Watts In Store
(Storing Renewable Energy)

Watts In Store
(Storing Renewable Energy)

By

Remi Wilkinson
Senior Analyst

CarbonFree undertakes consultancy, research and analysis for vendors, investors and energy providers.

For further information contact:-

CarbonFree
20 Leaden Hill, Orwell
Royston, Herts.
SG8 5QH
UK
Tel. ++ 44 (0) 1223 208926
Email info@carbonfree.co.uk
Web www.carbonfree.co.uk

Contents

Watts In Store

Approximately 900 KWh of solar energy falls on each square metre of Europe and the USA each year. New York and London receive in excess of 1000 TWh of solar energy per annum. However, this energy is diffuse and the majority of it is received at times when people are trying to cool rather than heat their homes and offices. Nearer the equator the solar energy available per square metre is far higher than 900KWh per annum – however local demand for this energy is lower than it is outside of the solar belt. While wind energy is available outside of the solar belt and during darkness hours it, like solar energy, is intermittent. Therefore, it is important when considering the wide scale use of renewable energy, to find a way of storing that energy. Then it can be transported from one region to another and deployed in a way that overcomes the intermittent supply of renewable energy.

All supplies of energy, regardless of their source, are potentially intermittent. Oil is extracted in parts of the world that are politically unstable and gas supplies are vulnerable to technical and political disruptions that affect distribution. At the same time, public reaction to a single incident at a nuclear power station can result in several months of disruption while the plant remains off line. But conventional energy providers have access to long supply chains that provide a buffer against irregular supply. A retailer using wind turbines to provide power must place the turbine close to its store and when the wind stops blowing the power supply is cut. Meanwhile the same store can receive an uninterrupted supply of electricity generated in oil-powered power stations. Even if supplies of oil are disrupted there is usually enough fuel in the supply chain to power the store until the flow of oil can be restored.

However, in its infancy, even the oil industry suffered from intermittent supplies. Barrel suppliers and storage tank manufacturers, who solved the storage problems were well rewarded. One of the ways companies such as Standard Oil manoeuvred themselves into such strategic positions within the oil industry was by lengthening supply chains. Companies who can lengthen the alternative energy supply chain will be equally well placed as the market for new sources of energy develops.

This report examines the market for stored renewable energy and the companies that are already active in this area. It looks at a range of technologies that can be used to convert renewable energy for transportation or deferred use.

Also considered is the business case for energy storage and distribution within 'Urban Heat Islands'. Cities provide an interesting example of the potential of stored renewable energy. The solar energy and heat created by activities within cities is temporarily locked into physical infrastructure such as roads and buildings. This report examines a scenario that could provide companies, that are able to unlock this energy, with robust business models and revenue streams.

At a Glance

Approximately 900 KWh of solar energy falls on each square metre of Europe and the USA each year. However, this energy is diffuse and intermittent.

The growing use of renewable energy will stimulate the market for a wide range of energy storage technologies that can be deployed to overcome the intermittent supply of renewable energy.

Oil and coal are stores of energy and bio-fuels and hydrogen have the potential to move into this space. As in the early days of the oil industry, players with the infrastructure to distribute energy will dominate the renewable energy sector.

Bio-fuels and hydrogen fuel cells will fight each other for market share within the automotive sector while fuel cells will also carve out a niche market within the residential energy sector.

Urban Heat Islands could provide opportunities energy companies that use geothermal technology to collect and market excess heat energy.

This report examines the opportunities for technology vendors and nextgen energy companies in the renewable energy storage market. Also considered is the business case for energy storage and distribution within 'Urban Heat Islands'.

Included in this report are profiles of:- D1 Oils, Wind Hydrogen, Ballard Power Systems, Ooms and Pentadyne.

1 Introduction

The key advantage of renewable energy sources, especially wind and solar, is their abundance and relatively widespread availability. The fundamental problem, if they are to be used for electricity supply, is their variability and intermittent nature. The power generated varies over a twenty-four hour period and is seasonal. In its raw form, renewable energy cannot be relied upon to provide continuous base-load (the minimum amount of electricity that needs to be delivered at all times) or peak power when needed. In practice, renewable energy can only provide about 10% to 20% of the capacity of an electricity grid and cannot be considered an economic substitute for fossil fuels. In order to improve the business case for installing renewable energy power plants, energy suppliers must have multiple sources to provide almost 100% back-up of renewable energy generation to meet demand, or have some means of storing renewable energy on a large scale. This results in very high generating costs by today's standards.

In its raw form, renewable energy cannot be relied upon to provide continuous base-load or peak power when needed.

In addition, today's grid systems require electricity demand to exactly match supply. Failure to achieve this causes frequency fluctuations leading to the instability of the grid. The intermittent nature of renewable energy means that feeding it directly onto the grid without adequate load management creates instability.

The intermittent nature of renewable energy means that feeding it directly onto the grid without adequate load management will result in instability.

At first sight, it would seem that renewable energy is not cost-effective, nor of acceptable quality to be considered as a primary energy source. However, these technologies will be increasingly required to contribute to the world's energy supplies in order to cope with increasing energy demands and to counter the threat of climate change.

Ensuring reliability and quality of supply requires significant load management, energy storage and back up energy source. It would be possible to deploy back-up power plants running with relatively cheap fuel such as gas. However, a stored energy source is preferable to an auxiliary gas power plant as it results in cost savings in fuel and in the building of generating facilities and transmission lines to cover peak loads. It is therefore important to find solutions to the efficient storage of large amounts of renewable energy.

Energy storage devices are also required in applications other than electricity supply. They are needed to provide heat and hot water to buildings and industry in weather conditions that are unsatisfactory for generating renewable energy, and to power vehicles and consumer portable electronic devices such as personal computers, mobile phones, personal digital assistants, and audio equipment.

Energy storage devices are also required in applications other than electricity supply. They are needed to provide heat and hot water to buildings and industry in weather conditions that are too poor to generate renewable energy

There are also cases where the short term storing of kinetic energy or the long term storage of heat energy are of value and can smooth out peaks and troughs in both demand and supply.

2 Intermittence

The intermittent nature of renewable energy presents problems with availability and system stability. Unlike conventional power plants, intermittence does not allow the output of renewable energy systems to be adjusted to meet demand. Also, renewable energy power plants will shut down when a fault causes a voltage drop, unlike conventional plants that continue to generate, thereby supporting the system's stability. This is because, by law, inverters that convert the direct current (DC) into alternating current (AC) in grid-connected renewable energy systems are set up to cut out the instant that grid electricity goes down. This is to prevent electricity entering the grid system which could endanger engineers working on the lines. Until grid codes, (which among other things define the electrical behaviour in critical grid situations) are defined for renewable energy plants, the situation regarding stability will continue.

Unlike conventional power plants, the problem of intermittence does not allow the output of renewable energy systems to be adjusted to meet demand.

In regions with low electricity demand and large wind generation facilities interconnected with other regional or national grid facilities, the electricity exported can cause significant negative impacts in neighbouring countries. Wind farms in northern Germany have caused problems in the Dutch and Polish systems. In December 2004, electricity exported from Germany to the Netherlands was more than twice the amount expected in the exchange programme. This caused critical problems in the grid. The integration of renewable energy generation systems has thus become a regional problem rather than a national one.

Rapid changes in wind or solar power can be accommodated through power shedding - a power company "throwing away" energy while it gets the system into balance - but this represents a waste of a resource and loss of revenue to the power company.

Today's grid systems operate with minimal storage because of the reliability of conventional power plants. Grid systems with significant and growing renewable energy sources will require more and larger storage facilities to resolve the problems of intermittence. In Spain and the UK where operators of wind turbines are charged for feed-in deviations, energy storage installations can be used to hedge against in-feed power fluctuations, thereby avoiding high costs for balancing power. A flexible grid with sufficient storage capacity would lower the pressure to build new power plants and transmission lines, prevent regional black-outs, and speed the adoption of renewable energy by transforming intermittently produced power into steady reserves.

Energy storage installations can be used to hedge against in-feed power fluctuations thereby avoiding high costs for balancing power.

3 Energy Storage Systems

3.1 Electricity storage

Electricity storage systems can store power from conventional fossil fuel and nuclear sources as easily as they can store power from renewable sources.

Electricity storage systems are as applicable to conventional power generators as they are to the nextgen operators.

Current systems used for electricity storage include pumped hydro (up to 2000 MW), compressed energy storage (10 MW – 300 MW), batteries (1MW – 20 MW), fuel cells (0.1W to 5 MW), flow batteries (1 kW to many MW), super-capacitors (10 kW – 100 kW), super-conducting magnetic energy storage (1MW – 10 MW), and flywheels (10 kW – 1 MW).

Development of energy storage applications began during the early days of electricity generation and technologies considered included flywheels and compressed air.

In power supply applications, they are used to fulfil various functions. Flywheels and SMES systems are used for improving the quality of the electricity - making the voltage and frequency uniform when there are sudden falls or increases in voltage, or frequency fluctuations. Batteries are used for bridging, for example where stored energy is used for seconds to minutes to assure continuity of service when switching from one power source to another. Pumped hydro, CAES, and flow batteries are used for load levelling - supplying and removing power to and from the grid to flatten out variations in the demand for power.

3.1.1 Pumped Hydro

Pumped hydro storage is the oldest, largest, and most effective of all the commercially available large-scale energy storage technologies. It has the largest electricity storage capacity - over 2000 MW - and among the longest storage periods, typically more than six months. Pumped hydro uses two water reservoirs, one higher up than the other. During off-peak hours, water is pumped from the lower reservoir to the upper reservoir. When required, the water is dropped back to the lower reservoir, generating electricity. Reversible turbine assemblies act as pump and turbine. Taking into account evaporation losses from the exposed water surface and conversion losses, approximately 70% to 85% of the electrical energy used to pump the water into the elevated reservoir can be regained. Pumped hydro installations are used for load levelling and operate on a daily schedule.

Pumped hydro has the largest electricity storage capacity - over 2000 MW - and among the longest storage periods, typically more than six months.

Partly due to the large scale and the relatively simple design, the operating cost per unit of energy is among the cheapest. The cost of storing energy can be an order of magnitude lower in pumped hydroelectric systems than in, for example, superconducting magnetic storage systems.

The key disadvantage of this storage technique is its dependence on specific geological formations. Two large volume reservoirs with sufficient head of water between them are required. This often requires locating the plants in remote places like mountain regions where construction is difficult and the power grid is not close. The second greatest disadvantage is the high capital cost needed to build the dams and install the enormous underground pipes. Thirdly, there's a huge impact on the local habitat resulting from the daily fluctuation of the water level.

