Aberdeen Heat & Power

Water Source Heat Pump (WSHP) report
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THE CHALLENGE FUND

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Aberdeen Heat & Power

The application of a large scale open water source heat pump and thermal store within an existing combined heat and power (CHP) and district heating system

This report has been sponsored by the Local Energy Challenge Fund which has been created to demonstrate the value and benefit of local low carbon energy economies. The new fund coincides with the launch of the Community Energy Policy Statement which sets out the Scottish Government's record of support for community energy and new ambition for holistic local energy solutions.

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Contents

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Abbreviations used

AH&P	Aberdeen Heat & Power Ltd
ASC	Available Supply Capacity
ASHP	Air Source Heat Pump
BODC	British Oceanographic Data Centre
CHP	Combined Heat and Power
CHPQA	CHP Quality Assurance programme
CoP	Coefficient of Performance which, in the case of a heat pump, is the ratio of heating supplied to the electrical energy consumed.
DECC	Department of Energy and Climate Change
DH	District Heating
DHN	District Heating Network
EA	Environment Agency (covers England only)
EU EED	European Union Energy Efficiency Directive
ESCo	Energy Supply Company
HDPE	High-density Polyethylene Pipe
MEF	Marginal Emissions Factor
NT	National Trust
PLC	Programme Logic Controller
SCaDA	Supervisory Control and Data Acquisition
SEPA	Scottish Environment Protection Agency
SPF	Seasonal Performance Factor
WSHP	Water Source Heat Pump

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Abstract

This paper investigates the feasibility of using a river or sea water sourced heat pump (WSHP) system to supply heating to the Aberdeen Heat and Power (AH&P) district heating system. Of the three systems currently operated by AH&P, the largest Seaton was chosen due to its proximity to water resources, namely, the sea and the river Don as well as the potential for expansion at the Seaton energy centre. The heating demand of the Seaton system is expected to continue to increase which will require the company to invest in new plant. The feasibility of a potential system was modelled using energyPRO software which allows the user to carry out a comprehensive, integrated and detailed technical and financial analysis of cogeneration systems. The quantity of heat contained within the River Don is also determined through the examination of flow rate and water temperature data datasets. An ammonia heat pump system is designed to extract and upgrade the heat from the river water to a heating supply at a temperature of 80°C. The financial feasibility and carbon footprint has also been analysed and discussed.

1. Introduction

AH&P was set up in 2002 with the specific aims of developing and operating district heating systems in Aberdeen to deliver affordable heat for hard-to-heat properties, in particular hard-to-heat high rise blocks, where a large proportion of residents resided in fuel poverty. The further aim was to assist Aberdeen City Council in carbon reduction targets through delivery of low carbon heat from combined heat and power systems. The company's aims still remain the same today and to achieve greater flexibility and diversity of operation the district networks also connect to nearby public and semi-public buildings. The longer term aim is to extend the district network throughout the densely populated public and commercial areas of Aberdeen to achieve a network of linked energy centres which could operate on a variety of fuel sources, thus giving further diversity and efficiency of operation.

The company supports and operates energy centres at three sites, namely Stockethill, Hazlehead and Seaton, and now supplies over 2000 flats in 26 multi-story blocks and 13 public buildings. Carbon emissions from these buildings have reduced by 45% and typical fuel costs to tenants have been reduced up to 50% over the previous heating system. Customer satisfaction surveys have indicated that tenants are very satisfied with the heating system. The schemes have received four high profile awards:

- UK Housing Awards 2008 – Increasing Environmental Sustainability
- UK Housing Awards 2008 – Outstanding achievement in Housing in the UK
- COSLA Excellence 2008 silver award
- The 2013 award for Excellence from Global District Energy Climate Awards

The Company continues to develop their district heating network and has installed a £1m extension of underground mains towards the City Centre which provides heat to the Council's Town House and other public buildings én route. A fourth energy centre is under construction in Tillydrone which will initially supply seven residential high rise blocks consisting of 450 flats, with capacity to supply heat to the wider Tillydrone community in the future, while the original Stockethill project has recently been doubled in size with an additional four blocks of flats connected and a new CHP engine installed in the extended energy centre.

The company relies solely on natural gas fired CHP plant and boilers to provide heat for distribution and for electricity generation which is mainly sold to a consolidator via the National Grid. The imperative of diversifying fuel sources and reducing carbon emissions has led AH&P to examine the feasibility of deploying a large WSHP to supplement the heat provided by the CHP plant. By siting the WSHP close to the CHP engine, electricity which otherwise would be exported to the grid, can be used for the operation of the WSHP. Results from the modelling of the system with the WSHP against an alternative case of adding an appropriately sized CHP plant to the current plant configuration indicates that substantial carbon and cost savings can be made due to the efficiency of the WSHP and also favourable reductions in the utilisation of peak load boilers and CHP plant.

This report presents the main findings from the modelling taking into account anticipated future heat demand increases, availability of low grade heat from proximate water resources and availability of different capacities of WSHP plant. It is expected that an appropriately sized heat pump could contribute much of the base load heat demand for any of the AH&P DH schemes without incurring a high carbon overhead or unaffordable capital and operational costs.

2. Background

2.0 Why Consider a Heat Pump?

Heat pumps – hailed as "game changing" by UK Energy Secretary Ed Davey in March 2014 and advocated by Professor Paul Younger, Rankine Chair of Engineering at Glasgow University – were first described by William Thomson, the first Lord Kelvin, at Glasgow University in 1852.

Modern heat pumps use electricity to turn cool water from rivers and lakes into hot water. Technology developed in Scotland is already being used to heat 8˚C water from a fjord in Norway to 90˚C.

 Water's ability to retain heat is far greater than the air, which heats up and cools down very quickly. Any open body of water, whether a river, the sea, canal, loch or lake, can be seen as both a plentiful and a replenishable sink of low grade heat which is ultimately derived from solar energy.

In respect to Scotland, there are numerous rivers such as the Clyde, Tay, Dee and Don as well as 9,910km of coastline giving access to exploitable and renewable low-grade water-based thermal energy.

The water supply pipes for a WSHP system transfer lower-grade heat with the ground itself acting as the insulator whereas district heating pipes connecting an energy centre with buildings on the heat network have to be heavily insulated to minimise heat losses. During the summer, when the ground is warmer, the water may even pick up energy as it flows from one point to another.

A heat pump as a form of renewable technology is eligible for the Renewable Heat Incentive (RHI). The RHI is viewed as a key factor in meeting the Scottish Government target of 11% of heat demand from renewables by 2020, and will play a significant role in decarbonising the heat sector by 2050.

2.1 Existing examples of use of large scale WSHPs

2.1.1 Duindorp, Netherlands[1]

The City of Hague has developed an innovative district heating concept that consists of a seawater central supply unit with a heat exchanger and heat pump unit that uses the nearby sea as a temperature source. The Hague and Vestia Housing Corporation have partnered with Deerns engineering consultancy to implement this energy source in the reconstruction of 800 of the 3,000 dwellings located within Duindorp - a settlement along the North Sea Coast consisting mainly of small former fishermen family houses built between 1915 and 1931. Heat is extracted from the sea whose temperature varies between 4-20°C to be upgraded 50-65°C, sea water heating station compensates for mismatch between low sea temperatures in winter and high heat demand versus the opposite in summer. In summer the centralised heat pump is by-passed with sea water passing through to a heat exchanger. Domestic scale heat pumps are installed in each dwelling. The scheme claims to reduce CO_2 emissions by 50% compared to the reference case and does not require a gas infrastructure. Other features are a short sea water trajectory, low transportation temperature and energy expenditure.

The cost of the project was met by a consortium local government and the private sector and breaks down with approximate figures as follows: domestic heat pumps €3m, heat network €2m, seawater heating plant €2.6m, total: €7.6m

2.1.2 Drammen, Norway[2]

The project was commissioned in 2011 with three heat pump systems giving a combined capacity of 14 MW for heating over 6,000 homes and businesses in the city of Drammen. The district heating system is owned and operated by Drammen Fjernvarme who have the rights to the concession area given by the Drammen Municipality. This requires all new buildings larger than 1000 m^2 to be built with a water-based heating system and connected to the district heating system. The heat pump uses the natural refrigerant ammonia that has zero global warming potential effect, relatively low toxicity and is easy to detect due to its pungency.

The plant draws in sea water from an inlet which is 1km out into the fjord and 35m under the surface. There, the water temperature is stable year round at 8°C with a variation of one or two degrees making it ideal for the heat pump to extract heat. In winter, the water is slightly warmer (9°C) than in the summer (8°C) when there is melt water coming off the mountains. The water is cooled by low pressure liquid refrigerant.

The system heats water to 90°C using a vapour-compression refrigeration cycle for use in building heating and hot water systems. The system has an average coefficient of performance (COP) of 3.0 and with the low cost of hydro-based electricity in Norway it is cheaper to run a heat pump than a gas or electric boiler.

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[1] See Duindorp case study summary, conference presentation "Seawater Heating Plant" by Paul Stoelinga and article in CleanTechnica.

[2] See the case study presented at the Institute of Refrigeration, April 2011. Also ehpa article

2.1.3 Värtan Ropsten, Stockholm[3]

With a total capacity of 180 MW, the sea water based heat pump system at Värtan Ropsten in Sweden, is claimed to be the world's largest. The system became fully operational in 1988 and is now operated by the Finnish energy company Fortum.

The system consists of six Unitop® 50FY heat pump units using the R134a haloalkane refrigerant which is hazardous and has a high global warming impact of 1,410 **[4]**. Each unit has a heating capacity of 30MW and uses 8MW of electricity. Output can be varied down to 10% of full capacity.

In summer warm surface water is abstracted from the sea and in winter water is taken via an inlet at a depth of 15m where the temperature is at a constant +3°C. In winter, sea water is ingested at +2.5°C and returned at 0.5°C

The water return and supply temperatures for the DH system are typically 57°C and 80°C.

2.1.4 Kingston Heights development[5]

In this West London scheme water is extracted through intakes positioned 2.5m below the surface of the river Thames, where the temperature is relatively constant year-round. After filtering, heat is transferred from the river water to a secondary circuit that links to a plant room where WSHPs increase the water temperature before distribution to mini plant rooms, where the temperatures are boosted further. The system is capable of delivering 2.3MW of heat to 137 apartments and a 142-bedroom hotel.

When the developer was asked whether he is confident that a system of government subsidies will reduce the pump system's £2.5 million price tag sufficiently to make the technology commercially viable on a large scale, he responded: *"It's very difficult to be precise when it comes to the cost of installing the system - each one will be different. However, it should be possible to install the system for the same sort of money as combustion-based technology and with the support of the government's renewable heat incentive, it should be commercially viable."*

The developer is positive about advising other developers to do this from a technical, commercial and environmental standpoint. He believes that the benefits that will accrue to the residents in the development and the hotel owner will be significant in terms of reducing energy bills as well as in terms of increased energy efficiency and reducing carbon emissions.

Water is abstracted from the river having passed through a technologically advanced stainless steel filter that ensures that no marine life can enter the system. The abstraction filters are fitted with an automated backwash system that is able to 'blow away' any detritus from the filter's mesh in order to ensure that an optimum flow is maintained at all times. That water is then passed through a second, even finer filtration process, to get rid of any silt before being fed through the heat exchangers. An internal closed loop system then transfers the captured thermal energy to an internal plant room in the Kingston Heights development about 200m away.

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[3] See: http://www.friotherm.com/webautor-data/41/vaertan_e008_uk.pdf

[4] See List of refrigerants: http://en.wikipedia.org/wiki/List_of_refrigerants

[5] See: http://www.cibse.org/Knowledge/Case-Studies/CIBSE-Case-Study-Kingston-Heights

Having passed through the heat exchanger the river water is transferred, untreated in any way, back to the river. It is expected to be slightly cooler by approx. 2°C with a return temperature of 7-9°C compared with 8-10°C when extracted. According to the developer *"the return water is instantly assimilated into the main body of water and returns to ambient temperature almost immediately"*. As an element of the agreement with the Environment Agency (EA), any water returned to the river from the closed loop system within the development will be within ±3°C of the river temperature.

