td>£1.1-1.3 million per MW</td>
<td>Likely to be core zone only</td>
<td>Less attractive for areas with low population densities and in areas with detached houses due to cost of expenses. Should be considered for all new large scale housing developments to maximise on economies of scale.</td>
<td>Low</td>
</tr>
</tbody>
</table>
2.5 Analysis of Selected Options – Increasing Demand

The study identified the following solutions in increasing demand: heated growing spaces, crop drying, heated anaerobic digesters, ammonia as a fuel, fertiliser production, refrigeration and cooling, heating for industrial processes, hot and cold water leisure facilities, and desalination. The solutions can be applied behind the meter whereas others are applicable more widely as shown in the table below.

<table>
<thead>
<tr>
<th>Table 2.34 Increasing demand solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Behind the meter</strong></td>
</tr>
<tr>
<td>Heated growing spaces</td>
</tr>
<tr>
<td>Heated anaerobic digesters</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

2.5.1 Heated Growing Spaces

**Description of the switching option, solution or technology**

Heated and artificially lit polytunnels could be used in Orkney to grow food that would not normally grow in these latitudes and to extend the growing season.

As most of Orkney is already used for agriculture there is sufficient farmland available on most islands.

**Technology maturity and possible timescales for deployment**

Polytunnels are a mature technology but would need to be insulated to prevent heat loss and would need to be study enough to stand up to the Orkney weather. Additional switching control mechanisms and storage heating would be required but these kinds of technology have already been implemented in buildings. This is a fairly low tech solution that could be deployed in a fairly short timescale.

**Assessment of grid balancing benefit**

The energy requirement will vary between crops but taking an average energy requirement of ~1kWh/m²/day\(^{128}\), which is equivalent to 170kW for an acre on average over a year.

This is a scalable solution from one polytunnel to industrial scale horticulture such as in the Netherlands.

This solution could be deployed anywhere on Orkney where there is sufficient land for growing but is best used either close to turbines where the curtailed energy could be used directly or in a curtailed zone where increasing demand would have a beneficial effect on the curtailment of the turbine.


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Seasonal variability of wind matches well with need for heat and light over the winter months.

**Potential local impacts**

Polytunnels have a low visual impact associated with the landscape assuming they are dispersed and located near dwellings, larger and larger groupings of commercial style polytunnels would have larger visual impact.

Positive socio-economic impact. Depending on how the enterprise is set up this could either be a commercial venture or a community project where rather than selling the produce the space is rented to people in the community to grow their own food or a combination of the two.

**Costs**

£25,000 to £70,000 per acre\(^{129}\) using about 170kW per acre. Assuming that six acres might be achievable this is equivalent to 1MW at a cost of about £300,000.

**Examples of previous projects or case studies**

Eday is in the process of putting up heated polytunnels to use some of the curtailed wind energy. Heated polytunnels have also been trialled in the past on Benbecula.

**Key stakeholders to engage for further development**

- Agricultural & food production sectors
- Community Energy Scotland
- Community Development Trusts
- Voluntary Action Orkney
- Orkney Farmer Market Association
- Public sector (procurement of food for schools/hospitals etc)
- National Farmers Union
- Local shops

**Next steps**

The next steps associated with heated growing spaces include:

- Discussions with Eday and Benbecula projects to discuss opportunities and pitfalls.
- Engagement with grant awarding organisations i.e. Rural Payments and Inspectorate Directorate in relation to agricultural land.
- Engage with local shops to establish demand and willingness to participate and purchase locally grown produce.
- Research cooperative style food supply business to support number of small farms supplying local shops.

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.35 Suitability assessment – Heated growing spaces

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heated growing spaces</td>
<td>Mature</td>
<td>Very short</td>
<td>£0.3 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Low cost, scalable, short term solution using mature technology</td>
<td>Very high</td>
</tr>
</tbody>
</table>
2.5.2 Crop Drying

*Description of the switching option, solution or technology*

Grain drying is one of the most energy consuming processes on farms. If the grain is wet as it can be after a rainy harvesting period, drying can consume as much energy as all field works together.

Interest has been shown locally in a drying solution whereby crop quality is improved by utilising constrained energy. In Orkney, the harvest of barley covers an area of approximately 4,900 hectares130. Cereal crops in Scotland have average moisture content in the range of 18-22%.

The best solution is to dry the crops immediately after harvesting to preserve the nutrients in the crop and reduce the weight for transporting. Dried grass has a much higher market value and the potential to replace bought in concentrates.

Dried barley also has a higher market value and could be an alternative to the addition of chemicals such as Propcorn, Alkagrain and Maxammon. Nonetheless, the urea crop treatments are restricted to low moisture grain which could be achieved through any of the proposed methods131.

Air-source heat pumps could be considered as well in the crop drying process to provide a controllable drying environment (temperature and humidity).

The paper, ‘Crop Drying with Heat Pumps’132, looked at the energy required to dry 4000 bushels (87 tonnes133) of grain which used two different methods: A heat pump system used 14.6kW and 30.7kW for the resistance heat-fan system.

*Technology maturity and possible timescales for deployment*

Pneumatic dryers and spray dryers are mature technologies which use standard industrial equipment (e.g. feeder, motor, burner, drying chamber, cyclone, exhaust fan, pumps). Short-time timescale is estimated for the deployment of this technology, considering existing equipment and industry in Orkney. Heat pumps are a mature technology with a short-term deployment timescale.

*Assessment of grid balancing benefit*

**Size of the grid balancing benefit (MW peak demand/generation shifting)**
Crop drying has the ability of utilising up to 300kW of surplus curtailed electricity during harvesting seasons in Orkney. This is outlined below.

**Size of the market**
A typical gas burner uses 0.02 gallons LPG along with an electric fan that uses approximately 0.01kWh electricity per bushel per percentage point134. The energy content of LPG is 91,420

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130 http://www.scotland.gov.uk/Publications/2014/06/3709/downloads
131 http://www.kwforagesystems.ie/News/47/Options-for-storage-of-grain-on-farm
133 http://www.smallgrains.org/springwh/June03/weights/weights.htm
Btu/gal, which is converted to 26.8kWh/gal. This was calculated to a requirement of 0.563kWh of LPG per bushel per percentage point\textsuperscript{135}. The estimated overall energy requirement was estimated to 0.546kWh per bushel per percentage point.

One hectare of farm produces an average of 0.0167 tonnes of grains. For Orkney, given a total 4,900 hectares, this will result in 81.7 tonnes or 3752.4 bushels of grain harvest. Orkney grain has a 22% water content that is typically reduced to 16% under standard crop drying procedures. This results in a corresponding reduction of 6 percentage points.

Given the above, the total energy for drying all the crops in Orkney is estimated to be 12MWh - 14MWh per harvest. The total time for drying all the bushels is 37-40 hours per annum given a small scale crop dryer (100 bushels per hour) suitable for Orkney. The resulting power required for the drying process ranges from approximately 0.3MW to 0.4MW.

**Scale of solution relative to Orkney situation.**
Typical crop-drying installations would only operate through the harvest season in Orkney which goes on for 1-2 months per annum. Actual crop drying would entail a total of 37-40 hours, given a crop dryer of 100 bushels per hour. The short-medium term implementations would involve relatively small scale installations ranging in size from 0.1MW for domestic crop dryers to 0.3MW-0.4MW for small scale dryers.

**Scale of solution relative to local constraint situation or household.**
The local grid constraint in Orkney would offer much more power than can be taken up by large scale implementation of crop drying facilities owing to the very low energy consumption of 0.01kWh of crop drying processes as well as the relatively low produce of dryable crops as well as the infrequency of the application.

**How well does it match (temporally and geographically) with the energy generated from renewable sources (mostly wind in the case of Orkney)**
Crop drying is a very seasonal activity with very short timescales of application in Orkney. It however matches well with the variability of wind and marine generation as the drying technology can be ramped up or down to match changes in power supply from the grid.

Geographically, the ability of the technology to be feasibly applied to the outer isles with existing farming activities makes it a good match for spreading consumption to the outer zones.

**Zone of influence**
The crop drying process is widely applicable on the mainland as well as across the outer isles. This is due to the widespread farming of cereal crops in the county. More data is needed on the crops grown and animal feed imported (as the vast majority of crops currently grow are for animal feed) for each of the DNO zones in order to assess the size of the grid balancing benefit in each zone.

**Assessment of CO\textsubscript{2} benefit.**
Crop drying using curtailed wind sourced electricity as compared to standard conventional electricity will lead to a reduction of 893.21 gCO\textsubscript{2}/kWh of carbon emissions.

\textsuperscript{134} http://www.bbe.umn.edu/prod/groups/cfans/@pub/@cfans/@bbe/documents/asset/cfans_asset_290081.pdf
\textsuperscript{135} http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf
**Potential local impacts**

Crop drying has no major environmental impacts apart from those based on standard construction of drying silos.

**Costs**

Grain drying represents a major cost for arable farmers with fossil fuel costs of the order of £10,000 for a 200 ha arable farm (£1/m²). The total cost for the barley harvested on Orkney would therefore be about £245,000.

Given that the power required for the drying process ranges from approximately 0.3MW to 0.4MW the cost per MW is therefore around £0.8 million per MW.

The Non-Domestic Renewable Heat Incentive pays 2.5p/kWh for air-source heat pump units that supply large-scale industrial heating\(^\text{136}\).

**Examples of previous projects or case studies**

Heat pump assisted drying of agricultural produce:
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3550864/

Air-source heat pump system for drying application:

George Leslie, locally has been working at improving a previous drier design to build a prototype solution.

**Key stakeholders to engage for further development**

- Agronomy Institute: has access to crop drying and storage facilities\(^\text{137}\).
- National Farmers Union
- Rural Payment and Inspectorate Directorate
- Local farmers
- Local Authority (OIC)

**Next steps**

The next steps associated with crop drying are:

- Undertaking a literature review and market research to ascertain whether crop/grass driers can offer a real economic opportunity across Orkney.
- Engaging with the farming sector to establish level of interest and practicalities
- Undertaking feasibility study for Orkney

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.


\(^{137}\) http://www.hilinks.uhi.ac.uk/files/BSB_Agronomy.pdf
### Table 2.36 Suitability assessment – Crop drying

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop drying</td>
<td>Mature</td>
<td>Short</td>
<td>£0.8 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Seasonal activity which would have little impact on the year round electrical energy demand.</td>
<td>Low</td>
</tr>
</tbody>
</table>
2.5.3 Heated Anaerobic Digesters

Description of the switching option, solution or technology

Anaerobic digestion of farm wastes have been trialled in Orkney\textsuperscript{138}. These systems do not run optimally in these latitudes because the temperature is often too cold. Surplus energy from curtailed wind turbines could be used to heat these systems to make the biogas production more efficient.

Technology maturity and possible timescales for deployment

Anaerobic digestion is a fairly mature technology. Additional switching control mechanisms and storage heating would be required but these kinds of technology have already been implemented in buildings.

This is a relatively low tech solution that could theoretically be deployed in a short timescale but the potential problem that would slow down the uptake of this solution would be that most farms are not designed to collect slurry. Getting farmers on board and retrofitting farm buildings to be able to collect and process the slurry for use in the anaerobic digester would take time.

Assessment of grid balancing benefit

An example 660 m\textsuperscript{3} digester used 32kWh per day for a 20 tonne per day digester which is equivalent of about 25kW\textsuperscript{139}. Orkney has about 85,000 cattle\textsuperscript{140}. Assuming a round figure of about 9.6 tonnes of slurry per cow per year, if housed for 50\% of the year\textsuperscript{141}, the cows in Orkney would produce 816,000 tonnes of slurry per year (4,471 tonnes per day). This equates to 224 digesters of the size given above using 5.6MW of power.

There are no operational anaerobic digesters on Orkney however future anaerobic digesters could use this technology and could be deployed anywhere on Orkney where there is an anaerobic digester but, as with heated polytunnels, is best used either close to turbines where the curtailed energy could be used directly or in a curtailed zone where increasing demand would have a beneficial effect on the curtailment of the turbine.

Seasonal variability of wind matches well with need for heat over the winter months.

More data on the number and size of farms is needed to assess the grid balancing benefit of this option in each DNO zone. As there are no currently operational anaerobic digesters the rate on implementation of this option is likely to be slow.

\textsuperscript{138} http://crisenergy.co.uk/
\textsuperscript{139} http://www.afbini.gov.uk/afbi-ad-hillsborough-27-months-june-11.pdf
\textsuperscript{141}http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,17978&_dad=portal&_schema=PORTAL
Potential local impacts

Any effect from anaerobic digesters will be minimal as the digester will usually be built with an existing farm setting.