There are over ninety pumped hydro system installations throughout the world: in Australia, Bulgaria, Canada, China, Czech Republic, France, Germany, Ireland, Norway, and Japan. They include the 850 MW Rocky Mountain scheme in Georgia, USA; the Dinorwid and Ffestiniog plants in Wales, UK; the Tianhuanping plant in China, and the Raccoon Mountain plant in Tennessee, USA.

There are over ninety pumped hydro system installations throughout the world.

In 2003, hydroelectric storage facilities around the world provided about 90 GW of electricity - approximately 3% of global electricity capacity. In the early 1990s, pumped hydro accounted for nearly 3% of the summer electricity capacity in the USA. However, pressure from deregulation caused investment to decline. In Europe and Japan, the proportions of pumped hydro capacity in the grids are about 5% and 10% respectively.

In 2003, hydroelectric storage facilities around the world provided about 90 GW of electricity - approximately 3% of global electricity capacity.

Prospects for this technology are limited in most industrialised countries due to high development costs, long lead times, and the necessity to locate them in very rural areas due to their size. The current focus for development of this technology is increasing the power rating of existing facilities and increasing their operating efficiency by 10% to 15% through the use of advanced pumps, impellers, and variable-speed drives.

3.1.2 Compressed Air Energy Storage (CAES)

In compressed air energy storage, off-peak power taken from the grid is used to pump air into a sealed underground cavern to a high pressure of between 60 and 75 bar. This technology has a high storage capacity comparable with pumped hydro, has specific geological requirements, and requires a suitable location near transmission lines and fuel supplies.

This technology has a high storage capacity compared with pumped hydro. It has specific geological requirements, and requires a suitable location near transmission lines and fuel supplies.

Air can be stored underground in naturally occurring aquifers, rock caverns (solid rock is excavated), salt caverns (salt is dissolved away), constructed caverns, or abandoned mines. In general, rock caverns are about 60% more expensive to mine than salt caverns for CAES purposes. Aquifer storage is by far the least expensive method and is therefore used in most of the current CAES installations.

Typically, compression is done with a motor-driven turbo-compressor. As part of the compression process, the air is cooled prior to injection to make the best possible use of the storage space available. When needed, the air's high pressure can drive turbines as the air in the cavern is slowly heated and released. More often, the compressed air is mixed with natural gas and they are burnt together in the same fashion as in a conventional gas turbine plant. Plants are designed to operate on a daily cycle, charging at night and discharging during the day.

The system described above is referred to as a diabatic system because it involves a transfer (or loss) of energy. The storage efficiency of diabatic CAES plants is reduced by cooling the air before it enters the cavern, and by reheating the air prior to burning it with the fuel. A more advanced technology using an adiabatic cycle is being developed which involves a zero net gain or loss of heat. In this Advanced Adiabatic CAES (AA-CAES) technique, the heat energy is extracted and stored separately before the compressed air enters the cavern. When energy is required by the grid, the compressed air and heat energy are recombined, and expanded through an air turbine. This adiabatic CAES benefits from higher storage efficiencies and, notably, zero CO2 emissions.

A more advanced technology using an adiabatic cycle is being developed which involves a zero net gain or loss of heat.

A typical CAES system will store around 10 MW – 300 MW, and can be used to store energy for more than a year given that losses are minimal.

Due to the geographical restrictions that limit the potential of underground CAES systems, current research is focused on the development of systems with fabricated high-pressure storage tanks. However, these cannot, at the moment, be manufactured at reasonable cost with current technology and the scales proposed are relatively small compared to underground CAES systems.

Due to geographical restrictions that limit the potential of underground CAES systems, research is now focused on the development of systems with fabricated high-pressure storage tanks.

The advantages of CAES systems include significant storage capacity at relatively low cost ($400 to 600 per kW), proven technology, fast start-up (seconds from hot spinning reserve condition, 5 – 12 minutes from cold metal), and ramp rates of 30% maximum continuous rating per minute. By comparison, conventional combustion turbine peaking plants typically require 20 to 30 minutes for a normal start-up.

At present there are only two CAES plants in operation in the world although several others are planned. The operating systems are the 110 MW facility at Alabama Electric Cooperative in McIntosh, Alabama, USA, and the 290 MW installation at E.N Kraftwerk in Huntorf, Germany. Installations under development in the USA include the 2700 MW facility in Norton, Ohio, the 540 MW facility in Markham, Texas, and the 100 MW - 200 MW Eagle Grove aquifer-based facility in Iowa serving regional wind facilities. Energy Storage and Power Corporation (ESPC; www.espcinc.com) have carried out extensive studies on the integration of wind power and landfill gas generators with small scale CAES, but, as yet, no field trials have been conducted.

Energy Storage and Power Corporation have conducted extensive studies on the integration of wind power and landfill gas generators with small scale CAES.

www.espcinc.com

3.1.3 Batteries

A battery is an electrochemical device that converts chemical energy into electrical energy, and is the oldest established way of storing electricity. It consists of two electrodes, an anode and a cathode, and an electrolyte in a container or reactor. In a standard battery, the electrolyte is confined within the container. Batteries that are either in use and/or potentially suitable for power plant scale applications include lead acid, nickel cadmium, sodium sulphur, sodium nickel chloride, and lithium ion.

Battery systems are used for load levelling, spinning reserve, frequency control, power quality, and uninterruptible power supply (UPS) where the battery is used if the main power fails to provide an uninterrupted supply. However, due to cost and performance limitations, particularly their relatively short life spans, large-scale lead-acid battery installations are not an adequate complement to intermittent renewable energy sources.

Examples of battery installations are the 1 MW (4MWh energy) lead acid ESCAR Battery Storage System at the Iberdrola Technology Demonstration Centre in Madrid, Spain, used for load levelling, the Golden Valley power company in Fairbanks, Alaska used as a spinning reserve, the 20 MW lead acid battery facility in Puerto Rico Electric Power Authority, and the sodium sulphur 100 kW peak facility owned by American Electric Power.

Due to cost and performance limitations, particularly their relatively short life spans, large-scale lead-acid battery installations are not an adequate complement to intermittent renewable energy sources.

3.1.4 Fuel Cells And Hydrogen

Fuel Cells As Storage Devices

A fuel cell is an electrochemical cell, similar to a battery, which converts chemical energy into electrical energy. It differs from a battery in that it is designed to produce electricity from a continuous external supply of oxygen from the atmosphere and fuel - usually a gaseous fuel such as hydrogen or methane. Unlike a battery, the amount of fuel is not limited to the storage capacity of the unit. In the case of hydrogen fuel cells, the only by-products are heat and water. The conversion of the fuel to energy takes place without combustion, and is, therefore, highly efficient, clean, and quiet.

Many different types of fuel cell have been created using different electrolytes including alkaline, polymer electrolyte membrane (PEM), molten carbonate, and solid oxide.

Many different types of fuel cell have been created using different electrolytes including alkaline, polymer electrolyte membrane (PEM), molten carbonate, and solid oxide. Alkaline fuel cells have an output ranging from 300 W to 2 kW. PEM systems of 50 kW – 250 kW have been developed and are most suitable for vehicles as they can vary their load quickly. Solid oxide fuel cells (SOFC) can be used in big, high power applications and their power output is around 100 kW.

Fuel cells have several advantages over batteries:

- They are modular and can be used as building blocks for systems from kW to multi-MW capacity.
- They provide a much higher power density - power obtained per unit mass or volume.
- The system charge rate, discharge rate, and storage capacity are independent variables - increasing the volume of the electrolyte tanks increases the amount of energy that the system can store and release.
- Increasing the number of cell stacks increases the power that the system can generate.
- Studies suggest that they will be far easier to recycle than batteries. In the case of PEM fuel cells, the basic components are easier to separate and reprocess than any type of battery. Recovery rates of the platinum group metals (PGMs), for example, are well over 99%.

In the case of PEM fuel cells, the basic components are easier to separate and reprocess than any type of battery. Recovery rates of the platinum group metals (PGMs), for example, are well over 99%.

Fuel cells are being used as a replacement for batteries in back-up applications where an uninterruptible power supply is critical, such as hospitals, computer data centres and telecommunication transmitter towers.

Fuel cell storage components are also being developed for portable electronic devices. In this application, fuel cells provide a much longer life than batteries (up to ten times longer), and refuel quickly with a liquid or gaseous fuel. Direct methanol/ethanol fuel cells (DMFC/DEFC) have a longer operating time than current lithium ion batteries and can be recharged by simply replacing the disposable fuel cartridge. Samsung's prototype DMFC (developed by Medis Technologies) weighs only 90 grams, and for wireless handsets, it provides 40 days of standby and 20 hours of talk time. Motorola has developed a DMFC which will power a laptop computer for up to 20 hours.

Fuel cells are being used as a replacement for batteries in back-up applications where an uninterruptible power supply is critical, such as hospitals, computer data centres and telecommunication transmitter towers.

Prototypes have also been developed by Sony, Casio, DCH, Intelligent Energy, Manhattan Scientifics and others. There are many challenges to be overcome in the engineering, material sourcing, and sizing (one-tenth of a watt to 50 W) of fuel cell alternatives to the rechargeable battery, but once overcome, the market is huge.

Fuel Cells as Electricity Generators

Fuel cells can be used as electricity generators, and systems are being developed in sizes of 250 kW to 5 MW for peak load power. These systems have promising electrical conversion efficiencies of over 70 - 80%. This compares with a conversion efficiency of 55 - 60 % by the very latest gas and steam turbine combined/advanced cycle power plants, though many base load plants realistically linger at around 35% or even lower.

Fuel cells can be used as electricity generators, and systems are being developed in sizes of 250 kW to 5 MW for peak load power. These systems have promising electrical conversion efficiencies of over 70 - 80%.

The fuel used is usually hydrogen. Hydrogen can be produced by the electrolysis of water or by reforming natural gas (methane) with steam. Using electrolysis, the amount of greenhouse gases formed depends on the source of the power – fossil fuel, nuclear, wind, or solar. The by-product of the process using methane is carbon dioxide which has an adverse effect on greenhouse gas emissions. However, it should be borne in mind that that methane is about twenty times more potent in its greenhouse effect than carbon dioxide. About 50 kWh is required to produce a kilogram of hydrogen by electrolysis, so the cost of electricity is crucial.

Fuel cells are being used as a replacement for conventional combustion power plants, and generators. The technologies being developed for these applications will generate electricity from hydrogen - supplied directly or via hydrogen-rich fuels like natural gas, propane, etc. Some cells will use pressurised hot gases coming out from the fuel cell stack to drive a turbine, generating even more electricity - contributing approximately 25% extra electric power.

Fuel cell powered cars are at the prototype phase of development, while fuel cell powered buses have operated on a trial basis in several cities.

