FACT SHEET 16: ENERGY STORAGE

Why is Energy Storage Needed?

Energy is not always produced when and where it is needed. Sometimes it is necessary to store energy so it can be transported to a different location or kept for a later time. For fossil fuels and biomass this is comparatively easy. These fuels are themselves sources of chemical energy and can be stored and transported in containers or pipelines.

Storage is a problem for the renewable energy sources, wind, solar, tidal and wave, that produce electricity intermittently. For example, imagine a hot humid night in a city dependent on wind and solar powered electricity. Everybody's fridges and air-conditioners are making a maximum demand for electricity, but the wind is not blowing and it is dark. The lights go out!

If renewable energy is going to significantly displace fossil fuels, new methods of storing large amounts of energy need to be developed. Even with fossil fuels, energy storage is used to defer electricity demand from peak to off peak times.

The length of time required for storage varies according to the circumstances. Storage for only a few minutes is needed to smooth the variations from a gusty wind source but longer storage times are required to provide for calm days. Overnight and sometimes several days storage is needed for solar power. Storage may even be needed from summer to winter or over several years of dry seasons. The battery for a heart pacemaker needs to store a small amount of energy (5mWh) for 5 to 10 years.

Forms of Energy Storage

Energy can be stored in most of its forms. The most developed ways are as heat, chemical energy and gravitational potential energy.

SENSIBLE HEAT

Energy can be stored in materials by making them hotter. This is called storing energy as sensible heat, and is excellent for domestic uses up to about to 80°C. For example, in well designed houses the sun shines in through a window in winter and the walls, floor, ceiling and objects in the room get hotter. Even after the sun has set the room will stay warm as the walls, floor, ceiling and other objects slowly cool down.

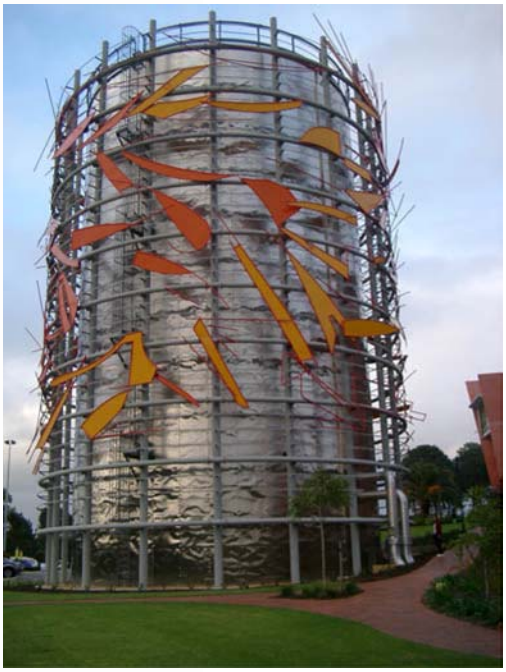

Figure 1.
Chilled water tank at Curtin University

Solar water heaters store hot water in insulated tanks. Water is an excellent material for storing heat because it has a high heat capacity (4.2 kJ/kg.ºC).

Curtin University of Technology in Western Australia uses a very large chilled water storage tank to reduce its air-conditioning costs.

LATENT HEAT

More energy can be stored as latent heat. The latent heat of fusion of ice = 333.5 kJ/kg. This means that every one kilogram of ice that melts absorbs 333.5kJ from its surroundings. It will also release this amount of energy when it freezes again. To cool drinks down we put ice in them. Ice storage is sometimes used in commercial buildings to absorb heat in the middle of the day when electricity prices are high.

A number of phase change materials that melt at around 25ºC are being developed so as to use the higher storage capacity of latent heat for maintaining comfortable room temperatures throughout the day. Phase Change Material (PCM) treated wallboard, a lightweight building construction material, is being tested in California. So far, only research samples exist but if proven effective this material would allow thermal storage to become part of the building's structure. This would permit the storage of high amounts of energy without changing the temperature of the room. So when the room is hot the PCM absorbs the energy and changes to a liquid stage cooling the room. As the room cools the PCM changes back to a solid releasing its stored energy (Lawrence Berkeley National Laboratory).

