INNOVATIVE GREEN TECHNOLOGIES FOR A SUSTAINABLE HARBOUR

E-Harbours towards sustainable, clean and energetic innovative harbour cities in the North Sea Region

ACKNOWLEDGEMENT

This report acknowledges the support and input of many experts. We thank all those who have provided input and contributions and helped to shape the document. Thanks also to The Interreg IVB North Sea Region Programme for supporting this project.

GLOSSARY

CO_2	Carbon Dioxide Gas
kWh	kilowatt hours of energy
MWh	Megawatt hours of energy (1MWh = 1000kWh)
GWh	Gigawatt hours of energy (1GWh = 1000MWh)
t	Metric Tonne
m^2	Square meter
l	liter
NSR	North Sea Regions
VPP	Virtual Power Plant
EU	European Union
ICT	Information and Communication technology
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
CAPEX	Capital Expenditure
OPEX	Operating Expense
PV	Photovoltaic
SWH	Solar Water Heating
EfW	Energy from Waste
WT	Wind turbine
H2O	Water
H_2	Hydrogen
O_2	Oxygen
CHP	Combined Heat and Power
GF	Green Fuel

EXECUTIVE SUMMARY

This report has been carried out as part of a pan European project called **E-Harbours, E-Logistics in NSR Harbour Cities**, awarded by the Interreg IVB North Sea Region Programme.

In this report, an overview of the different innovative energy technologies is presented. A description of smart grids, virtual power plants, renewable and green fuel technologies is summarised.

It should be noted that the report is not aimed at providing a summary of all the available technologies that can be applied in a harbour set up. This document focuses on describing some of the most important technologies; some of the mature ones or some of the technologies that are anticipated to play a key role in future harbour energy systems. It takes into account that the use of renewable energy within a harbour can lead to a potential unbalancing effect with the local electrical grid network, as the generation of renewable energy often does not match the local energy demand. This document, therefore, introduces the concept of Smart Grid and Virtual Power Plant (VPP), and the need to introduce controllable loads that can be switched on and off as and when renewable energy is available hence leading to an effective, efficient and clean balancing of the electrical grid.

In summary, the E-Harbours project is highly committed to increasing the uptake of renewable energy in a harbour area, by providing innovative green solutions, therefore supporting government policymakers to reach local and regional environmental targets.

KEY FINDINGS

- Smart Grids can play a major role in better managing harbours energy
- A harbour environment is ideal for VPP
- Hybrid electric vehicles can be used in a harbour
- Hybrid electric boats are more efficient than diesel based engines
- Harbours can become 100% clean if all boats and vehicles operating in and within the harbour are converted to electrical power
- If all boats and vehicles are electrically converted, no water pollution and/or air pollution at the point of use will arise
- All harbours have access to natural resources that can be harnessed - such as sunlight, wind and others
- A hydrocarbon-based harbour economy threatens the actual functioning of the North Sea Region harbours
- Harbours must adopt alternative energy methods based on local green technologies and better energy consumption means
- A Ground Source Heat Pump can meet a harbour's heating requirements
- Solar water systems can reduce the cost of traditional heating systems

- Solar Photovoltaic can reduce the cost of electrical power
- Wind Turbines can be installed away from a harbour and use VPP or Smart Grids to alleviate emissions and energy related outgoings
- Biodiesel can be produced from algae; it is biodegradable and non toxic
- Green fuel in particular (and fuel in general) can be produced locally within the harbour area
- Hydrogen fuel can be produced locally
- Sustainably produced hydrogen can be used in petrol internal combustion engines (for ferries, small fleets of boats, etc.)
- Only electricity, water and air are required to produce ammonia
- Ammonia fuel can be produced locally
- Ammonia fuelled vessels can reduce operational costs dramatically
- Boats can be converted to run on ammonia fuel
- Biofuel and biogas can be produced using fish waste and algae
- Biofuel and biogas fuel can be produced locally and boats as well as harbour heavy duty vehicles can be converted to utilise these fuels
- Marine energy can be used to produce electricity in the harbour
- Harbours can use active breakwaters to produce electricity from wave power

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INTRODUCTION

Nowadays there are many different types of energy technologies that can be used in a harbour. The large number of technologies available is making it more difficult for the harbour community to understand what technology can be used and implemented in a harbour setup.

This report aims to support the harbour community to increase its awareness of energy technologies. It provides and disseminates an overview of the different energy technologies that can be employed to reduce the energy dependence of harbours.