In a vehicle, a fuel cell engine replaces the internal combustion engine, and hydrogen replaces petrol and diesel. Fuel cell powered cars are at the prototype phase of development, while fuel cell powered buses have been in operation on a trial basis in several cities, including Vancouver, Chicago and Palm Springs. In 2003, ten European cities including London started a two-year trial of thirty Mercedes EvoBus fuel cell powered buses. Three of these went into service in the UK in January 2005. Ballard Power Systems are producing the fuel cell engine, EvoBus is building the rest of the bus, and Shell BP is providing the hydrogen fuelling facilities. Applications for marine power are also under development, both for shipping and submersible craft.

Hydrogen, used as a fuel, can be considered as a storage medium given that, once produced, it can be bottled and used to power fuel cells whenever and wherever the need arises. Using hydrogen as fuel is seen as a possible solution to the problem of intermittency and the low availability of renewable energy. Renewable energy could be used to produce hydrogen during off peak periods or when the renewable source is generating more energy than meets demand instead of trying to match the output of renewable energy plants to demand.

Renewable energy could be used to produce hydrogen during off peak periods or when the renewable source is generating more energy than meets demand instead of trying to match the output of renewable energy plants to demand.

Examples of hydrogen energy storage schemes include the operating Hydrogen and Renewables Integration (HARI) project in Leicestershire, UK; the operating PURE project in Unst, Scotland, UK; the proposed FIRST (Fuel cell Innovative Remote Systems for Telecommunications) project in progress in Madrid, Spain; and the operating Hunterston Hydrogen Project in Scotland, UK. Wind Hydrogen Limited has also carried out trials.

In the HARI project, a 36 kW electrolyser, a 2856 Nm³ pressurized gas store and two fuel cells were added to an existing renewable energy system that feeds commercial and domestic loads on a local mini-grid. The fuel cell units are configured for Combined Heat and Power (CHP) operation. The renewable energy sources include two wind turbines generating 50 kW combined, solar photovoltaic (PV) arrays totaling 13 kW peak output, and 3 kW of micro-hydro generators. There are plans to include fuel cell vehicles in the scheme that will be fuelled by the hydrogen to model a complete hydrogen economy. The bottles of hydrogen store the equivalent of about 3800 kWh of electricity, providing up to three weeks of back-up through periods without any renewable energy harvest.

In the HARI project, a 36 kW electrolyser, a 2856 Nm³ pressurized gas store and two fuel cells were added to an existing renewable energy system that feeds commercial and domestic loads on a local mini-grid.

The PURE demonstration project is an off-grid stand-alone system that uses surplus wind energy to generate hydrogen through the electrolysis of water to provide the energy needs of a remote rural industrial estate. The hydrogen is then bottled, and converted back into electricity using a fuel cell, or used directly as fuel.

FIRST, the EU funded a power supply project for telecommunication repeater stations in remote locations. The system comprises a photovoltaic assembly, a battery, an electrolyser, a hydrogen storage system, and a fuel cell. The average load of the repeater is 150 W. In normal operation, solar energy is used to power the station, with excess energy stored in a battery. An electrolyser produces hydrogen during sunny periods. This is stored in a metal hydride system. When there is an energy shortage, the fuel cell system uses hydrogen to generate electricity which is then stored in the battery.

FIRST, the EU funded a power supply project for telecommunication repeater stations in remote locations. The system comprises a photovoltaic assembly, a battery, an electrolyser, a hydrogen storage system, and a fuel cell.

The Hunterston project in Ayrshire is a 92 MW wind project with a 15 MW hydrogen electrolysis and generation set.

Notwithstanding its advantages, hydrogen based storage is too costly to be economical at this time. It would be practical to use solar energy to generate hydrogen only if the cost of doing so were to drop to about 1 US cent per kWh. This price point is likely to take decades rather than years to realise, and is much lower than the current cost of solar energy from photovoltaic cells, which is about 25 US cents per kWh. In addition, careful consideration needs to be given to the licensing, storage, and location of hydrogen given its highly flammable nature.

Although electrolysers are considered a mature technology, it has become apparent that powering them from intermittent or dynamic energy sources will require substantial modification in order to improve their efficiency, durability, and cost in this demanding situation.

Although electrolysers are considered a mature technology, it has become apparent that powering them from intermittent or dynamic energy sources will require substantial modification.

The intermittent nature of the electrolyser's operation threatens to shorten its lifetime; so alternative energy storage devices such as batteries are still required to smooth the short-term fluctuations in electrical supply.

3.1.5 Flow Batteries

A flow battery, sometimes referred to as a redox battery, is a battery in which the electrolyte is flowed through a reactor - an electrochemical cell, cells, or cell stacks - in which chemical energy is converted to electricity. The electrolyte is stored externally, usually in tanks, and is usually pumped through the cells in the reactor. Unlike conventional batteries, they can charge and discharge power without deteriorating, and can charge and discharge at high rates in a fraction of the time needed for other batteries. Also, unlike other energy storage devices such as ultra-capacitors and flywheels, which produce only enough energy to cope with brief voltage fluctuations, flow batteries have the ability to store enough power to unburden a transmission line for several hours or to store energy from large gusts of wind such as is common in hurricane-prone regions.

A flow battery, sometimes referred to as a redox battery, is a battery in which the electrolyte is flowed through a reactor - an electrochemical cell, cells, or cell stacks - in which chemical energy is converted to electricity.

A flow battery is a special type of fuel cell. The difference is that, in a fuel cell, the electrolyte remains at all times within the reactor and the fuel is flowed into the reactor, whereas, in a flow battery, the electrolyte is sourced externally from the reactor and the fuel is dissolved in the electrolyte. In addition, unlike fuel cells, flow batteries are not based on rare or valuable materials. Fuel cells typically use platinum or other expensive catalysts to speed the oxidation of their energy carrier. The material at the heart of the most commercially available flow battery is vanadium, a plentiful, non-toxic metal.

The material at the heart of the most commercially available flow battery is vanadium, a plentiful, non-toxic metal.

Flow batteries are also distinguished from fuel cells in that the chemical reaction is reversible, and can therefore be recharged without replacing the fuel. The spent reactants are regenerated from the products by thermal, electrical, photochemical or radiochemical methods. When used in this way, they are called reversible flow batteries or regenerative fuel cells. For grid applications, not having to provide fuel avoids the need to create new fuel or distribution systems. Regenerative fuel cells are nearly always based on PEM Fuel Cells (a.k.a. proton–exchange fuel cells), although metal air fuel cells can also be regenerative.

The most popular flow battery on the market uses vanadium redox technology. Charged vanadium is used in a dilute sulphuric acid solution to store energy. Established technologies include zinc/halide, bromine/polysulphide based systems. The appeal of flow batteries is that for grid applications, they combine the strengths of both conventional batteries and fuel cells. Vanadium redox batteries are suitable for a wide range of energy storage applications for power companies and industrial users. These include enhanced power quality, uninterruptible power supplies, peak shaving, increased security of supply and integration with renewable energy systems. The majority of development work has focused on stationary applications due to the relatively low energy density of vanadium redox batteries.

Vanadium redox batteries are suitable for a wide range of energy storage applications for power companies and industrial users.

Flow batteries are usually considered for relatively large (1 kW – many MW) stationary applications. These are load levelling, peak shaving (where demand spikes are met by the battery), and UPS. In addition, as flow batteries can be rapidly recharged by replacing the electrolyte, they may be suitable for powering electric vehicles.

Because flow batteries can be rapidly recharged by replacing the electrolyte, they may be suitable for powering electric vehicles.

Flow batteries currently sell for about US$450 per kWh. Operating and maintenance costs of flow batteries are dramatically lower than for gas-powered stations – 3.6 US cents per kWh compared with 9 US cents per kWh. One drawback of flow batteries is that the storage tanks containing the electrolytes can be enormous. Another concern is the toxicity of the electrolyte. Under normal circumstances, there is no human exposure to the electrolyte, which is stored in lined and double-walled tanks. However, leaks are possible. One solution to the risk of a major leak is the distribution of many small batteries as back-up power sources over a large network of small installations.

The first vanadium-based energy storage system in the US is a 250 kW eight-hour (2 MWh) system that began operating in March 2004 in Castle Valley, Utah. It was developed in partnership between the power company Pacific Corp. and the vanadium-based battery developer VRB Power Systems. The Castle Valley system is charged overnight by base load resources, and supplements the supply of power to a small community during the hottest part of the day, when the distribution feeder is overloading. This arrangement helped Pacific Corp. avoid having to install a new transmission line to Castle Valley, and increased the utilization of existing infrastructure.

The first vanadium-based energy storage system in the US is a 250 kW eight-hour (2 MWh) system that began operating in March 2004 in Castle Valley, Utah.

Another example of a flow battery installation is King Island in Australia. King Island has been installing wind turbines, ranging in size from 250 kW to 850 kW, to complement and supplement the existing four 1.5 MW diesel generators. However, by the time the fifth wind turbine was installed, the balancing of the island's grid was becoming problematic. To assist with system balancing, the local power company, Hydro Tasmania, subsequently installed a 200 kW four-hour (800 kW) VRB-ESS flow battery system from Pinnacle VRB Ltd. The VRB-ESS has provided three benefits to the power grid since its start-up in November of 2003: it has made it possible to use the off-peak wind energy stored to provide peak demand, improved the operation of diesel units (reduced frequent start-ups with minimal run-time), and provided frequency regulation and voltage control to assist with higher wind energy integration.

In Japan, where electricity companies are required to generate a portion of their energy from renewable sources, the power company J-Power added a 4 MW, 90-minute (6 MWh) vanadium-based flow battery to the existing 30 MW Tomamae wind farm in Sapporo. The wind farm charges the storage system, and the storage system levels the output of the wind farm to the broader distribution grid. When the wind rises or falls over the course of a few seconds, the storage system smoothes the frequency variations that would normally arise. This protects energy consumers from fluctuations in their power quality. When the wind suddenly cuts out, the flow batteries can provide burst power up to 6 MW, creating the power bridge that gives power companies the chance to bring peaking plants or other generation resources online.

In Japan, where electricity companies are required to generate a portion of their energy from renewable sources, the power company J-Power added a 4 MW, 90-minute (6 MWh) vanadium-based flow battery to the existing 30 MW Tomamae wind farm in Sapporo.

Over twenty other flow battery systems are in place around the world, with tens of thousands of reliable charge-discharge cycles on record. Several of them are operating on wind farms in Japan and Tasmania, and as part of a remote power supply in Canada.

Over twenty other flow battery systems are in place around the world.