2.1.5 Plas Newydd, Anglesey[6]

The 300kW marine source heat pump is the first commercial marine WSHP to be installed in the UK and provides all of the heating needed by the 18th-century mansion and gardens owned by the National Trust. The upgrade cost £600k and is expected to save around £40k a year in operating costs by displacing the oil-fired heating system which used to consume as much as 1,500 litres of oil a day in winter.

The award winning system takes sea water from the Menai Strait at 60m from the shoreline, through pipes to a heat exchanger on the shore. The pipes going into the sea are protected with caissons and blended into the shorescape using rocks. After passing through heat exchanger water (or glycol?) is then pumped up 30m of cliff face to the mansion's boiler house where the heat pump upgrades the heat to 55°C. Pre-insulated pipe then carries the heated water 100m to the Country House itself where it is used to heat the building at a temperature suitable for conservation and provide domestic hot water.

The system became operational since May 2014 and is performing well according to the NT who have reported a CoP of 4.08 and a SPF **[7]** of 2.82 as of December.

2.1.6 Portsmouth Port Terminal Building[8]

The Port Terminal is the sole user of a seawater heating system for use in a commercial building. According to their website, it is the first public building in the UK to be heated and cooled using thermal energy from seawater, dramatically reducing its carbon footprint and using only 20% of the energy of a traditional boiler/chiller system.

2.1.7 Alaska Sea Life Centre[9]

The Centre which is situated at almost 60° Latitude, consider themselves to be early adopters of sea water source heat pump technology, having chosen this technology over that of ASHP due to the higher CoPs achievable with WSHPs. This recently constructed system (2012) is relatively small, rated at 80-85kWe input and 288kWth output. The plant had a capital cost of $833,330 (£525k), annual glycol pumping cost of $24,833, electricity consumption of $61,300 and O&M of $10,000. The main objective of the project is to reduce GHG emissions and heating costs by eliminating dependency on fuel oil.

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[6] See BBC article, Heat from the sea to warm historic house: and National Trust article
[7] See: http://www.thegreenage.co.uk/coefficient-of-performance-seasonal-performance-factor/
[8] See: http://www.portsmouth-port.co.uk/about_us/port_information#sthash.PjVv807V.dpuf
[9] See: http://acep.uaf.edu/media/60861/ASLC-REAP-Forum-Presentation.pdf

2.1.8 Nakanoshima district, Osaka[10]

As part of a drive to reduce GHG emissions WSHPs have been installed in the Nakanoshima district of Osaka and made operational since 2004 to replace boilers and electric water heaters. Nakanoshima has abundant water resources in the form of two rivers with water extracted from the Dojimagaw and discharged into the Tosaborigawa. The extraction-return temperature change is kept within a range of less than ±3℃ which is considered not to significantly impact on river life.

2.2 The large scale WSHP market sector

The large scale heat pump sector is strongly related to the well-developed refrigeration sector, however, the application of large scale WSHPs to the DH sector has been historically limited to Scandinavia, Switzerland and Japan. That appears to be changing under pressure from the EU Energy Efficiency Directive (EED) and as Governments, including those of the UK and Scotland **[11]**, seek to diversify away from fossil fuel dependency.

So far there only appear to be two companies offering products, namely Friotherm and Star Refrigeration.

2.2.1 Friotherm AG[12]

Friotherm has its roots in the Sulzer group and offers heat pumps, chillers, components and services. The company became legally independent of its previous owners by means of a management buyout in 2005.

Friotherm offer the Unitop® range of Heat Pumps and Chillers which span from 1MW to 10MW in capacity and are aimed at the district cooling and district heating sectors. Each Friotherm product of is designed and configured according to the specific needs of a client.

2.2.2 Star Refrigeration[13]

The Glasgow based Star Refrigeration company offer the Neatpump range of heat pumps which use relatively benign Ammonia as a refrigerant. Neatpumps are available with capacities ranging from 350kW to 8MW with multiple modules offering a practically limitless capacity. There are several models of water sourced heat pumps within the range.

3. Potential low grade heat sources

Recent work by the Scottish Government indicated that the total heat demand for all settlements within 1km of the coast is 31TWh/yr and that the total (non-electrical) heat is demand 87TWh/yr for all of Scotland although not all this demand is for low grade heat, i.e. some demand is for higher grade, industrial heat **[14]**.

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[10] Town creation by making use of "river water" summary.

[11] See: Scottish Government: Towards Decarbonising Heat: Maximising the Opportunities for Scotland: Draft Heat Generation Policy Statement for Consultation, March 2014: http://www.gov.scot/Publications/2014/03/2778

[12] Friotherm AG: http://www.friotherm.com/

[13] An overview of the Neatpump range can be viewed here

[14] See the presentation by Hugh Muschamp at the Stratego Coaching Session 1, 17 Nov 2014:

Unused excess heat sources and resources cited by the Scottish Government include waste water treatment works, cooling towers, abandoned mine workings, rivers, geothermal, solar and EfW plants.

In August 2014 DECC launched their river source heat map **[15]** which shows that there is around 40 urban rivers and estuaries in England that could provide large-scale renewable heating supplies to local communities through water source heat pumps.

Useful work has already been done in Scotland in relation to using rivers for their low grade heat content **[16] [17]**.

Various heat sources have been identified in the Aberdeen City area as follows.

3.1 Rivers Don and Dee

Typically, the WSHP would take water from the river and return it at a lower temperature, by approximately 2°C. The advice that AH&P has received from SEPA indicates that such an extraction might be classifiable as a near-lossless abstraction although SEPA have said that AH&P would need to provide a more detailed explanation of intention as part of the application process **[18]**.

Care has to be taken in the placement of the pipes (generally coiled on mats and called pond mats) or panels to avoid any boat traffic or debris which might float past but once submerged (usually at least a meter deep) they would normally not require any further attention.

In Aberdeen there are two significant rivers one of which, the Don, passes close to the AH&P energy centres at Tillydrone and Seaton and is therefore considered below. The other, the Dee, has a flow rate **[19]** which is greater than although of a similar order of magnitude to that of the Don.

3.1.1 Flow rate

A dataset of the flow rate as measured close to the Parkhill Bridge (A947) at Persley was obtained from the Centre for Ecology & Hydrology **[20]**. The readings have been taken daily starting from 1 Dec 1969 up until 30 Sep 2013. The rate varies from 3.553 m^3/sec to 327.5m^3/sec with an average of 21.14m^3/sec and standard deviation of 18.92m^3/sec.

It is anticipated that the main operation period for the heat pump system will be during the winter months and therefore a flow duration curve was constructed, as depicted Figure 1 below, using flow rate data for the period 1 Oct to 30 April each year for the years 1969 to 2012. The curve gives a more reliable prediction for flow rate of the River Don and corresponds to that used by SEPA to help determine the amount of water that can be extracted from the river without detrimental impact to the environment. To illustrate with an example using the graph below, the Don flow rate is predicted to be higher than 10m^3/s for 76% of days during this period. The only limitation of this approach is that it

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[15] DECC's high level water source heat map is aimed at local authorities, community groups and private developers.

[16] The Conference "Harnessing Heat from Rivers" was hosted by Scottish Renewables and held on 10 Sept 2014.

[17] The potential for using the river Kelvin is explored in the paper "Heating Glasgow University with River Sourced Heat Pumps", 2014: http://www.gla.ac.uk/media/media_344366_en.pdf

[18] See the SEPA abstraction regime http://www.sepa.org.uk/water/water_regulation/regimes/abstraction.aspx

[19] The Dee has a flow rate of 3.664m^3/sec to 571.5m^3/sec as measured by the "Dee at Park" SEPA monitoring station close to the settlement of Drumoak in Aberdeenshire.

[20] The Centre for Ecology & Hydrology, National River Flow Archive Data Holdings: http://www.ceh.ac.uk/data/nrfa/data/data_holdings.html

does not account for possible climate change effects or unusual weather events such as a prolonged deep freeze or drought.
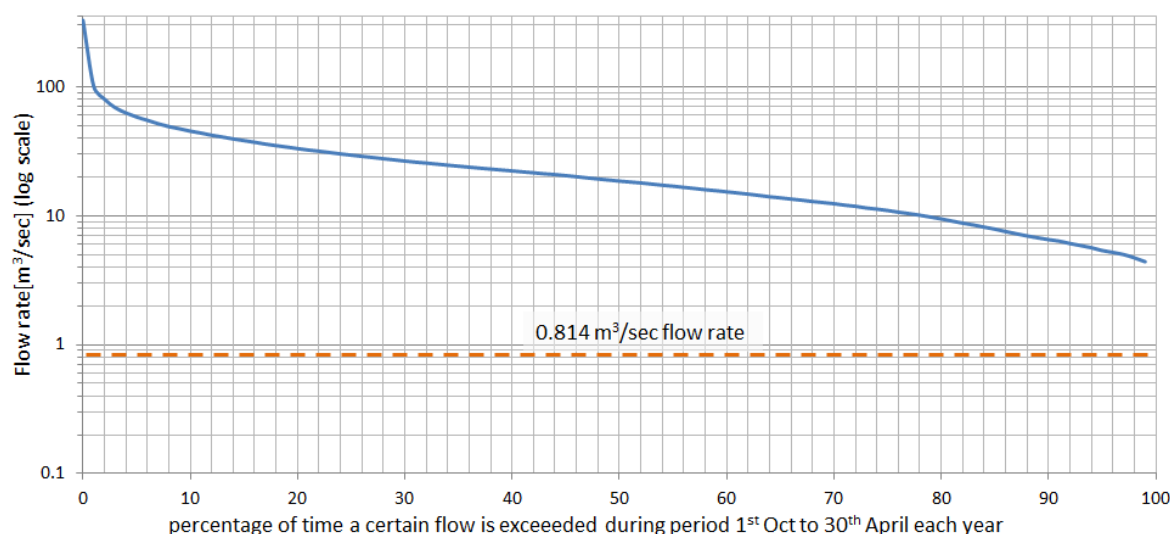
Figure 1 – River Don flow patterns

3.1.2 River Don temperatures

It is important to develop a good understanding of the river temperature patterns due to the risk that the temperature falls below the threshold (typically ≤3 °C) at which the evaporator section of the heat pump can freeze and potentially damage the system. A second risk is that the temperature falls below 4°C which would lower the Coefficient of Performance (COP) of the heat pump system to the point that requires the system to be switched off.

River temperatures were obtained from SEPA **[21]** who checked their monitoring location for the waterbody Dyce to the tidal limit and provided a summary of statistics as per table 1 below.

No. samples	Avg.	Min	Max	Std. dev.	Start date	End date
171	9.76	0.0	21.3	4.97	22 Feb 2000	19 Nov 2014

Table 1 – River Don temperature spread

According to SEPA, river temperatures further up the catchment are likely to be more variable and have a wider range.

Although the SEPA figures suggest that for most of the year the temperatures would not fall below 4°C, given the time period over which the data was collected and the limited number of data points, a more detailed temperature survey might need to be taken over the winter months. River temperature data can be collected using easily affordable temperature loggers **[22]** placed in the river with typical reading resolutions of 0.1°C, an accuracy of ±0.2°C and can record temperature every hour over a period of several months. Such a degree of accuracy would be sufficient for establishing the viability of water abstraction to supply a WSHP.

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[21] Scottish Environment Protection Agency: http://www.sepa.org.uk/
[22] Examples include the ThermaData® and Tinyttag model ranges.