A local company in Western Australia markets a phase change material encapsulated in lightweight plastic and melting at 29ºC. It is recommended for use under floor and in other building applications.

TEAP phase change product

One problem associated with high temperature solid-liquid energy storage systems is how to contain the materials; because their volume changes as they change from one state to another. Most materials take up a smaller volume as they cool; water however expands below 4ºC. This is why glass cool drink bottles can explode in the freezer. The liquids may also corrode the containers causing dangerous chemical leakage. Heat storage, whether latent or sensible, is dependent on good insulation and will only last a limited time

Refrigerated air conditioning depends on the latent heat of evaporation of the working fluid to move the heat energy from inside a house to outside. The gaseous fluid is compressed outside the house and turned into a liquid so it releases the latent heat it had stored. This liquid is pumped into the part of the air-conditioner inside the room and allowed to turn back into a gas. To do this it needs energy which it takes from the warm air in the room. The gaseous fluid goes back outside and is compressed again releasing the heat to the outside.

CHEMICAL ENERGY STORAGE

More energy can be stored per kilogram using chemical energy storage than by using either sensible or latent heat storage. Fossil fuels and biomass are forms of chemical energy storage.

In a chemical reaction the arrangement of the atoms in the molecules are changed. Some bonds between atoms will be broken and different bonds will be formed. To break the bonds energy has to be supplied to the molecules but as new bonds are formed energy is released. The difference between the amount of energy needed to break the bonds and the amount of energy released when new ones form determines if the chemical reaction as a whole is an energy absorber or an energy emitter. A chemical reaction that needs energy for it to take place is called endothermic. One that releases energy is called exothermic.

Burning methane in oxygen (which is one of the gases in the air) produces carbon dioxide, water vapour and heat. A little heat is needed to break the bonds of the atoms in the methane and oxygen (usually provided by a spark in the cylinder of an internal combustion engine) but a great deal of heat is released as they reform into new compounds. A good example is the controlled explosion of the gas in the cylinder of an internal combustion engine.

Water can be electrolysed to provide hydrogen as a way of storing energy. Energy has to be provided to break the bonds between the hydrogen and the oxygen in water and not as much energy is returned when hydrogen atoms join with other hydrogen atoms to form hydrogen gas. The same applies for oxygen. So in total turning water into oxygen and hydrogen requires energy.

$$2H_2O \underset{\text{Combustion}}{\overset{\text{Electrolysis}}{\rightleftharpoons}} 2H_2 + O_2$$

The hydrogen is then stored or transported to where it is needed and the reverse process takes place. A little energy is needed to break the bonds between the hydrogen atoms in the hydrogen gas but when these atoms join up with oxygen atoms lots of energy is released. So the reaction is a net producer of energy. If this process was 100% efficient then between 120MJ and 140MJ would be released per kg of hydrogen used (US Department of Energy) (1kg occupies 12m^3 at room temperature and pressure).

There are two main problems with using hydrogen to store energy. The first is to reduce the capital cost and energy losses associated with turning water into hydrogen and oxygen. The second problem is how to store the hydrogen until it is needed. More discussion of these problems is in the fact sheet Hydrogen Economy.

BATTERY STORAGE

Rechargeable battery storage is a well understood technology. The energy is stored chemically and can be delivered as direct current to where it is needed. As the demand for energy changes batteries can easily be added or removed. The system is easy and quick to set up, usually fairly compact, quiet and non-polluting as long as the batteries are disposed of in an environmentally responsible manner.

There are problems with the current battery technology. Lead-acid batteries can only deliver 30-40 Wh/kg (0.144MJ/kg) and they don't last more than 10 years. They are quite expensive at around $600/kW for 3 hours of storage capacity (EPRI). To make battery storage a useful alternative, batteries have to be developed that will last up to 30 years for the same cost. Lead/acid batteries are also very heavy and this makes them unsuitable for powering vehicles, except in special situations. Other types, for example the Vanadium Redox battery, are being developed but are not widely used.