Costs

The capital cost of an anaerobic digester plant per cubic meter of digesting capacity tends to sit in the range of £400 to £750/m$^3$, averaging somewhere slightly over £500/m$^3$ (different systems and feedstock will vary their costs enormously). Smaller plants, using residues from 100 cows or 1,000 pigs, with a digester of 150 m$^3$ costing £60,000 to £70,000. Larger plants can benefit from greater economies of scale making the likely return on capital more positive. For a digester of the size of the example used (of 660 m$^3$) a cost of £330,000 is estimated per digester (£13 million per MW).

Examples of previous projects or case studies

Stornoway bio-digester

Key stakeholders to engage for further development

- Agriculture sector
- OIC waste services
- National Farmers Union (NFU)
- Rural Payments and Inspectorate Directorate (RPID)

Next steps

The next steps associated with heated anaerobic digesters include:
- Engagement with the agriculture sector
- Feasibility study to assess capital costs of retrofit and benefits to farmers.
- Discussion with operators of anaerobic digesters and past tests of anaerobic digesters within Orkney to understand practicalities in Orkney environment

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.37 Suitability assessment – Heated anaerobic digesters

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heated anaerobic digesters</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£13 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>High cost per MW along with the fact that there are no operational anaerobic digesters in Orkney mean this is an option that would take a long time to implement.</td>
<td>Low</td>
</tr>
</tbody>
</table>
2.5.4 Ammonia as a fuel

Description of the switching option, solution or technology

Currently, the majority of Ammonia is produced by the Haber-Bosch (H-B) process. This dates back to the 1920s and importantly helped to serve the agricultural sector the means to meet growing demands for greater crop production. The process itself centres on passing nitrogen and hydrogen over iron catalysts at high temperatures and pressure. Once cooled this then forms liquid ammonia\(^{142}\). Generally, the hydrogen used within this process is sourced from reforming natural gas (methane). Ammonia sourced from fossils fuels is referred to as ‘Brown Ammonia’. For every metric tonne of ammonia produced in this method 1.8 metric tonnes of CO\(_2\) enters the atmosphere\(^{143}\).

Ammonia, like hydrogen, can be produced from power generated from renewable sources and offers an alternative method of energy storage. This is known as ‘Green Ammonia’; as no carbon emissions are associated with the process.

The synthesis of ‘green’ ammonia involves combining hydrogen, obtained by electrolysis of water, and nitrogen, which is relatively easily removed from air. The chemical reaction is shown below.

\[
3H_2 + N_2 \rightleftharpoons 2NH_3 + 92.5kJ
\]

This has been a known means of producing ammonia for many years, but has been overshadowed by the convenience and relatively low prices of natural gas. In recent years the desire to minimise further impacts of the natural environment and reduce the dependency on ever expensive fuels has come to the fore making this method a promising solution for ammonia production as well a method for storing energy from renewable sources.

Ammonia can be produced, through the Solid State Ammonia Synthesis (SSAS) method. This process mainly differs the H-B process as it doesn’t require the use of separate electrolysis stage in order to produce hydrogen. A proton conducting membrane is heated to 550°C. Water is vapourised on one side of the membrane; where it dissociates into oxygen and protons. On the other side of the membrane nitrogen from the atmosphere is applied. A voltage drives the protons through to the nitrogen side to produce ammonia (NH\(_3\))\(^{144}\).

Figure 2.28 illustrates the basis behind production, storage and use of ‘green’ ammonia. In the same regard as the use of hydrogen energy.

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\(^{142}\) http://www.chemguide.co.uk/physical/equilibria/haber.html

\(^{143}\) http://www.hydroworld.com/articles/hr/print/volume-28/issue-7/articles/renewable-fuels-manufacturing.html

\(^{144}\) http://nhthree.com/ssas.html
storage, separate technologies are required to produce the ammonia and to then utilise it. There are a number of ways in which ammonia can then be used as a power source: 1) as a carrier for hydrogen; 2) used as a fuel for special combustion engines; 3) as a fuel for Solid Oxide Fuel Cells (SOFC), to produce electricity; and 4) as a fertiliser, or ingredient in nitrogen based fertilisers (Section 2.5.5)

The idea of using both ammonia and hydrogen, as fuel sources, have been around for many years, but hydrogen has received a much greater backing to date. However, utilising ammonia as an energy storage medium has a number of clear advantages:

- Liquid ammonia contains 50% more hydrogen, by volume, than can be found in cryogenic liquid hydrogen.\(^{145}\)
- Hydrogen is scentless, whereas ammonia is easily detected due to its pungent smell. The concentration at which people can naturally detect ammonia differs, but generally this with 5-50 parts per million (ppm). Above 100 ppm this concentration become uncomfortable to be exposed to, and greater than 300 ppm can begin to become hazardous.\(^{146}\)
- Ammonia is not as flammable as hydrogen within air and has a higher and narrower explosive limit. Ammonia requires a 15 – 28% mix to air, whereas hydrogen requires a 4% - 75% mix with air to become explosive.\(^{147}\)
- Ammonia is already produced and transported internationally. The majority of this is for agriculture. Ammonia is currently rated at the 2nd most produced chemical product. An international infrastructure already exists to transport is as well. In the USA alone over 3,000 miles of pipelines are dedicated to this purpose.\(^{148}\)
- Ammonia is easier to store and requires a significantly lower capital investment to do so. Ammonia can be stored as a liquid at 150 PSI. This only requires a regular steal tank. Hydrogen is required to be stored 5000-10,000 PSI; which requires compressed air tanks often made from carbon fibre.\(^{149}\)

**Technology maturity and possible timescales for deployment**

Ammonia has been produced as a fertiliser for roughly 100 years. Understandably there is already a significant infrastructure around the world producing and shipping ammonia for this purpose. ‘Green’ Ammonia has been produced from hydro plants for years, but its production from wind and solar technologies is still at the demonstration phase.

A company called ‘Proton Ventures’, situated in the Netherlands, has developed a plan for “Mini Ammonia Units” capable of drawing power from wind turbines and a water supply in order to produce ammonia to required quantities. A concept drawing of this can be seen in Figure 2.29. Designs can be scalable

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\(^{145}\) http://www.hydroworld.com/articles/hr/print/volume-28/issue-7/articles/renewable-fuels-manufacturing.html

\(^{146}\) http://www.epa.gov/oem/docs/chem/ammonia.pdf

\(^{147}\) https://www.mathesongas.com/pdfs/products/Lower-(LEL)-&-Upper-(UEL)-Explosive-Limits-.pdf


\(^{149}\) http://www.eoearth.org/view/article/153626/

\(^{150}\) http://www.hydroworld.com/articles/hr/print/volume-28/issue-7/articles/renewable-fuels-manufacturing.html
in order to produce between 3 kg (5kWe) and one tonne of ammonia per day (11.5MWe)\(^{151}\).

With respect to deployment timescale. This mini ammonia unit has a modular construction and transportable, thus construction could be estimated to be in the region of two years.

**Assessment of grid balancing benefit**

Ammonia has the potential to provide services to multiple sectors, and ammonia from renewable sources has the potential to reduce the carbon footprint of agriculture, heating, transport and power generation.

Due to economies of scale it is most likely that a facility producing and storing ammonia would be centralised in a location away from built up areas. Utilising ammonia as an energy storage method would require a corresponding market pull for the ammonia it produces; be it locally or within a transportable range.

The size of any grid balancing effect depends on the size of the ammonium production facility which will in turn be sized best fit the scale of curtailed energy in each location. The production of ammonia through a SSAS plants can be expected to operate at an efficiency of 7,500kWh/tonne NH\(_3\) (70%) \(^{152}\). This equates to 0.133 tonnes NH\(_3\)/MWh. Figures have also suggest that a 1MW SSAS facility could produce 3.2 tonnes of ammonia per day\(^{153}\).

**Potential Impacts**

<table>
<thead>
<tr>
<th>Potential impact</th>
<th>Lifecycle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG Emissions</td>
<td>Construction</td>
<td>There will be GHG emissions attached to the facility during construction. This will come from the manufacturing and transportation of the components, and the construction of the facility itself. The scale of these emissions will be proportional to the scale of the facility chosen. It was not possible to obtain GHG emission figures for the construction of H-B or SSAS technologies.</td>
</tr>
<tr>
<td>Operation</td>
<td>There are no GHG emissions directly produced from the manufacture of ammonia from renewable energy; as water, air and renewable energy will be the only feedstock. This method has the potential to offset ammonia produced from natural gas, which can have CO(_2) emissions as high as 1.8 kgCO(_2)/kgNH(_3) (^{154}). Any risk of Nitrogen Oxides (NO(_x)) can be neutralised by sacrificing a small portion of the ammonia in order to make the NO(_x) benign(^{155}).</td>
<td></td>
</tr>
<tr>
<td>Land Use</td>
<td>Construction</td>
<td>The direct use of land will depend upon the scale of intervention required and whether deployment is within a centralised or distributed configuration. The land use requirement for synthesising ammonia was not obtainable. But fuel cells can be expected to require roughly 16.7 m(^2)/MW(^{156}). It is not expected that land use during construction will be any greater than the final facility; with exception to any temporary constructions (i.e. access roads, etc.).</td>
</tr>
<tr>
<td>Operation</td>
<td>The use on land during operation will be dependent upon the scale of intervention deployed. There should be minimal indirect use of land as water, air and grid electricity are the only feedstock. However, additional land will need to be cordonned</td>
<td></td>
</tr>
</tbody>
</table>

\(^{151}\) [http://content.media.cebit.de/media/000140/0140373eng.pdf](http://content.media.cebit.de/media/000140/0140373eng.pdf)  
\(^{152}\) [http://nh3fuelassociation.org/2013/01/01/nhthree-ssas/](http://nh3fuelassociation.org/2013/01/01/nhthree-ssas/)  
<table>
<thead>
<tr>
<th>Potential impact</th>
<th>Lifecycle</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Use</td>
<td>Construction</td>
<td>No significant impacts on water use should be expected during construction.</td>
</tr>
<tr>
<td></td>
<td>Operation</td>
<td>The production of ammonia requires significant quantities of water in the electrolysis stage. This can be sourced from sea water and does not need to draw from fresh water sources. In order to produce one tonne of ammonia 420 gallons of water is required(^\text{157}). Significant quantities of water are required in order to act as a cooling medium for the electrolyser(^\text{158}). Exact figures of water requirements for this purpose were not available.</td>
</tr>
<tr>
<td>Socio-economic Impacts:</td>
<td>Construction and Operation</td>
<td>Producing an ammonia industry on Orkney would create a market that does not already exist. This would create employment. As with hydrogen, there is a perceived health and safety risk in using ammonia has an energy storage method. This would need to be addressed in order to maximise uptake.</td>
</tr>
</tbody>
</table>

**Costs**

**Capital Cost:** As this technology is still developing it was not possible to obtain the price ranges for a facility of this nature. However, estimates are in the range of £400k-930/MW, with storage tanks suitable for storing ammonia cost roughly £40/MWh\(^\text{159}\) (£320/tonne).

**Operation and Maintenance:** It was not possible to obtain accurate estimates for operational and maintenance costs for the H-B or SSAS technologies. However, annual OPEX is approximately £217/kW for stationary fuel cells\(^\text{160}\).

**Revenue:** As in a similar manner to other energy storage options for Orkney, the revenue potential will be bound within the additional generating potential for currently curtailed turbine operators. However, similar to hydrogen production, ammonia is a product that can also be sold in order to produce additional revenue. The approximate market value of ammonia is £650 per tonne and estimates put the production cost of ammonia at roughly £330 per tonne\(^\text{161}\).

**Examples of previous projects or case studies**

Examples of previous projects include:
- A megawatt scale SSAS facility in Juneau, Alaska\(^\text{162}\).
- A SSAS facility for the Royal Silver Company, in Bolivia, in order to produce ammonia for their silver smelting process\(^\text{163}\).
- In the 20th century there were believed to have been roughly 10 plants producing ammonia from hydro stations internationally. The majority of which later closed due to competition from cheaper ammonia sourced from natural gas\(^\text{164}\).

