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Overview on Renewable Energy Technology

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1. Introduction

It is a fact of life that energy is central to our modern civilisation. With an ever increasing population, demanding more and more energy per person, there is great pressure on the resources of the world to provide this energy. Fossil fuels such as coal, oil and natural gas have fuelled global development over the past few centuries, and continue to do so. However, growth based on fossil fuels cannot continue indefinitely because the supply of fossil fuels is finite. This paper has been prepared to provide an overview of existing and emerging alternatives to energy supplied by fossil fuels, to meet our ever increasing demand. Specifically, this paper will focus on Renewable Energy technologies.

Renewable Energy – New energy?

Renewable energy is anything but new. Prior to the industrial revolution, the vast majority of energy utilised by mankind was renewable. Wood was used to heat homes and cook food; ships used sails to capture wind energy, as did windmills; water wheels captured hydropower and passive solar energy gave warmth. However, in the modern sense, renewable energy technologies refers to specialised and often highly engineered systems which can extract energy from renewable resources.

What is renewable energy? (Definition)

Fossil energy, such as coal, oil or natural gas, is finite – it cannot be replenished once it is exhausted. On the other hand, renewable energy is essentially inexhaustible – no matter how much energy is extracted, the resource will continue. Renewable energy resources are therefore replenished by natural phenomena. This definition therefore excludes nuclear energy which relies on a globally exhaustible supply of uranium which is enriched in an unnatural manner. Renewable sources of energy are wind, solar energy, wood and other plant material (commonly referred to as biomass), hydropower, geothermal energy, wave energy and tidal energy.

Why are these types of energy renewable? The sun is the source of most types of renewable energy. Solar energy obviously comes from the sun, but so does wind energy as the unequal heating and cooling of the Earth’s surface combined with the rotation of the Earth creates the wind. Evaporation from the oceans creates rainfall which ultimately provides hydropower. Growth of plants using the sun’s energy creates biomass, which is renewable as long as the supply of plant material is replaced (ie through managed forestry or agriculture). Wave power is created by the wind acting on the surface of water, and tidal power is created by the gravitational pull of the sun and the moon on the oceans. Only geothermal energy is completely independent of the sun and is caused by the radioactive decay of minerals in the Earth’s core which generates vast amounts of heat.

In summary, the International Energy Agency defines renewable energy thus:

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.

History

The first modern hydropower plants and wind turbines appeared in the late 1800's as a response to increasing industrialisation. While some large wind turbines were experimented with, large-scale hydropower became widespread and today provides about 15% of the Earth's electricity needs. Because of the widespread use and the maturity of this technology, it is often not included in reviews of "new" renewable energy technologies, and is not detailed in this paper.

Sporadic use of other forms of renewable energy continued throughout the first half of the 20^{th} century. For example, early wind turbines installed to power isolated farms became widespread, and geothermal energy was first used to generate electricity in Italy in 1904. However such use was gradually displaced in the industrialised world due to electrification (the spread of the electricity grid) powered by centrally located fossil fuel power stations. But it was during the oil crisis of the 1970's that renewable energy really came to the fore once more. During this period the modern forms of new renewable energy technologies that we see today evolved, and since then their capacity and installed numbers have gradually increased. This increase has rapidly accelerated in recent years due to increasing oil prices, increasing demand for energy and the insecurity of fuel supply. Climate change has also favoured renewable energy technologies as they produce less greenhouse gases than energy from fossil fuels.

European and Global targets and figures

There are many targets across Europe for increasing the supply of energy from renewable sources. Each country has its own targets, some based on the percentage of electricity supplied from renewable sources and some based on the reduction of carbon emissions associated with the supply of that energy. The 2009 EU Renewable Energy Directive attempts to place an overarching target on the EU Member States which can be summarised as follows:

- 20% of the EU's energy demand should be supplied from renewable resources by 2020
- 20% increase in energy efficiency by 2020
- 20% reduction in CO_2 emissions by 2020

Each Member State has its own binding target to assist in meeting the EU goal of 20% of energy from renewable resources by 2020. For example, the UK's target is 15% of its energy, while Denmark's target is 30% and Latvia's is 40%.

The current negotiations in Copenhagen may lead to a new international agreement on reducing CO_2 emissions.

Some non-EU targets for renewable energy include:

- 10% of electric power capacity in China to come from renewables by 2010 (about 60GW)
- 30PJ of added renewable energy by 2012 in New Zealand
- 50,000m2 of solar thermal systems in Singapore by 2012 (about 35MW)
- 500MW wind power by 2015 in the Dominican Republic

Types of Energy – Electricity, Heat, Transport

Renewable energy technologies convert renewable energy resources into useful forms of energy. There are three main forms of energy used by society – electricity, heat and transport (kinetic energy). Every building requires a mix of energy – electricity for lighting, electrical goods, computer systems, ventilation, and so on; heat for space heating, hot water and cooling. It is important to understand energy demands in order to be able to design effective systems to supply energy, whether on a local scale or on a national scale.

2. Wind Energy

Wind Resource

In order to determine the technical resource (electrical energy) which can be extracted from the natural wind resource of Azerbaijan or any region, it is necessary to determine the frequency distribution of the wind speed and its directional component. Having this information allows an estimation of the quantity of electricity generated by a wind turbine over a period of time, typically annually, to determine the cost effectiveness of the project.

History

The familiar horizontal axis windmill emerged in Europe in the 12^{th} century and was used for grinding corn, dyes and spices. In the Mediterranean, a triangular shaped sail was developed, attached to multiple radial arms. In Northern Europe, a four-bladed design was more common. However, the use of windmills declined as fossil fuels fed the industrial revolution.

Modern wind turbines are used to generate electricity. There have been a several distinct lines of development of this technology, but it was the Danish and German designs pioneered in the 1970's oil crisis and developed during the 1980's which became commercially viable in the 1990's. These utility scale turbines were small by today's standards, at around 250kW. The trend since then has been to develop larger turbines capable of generating significantly more electricity. Common turbines today are capable of producing more than ten times the electricity of the turbines of the 1990's, at 3MW capacity. The largest wind turbine currently installed is 6MW.

Wind Mapping

Most European countries have developed wind maps. Perhaps the most user friendly is that developed in Ireland and Northern Ireland by TrueWind Solutions. This map allows users to select any location in the country and be given with an estimation of wind speeds at 25m, 50m, 75m and 100m above ground level. Large scale wind turbines and wind farms will still require wind monitoring prior to installation in order to determine the expected output from the turbines in each site. This is achieved with the installation of an anemometer on a mast, installed at the hub height of the proposed wind turbines. Typically, at least 6 months of data, recording wind speeds and wind direction is required.