Through this report, harbour masters, owners, policy makers and business organisations will be able to learn and apply effective energy, e-mobility, renewable and green fuel technologies. This will support them to identify how to reduce their imported energy consumption and target with great effectiveness their emissions through the different green sustainable energy solutions provided in this document.

This report is therefore divided into two (02) sections. The first section of the report provides the aims and objectives. The second section is divided into six (06) subsections and describes some of the different energy technologies available for a sustainable harbour. The first and second subsections describe the Smart Grid and a VPP. The third subsection summarises the different main electric mobility options that can be used in a harbour. The fourth subsection provides a recap on some of the rationale behind the need for renewable and green fuel in a harbour. The fifth section summarises the reasons for the need for renewable and green fuel in the Scalloway Harbour showcase. The final subsection illustrates some of the most common renewable and green fuel solutions that can be used in any harbour.

AIMS

The E-harbours Project as a whole aims to create a lasting change towards sustainable energy logistics for North Sea Region (NSR) harbour cities. It aims at setting innovative energy standards to create a transformation of the energy network in harbour areas.

This report intends to increase the understanding of the energy technology that can be used in most of the NSR harbours. Specifically, this report provides some descriptions on smart grids, Virtual Power Plants, e-mobility, renewable technologies and how to produce green fuels.

The information described can be used by decision makers in any other NSR or European harbour and beyond, to shape the future energy of harbours.

The technologies described are universally applicable to any small, medium or large harbour.

Of key significance; the technologies described in this document have been selected as they can support an effective implementation of a green, sustainable and energy sound harbour.

OBJECTIVES

After reading this report, the reader should be able to:

1. Have a clearer understanding of the different types of technology available for devising a harbour sustainable energy management system.

2. Understand the difference between Smart Grid and Virtual Power Plant.

3. Define the different types of electric mobility options.

4. Understand some of the renewable technologies that can be used in a harbour setup.

5. Have a better understanding of the different means to produce green fuel.

6. Apply some of the technologies described in this document to harbours.

7. Understand how to store excess energy generated by renewable sources.

TECHNOLOGIES AVAILABLE FOR A SUSTAINABLE ENERGY MANAGEMENT SYSTEM

The sections below summarise some of the technologies that are available for the development of a sustainable energy management system for harbours in general, and for Scalloway Harbour in particular. The technologies that are described are as follows:

- Smart Grid technology
- Virtual Power Plants
- Electric mobility
- Renewable technologies

WHAT IS A SMART GRID?

There are many different definitions available to describe Smart Grids. In essence, and for the purpose of the Scalloway E-harbour project showcase, a Smart Grid is simply an electrical grid network that is controlled, managed and monitored using Information and Communication Technologies (ICT). In other words, computers, communication and other information technologies (also known as ICT) have been introduced to better monitor, control and manage the complex electrical grid network.

Historically, electrical grid networks have a few large electrical centralised generation plants located around the country supplying customers. The system consisted of large scale generation plants, transmission lines, distribution lines and customers. This system is shown in Figure 1.

As more and more customers become connected to the electrical infrastructure (more houses, more businesses, etc. connected to the grid), the electrical grid becomes more and more complex, thereby difficult to control manually. This is where the smart grid concept was introduced, using ICT to monitor, control, manage and automate the decision making process.

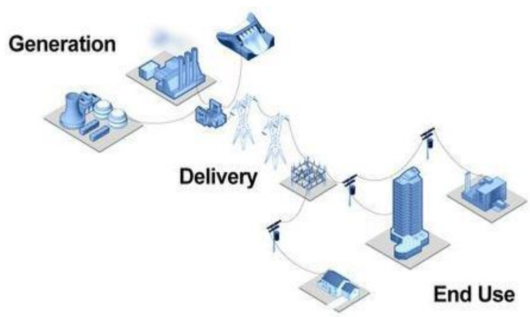

Figure 1 – Grid network configuration with localized power generation[1].

Since their introduction, Smart Grids have become very important to the network operators. The introduction of what is known as 'distributed power generation' into the electrical network, such as wind and solar power generation, has accentuated the need for

[1] www.smartgridnews.com - *Smart Grid 101: The electricity Ecosystem*

Smart Grids. The rationale is that as soon as a distributed generation is installed onto the grid network (e.g. a wind turbine) the network operators are confronted by new issues to control the balancing of the grid. For instance, the power generation of a wind turbine is by definition intermittent, hence unpredictable. Therefore a network operator would be required to manage this unpredictable wind generation resource. The operator would be required to switch on a backup power generation (e.g. a diesel generator) in the case of the wind generator not being productive. In turn, the operator would be required to switch off the generator if the wind turbine was consistently generating. This would be fine if there was only one wind turbine generation site installed and connected onto the network. In reality, the issue becomes far more complex as thousands of distributed generation (thousands of wind and solar systems) are installed every year.