\(^{157}\) http://www.hydroworld.com/articles/hr/print/volume-28/issue-7/articles/renewable-fuels-manufacturing.html
\(^{158}\) http://phys.org/news111926048.html
\(^{161}\) http://www.evaluationsonline.org.uk/evaluations/Documents.do?action=download&id=677&ui=basic
\(^{162}\) http://www.akenergyauthority.org/EmergingEnergyTechnologyFund/EETF-AC_Stage1_Review/Abstracts/001.pdf
\(^{163}\) http://lehthree.com/ssas.html
\(^{164}\) http://www.hydroworld.com/articles/hr/print/volume-28/issue-7/articles/renewable-fuels-manufacturing.html
**Key stakeholders to engage for further development**

Local turbine operators
Region grid operator (SSE)
Local council (Orkney Islands Council).
Product manufacturers/ operators

**Next steps**

The next steps associated with ammonia production includes:
- Feasibility studies and data gathering in order to evaluate the capacity on the grid for ammonia production; local capacity for storage; local demand for ammonia based products; suitable location on Orkney for a facility of this nature; and capacity.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.38 Suitability assessment – Ammonia as a fuel**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia as a fuel</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£0.4-0.9 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>The possibility of using ammonia as a fuel has several advantage over other low carbon fuel options such as hydrogen but is still very much at the demonstration stage, so should be highlighted as an option for future investigation.</td>
<td>Medium</td>
</tr>
</tbody>
</table>
### 2.5.5 Fertilisers Production

**Description of the switching option, solution or technology**

In terms of embodied energy, the major component in agricultural fertiliser production is ammonia (\( \text{NH}_3 \))\(^{165} \). Ammonium nitrate, ammonium sulphate, ammonium phosphate and urea-based fertilisers are commonly used in agriculture for their rich nitrogen content and all are obtained using ammonia as feedstock.

Traditionally the Haber-Bosch (H-B) process is utilised to produce ammonia from hydrogen and nitrogen. But Solid State Ammonia Synthesis (SSAS) is an emerging technique also producing ammonia but with greater efficiency. The production of ammonia is detailed further in Section 2.5.4 (ammonia energy storage).

Ammonia, produced through the H-B or SSAS process can be directly applied to crops as a liquid fertiliser. In this form the ammonia will vaporise on contact with the soil and must be placed 10 to 20 cm below the surface. This is done using tractor drawn knives and sharks. The vapourised ammonia quickly reacts with the water within the soil to produce ammonium (\( \text{NH}_4 \)). Liquid ammonia can also be produced through diluting ammonia with water; producing aqua ammonia; however this reduces the nitrogen content from 82% to 22%. This does not require the same injection into the soil\(^{166} \). Much of the ammonia produced today is reacted through the Ostwald process to produce Nitric Acid (\( \text{HNO}_3 \)). This is then used to produce the nitrogen based fertilisers mentioned previously\(^{167} \).

**Technology maturity and possible timescales for deployment**

The production of ammonia from hydrogen and nitrogen is a mature process, which has been practised for almost a century; mainly through the H-B process. Ammonia has been used as a fertiliser ever since the H-B process was created in the 1920’s\(^{168} \). Ammonia is the 2nd most mass produced chemical around the world. There already exists a mass production, transportation and distribution network centred on the agricultural sector. For examples, in the USA alone there exists in excess of 3000 miles of pipeline dedicated to the distribution of ammonia\(^{169} \).

There are a number of suppliers for hydrogen and nitrogen systems within the UK:

- Hydrogen electrolyser: ITM Power and Hydrogenics
- Nitrogen production: Dundee Nitrogen Company and In House Gas (Manufacturing) Ltd\(^{170} \)

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165 http://scifun.chem.wisc.edu/chemweek/pdf/Agricultural_Fertilizers.pdf  
167 http://www.chm.bris.ac.uk/motm/ammonia/Ammonia%20MOTM.htm  
168 http://people.idsia.ch/~juergen/haberbosch.html  
169 http://content.media.cebit.de/media/000140/0140373eng.pdf  
**Assessment of grid balancing benefit**

A Dutch company (Proton Ventures) produces an ammonia producing facility that can be scaled within the kW to MW scale; producing up to a tonne of ammonia per day from renewable energy, water and air\(^{171}\).

Approximately, 30,000 tonnes of fertiliser are imported annually to Orkney\(^{172}\). Calculations within Section 3.6.1 of the ‘Orkney-wide energy audit 2014 - Energy Sources and Uses’ Report have estimated that the nitrogen content of these imports equates to approximately 5,908 tonnes. Referring to the chemical reaction in Section 2.5.4 above the nitrogen content in the fertiliser imported to Orkney is equivalent to 7,174 tonnes of ammonia. Assuming that the SSAS process represents the most efficient method of synthesising ammonia and requires 8,000kWh per tonne of ammonia\(^{173}\), then this quantity of ammonia would require 57.39GWh of electrical power per year.

If fertilizer can be produced more cheaply than conventional mean using curtailed electricity the limiting factor for production will be the amount of curtailed energy as the fertilizer is fairly easy to transport. Therefore any analysis on the impact of this option of grid balancing within each of the DNO zones will require analysis of curtailment patterns within each zone.

Figure 2.30 demonstrates the significant savings in CO\(_2\) emissions as a result of producing green ammonia for fertiliser in comparison to using brown ammonia for the same purpose\(^{174}\). It demonstrates that sourcing the hydrogen, within the ammonia based fertiliser, from renewable sources can significantly reduce GHG emissions. The remaining emissions are a product of the application of the fertiliser using conventional fossil fuel powered machinery (i.e. tractors, etc.).

**Potential local impacts**

There are a number of environmental and health consideration with operating with ammonia\(^{175}\) however ammonia is a commonly handled and transported chemical in the worldwide and using existing measures ammonia can be handled safely.

**Costs**

Available data on predicted capital expenditure (CAPEX) varies between sources, but can be expected to be in the range of £400-930/MW\(^{176}\); however, facilities on a small scale can be

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\(^{171}\) [http://content.media.cebit.de/media/000140/0140373eng.pdf](http://content.media.cebit.de/media/000140/0140373eng.pdf)

\(^{172}\) Pers. comm. (Birsay Farmers Ltd)


\(^{175}\) [http://www.ndhealth.gov/epr/resources/anhydrous.htm](http://www.ndhealth.gov/epr/resources/anhydrous.htm)
expected to be higher. Another source details the SSAS technology at approximately £125,000 per tonne per day, and £475,000 per tonne per day for the H-B technology\textsuperscript{177}. Storage can be in the region of £40/MWh\textsuperscript{178}. The level of capital expenditure required for storage would be highly dependable on seasonal demand for ammonia. However, storage for 7,174 tonnes of ammonia, at 4,318 Wh/kg, would cost roughly £1.24 million. A report produced for the Scottish Enterprise investigated the feasibility of producing ammonia for fertiliser on a farm from wind power. The report predicts a 15-30 year payback period\textsuperscript{179}.

It was not possible to obtain a figure to represent predicted operational and maintenance costs for this solution.

The previously mentioned report prepared for Scottish Enterprise also predicted that under certain scenarios it was possible for unit costs for ammonia fertiliser to be a low as £330 per tonne. Where the market price is roughly £600 per tonne\textsuperscript{180}. This provides significant potential to sell excess ammonia to other farmers.

\textbf{Examples of previous projects or case studies}

The University of Minnesota has been trialling the production of ammonia fertiliser for local farmers; sold through a local co-operative\textsuperscript{181}.

A study prepared for Scottish Enterprise, by Ricardo-AEA, titled ‘Rural Study into Ammonia-Hydrogen Production’ investigates the feasibility of siting ammonia fertiliser production facilities on farms within Scotland. It states this method of energy storage as perfectly feasible and lists the potential for addition revenue to farmers. The report continues to highlight the potential for future roll-out of this concept to Orkney\textsuperscript{182}.

\textbf{Key stakeholders to engage for further development}

- Local council (OIC)
- Orkney farming community
- Engineering companies
- Local turbine operators
- Region grid operator (SSE)
- NFU
- RPID
- Northlink/Pentland Ferries, Streamline shipping

\textbf{Next steps}

The next steps associated with fertiliser production include:

\begin{itemize}
  \item 176 \url{http://leightyfoundation.org/w/wp-content/uploads/ammonia_08-29sept-msp-podium.pdf}
  \item 177 \url{http://www.claverton-energy.com/wordpress/wp-content/files/NHthree_SSAS_Oct2007_Final.pdf}
  \item 178 \url{http://leightyfoundation.org/w/wp-content/uploads/ammonia_08-29sept-msp-podium.pdf}
  \item 179 \url{http://www.evaluationsonline.org.uk/evaluations/Documents.do?action=download&id=677&ui=basic.}
  \item 180 \url{http://www.evaluationsonline.org.uk/evaluations/Documents.do?action=download&id=677&ui=basic.}
  \item 181 \url{http://renewables.morris.umn.edu/wind/ammonia/}
  \item 182 \url{http://www.evaluationsonline.org.uk/evaluations/Documents.do?action=download&id=677&ui=basic.}
\end{itemize}
• Undertake a feasibility study into the cost effective production of locally produced ammonia fertilisers.
• Identification of applicable locations to determine possible sites of operation that minimise impact.
• Determining the seasonal demand for ammonia based fertilisers could highlight the level of production and storage that would be required.
• Gathering data on the use of ammonia based fertilisers of neighbouring regions to Orkney.
• Data on the variety of fertilisers used within Orkney.

**Suitability of option to current Orkney situation**

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

**Table 2.39 Suitability assessment – Fertilizer production**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer production</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£0.4-0.9 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>As a commodity that is already imported into Orkney, fertiliser production is a solution that could have far reaching benefits and make a large impact on electricity use.</td>
<td>High</td>
</tr>
</tbody>
</table>
2.5.6 Refrigeration and Cooling for Industrial Processes

Several industries utilise refrigeration, freezing and cooling processes in their production which caters to a significant use of electricity and subsequent increase in cost of production and carbon footprint.

Description of the switching option, solution or technology

The following table (Table 2.42) outlines the most suitable industries that apply generally high usage of electrical refrigeration that may be suitable for the Orkney scenario.

<table>
<thead>
<tr>
<th>Energy Rank</th>
<th>Sector</th>
<th>Electricity costs as a percentage of GVA</th>
<th>Size</th>
<th>Estimated energy consumption (MWh/year/industrial unit)</th>
<th>Suitability Rank in Orkney</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gas compression and liquidation</td>
<td>36</td>
<td>M</td>
<td>4,000-15,000</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Data Centre</td>
<td>33</td>
<td>S</td>
<td>5,000-12,000</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Refrigeration for food</td>
<td>8</td>
<td>S</td>
<td>3,000-6,000</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2.40 Industry examples with high refrigeration demands

Of the three switching solution examined in the study, the optimal solution was identified as the relocation of existing data centres and allocation of new ones in the county of Orkney in order to capitalise on the surplus generation which is currently being curtailed.

Data centres worldwide pose a new and quickly growing industry whose electricity consumption currently represents between 1.5% and 2% of total global energy use. According to InfoTech, 50% of energy used in data centres is for cooling\(^{183}\). This is growing at a rate of 12% a year and represents a huge carbon footprint and a major draw on scarce generation capacity\(^{184}\). The integration of data centres to Orkney will doubly meet the UK’s reduction of carbon emissions targets by allocating the industry away from coal sourced electricity as well as utilising the full potential of renewable energy resources on the island.

Technology maturity and possible timescales for deployment

The data centre technologies being analysed for Orkney is a mature technology. There are currently several green grid data centres being implemented in other parts of the UK, such as in Shetland. The utilisation of the surplus electricity is critical for the inevitable 12% per annum growth in the industry.

Time scales

Typical data centre installations may take up to two years for construction. However, given renting or hiring of existing buildings, this period may be shortened to under a year. There are


no large industrial permits required for data centres which will lead to quicker planning permissions.

**Size of the grid balancing benefit**
The grid shifting capability of this technology is quite suitable for the Orkney scenario owing to the predesign of battery coupled data centres that are always connected to standby UPS (Uninterruptable Power Supply) systems. By integrating data centre UPS and battery storage, data centres may be an optimal solution for up-taking the curtailed power from the surplus wind resource.

**Assessment of grid balancing benefit**
Typical data centres include backup storage battery installations which may deal with a possible variations in supply offered by the wind energy offered by the grid. There may be a challenge in the seasonal variation as the data centres are expected to be operational at peak loads throughout the year. This may present a challenge and may require extensive importation of electricity from the south.

Heat that is generated from the data centre could in turn be utilised in other schemes such as a potential district heating scheme. Typically for a 5MW installation a heat recovery of 500kW to 1MW should be expected.

**Size of the market**
There is a growing need of data centres worldwide and the potential for this to be utilised by the Orkney grid is scalable to capitalise on the wind energy. Orkney on its own does not have a great need for a data centre but this is a global in situ export. Orkney has almost 10,000 homes which are mostly serviced by a standard data link. This may be improved on by a data centre on the island.

**Scale of solution relative to Orkney situation**
The power and heat load density is determined by planned server density. Average loads in the most recent data centres range from 1,000 to 1,500 W/m², often with additional high density provisions to accommodate cabinets with cooling loads of 10kW or more.