3.1.6 Supercapacitors

A supercapacitor, or ultracapacitor, is an electrochemical capacitor with characteristics of both batteries and capacitors. Capacitors consist of two conductive parallel plates separated by a dielectric insulator. The plates hold opposite charges that generate an electric field. Unlike in batteries where energy is stored in chemical form, capacitors store energy in the field. Supercapacitors are usually made with carbon nanotubes and polymers.

Supercapacitors can store an unusually large amount of energy relative to their size when compared with ordinary capacitors. They are used by electricity companies to regulate power quality, for load levelling, and are of particular interest in automotive applications for hybrid vehicles and as supplemental storage for battery electric vehicles. Supercapacitors can replace batteries in applications ranging from mobile phones to cars.

Supercapacitors are used by electricity companies to regulate power quality, for load levelling, and are of particular interest in automotive applications for hybrid vehicles and as supplemental storage for battery electric vehicles.

Supercapacitors have several advantages over batteries. They operate at lower temperatures and have very high rates of charge and discharge. They can discharge in milliseconds and are capable of producing enormous currents, hence their usefulness in load levelling applications and fields where a sudden boost of power is needed in a fraction of a second. They suffer little degradation over hundreds of thousands of cycles thus giving them a very long life time which reduces maintenance costs. They have good reversibility, a high cycle efficiency (95% or more), and the materials used are low in toxicity. Its disadvantages include a considerably lower amount of energy stored compared with batteries, and voltage variation with the amount of energy stored.

ISE Corporation (www.isecorp.com) builds petrol and diesel hybrid-electric drive systems for buses and trucks which use supercapacitors designed by Maxwell Technologies (www.maxwell.com). Honda has developed its own supercapacitor which it uses in its hydrogen-powered fuel cell car, the Honda FCX.

3.1.7 Superconducting Magnetic Energy Storage (SMES)

SMES systems store energy in a magnetic field created by the flow of direct current in a coil of superconducting material that has been cryogenically cooled to a temperature below its superconducting critical temperature. A typical SMES system has four parts: a superconducting coil, a power conditioning system, a cryogenically cooled refrigerator, and a cryostat/vacuum vessel. Superconductors have zero resistance to direct current (DC) at low temperatures so that heat dissipation due to resistance of the coil is eliminated. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely.

SMES systems store energy in a magnetic field created by the flow of direct current in a coil of superconducting material that has been cryogenically cooled.

The stored energy can be released by discharging the coil. In power supply applications, SMESs are used as a daily storage device to improve power quality, being charged from base load power at night and meeting peak loads during the day. The most important advantage of SMES systems over other storage methods is that the time delay during charge and discharge is relatively short. Power is available almost instantaneously and very high power output can be provided for a brief period of time. Other energy storage methods, such as pumped hydro or compressed air have a substantial time delay associated with the conversion of energy back into electricity.

The most important advantage of SMES systems over other storage methods is that the time delay during charge and discharge is relatively short.

SMESs are highly efficient at storing electricity (greater than 97% efficiency). Currently, SMES systems are able to store up to about 10 MW. Theoretically, much higher capacities can be achieved. SMES systems are environmentally friendly as superconductivity does not produce a chemical reaction. In addition, toxins are not produced in the process.

3.1.8 Flywheel Storage

A flywheel is, in essence, a mechanical battery – a heavy wheel (rotor) spinning at very high speeds about an axis in a vacuum chamber. The rotors normally operate at 4,000 revolutions per minute (rpm), but advanced flywheels are made of high strength carbon-composite filaments that spin at speeds from 20,000 to 100,000 rpm. The vacuum chamber minimizes aerodynamic losses, and the use of superconducting electromagnetic bearings can virtually eliminate energy losses through friction. A flywheel can be used to store energy by combining it with an electric motor that accelerates the flywheel to store energy, and to produce electricity from the energy stored in the flywheel using the same motor as a generator. Flywheels can be used to store energy over a long period of time. The energy is then released over a shorter period of time thus magnifying its power output for that brief period.

Flywheel power storage systems have storage capacities comparable to batteries and faster discharge rates. They are used to improve system stability, and to provide uninterruptible power supply, bridging, and spinning reserve?.

Flywheel power storage systems have storage capacities comparable to batteries and faster discharge rates. They are used to improve system stability, and to provide uninterruptible power supply, bridging, and spinning reserve. They have advantages for remote sites, including long life, low maintenance, tolerance of temperature extremes, and lack of environmental impact.

The materials used in flywheel storage systems are generally non-hazardous, and consist mainly of steel, aluminium, copper, glass and carbon fibre, epoxy resin, silicon, and NdFeB (made from neodymium, iron, and boron) rare earth magnets. Much of the mass consists of metal that can be recycled.

Flywheel systems have great potential. However, their cost and as yet unproven long-term reliability may be potential drawbacks. Much work needs to be done to improve them. Firstly, their use is hampered by the danger of explosive shattering of the wheel when overloaded. Secondly, they suffer idling losses (i.e. the energy lost when a spinning flywheel is on standby) of up to 2% due to external forces such as gravity.

Flywheels are hampered by the danger of explosive shattering of the wheel when overloaded and idling losses.

Because of the latter, flywheels need to be pushed once in a while to maintain their speed. Some companies have made flywheels with almost zero idling losses, but they spin at low speeds. These flywheels only produce 5 - 10 kW of power.

Developers of UPS flywheel energy storage systems include:-

Active Power
www.activepower.com
AFS Trinity
www.afstrinity.com
Beacon Power
www.beaconpower.com
Pentadyne
www.pentadyne.com
Piller
www.piller.com
SatCon
www.satcon.com
Urenco
www.urenco.com/flycylinder

Flywheels are one of the most promising technologies for replacing conventional lead acid batteries as energy storage systems for a variety of applications. Flywheel UPS markets include power stations, commercial buildings, electric rail, vehicles, clean power sources (solar and wind), economical rural electrification systems, and stand-alone, remote power units commonly used in telecommunications outposts. They are also used as power sources in satellites and for space exploration.

Installations in renewable energy systems are still relatively rare. Existing applications are associated with wind turbines in remote areas where they are used for power quality improvement and fuel savings in wind-diesel hybrid systems. The ability to cycle continuously at high power, with storage times of the order of seconds to minutes, and the high cycling lifetime, are the key features of flywheels in the wind power smoothing application. In a wind diesel hybrid system, flywheels can be used to provide bridging during the scheduling of diesel generating sets, and following wind turbine trips. Used as a spinning reserve, it replaces a diesel generator running on low load which is wasteful of fuel and reduces the diesel engine lifetime.

An early application of the use of a low-speed synchronous flywheel in a wind-diesel system was installed at Punta Jandia, Fuerteventura in Spain in 1993. The wind-diesel system including flywheel energy storage at Denham in Australia (developed by Western Power and Power Corporation) is probably the largest application, where three Enercon E-30 wind turbines have total rated power of 690 kW.

Another example of flywheels being used with wind turbines is the system in Dogo Island, Japan, where in 2003, Fuji Electric installed a 200 kW UPT KESS flywheel from Urenco Power Technology in conjunction with a 3 x 600 kW installation of De-Wind D4 wind turbines to evaluate how wind generators can be a viable source of power on remote islands with weak links to the mainland power grid. The aims of the project were to stabilize the frequency variations stemming from the turbines, capture excess energy from short-term wind gusts, optimize the operation of (or eliminate the need for) diesel generators on the island, and eliminate the need for additional spinning reserve due to the introduction of the wind turbines.

An example of flywheels being used with wind turbines is the system in Dogo Island, Japan, where in 2003, Fuji Electric installed a 200 kW UPT KESS flywheel from Urenco Power Technology in conjunction with a 3 x 600 kW installation of De-Wind D4 wind turbines

www.fujielectric.co.jp

The UPT KESS improved the island's power grid efficiency and increased the penetration rate of the wind turbines. The flywheel unit's ability to provide a stabilizing capability to the highly variable wind turbine power was essential in allowing Fuji Electric to connect the wind turbines to the island's relatively weak electrical transmission system. As a result of this success, Fuji Electric is now looking for further deployment opportunities of the UPT KESS technology to provide reliable wind-generated energy as a viable supply alternative in other locations.

3.2 Thermal Storage

Rocks, water, and phase change materials can be used as storage media for storing heat from the sun. The earth can also be regarded as an energy storage medium in its use for geothermal heating and cooling. Ground and water-source heat pumps are being used to bring heat from underground or from nearby aquifers during cold months and to dispose of waste heat during summer months. Geothermal technology is examined in greater detail in the CarbonFree 'Householders as energy Providers' report.

The earth can also be regarded as an energy storage medium in its use for geothermal heating and cooling.

3.2.1 Rock Based

As a storage material, rocks are cheap and readily available, have good heat transfer characteristics with air (the transfer medium) at low velocities, and act as their own heat exchanger. Air solar collectors are usually used, combined with a heat pump, to blow hot air into building-integrated rocks or a rock storage area to provide heating. In general, the faster the airflow and/or the smaller the rock size, the greater the power requirement. Air solar collectors are cheaper and more maintenance-free than liquid collectors, and are therefore more appropriate for residential heating.

Rock storage is the most reliable of the three thermal storage systems because of its simplicity. Once the system is installed, maintenance is minimal and few things can adversely affect the performance of the storage.

Rock storage is the most reliable of the three thermal storage systems because of its simplicity. Once the system is installed, maintenance is minimal and few factors can adversely affect the performance of the storage. The main disadvantages are their low heat-storage to volume ratio compared to water and phase-change materials. This means that a bigger storage area is needed, making for difficulties with water condensation and microbial activity. If the dew point of the air coming into the storage is higher than the rock temperature, the moisture in the air condenses on the rocks. Moisture and heat in the rock bed can lead to microbial growth.

3.2.2 Water Based

Water as a storage material has the advantages of being inexpensive and readily available, having excellent heat transfer characteristics, and being compatible with existing hot water systems. Its major drawbacks include difficulties with system corrosion and leakage, and more expensive construction costs. Because heat-storage-to-volume ratio is five times greater than rock and liquid solar collectors are more efficient, liquid collection and storage systems can be very practical where close maintenance is available - such as in multiple-residence or industrial buildings. They also have an advantage where the ultimate use is hot water - such as in a dairy barn or food processing facility, where the water storage system can be directly coupled with an existing water heating system, or where space is limited. The water tank can easily be buried below ground to save space.

Water as a storage material has the advantages of being inexpensive and readily available, having excellent heat transfer characteristics, and being compatible with existing hot water systems.

Seasonal Thermal Storage

A seasonal thermal store, also known as a seasonal heat store or inter-seasonal thermal store, is a store designed to retain heat deposited during the hot summer months for use during colder winter weather.

The heat is typically captured using solar collectors, although other energy sources are sometimes used separately or in parallel. Seasonal thermal stores are found on a variety of scales, from those installed in individual houses to those serving neighbourhoods through district heating.