Wind Turbine Design

The blades of a large wind turbine are typically made from pre-impregnated glass reinforced epoxy resin moulded over wooden blade formers. Being aerodynamically shaped, they capture the force of the wind by generating lift in a direction perpendicular to the flow of the wind. This causes rotation which is imparted to the rotor assembly, connected to a gearbox. The rotor turns at a speed between 13 and 30 revolutions per minute (rpm), which the gearbox raises to around 1,500 rpm. In order to control the output from the generator, the rotational speed of the rotor in most turbines is fixed at two speeds, depending on the wind speed. In high speed winds, to protect the turbine and rotor, the blades of the wind turbine will change in pitch angle. In extreme winds, such as gale force conditions, brakes will hold the rotor firmly and the pitch angle of the blades will be set to present as low a profile to the wind as possible. If these systems were not in place, sudden rapid changes in wind speeds could send massive power surges through the rotor and gearbox.

Tower height is vitally important, and a modern 2MW turbine with a rotor diameter of 80m would have a nacelle sitting on top of a 60 – 90m tower. The height required is determined by the mean wind speed and the topography of the location – which give an indication of the expected output of the turbine and hence dictate its economic viability. The additional cost of having a taller tower can be more than offset by the additional electricity generated.

Wind Turbine Output and Load Factor

Load factor is used to compare the output of wind turbines in different locations. It is an expression of the percentage of time, for example over a one-year period, at which the turbine operates at its rated capacity. For example, a 1MW wind turbine in a location which has a load factor of 30%, will generate 2.6GWh of electricity in one year. The load factor is a direct representation of the average wind speed of the site at the height of the turbine nacelle coupled with the efficiency of the turbine generator. In simple terms, the output of a wind turbine over one year can be calculated using the following formula:

$P = C \times LF \times 8760$

Where P = Power generated (electricity) in kWh
C = Rated capacity of the wind turbine in kW
LF = Load Factor
8760 = number of hours in one year.

Therefore, in our example above, P = 1000 x 0.3 x 8760 = 2628000 kWh = 2.6 GWh

Turbine Components

The gearbox is integral with the other drive components and is located in the nacelle of the wind turbine. The nacelle, in turn, is located on top of the tower. Gear boxes come in a range of configurations, but some modern wind turbines such as the Enercon machines have options for a gearless configuration. In these direct-drive machines, the rotor connects directly to the electricity generator. In this type of wind turbine, the output from the specially wound generators is controlled through the use of power electronics. Such direct-drive wind turbines with power electronics offer the advantages of better power quality, lower noise, lower cost, less stress on the rotor and higher energy output.

The control system of the wind turbine must ensure that the output from the wind turbine or wind farm does not disturb the grid frequency. Blade pitch control, as stated, coupled with yaw control of the nacelle, manages to maintain optimum energy capture. An integral anemometer on the nacelle provides wind speed and directional information to the control mechanism.

From the grid perspective, wind farms operate as single entities, and will be treated as such by the grid system controllers. Modern wind farms operate totally unmanned with remote monitoring providing turbine performance data to the wind farm operator.

Typically, wind farms achieve very high levels of dependability, operating effectively for 98% of the time, with approximately 40hours per year scheduled downtime.

Environmental Impacts of Wind Developments

The most significant environmental impact of a wind farm is that of visual intrusion. Whilst the environmental benefits of wind power involve the generation of electricity without the release of carbon dioxide, particulates or other pollutants, and can provide indemnity against rising electricity costs, there can be knock-on effects to tourism if sited in a particularly sensitive area such as a national park.

Radio and television signals, telecommunications and radar can also be disrupted by wind farms. This interference is caused by the size of turbines, their design and material construction. However, many of these impacts can be mitigated through careful planning of the location of the wind farm, for example away from the flight path of airports.

Trends and Developments

3. Solar-Thermal Energy (for power and water)

The sun is the major source of heat on Earth, and there are many types of solar panels now developed to actively convert the sun's energy into other forms of useful energy. Solar thermal systems absorb or concentrate the sun's energy to heat water, or other liquid, to a form which can be used in buildings – typically for hot water uses. However, recent experiments with solar energy have resulted in large scale systems which can concentrate the sun's energy sufficiently to raise steam, which can then be used via a turbine to generate electricity.

Solar Thermal Development

The first solar water heaters were merely black tanks located outside and filled with water. These lost their captured heat during the cold nights, and were replaced by a separate tank and collector system in the early 20th century. One early system developed in America incorporated a collector made of pipes attached to a metal backing inside a glass-covered box. The pipes then ran to an indoor insulated tank. Being higher than the collector panel, hot water naturally rose during the day into the tank and a circulation was created. This type of system in now very common across the globe, with little modification except perhaps a pump. The oil price scares of the 1970's saw major markets for solar water heating systems emerge in Spain, Japan, the Middle East and Asia.

Solar thermal for hot water

In modern terms, solar panels are most commonly used to provide domestic hot water – that is hot water used in buildings. The widespread use of these systems should not be underestimated as a means of reducing national reliance on fossil energy. There are two main types of collector: flat plate and evacuated tube.

The flat plate panels are essentially pipes on a black metallic surface contained below glass in an insulated box. The more glazing, the better the light absorption, although flat plate panels will reflect up to 10% of the incident radiation. The system must be robust enough to withstand weather conditions such as wind and snow loading and atmospheric pollutants. The collector cover, typically glass but can also be made of acrylic, should allow high transmission of visible light radiation (wavelengths up to 2.4 micrometres) but low transmission of infra-red (wavelengths over 3 micrometers) to prevent heat energy escaping.

Evacuated tube collectors have rows of parallel glass cylinders containing a metal fin attached to a closed copper pipe running down the centre. Within this heat pipe is a special fluid which boils at the hot end and condenses at the cold end. This has the advantage of transferring large amounts of heat for a relatively small increase in temperature. For this reason evacuated tubes are considered more efficient than flat plates in northern climates.

In Europe, solar thermal collectors can supply up to 60% of a building's hot water needs, when tilted appropriately to the sun – directly facing the sun at midday. On a sunny day direct light radiation can approach a power density of 1kW/m2.

Solar thermal for space heating

Solar thermal collectors can also be used for space heating and space cooling. The development of solar thermal panels for space heating has been slow in colder climates since the main requirements for space heating are at night and during the winter when solar radiation is much reduced. This means that the provision of space heating in buildings, powered by solar thermal energy, requires excessively large solar collector panels and hot water storage vessels. This can create an additional requirement to dump large amounts of heat in the summer months when solar radiation is high and there is little or no requirement for space heating.

Recent technological advances in sorption chilling may provide an answer to this problem. Adsorption or absorption chilling is over 80% efficient at converting heat energy into cooling, and so can displace the need for air conditioning equipment. Solar thermal sorption technology is currently being tested across Europe and can lead to a 50% decrease in the costs associated with traditional air-condition of a building if 85% of the cooling requirement is met by solar thermal energy. The obvious next step is to use the large collector array to supplement space heating requirements in the winter months and space-cooling requirements in the summer months. This type of system is of relevance to any large buildings, such as hotels, offices, laboratories, public buildings or apartment complexes.