**Scale of solution relative to local constraint situation or household**
The cost of ICT infrastructure will make it unfavourable to pursue this to the local constraint zone.

**How well does it match (temporally and geographically) with the energy generated from renewable sources**
This solution matches really well for peak load demands for the energy generated from the renewable energy resources but only if implemented in tandem with a storage solution. The scalability of the project may mean that the energy deficit may increase in future leading to a net importation to match the growth of the industry.

Geographically, aside from the additional cost of the ICT infrastructure, Orkney’s relatively low temperatures ranging from -1 to 15°C annually are very conducive to the efficiency of cooling of data centres.

**Zone of influence**
In order to capitalise on economies of scale mean that a data centres project is more likely to be designed as a singular installation than a distributed. Any potential project aimed at increasing electricity demand to meet needs to take into account current and potential future curtailed energy availability and further data analysis of curtailment patterns would be required to assess the applicability of this option to each of the DNO zones.

**Assessment of CO₂ benefit**

The carbon emissions will be vastly reduced as compared to data centres installed on the mainland which typically cause emissions of up to 200g CO₂/m³ (185). Also the adding of renewable power to the mix can help reduce a data centre’s overall emissions by 98% when combined with other strategies such as the capture of heat and design of equipment186.

**Potential local impact**

There are generally no unique local impacts in implementation of data centres except the ones related to standard construction procedures. There is little environmental impact on the creation of data centres for the utilisation of the current surplus of energy in the grid. Consumers are likely to have an additional benefit of the creation of high speed data access that may boost communication for the islands and the grid systems.

**Costs**

A typical data centre will cost £9,000-11,000/m² 187. Taking an average demand of 1.5kW/m² and additional cooling cabinets of 10kW/m², it is estimated that the cost of the data centre that will be sufficient to cater to the surplus supply offered by Orkney’s grid, which will be approximately 435 m². This translates to a cost of £4.269 million for a 5MW peak load data centre (0.85 million per MW).

This however does not represent further infrastructure required to support the final design. There will be an included cost of ICT infrastructure that comprises the cost of fibre optic cabling or satellite transmission and data centre modules or equipment. This may represent an additional £14 million pounds for a fibre optic link to the island 188. It is estimated that the total cost of this project may range from £20 million - £40 million depending on the scale of implementation.

**Examples of previous projects or case studies**

4MW Black Hill Industrial Estate and Port Business Park Alchemy Plus Data Centre in Shetland189.

185 http://www.apcmedia.com/salestools/DBOY-7EVHLH/DBOY-7EVHLH_R0_EN.pdf
186 https://energy.stanford.edu/news/data-centers-can-slash-co2-emissions-88-or-more#sthash.6kRUDWXg.dpuf
188 http://www.shetland.gov.uk/news-advice/ShetlandIslandsCouncil-InformationBulletins-TelecomCableInfrastructure.asp
Key stakeholders to engage for further development

- Consultation with Internet Service Providers would be critical in design of suitable data centres.
  - IT businesses

Next steps

The next steps associated with refrigeration and cooling for industrial use include:

- Identification of and careful consultation with potential investors
- A push for a more stable fibre optic link to support the industry.

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.41 Suitability assessment – Refrigeration and Cooling for Industrial Use

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigeration and Cooling for Industrial Use</td>
<td>Mature</td>
<td>Medium</td>
<td>£0.85 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>This would have a significant impact on electricity demand but the timescales and willingness of companies to relocate is hard to define and the planning implications could delay this option considerably.</td>
<td>Medium</td>
</tr>
</tbody>
</table>
2.5.7 Heating for Industrial Processes

Description of the switching option, solution or technology

Process heat is the supply of thermal energy during the manufacture of basic materials and goods. Process heating is highly energy intensive, accounting for a significant percentage (10% to 15%) of total production costs in industries: such as the direct smelting of metallurgical substances; the indirect or peripheral heating components used in the chemical industry, such as boilers, fired heaters, heated reactors, distillation columns, calciners, dryers and heat exchangers.

![Figure 2.32 Smelting Plant](image)

The strategy analysed in this study involves the increase in electrical demand from Orkney's grid through strategic Demand Side Response (DSR) involving fine tuning industrial heating processes. This would involve both the expansion of current industries and the relocation of currently existing ones on the mainland, that are dependent on electricity sourced from conventional fuel. Through industrial automation, key electrical processes can be timed to take place during moments of peak power production.

The study revealed the following energy intensive industries, with a high percentage of gross value added by their respective electrical costs, which may be suitable for relocation to Orkney. These are illustrated in the table below:

**Table 2.42 Energy Intensive Industries**

<table>
<thead>
<tr>
<th>Energy Rank</th>
<th>Sector</th>
<th>Electricity costs as a percentage of GVA (Gross Value Added)</th>
<th>Typical Potential Large Scale Implementation Consumption (MW)</th>
<th>Technical potential for DSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fertilisers and nitrogen compounds</td>
<td>36</td>
<td>2.5-10</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>Industrial gases</td>
<td>31</td>
<td>3-8</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>Inorganic basic chemicals</td>
<td>30</td>
<td>0.5-5</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>Non-wovens and articles made from nonwovens</td>
<td>22</td>
<td>0.5-4</td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>Household and sanitary goods</td>
<td>20</td>
<td>0.5-10</td>
<td>Moderate</td>
</tr>
<tr>
<td>6</td>
<td>Preparation and spinning of worsted-type fibres</td>
<td>18</td>
<td>1-5</td>
<td>Moderate</td>
</tr>
<tr>
<td>7</td>
<td>Clays and kaolin</td>
<td>17</td>
<td>0.1-1</td>
<td>Moderate</td>
</tr>
<tr>
<td>8</td>
<td>Hollow glass</td>
<td>15</td>
<td>0.5-5</td>
<td>Moderate</td>
</tr>
<tr>
<td>9</td>
<td>Refineries</td>
<td>14</td>
<td>1-5</td>
<td>Limited</td>
</tr>
<tr>
<td>10</td>
<td>Man-made fibres and threads</td>
<td>14</td>
<td>0.5-5</td>
<td>Moderate</td>
</tr>
<tr>
<td>11</td>
<td>Ship building and repair</td>
<td>14</td>
<td>0.5-10</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Technology maturity and possible timescales for deployment

The premise for using renewable energy to provide energy for energy intensive industries, is not new. Hydro power plants were built in the 50s to provide power for aluminium smelters but have since closed due to completion from cheaper electricity in places such as Iceland.

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191 [https://www.census.gov/econ/overview/ma0400.html](https://www.census.gov/econ/overview/ma0400.html)
The industries being analysed for Orkney are already currently being undertaken in other parts of the UK.

Most of the industrial applications are proven technologies. The implementation of DSR is technically semi-mature and is only in the last five years being actively applied across the national grid. Demand response design for Orkney will involve modification from standard DSR procedures which are set out to reduce the electrical load, whereas in Orkney it will be detailed to increase the load on the grid.

For large scale industrial applications in Table 2.42 above, there are various planning permissions required. Some of which include environmental impact assessment for production of inorganic basic chemicals and refineries. In addition to that, there is extensive infrastructure required for the implementation which may is likely to lead to the medium-long term terms of deployment typically ranging from 3-5 years such as in the case of production of industrial gases as well as fertilisers and nitrogen.

For small and medium scale industrial applications such as the production of clays and kaolin as well as the textile industry will typically require very short time-scales for deployment ranging from 0.5-2 years.

**Assessment of grid balancing benefit**

By strategic design, the industries investigated in Table 2.42 will be designed to operate at a delayed response to match the surplus supply of electricity from Orkney’s grid. This will involve the application of smart grid ANM based automation in the DSR design. This will be highly suitable for processes which can handle variations in power supply and whose manufacture is typically not time dependent. These are mainly distillation columns, boilers and heat exchangers.

**Size of the grid balancing benefit**

The strategic design and automation of processes to match ANM commands can typically shift the whole demand for heating processes to the periods when the electrical supply is the highest. This will range from 100kW for small scale industries, such as textile production, clays and kaolins, to an average of 5MW for fertilisers and nitrogen compounds.

The operation of process heating can be paired with variable generation profiles as it can easily be ramped up and down to match demand. Implementation of the industrial processes can be split into various stages with each stage being assigned different DSR profiles that would match the production from the ANM from Orkney grid. This makes it a suitable choice for grid balancing services.

Any potential project aimed at increasing electricity demand to meet needs to take into account current and potential future curtailed energy availability.

**Size of the market**

The potential for local demand of products from each of the process heating industries in Table 2.42 is quite small owing to the relatively low population on the island. However, there are opportunities for export that may, upon further study, prove competitive as compared to similar industries in other locations such as the production of hydrogen based fertilisers and nitrogen compounds where minimal raw materials are sourced from other locations.
Scale of solution relative to Orkney situation
The industrial development of the heat intensive industries to the island will generally be scalable to the whole of Orkney ranging from 500kW to 5MW peak curtailed production. For this reason a distributed approach would be as technologically advantageous as a centralised approach.

Scale of solution relative to local constraint situation or household
The small scale industries such as clays and kaolin have the potential for being located on a small holding entrepreneurial bases on the outer isles. These will typically be supported by the community wind farms ranging from peak demands of 10kW - 500kW.

How well does it match (temporally and geographically) with the energy generated from renewable sources
Generally, the inclusion of heating industries provides a suitable match for the variable renewable energy resources generated from the island, provided a properly designed all-encompassing DSR system to take up the surplus grid energy. But when it comes to variability of wind energy, there may be challenges in executing processes which require consistent power in their production. This can be mitigated by separating various stages of production and allocating various stages to different ANM profiles.

Production of fertilisers and nitrogen compounds can be integrated with the hydrogen production options which would doubly act as an energy storage solution, as well as a raw product for the two industries.

Zone of influence
The relocation of the industries to the local community can be implemented to either match Orkney-wide distribution of energy or locally in the zone where there is surplus generation. For some of the industries this will be suitably on the core zone rather than on the outer isles owing to the logistics of transport and distribution and the economies of scale of a larger plant as compared to distributed ones.

Any potential project aimed at increasing electricity demand to meet needs to take into account current and potential future curtailed energy availability and further data analysis of curtailment patterns would be required to assess the applicability of this option to each of the DNO zones.

Assessment of CO2 impact
The carbon emissions will vary greatly depending on the industry investigated. The greenhouse gases: CO₂(carbon dioxide), CH₄ (methane) and NOx (nitrogen oxides) are produced during the manufacture of nitrogen fertiliser whose effects can be integrated into the equivalent amount of CO₂. This is about 2kg of CO₂ equivalent for each kilogramme of ammonium nitrate resulting in a significant increase in emissions for this industry.

For each industrial application, considering only the manufacturing process, will present a reduction of emissions from 490-820 gCO₂eq/kWh to 11 gCO₂eq/kWh due to the utilisation of the renewable energy resources on the island; compared to conventional energy powered stations or diesel generator backed generation shifting as is the case with most of the DSR
applied elsewhere\textsuperscript{192}. Factoring conventional energy powered transport to and from the island will cause an increase in carbon emissions of about 0.0403 kg of CO\textsubscript{2} per tonne-mile\textsuperscript{193}. This will result in additional carbon emissions of 1.249 kg of CO\textsubscript{2} per tonne of raw materials and finished products based on shipping across the shortest channel from the mainland\textsuperscript{194}.

**Potential local impacts**

There is general potential of air pollution from the location of the manufacturing industries in Table 2.42 which may include Nitrous and Sulphite oxides.

Potential for water pollution of from industrial waste production. May affect the marine biodiversity of the region and subsequently local fishing industry.

**Impact on customers**

The study identified the following socio-economic benefits of relocating process heating industries in Orkney:

- Increased income from economic benefits of local industrial products.
- Creation of employment.
- Availability of cheaper locally produced goods.

**Costs**

The study estimated that the typical costs for large scale implementation of the industries above range from £500,000 per MW for household and sanitary goods to £5 million per MW required for industries such as fertilisers and nitrogen production. For smaller production kits, the take up of electricity may range from less than £20,000 per 100kW to £100,000 per 100kW of demand installed.

Generally, the utilisation of process industries as a curtailment option has a range of medium to large costs per MW consumed. Financial assessment of relocation of a majority of the industries shows a significant increase in operational costs due to the nature of external sourcing of raw materials from other regions and sourcing the finished products back to the mainland. Geographically, relocation of industries which are dependent on externally sourced raw materials may prove to be uneconomically feasible due to the cost of transportation.