Therefore, the outmost main issues with the control of the grid network lie with the fact that, in the past, the network operator was in control of the generation, transmission and distribution systems - which made it easier to monitor and control as the demands change - while today, the introduction of distributed generation made the generation sporadic and unpredictable that without ICT technologies, it is almost impossible to monitor, control and manage the grid network.

In summary, since the introduction of intermittent and distributed renewable generation sources (wind, solar, wave tidal, etc.), the network operators cannot single-handedly control the generation output from these sources. For example, when there is wind then wind turbines will produce electricity. Similarly when there is good solar radiation conditions, a solar photovoltaic plant will generate. Therefore, the network operator must be able to take action and make decisions much quicker to balance the energy system. In order to perform good decision making, the grid operator must be able to get information quickly and effectively to run the grid efficiently and with almost no risk of collapsing (risk of black out). This is where the Smart Grid comes into action; providing a means to support decision making, monitoring, control and easy grid management. Figure 2 illustrates a Smart Grid based system, where it can be seen that a Smart Grid is at the centre of monitoring, control and management of the grid network.

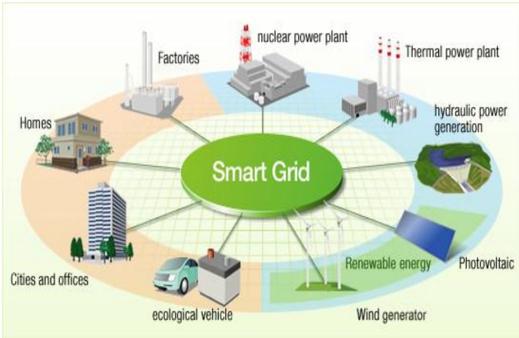

Figure 2 – Grid network based on Smart Grid system with both localised and distributed power generations.[2]

Smart Grids provide the ability to gather live data, allowing the grid owner to make quick decisions as and when needed, hence proving advantageous when compared to the old grid control systems as follows:

- A better and more efficient transmission/ distribution of power throughout the network.
- Improved balancing, security and availability of the network.

[2] http://www.hitachi.com - *Environmental activities*

- Better maintenance schedules based on data collected and analysed.
- Allows the integration of large-scale renewable installations.
- A quick and effective reinstatement of power after blackouts or electrical network issues.

Since the term 'Smart Grid' has become very fashionable, a proliferation of different definitions is used, blurring the meaning of the concept. One simple, short and popular definition of a Smart Grid is as follows: '***an electricity network that is coupled with an ICT-network***'.

This definition underscores that the gathering of information about developments in supply and demand is vital for a smooth operation of the electricity network. It is only possible to work towards a smarter electricity system when take decisions are made on the basis of the information gathered, thereby improving the efficiency and the sustainability of the network.

WHAT IS A VIRTUAL POWER PLANT?

A Virtual Power Plant is one of many subsets of Smart Grids. The basic idea of a VPP is that a number of small scale electrical generation units can be operated and controlled remotely as if they formed one single huge power plant, like a conventional coal fuelled plant.

For example, 10 generator sets of 100kW, each installed at different site locations, would equate a 1MW power station located at a single site. The difference is that the 10 generators could be controlled remotely and only switch on generators when they are needed and switch off when they are not. This is the essence of VPP; where the generation resource available is scattered around and is used more effectively as well as better controlled through a centralised system. Figure 3 illustrates this concept.

Figure 3 – Diagram for a Virtual Power Plant (VPP)

The idea of VPP can be used with renewable energy sources of generation. Think of several different location sites where wind turbines are installed – when the wind turbines operate, these wind turbines could form a part of a VPP. The issue is that we cannot control the time where the wind turbine start generating due to their intermittency.

Unfortunately, individual units (especially wind turbines and solar farms) cannot guarantee a stable production level of power around the clock: their generation cannot be controlled as and when needed. For instance, wind turbines only operate when there is wind and solar power only operate when there is daylight, both of which are out with human control.

To have a full operational VPP with a good grid balancing system when using intermittent renewable energy, there is a need therefore for a centralised controllable system. Here, a number of generation and consumption systems can be switched on and off, thereby leading to a better balancing of the grid network.