3.1.3 A note on climate change effects

Observational weather data collected since 1961 clearly shows that the climate in Scotland has changed significantly over the last 40 years with average temperatures in Scotland increasing by 0.5°C since 1914 and most areas have experienced a significant rise in precipitation. This is most pronounced in winter months with the East of Scotland experiencing a 36.5% increase and the North and West of Scotland both receiving a 67-69% increase in precipitation over 1961 levels. The only notable exception is during the summer months in the North of Scotland which has seen a decrease in precipitation levels with some parts of the North West being up to 45% drier **[23]**.

3.2 Sea water

Sea water, like any water, has the ability to retain heat for a long period of time and due to the specific heat of water it takes a lot of heat to warm it or indeed to cool it. This ability to retain heat allows significant quantities of heat to be extracted close to urban areas with high heat demand without detriment to the marine environment. Operational experience from the Drammen system indicated that a 1˚C higher temperature in the sea gives a COP increase of 1.3% and performance increases of 2.8%.

For a coastal abstraction registration with SEPA is required. An extraction licence is generally required for any extraction above 20m^3/day, this generally means anything above a 4kW water source heat pump needs an extraction license if the heat pump runs 24hrs a day. Discharge consent is also required and it is important to consider what happens to the colder water after it has flowed through the heat pump.

The design of seawater intake systems needs to consider a multiplicity of conditions such as scouring, filtering and corrosion, however, long experience has been accumulated through, for example, the operation of desalination plants **[24]**. Laying the pipes out to sea may require permission from the Crown Estate and the Harbour Board.

Some of the issues and potential barriers are:

➢ Due to the corrosive nature of seawater on the associated infrastructure requires special (and often expensive) materials.

➢ The sea water intake can be prone to fouling which can be from biological sources, the effects of corrosion or sludge from ships or a combination of these factors.

➢ Depending on distance from the shoreline, the caissons enclosing the pipes, or the pipes themselves if caissons are not used, and sea water intake may be vulnerable to anchor drag.

➢ Obtaining permits.

➢ Pipes crossing or under the beach and breaching the sea wall.

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[23] Education Scotland: Climate change in Scotland
[24] See the Design Guidelines of Seawater Intake Systems: http://www.desware.net/Sample-Chapters/D11/D05-002.pdf

3.2.1 Sea Water conditions and temperatures

Sea water temperatures were obtained from BODC **[25]** for the BODC reference 399068 which is 1.62km from the Seaton energy centre and 1.2km from the shoreline. Temperatures were measured on 22 Jan 1992 and range from 6.71^{o}C at the surface through to 6.97^{o}C at 11m depth.

3.2.2 The Crown Estate[26]

In Scotland the Crown Estate manages about half of the coastal foreshore and almost the entire seabed and has a significant role in supporting ports and harbours as well as offshore renewable energy. Their role is to make sure that the assets they invest in and manage are sustainably worked and developed to deliver the best value over the long term. All their annual revenue profit is paid to the UK Government.

Over the past 15 years the Crown Estate Marine Stewardship Programme has invested over £10m in community projects and scientific research to support and enhance the UK's marine assets. It might behove AH&P to explore this as a possible source of funding to help cover the cost of sea pipes.

3.2.3 Aberdeen Harbour[27]

Aberdeen Harbour Board would need to be approached and advised of a planned pipeline deployment, and also in respect of any future potential of sea extraction in respect of the Harbour Board's long term ambitions to construct a new harbour in the Nigg Bay area..

3.4 Rubislaw quarry

Rubislaw quarry is a privately owned **[28]**, former granite quarry located at the Hill of Rubislaw in the west end of the City. With a depth of 142m deep and a diameter of 120m, it is one of the largest man-made holes in Europe.

The quarry is now filled with water and therefore it may be possible to abstract water and return it at 2°C lower temperature without adverse effects due to the large volume of water accumulated. However, no investigation has been carried out due to the remoteness of the site from existing AH&P heat networks.

Recent research work has been carried out by the University of Strathclyde engineering Department on the performance of a reservoir-based water source heat pump **[29]**.

3.5 Waste water treatment works

Kelda Water Services Grampian **[30]** operates waste water treatment facilities in the NE of Scotland including at Nigg and Persley. Kelda use an anaerobic digestion process to treat sludge which produces a valuable agricultural by-product and creates heat and power for their sites.

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[25] the British Oceanographic Data Centre – see: http://www.bodc.ac.uk/

[26] See: http://www.thecrownestate.co.uk/our-business/in-scotland/

[27] See: http://www.aberdeen-harbour.co.uk/

[28] The Quarry is owned by Rubislaw Quarry Aberdeen Limited – see: www.rubislawquarry.co.uk

[29] Assessing the performance of a reservoir-based water source heat pump, MSc thesis by A.C.Morton, 2013.

[30] See: http://www.keldawater.co.uk/our-operations/kws-grampian.aspx

Although Kelda's sites are remote from existing AH&P heat networks, it may be useful for AH&P to determine whether Kelda returns warm water to the sea or river in the event a more proximate heat network was being considered as part of a future expansion. There are instances of waste water treatment plants in Norway and Japan whereby the relatively warm waste water is used as a feed to a water source heat pump.

4. Some important considerations

4.1 System monitoring

AH&P use a building energy management system (TREND) with the principal role of monitoring temperatures and pressures at crucial points in the three AH&P networks. TREND enables problems such as leaks or poorly performing components to be timeously identified. In addition there are gas and heat flow meters at various points in the system. The deployment of a WSHP would necessarily require the installation of additional monitoring instrumentation.

4.2 Available Supply Capacity[31] (ASC)

ASC or "availability" refers to the amount of electricity that the Distribution Network Operator (DNO) is required to make available for your site. Essentially, it is the maximum electricity you can draw from the grid at any one moment, without incurring hefty financial penalties.

ASC is measured in Kilo Volt Amperes (kVa), and for half-hourly metered sites is charged on a monthly basis as a standing charge. Any site with a requirement of 100 kVa should be half-hourly metered.

If AH&P installs a 4MW output heat pump then there could be an additional ASC charge to cover the supply of electricity from the grid direct to the heat pump. This requirement would be necessary to cover periods when there was insufficient electricity generated by the CHP plant for the WSHSP. Alternatively the system could be designed such that the WSHP would be powered down if there was insufficient generated electricity available to run the system

Assuming the WSHP is running at full capacity then the electric demand will be 1,378.5kW which corresponds to approximately 1,750kVa and translates to a £210 daily charge or £76,650 per annum.

4.5 Cooling water

The water returned from a WSHP will be at an approx. 2°C lower temperature than the extracted water which makes it potentially useful for cooling purposes in buildings such as office blocks, laboratories and, in particular, data centres. In Aberdeen there are existing datacentres, as well as centres under construction such the brightsolid [32] Tier III Data Centre located at the Aberdeen Journals' Lang Stracht site.

The integration of DH and data centres is well established in Sweden and Finland where DH companies take the surplus heat from the centres and, in what appears to be a growing trend, supply cooling water to centres as well as other public and commercial buildings [33].

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[31] For more detail see: http://utilitiessavings.co.uk/resources/available-supply-capacity/

[32] See: brightsolid to open Aberdeen Data Centre, 13 Oct 2014:

[33] Helsingia Energia have produced as useful summary on District Cooling: a cooling solution for climate challenges

The cost of cooling is high in the UK with 1kWh of cooling costing 3p to produce **[34]** and therefore the sale of cooling water could be a valuable source of income for AH&P. However, as with DH, the delivery of cooling water would require the construction of a sub-surface network of dedicated pipes with concomitant civils costs albeit the level of insulation need not be of the same specification as that used by heating pipes and the cost of civils could be offset in situations where heating pipes are being laid as part of the same project.

A recent workshop **[35]** jointly organised by the UK District Energy Vanguards Network and the RESCUE **[36]** project addressed the opportunities and challenges of district cooling in the UK.

4.6 Thermal storage

Water based thermal stores as large as 20,000m^3 have been used reliably for decades in the context of DH networks. The use of an appropriately sized thermal store alongside a large WSHP on a heat network enables a greater flexibility of system operation, in particular, enabling the WSHP to be run during the night when there can be a surfeit of supply of electricity and a shortage of demand across grid, and the potential for lower tariff charges. The WSHP can then be shut off or run at part-load during the day to permit maximal electricity production from the CHP plant.

The benefits of including thermal storage have been demonstrated in several studies, in particular, increased operational flexibility of the system, improved balance sheets, greater utilisation of plant and lower GHG emissions.

4.6.1 Cost of thermal store

The cost for buying and installing a thermal store larger than 5m^3 are not listed in catalogues which reflects the requirement for larger stores to be fabricated to fit a specific site and DH system.

According to a Tyndall Centre study **[37]**, the cost of thermal storage is approx. £1,000/m^3 whereas a recent study by UKERC **[38]** indicates that for tank-based thermal stores systems with a volume of around 300m^3, typical of DH systems in the UK, a cost of approx. £390/m^3 should be expected.

5. Heat Pump system

5.1 Case 1 – locating the WSHP at the Seaton energy centre

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[34] Conversation with David Pearson of Star Refrigeration, 14 Nov 2014.

[35] In July 2014 the District Energy Vanguards Network met for a workshop on Smart Cooling in Urban Europe. The workshop agenda (with links to presentations) can be found here.

[36] The project REnewable Smart Cooling for Urban Europe aims to address the key challenges for the further development of district cooling using low and zero carbon sources: http://www.rescue-project.eu/home/

[37] The potential for thermal storage to reduce the overall carbon emissions from district heating systems, Jan 2013: Tyndall Working Paper 157

[38] UKERC study: The Future Role of Thermal Energy Storage in the UK Energy System, 25 Nov 2014.

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The Seaton energy centre and network is the most extensive of the three sites operated by AH&P. Current heat demand is approximately 25GWh per annum with an annual demand growth rate of 4% as more buildings are connected up.

The outgoing flow temperature at Seaton is typically 80°C with a return of 50°C during the cold season and 75°C with a return of 50°C in the warmer part of the year.

The Seaton energy centre has sufficient space to house the WSHP and it is also only 500m from the shoreline and 850m to the centreline of the mouth of the River Don. In both cases, the WSHP feed pipes would need to traverse a municipal golf course and possibly a football pitch.

Of the two water sources, the more desirable would appear to be sea water extraction due to the more stable temperatures and potentially easier access to the shoreline via an existing opening under the Beach Promenade. In the case of the River Don route either a busy road would need to be closed while pipelines were trenched or directional drilling would need to be undertaken using specialised equipment.

Figure 2 - possible route for sea water pipes

5.1.1 Sea water pipework construction

A specialist subcontractor will have to be engaged for the pipe laying.

HDPE pipes **[39]** of 350mm diameter with a length of approx. 1,600m should be appropriate and sufficient. The return pipe need not be as long as the intake pipe.

The pipes will need be laid on the seabed and anchored by fitting concrete weight rings (anchors/blocks) and fastenings. A summary **[40]** of the necessary operations might be as follows:

a) Carry out a survey of the sea bed to be able to plan required operations before laying the pipes.

b) Use crane to fit concrete weight rings onto the HDPE pipes floating over the sea surface then position the pipes.

c) Prepare offshore and onshore trenches for the pipelines. In this regard, the predetermined route on the seabed would need to be excavated, dredged, graded, and levelled by using a floating crane, underwater stone crusher, hydraulic polyp grab, and rock drillers. On the sea bottom, rocky parts would need to be broken and holes filled.