An option to counter the high cost of energy in transport would be to use renewable energy powered electric ferries. These will vary on an industry to industry approach and will require extensive logistical and economic analysis to minimise energy used in transport.

**Examples of previous projects or case studies\textsuperscript{195}**

- Energy Demand Research Project (EDRP) Project Trials (2007-2010)
- Norway EFFLOCOM Trial (2001-2004)
- Northern Ireland Powershift trial (2003-2004)

\textsuperscript{192}http://report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_annex-iii.pdf

\textsuperscript{193}http://fluglaerm.de/hamburg/klima.htm

\textsuperscript{194}Scrabster-Stromness shipping route.

Key stakeholders to engage for further development

There is a potential in reviving some of the more traditional industries such as clay and textile industries and new manufacturing such as glass production. This will require engagement with the local artisans who may either benefit or be adversely affected by a potential competitive market in the industry. It will also be necessary to fit facilities with DSR systems to manage their power usage to match the peak surplus supply from the grid.

It is also important to involve the local distribution network as the industrial processes which are uninterruptible may cause a significant draw of power that may conversely cause power insufficiency during production periods when the power supply in the grid goes below peak production, for example in summer.

Next steps

The next steps associated with heating for industrial process includes:

- For each of the above industrial applications, there needs to be a comprehensive study on the economic feasibility of the particular projects. It must be noted that most potential production will be for export and that the increase in cost of shipping in of raw materials and shipping out of final goods is likely to limit the execution of many of the industries above particularly on the outer islands.
- Engagement with national grant awarding bodies could identify opportunities for local grants to be made available for industries supporting the wider aim.

Notes:

It is important to note that for some of the processes above, the process heat may be required continuously once the process has started. This may be a challenge in designing of the grid automation to take up power changes with intermittently varying supply from the grid.

High volume throughput is also negatively affected by interruptions in the process resulting in essential power being drawn from the grid or diesel options. This will be counterproductive in the green energy emissions reduction.

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.43 Suitability assessment – Heating for industrial processes

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating for industrial processes</td>
<td>Mature</td>
<td>Medium</td>
<td>£0.2 - 5 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>With the exception of small scale fertiliser production for use on the islands, it is unlike that the transportation costs for other industrial processes (where raw material and goods produced need to be shipped in and out) will be cost effective.</td>
<td>Low</td>
</tr>
</tbody>
</table>
2.5.8 Hot and Cold Water Leisure Facilities

**Description of the switching option, solution or technology**

An accepted method of reducing local grid congestion and wind turbine curtailment is to increase the local demand for energy. An intensive use of energy can be found within thermal demand. Examples being space heating, swimming pools and refrigeration, ice rinks and spas.

It is understood that any increase in power demand, through the management of thermal demand, should have a zero or minimal financial impact on domestic dwellings and current business operators. However, additional revenue can be sourced from implementing additional services to the islands that will generate money.

**Technology maturity and possible timescales for deployment**

All technologies considered within the management of thermal demand are mature. This option for managing grid constraints is suggesting the electrification of thermal demand and adding tried and tested services that can be powered by already constructed renewable technologies. The majority of options would not be expected to take more than two years to deploy.

**Assessment of grid balancing benefit**

In order to understand the power requirements of a potential swimming pool, to absorb excess renewable energy, details were taken from existing pools. A typical swimming pool can be expected to draw 237kWh/m²/year for electrical demand and 1336kWh/m²/year for heating. Stromness swimming pool can be expected to draw 231.4MWh/year for electrical demand and 703.06MWh/year for heating.

In order to gain a similar understanding of the power requirements of an ice rink facility, most likely situated within Kirkwall, details were gathered from three existing ice risks in Finland. The following details these (Table 2.44).

<table>
<thead>
<tr>
<th>Ice Rink</th>
<th>Ice Pad Size</th>
<th>Seats</th>
<th>Skating Season</th>
<th>Heating Consumption</th>
<th>Electricity Consumption</th>
<th>Energy per Year (MWh)</th>
<th>Energy per Year per m² (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Rink 1</td>
<td>58 x 28 m</td>
<td>400</td>
<td>12 months</td>
<td>760MWh/year</td>
<td>720MWh/year</td>
<td>1,480.00</td>
<td>0.91</td>
</tr>
<tr>
<td>Ice Rink 2</td>
<td>58 x 28 m</td>
<td>600</td>
<td>8.5 months</td>
<td>395MWh/year</td>
<td>490MWh/year</td>
<td>885.00</td>
<td>0.54</td>
</tr>
<tr>
<td>Ice Rink 3</td>
<td>58 x 28 m</td>
<td>400</td>
<td>8 months</td>
<td>710MWh/year</td>
<td>710MWh/year</td>
<td>1,420.00</td>
<td>0.87</td>
</tr>
</tbody>
</table>

All of these rinks are of a substation scale (58m by 28m) and greater than would be expected to be feasible for Orkney. However, this gives a ball park figure for expected additional draw on the grid for an ice rink facility. Operating within an estimated range of 0.54-0.91MWh/year/m².

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197 International Ice Hockey Federation, Technical Guidelines of an Ice Rink, Chapter 3
There are no available data sets detailing the power requirements of a spa, but: sauna stoves can be expected to operate around the 10kW rating\textsuperscript{198}, and commercial Jacuzzi can be expected to be rated above 10kW\textsuperscript{199}.

Any potential project aimed at increasing electricity demand to meet needs to take into account current and potential future curtailed energy availability and further data analysis of curtailment patterns would be required to assess the applicability of this option to each of the DNO zones.

**Potential local impacts**

There are generally no unique local impacts in implementation of this kind of facility except the ones related to standard construction procedures.

**Costs**

Building an indoor ice rink could be expected to reach close to, or above, £1 million. Examples of swimming pools have highlighted that a capital cost within the millions can be expected\textsuperscript{200}.

The above examples use about 1000 MWh per year (roughly 100kW throughout the year). Therefore cost per MW are in the region of £10 million per MW.

**Examples of previous projects or case studies**

There are currently no available projects or case studies investigating, or practising methods of, actively limiting curtailment by increasing power demands through the management of hot and cold water habits.

**Key stakeholders to engage for further development**

Key stakeholders that should be considered within the study of this option for Orkney should include: domestic power generators, with an investigation into minimising exported power through increasing their own demand; Orkney Islands Council; tourist interest groups, to help understand useful amenities that could great power demands; and region grid operator, SSE, and the Pickaquoy Trust.

**Next steps**

Examples of next steps for heating for hot and cold leisure facilities include:

- Next steps should include investigations and data gathering into local use of heating oil and a feasibility study into the electrification of this demand. Data on amenities available and their power requirements could highlight areas were additional services could fill any holes in the market.
- A study into the impact of a given amount of increased thermal demand on the level of reduced curtailment.

\textsuperscript{198} http://www.saunashop.co.uk/sauna-faq/  
\textsuperscript{199} http://hydrother.com/Products/Commercial_Hot_Tubs/Commercial_Hot_Tub_Buying_Tips.html  
\textsuperscript{200} http://www.swimming.org/assets/uploads/library/CAPITAL_COSTDETAILS_25m_and_20m_POOLS.pdf
Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.45 Suitability assessment – Hot and Cold Water Leisure Facilities

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot and Cold Water Leisure Facilities</td>
<td>Mature</td>
<td>Medium</td>
<td>~£10 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>This option is too expensive for the fairly small electrical demand that it would generate however if new facilities of this nature were going to be built then this option should be looked at in conjunction with DSM.</td>
<td>Low</td>
</tr>
</tbody>
</table>
2.5.9 Desalination

Desalination is the process of extracting fresh water from sea water, leaving behind salt. This process may also be applied to ground water, brackish water and as part of recycling of waste water and sewage processes.

Desalinated water may be used for industrial, human consumption or agricultural purposes. There may also be a use for reject brines where hydrated lime and sodium carbonate (soda ash), used in fertiliser production, are the two main secondary consumables that may arise from desalination process.

Description of the switching option, solution or technology

Desalination is a relatively high energy intensive process. In Orkney, the excess generation from wind may be used in the desalination process in order to simultaneously provide a sustainable water resource as well as mitigate the curtailment of wind based electricity generation. The use of reverse osmosis technologies can be designed in line with ANM to switch on when there is surplus generation on the grid.

Orkney currently does not have a water shortage but it is possible that desalination could be used to improve the water quality. By developing a combined seawater desalination and sewage treatment integrated system, Orkney could use electricity produced during peak production as well as to improve its waste water treatment schemes and as well as water supply.

Orkney's water quality, according to Scotland River Basin Management Plan, is 98%. But their aim is for 100% of water bodies to reach good or high ecological status by 2027. This has the potential of creating a surplus supply that may be fed to the local industrial processes or even exported; as well as provide an increase in overall electrical demand, by locating a desalination based salt production industry on the islands. This may be achieved by targeting the following challenges using desalination processes:

- Point source pollution from sewage treatment which is a pressure on the Loch of Stenness catchment and coastal waters around Scapa Flow.
- Abstraction and flow regulation for drinking water supply which is a pressure on the Burn of Boardhouse, Heldale Water and Loch of Kirbister.
- These two challenges may be mitigated by applying desalination processes, which will concurrently increase the demand for electricity to diminish curtailment of generation.

Technology maturity and possible timescales for deployment

By 2050 it is predicted that the number of desalination plants across the world will more than double with a further 18,500 desalination plants becoming operational. In the UK, at least four municipal desalination plants and up to 800 smaller units could be providing water to UK

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201 http://www.sepa.org.uk/water/river_basin_planning/area_advisory_groups/orkney_and_shetland/condition_and_objectives.aspx
households and industry\textsuperscript{202,203,204}. Desalination through reverse osmosis membranes is a proven technology which has been shown to extract the highest rate of water per unit of energy expended as compared to the other technologies such as Multiple Desalination and Flashing (MDF), Multiple Effect Flash (MEF) and Multi-Stage Flash (MSF). The technology is mature and would generally take a medium to long-term timescale of deployment.

Typical implementation of desalination plants will involve extensive environmental impact assessments owing to a potential impact on the marine environment. In addition to that the planning and construction may take 2-3 years as a minimum.

\textbf{Assessment of grid balancing benefit}

\textbf{Size of the grid balancing benefit}

Energy consumption of sea water desalination can be as low as 3\textit{kWh/m}^3\textsuperscript{205}, which includes pre-filtering and ancillaries. This is similar to the energy consumption of existing fresh water supplies transported over large distances, but much higher than local fresh water supplies which use 0.2\textit{kWh/m}^3 or less. This would result in an energy demand of 6 times per m\textsuperscript{3} for water processing in Orkney. This translates to demand of 0.4\textit{MW} for continuous production of water supply. For a peak generation shifting, the amount of power required for desalination processes suitable to the Orkney water demand and potential generation of salt may vary from approximately 1-3\textit{MW}\textsuperscript{206}.

It must be noted however that the salt extraction in itself is a low energy process (0.02\textit{kWh/kg}) as in the salt processing plants, the main usage of electricity would for the operation of pumps and agitators in the chemical reactors and fluid transfer circuits\textsuperscript{207}.

\textbf{Size of the market}

According to Scottish Water, Orkney has a low level of water stress\textsuperscript{208}. The total demand for water given an average usage of 150 litres per person amounts to a total domestic water demand of 3,300 m\textsuperscript{3} per day or approximately 1.2 million m\textsuperscript{3} per annum. Taking an average of 3\textit{kWh/m}^3, desalination for domestic water would result in annual demand of 9.9\textit{MWh} per day and 3.6\textit{GWh} per annum.

\textbf{Scale of solution relative to Orkney situation}

For a solution of 5\textit{MW}, the ideal demand would require a plant that produces an average of 8-12 times the water and salt needs of the community which would greatly surpass the water needs of the community. Water exportation is not geographically or economically feasible.

\textsuperscript{202} http://desaldata.com/
\textsuperscript{203} http://www.icheme.org/media_centre/news/2013/water-challenges-make-uk-desalination-plants-more-likely.aspx#.VDZVLfdWSo
\textsuperscript{204} http://www.waterworld.com/articles/2013/09/uk-could-have-four-municipal-desalination-plants-by-2050-says-icheme.html
\textsuperscript{205} "Energy Efficient Reverse Osmosis Desalination Process", p343 Table 1, International Journal of Environmental Science and Development, Vol. 3, No. 4, August 2012
\textsuperscript{206} *Assumption: Demand at 40%.
\textsuperscript{207} Feasibility of salt production Corn inland RO desalination plant reject brine: A case study Mushtaque Ahmed. 2002
Scale of solution relative to local constraint situation or household
Desalination as noted from the table in CAPEX section shows a significant increase in cost of water for smaller production estimates. This means that the use of desalination for marginal isles will not be economically feasible.