Therefore, the combination of different and distributed renewable sources with a number of controllable loads can be used to form a Smart Grid. The VPP will be the control system for the energy generation (wind, solar, diesel generators, etc.) while the Smart Grid will be the overall control system that controls the VPP and the load (processes, heaters, other appliances).

By evening out the different peaks from the renewable source (peaks occurs when there is more renewable generation than the load can absorb), and storing that energy as heat (or other storage mechanisms such as batteries, etc.), the energy generation and its utilisation can be more predictable and stable.

In summary, the core of a Virtual Power Plant consists of a coordinated centralised control mechanism that takes coherent decisions regarding a number of generation facilities. A VPP control system would switch on and off a generation system, based on its availability (say if there is no wind, then the VPP will switch on a diesel generator instead, while if there is strong wind generation, then the VPP will switch off the diesel generator or leave it on standby operation).

In addition to the above, a VPP can be supported by a Smart Grid where end users electricity demand profiles can be used, resulting in a more predictable and stable outcome. Therefore, a VPP supported by a Smart Grid creates better conditions for the introduction of new renewable energy sources.

To summarise, a Smart Grid can be seen as a system that links a VPP generation (wind, solar, biogas, etc) to the consumption product (electric heater, ice making machine) and to the energy storage mechanism (hot water tank, battery) via a centralised control, management, monitoring and automatic system.

Figure 4 shows the integration of these technologies.

Note that the owners of a Virtual Power Plant can, in many cases, negotiate a much more favourable contract with electricity companies as a VPP offers extra flexibility to the grid owner.

A harbour environment offers a unique opportunity for the installation of a VPP as in many cases, a harbour consists of large warehouses where green energy systems can be installed. It is also known that in some cases, a harbour owns land at different locations, which can be used for installing green energy such as wind and others, which in turn can be operated/controlled using VPP and a Smart Grid.

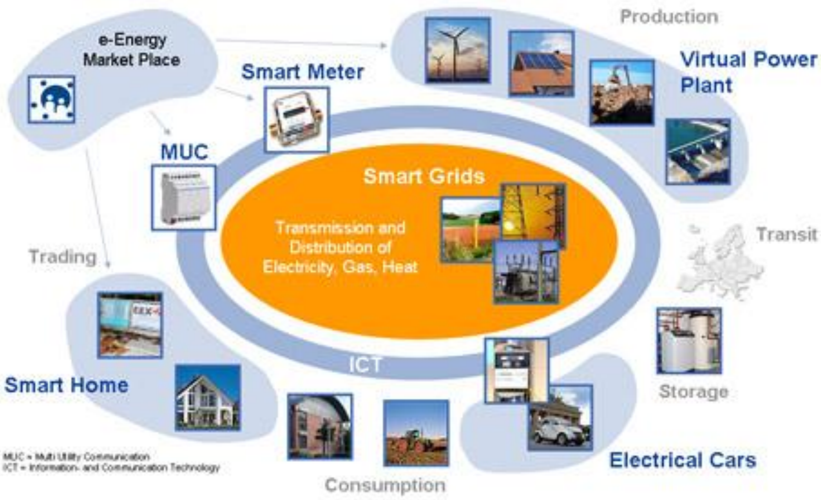

Figure 4 – Diagram showing how a Virtual Power Plant (VPP) relates to other ICT technologies[3].

A harbour environment is ideal for a Virtual Power Plant (VPP) system

[3] http://www.rwe.com - *Smart Grid*

One of the core aims of the E-harbours project is to enhance the development of electric mobility (both on land and on water) in the participating harbour regions. State of the art electric mobility technologies identify three main types of electric vehicles:

- **Standard Electric vehicles (EV)**: a standard electric vehicle is a vehicle that is fully powered by electricity. This means that the mechanical motion/movement is achieved through the sole use of the power stored in batteries available inside the vehicle. In this configuration, batteries are recharged in most cases via a connection with the electricity grid. The most common plug used for charging an electric vehicle is shown in Figure 5.

It is important to be aware that electric vehicles are not associated with emissions at the point of use of the vehicle. Therefore, in terms of the *tank to wheel* energy use, they are significantly cleaner and produce much lower carbon emissions than internal combustion engines (at point of use).

It is critical to highlight that if electric vehicles do not have or have limited emissions at the point of use, they still are associated with emissions when being charged from the grid, where most of the generation is hydrocarbon based. Therefore, an organisation cannot justify that by using an electric vehicle, it reduces emissions. In this case, it only displaces/shifts the emissions to a different location: at the generating power station.