Applications

Buildings with high requirements for hot water are suitable for large solar thermal collector arrays. Typically, these buildings include hotels, hospitals, airports, public buildings, care homes, leisure facilities, and so on. If the building also contains a swimming pool, then the relevance of solar water heating is even greater. In the USA alone, it is estimated that the energy supplied to heat swimming pools every year by solar thermal panels is equivalent to the output of ten nuclear power stations.

Designing solar thermal systems

Solar thermal panels must be oriented to face the sun. In the northern hemisphere this means facing south. The angle of tilt depends on the latitude. Using tracking systems to move the panels on an east to west axis to track the sun is impractical due to the pipework, so much work has been done to determine the optimum tilt angle. At a latitude of 40^{o}, such as Baku, the optimum tilt angle in summer is 13^{o} above horizontal and in winter it is 54^{o} above horizontal. Therefore an optimum orientation for a fixed system to gain the maximum amount of solar radiation in Baku is facing due south at an angle of 32^{o} above horizontal.

Solar thermal for power generation

Concentrated solar power (CSP) is being developed for application in the sunniest parts of the world. These systems use mirrors or lenses to focus the sun's rays on a small area to raise temperatures capable of generating electricity via a steam or gas turbine. Since CSP plants generate heat prior to conversion to electricity, this heat can be stored much easier than electricity and used to generate electricity during the night, so CSP plants can operate 24 hours per day. Currently there is about 600 MW of CSP operating in regions such as the Mojave Desert, California, Australia and in Spain. A further 14,000 MW are at various developmental stages.

4. Photovoltaic

Photovoltaic (PV) panels produce electricity when sunlight shines on their solid-state semiconducting material – usually silicon. Unlike concentrating solar power plants, which require large areas, solar PV has a multitude of applications owing to its property of generating electricity directly, without the need for conversion from heat. PV panels are used everywhere from the International Space Station and orbiting satellites to wristwatches, motorway signs and lighting. They are frequently used in remote parts of the developing world.

Photovoltaic Cells, Modules and Arrays

Individual PV cells are thinly sliced wafers of silicon which have been polished, doped and had an anti-reflective coating applied. With the addition of electrical contacts, these cells can be placed on a laminate to from a PV module. Several modules, or PV panels, connected together are referred to as a PV array.

PV Cell Development

The French physicist, Becquerel, is credited with discovering the photovoltaic effect when he noticed in 1839 that light increased the output voltage of a wet cell battery. The first solar cells were constructed from Selenium in the late 1800's but were only about 1% efficient. Higher efficiencies evolved with the development of semiconductors and silicon PV cells doped with boron and phosphorous, increasing efficiency of conversion above 6% in the 1950's.

Large scale PV arrays or solar farms are being deployed in Europe and America. Spain currently has the largest PV array at the Olmedilla PV Park which is 60MW.

How PV Works

A silicon solar cell is a wafer of p-type silicon with a wafer of n-type silicon attached to one side. Doping silicon with phosphorous produces p-type, while doping with boron produces n-type. When a photon of light energy enters the PV cell, it can displace an electron in the junction between the p-n type silicons. The electron tends to migrate into the n-type silicon, creating a "hole" which migrates to the p-type silicon. The electron motion creates current which is collected by metal strips on the surface of the PV cell. Voltage develops between n-type silicon and the p-type silicon with electrons leaving the n-type and re-entering the p-type to recombine with a "hole". It is this flow of electrons which produces electricity.

Types of PV

The majority of PV cells are made of monocrystalline silicon, produced using a slow and expensive process. They have a distinct circular or square shape. Polycrystalline silicon is cheaper to produce and consists of small, randomly aligned grains of monocrystalline silicon. They have a slightly lower efficiency than monocrystalline.

Thin film PV consists of silicon deposited on glass, plastic or metal. Developed in the 1990's, this PV technology has the distinct advantage of lower costs and greater flexibility. When deposited on glass, it forms a semi-transparent layer, which can be used to provide shading as well as generating electricity. Silicon deposited as thin film is amorphous, insofar as it doesn't have a defined crystalline structure. This means it is less efficient, but with applications as varied as shading canopies and windows, it is likely to be of significant relevance to the built environment.

PV Concentration

Lenses and mirrors can concentrate incident light onto the surface of PV cells, and have been used for some time. This can significantly increase the amount of electricity generated, for example by up to several hundred times. These high concentrations can be achieved using solar tracking systems which follow the sun during the day and over the course of a year. These mechanisms are often referred to as Heliostat Concentrator Photovoltaics (HCPV). HCPV systems are mostly confined to areas of high solar irradiance, as the energy required moving the concentrator can make it impractical in less optimum locations. At high concentrations, where mirrors can increase solar energy to over 500 suns, the temperature created within the PV cells is too great for standard silicon technology. In these systems, multijunction PV cells based on Gallium arsenide and Germanium have now been commercialised and other materials such as Indium phosphide are being developed. Unlike silicon cells, the efficiency of these systems increases with temperature.

5. Biomass

Biomass is a collective term used to describe a wide range of organic material, and is considered renewable so long as the biomass resource is either inexhaustible or is being continually replenished. Biomass is the oldest form of energy utilised by mankind as it includes the burning of wood. However, in modern renewable energy classification, the simple burning of wood in an open fire is not considered a renewable energy technology. Modern renewable energy technologies which utilise biomass must be highly efficient and advanced technologies which capture the energy of the resource.

Energy from Biomass

Biomass is composed of complex organic material which was once living. When alive, in the form of plants, it absorbed CO_2 from the atmosphere during photosynthesis and combined this CO_2 with water to form sugars. These sugars were then broken down and rebuilt into the structure of the plant. It is the strong chemical bonds between carbon atoms which provides the energy from biomass when these bonds are broken, typically during combustion. Biomass is therefore a form of chemical energy.

Unlike fossil fuels, which also provide chemical energy in the form of carbon bonds, the combustion of biomass does not release additional quantities of CO_2 into the atmosphere provided the biomass resource is replaced – ie more trees are planted to replace those harvested. The replanting of the biomass resource results in the growth of plants which then absorb this CO_2 back from the atmosphere. Hence the lifecycle production of CO_2 from biomass is close to zero. The CO_2 released from the combustion of fossil fuels such as coal, oil and gas can only be captured using the developmental solution of Carbon Capture and Storage. This may provide a technological solution in the future, but as yet there are only a handful of sites currently capturing carbon and storing it underground, with unproven consequences.

Types of Biomass

Wood

Wood is the most obvious form of biomass available, and any form of wood is considered to be a renewable resource if it is part of sustainably managed forestry. The wood can be directly combusted in a power station to generate electricity and/or heat, but it can also be processed into a more refined product such as wood chips and wood pellets.

Energy Crops

Energy crops are grown throughout the world. In Europe the main crop grown for energy is Rape. Rapeseed oil can be used without modification for generating electricity and/or heat via combustion. It can also be used in transport as a replacement for diesel in converted engines. When processed to biodiesel it can be used in conventional diesel engines. In general, energy crops can be defined a wood, such as short rotation coppiced willow (SRC) or Eucalytpus, or crops grown for fermentation to ethanol or whose seeds can be pressed for oil such as hemp or rape.