How well does it match (temporally and geographically) with the energy generated from renewable sources (mostly wind in the case of Orkney)
The potential for wind for desalination and waste treatment processes in the case of Orkney is relatively high with the demand for water purity maintenance. However the demand for fresh water from desalination as well as the supply and distribution of sea-water mined mineral salts is very low. This technology is unlikely to be a suitable match to the current curtailment hurdles.

Zone of influence
Any potential project aimed at increasing electricity demand to meet needs to take into account current and potential future curtailed energy availability and further data analysis of curtailment patterns would be required to assess the applicability of this option to each of the DNO zones.

Assessment of CO2 benefit
The carbon footprint for desalination in the Orkney case would marginally increase owing to the current production of water methods. Current methods emit 1.5 tonnes of CO\textsubscript{2} per million gallons\textsuperscript{209}. Desalination would produce about 1.8 tonnes of CO\textsubscript{2} per million gallons. This is majorly due to the increase in industrial building carbon footprint as well as off-peak generation that may require importation of electricity.

Potential local impacts
Water intake structures cause adverse environmental impact by pulling of fish and shellfish, or their eggs, into the system. Larger organisms may be killed or injured if trapped against screens at the front of an intake structure.

The brine outflow from the desalination plant may damage the local bio system by creating an imbalance in salinity. In addition to that it may be increased in temperature; and contain residues of pre-treatment, cleaning chemicals, reaction by-products and heavy metals due to corrosion. All these are likely to affect the bio-diversity in the location of the potential desalination plant.

Impact on customers
Even though the problem of curtailment may be met by oversizing the desalination plant. The increased cost of water production may lead to an unfavourable outlook for Orkney customers.

There may also be strong opposition due to sensitivity of aquatic life to the local community in relation to desalination plants.

A facility of this nature may also significant increase water prices.

\textsuperscript{209} http://edition.cnn.com/2012/01/20/world/meast/carbon-cost-water-uae/index.html
**Costs**

Estimated capital costs for a medium sized desalination plant is based on the Spain Veolia El Prat del Llobergat 14,000 m$^3$/day at £5.12 million and a per unit capital cost of £367/m$^3$/day$^{210}$. The current cost of water in Orkney is £1.264 per cubic meter$^{211}$.

The estimates below show that the total potential cost of desalinated water for the islands of Orkney, as well as the mainland, would be significantly higher than the cost of ground water.

**Table 2.46 Potential desalinated water costs**

<table>
<thead>
<tr>
<th>Location</th>
<th>Production (m$^3$/day)</th>
<th>Total water cost £ for 1 MW plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainland</td>
<td>1,000 – 4,800</td>
<td>£367,000 - 1,761,600</td>
</tr>
<tr>
<td>Outer isles</td>
<td>250 – 1,000</td>
<td>£91,750 - 367,000</td>
</tr>
</tbody>
</table>

**Examples of previous projects or case studies**

The first large-scale plant in the United Kingdom, the Thames Water Desalination Plant, was built in Beckton, east London for Thames Water by Acciona Agua.

- Germany-based engineering company Synlift Systems has implemented pilot wind-powered desalination units in the Gulf region, which integrate off-the-shelf wind turbines and RO desalination technology$^{212}$.

**Key stakeholders to engage for further development**

The key stakeholders for this technology are the water treatment and supply organisations such as Scottish Water, the local council (OIC) as well as the local fisheries and Scottish Environmental Protection Agency (SEPA).

**Next steps**

The next steps associated with desalination includes:

- A discussion with key stakeholders to gather wider views on this proposal would be valuable, to help identify potential areas for further studies and research that could help establish whether this is a feasible option.
- investigation of possible climate change effects that may see the greater region affected by water shortages in the future.

**Notes**

This technology would only be suitable for implementation as a curtailment option if used in conjunction with some of the other relocated industrial processes which may include a combined power intake of heating and cooling, treatment of waste and simultaneously production of feed water. This would thus provide a larger uptake of the surplus supply of wind generated electricity.

---

Suitability of option to current Orkney situation

The following table summarises the overall suitability of this option for the current Orkney situation based on the information in the sections above and scored against the criteria set out in Table 2.1. The scores are collated for all the options in Section 2.6.

Table 2.47 Suitability assessment – Desalination

<table>
<thead>
<tr>
<th>Solution</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desalination</td>
<td>Mature</td>
<td>Medium-long</td>
<td>£~0.3 - 1.7 million per MW</td>
<td>All zones depending on where deployed but limited by the demand for water.</td>
<td>The increased cost of water production compared to the existing supply mean this is not an attractive option.</td>
<td>Very Low</td>
</tr>
</tbody>
</table>
Conclusions

The report provides the most comprehensive baseline of energy information for Orkney to date. This should now be used as a benchmark to help determine energy related policy and decision making within and outwith Orkney.

This study has shown what Orkney has achieved so far. Over the last 15 years Orkney has installed enough capacity to generate 103% of its electricity demand in 2013. The islands have now reached the point where further increases in generation capacity are limited by the grid. There is however still a desire and a need to adopt renewables further. This would bolster electricity supply away from fossil fuels and to maintain and even further increase the economic and social contribution made by renewable energy to the Orkney Islands.

The proposed strategies provide an initial assessment of a number of options and highlights where potential is most likely to be found as well as indicating the actions that need to be taken to deliver in these areas. The benefits to Orkney as a whole for investigating and developing switching strategies can enhance its reputation as an energy laboratory as well as the direct financial and environmental benefits associated with increased electrification.

Further initiatives and work is now required to turn this list of actions into real on the ground activities and projects. It is hoped that this document will help focus these discussions to a point whereby the next level of decision making can take place and action to address the energy issues facing Orkney can be taken. This will need to be delivered by different agencies working together and the potential of the options described could give communities real energy security and a range of potential income generating projects.

Undertaking such actions in the Orkney community will take a considerable effort and need strong co-ordination if it is to be successful.
2.6 Next steps for energy switching options

Sections 2.2 to 2.5 above outline a number of possible options that could be taken forward. In order to highlight those options that are thought to have the most potential, each of them have been scored against the criteria set out in Table 2.48, and as shown in Table 2.49. Each option has an overall suitability score which reflects the potential suitability and value of the option to the current challenges in Orkney.

Table 2.48 Scoring criteria

<table>
<thead>
<tr>
<th>Suitability</th>
<th>Very low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology maturity /</td>
<td>Standard</td>
<td>Semi-mature</td>
<td>High</td>
<td>Mature - Widely applied</td>
<td>Standard technology solution</td>
</tr>
<tr>
<td>suitability</td>
<td>solution</td>
<td>demonstration projects exist</td>
<td>widely applied</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Costs £/MW installed</td>
<td>&gt; 100 million/MW</td>
<td>&gt; 1 million/MW</td>
<td>Low &gt;10k/MW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possible timescales for deployment</td>
<td>Very long term - more than 10 years</td>
<td>Long term - more than 5 years</td>
<td>Medium-term - within 3-5 years (completed by 2017-19)</td>
<td>Very short term - within 1 year</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.49 Overall suitability of proposed options

<table>
<thead>
<tr>
<th>Option</th>
<th>Technology maturity / suitability</th>
<th>Possible timescales</th>
<th>Cost per MW installed (storage or demand, worst case)</th>
<th>Zone on influence</th>
<th>Comments</th>
<th>Overall suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>Grid upgrades</td>
<td>Standard technology solution</td>
<td>Medium</td>
<td>Shapinsay upgrade (~£10 million, 10km)</td>
<td>Zones 2, 2a and 2b, Zones 1 and 1a</td>
<td>Would remove some constraints to generators on the North Isles. Costs refer to total rather than per MW costs as increased capacity is not known.</td>
<td>Medium</td>
</tr>
<tr>
<td>Use of dynamic line ratings</td>
<td>Mature - Widely applied</td>
<td>Very short</td>
<td>~£0.2 million for the Burger Hill-Kirkwall line for an additional 4 MW of generation (~50k/MW)</td>
<td>Zones 1 and 1a (wider if deployed on other lines)</td>
<td>Understood technology and uses existing infrastructure.</td>
<td>Very high</td>
</tr>
<tr>
<td>Expansion of the ANM for new sub 50kW generators</td>
<td>No technology solution available</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>SSEPD R&amp;D project did not find a suitable, cost effective, technology solution for this purpose.</td>
<td>Very Low</td>
</tr>
<tr>
<td>Storage and demand management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Battery Storage</td>
<td>Semi-mature at scale required</td>
<td>Short</td>
<td>£0.95-3.2 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Scalable solution which is becoming more common for large scale storage, however still fairly have a high cost per MW and low energy density (which is a problem for transport solutions).</td>
<td>Medium</td>
</tr>
<tr>
<td>Option</td>
<td>Technology maturity / suitability</td>
<td>Possible timescales</td>
<td>Overall suitability</td>
<td>Cost per MW installed (storage or demand, worst case)</td>
<td>Zone on influence</td>
<td>Comments</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>----------------------------------</td>
<td>---------------------</td>
<td>--------------------</td>
<td>-------------------------------------------------------</td>
<td>------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Hydrogen Storage and Fuel Cells</td>
<td>Semi-mature</td>
<td>Long</td>
<td>Low</td>
<td>£1.2 million per MW</td>
<td>All zones</td>
<td>Scalable solution which is becoming more common for large scale storage however still fairly have a high cost per MW and low energy density (which is a problem for transport solutions). There are few places in the UK where land height is greater than 100m high and topographically they are not suitable for hydropower.</td>
</tr>
<tr>
<td>Option</td>
<td>Technology maturity / suitability</td>
<td>Possible timescales</td>
<td>Cost per MW installed (storage or demand, worst case)</td>
<td>Zone on influence</td>
<td>Comments</td>
<td>Overall suitability</td>
</tr>
<tr>
<td>------------------------------------</td>
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<td>-------------------------------------------------------</td>
<td>----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>District heating</td>
<td>Medium</td>
<td>Long</td>
<td>£1.1-1.3 million per MW</td>
<td>Likely to be core zone only</td>
<td>Less attractive for areas with low population densities and in areas with detached houses due to cost of expenses. Should be considered for all new large scale housing developments to maximise on economies of scale.</td>
<td>Low</td>
</tr>
<tr>
<td>Increasing demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heated growing spaces</td>
<td>Mature</td>
<td>Very short</td>
<td>£0.3 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Low cost, scalable, short term solution using mature technology</td>
<td>Very high</td>
</tr>
<tr>
<td>Crop drying</td>
<td>Mature</td>
<td>Short</td>
<td>£0.8 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>Seasonal activity which would have little impact on the year round electrical energy demand.</td>
<td>Low</td>
</tr>
<tr>
<td>Heated anaerobic digesters</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£13 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>High cost per MW along with the fact that there are no operational anaerobic digesters in Orkney mean this is an option that would take a long time to implement.</td>
<td>Low</td>
</tr>
<tr>
<td>Ammonia as a fuel</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£0.4-0.9 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>The possibility of using ammonia as a fuel has several advantage over other low carbon fuel options such as hydrogen but is still very much at the demonstration stage, so should be highlighted as an option for future investigation.</td>
<td>Medium</td>
</tr>
<tr>
<td>Fertilizer production</td>
<td>Semi-mature</td>
<td>Medium</td>
<td>£0.4-0.9 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>As a commodity that is already imported into Orkney, fertiliser production is a solution that could have far reaching benefits and make a large impact on electricity use.</td>
<td>High</td>
</tr>
<tr>
<td>Refrigeration and cooling</td>
<td>Mature</td>
<td>Medium</td>
<td>£0.85 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>This would have a significant impact on electricity demand but the timescales and willingness of companies to relocate is hard to define and the planning implications could delay this option considerably.</td>
<td>Medium</td>
</tr>
<tr>
<td>Heating for industrial processes</td>
<td>Mature</td>
<td>Medium</td>
<td>£0.2 - 5 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>With the exception of small scale fertiliser production for use on the islands, it is unlike that the transportation costs for other industrial processes (where raw material and goods produced need to be shipped in and out) will be cost effective.</td>
<td>Low</td>
</tr>
<tr>
<td>Hot and Cold Water Leisure Facilities</td>
<td>Mature</td>
<td>Medium</td>
<td>~£10 million per MW</td>
<td>All zones depending on where deployed.</td>
<td>This option is too expensive for the fairly small electrical demand that it would generate however if new facilities of this nature were going to be built then this option should be looked at in conjunction with DSM.</td>
<td>Low</td>
</tr>
<tr>
<td>Desalination</td>
<td>Mature</td>
<td>Medium-long</td>
<td>£0.3 - 1.7 million per MW</td>
<td>All zones depending on where deployed but limited by the demand for water.</td>
<td>The increased cost of water production compared to the existing supply mean this is not an attractive option.</td>
<td>Very Low</td>
</tr>
</tbody>
</table>
In order for any of these strategies to be adopted a number of specific actions will need to be taken. Within the Energy Switching section of the report (Section 2) suggestions as to the next steps have been made for individual proposals as well as a list of possible stakeholders. The table below highlights those actions for the high or very high priority options only.