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[39] See: https://plasticpipe.org/pdf/high_density_polyethylene_pipe_systems.pdf

[40] This summary is based on a description of the construction of the seawater intake pipelines of a desalination plant in Libya by the ARAS company.

d) The onshore part of the HDPE pipes will be laid into the trench dug onshore by using a land crane and excavator.

e) The offshore part of the HDPE pipes and the intake heads will be submerged into the sea and laid into the trench at predetermined coordinates by a floating crane and tug.

f) Additional concrete weight anchors may need to be fixed onto the submerged pipes.

g) Sacrificial anodes may need to be installed on metallic parts of the equipment for cathodic protection against corrosion.

h) During the pipe laying and in its final position, stress and tightness analyses will need to be done. Underwater flange connections will need to be tightened by divers using a torque meter.

i) For cleaning, maintenance, and repair works of the pipeline system a pig launcher system connecting the basin and the HDPE pipelines will possibly need to be installed, fitted and aligned onshore.

j) Marker buoys will possibly need to be installed by using GPS at predetermined coordinates for establishing an offshore warning system.

k) After the pipes and intake head are laid and the trench backfilled, inspection dives may be necessary.

l) Final levelling of the pipes and intake head may need to be made by using water jets and underwater rock drillers and the spaces under them filled by placing fabric formwork bags. Fabric formwork bags may also be used for scour protection by placing these around the pipes and intake heads along the route of whole pipeline.

5.1.2 Water extraction from an open loop borehole[41]

Consideration might also be given to the abstraction of groundwater from the sub-surface area close to the energy centre. AH&P understand that usable quantities of water would be available as the water-table is close to the surface in the Seaton area, although this would require to be fully substantiated. Such an abstraction requires the sinking of one or more boreholes for extraction together with one or more boreholes to enable the recharging of the groundwater or discharging the cooled water to a water course such as a stream or the sea. A submergible water pump will be installed at the bottom of the abstraction borehole.

Assuming the WSHP ran continuously for 24 hours at full output, then the maximum daily water requirement would be 21,172m^3. The extracted water temperature needs to be above 4°C and the water might need to be filtered depending on the maximum permissible particle size for the primary loop. The will also be maintenance and flushing considerations. AH&P would need to apply to SEPA for an abstraction and a discharge license as there a risk of Groundwater depletion due to excessive pumping **[42]**.

An important aspect of borehole extraction is the use of sand packs around the lower section of the well which filter the ground water as it flows into the slots set into the PVC casing at the bottom of the well.

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[41] For a summary of borehole heat pump systems, see: http://www.eartheat.com/borehole-heat-pumps.html

[42] For a description of the causes and effects of groundwater depletion, see here.

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Boreholes have to be specifically designed around parameters such as the amount of water to be extracted, the sub-surface geology and the depth required. Cost escalation can occur if, for example, the well needs to be drilled deeply or if the geology is difficult which then may require steel rather than PVC casing for some sections of the well. However, once drilled and commissioned a well can last for many decades.

5.1.2 Water extraction from a trench

Due to the proximity of the river Don, there is a reasonable possibility that the area around the Seaton energy centre is underlaid by gravels from alluvial deposits saturated with seawater in which case it would be straightforward to extract significant volumes of water via a large trench **[43]**. Such a trench would be approx. 1m width by 3m in length with a depth of 5m and supported internally by concrete rings. There would need to be approx. 100m between the trench and the discharge location. To establish the suitability of the area for extraction a survey would need to be commissioned to establish the depth and extent of the gravels. Typically a series of boreholes of 8 to 10 inches in diameter and approx. 10m in depth would be drilled. SEPA might also have information from their records.

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[43] From a conversation with Michael Moggeridge of Land & Water Resource Consultants Ltd (LWRC)

5.2 Case 2 – locating the WSHP at the Tillydrone energy centre

The Tillydrone energy centre will be completed early this year and will initially house a natural gas fired CHP engine with a capacity of 1,063kWe. The centre has sufficient spare floor area and ceiling height to house a WSHP and is relatively close (~0.3km) to the river Don. A short distance downstream is the site of the flume of a former paper mill where the river flow was initially used as a power source and subsequently as a point of water abstraction. The route to this point is ~0.46km and is depicted in red in Figure 4 with the shorter route in yellow.

The scheme, which is currently under construction, will initially supply heat to seven blocks of flats with an estimated heat demand of 5,384MWh per annum. To justify the deployment of a WSHP an additional heat demand of perhaps as much again would have to be found.
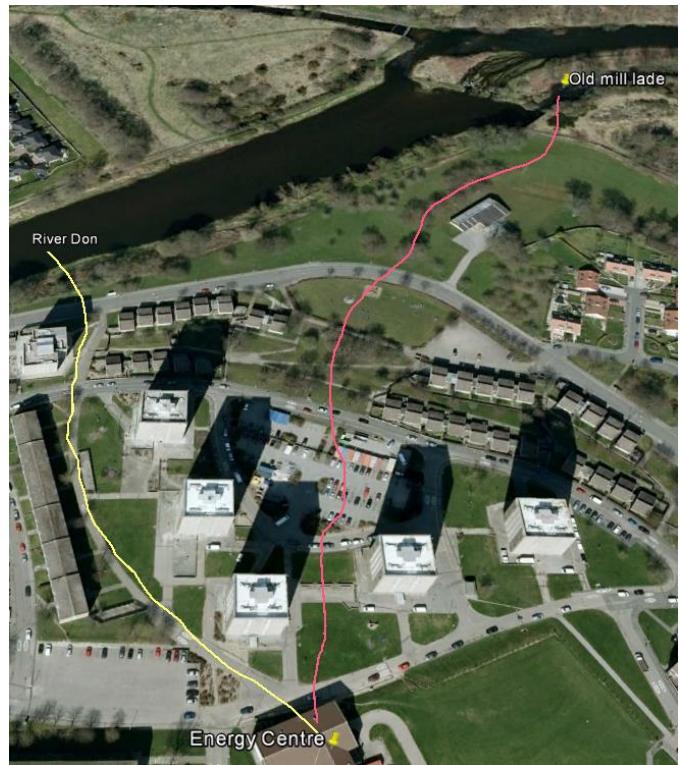
Figure 3 - Google Earth image of notional river pipe routes for Tillydrone scheme

The cost of the water extraction infrastructure from a fresh water source is approx. 20% cheaper than that for sea water extraction **[32]**.

5.3 A generalised case applicable to Scottish coastal and riverine settlements

Coastal communities, defined as within 5km of the coast, make up 41% of the total population of Scotland, with 68% of the coastal population living within the 'developed coast' which consists of urban areas such as large towns and cities. 14% of the coastal population live within the 'undeveloped coast' which consists of small towns and rural holdings as well as agricultural and forestry land **[44]**.

There are 153 settlements in Scotland with a population in excess of 4,000 **[45]**. For non-coastal settlements, the majority have practical access to a large volume water resource such as a river, canal, loch or reservoir.

Some of these settlements will be off-mains gas **[46]** and some will host areas which have high heat demand such as high density housing estates or industrial and commercial zones. It is this subset of settlements which might be potentially suitable for a WSHP, thermal storage and heat network combination which, with some coordination, could benefit from economies of scale and improving supply chain performance.

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[44] From "Scotland's Coastal Assets", James Hutton Institute

[45] From "Mid-2012 Population Estimates for Settlements and Localities in Scotland", National Records of Scotland.

[46] Around one third of Scottish houses are off-mains gas - mainly in small towns and rural areas - of which roughly one quarter will be local authority/housing association properties. Scotland's Renewable Heat Strategy: Recommendations to Scottish Ministers

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Such a combination could also make use of a biomass boiler as the primary heat source which would require a covered area for fuel storage but would not incur ASC charges.

5.3.1 WSHP, thermal storage and grid balancing

One advantage of using a WSHP over a biomass boiler is that a WSHP could be a useful consumer of grid electricity for periods where there is generation surplus to consumption demand. The imbalance between power generation and consumption is reflected in the 'Settlement and Trading Charges' of the Balancing and Settlement Code (BSC) [47] or, alternatively, the system frequency can be used as a measure of the state of balance of the system [48]. These imbalances can be resolved via the temporary measure of taking generation off-line with consequential payments known as "constraint charges" which resulted in £89.34m paid out to Scottish based generators in 2014 as per figure 4 overleaf.
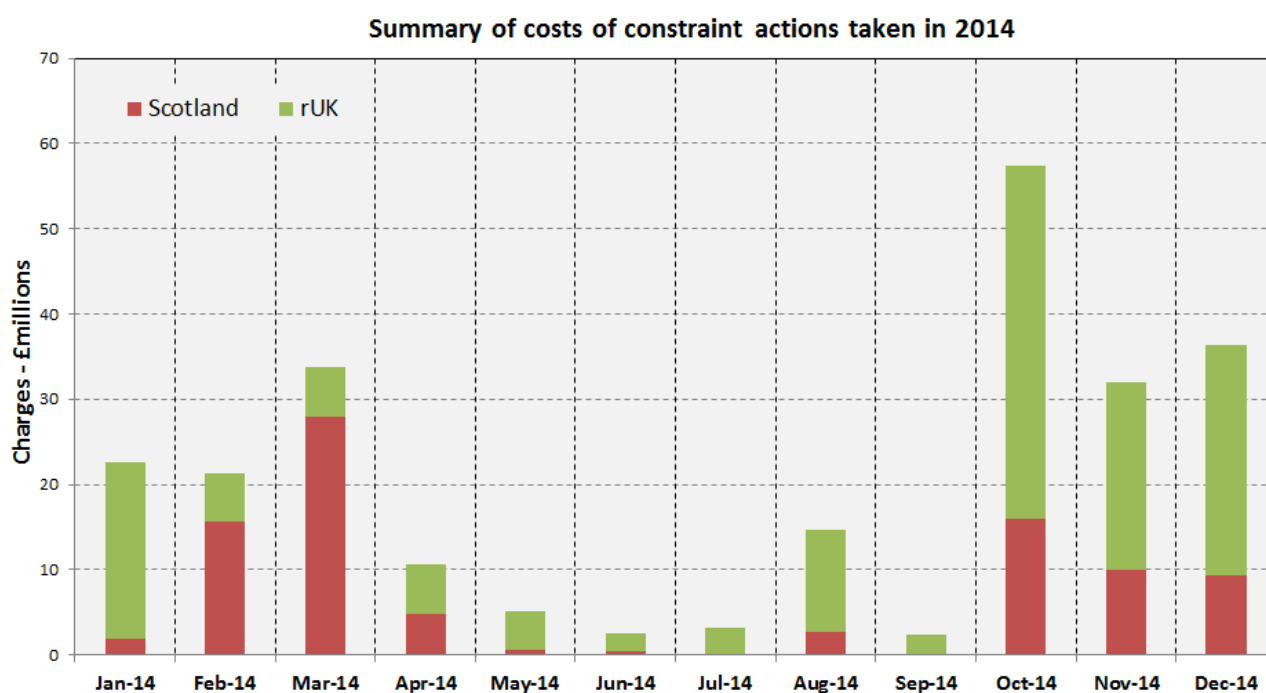

Figure 4 - constraint charges for Scotland and rest of UK 2014 [49]

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[47] See here for a detailed explanation of the wholesale electricity market.
[48] See the National Grid electricity operational information pages.
[49] Taken from the National Grid monthly balancing services reports.

6. Seaton results

The results described in this section are derived from successive energyPro simulations for the two system cases labelled A) and B) as per figures 4 and 5 below.

The simulations for the two cases cover a period of 15 years with heat demand increasing by 4% per annum.

Each simulation was run through energyPro both with and without a 200m^3 thermal store.

Chart outputs for simulations **without a thermal store** are depicted with a **broken line** and are **labelled 'NS'** in the chart legend.