Wood chips can be derived from willow grown as an energy crop, and willow is particularly suited to Northern European climates.

Waste

Organic waste materials are also a source of renewable energy. Sewage, for example can be dried and burnt in a combustion plant. It can also be converted to a gas via anaerobic digestion, which is then combusted. Waste wood material from forestry can be successfully utilised as a renewable resource. In 2004, Balcas Sawmill in Northern Ireland became the world's first sawmill to generate renewable electricity by burning waste wood which was then used to run a pellet producing plant that pressed waste sawdust into wood pellets for sale as a renewable fuel.

Municipal waste and industrial wastes can also contain large amounts of organic material, often in excess of 80% of the waste stream. Waste incinerators take advantage of this resource, but as the waste stream will also contain significant amounts of fossil fuel derived products, such as plastic, it is only the organic fraction which is considered renewable.

Conversion Technologies

The most common means of extracting the chemical energy contained within biomass is to oxidise the material via combustion. Many power plants now operate exclusively on biomass, and a much greater number co-fire biomass with fossil fuel such as coal. In 2007, the UK gave permission to construct a 350MW biomass power station fuelled by sustainable forests in the USA and Canada. Costing £400 million, it is due to be the largest dedicated biomass power plant of its kind in the world.

Aside from combustion, there are various techniques to improve the fuel quality and energy extracted. Gasification, for example, is a process of creating a gaseous fuel from the solid biomass, requiring a combination of temperatures and pressures to initiate the conversion. This process is not a new development, having been used to convert coal into a gas for distribution in towns prior to the use of natural gas. The synthetic gas, or syngas, produced from gasification is a mixture of methane, hydrogen, CO_2, CO and nitrogen. Large-scale gasification plants have been operating effectively in Germany, Finland and Austria, for example, for several years.

Pyrolysis is similar to gasification in that it produces a syngas, but the heating of the biomass is conducted with virtually no air present. A historic example of this process is the production of charcoal from wood. At a large scale, pyrolysis has been proven successfully as an excellent treatment method to extract energy from mixed waste streams. Leaving contaminants such as metals ready to be recycled.

Anaerobic digestion is an entirely natural process which sees the creation of a biogas (up to 70% methane) from organic materials. The process takes place in a sealed vessel in the absence of oxygen and relies on anaerobic bacteria to break down complex carbohydrates in biomass into methane and CO_2. Anaerobic digestion is particularly useful for treating wet organic material, as energy is not required to dry the feedstock. Landfill gas is a variation of this process and it is produced when organic wastes are buried at landfill sites.

Recent Developments

The European wood pellet market, although still in its infancy, leads the rest of the world if you consider pellet markets on a global scale. While the industry is characterised by dynamic growth, it is not easy to establish a balanced growth of pellet demand and supply. Larger nations such as Russia, China and India are only beginning to enter the industry in terms of production and consumption. They will undoubtedly become significant global market players and this will lead to considerable change within the existing international framework.

6. Small-Hydro

Over 80% of the world's renewable electricity is generated by hydroelectric plants. Together, these plants generate about one fifth of the total electricity required globally. At 22,500MW, the Three Gorges Dam in China is currently the world's largest electricity generating plant of any kind. Individual countries' hydroelectric potential does depend greatly on topography, as large-scale schemes draw water from reservoirs restrained by dams. However even a flat country such as the Netherlands has around 40MW of hydroelectric generating capacity. Norway, with its rich reserves of offshore oil and gas in the North Sea, surprisingly generates 98% of its electricity demand from hydroelectricity. This, of course, means that Norway receives considerable wealth from the sale of its fossil fuels.

This paper focuses on small-scale hydro, rather than large dams. Small-scale hydro is considered to have a capacity of less than 10MW in Europe.

History

Water wheels have been used for many centuries for purposes such as driving corn and grain mills. By the 18^{th} century water wheels were driving the machinery of the industrial revolution, including textile mills and bellows. A century later, the first water-driven electricity generating turbines were developed. For example, the oldest operational hydroelectric plant in the USA, in Mechanicville on the Hudson River, New York, has seven 750kW hydroelectric turbines. It began generating in 1898.

Technological improvements have continued, allowing modern small-scale hydroelectric turbines to include micro-turbines (below 500kW) and pico-turbines (below 50kW). With these advances, turbines can extract useful power outputs from fast-flowing water in small rivers.

Basics

The potential energy of water is stored behind the dam, or is a measure of the height at which it can fall (known as the head). This potential energy is converted to kinetic energy as the water flows through the turbine, producing electrical energy. The rotating turbine is normally connected to the generator through a shaft and gearbox. The level of electricity generation is determined by the energy contained within the flowing water as it passes through the turbine and the efficiency of the conversion to electricity.

Output Power from Hydro Schemes

Modern, well designed hydroelectric installations can be very efficient at converting the kinetic energy of water into electricity. Efficiencies of more than 85% are possible. In calculating the power output of a small-scale hydroelectric turbine, the following formula is used:

$$P = \rho \, g \, H \, Q \, \eta$$

Where
P = rated power output (kW)
ρ = water density (kg/m^3)
g = acceleration of gravity (m/s^2)
H = net head (m)
Q = water flow rate (m^3/s)
η = turbine efficiency

In simple terms, ρ, g and η can be assumed to be constants, the product of which is a value of 6.

However, in reality, water flow rate is likely to be constantly changing, and just as is the case with wind turbines, an average flow rate, or flow rate curve must be calculated. For example, in an assumed site which has a net head of 100m and a flow rate of 1m^3/s, the output of the turbine will be $P = 6 \times 100 \times 1 = 600$kW. If the head were only 10m, but the flow rate was 10m^3/s, the power output would be $P = 6 \times 10 \times 10 = 600$kW. So, in this simple example, a lower head can be compensated with a higher average flow and give the same electrical output.

Types of Hydroelectric Turbines

A typical small-scale hydro scheme will consist of a water intake system, associated with a weir, sluice or dam; a headrace which is a short channel conveying water to the penstock which is a pipe that takes the water to the turbine. Inside the turbine house is the turbine, gearbox, electrical switching, controls, power factor correction equipment and generator. Finally, an outflow returns the water to the river.

A range of turbines have been developed to extract energy from a variety of flow and head conditions. There are two main classifications: impulse turbines and reaction turbines. Impulse turbines capture energy from a high speed jet of water using specially shaped cups. The water striking these cups (impulse) drives the rotation of the turbine. In reaction turbines, a series of blades extracts energy. The water flows over the blades causing a pressure differential (reaction) that rotates the shaft.