Table 2.50 Actions for high and very high priority options

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of dynamic line ratings</td>
<td>• Further engagement with the network operator to explore the potential to role this out further.</td>
</tr>
<tr>
<td>Demand side management</td>
<td>• Further engagement with Heriot-Watt University to maximise outcomes and opportunity for transferring outcomes from Findhorn to Orkney.</td>
</tr>
<tr>
<td></td>
<td>• Further investigation, if data is available, to look at the scale of the grid balancing benefit on the individual DNO zones.</td>
</tr>
<tr>
<td>Electric vehicles</td>
<td>• The installation of ‘Rapid chargers’ at key locations to support the use of EVs.</td>
</tr>
<tr>
<td></td>
<td>• Extensive installation of ‘Fast Charge’ points throughout the county.</td>
</tr>
<tr>
<td></td>
<td>• Direct engagement with constrained turbine owners to encourage a shift to EVs.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with national grant awarding bodies to support a shift towards procurement of EVs.</td>
</tr>
<tr>
<td>Electric ferries</td>
<td>• Undertake a feasibility study into the potential of replacing existing diesel ferries which are at the end of their commissioning periods with electric ferries.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with other relevant stakeholders that have experience with electric ferries (e.g. Caledonian Maritime Assets Ltd.) to learn from their experiences.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with battery technology developers to match the demand of the vessels for longer routes.</td>
</tr>
<tr>
<td></td>
<td>• Exploration of the potential for ‘cold ironing’ should be explored with the ferry operators.</td>
</tr>
<tr>
<td>Hydrogen ferries</td>
<td>• Undertake a feasibility study into the potential of replacing existing diesel ferries which are at the end of their commissioning periods with hydrogen ferries.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with other relevant stakeholders that have experience with electric ferries (e.g. Caledonian Maritime Assets Ltd.) to learn from their experiences.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with fuel cell technology developers to match the demand of the vessels for longer routes.</td>
</tr>
<tr>
<td></td>
<td>• Exploration of the potential of conversion of engines to directly burn hydrogen.</td>
</tr>
<tr>
<td>Electrification of Heating Systems</td>
<td>• Analysis of EST home analytics data to look at the heating systems used in the current housing stock to give a better estimate of the market.</td>
</tr>
<tr>
<td></td>
<td>• Determine and publicise impact on customers looking at installation costs versus running costs of different heating systems including RHI payments for applicable technologies.</td>
</tr>
<tr>
<td></td>
<td>• Investigate the likely demand created by switching fuels for small turbine owners who are currently using non electrical heating for hot water and space heating.</td>
</tr>
<tr>
<td></td>
<td>• Economic analysis cost of wind to heat versus selling to the grid and electric heating.</td>
</tr>
<tr>
<td></td>
<td>• Engage with national and local grant awarding bodies to establish grant for local residents encouraging shift from fossil fuel to electric for installation costs</td>
</tr>
<tr>
<td></td>
<td>• Engagement with SSE or other operator to establish opportunity for Orkney specific tariff to encourage a shift from fossil fuel to electric.</td>
</tr>
<tr>
<td>Heated growing spaces</td>
<td>• Discussions with Eday and Benbecula projects to discuss opportunities and pitfalls.</td>
</tr>
<tr>
<td></td>
<td>• Engagement with grant awarding organisations i.e. Rural Payments and Inspectorate Directorate in relation to agricultural land.</td>
</tr>
<tr>
<td></td>
<td>• Engage with local shops to establish demand and willingness to participate and purchase locally grown produce.</td>
</tr>
<tr>
<td></td>
<td>• Research cooperative style food supply business to support number of small farms supplying local shops.</td>
</tr>
<tr>
<td>Fertiliser production</td>
<td>• Undertake a feasibility study into the cost effective production of locally produced ammonia fertilisers.</td>
</tr>
<tr>
<td></td>
<td>• Identification of applicable locations to determine possible sites of operation that minimise impact.</td>
</tr>
</tbody>
</table>
Determining the seasonal demand for ammonia based fertilisers could highlight the level of production and storage that would be required.

Gathering data on the use of ammonia based fertilisers of neighbouring regions to Orkney.

Data on the variety of fertilisers used within Orkney.

There are recurring areas of focus that appear to apply across many of the proposals and include for example:

- Identifying key stakeholders (specific to each proposal);
- Engaging with stakeholders (individual organisations, businesses but also sector groups i.e. agriculture);
- Consultation with communities and wider Orkney population (to raise awareness and understand concerns);
- Undertaking feasibility studies and more specific pieces of work (to help identify technological and socio-economic and environmental aspects);
- Identifying and initiating medium/ longer term research opportunities (with Heriot-Watt University International Centre for Island Technology, UHI (Orkney College) and other Higher Education Institutions associated with the specialist areas);
- Gathering more data and information (through short projects within existing organisations/ contracted or by utilising placement opportunities);
- Monitoring and measuring (specific programmes focussed on a particular issue to provide data in order to make a specific decision);
- Understanding behaviour change (to maximise and encourage participation in schemes aimed to support Orkney wide strategies); and
- Investigating Orkney specific financial/ other incentives (linked to encouraging a shift in behaviour/ decision making).

In addition to the above there is also a need to consider the following:

- How Orkney as a whole (i.e. different organisations) will approach the strategic delivery of such projects(s) in order that the Orkney communities benefit from the decisions and actions taken, by working together and supporting each other;
- Who the key organisations are within Orkney in relation to taking forward the outcomes of such a report, is it a number of organisations, is it a single organisation, is it a new organisation
- What relationships need to be established and/ or strengthened outwith Orkney to maximise opportunities within Orkney;
- How to provide Orkney businesses with the support (skills, knowledge) to maximise the opportunities for new business streams (i.e. shifting away from fossil fuels); and
- Understanding and calculating the risks associated with individual projects or the wider ambition based on different future scenarios (helping alleviate concerns or identifying previously unknown risk factors).

This study has shown what Orkney has achieved so far. Over the last 15 years Orkney has installed enough capacity to generate 103% of its electricity demand in 2013. The islands have now reached the point where further increases in generation capacity are limited by the grid. There is however still a desire and a need to develop more renewables energy projects on Orkney in order to decrease our dependence on fossil fuels and to further increase the economic and social contribution made by renewable energy to the Orkney Islands.
The proposed strategies provide an initial assessment of a number of options and highlights where potential is most likely to be found as well as indicating the actions that need to be taken to deliver in these areas. The benefits to Orkney as a whole for investigating and developing switching strategies can enhance its reputation as an energy laboratory as well as the direct financial and environmental benefits associated with increased electrification.

Further initiatives and work is now required to turn this list of actions into real on the ground activities and projects. It is hoped that this document will help focus these discussions in order that the next level of decision making can take place and action to address the energy issues facing Orkney can be taken. The actions in the table above need to be allocated to specific organisations following review and agreement. This will need to be delivered by different agencies working together and the potential of the options described could give communities real energy security and a range of potential income generating projects.

Undertaking such actions in the Orkney community will take a considerable effort and need strong co-ordination if it is to be successful. The prize if this initiative is taken will be considerable.
### 3 Bibliography

Numbers below refer to the associated footnotes.

<table>
<thead>
<tr>
<th>No.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Highlands and Island enterprise, 2007. Assessment of the Grid Connection Options for the Scottish Islands. [online] Available at: &lt;www.hie.co.uk/subsea-cable&gt;.</td>
</tr>
<tr>
<td>17</td>
<td>Centre for Low Carbon Futures. Energy Storage Factsheets [online] Available at: <a href="http://www.lowcarbonfutures.org/energy-storage-factsheets">http://www.lowcarbonfutures.org/energy-storage-factsheets</a>.</td>
</tr>
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<td></td>
<td>Reference</td>
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</tbody>
</table>


40 Targets for on-board hydrogen storage systems: Current R&D focus is on 2010 Targets. [online] Available at: <http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/freedomcar_targets_explanations.pdf>.

41 Personal correspondence with Nigel Holmes (CEO) – Scottish Hydrogen and Fuel Cell Association


47 Personal correspondence with Nigel Holmes, Scottish Hydrogen and Fuel Cell Association


<http://www.nissanusa.com/electric-cars/leaf/charging-range/>


Economy 7 Tariffs. [online] Available at: <http://www.ukpower.co.uk/home_energy/economy-7>.


Jonathan Porterfield, Eco-Cars Ltd.


Jonathan Porterfield, Eco-Cars Ltd.


University of Exeter. Calculation of CO2 emissions [online] Available at: <http://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm>.


<table>
<thead>
<tr>
<th>Page</th>
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<tr>
<td>107</td>
<td>Roads2HyCom [online] Available at: <a href="http://www.ika.rwth-aachen.de/r2h/index.php/Main_Page">http://www.ika.rwth-aachen.de/r2h/index.php/Main_Page</a>.</td>
</tr>
<tr>
<td>110</td>
<td>Shapinsay Low Carbon Transport Study. 2014</td>
</tr>
<tr>
<td>117</td>
<td>Actual efficiencies may range from ~70% for old boilers to 90% for new ones</td>
</tr>
<tr>
<td>118</td>
<td>Actual efficiencies may range from ~70% for old boilers to 90% for new ones</td>
</tr>
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<td>Page</td>
<td>Reference</td>
</tr>
<tr>
<td>------</td>
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<td>131</td>
<td>kW Forage Systems. Options for storage of grain on farm [online] Available at: <a href="http://www.kwforagesystems.ie/News/47/Options-for-storage-of-grain-on-farm">http://www.kwforagesystems.ie/News/47/Options-for-storage-of-grain-on-farm</a>.</td>
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<td>133</td>
<td>Small Grains [online] Available at: <a href="http://www.smallgrains.org/springwh/June03/weights/weights.htm">http://www.smallgrains.org/springwh/June03/weights/weights.htm</a>.</td>
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<td>138</td>
<td>C Ris Energy. Where there’s much there’s gas! [online] Available at: <a href="http://crisenergy.co.uk/">http://crisenergy.co.uk/</a>.</td>
</tr>
<tr>
<td>150</td>
<td>Hydroworld, 10 January 2009. Renewable Fuels: Manufacturing Ammonia from Hydropower</td>
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<td>Number</td>
<td>Source</td>
</tr>
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<td>--------</td>
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<td>151</td>
<td>Proton Ventures, 15 March 2010. Mini-Ammonia Production Unit Presentation</td>
</tr>
<tr>
<td>152</td>
<td>NH3 Fuel Association, 1 January 2013. NHThree, SSAS [online]</td>
</tr>
<tr>
<td>167</td>
<td>University of Bristol. Ammonia</td>
</tr>
</tbody>
</table>


[online] Available at: http://fluglaerm.de/hamburg/klima.htm>.


Desal Data.[online] Available at: <http://desaldata.com/>.


"Energy Efficient Reverse Osmosis Desalination Process", p343 Table 1, International Journal of Environmental Science and Development, Vol. 3, No. 4, August 2012

*Assumption: Demand at 40%.