The experimental "Jenni-Haus" built in 1989 in Oberburg, Switzerland has three tanks storing a total of 118 m3 of water providing more heat than is required to heat the building.

Switzerland and Germany have been notable pioneers in the use of individual house seasonal heat stores. The experimental "Jenni-Haus" built in 1989 in Oberburg, Switzerland has three tanks storing a total of $118m^3$ of water providing more heat than is required to heat the building. The Zero Heating Energy House completed in 1997 in Berlin as part of the International Energy Agency (IEA) Task 13 low energy housing demonstration project, stores water at temperatures up to 90°C inside a $20m^3$ tank in the basement, and is now one of a growing number of similar properties.

At the neighbourhood level, the Wiggenhausen-Süd solar development at Friedrichshafen features a $12{,}000m^3$ reinforced concrete thermal store linked to $4{,}300m^2$ of solar collectors, which will supply the 570 houses with around 50% of their heating and hot water. A different approach was adopted by the Drake Landing Solar Community development in Okotoks, Alberta. Here the store is created from the ground itself, with solar heated water pumped into a Borehole Thermal Energy Storage (BTES) system. This consists of 144 boreholes, each 37m deep, which heat the ground to a maximum of around 90°C.

The Drake Landing Solar Community development in Okotoks, Alberta use a store created from the ground itself, with solar heated water pumped into a Borehole Thermal Energy Storage (BTES) system.

www.dlsc.ca

Solar Pond

A solar pond is large-scale solar energy collector with integral heat storage for supplying thermal energy. A solar pond is simply a pool of water that collects and stores solar energy. It contains layers of salt solutions with increasing concentration (and therefore density) to a certain depth, below which the solution has a uniform high salt concentration. When solar radiation is absorbed, the density gradient prevents heat in the lower layers from moving upwards by convection and leaving the pond. This means that the temperature at the bottom of the pond will rise to over 90ºC while the temperature at the top of the pond is usually around 30ºC. The heat trapped in the salty bottom layer can be used for many different purposes such as space heating, industrial hot water, water desalination, refrigeration, drying, or driving a turbine for generating electricity.

A solar pond is large-scale solar energy collector with integral heat storage for supplying thermal energy. A solar pond is simply a pool of salt water that collects and stores solar energy.

The low cost of this technique is particularly attractive for rural areas in developing countries. Very large area collectors can be set up for just the cost of the clay or plastic pond liner. The system is however relatively difficult to maintain, and has several disadvantages: the salt gradient is very delicate and is easily upset by wind, the pond can foul up with algae, the liner can spring a leak, the evaporated surface water needs to be constantly replenished, and the accumulating salt crystals have to be removed and can be both a valuable by product and a problem.

An example of a solar pond project is the 6,000 square meter solar pond in Bhuj, India that supplied 15,000 cubic metres of hot water to Kutch Dairy.

It was estimated that the solar pond could save over 935 metric tonnes of lignite per year if the pond is used to its full capacity, i.e. a saving of $19,000 annually.

3.2.3 Phase Change Materials

Phase-change materials (PCMs) are chemical substances that undergo a solid-liquid transition at temperatures within a desired range. During the transition process, the material absorbs energy as it goes from a solid to a liquid and releases energy as it goes back to a solid. What makes a PCM desirable for heat storage is its ability to hold greatly varying amounts of energy at the same temperature. At least a dozen chemical compounds that change phase at temperatures within the useful range for space heating are being studied as potential heat storage materials. However, only Glauber's salt is being sold commercially.

Phase-change materials (PCMs) are chemical substances that undergo a solid-liquid transition at temperatures within a desired range. During the transition process, the material absorbs energy as it goes from a solid to a liquid and releases energy as it goes back to a solid.

Glauber's salt (sodium sulphate decahydrate), has a high heat-storage-to-volume ratio, and thus requires only one-eighth of the space required by rocks and two-fifths of the space required by water for comparable heat storage. Glauber's salt changes phase at 32°C and has a 251 kJ/kg latent heat (amount of heat absorbed or released during phase change). The disadvantages of Glauber's salt are its cost relative to rock and water, and various technical problems (e.g., packaging problems due to its poor thermal conductivity and its corrosive nature). Such problems need to be resolved before the reliability of PCMs can be assured.

Until recently, research has been primarily concerned with inorganic PCMs (i.e. those based on salt hydrates such as Glauber's salt, potassium fluoride tetrahydrate, calcium chloride hexahydrate, zinc nitrate hexahydrate etc. However, they require support and containment and cannot therefore be directly incorporated into building materials. In the last 20 years, research into organic PCMs such as carboxylic acids and polyalcohols have thrown open the possibility of porous building materials such as gypsum wallboards and concrete blocks being impregnated with PCMs, therefore not requiring separate space and infrastructure.

> Research into organic PCMs have thrown open the possibility of porous building materials such as gypsum wallboards and concrete blocks being impregnated with PCMs, therefore not requiring separate space and infrastructure.

Tests showed that organic PCMs can give 15% savings in heating energy depending upon the PCM and building material used. However, climatic conditions significantly affect the performance of the storage. The payback period in Madison was found to be 10 years and twice that in Helsinki.

The current generation of inorganic and organic PCMs have chemical traits that inhibit their use, but solutions are being found to these. It will take some time before they can be commercially viable.

> Both inorganic and organic PCMs have chemical traits that inhibit their use.

3.3 Fuels From Biomass

Biomass is any biological material that can be used as fuel. The major types of biomass are wood wastes, agricultural wastes, crops grown specifically for energy production (energy crops such as willow, miscanthus, sugar cane, sugar beet, wattle, eucalyptus, and oil seed rape), and animal farm wastes.

Biomass represents one of earth's energy stores and can be used to produce other solid, liquid, and gaseous fuels that can be packaged or bottled and used wherever necessary. In this regard, like hydrogen, bio-fuels can be regarded as energy storage. Biomass is the only available renewable energy source that can produce competitively priced fuels for transport in large quantities. It is already possible to obtain fuels from biomass that have very similar properties to those of conventional fossil fuels.

Biomass is currently the only available renewable energy source that can produce competitively priced fuels for transport in large quantities.

In recent years, mechanised farming practices and surplus food production in the industrialized countries has led to agricultural land being left fallow. In 2001, 5.7 million hectares (15%) of usable land in Europe was left fallow. This makes it possible to grow more and more energy crops using fallow land that will increase the options for renewable fuel sources. Table 1 shows the amount of energy that can be obtained from energy crops.

In 2001, 5.7 million hectares (15%) of usable land in Europe was left fallow. This makes it possible to grow more and more energy crops using fallow land that will increase the options for renewable fuel sources.

Crop and Energy Yields

Crop	Energy yield (GJ/hectare/year)
Miscanthus/switch grass	180 - 260
Sugar cane	400 - 500
Sugar beet	30 - 200
Rape seed	50 - 170

Several processes are used to produce bio-fuels from biomass. The thermal conversion processes of pyrolysis and gasification convert biomass into bio-oil and biogas. Both processes involve heating the feedstock in the presence of less oxygen than is required for complete combustion. The biological processes of fermentation (usually using yeast) and anaerobic digestion (using bacteria) produce ethanol and bio-gas. Seeds are crushed to produce oils such as sunflower oil and rape seed oil. Combustion processes produce solid bio-fuels such as charcoal. All of these fuels find use in chemical, heating, electricity, and transport industries.

Dry biomass is increasingly used in gasification systems to generate combustible gases. The composition of the gas will depend on the nature of the gasification process used. Synthesis gas, for example, is a mixture of hydrogen and carbon monoxide and is used in the formation of a variety of liquid fuels. Wheat, barley, rye, sugar cane, and sugar beet are usually converted into ethanol which is a chemical widely used in the petrochemical industry and can power vehicles.

Leguminous plants such as grasses can be processed together with manure or waste to produce biogas that is mainly ethanol and carbon dioxide. Biogas can be used to fuel gas turbines to produce electricity, boilers to produce process heating or space heating, and vehicles adapted to using it. Its main advantage over other biomass-derived gases is that it can be burned directly in any gas-fired plant, or injected into the natural gas network. Oil crops can be used to produce bio-oil or bio-diesel. Biodiesel can be used to power vehicles, and both can be further transformed into gaseous and liquid fuels. Similarly, farm animals produce slurries that can be used in anaerobic digesters to produce biogas.

Oil crops can be used to produce bio-oil or bio-diesel. Biodiesel can be used to power vehicles, and both can be further transformed into gaseous and liquid fuels.

Hydrogen can be produced from a broad range of biomass sources containing carbohydrates, cellulose, or proteins using biological processes. Under anaerobic conditions, bacteria are able to convert the biomass into hydrogen, biogas, and ethanol. Typical yields are in the range of 0.6 to 3.3 molecules of hydrogen per molecule of glucose, depending on the particular bacteria used. The hydrogen can be used to power fuel cells. Fuel cells require very clean fuels and are sensitive to certain substances like the sulphur present in biomass. Purification of the gases is therefore essential, and there are many chemical companies such Power+Energy Inc.(www.purehydrogen.com), and QwestAir (www.qwestairinc.com) that sell purification systems.

Under anaerobic conditions, bacteria are able to convert the biomass into hydrogen, biogas, and ethanol.

There are many types of liquid bio-fuels. In general, production costs are high compared to petroleum-derived products. It costs around twice as much to make a litre of bio-fuel compared to a litre of petroleum-derived diesel (though this depends on the price of crude oil), and it requires about 1.1 litres of bio-fuel to replace 1 litre of diesel. The major market for liquid bio-fuels is the transport sector, although products have also been developed for direct use in boilers and engines for heat and electricity production.

The major market for liquid bio-fuels is the transport sector, although products have also been developed for direct use in boilers and engines for heat and electricity production.

- Bio-ethanol: This is a colourless liquid, and is the most widely produced bio-fuel in the world with Brazil (which uses sugar cane as feedstock) and the US (which uses corn) being the leading producers. In 2003, world production was 18.3 million tonnes. Bio-ethanol is mostly obtained by fermentation of sugar beet, sugar cane, corn, barley, wheat, woody biomass, or black liquor (a liquid remaining from pulpwood cooking in the soda or sulphate paper-making process). Normal vehicles, when modified to use bio-ethanol, can run on a 15% blend of bio-ethanol and petrol. The emissions from ethanol are cleaner than those from petrol. An 85% ethanol-15% petrol blend can reduce greenhouse gas emissions by 60 - 80% compared with pure petrol. In December 2005, British Sugar announced the start of a project to construct a bio-ethanol plant Wissington, near Downham Market, Norfolk, UK. The plant is expected to produce 70 million litres of bio-ethanol each year using sugar beet to produce the fuel. The plant is expected to start producing in early 2007. There is a large scale bio-ethanol production facility in Abengoa in Spain.