The two system cases are as follows:

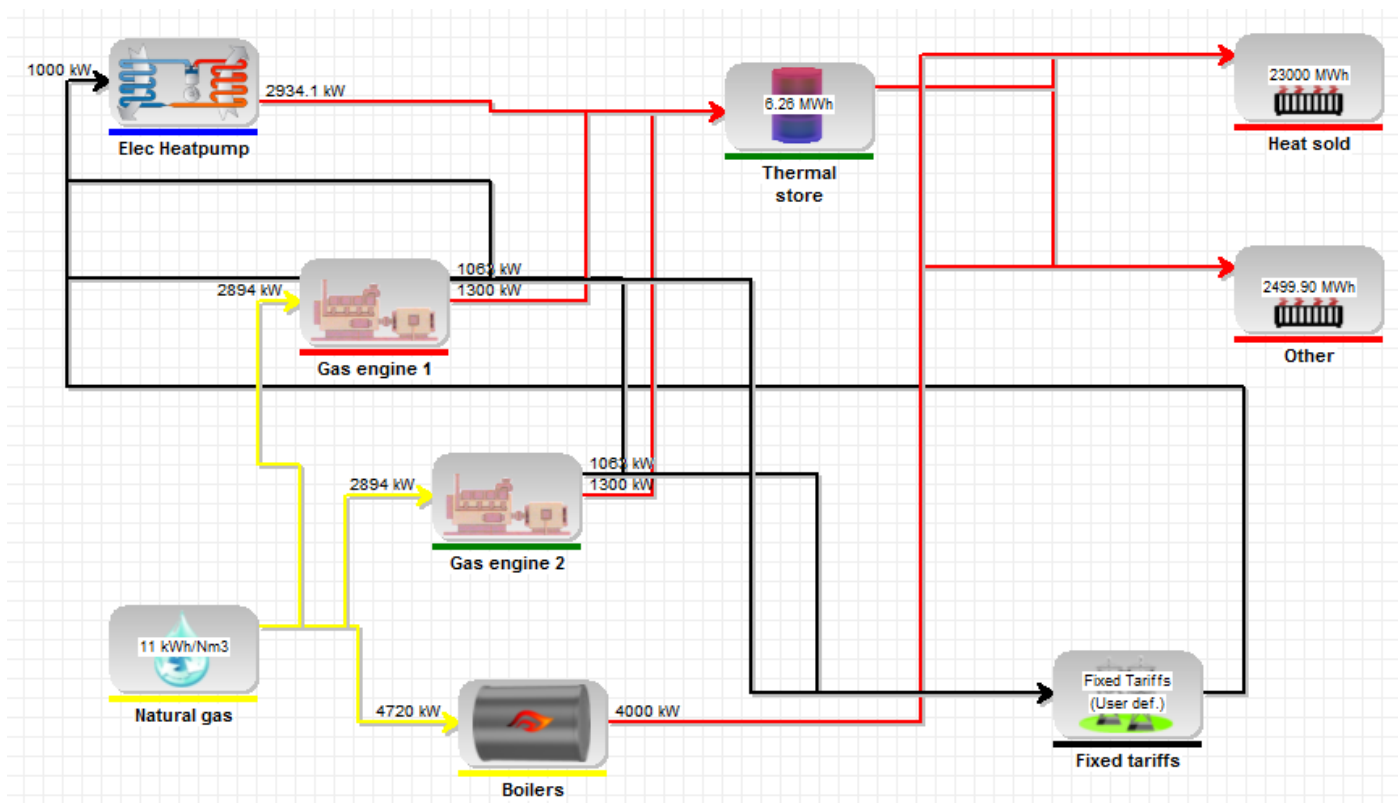A) Two 1,063kWe (1,300kWth) CHP plants and one 2,934kWth WSHP as per figure below.

Figure 5 - Proposed CHP, WSHP and boiler system case for Seaton

B) Two 1,063kWe (1,300kWth) and one 2,679kWe (2,646kWth) CHP plants as per figure below.
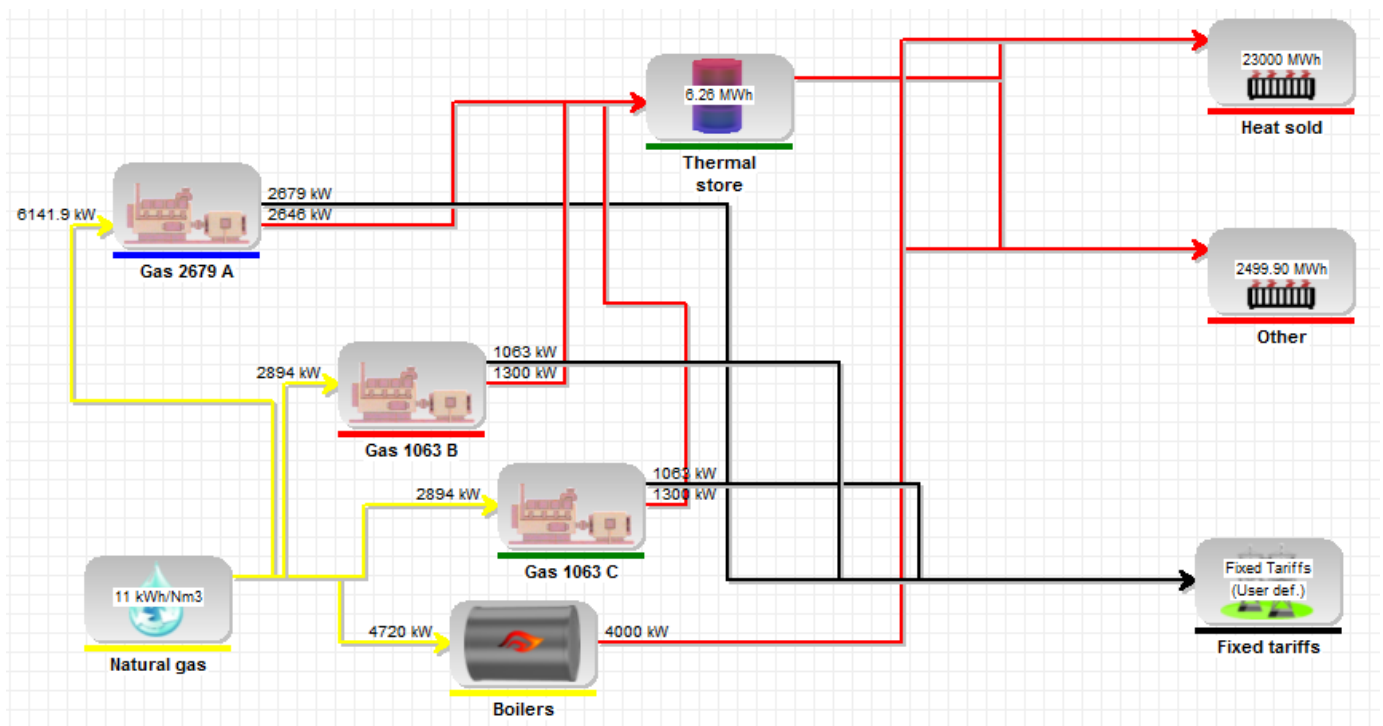

Figure 6 - Alternative CHP and boiler system case for Seaton

6.1 operation

6.1.1 Electricity production

The chart below depicts electricity exported to the grid. For the WSHP case A) there are two CHP plant producing electricity but with an increasing proportion of their total production (27% in 2015, 48% by 2029) being used to drive the WSHP and its associated water extraction pump.
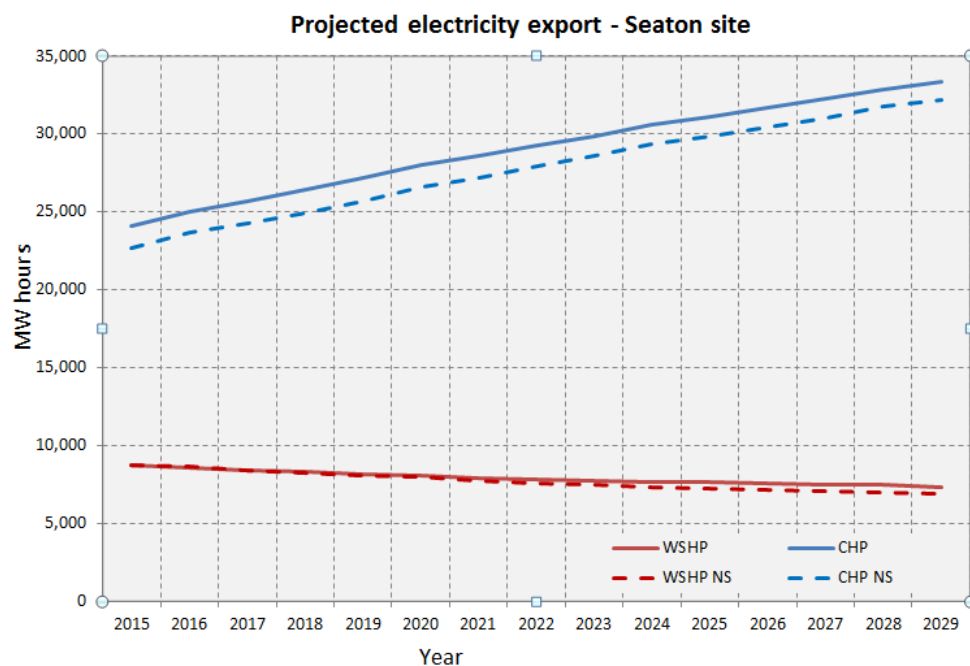

Figure 7 - Electricty export MW hours per annum

6.1.2 Gas consumption

Clearly, the consumption of gas is markedly lower for WSHP case A) with consequential lower gas costs and CO_2 emissions.
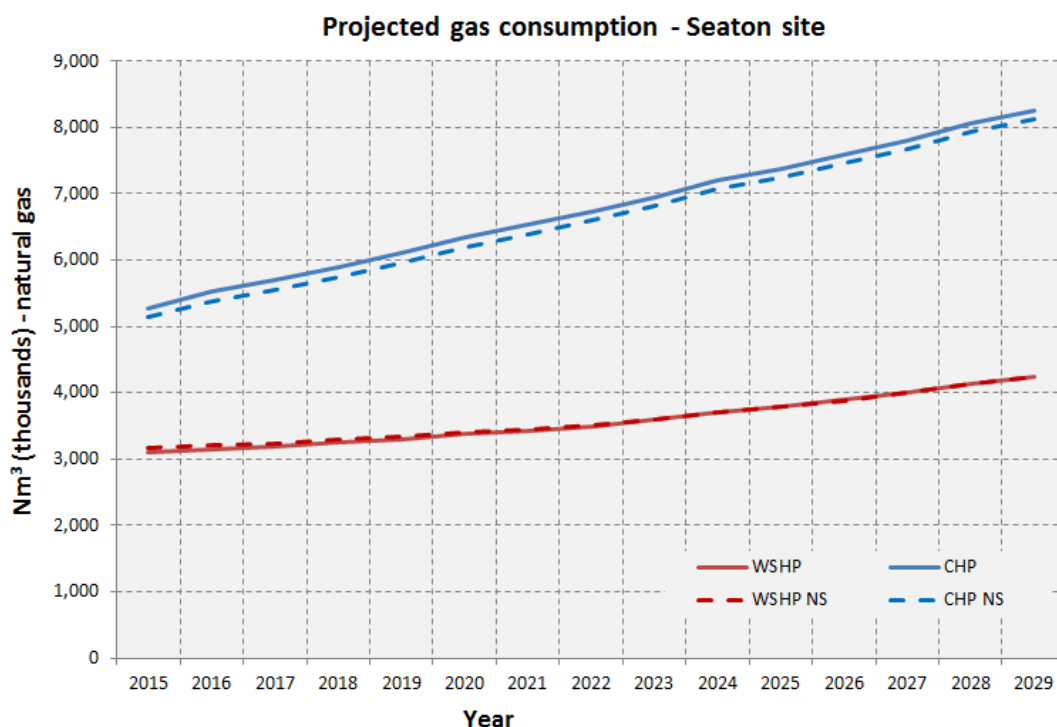
Figure 8 - Natural gas consumption