Types of hydro turbine include Francis Turbines, Kaplan or Propeller Turbines, Pelton Turbines, Turgo Turbines and Cross-flow Turbines

7. Geo-Thermal Energy

Deep geothermal energy is the only renewable energy resource which is not influenced by the sun. This form of renewable energy is created by the continual radioactive decay of elements in the Earth's core, generating vast amounts of heat. Convection currents bring this heat to beneath the Earth's crust as molten magma. Humans have been using this heat since prehistoric times and the Romans used it for space heating. Today, geothermal energy provides significant proportions of the electricity required in countries such as Kenya, Costa Rica, Iceland and the Philippines. These countries are located near to plate boundaries in the Earth's crust where the thermal resource is found closer to the surface.

Depth of Geothermal Resource

There is latent heat available in the top layers of the ground, but this is not deep geothermal energy. Rather this is simply heat stored in the soil and in the top layers of rocks from the heat absorbed from the sun. This energy is used extensively to provide space heating in microgeneration systems, but not for the generation of electricity. Beneath this resource, the temperature through the Earth'c crust rises by about 25oC to 30oC for every kilometre. Where the crust is thinner at plate boundaries the rise is much greater. The deep geothermal energy resource required to raise steam and generate electricity can therefore lie at a depth of several kilometres. Aquifers and hot springs can bring this resource much closer to the surface and can be tapped into. If no aquifer is available, then an artificial fracturing of the hot dry rocks at depth can provide a conduit to raise the temperature of water pumped down, and returned to the surface as steam.

Mapping

Recent work on mapping the deep geothermal resource has produced some surprising results. For example, in Ireland, the 2005 report on the Geothermal Potential of Northern Irleand defined temperature profiles for depths of 100m, 500m, 1000m, 2500m & 5000m in Northern Ireland. This was followed by a report in 2008 estimating the total energy stored in target reservoir formations. Northern Ireland is far from a plate boundary and yet it was calculated that at least 4000 MWh of heat energy is stored in just four target geothermal reservoirs at depths ranging from 2200m to 2800m. This information was made possible by the existence of several boreholes from which temperature readings were collected at depth.

In Unterhaching in Germany, a geothermal power plant with a power output of 47MW of heat for district heating and 4.3MW of electricity is fed from a geothermal reservoir with an annual storage capacity of 1069MWh at a depth of 3600m.

Electricity Generating Technologies

Geothermal electricity can be generated in power stations which use gas turbines. There are three main types: flash steam, dry steam and binary cycle.

The most common type of geothermal power station uses flash steam technology. In this system, hot water is drawn from depth at around 180°C and at sufficient pressure to remain as a liquid. When the water reaches the surface, the drop in pressure causes it to flash into steam which is then used to drive the turbine. Any water not flashed to steam is injected back into the underground reservoir. In a similar system, dry steam power plants extract steam rather than water from the underground reservoirs. This steam must be filtered and purified before it can be used to drive the turbine. The steam can be condensed and returned to the reservoir. The third type of geothermal power plant, binary cycle, can utilise much lower temperatures, from 100°C to 180°C, which makes it applicable to a far greater resource. In this system, hot water is extracted and passed through a heat exchange system, transferring the heat to pipes containing fluids such as iso-butane or iso-pentane. These fluids boil at a lower temperature than water, and the resulting gases can be used to drive the gas turbine. Binary cycle power plants cost less, are more efficient and more widely applicable to the available resource.

Rocks which do not have an associated water or steam resource, known in Europe as Hot Dry Rocks (HDR), can also be developed to provide geothermal power. The key characteristic of HDR geothermal energy (in America it is known as Enhanced Geothermal) is that the boreholes extend down into hard rock at depths of over 10km. Typically, to boreholes are drilled some distance apart and the rock between them is fractured. Water can then be pumped down one borehole (the injection well) and extracted as hot water or steam from the other borehole. This system can be used virtually anywhere because of the depth of the boreholes. However, incidents of HDR geothermal triggering earthquakes have been reported and the HDR project in Basel, Switzerland has been suspended for this reason.

Geothermal Heat and Distribution

Rather than using the high temperatures of deep geothermal energy to raise steam and generate electricity, it can also be used effectively to provide space heating, hot water, industrial heat or meet other heat demands. In the case in Unterhaching, Germany, heat output represents 10 times the power output of electricity from the generating station. This heat is captured and transported though a district heating systems, supplying cheap heat to the town of Unterhaching. The majority of direct heating using deep geothermal energy is utilised in space heating.

8. Marine Technologies

Countries with access to the sea can develop marine renewable energy technologies. These are particularly useful where the body of water is large enough to develop significant waves and tides, as is the case in the world's oceans. Offshore wind is not a mature technology and the UK is now the world's largest centre of offshore wind technology, having overtaken Denmark. All offshore wind farms are currently in northern European waters, but China, the USA and Canada have projects at various stages of development.

Wave Energy

Estimates put the European wave energy resource at 400TWh which represents 17% of the EU demand for electricity. Countries such as Portugal, France, the UK, Ireland and Norway are best placed to obtain the maximum wave energy – a result of the westerly winds which create the waves. Wave energy is, however, difficult to harness. The technology required to extract energy from waves involves a system of reacting components which move relative to each other when acted upon by the waves.

Types of Wave Generators

There are several types of wave energy converters which use different properties of waves to create rotational force to drive turbines. Among the earliest were the "Salter Ducks" developed in Scotland in the 1970's which rise and fall in the waves and a special turbine converts this movement into electricity. In Oscillating water column (OWC) devices, a column of seawater is enclosed, but open to the sea at the bottom. The rise and fall of waves produces a rise and fall in the column, which can then push air through a turbine or the water itself can drive the turbine. One distinct disadvantage of this type of technology is that the water or air flows in two directions – up and down. The Wells turbine was designed in the 1980's to overcome this problem by creating rotation in one direction from flows in two directions, but it suffers from a loss of efficiency.

In Norway, the tapered channel wave energy converter was developed. This uses a tapering channel to capture and increase the force of the water until it flows into a reservoir. An inlet pipe to the reservoir contains a turbine. This system requires an excellent average wave energy to be able to exert enough force on the turbine. Also using a reservoir, overtopping wave energy converters capture seawater which spills over the top of a wall. The seawater then escapes past a turbine at the bottom.

Recently developed wave energy converters include point absorbers and terminators. These systems amplify the movement of the waves. Point absorbers can extract energy from multiple directions. An example is the "Oyster" which consists of a large flap attached to a shallow seabed which is pushed when a wave flows over it, and then back again. This pumping effect is used to drive pressurised water to a generating station onshore. A full size Oyster was installed in Scotland in November 2009. Terminators are similar but restrain the force of the wave in a single direction. Attenuator wave energy converters are similar to terminators but are long floating structures oriented parallel to the direction of the wave, rather than perpendicular. They ride the waves, much like a ship, and one section of the device is restrained against its neighbour, a force which can be utilised. "Pelamis" is a Scottish attenuator which comprises the world's first commercial wave farm – 3 x 750kW Pelamis devices off the coast of Portugal.