ENERGY STORED AS POTENTIAL ENERGY

Energy stored under tension or pressure is called potential energy. **Springs** in wind up clocks and clockwork toys are familiar, small scale examples of this type of storage.

Hydroelectric dams store huge amounts of renewable gravitational potential energy. They can store extra energy by using **Pumped Hydro**. When excess electricity is available this can be used to pump water up into a storage tank, dam or reservoir. This water can then be released to run down through a turbine to produce electricity. This is a well developed and reliable technology that provides an instant source of energy once the initial pumping has been done. However, it requires a large, nearby, high dam to store significant quantities of energy.

Pumped storage is used at Tumut 3, Snowy Mountains, Wivenhoe Power Station, Queensland and at Shoalhaven NSW. Cheaper off-peak power is used to pump water to generate electricity at times of peak demand. There is some loss of energy in the process.

Compressed Air can be used in many energy storage situations. For example the cylinder of air that gets compressed when you open the fly wire door stores enough energy to close the door again when you have gone through. Large volumes of compressed air can be stored in natural caverns, old mines or aquifer reservoirs and used to drive large turbines to make electricity. This is being done in Germany and the USA. In all situations energy has to be used to compress the air in the first place. Where the energy comes from will determine how useful this form of energy storage is.

ENERGY STORED AS KINETIC ENERGY

Flywheel Storage can be found in many mechanical situations where the mechanical energy output has to be smooth and consistent but the mechanical energy input may be somewhat irregular. In this situation excess energy is stored for a short time in a spinning disk (on steam trains it was spinning brass balls called the 'governor'). For this type of energy storage, disks of low mass but high strength are needed. Flywheel storage is only used to store energy for short periods.

At Denham, on Shark Bay in Western Australia, two 4-tonne steel flywheels store excess wind energy, produced during gusts, by spinning faster. The flywheels then release that energy during lulls in the wind, themselves slowing down in the process (Western Power Corporation).

MAGNETIC ENERGY

Energy can be stored for a very long time in the induction coil of an electromagnet if the coil is made of superconducting material. The only problem is that high temperature superconductors have not been produced yet so the whole apparatus has to be cooled close to absolute zero making this technology too expensive and complicated for commercial use.

Abbreviations

W – watt

kW - kilowatt

MW – mega watts

MWe – mega watts electricity

kJ/kg – kilojoule per kilogram

MJ/kg – megajoule per kilogram

mWh – milliwatt- hours

Wh/kg – watt hours per kilogram

References

Lawrence Berkely National Laboratory Latent Thermal Storage – Decentralised Latent Storage in Buildings.

South East Queensland Water Corporation Limited SEQWater's Dams http://www.seqwater.com.au/content/standard.asp?name=WivenhoeDam

University of New South Wales Vanadium Redox Battery http://www.ceic.unsw.edu.au/centers/vrb/

Western Power Corporation Denham Wind Diesel, the official Denham Wind diesel Project Site http://www.westernpower.com.au/subsites/denham_wind_diesel/technology_products.shtml

For More Information

For more information on amounts of energy stored by each type of storage system (list them) visit the RE-Files

Feustel, H.E. and C. Stetiu, Thermal Performance of Phase Change Wallboard for Residential Cooling Application Lawrence Berkeley National Laboratory, Report LBL-38320, 1997

Energy storage by Jensen J , Newnes-Butterworths

Solar Engineering of Thermal Processes by Duffie, J. A. and Beckman, W. A., Wiley Interscience

"Status of First US CAES Plant", EPRI Journal Vol 13 No. 8 pp 49-52 (1988)

"The Chino Battery Facility" EPRI Journal Vol 13 No.2 pp 46-50 (1988)

"The New Semiconductors" by Lihach, Nadine, EPRI REPORT EL 5634 SR (1988)

"Modern Battery Technology" by Clive, D. S. and Tuck, E. D., Ellis Hordwood (1991)

United States Department of Energy, Renewable Energy and Energy Efficiency, Properties of Hydrogen.

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