In the case that an electric vehicle is charged from a renewable source, then in this instance, it is possible to say that an electric vehicle has zero emission and therefore, it is green and sustainable.

Figure 5 – Common plug used for charging an electric vehicle[4]

- **Hybrid Electric Vehicles (HEV)**: an HEV is in most cases defined as a vehicle that combines three main technologies:

  - A conventional petrol based internal combustion engine.
  - A battery bank.
  - An electric motor.

The petrol engine is used to produce electricity. This electricity is used to either charge the battery bank or directly supply electric power to the electric motor, thereby providing motion.

Batteries are recharged in many ways. They can reclaim energy when the car brakes, during freewheeling of the vehicle (not all HEV do perform this), or by receiving the converted mechanical energy from the petrol based

[4] http://www.renewableenergyworld.com - *Top Five Electric Vehicle Developments*

internal combustion engine into electricity. **An HEV can be considered as a 'green' vehicle only if it uses green biofuel.**

- **Plug in Hybrid Vehicles (PHEV):** A PHEV combines the qualities (and the drawbacks) of hybrids and EVs. In essence, it is a hybrid vehicle that uses a petrol engine and an electric motor, plus a larger battery pack (when compared to the HEV). The battery can, in this instance, be recharged via a standard household electric socket. **A PHEV can only be considered 'green' if its battery bank is charged using 'green' energy and that the fuel is green biofuel.**

Using electric vehicles in a harbour set up can have several benefits. **If conventional combustion engines vehicles are replaced by electric vehicles, a direct improvement of air quality in the vicinity of the harbour can be achieved. Noise levels, lower operational costs (electrical power is cheaper than fuel) and other localised environmental parameters can also be improved. In addition, electric vehicles can be used in conjunction with Smart Grids and renewable power as a dumping load.**

In other words, the introduction of battery powered vehicles within a harbour provides a significant opportunity for the development of large energy storage. This is especially true for large scale harbours, where many electric vehicles could be used acting as dumping load during excess renewable energy generation.

For instance, when there is solar power available, electric forklifts could be charged. When no more power is available from the solar source, the vehicles can be used. In the case that electric vehicles are used during high power generation, dump load such as heaters, cooling systems, freezers, hot water tanks or others can be used. Two sets of batteries could also support the 24/7 usage of a vehicle: the first set is used in the vehicle while the other one is being recharged.

The most common drawbacks of electric vehicles are the reduced distance range achievable and the long charging time of the battery. However, a harbour area is usually a closed system with relative short driving distance and relatively predictable usage. Therefore, the utilisation of electrical vehicles within harbours could be optimised for each specific harbour and allowing to overtake the current performance limitation of the electrical vehicles.

The three different electric mobility applications described above can be used and also applied to navigation electric mobility i.e. electric boats, electric hybrid boats and plug in hybrid electric boats.

It is clear that harbours of the future can become 100% clean if all boats and vehicles operating in and within the harbour are converted to electrical power. No water pollution and/or air pollution at the point of use will occur.

WHY RENEWABLE ENERGY AND GREEN FUEL? - QUICK RECAP -

One of the main aims of the E-harbours project is to increase the sustainability of harbours by promoting and facilitating the uptake of Renewable Energy (RE) and Green Fuel (GF) in a harbour set up. The idea is to use Green Energy produced from ***local, natural, endless green resources.*** This would provide great economical, environmental and operational benefits for any NSR located harbour, whether it is a small to medium size or a large harbour.

As shown in Report 1, the majority of NSR harbours face energy insecurity as they rely heavily on imported hydrocarbon based energy. This problem is particularly evident and accentuated in remote harbour areas, where the energy used is almost 100% based on hydrocarbon. Unfortunately, the hydrocarbon used in remote communities is 100% imported, making it more difficult to access, expensive and completely out with the control of the local harbour users.

The above highlighted issue with importation of hydrocarbon leads to the high cost of electricity, the continuous increase of fuel prices and the consequential environmental pollution for using oil based energy sources. Consequently, it is clear that a hydrocarbon-based harbour economy creates further pressures onto harbours organisations, which in the short to medium terms threatens the actual functioning of the harbour. Therefore, it is crucial and urgent to action the sourcing and uses of alternative energy methods based on local, clean and reliable resources.

A hydrocarbon based harbour economy threatens the actual functioning of the North Sea Region harbours

It is critical that harbours adopt alternative methods based on local green technologies and better energy consumption means

WHY RENEWABLE ENERGY AND GREEN FUEL IN SCALLOWAY HARBOUR?