Feasibility of salt production Corn inland RO desalination plant reject brine: A case study Mushtaque Ahnred. 2002


frontier-for-renewable-energy-part-2/.
## 4 Abbreviations, Acronyms & Definitions

### 4.1 Abbreviations & Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADMD</td>
<td>After Diversity Maximum Demand</td>
</tr>
<tr>
<td>ANM</td>
<td>Active Network Management</td>
</tr>
<tr>
<td>APU</td>
<td>Auxiliary Power Unit</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Capital Expenditure</td>
</tr>
<tr>
<td>CES</td>
<td>Community Energy Scotland</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>CPP</td>
<td>Critical Peak Pricing</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DNO</td>
<td>Distribution Network Operator</td>
</tr>
<tr>
<td>DSM</td>
<td>Demand Side Management</td>
</tr>
<tr>
<td>DSR</td>
<td>Demand Side Response</td>
</tr>
<tr>
<td>ECS</td>
<td>Energy Complementary System</td>
</tr>
<tr>
<td>ESS</td>
<td>Energy Storage System</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicle</td>
</tr>
<tr>
<td>FC</td>
<td>Fuel Cell</td>
</tr>
<tr>
<td>FCV</td>
<td>Fuel Cell Vehicle</td>
</tr>
<tr>
<td>FIT</td>
<td>Feed-in Tariff</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>GVA</td>
<td>Gross Value Added</td>
</tr>
<tr>
<td>GWh</td>
<td>Gigawatt hour</td>
</tr>
<tr>
<td>H₂</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>H₂O</td>
<td>Water</td>
</tr>
<tr>
<td>H-B</td>
<td>Haber-Bosch</td>
</tr>
<tr>
<td>kWe</td>
<td>Kilowatt-electric</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt Hour</td>
</tr>
<tr>
<td>Li-ion</td>
<td>Lithium-Ion</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquid Petroleum Gas</td>
</tr>
<tr>
<td>m/s</td>
<td>Meters per Second</td>
</tr>
<tr>
<td>MJ</td>
<td>Megajoule</td>
</tr>
<tr>
<td>mph</td>
<td>Miles per hour</td>
</tr>
<tr>
<td>ms</td>
<td>millisecond</td>
</tr>
<tr>
<td>MSF</td>
<td>Multi-Stage Flash</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>MWe</td>
<td>Megawatt-electric</td>
</tr>
<tr>
<td>MWh</td>
<td>Megawatt Hour</td>
</tr>
<tr>
<td>NFU</td>
<td>National Farmers Union</td>
</tr>
<tr>
<td>NH₃</td>
<td>Ammonia</td>
</tr>
<tr>
<td>NHS</td>
<td>National Health Service</td>
</tr>
<tr>
<td>NNFG</td>
<td>New Non-Firm Generation</td>
</tr>
<tr>
<td>NOx</td>
<td>Nitrogen oxides</td>
</tr>
</tbody>
</table>
4.2 Definitions

After Diversity Maximum Demand
After Diversity Maximum Demand refers to the maximum power demand of a group of customers divided by the number of customers; expressed in kilovolt amperes (kVA).

Active Network Management
The Active Network Management system is a form of DSM that relies on the smart use of information relating to supply and demand, then making alterations to them in order to balance the network.

Auxiliary Power Unit
Auxiliary Power Units provide power to a vehicle, to systems other than propulsion.

Battery Electric Vehicle
Vehicles that are completely powered by electrical power stored in banks of batteries.

Capital Expenditure
The costs required to initially fund construction and start-up of a project.

Community Energy Scotland
Community Energy Scotland is an independent Scottish charity established in 2008 that provides advice and financial support for renewable energy projects developed by community groups in Scotland. The stated aim of Community Energy Scotland is ‘to build confidence, resilience and wealth at community level in Scotland through sustainable energy development’.

Combined Heat and Power
A Combined Heat and Power unit will provide both heat and power energy from a fuel source. An example would be a unit that combusts fuel to power an electrical generator and the heat from this combustion is captured to meet a dwelling’s thermal demand as well.
**CO₂**
Carbon dioxide (chemical formula CO₂) is a naturally occurring chemical compound composed of 2 oxygen atoms each covalently double bonded to a single carbon atom. The environmental effects of carbon dioxide are of significant interest. Carbon dioxide is an important greenhouse gas and burning of carbon-based fuels since the industrial revolution has rapidly increased its concentration in the atmosphere, leading to global warming.

**Critical Peak Pricing**
Critical Peak Pricing is the action, by utility companies, of adjusting power costs during predicted peak demand periods in order to influence customers into using less power at these times.

**Direct Current**
Direct current (DC) is the unidirectional flow of electric charge. Direct current is produced by sources such as batteries, thermocouples, solar cells, and commutator-type electric machines of the dynamo type.

**Distribution Network Operator**
Distribution Network Operators manage the distribution networks that lay between the transmission network and the end users. DNOs do not sell electricity; this is done by electricity suppliers.

**Demand Side Management**
Demand Side Management is another means of balancing the power grid. It relies on the modification of consumer demand for energy through various methods such as financial incentives and education. Usually, the goal of demand side management is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times such as night-time and weekends. Peak demand management does not necessarily decrease total energy consumption, but could be expected to reduce the need for investments in networks and/or power plants for meeting peak demands.

**Demand Side Response**
Demand Side Response is the active adjusting of power demand by energy users when a signal is provided from the energy supplier.

**Energy Complementary System**
An Energy Complementary System is the use of additional technologies to increase the functionality of a facility. For example, a battery paired with a wind turbine to continue providing power when the wind speed reduces.

**Energy Storage System**
Energy Storage Systems covers a wide variety of technologies. From large scale pumped hydroelectric plants to small electrical batteries.

**Electric Vehicle**
Electric vehicles utilise electric motors instead of combustion engines for propulsion.

**Fuel Cell**
Fuel Cells produce electricity from a chemical reaction within its fuel. Hydrogen is a common fuel source in fuel cells.

**Fuel Cell Vehicle**
A Fuel Cell Vehicle uses a fuel cell in order to produce electrical energy from a chemical reaction from its fuel, in order to power electric motors.

**Feed-in Tariff**
A Feed in Tariff is the money an energy generator can get paid from their energy suppliers for exporting back into the grid.
Greenhouse Gas
A greenhouse gas (sometimes abbreviated GHG) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth’s atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Gross Value Added
Gross Value Added is a monetary value indicating what a new good or service adds; less the cost of inputs.

Gigawatt hour
A Gigawatt Hour is a measure of energy. This can be used to represent a measure of work done over a given period of time. For example, a 1 GW turbine generating for one hour will produce 1GWh of energy.

Haber-Bosch
A process for manufacturing ammonia on an industrial level. It was invented by Fritz Haber and Carl Bosch in 1920. It works by combining hydrogen and nitrogen between iron catalytic plates several times at high temperature and pressure.

Kilowatt-electrical
A Kilowatt-electric is a measure of power; specifically electrical power.

Kilowatt Hour
A Kilowatt Hour is a measure of energy. This can be used to represent a measure of work done over time. For example, a 1kW turbine generating for one hour will produce 1kWh of energy.

Liquid Petroleum Gas
Liquid Petroleum Gas is natural gas produced during oil refining that contains propane and butane. It can also be extracted during the natural gas production process. LPG can be used for powering cars as well stationary generators.

Megajoule
A Megajoule is a measure of energy. It equals 1,000 kilojoules. One joule per second also equals one watt.

Multi-Stage Flash
Sea water is distilled by being, at several stages, flashed into steam. These stages continue to reduce the salinity until the end of the process.

Mega Volt-Amp
A Megavolt Ampere is equal to one million volt amperes. A volt ampere is another measure of power, like watts, however it is an indication of losses within the system. These losses are generally as a result of inductive or capacitive loads; like transformers and electrical motors.

Megawatt
A Megawatt is a measure of power. It is equal to 1,000kW. One Joule per second is equal to one Watt

Megawatt-electric
A Megawatt-electric is a measure of power; specifically electrical power. It is equal to 1,000kW.

Megawatt Hour
A Megawatt Hour is a measure of energy and work. It is equal to 1,000kWh. For example, a 1MW turbine operating continuously for one hour will generate 1MWh.
National Farmers Union
The National Farmers Union represents the interests of farmers and growers within the UK.

NHS
The four publicly funded health care systems in the countries of the United Kingdom are referred to as the National Health Service.

New Non-Firm Generation
New Non-Firm Generation is the generation capacity added to Orkney network as a direct result of the ANM system. It is ramped up and down as demand dictates. This is equal to approximately 25MW of additional renewable generation.

Orkney Housing Association Ltd
The Orkney Housing Association Ltd is a registered social landlord, and a registered non-for-profit charitable organisation, whose aim is to provide low cost housing in Orkney. The organisation was set up in 1985 and is responsible for the construction of approximately 40 households a year.

Operational Expenditure
Operational Expenditure represents the costs a project, of facility, would incur over its projected life time. For example, fuels, repairs, replacements, etc.

Plug-in Electric Vehicle
Plug-in Electric Vehicles represent those vehicles powered by electricity, via battery banks, and plug-in to a power source when not in use.

Plug-in Hybrid Electric Vehicle
Plug-in Hybrid Electric Vehicle use a mixture of fuels and electrical energy in order to maximise range per unit volume of fuel. The electricity is stored within banks of batteries that can be charged when not in use by being plugged into an energy source. These batteries can generally also be charged by the combustion engine.

River Basin Management Plan
The River Basin Management Plans were set up to improve water quality and protect water environments

Renewable Heat Incentive
The Renewable Heat Incentive is a financial support programme incentivising the heating of buildings from renewable energy but paying customer for doing so.

Renewable Obligation Certificate
Renewable Obligation Certificates are used by energy suppliers to demonstrate they are sourcing sufficient levels of power from renewable generators. Operators of renewable generators earn ROCs for certain levels of green energy produced. Then these ROCs can be traded to other parties for additional income. ROCs are generally only for larger scale generators.

Solid Oxide Fuel Cell
Solid Oxide Fuel Cells are a breed of fuel cell that utilises a solid oxide or ceramic electrolyte in the centre of the cell.

Solid State Ammonia Synthesis
Solid State Ammonia Synthesis, like the Haber-Bosch process, is used in the production of ammonia on an industrial level. The process takes in water and air in order to obtain the hydrogen and nitrogen required to form the ammonia. The SSAS process is more efficient and requires less energy than the Haber-Bosch process.

Scottish and Southern Energy Power Distribution
The regional distribution network operator in Orkney and the north of Scotland.

**Tonnes of Oil Equivalent**
Tonnes of Oil Equivalent is a measurement of the amount of energy released from burning one tonne of crude oil (approximately 42 gigajoules).

**Time of Use**
Time of Use pricing is a tariff that can be paired with a smart meter within homes and business in order to allow customers to make smarter decisions of their energy demands. An example of an effective use of this is to shift large power demands to off-peak times, when power is cheaper.

**University of Highlands and Islands**
The University of the Highlands and Islands is a federation of 13 colleges and research facilities within the said region.

**Uninterruptable Power Supply**
Uninterruptable Power Supplies are units employed in systems that can't afford to lose power expectantly. This includes hospitals, data centres etc. A UPS will often be a battery that will act immediately and last long enough for a backup generator to come on line if necessary.

**Vanadium Redox Flow Battery**
Vanadium Redox Flow Batteries are a breed of flow batteries which differ from conventional electrochemical batteries by storing the electrolytes in separate tanks. When the stored electrical energy is required then these are reacted them together at a centralised membrane.

**Watt Hour**
A watt hour is a measure of energy. It is equal to 1,000th of a kWh.
## 5 Gross calorific values

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Gross calorific value</th>
<th>Density</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat</td>
<td>13800 – 20500 kJ/kg</td>
<td></td>
<td><a href="http://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html">http://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html</a></td>
</tr>
</tbody>
</table>
6 Standard conversion factors

6.1.1 Scientific prefixes
The following prefixes are used for multiples of joules, watts and watt hours:

- kilo (k) = 1,000 or $10^3$
- mega (M) = 1,000,000 or $10^6$
- giga (G) = 1,000,000,000 or $10^9$
- tera (T) = 1,000,000,000,000 or $10^{12}$
- peta (P) = 1,000,000,000,000,000 or $10^{15}$

6.1.2 Energy
1 tonne of oil equivalent (toe) = 41.868 GJ = 11,630 kWh

<table>
<thead>
<tr>
<th>Ktoe</th>
<th>toe</th>
<th>GJ</th>
<th>kWh</th>
<th>MWh</th>
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<tr>
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<td>0.278</td>
<td>0.001</td>
<td>0.000001</td>
<td></td>
</tr>
</tbody>
</table>

6.1.3 Weight
1 kilogramme (kg) = 2.2046 pounds (lb)
1 pound (lb) = 0.4536 kg
1 tonne (t) = 1,000kg = 0.9842 long ton = 1.102 short ton (sh tn)
1 Statute or long ton = 2,240 lb = = 1.016 t = 1.120 sh tn

6.1.4 Volume
1 cubic metre (cu m) = 35.31 cu ft
1 cubic foot (cu ft) = 0.02832 cu m
1 litre = 0.22 Imperial gallons (UK gal)
1 UK gallon = 8 UK pints = 1.201 US gallons (US gal) = 4.54609 litres
1 barrel = 159.0 litres = 34.97 UK gal = 42 US gal

6.1.5 Length
1 mile = 1.6093 kilometres
1 kilometre (km) = 0.62137 miles

6.1.6 Temperature
1 scale degree Celsius (C) = 1.8 scale degrees Fahrenheit (F)
For conversion of temperatures: $^\circ$C = $5/9 (^\circ$F –32); $^\circ$F = $9/5 ^\circ$C +32

6.1.7 Area
1 acre = 0.404686 hectares