Normal vehicles, when modified to use bio-ethanol, can run on a 15% blend of bio-ethanol and petrol. The emissions from ethanol are cleaner than those from petrol. An 85% ethanol-15% petrol blend can reduce greenhouse gas emissions by 60 - 80% compared with pure petrol.

- Ethyl t-butyl ester (ETBE): This is a bio-fuel made from bio-ethanol than can be blended with petrol in proportions up to about 17%. Methyl–butyl ester (MTBE) has similar properties.

- Bio-methanol: This is similar to bio-ethanol but is more damaging to engine components, and can be made by the gasification of biomass.

- Biodiesel: This is produced by the esterification of fatty acids produced from vegetable oils. Commonly-used feedstocks are rape seed oil, sunflower oil, and used cooking oil. Practically all diesel engines can be run on biodiesel or blends of biodiesel and normal diesel.

The EU is the principal region of the world with a developed market for biodiesel because of its established market for diesel engines. Emissions of carbon dioxide are 2.5 kg per litre less for biodiesel than for fossil fuel diesel. Emissions of hydrocarbons and soot are also lower than for fossil fuel diesel. In addition, bio-diesel releases fewer sold particles and contain no sulphur. Nitrogen oxide emissions are higher because of the presence of nitrogen in the biomass material.

- Synthetic fuel or biogas-to-liquid (BTL) fuel: Examples of BTL fuel are BTL-diesel and dimethylether (DME). BTL-diesel meets all the standards for normal diesel. DME is a fuel of diesel quality with physical characteristics similar to liquefied petroleum gas (LPG). The first commercial plant for BTL-diesel in the world is to be commissioned in 2009 in Freiburg, Germany and will produce 13,000 tonnes a year.

- Bio-oil: Its main use is as an intermediate for production of other products. However, it also has a direct application in boilers and furnaces for heat production and in static engines for heat and electricity generation.

Marine bio-mass such as plankton, algae, and other marine based organisms have not yet been exploited for their potential as a source of fuel. Given the volume of the seas and oceans, this source could provide a formidable contribution to the energy source mix.

Marine biomass such as plankton, algae, and other marine based organisms has not yet been exploited for their potential as a source of fuel.

4 The Market for Renewable Energy Storage

4.1 Market Inhibitors

Energy storage systems compete with fossil fuel and nuclear power based energy sources. These are responsive to fluctuations in demand and nuclear power has, in the uranium fuel rod, its own inbuilt store of energy.

Energy storage systems compete with fossil fuel based energy sources that are responsive to fluctuations in demand.

With compressed air and flywheel-based solutions there is also the question of credibility – even though these technologies have existed for several decades their use is limited to a few niche applications. A significant effort was put into the development of these systems during the early days of the electricity generating industry in an attempt to smooth out troughs and peaks in demand. However, grid operators found ways of making power stations more responsive. The introduction of nuclear powered electricity generation almost eliminated demand for medium or long-term electricity storage capacity.

Oil, gas and, to a limited extent, coal are used by homeowners as a store of energy that can be rapidly converted into heat. Geothermal based storage systems are making some inroads into this market but even with conventional fuel prices at record levels, homeowners are reluctant to replace their central heating systems and few have enough confidence to invest in what they regard as an untried technology.

4.1.1 Competitors on Both Fronts

Both bio-fuels and hydrogen fuel cells are used within the automotive sector and so compete with each other as well as with incumbent, fossil based, fuels. Bio-fuels have a competitive advantage over fuel cells as, after the fuel leaves the refinery mixed with conventional fuels, it can be fed into the existing automotive fuel supply chain. By contrast, fuel cells require specialist cars and a new refuelling infrastructure as well as investment by the motorist. Bio-fuels are compatible with an 'as is' automotive market.

Both bio-fuels and hydrogen fuel cells can be used in the automotive sector and so compete with each other as well as fossil based fuels.

Growth of the bio-fuel market will be limited by supply and price pressures caused by competition between fuel producers and the food industry for farmland on which to grow raw materials, such as oil seed rape and palm oil. These raw materials are also used in a wide range of food products.

With penetration of the automotive sector proving difficult, fuel cell technology providers are spreading risk by attacking other markets – one of these is household and commercial premises energy storage. Here they come into competition with gas providers who are able to store energy in disused gas and oil fields from where it is retrieved during periods of peak demand.

One of the biggest threats to an energy storage equipment vendor is the adoption and successful deployment, by renewable energy providers, of the same sort of energy management and demand prediction technology that has revolutionised the electricity generation.

4.1.2 Predicting Availability

The ability to predict short and long-term variability and availability of weather-driven renewable resources will enable better use of these energy sources, and will help in planning when conventional sources need to be brought on line. While this will increase the acceptance and integration of renewable energy by power companies and be a major source of cost savings it might also depress the market for larger scale energy storage projects.

The ability to predict short- and long-term variability and availability of weather-driven renewable resources will enable better use of these energy sources, and will help in planning when conventional sources need to be brought on line.

Predicting supply more accurately would maximise operational efficiency, and increase the value of renewable energy generation and transmission assets in terms of power availability, congestion management, system stability, and being able to plan when conventional sources need to be brought on line. The Wind Force 12 document prepared by the Global Wind Energy Council provides a blueprint for achieving 12% of the world's electricity from wind power by 2020. This goal is almost twice as aggressive as the figures published by groups in the US and China, but it is considered to be an achievable goal.

A number of commercial wind energy forecasting services are now available, such as 3Tier Environmental Forecast Group, but forecast errors are still significant and improvements are needed. The quality of a wind energy forecast depends on accurate weather data over a large area, knowledge of the local terrain, and modelling of local terrain effects.

A number of commercial wind energy forecasting services are now available, such as 3Tier Environmental Forecast Group

www.3tiergroup.com

Predicting when a significant frontal system will pass and when extreme local weather events will occur are crucial for a power system operator who must prepare for changes in wind plant output. For example, with a good wind forecasting system, in 2008 the New York state power company grid is projected to realize annual savings of $95 million. In the US, the forecasting component alone, is projected to save over one billion dollars annually by 2020. Even more savings are possible in China from state-of the-art wind forecasting. Extrapolating to worldwide wind capacity, the potential annual savings is $1.4 billion today and perhaps $34 billion in 2020. Depending on forecast location and on data quality and availability, current systems might capture half of that annual savings.

With a good wind forecasting system, in 2008 the New York state power company grid is projected to realize annual savings of $95 million.

Today, accurate and continent-wide scale measurements of ground solar radiances are provided every fifteen minutes by the European Space Agency's Meteosat Second Generation Satellite. This method is more accurate than ground measurements when the distance to the next ground station is greater than about 30 km. Integrating this information with the business practices of the solar industry is the objective of the ENVISOLAR Project (Environmental Information Services for Solar Energy Industries) funded by the European Space Agency (ESA).

4.1.3 Improved Grid Architecture

Changing the way the current grid works is also fundamental to increasing the proportion of renewable energy used. Grid codes need to be changed to allow renewable energy generating facilities to keep working when there are problems on the grid in the same way as it works for conventional facilities.

Improved grid management tools will be required to enable the current grid to the meet the needs of renewable energy generation.

Improved grid management tools will be required to enable the current grid to meet the needs of the renewable energy generation. Perhaps also to create a regional, and eventually, a world-wide web of renewable energy grids to share and distribute renewable energy resources. This is not such a far-fetched notion. In May 2006, Airtricity (www.airtricity.com), the Irish renewable energy company that develops and operates wind farms in Ireland, Scotland, and the USA unveiled plans to build a pan-European sub-sea electricity grid at an initial cost of $ 28 billion.

The Supergrid would initially connect a 10 MW wind farm in the North Sea with the electricity grids in Britain, Germany, and the Netherlands, the ultimate aim being to create a system that would link offshore wind farms in the Mediterranean to the Bay of Biscay, the Atlantic, the North Sea, and the Baltic Sea.

Airtricity's aim is to develop large-scale interconnectivity to overcome short falls in the supply of wind power when there is no wind, so that Europe would have access to wind power at all times because there would always be sufficient wind in some part of the network. The power generated would be a common European asset rather than a national asset since wind is a continental resource. It is conceivable that in future, we could see a power supply system that generates electricity from renewable sources and uses fossil fuels for supplementation.

Airtricity's aim is to develop large-scale interconnectivity to overcome short falls in the supply of wind power when there is no wind.

4.2 Market Drivers

Continued growth in the renewable energy market, supported by rising fossil fuel prices, will be the key driver for the take-up of energy storage technology. For this reason, it will become increasingly important for vendors to form partnerships or close working relationships with alternative energy solution providers. If it is unable to solve the problem of how to store the energy captured, the renewable energy sector will find growth elusive until demand for fossil fuel consistently exceeds supply.

Continued growth in the renewable energy market, supported by rising fossil fuel prices, will be the key driver for the take-up of energy storage technology.

Although the storage technologies of choice for the renewable energy industries are bio-fuels and fuel cells – with geothermal energy representing a renewable energy application in its own right – there is still space in the market for compressed air and flywheel based systems.

Flywheel based energy storage technology providers downsized their products when they discovered electricity grid operators had no need for large installations. In the same way fuel cell vendors are attempting to move away from a total reliance on the automotive sector and develop low cost systems for use within the household energy market.

4.2.1 Take Your Partners

There are potential rewards for vendors who can provide small-scale renewable energy companies with a solution that will store energy for up to 24 hours so that solar energy can be used at night. There may also be a market for devices that can store wind generated energy for longer periods. A growing interest in microgeneration and rising fuel bills will be important drivers for fuel cell vendors within the household energy supply market.

There are potential rewards for vendors who can provide small-scale renewable energy companies with a solution that will store energy for up to 24 hours so that solar energy can be used at night.

In the short term, the automotive industry will provide the fuel cell industry with the partnerships it needs to push forward with research and development. In the medium term, it will provide revenue as manufacturers start to install fuel cells in the next generation of automobiles. Howeverthe fuel-cell powered car may prove to be the 21st century version of the horseless carriage which is eventually replaced with a radical new approach to personal transport.

Whether this replacement will employ fuel cell technology is unclear. It is also unclear whether bio-fuels will be part of this solution. It is more likely bio-fuels will take an increasing percentage of the auto fuel market over the medium term – 10 years – but lose ground as motor transport evolves over the long term – 25 years.

4.2.2 An Enabling Technology

Concerns regarding the safety and economics of nuclear power and the environmental impact of fossil fuel based electricity generation could see geothermal heat storage pushed out of its niche market during the next decade. Currently, nuclear power offers the relatively rapid response time required to even out peaks and troughs in electricity demand and in uranium, power station operators have a relatively low cost and efficient energy storage system.