Shetland is a particularly good example of a remote location relying heavily on hydrocarbon and not maximising the opportunity of RE and GF. For instance, in 2008 alone, 96% of the energy used in Shetland was derived from imported hydrocarbon energy sources[5]; a cost to the local community of around £ 22 million[5]. This cost is, in reality, hard earned income lost and non recoverable to the local Shetland community as for any imported litre of hydrocarbon fuel, the Shetland community export their income.

On the other hand, Shetland harbours have a unique opportunity to take advantage and lead on the renewable agenda for harbours. For instance, Shetland are host to the most productive wind turbine in the world, with a load factor of 59%[6] and located just a few kilometres away from Scalloway Harbour. This illustrates the wind resource available to supply the harbour with green electricity.

In addition to the wind, the high availability and potential for renewable energy in Shetland such as tidal resources, and even solar, makes the Shetland's Scalloway Harbour showcase a unique location for demonstrating the benefits of using local renewable resources, and increasing the sustainability of the harbour and the local community.

Several technologies and opportunities are available to support the move of Scalloway Harbour from a near 100% hydrocarbon based harbour into a highly sustainable one. This could imply new means for fuelling boats and land vehicles, the integration of renewable into the local electricity network, the optimisation of cooling and heating processes by using Smart Grid technology and the identification and installation of efficient environmental friendly waste processes amongst many others. To this end, the sections below present some of the potential technologies that can be considered for the Scalloway Harbour showcase, as much as they can be applied to other harbours.

[5] Shetland Energy source analysis, http://www.pureenergycentre.com/pureenergycentre/Energy%20Analysis%20Report.pdf

[6] Massive Wind Farm Project Approved on Shetland Islands, Scotland: http://www.renewableenergyworld.com

- **Ground Source Heat Pumps** (GSHP): a ground source heat pump system is simply a device that extracts ground/soil heat and dissipates it for heating houses or other premises (business, etc.). Like a refrigerator or air conditioner, GSHP systems use a compressor to force the transfer of heat from the ground to a surrounding given space. A typical GSHP has a high capital cost but very low operational cost (if electricity cost is low) and it can provide heating for more than 20 years.

Space heating for Scalloway Harbour offices and hot water requirements could be met using GSHP technology. However, the associated cost with the implementation and the operating cost can be significant if not implemented correctly. Similarly, there are now new techniques available to extract heat from the shore water/sandy type soils. Again Scalloway Harbour heating requirements could be met using these techniques. See Figure 6.

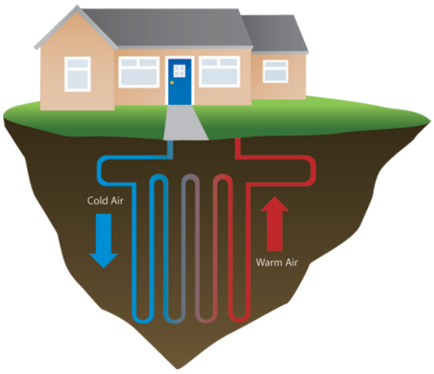

Figure 6 – Diagram of Ground source heat pump[7]

Ground Source Heat Pump can meet harbour heating requirements

- **Solar Water Heating (SWH):** Solar water heating systems convert solar energy into heat, warming up water and storing it into hot water tanks (see Figure 7). Other technologies like oil or biofuel based boilers can be used as backup to cover the hot water needs when solar irradiation is not available.

Figure 7 – Example of Solar water heating system with solar collectors[8]

Solar water heating systems are ideally suited to reduce the energy consumption of traditional heating systems and for low temperature under floor heating systems. **The substantial amount of roofing surface at any harbour has the potential to be used to accommodate SWH**

[7] http://www.whealjanemasterplan.co.uk/geothermal-technology-ground-pumps.aspx

[8] http://www.tapshop321.com/blog/index.php/326/solar-water-heating-for-the-home/

panels and reduce energy costs associated to heating water.

Solar water systems can reduce the cost of traditional heating systems

- **Solar Photovoltaics (PV):** Solar energy potential in the Shetland Islands is quite poor during the winter time, but quite good in the summer. Annual average irradiation is just under 900kWh/m^2. Solar PV can operate very well during the summer period due to the prolonged daylight and low Shetland ambient temperatures.

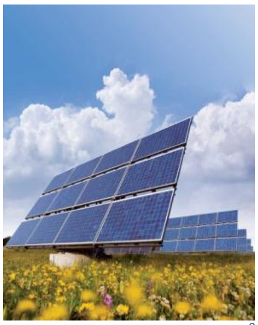

Figure 8 – Solar Photovoltaics[9].