6.1.3 Case A) utilisation

Utilisation of the WSHP increases to meet growing heat demand with consequential but less marked increase in CHP utilisation. The effect of a thermal store is also notable in reducing boiler usage.
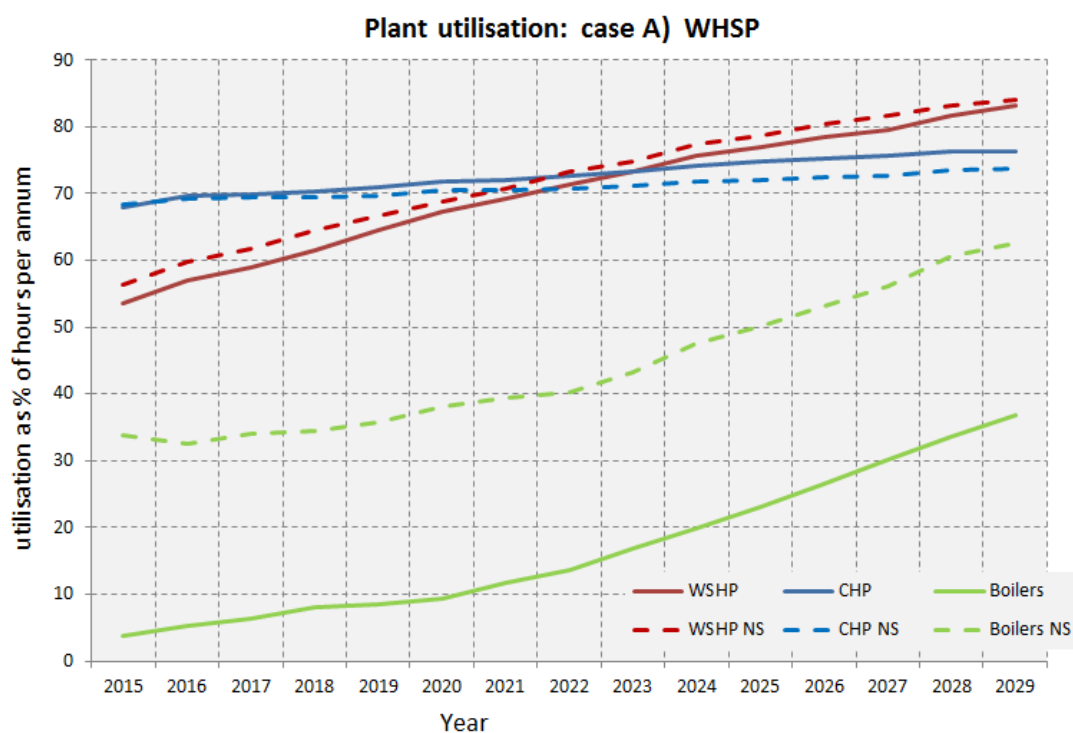
Figure 9 - Plant utilisation for Case A)

6.1.4 Case B) utilisation

Utilisation of the CHP plant increases to meet growing heat demand more markedly than in case A). As with case A), the effect of a thermal store in relation to boiler usage is also notable.

Plant utilisation: case B) CHP

Figure 10 - Plant utilisation for case B)

6.1.5 Boiler heat output

In both case A) and B), the effect of a thermal store is to reduce the dependency on peak load boilers.

Projected boiler output

Figure 11 - Boiler output for case A) and B) with and without thermal store.

6.2 Financial model

6.2.1 The non-domestic Renewable Heat Incentive (RHI)

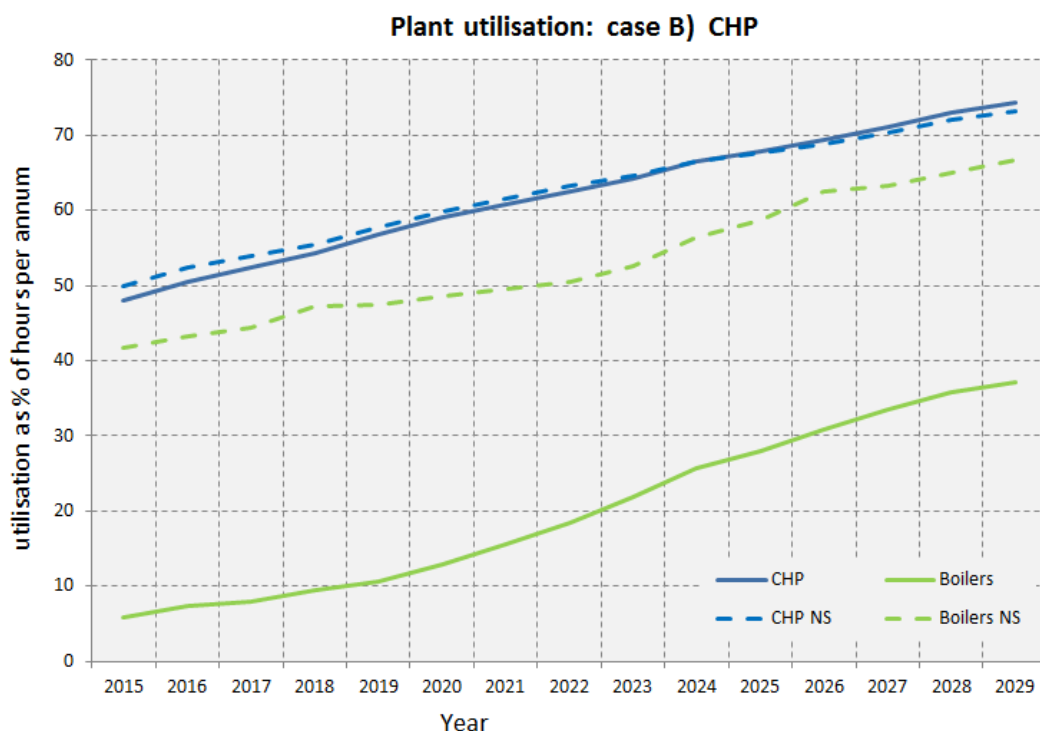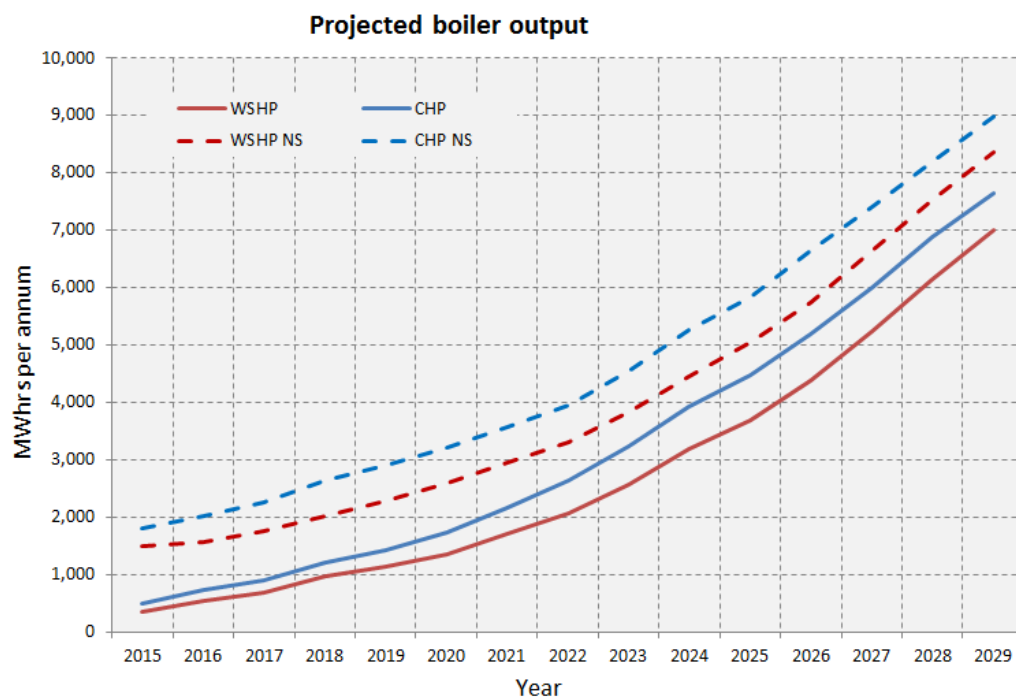The RHI is a payment system for the generation of heat from renewable energy sources administered by Ofgem and similar to the Feed-in Tariffs scheme for renewable electricity. It became active in the UK on 28 Nov 2011 for non-domestic heat production.

RHI is a key measure for meeting the Scottish target of 11% of heat demand from renewables by 2020, and is intended to play an important role in decarbonising the heat sector by 2050, with significant progress being made by 2030.

6.2.2 Summary of how RHI works

RHI payments are made quarterly at a certain amount per kilowatt hour (kWh) of heat generated from the WSHP. How much RHI payment received depends on:

> ➢ The type of technology installed.
>
> ➢ How much heat the WSHP can produce (its capacity).
>
> ➢ How much heat is actually used.

WSHP RHI tariffs have two payment rates called 'tiers' with the tier 1 rate paid up to a certain limit and, if more energy is used beyond this limit, the rest of the energy is paid at the tier 2 rate.

Non-domestic installations receive RHI payments based on the total measured heat output of the WSHP and therefore heat and electrical metering will need to be installed to monitor the usage and performance of the WSHP.

6.2.4 Tariff

For WSHPs the tariff is split in two parts, 8.7p/kWh for the first 1314 hours of operation, (a 15% load factor) and 2.6p/kWh for any operation above 1314 hours **[50]**. The tariff structure is designed to stop the generation of heat for the purpose of overclaiming the tariff.

Ofgem is responsible for publishing quarterly tariff tables showing the tariffs that will apply for each tariff period following DECC's quarterly tariff announcement.

DECC reviews the scheme's expenditure forecast based on the number of accredited installations and announces any changes to the tariffs that will apply in future. DECC advises whether any tariffs will be reduced, the level of reduction, what the new tariffs will be, and when they will take effect. The maximum level of reduction for any quarter, which is also known as "digression", is set at 5%.

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[50] A worked example can be found in Ofgem's website. Non-domestic RHI Guidance Volume Two: Ongoing Obligations and Payments (Version 3.1) pages 35 and 36

### 6.2.5 Projected net cash inflow and the effect of RHI

To ascertain the viability of generation plant purchases an income projection was undertaken using current prices for gas purchase and per unit heat and electricity sales but with an expanding heat demand based on the average previous years' growth of 4% per annum. These projections are depicted in **figure 12** below and are based on estimated AH&P costs, results from energyPro and parameters such as current RHI tariffs as laid out in **Appendix B**. The noticeable uplift in cash inflow in 2024 marks the completion of the loan repayments.
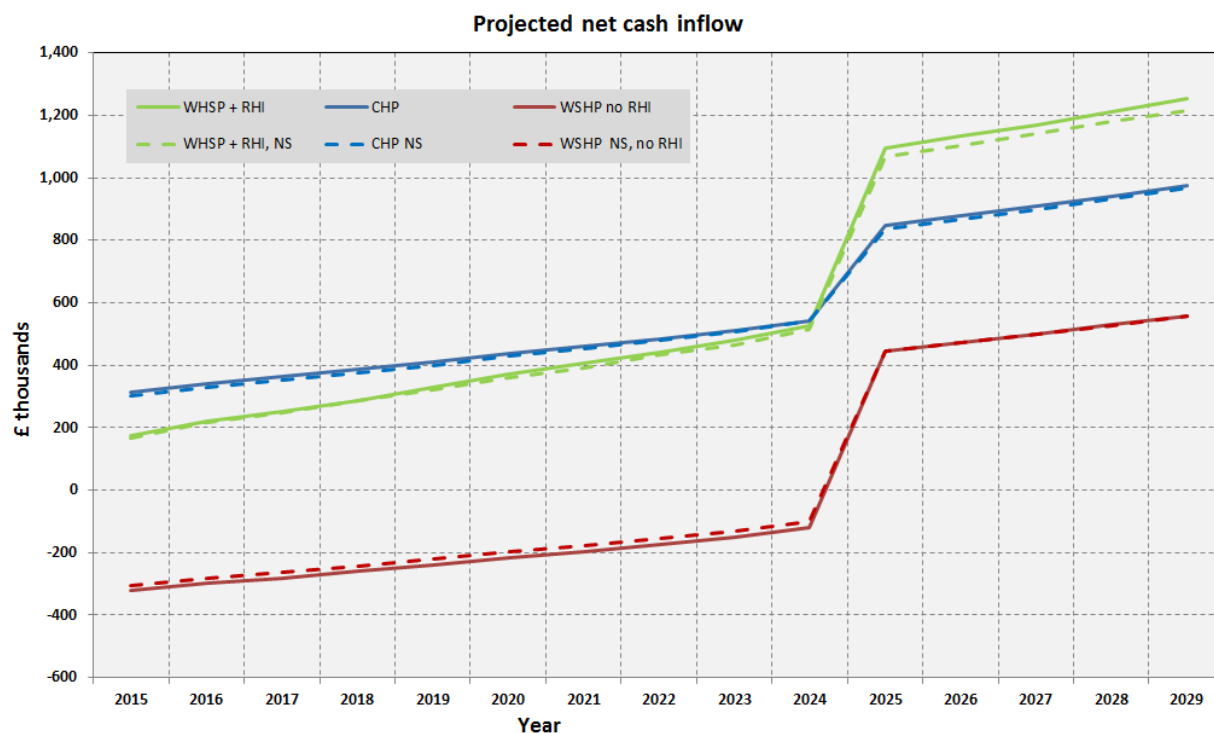
Figure 12- Income streams for case B) and case A) with and without RHI.