Future Developments

Modern wave energy technologies are currently in their infancy, with just one wave farm generating commercially. However countries with the resource – Ireland, UK, Portugal, North America, South Africa, Australia and New Zealand, among others, are certainly investing in development projects. For example, the UK has announced the development of a wave hub offshore. This is essentially an extension of the onshore electricity grid to a point off the south west coast, to which wave energy converters could connect. This prospect would significantly increase the attractiveness of the location to developers as the costs of installing subsea cable back to the shore have been removed. The energy potential of the waves is greater than that of the tides, and is more readily accessible in more locations.

Tidal Energy

Tides caused by the gravitational pull of the sun and moon give rise to enormous amounts of energy in the world's oceans and seas. The ebb and flow of the water in tidal currents (tidal stream) and the rise and fall of sea level in the tides (tidal range) are utilised by tidal energy technologies to extract energy from this resource.

Types of Tidal Generators

Tidal stream energy converters work in exactly the same way as wind turbines – blades, connected to a rotor shaft and generator, rotate as the tidal current flows over them. Rapid tidal current flows are located in many places around the world, particularly where a narrow inlet or bay forces the flow to increase. Sites have been identified at several locations around the British Isles, the west coast of Canada, the Straits of Gibraltar, the Bosphorous and in south-east Asia and Australia. Since water is more than 800 times denser than air, useful energy can be extracted with blade diameters much smaller than those of wind turbines, but the technologies must be robust to withstand an underwater environment. The world's first grid-connected prototype tidal stream turbine was connected in Kvalsund, near Hammarfest, Norway in 2003. Seagen, a 1.2MW device was installed in the narrow inlet to Strangford Lough, Northern Ireland in 2008 and is currently the largest tidal stream turbine in operation.

Shrouding the turbine in a venturi-shaped duct creates an area of low pressure behind the turbine, increasing its efficiency and protecting the blades from debris.

A tidal barrage, on the other hand, is a large dam built across a river delta. This captures the incoming tide, retains it and, when the height differential between the trapped water and the sea is sufficient, the water is released through tunnels containing turbines. The world's largest tidal barrage is across the Rance estuary in France. It was completed in 1966 and has a peak generation capacity of 240MW.

Future Developments

Several tidal barrage sites are under serious consideration or development across the globe. Perhaps the largest is the proposed Severn Barrage in the UK. Such a barrage might have 200 hydroelectric turbines and provide 8,000MW of electricity – about 7% of the electricity demanded by England and Wales.

9. Small-Scale Applications and Island Solutions

Small-scale renewable energy systems can provide an ideal form of reducing the energy demand at the point of use – typically households, offices, schools, public buildings and industry. They can also provide useful forms of energy in areas which are not connected to the electricity grid, known as island solutions. Technologies below 50kW electrical and 100kW thermal are generally referred to as microgeneration technologies. Estimates state that these systems can provide between 30% and 40% of the energy demand in a countries' buildings.

Microgeneration Technologies

Solar Thermal

Already described, individual solar thermal panels are ideal for generating domestic hot water for use in homes and other buildings. 60% of a households annual demand for hot water can be supplied by solar thermal, rising to 100% in the summer months, reducing the demand for fossil energy. The market for solar thermal doubled in Germany in 2008, bring the EU area of solar thermal panels installed to 4,600,000 m^2.

Photovoltaic

Some countries, most notably Germany and Spain, have incentivised the installation of PV panels on private buildings. Growth in the EU market for PV in 2008 was 151.6% over 2007. 80% of the world's PV is now installed in the EU, with the majority being building-integrated rather than in large-scale power plants. Germany remains on top, in terms of installed capacity with 5311MW grid connected and 40MW off-grid or island generation.

Micro Wind

Micro wind turbines have been used for many decades in isolated rural locations to supplement electricity from the grid. These systems have seen a lot of interest in recent years, particularly in the UK. Incentives from the Northern Ireland government to households and communities has resulted in an increase from 855kW installed in 2005 to 7560kW in 2008.

Biomass Heat

Small-scale biomass can be utilised in biomass boilers to provide space heating and hot water. Typically operated by pellets, this technology is commonplace in densely forested countries such as Latvia, Sweden, Austria and Russia. Some small-scale renewable energy technologies have been developed which gasify logs, pellets or wood chips. 2008 saw nearly 500,000 domestic wood heating appliances sold in France alone.

Heat Pumps

Heat pumps extract low-grade heat from the soil, boreholes (up to 100m), water or the air to supply space heating and hot water. Working on the same principle as a refrigerator, a heat pump compresses a refrigerant in a closed loop, increasing the temperature extracted from the external collector to around 35^{o}C. This heat is then extracted and transferred to the building. Over 100,000 units have been installed annually in the EU over the past three years. Heat pumps consume electricity to operate the compressor, but for every unit of electricity consumed, the heat pump will produce about 4 units of useful heat, making it 400% efficient. However, a heat pump is only truly renewable if the electricity consumed also comes from a renewable source.

Combined Heat and Power

Combined heat a power (CHP) units comprise electricity generating plants from which the heat generated is captured and transferred to a distribution system. Renewable fuels such as biomass, pure plant oils and biodiesel are fuelling small-scale CHP systems in greater numbers, although this is an emerging application of an existing technology. Biofuel such as biodiesel can fuel CHP engines as small as 10kW, producing about 20kW of heat. These systems are ideal in locations where there is a continual demand for heat and electricity, such as industrial processes or hotels.

10. Selected Options for Renewable Energy

The heat and electricity generated by renewable energy technologies can be utilised wherever there is a demand. Electricity fed into the grid is, of course, no different to the electricity generated by conventional fossil fuel power stations, and heat from renewable sources can also link in to district heating systems fed by fossil energy. However, there are some applications of renewable energy technologies which are particularly relevant for reducing the consumption of fossil energy.

Renewable Energy for Desalination

Desalination provides freshwater from seawater and is relevant in parts of the world which have low rainfall but high populations and which are located next to the sea. The various technologies such as reverse osmosis and flash distillation are all energy intensive, and it must be considered if the cost of desalinating seawater is effective when compared to the recycling of water or tapping into other freshwater reserves. However, this energy intensity can be effectively reduced by applying renewable energy solutions to the site. One such site in Perth, Western Australia, receives part of its electricity requirement from a wind farm. Another site, the Gold Coast desalination plant had been proposed to have all of its energy requirement met by renewable energy, but is currently buying certificates from existing renewable energy generators so as to offset its carbon emissions.

Effective Systems

The most effective means of desalination remains reverse osmosis – using pressure to remove salt from water by passing it through a semi-permeable membrane and renewable electricity generating systems can be effectively installed onsite to supplement the electricity required. If the plant is next to the coast, then marine technologies such as tidal stream or offshore wind may be employed. Solar PV may also be useful as the climate may already suggest significant amounts of sunshine. The Middle East is the global centre for desalination, containing about 75% of world's desalination capacity. It is possible to use solar power in desalination, usually of groundwater in remote locations. This application has been used since the 1950's, and can incorporate reverse osmosis or evaporation and condensation.