The most suitable PV technology is monocrystalline modules as they can achieve higher efficiencies (around 17%) compared with other polycrystalline modules (around 13%). However, with the latest modern manufacturing techniques, high quality polycrystalline technology can be as effective as many monocrystalline technologies. On the other side, the performance temperature coefficient is better with polycrystalline cells rather than monocrystalline. The cells heat up more slowly than mono-crystalline. As a general rule, polycrystalline reaches better yields in southern Europe than mono-crystalline ones, while monocrystallines are preferred in northern Europe. Figure 8 illustrates solar photovoltaics.

As harbour areas have a large number of warehouses with large roof space available, **it is possible to reduce energy consumption using solar PV.**

Solar Photovoltaic can reduce the cost of electrical power

- **Wind Turbines (WT):** Shetland is one of the best places in the world for wind energy. The wind generation potential is higher than any other place in Europe. The average yearly wind speed is around 7.5m/s[10]and Shetland hosts one of the most productive wind turbines in the world: that is Betsy, with a load factor over 59% [6]. Due to this high potential, wind turbines can provide most of the electricity required for Scalloway Harbour. Figure 9 illustrates a wind turbine.

The high intermittency of wind would in many cases impose the utilisation of a Smart Grid in order to balance the energy flow between electrical generation, utilisation and storage. Though wind energy can lead to high green

[9] http://www.vacengmat.com

[10] Shetland in statistics 2005 http://www.shetland.gov.uk/council/documents/sins2005.pdf

energy production and substantially decrease energy financial outgoings, there are very few potential for harbour sites to install wind turbines due to the lack of space for installing the wind generators. **When there is no space available for installing a wind turbine, the best method for harbours to own wind generation is to install wind systems away from the harbour and use VPP or Smart Grids to alleviate their emissions and outgoings.**

Wind Turbines can be installed away from the harbour and use VPP or Smart Grids to alleviate emissions and energy related outgoings

Figure 9 – Wind Turbine[11]

- **Energy from Waste (EfW):** In general, harbours are hubs that produce large amount of waste. The presence of large vessels bringing waste onshore, heavy industrial machines dumping waste products, large/small manufacturing and fish processing plants create large quantity of waste, which can impact the harbour economically, logistically and environmentally.

Advanced technologies are able to convert most of the biodegradable waste into useful biogas. Using anaerobic digestion technology and in-vessel composting processes, biodegradable waste can produce biogas to be used to generate stationary electrical power or for transport applications (marine or on land). Figure 10 illustrates a biogas storage system.

Biogas plants require large amount of biodegradable waste in order to be economically valuable, therefore there is a requirement to expand the waste recovery analysis to a wider area rather than the harbour only. **Shetland has already a waste to energy plant, namely SHEAP, which sometimes requires to import waste to support its activities (Figure 11). Therefore, it may well be that there is not enough waste in within the Scalloway Harbour to justify the capital investment for a waste to biogas plant.**

Figure 10 – Example of Biogas storage system

11 http://www.pureenergycentre.com/pureenergycentre/Wind_Turbine/eoltec_6kW_wind_turbine/eoltec_6kW_wind_turbine.php

Figure 11 – SHEAP, Shetland waste to energy plant.

Figure 12 – Algae used for biomass or biofuel[12].

Biodiesel can be produced from algae; it is biodegradable and non toxic

- **Biomass and Biofuel:** These technologies allow for producing energy from living organisms rather than fossilised ones. **A harbour, due its geographical location, is an ideal candidate for biomass and biofuel production**; the high potential for algaculture creates a unique opportunity to produce fuel locally. As an energy source, **algae can be used either directly as biomass to produce electricity or heat (usually by direct combustion on steam turbines and gasifiers) or converted into biofuel, such as biodiesel for transportation. Figure 12 illustrates an example of algae that can be used for producing biofuel.**

Biodiesel can be used in any diesel engine when mixed with mineral diesel. It is safe to handle and transport because of the biodegradable nature of the diesel and its low toxicity. In addition, production of biofuel with algae does not affect fresh water resources, as it can be produced using ocean and wastewater.

Energy produced by algae is still a technology under development to improve its production. Currently, intense R&D activities are focused on enhancing productivity and reducing cost. The activities in this field are being pushed by the increase in oil price and the need to reduce the reliance on imported energy sources.