Concerns regarding the safety and economics of nuclear power could see geothermal heat storage pushed out of its niche market during the next decade.

How to dispose of spent fuel is remains a problem. Burying spent fuel in deep caverns carved into rock involves large-scale civil engineering projects. These projects are comparable in cost and complexity to some of the major geothermal projects proposed as a means of providing medium to long-term storage of heat energy.

The need to reduce the ambient temperatures within large urban conurbations - to reduce the environmental impact of cities, make life bearable for inhabitants in summer and provide heat energy in winter months - could be a key driver for geothermal energy storage technology. While, in some markets, energy storage vendors are competing with each other, they could mount a combined attack on the incumbent electrical energy market using geothermal technology. Installation of geothermal energy systems could reduce the demand for the electricity used to heat and cool homes and offices. Likewise, fuel cell technology could also be used to store electrical energy generated by solar panels and wind turbines.

The need to reduce the ambient temperatures within large urban conurbations could be a key driver for geothermal energy storage technology.

5 Urban Heat Islands

When examining the storage of renewable energy it is worthwhile considering the flow of energy, in particular thermal energy, within large urban conurbations. The phenomenon of Urban Heat Islands provides interesting opportunities and business models that could be exploited by for a range of organisations in the energy sector - including emerging renewable energy companies.

5.1 Ten Degrees of Difference

The temperature within a large city can be as much as ten degrees higher than in the surrounding countryside. The reason for this becomes obvious when considering the energy flows in a city such as London. London consumes as much energy as a country the size of Greece. Each of its 7.5 million residents uses approximately 20 MWh of gas or electrical energy per annum. In addition, people entering the city each day, and the vehicles transporting goods and materials, consume energy. There is even a contribution to the energy flow from the conversion of food, eaten by the population, into heat. Most of this energy, in excess of 150 TWh per annum, ends up as heat that raises the temperature of London's infrastructure and atmosphere.

The temperature within a large city can be as much as ten degrees higher than in the surrounding countryside. The reason for this becomes obvious when considering the energy flows in a city such as London.

In addition to the energy produced by human activity, London's 1,579 km² receives a total of 1400 TWh of solar radiation per annum (three times the amount of energy that flows through the UK's electricity grid.) In the surrounding countryside solar energy is absorbed into the ground where, if it is not extracted using ground based geothermal technology, it is returned slowly into the atmosphere. However in London a significant proportion of the 1400TWhs of energy that the sun provides is trapped in man made infrastructure such as roads and buildings. Rather than being absorbed into the ground this energy is quickly radiated into the atmosphere.

This energy, though, is highly dispersed and locked for only a short time in the fabric of buildings and the surface of roads. Capturing this heat for redistribution would, in most cases, only be cost effective if the technology to do it was built into the infrastructure during the construction phase rather than retrofitted at a later date.

Geothermal technology should be built into the infrastructure during construction phase.

Technology such as that supplied by Ooms of the Netherlands could, in some cases, make the capture of urban heat energy an attractive proposition. However careful consideration would need to be given to the amount of energy required to extract and redistribute heat energy.

An organisation seeking to trade urban heat energy would base their business on a model that combined elements of renewable energy capture and conservation. There are a range of funding and trading arrangements these businesses could enter into with organisations and city authorities.

An organisation seeking to trade urban heat energy would base their business on a model that combined elements of renewable energy capture and conservation.

5.2 London Underground – A Man Made Geothermal System

When it was constructed, engineers assumed that the heat generated in the underground sections of London's mass transit system would be flushed out as trains moved through the tunnels. Over the years the opposite has occurred and trains warmed by the sun in the open parts of the London Underground system – 55% of it is above ground – have been depositing heat in the system's tunnels.

Heat energy dissipated by the millions of passengers who pass through the London Underground and the electric motors that power trains have, over the years, added to the energy now stored in the clay surrounding the system's tunnels and underground walkways. In the summer, during busy times of day, the temperature on trains becomes dangerously high. On occasions when power has failed, and unventilated carriages have become trapped between stations, a number of passengers have required medical attention after suffering from heat exhaustion.

Heat energy dissipated by the millions of passengers who pass through the London Underground and the electric motors that drive the trains have, over the years, added to the energy now stored in the clay that surrounding the system's tunnels

Over the years the management of London's Underground have been seeking a solution to the overheating problem and at one time offered a cash prize to the person or organisation that presented it with a workable solution. In theory it should be possible to construct an energy business based on the extraction of heat energy from the underground transit system and its sale to businesses located in buildings above ground.

This is an attractive proposition although a number of issues would need to be resolved before it was viable. Businesses would only be interested in purchasing energy during winter while London Underground would like to cool their infrastructure during the summer. One solution might be to extract the heat from tunnels then store it into an aquifer until it is required. It might also be necessary to find a means of turning the heat into electrical energy that could be sold to businesses at any time of year.

There might also need to be some financial mechanism put in place that rewarded long term cooling of the underground system. The transit provider would also need to be persuaded to add geothermal extraction technology to any expansion of the underground system and to existing parts of the system that are being modernised or renovated.

The transit provider would have to be persuaded to add geothermal extraction technology to any expansion of the underground system and to existing parts of the system that are being modernised or renovated.

In some cases, it might be possible to encourage the owner of a piece of overheating infrastructure to enter into a deal by sharing some of the revenue gained by selling that heat to nearby businesses. However in the case of London Underground it is not clear whether or not the transit operator retains ownership of the heat that it has been feeding into the clay surrounding the train tunnels for the past few decades.

A novel scheme for cooling mass transit systems in Russia has already been patented. This is based on running water through an open channel between the tracks of an underground railway system then extracting the heat the water collects using a heat pump.

A novel scheme for cooling mass transit systems in Russia has already been patented.

5.3 Micro Climate of Change

As the world's population continues to migrate from the countryside into cities there will be increased interest in the impact of urban heat islands on the local and global environment. Solar heat retention and concentrated energy use will become key issues and addressing these issues with novel heat extraction and storage solutions will become an important niche markets within both the energy and construction sectors.

Heat extraction and storage solutions will become an important niche markets within the energy and construction sectors.

6 Conclusions

During the 1950s there was strong interest in energy storage as a means of resolving mismatches between supply and demand for electricity. As a large proportion of electricity is now generated by burning fossil fuels, which are themselves a form of stored energy, the demand for electrical or thermal energy storage systems has never been great enough to warrant deployment. Dual tariffs ironed out peaks and troughs in demand for electricity by encouraging consumers to stagger consumption and to store energy in storage heaters.

Interest in energy storage technology has been revived by the increasing use of renewable energy systems that have very short supply chains and require energy to be used at the point and time of production.

Technology that can store energy and therefore lengthen the supply chain for renewable energy, could be used by vendors who wish to position themselves strategically within the energy market. In some cases, the influence these vendors could exert would be disproportionately greater than their investment in technology and infrastructure.

Compressed air and flywheel based energy storage technology played a role in early energy storage projects. Now it is fuel cells, hydrogen generation and biomass production that are the current technologies of choice for renewable energy providers. This is especially true in the automotive sector where the two technologies compete with each other as well as with convention fossil fuel based systems.

There is still strong interest in hydro-based energy storage systems as a relatively low cost and simple means of providing long-term energy storage.

The energy storage market is highly dependent on the continuing growth of the renewable energy sector – which itself is being driven by high fossil fuel prices. Care needs to be taken that the amount of energy used to store and retrieve renewable energy is not greater than the energy stored. If this is the case, energy storage systems will themselves become victims of rising energy prices.

While a significant amount of research has been carried out into the use of geothermal energy storage, few systems have been deployed to date. Geothermal storage is particularly relevant within the renewable energy sector due to its potential to provide long term seasonal storage of energy.

Geothermal storage technology could provide the basis for innovative business models used by new entrants into the energy market to develop services within 'Urban Heat Islands' – for example charging residential and business customers for cooling buildings in the summer then selling heat back to the same customers in the winter. The technology could also be used to extract heat from underground rail systems and sell it to local businesses.

Traditionally, dual tariffs ironed out peaks and troughs in demand for electricity by encouraging consumers to stagger consumption and to store energy in storage heaters.

Energy storage technology could lengthen renewable energy supply chains.

Vendors of energy storage technology could occupy a strategic position within the renewable energy market.

Fuel cells, hydrogen generation and bio-fuels are the technologies of choice for renewable energy providers.

Interest also remains strong for hydro-based energy storage.

The viability of the energy storage market is dependent on the continued growth of the renewable energy sector – which itself is dependent on high oil prices.

Geothermal storage is particularly relevant within the renewable energy sector due to its potential to provide long term seasonal storage of energy.

Geothermal storage technology could provide the basis for innovative business models used by new entrants into the energy market to develop services within 'Urban Heat Islands'

Vendor Profiles

D1 Oils

D1 plan to produce 8,000 tonnes of biodiesel per year from a range of vegetable oil feedstocks using a continuous process. The UK based company's technology and processes are proprietary and so far the company has successfully completed refining tests for a range of vegetable oils, including rapeseed, soy, palm and jatropha.

Although the refinery is used as a stand alone processing plant, it is designed so that modules can be used in conjunction to scale up refining capacity as required. The largest such refinery is the 32,000 tonne refinery operated by D1 in Teesside, UK. Each modular unit is assembled off-site and brought to the site as a complete unit, allowing for increased speed of construction.

The company claims that biodiesel is making an immediate impact in reducing the world's dependence on the fossil fuels that contribute to global warming. It also points out that using biodiesel requires no major changes to either existing diesel engines or to the current distribution infrastructure of storage tanks and petrol stations that delivers diesel fuel to consumers.

D1's product can be used either in its pure form or blended with mineral diesel, biodiesel to lower levels of harmful emissions. Sulphur emissions are virtually eliminated. The level of emissions reduction depends on the percentage of biodiesel used. Pure biodiesel (B100) produces the greatest reductions in harmful emissions. However, lower levels of biodiesel blend, including 5% (B5) and 20% (B20), also significantly reduce emissions.

D1 Oils at a Glance

A UK based global producer of biodiesel. The company is building a global supply chain and network that is sustainable and delivers value from "earth-to-engine". Its operations cover agronomy, refining and trading.

www.d1plc.com

Analysis

Bio-fuels are an easily implemented energy storage solution for the transport industry. The ease at which they can be distributed using existing auto refuelling infrastructure is slowing the take-up of other alternatives to fossil fuel based systems such as fuel cells. Blending bio-fuels with conventional fuels enables the large oil companies to adopt a 'greener' image while continuing with business as usual.