The projections confirm the crucial role of RHI in making the WSHP case viable and also suggest that the addition of a thermal store would improve the income stream sufficiently to pay for its own cost. The benefit of a thermal store for the CHP case B) is not so apparent and points towards the need for more detailed modelling. The modelling of the system is uncertain due, not least, to the price volatility of natural gas as depicted in the **figure 13** below.
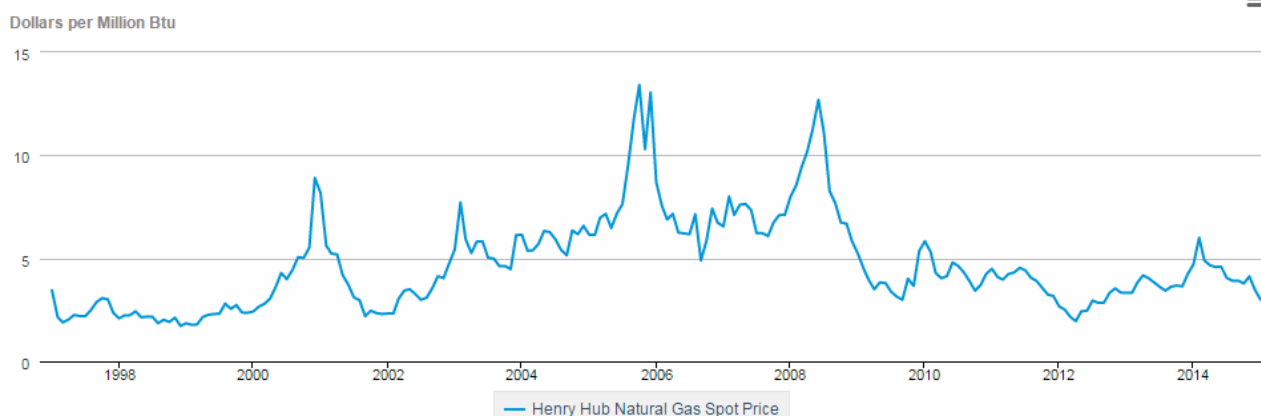
Figure 13 - Price volatility of natural gas

6.3 Carbon savings

6.3.1 Methodology and calculations

Carbon savings have been calculated by taking into account key greenhouse gas releases, primarily CO_2, from the following energy consumption processes:

a) Energy consumed by the CHP plant, WSHP and boilers to produce electricity and heat (Fplant).

b) Energy saved by not running individual domestic boilers (Fsave). This figure is based on annual heat sales of 23,000 MWh/yr.

c) Electricity not drawn down from the grid due to the operation of the CHP plant both with and without thermal storage (Egrid).

d) Energy used in production of the WSHP, thermal store and associated installation such as additional control instrumentation which is often referred to as "embodied energy" (Eem).

Conversion factors were applied to the above energies to give the amount of carbon saved in terms of tonnes of CO_2 per annum expressed as follows:

Csave = (Fsave*Cng/ηboil - Fplant*Cng - Eem + Egrid*CIgrid)/1000

Where:

Cng is the mass of CO_2 emitted per unit of energy from burning natural gas.

Cng is derived from the calorific value of natural gas (CVng = 39.6 MJ/Nm^3) converted to heat value (HVng) and the mass of CO_2 emitted per normal cubic metre (Mc=2.178 $kgCO_2/Nm^3$} as follows:

HVng = 39.6 * 1000 /3600 = 11 kWh/Nm^3

Cng = 2.178/HVng = 0.198 kgCO2/kWh

ηboil is the efficiency of domestic condensing boilers = 0.85

CIgrid is the grid carbon intensity which has a time dependent value according to the year.

6.3.2 Carbon emissions from embodied energy

The carbon emissions derived from the embodied energy of the thermal store the water source heat pump and associated installation need also to be taken into account.

Using figures from the Tyndall Centre thermal storage paper [35], this would be 153,631 kg of CO_2 for a $200m^3$ thermal store which, over a nominal 25 year lifetime of the store, equates to 6.1 tonnes of CO_2 emissions per annum.

Using manufacturer's data, the operating weight of two suitably sized WSHP units is 16,114 kg, the embodied energy of steel is 1,770 $kgCO_2$/tonne and therefore a very approximate guess would be 30,000 kg of CO_2 without taking into account materials other than steel, instrumentation or welded joins. To enable a figure to be included into the calculations, a multiplier of 2 has been used which gives we get an additional 2.4 tonnes of CO_2 emissions per annum over an estimated 25 year life cycle for the WSHP. In the absence of time and data, the additional 2,679kWe CHP plant in case B) has been taken into account with the same value.

For future considerations, it would be useful to establish a more accurate value for the embodied carbon of a range WSHPs via an approach to the manufacturers.

6.3.3 Carbon savings to 2029

The electricity produced from CHP-DH systems contributes significantly towards not only their financial viability but also the argument for supporting CHP as a low carbon energy source through the saving of higher carbon content electricity which otherwise would have been bought from the grid.

The CO_2 emissions saved by reducing the demand for electricity supplied via the grid is typically assessed by using an assumed grid emissions rate known as the "marginal emissions factor" (MEF). MEFs are higher than system average emission factors because the power stations that will be typically switched off in the short term (or not built in the long term) in response to a reduction in electricity demand are likely to be marginal plant such as non-CHP gas fired power stations rather than coal, hydro, wind or nuclear.

For those CHP-DH systems which are fuelled by natural gas as opposed to Energy from Waste (EfW) or biomass, an accurate estimation as to which MEFs to use is crucial in determining the degree to which these systems have a comparative advantage in terms of emissions savings over competing forms of energy generation. However, the recent Government methodology paper for emission factors **[51]** states that "*From 2013 emission factors per unit of electricity consumed will no longer be provided, since these were being previously misused*."

Therefore, for the purpose of this study, two sets of grid emission factors have been used with the first set erring towards low (i.e. optimistic) MEFs and the second set derived from the first but 25% higher as per table 2.

Year	Grid Carbon Intensity Units: kgCO2/kWh	
	low MEFs	high MEFs
2015	0.341	0.426
2016	0.331	0.414
2017	0.321	0.401
2018	0.311	0.389
2019	0.300	0.375
2020	0.288	0.360
2021	0.276	0.345
2022	0.263	0.329
2023	0.249	0.311
2024	0.235	0.294
2025	0.219	0.274
2026	0.203	0.254
2027	0.186	0.233
2028	0.168	0.210
2029	0.149	0.186

Table 2 - marginal emissions factors

Figure 14 overleaf depicts the projected emissions performance of the Seaton system for case A) and B) based on the MEFs in table 2. Clearly and predictably, case A) using the WSHP is the more sustainable due to the heat pump lowering the consumption of natural gas compared with case B) with the 2,679kWe CHP plant.

It should be noted that case B) becomes a net carbon contributor by 2022 where low MEFs are applied and 2025 for high MEFs.

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[51] 2013 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors

Projected carbon emissions savings - Seaton site
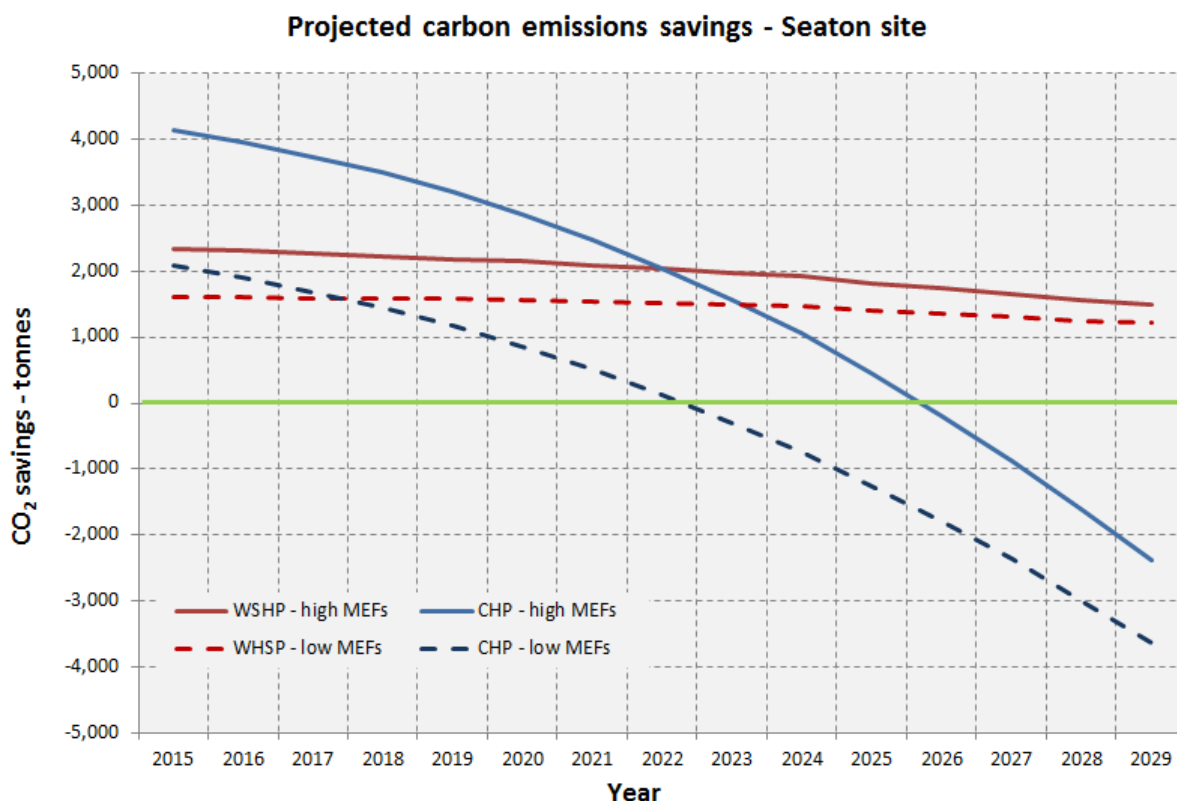
Figure 14- Projected carbon emissions savings

6.4 Discussion of results

The results confirm that if AH&P go down the route of buying a WSHP rather than an additional CHP plant then the emphasis of the Seaton site operation will become more orientated towards heat production at the expense of electricity sales.

The predicted income streams demonstrate that the RHI makes acquisition and commissioning of an appropriately sized WSHP a viable route to take if AH&P is to meet anticipated heat demand. Taking into account a quoted initial cost of the WSHP and that of the water extraction infrastructure, the expected payback period would be of the order of ten years at using a loan at 3.5% per annum.