Renewable Energy for Transport

Estimates place transport as being responsible for 73% of total oil consumption in Europe, and 21% of EU CO_2 emissions. The EU Biofuel Directive and the EU Renewable Energy Directive place targets on the percentage of transport fuel which should be from a renewable source: 4% by 2015 and 10% by 2020. The majority of this fuel will come from energy crops grown to produce bioethanol and biodiesel and additivies for petrol and diesel respectively. However, other renewable energy technologies can be effectively used to provide energy for transportation.

Biogas

Biogas produced from anaerobic digestion of organic material, often agricultural and municipal wastes, can be improved and injected into a gas distribution system. For example, the Laholm AD plant in Sweden now provides 30% of the natural gas heating supply for the local municipality. Since 2005, Sweden is also using this biogas to power a train running between the cities of Linkoping and Vastervik. Using two biogas engines, the train reaches speeds of 80mph and has a range of almost 400miles between refuels. Also in Sweden, biogas powered buses run in most cities and some cities such as Linkoping now have a 100% renewable urban transport network.

Electricity

Trains powered by electricity will receive a percentage of their electricity from renewable sources as the grid supplied electricity will have a renewable element. Electric cars, on the other hand, have yet to become widely available. Work on this sector continues, particularly in America where new electric cars are being developed with ranges of up to 300miles (480km) and top speeds of 80mph. As of 2009, the world's most popular electric car is the Indian REVAi. Other countries have significant development programmes. Iceland, for example, plans to convert all cars to electric by 2012. In Ireland there is a target for 10% of cars to be electric by 2020. The largest car factory in the UK has been granted £380m EU loan to develop electric car capacity, and President Obama has set a target for 1 million electric cars on the road in America by 2015.

Electric cars will, of course, increase the demand for electricity. But the generation of electricity from renewable sources has particular benefits for use in transport. In particular, wind energy, which is intermittent, is on average greater at night when the demand for electricity is lower. The prospect of millions of cars being charged overnight, fed by an electricity grid which has a high percentage of wind energy means that more wind turbines may be accommodated on the grid.

11. Grid Integration, Grid Management, and Storage

There are major barriers to the widespread development of renewable energy systems – cheap supplies of fossil fuels, capital costs, resource availability, public acceptance. However, from a technical standpoint, the greatest obstacle to be overcome is the ability of the existing electricity grid to be able to accept large amounts of renewably generated electricity in areas where the grid has limited capacity. Renewable energy resources can be located in remote areas where there is little or no grid infrastructure of adequate size to transport the generated electricity to areas of consumption such as urban centres or industry. In addition, the renewable energy resource can be intermittent, in that it is highly variable depending on the environmental conditions. This is an issue with wind energy, wave energy and solar energy. Managing this intermittency is a prerequisite to developing a grid which has a high percentage of these renewable energy technologies.

Grid Context

Denmark has a high level of wind energy penetration on its electricity grid, with 3179MW installed by the end of 2008, representing 24% of energy capacity in the west of Denmark and 11% in the east of Denmark. The difficulty arises when the level of penetration can reach a point where wind energy could conceivably be supplying more than the minimum demand, which occurs on a summer day. If the wind were to be supplying the bulk of this demand and suddenly the wind speed dropped unpredictably, the grid would crash, causing a blackout. This scenario can also occur when the demand for electricity is rapidly increasing, which especially occurs on winter mornings.

To deal with this issue in Europe, large grid transmission systems are being built, which can help by transmitting electricity long distances, from areas where there is excess generation to areas where there is insufficient generation. Denmark, for example, wishes to increase the level of wind energy generation to 50% of consumption. This necessitates a strong transmission system connecting the resource which is often in areas of weak grid infrastructure to areas of demand, and also to neighbouring countries.

Grid Upgrade

Upgrading the transmission system – high voltage grid at around 400kV – is expensive, but necessary, to adapt the grid system from one which traditionally distributed energy from centrally located fossil fuelled power stations, to one which can accommodate distributed renewable energy generating stations such as wind farms, marine energy and geothermal energy. Ireland has a weak grid system which is exacerbated by the fact that Ireland is an island and cannot readily export excess wind energy generation if there is too much wind on the system. To help alleviate this problem, large interconnectors have been built across the Irish Sea to Great Britain, totalling 1000MW. However, since the renewable resource of Ireland is dominated by wind which is strongest in the west, whilst the main population is in the east, it has been calculated that an additional 845 km of high voltage transmission lines will be required to develop the renewable content of grid electricity to 40%. The cost of the lines is estimated at €1bn. Ireland could, of course, continue to generated nearly all of its electricity from fossil fuels, but the study also concluded that the rising costs of fossil fuels, and the cost of the CO2 emitted, would negate any capital savings. Furthermore, rising population and electricity demands would eventually require grid restructuring anyway. By 2020 it was calculated that the operational costs of supplying Ireland with electricity would fall from €2000m to €1500m annually, with an annual cost of grid reinforcement of €63m, if 42% of the electricity were to come from wind and marine resources.

Managing Intermittency

Accepting large amounts of intermittent energy generation onto the grid, from wind and other renewable sources, can be effectively managed. Greater accuracy of predicting the resource is the key. Tools have been developed to allow accurate prediction of the wind resource to greater than 95% accuracy for 24 hours in advance. This is necessary to allow the grid operators to manage the dispatch of generating plants one day in advance. No technical system is 100% reliable, but redundancy – by providing overcapacity in generation – can reduce the risk. The grid study in Ireland showed that for this weak island system, a level of 42% renewable energy can be managed effectively with no loss of load over the course of one year. In the analysis, it was shown that the demand for spinning reserve was not met for just three hours in the year. Such as system was achieved by using the prediction tools to accurately predict the wind generation to 95% and then curtail wind turbine output when it exceeded grid stability. Wind turbine operators may not like to concept of allowing the grid operator to curtail turbine output, but it can be compensated.

Options for Energy Storage (Heat + Electricity)

Another means of managing the predictability of the wind resource is to convert the wind electricity into stored energy which can be dispatched upon demand. Pumped storage is common, and involves the creation of a dammed reservoir into which water is pumped when electricity is cheap and released via hydroelectric turbines when electricity is expensive, such as during periods of peak demand. Heat can also be stored or injected into a heat distribution system. Storage of heat during the night, for example from solar thermal systems, allows 24hr continual supply. This heat is stored in large, well insulated cylinders, or in underground aquifers.

If there are coastal valleys, then seawater can be pumped using wind turbines into storage dams. There are examples of this type if system in Japan, at Okinawa. In this scenario it is the hydroelectric dams which provide renewable electricity to the grid on demand, rather than intermittently. A proposal has been tabled to install three such plants in Ireland rated at 1000MW each. This is still controversial, but if approved could represent a solution to the intermittency of wind electricity. Approximately 2000 wind turbines would be needed to run the system. At an estimated cost of over €10bn, this proposal could make Ireland independent in terms of energy for electricity.