- **Marine Energy:** Many harbours may have the privilege to produce energy from marine resources, the most common potential are:

- **Tidal energy**
- **Wave energy**

Tidal energy is a form of hydropower that converts the energy of tides into useful forms of power, mainly electricity. **Tides are more predictable than other renewable energy sources, such as wind and solar power,** because tidal forces are periodic variations in gravitational attraction exerted by celestial bodies. This feature makes the technology very attractive due the relatively easy control and management when integrated into wider grid energy systems.

[12] http://inhabitat.com - *Ford Developing Biofuel From Algae for Use in Vehicles*

Tidal energy can be captured thanks to the vertical shifting of sea level, or the flow from the tidal stream. Therefore, two main generating methods are available:

- A **tidal barrage** is a structure like a dam used to capture the energy from masses of water moving in and out the harbour. Turbines produce electricity by using the tidal flow generated during the tidal cycle (see Figure 13).
- A **tidal stream generator** is a machine that extracts energy from moving tides. The most common type of tidal stream generator is the tidal turbine that operates with a similar concept to wind turbines, but located underwater.

Figure 12 – Tidal barrage energy in harbour[13].

Even if this is an attractive option among sources of renewable energy, tidal power has traditionally suffered from relatively high cost, low reliability and limited availability of sites with sufficiently high tidal ranges or flow velocities. However, recent technological developments and improvements have increased the interest and the development of this technology.

Wave energy is a technology that can extract energy by ocean surface waves and capture it for useful work, such as electricity generation, water desalination or the pumping of water (into reservoirs). Sea wave motion is used to generate hydraulic pressure, which is then transformed into electricity (see Figure 14).

Figure 13 – Example of wave energy device[14]

Harbours are usually protected with breakwater in order to create a safe anchorage area for vessels from the effects of weather. Breakwater structure is designed to absorb and dissipate the wave energy usually by using mass and stones. An innovative method that allows recovering the wave energy is represented by active breakwaters with integrated wave energy systems. **Active breakwaters are able to absorb the wave energy and convert it into useful electricity – see Figure 15 below.**

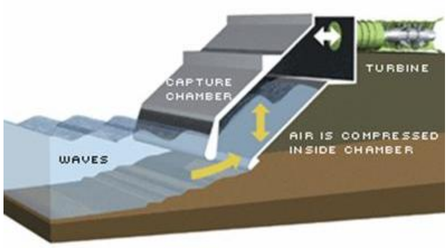

Figure 14 – Example of Active breakwaters[15]

[13] *http://renewableenergyindex.com - Uses of Tidal Energy*

[14] *http://www.futureenergies.com - First Commercial Wave Power Station*

[15] http://www.esru.strath.ac.uk

Harbour cans use active breakwaters to produce electricity from wave power

- **Hydrogen fuel:** Only two main things are required to produce hydrogen fuel: water and electricity. All harbours are located near a source of water and all have electrical power available locally. Electricity is used to split water into its two constituents; that is splitting H_2O (water), into H_2 (hydrogen) gas and O_2 (oxygen) gas.

Hydrogen would be a perfect solution to use in conjunction with VPP/Smart Grid as it can act as a dump mechanism for renewable energy. **Hydrogen can be used as fuel for boats/ferries, vehicles, heat and in any other form of energy**.

- **Ammonia:** Ammonia needs three main components to be produced. It needs power, water and air, all of which are plentiful in a harbour set up. To produce ammonia, nitrogen needs to be extracted from the air using electricity. This nitrogen is then combined with hydrogen to form ammonia. Hydrogen is produced from water using the process described above.

Ammonia is a very dense fuel; about half the density of current fuel. Therefore, an ammonia tank is double of a current vehicle tank, over the same distance. In other words, to drive a 60 litre tank vehicle, a 120 litres ammonia tank would be needed to cover the same distance (approximately).

It is very simple to convert an internal combustion engine to ammonia. Therefore ammonia is highly suitable for ferry and boat applications. It is also highly suitable for stationary electrical generation. The key point is that it can be produced locally for local consumption.

Similarly to hydrogen, ammonia can be used in conjunction with VPP/Smart Grid to reduce the dependence of a harbour on imported fuel.

Sustainably produced hydrogen can be used in petrol internal combustion engines and as a top up fuel for ferries, reducing naval and on land harbour emissions

It is very simple to convert an internal combustion engine to run on ammonia

Only electricity, water and air is required to produce ammonia

Ammonia can be used in ferries

If designed properly a harbour can produce its own 24/7 energy and fuel requirement form local renewable sources

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