While bio-fuels account for a small proportion of the energy used by the transport sector, companies such as D1 should be able to maintain a steady growth rate. The environmentally friendly image of their product should mean it is relatively resilient to any fall in the price of fossil based alternatives.

However, wide scale use of products such as pure biodiesel would see producers such as D1 encounter some of the problems associated with today's oil industry. Production of the raw materials to manufacture bio-fuels – be it rapeseed or jatropha - requires a significant amount of land. Governments around the world are already taking a keen interest in how bio-fuels affect agricultural policies. If these raw materials, which are also used by the food industry, become strategic commodities, governments may wish to take an increasing share of the revenue derived from them.

Another potential threat to the bio-fuel industry is the possibility of a radical innovation in personal transport that saw a switch to fuel cell or a similar hydrogen based energy source.

Wind Hydrogen

Wind Hydrogen develops energy solutions from wind and water and has offices in Wales, Scotland, and Sydney. Its aims are to develop wind farms in the UK, increase the value of wind farms by developing energy storage technologies related to the use of hydrogen, and conduct research and development into the emerging hydrogen economy. It has eight sites throughout the UK in various stages of development.

Currently the company is unlisted - its shareholders include the company's founders, key board directors and executives, and a limited number of private and institutional investors. The company is considering an IPO at a future date. Wind Hydrogen claims a growth rate in excess of 30%.

The wind-hydrogen plant operates in the following way:

When wind levels are high, output from the turbines in excess of the pre-determined supply is used to electrolyse water into hydrogen and oxygen. The hydrogen can then be liquefied or stored under pressure indefinitely – for example in salt caverns.

During periods of low wind speeds, the electricity produced from the wind turbines is supplemented by the combustion of stored hydrogen through internal combustion gensets or large format fuel cells.

Wind Hydrogen Limited.

Wind Hydrogen

Founded in 1994, this privately owned company is active within the UK's hydrogen industry.

It is also working within the Australian renewable energy sector, and begun exploring opportunities in the USA and New Zealand and is considering an IPO at a future date.

www.wind-hydrogen.com

Analysis

The company has patented a wind hydrogen based storage system that enables, by a combination of electrolysis and hydrogen combustion, energy generated from wind turbines to be stored and released as required. The challenge for the company is to translate this intellectual property into a working and commercially viable service. Currently, energy storage is not an important issue for the wind turbine operators and grids take all the electricity generated. Any peaks and troughs in demand are evened out using existing power generation infrastructure. However, if wind energy generation continues to expand to the point where it provides in excess of 20% of a country's electricity requirements, then turbine operators would be forced to deal with not only short-term peaks and troughs, but longer term outages caused by prolonged periods of calm weather. It will be at this point that the wind hydrogen system may begin to play an important role in the energy storage market.

Ballard Power Systems

Ballard Power Systems Inc. is based in British Columbia, Canada. The company designs, develops, and manufactures zero-emission proton exchange membrane fuel cell products. They manufacture fuel cells, fuel cell components, and electric drive systems for vehicles, and portable and stationary fuel cell generators and power electronics for electronics industry. Its key growth markets are in Japan and China.

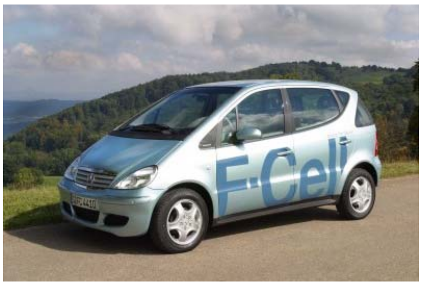
In Japan, Ballard has ventured into the residential co-generation (combined heat and power) industry with its latest prototype fuel cell, the Mark 1030 V3 which it has designed to meet the Japanese government's target of a ten year lifetime for the equipment. The company also has a joint venture with Ebara Corporation of Japan, called Ebara Ballard, which carries out research into fuelling processing sub-systems and is mandated to supply fuel cell generators to Japanese customers. It is supplying the Shanghai Fuel Cell Vehicle Powertrain Co Ltd. with fuel cell systems for vehicles. Ballard's competitors include Hydrogenics, Plug Power, FuelCell Energy, and Fuel Cell Technologies.

Competitors in the automotive fuel cell market include Plug Power who manufactures proton exchange membrane fuel cell systems. It was founded as a joint venture between DTE Energy, a diversified energy services company, and parent of Detroit Edison power company, and Mechanical Technology Inc, an early developer of fuel cells.

Ballard at a Glance

Canadian based fuel cell developer and manufacturer that has produced energy storage devices for the automotive industry. The company has recently undertaken a cost cutting exercise and attempted to break into the residential energy storage market.

www.ballard.com



Competitors include Plug Power manufacturers of proton exchange membrane fuel cell systems.

www.plugpower.com

Analysis

Within the automotive industry, Ballard's fuel cell technology offers an alternative to fossil based fuels such as benzene and diesel. However, it does not have the 'green' transport sector to itself and must compete for market share with bio-fuels. As a component supplier to the automotive industry, Ballard is highly dependent on the marketing strategies of major motor manufacturers. Wide-ranging changes in refuelling infrastructure are required before fuel cell technology can be introduced on any significant scale. However bio-fuels can be introduced gradually into the current motor refuelling infrastructure without the need for either the fuel supplier or the consumer to make any radical changes to how they refuel a car. For these reasons, Ballard has been correct in coupling its cost cutting exercise with diversification into the residential energy market.

In time bio-fuels may run up against capacity limits and motor transport may move away from its current refuelling model. However this may take more time than Ballard's shareholders will allow the company. For now, the key challenge for the company is to produce a unit that can be mass produced and is attractive, in terms of price, for alternative energy equipment providers seeking to enhance their small or medium scale solar or wind powered systems.

Ooms Avenhorn

Ooms Avenhorn Groep B.V. is a Netherlands based civil engineering and construction company that installs underground infrastructure, manufactures modified bituminous binders, and constructs houses and office complexes.

Ooms constructed the runways for Schiphol Airport and the current Mainport Schiphol. In the 1960s, the company moved into highway construction and undertook the earthworks for the planned extension of towns such as Hoorn and Enkhuizen. During this period Ooms set his sights on opportunities abroad. In the late 1970s, the company began developing its own range of specialist products and technology. It also expanded its initial international operations in Belgium and Germany into its current worldwide production of bituminous products. In 1977, following the oil crisis, Ooms also moved into housing construction

In partnership with WTH Vloerverwarming, it has developed the Road Energy System that heats and cools buildings and roads using the geothermal energy storage capabilities of aquifers.

In essence, the technology comprises an asphalt concrete layer and a water-bearing medium. The asphalt concrete absorbs energy easily and the water bearing medium is able to cool the asphalt in summer and heat it in winter. The warm and cold water are stored separately in the water-bearing medium. In winter, water is pumped up from the cold source and used for heating. The water, now cooled, is injected into the cold source after passing through the asphalt collector. In summer, the process works in the other direction. Water is pumped up from the cold source, used for cooling, and is then led through the asphalt collector, where it is further heated by the sun and then injected back into the heat source.

Ooms other activities include constructing floating districts and homes.

Ooms
Avenhorn Groep

Ooms Avenhorn at a Glance

A Netherlands based construction company formed in 1922. Was heavily involved in the construction of Schiphol Airport. During the 1970s, the company began a diversification program and has recently developed a geothermal based road energy system

www.ooms.nl

Analysis

The growing concern over the problems caused by heat build up in urban areas combined with steadily increasing fuel prices provides a range of opportunities for suppliers of geothermal energy storage systems. One key barrier to adoption is the difficulty in retrofitting the technology to existing infrastructure. In most cases the Ooms system is only practical if it is incorporated in a road or car park during the construction phase. High energy prices themselves could stall the property development and infrastructure construction market. However Ooms, being primarily a construction company, is well placed to take advantage of any opportunities that arise in infrastructure based geothermal systems. The technology itself is still in a relatively early stage of development and Ooms could face competition from companies that develop geothermal based technology to manage the heat energy in transit systems or office buildings.

Pentadyne

Pentadyne spent five years and more than $24 million developing flywheel technology for automotive applications, and successfully demonstrated the world's first turbine-flywheel powered car in January 1997.

The company regards the technology as ideally suited to replace conventional batteries in commercial and industrial power quality applications. It has acquired the intellectual property to incorporate the specialized flywheel technology into its power systems. Pentadyne also sees a market for flywheel power solution in hybrid-electric vehicles and for distributed generation and power recycling in other transport applications.

The company commercially launched its VSSdc product in 2003. The VSSdc, branded within the Liebert sales organization as the "Liebert FS", is now being sold through Liebert's worldwide channels. The product, which is UL and UL-c Listed, has been integrated into a large number of UPS models of diverse manufacturers and power levels. Pentadyne has successfully demonstrated a multi-unit system integrated into a high-power UPS system. This demonstration involved up to eight VSSdc units that work in parallel operation to deliver up to 1 MW of power.

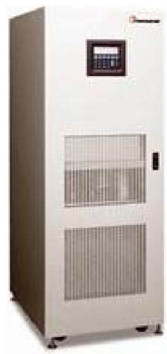
The company successfully completed its Series C round of financing, raising $18 million. Pentadyne recently entered into a distribution relationship with EHWA, the largest provider of UPS systems in Korea and has begun geographic expansion efforts in Europe.

PENTADYNE

Pentadyne at a Glance

Formed in 1993 as a privately funded US based research and developer of a specialised flywheel power system. It successfully demonstrated the world's first turbine-flywheel powered car in January 1997

www.pentadyne.com



Analysis

Like compressed air based energy storage systems, flywheels are often regarded as a legacy of the early days of electricity generation, which were no longer relevant once advanced grid management and more responsive power generating plants came on line. While flywheels were pushed into niche markets such as Uninterruptible Power Supplies they are now attracting broader interest as an energy store in hybrid vehicles. In theory flywheels and compressed air could be used in applications such as the storage of kinetic energy captured from wind turbines. Such systems could even out short-term peaks and troughs caused by gusty wind conditions.

In its present form Pentadyne’s product would prove too expensive for the microgeneration market. However it might be possible to market a smaller, less sophisticated device as a add-on for rooftop wind turbine systems should the market for wind based microgeneration continue to expand at its present rate. The company has also demonstrated that it is possible to use their products to provide storage systems with relatively high outputs. If this demonstration technology can be crystallised into a product Pentadyne may find a receptive market for it amongst medium sized wind turbine vendors.

£195 + VAT

Steinkrug Publications Ltd
20 Leaden Hill. Orwell
Royston Herts.
SG8 5QH UK

Tel. ++ 44 (0) 1223 208926
Email info@carbonfree.co.uk
Web www.carbonfree.co.uk