12. Application in the Context of Azerbaijan

Many, if not all, of the renewable energy technologies are applicable to some degree in Azerbaijan. With access to the Caspian Sea, the future of wind energy in the region may well lie offshore.

Resource Context

Azerbaijan has an abundance of renewable energy resources such as wind energy, solar energy, biomass and hydro. The announcement of recent funding to study these resources and determine the potential renewable energy which could be developed is very encouraging. This is a necessary step towards determining a strategy for developing the renewable energy resources of Azerbaijan.

Applicable Technologies

The Caspian Sea has insufficient tides to create either tidal stream or tidal barrage systems, but all of the other renewable energy technologies are applicable, depending on the measured level of the resource.

Wave power associated with the northern shore of the Absheron Peninsula or utilising a Pelamis-type device offshore is likely to offer the most viable wave energy solution. Since the prevailing wind direction over the Caspian is from the North and the wave height on the western coast is double that of the eastern coast, wave energy is an applicable technology worthy of exploration.

Geo-thermal energy, too, is likely to be a significant resource for Azerbaijan. The Geo-thermal Atlas of Azerbaijan published in 1998 by the Azerbaijan National Academy of Sciences provides detailed maps of the resource, both on land and offshore. According to a study by the Azerbaijan Technical University, Azerbaijan is rich in geo-thermal resources, with temperatures at around 90°C and sometimes at a depth of 1400m. This is well within the bounds of existing technologies used in geothermal energy extraction.

The wind resource in Azerbaijan would also benefit from detailed mapping, which would allow suitable sites and predicted electricity outputs to be identified. The "Master Plan of Wind Power Development of the USSR till 2010" in 1989 identified 110×10^9 kWh/year wind energy generation potential. The EBRD suggested an installed capacity of 3000 MW would be applicable in Azerbaijan for this resource, but that is likely to be reduced by site availability. The Caspian Sea coast has the best wind regime, with average wind speeds at 30m above the ground estimated to exceed 6m/s. The Absheron Peninsula is the optimal location as it is also in the vicinity of Baku. It is highly likely that the offshore resource is many times greater, and the learning of the northern European countries of Denmark, Germany and the UK could be applied to the Caspian Sea to develop offshore wind farms.

Azerbaijan receives a high annual amount of sunshine and is applicable for the development of both solar thermal energy and solar PV. These technologies at small scale are extremely versatile and applicable to buildings. Solar power plants, either thermal or PV, could be strategically located where there is sufficient access to the grid. Solar insolation per year averages 1715 kWh/m^2. This compares to an insolation level of around 1000 kWh/m^2/year for northern Europe, where household and building integrated solutions for solar power are incentivised.

Biomass is certainly applicable to Azerbaijan, and a study of the available resources and locations would determine the potential technical capacity. Waste from the cultivation of cotton and cereals is one such resource, as is forestry. Municipal organic waste and sewage wastes are other resources which could be developed. One estimate from the EBRD puts the available resource at 1000 tonnes of oil equivalent, which equates to 11,630 MWh output per year.

Small-scale hydro has significant developmental potential in Azerbaijan. In particular, the lower reaches of the Kura river, the Aras river and other rivers flowing into the Caspian Sea. Hydropower could conceivably provide up to 30% of Azerbaijan's electricity requirements. Currently, hydropower, dominated by large-scale dams, provides 11.4% of Azerbaijan's electricity. Small-scale hydro could provide up to an additional 25%. Development of the small hydropower sector is ongoing, and supported by a number of international projects.

Summary of Economics

Wind energy and hydro are arguably the most economic of the renewable energy technologies and as such are mature technologies. Much work has been done to compare the economics of renewable energy generation systems. However, the economics of generation will always be compared with the economics of fossil fuel fired power generating stations. Azerbaijan is blessed with a resource of fossil fuels, and this makes direct comparisons with renewable energy unfavourable. However, although electricity and heat may be generated cheaper through the use of fossil fuel resources, by utilising the inexhaustible supply of renewable energy, Azerbaijan is capable of generating wealth by exporting the fossil fuel resources. This is exactly what has led to

Norway's wealth, a country which generates 98% of its electricity from hydro, yet has huge reserves of oil and natural gas in the North Sea.

The economics of renewable electricity generation must also take into account the necessary upgrade to the grid infrastructure, to enable it to be able to accept large amounts of distributed generation rather than centrally located power stations. The All-Island Grid Study, sponsored by the governments of Northern Ireland and the Republic of Ireland, attempted to levelise the costs of renewable electricity and fossil electricity for Ireland by the year 2020, and to incorporate the societal costs – ie the costs of improving the grid. This study, the most advanced of its kind in the world, concluded that the societal costs of generating 42% of Ireland's electricity from wind and marine resources could be accomplished with just a 7% increase in cost, compared to a grid dominated by fossil fuel generation.

In order of merit, for Ireland, the renewable generation economics are led by wind. The levelised economics of wind generation, including the cost of construction, the annual cost of operation and maintenance and the costs of grid connection, resulted in a cost per kWh of electricity supply of €0.04, for the most economic wind farms. Costs were higher for less economic locations, depending on wind resource and distance from the grid. An additional 4000MW could be installed with a levelised cost per kWh below €0.06. Second generation tidal stream turbines – with outputs in excess of 1MW per turbine – produced a levelised cost of €0.10 per kWh generation to society in Ireland. Wave energy generation off the west coast of Ireland resulted in a levelised cost of €0.10 to €0.15 per kWh. Solar was not considered applicable to Ireland due to the lower levels of solar insolation, which is less than half that of Azerbaijan. The projected Ireland municipal, agricultural and industrial waste biogas (anaerobic digestion) showed a total resource capacity of 91MW of electricity. The levelised cost of this resource was calculated at ranging from €0.10 per kWh to over €0.40 per kWh. Incineration of municipal solid wastes which contain a high percentage of organic material was found to be €0.06 per kWh levelised cost for the most advantageous city location. Potential generation from municipal solid waste was estimated at 165MW for Ireland. Landfill gas generation, a form of anaerobic digestion, was found to have a levelised cost of €0.04 to €0.07 per kWh generation for the optimum sites. The levelised cost of Anaerobic Digestion of organic materials was found to range upwards from €0.09 per kWh and the combustion of dry agricultural wastes and energy crops (biomass) to generate electricity was found to be €0.07 per kWh. Finally, the geothermal resource, although subsequently shown to be significant in Ireland, was not measured in this study. Other studies have estimated that the cost of extracting this resource is from €0.05 to €0.10 per kWh. Finally, small hydro power plants can have very good economics, but this is determined by the flow and head of the hydro resource, coupled with the installation costs. Hydro can have a levelised cost of €0.034 per kWh, but is highly site dependent.

In conclusion, there has been significant work already in terms of analysing the renewable energy resource in Azerbaijan. Policies and strategies could be agreed to develop that resource and technologies with low levelised costs can be prioritised, if analysis shows that suitable locations exist. The locations for new renewable energy projects could be investigated and costed as part of this development.