The alternative case of acquiring for a CHP unit of 2,679kWe output has attractions compared to the WSHP case:

  ➢ A lower initial cost of approx. 68% of the WSHP and associated infrastructure;

  ➢ Greater electricity sales by a factor of two initially rising to a factor of four by 2029 although this is offset by lower gas consumption for the WSHP;

  ➢ Less importantly, AH&P are familiar with operating this type of technology.

However, there is a risk that if AH&P continue to rely on gas-fired CHP plant and the grid electricity carbon intensity falls to approx. $0.263 kgCO_2/kWh$ then the Seaton site will be a net contributor of carbon emissions rather than a net saver as it can be shown to be at present.

7. Conclusions and proposals

In the course of this year, AH&P will need to make a decision as to how to expand the capacity of the Seaton system to meet growing heat demand. The modelling of the Seaton system demonstrates that both the upgrade options under consideration, namely a WSHP and an additional CHP plant are viable. The following points may help to inform the deliberation:

Cost:

> The capital cost for the size of WSHP under consideration is approx. £4m depending on the type of water source abstraction and associated construction costs e.g. sea, river or ground water. By contrast, the additional CHP plant considered in this study would cost approx. £2.1m.

> The RHI makes the purchase of a WSHP a practical proposition; moreover, since AH&P can divert electricity from existing CHP plant to power the WSHP without incurring ASC charges, the potential viability of the WSHP is further enhanced. See section 6.2.5

> In both the WSHP and CHP case an application for a low interest loan to the District Heating Loan Fund **[52]** and/or other funding sources will need to be considered.

Business model:

> If AH&P wished to avoid the capital cost and risk of purchasing a WSHP then consideration might be given to an installation and maintenance agreement with the WSHP provider whereby the provider installs and operates the WSHP plant and sells heat to AH&P at an agreed price and period of time e.g. 10 years, after which AH&P is given the option of buying the plant at a depreciated cost. This model is often referred to as an "ESCO within an ESCO"

Carbon footprint:

> In relation to carbon emissions, the modelling shows that the WSHP has a significant advantage over an additional CHP plant assuming that grid decarbonisation continues at the current rate and that CHP plant at AH&P continues to use fossil fuel derived gas. See section 6.3.3

Familiarity with technology:

> Personnel at AH&P are already highly experienced in relation to CHP plant. If AH&P goes down the WSHP route then staff would be a need to be trained as WSHPs are based on quite different (refrigeration) technology.

Resilience:

> The inclusion of a WSHP in the generation portfolio of AH&P would increase the diversity of heat supply and therefore enhance the resilience of the system provided a reliable source of electricity can be guaranteed.

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52 The District Heating Loan Fund offers loans to support the development of district heating networks in Scotland.
Further information on accessing the scheme is available from the Energy Saving Trust.

Risk:

>   While the technology of installation a WSHP may be understood or gained, there is a perceived risk on development of such a project in respect of licensing and technicalities of extraction from the sea.   The work flow itemised under section 5.1.1 would need to be carefully researched in respect of potential capital cost implications and effects on the environment and marine life, along with the timescale required to plan and implement such measures.

If AH&P wish to consider the acquisition of a WSHP then a detailed study of the optimum method of extracting local (salt) water sources would need to be commissioned with a specialist company. If the result of this points towards abstraction from the sea, then an approach to the Crown Estate Marine Stewardship Programme or other source with a funding proposal to help cover the cost of sea pipes could be considered.

In the longer term there are other, more general avenues of research which might be usefully pursued perhaps as a joint venture with one or both of the Aberdeen based Universities and the City Council as follows:

➢   The compilation of a detailed map consisting of local heating and cooling demand which might be satisfied in the future by heating and cooling networks as part of a strategic energy plan for Aberdeen. Examples such as the possible utilisation of low grade heat from a waste water treatment plant or the need to satisfy cooling demand from server centres would be relevant. It is envisaged that this project would work in with the Scottish Heat Map project **[53]**.

➢   An investigation into electricity and heating provision for ships berthing at Aberdeen Harbour as is being done in Gothenburg **[54]**. This is especially important due to the consistently poor air quality in some parts of Aberdeen and is already the subject of consideration by the City Council.

➢   Further research might usefully be carried out to evaluate the feasibility of using WSHPs and thermal storage for grid balancing as outlined in section 5.3.1

Acknowledgements

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[53] See Scotland's Heat Map
[54] See Stena Line reduces emissions with district heating

Appendix A – assumptions used in energyPro modelling

A.1 External Conditions

Time series: Outdoor temperature [ºC]

Daily outdoor mean temperatures pertaining to the test case locale were obtained from the US based National Center for Atmospheric Research (NCAR) reanalysis project [55] and the UK based Met Office [56].

Planning period: January to December

	Average	Minimum	Maximum
January	3.7	-4.6	7.6
February	3.8	-1.6	9.2
March	5.7	-2.3	9.6
April	7.9	3.1	14.2
May	11.2	8.5	16.4
June	14	9.9	18.6
July	16.1	12.3	21.2
August	15.8	13.4	19.8
September	13.5	11.1	16.2
October	10.5	6.8	15.1
November	6.5	-0.6	11.6
December	4.6	-2.6	8.4
12 month period	9.5	-4.6	21.2

A more detailed analysis might usefully introduce wind speeds as an additional time varying external condition.

A heat value for natural gas of 11kWh/Nm^3 was assumed.

A.2 Heat Demand

Based on accumulated data from the Seaton operation, heat demand was modelled as two components:

> ➤ The fixed daily demand consisting of hot water and network losses accounting for 19.6% of annual demand.

> ➤ The weather dependent component accounting for 80.4% of annual demand.

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[55] US government Climate Prediction Centre: http://www.cpc.ncep.noaa.gov/products/wesley/reanalysis.html
[56] UKCP09: Gridded observation data sets: http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/

A basic daily heat profile cycle was assumed as per table and figure below where 10 represents the maximum daily demand.

Time   Ratio
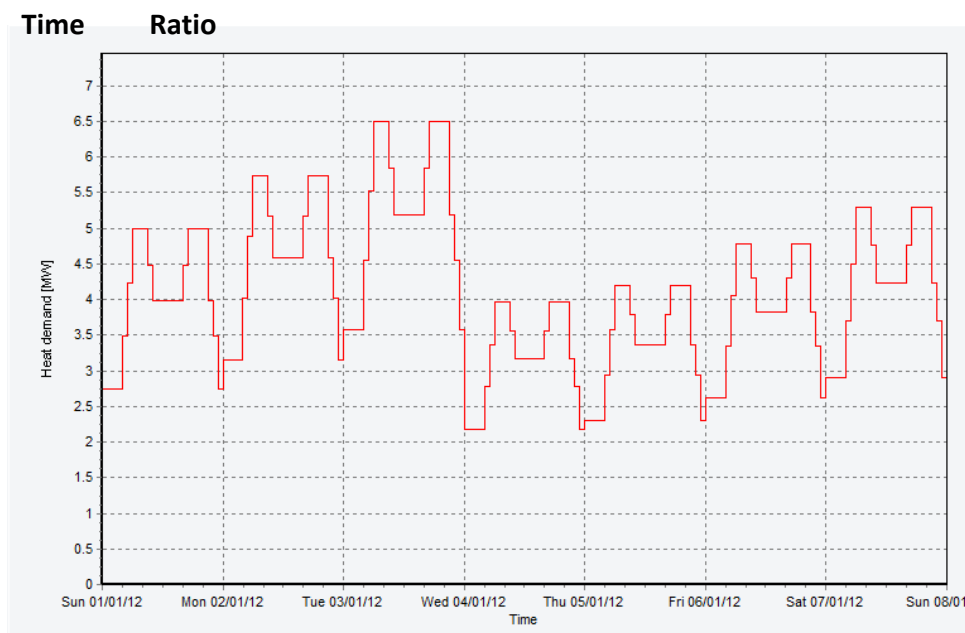
Time	Ratio
04:00	7
05:00	8.5
06:00	10
09:00	9
10:00	8
16:00	9
17:00	10
21:00	8
22:00	7
23:00	5.5

A.3 Energy Units

A.3.1 CHP units

The Seaton energy centre currently supports two natural gas fired GE Jenbacher J320 engines which normally run at an optimal maximum output with an overall efficiency of 81.6%; however, each unit can be efficiently modulated to 50% of maximum output as per table below. The characteristics of the additional Jenbacher J616 used in the modelling are also tabulated.

	Jenbacher J320					Jenbacher J616				
Fuel	**Heat**		**Electricity**			**Fuel**	**Heat**		**Electricity**	
[kW]	[kW]	[%]	(kW)	[%]		[kW]	[kW]	[%]	(kW)	[%]
2,894.0	1,300	44.9	1,063.0	36.7		6,141.9	2646	43.1	2679	43.6
1447.0	650.0	44.9	531.5	36.7		3,070.9	1,323	43.1	1,340	43.6

Each engine was assigned a minimum operation time of 4 hours and has on average six annual non availability periods of eight hours spread across the year for servicing.

A.3.2 Peak load boilers

The Seaton energy centre is currently supported by natural gas boilers with an overall efficiency of 84.7% which provide up to 4,000kW of heat to the network. The boilers were assigned a minimum operation time of 1 hour.

A.3.3 Water source heat pump

The WSHP has a minimum operation time of 1 hour and coefficient of performance dependent on output as per the table below.

Heat	Electricity Consumption	CoP	Pump
[kW]	[kW]		[kW]
2,934.1	927.5	3.16	72.5
1,457.2	484.2	3.11	36.0
740.7	298.8	2.48	18.3

An additional electrical load has been added due to the pumping required for the river or sea water extraction.

A.3.4 Thermal store

A thermal store with a net volume of 200m^3 and utilization of 90% was optionally specified. The temperature at the top of the store was set to 80°C and to 50°C at the bottom giving a difference of 30°C and a capacity of 6.3MWh.

Storage thermal loss was not modelled due to time constraints.

The store volume was chosen to cover one hours of heat demand at maximum load during the cold period.

A.3.5 Operation Strategy

The operational strategy gives the WSHP priority during the night as per table:

Priority of productions	Day	Night	Production to store allowed	Partial load allowed
Gas engine 1	1	1	Yes	Yes
Gas engine 2	2	3	Yes	Yes
Boilers	10	10	No	Yes
WSHP	3	2	Yes	Yes

A.3.6 Emissions

Constants used to determine emissions:

CO_2	All Production units	2.178	kg /Nm^3	Imported Fuel(Natural gas) / Heat Value(Natural gas)
NOx	Engines	7.27	gram /Nm^3	(FC(Gas engine 1) + FC(Gas engine 1)) / Heat Value(Natural gas)
NOx	Existing boilers	5.99	gram /Nm^3	FC(Boilers) / Heat Value(Natural gas)
SO_2	All Production units	0.01	gram /Nm^3	Imported Fuel(Natural gas) / Heat Value(Natural gas)

Appendix B – inputs used for projected net cash inflow

B.1 energyPro inputs (first year)

Configuration	Electricity produced	Electric consumed	Heat produced	WSHP Operation	Gas consumed
	MWh/yr	MWh/yr	MWh/yr	Hours	Nm3
Base case‡	15,490				4,514,161
WSHP no store	11,968	3,215	9,124	4,929	3,159,969
WSHP with Store	12,221	3,492	10,019	4,689	3,099,415
CHP+ no store	23,494		17,879		5,282,799
CHP+ with Store	24,099		19,046		5,278,357

‡The base case is the current plant at Seaton as of January 2015

B.2 Other parameters

Parameter	Value	Units
Capacity - WSHP	2,934	kWth
Capacity - CHP	2,646	kWth
RHI - Tier 1 - 8.7p/kw	8.7	p/kWhr
Tier 2 - 2.6p/kw	2.6	p/kWhr
Period of loan	10	years @ 3.5%
Duration of depreciation	20	years