TECHNOLOGY FUTURES

Shell GameChanger

New Production Sources

Solar, Wind & Wave

Energy, energy everywhere and all for the taking – but how best to take it? Harnessing the abundant, clean "renewable" energy that is available from the wind, waves and sun's rays could provide enough power to run the world. But finding cost-effective ways to do so remains a challenge. At present much renewable energy is still uncompetitive compared with hydrocarbons such as oil, gas and coal. Taken together, all renewable sources of energy being used today still only account for 3 per cent of global supply.

Breakthroughs in energy storage, transmission and demand-side management may help to remove some of the constraints that have historically limited the growth of renewable energy. The motor industry's work on electric cars, and government subsidies on their purchase and use, should drive down the cost of batteries while improving their performance.

And recent developments in superconductivity that dramatically cut the amount of power lost through connection cables could radically improve the practical value of offshore wave-power generators and wind turbines installed out of sight and mind of homeowners. As one of our experts put it, however: "There is no single magic bullet". After a day of discussion it was not hard to see why.

Solar

The sun is continually beaming abundant energy to the Earth as light.

“Global energy consumption is around 470 EJ (exajoules, or 10^{18} Joules) per year. The sun delivers to the earth almost 4 million EJ of energy. So theoretically the sun could provide at least eight thousand times the energy we need.”

But how do people capture and exploit this abundant gift? One of the most common ways is to use sunlight to heat water. For many years most homes in Japan, and in most developed hot countries, have had solar water-heating systems on the roof. Simple-to-fit kits are easy to buy. The panels can warm water on dull days and even work in cold climates. To operate in winter temperatures they must be filled with antifreeze and work with a heat exchanger. Though this makes the system more complicated and fitting trickier, it remains effective.

The key factor that determines the take-up and competitiveness of solar energy is the efficiency of the panels in converting sunlight energy to electrical energy, which dictates the size and weight of the panel needed, and the production cost of the panel itself.

“Photo-voltaic (PV) efficiency is currently 20 per cent, probably soon rising to 30 per cent – compare that to photo synthesis which is 2 per cent efficient. In the long term all energy will be solar.”

More details emerged as the discussions warmed.

“The best PV panels have a conversion factor of 19.5 per cent. The average is around 14 to 15 per cent. Cost is around a dollar to a dollar fifty per watt. The first generation PV was crystal. Second-generation thin-film PV is less efficient but cheaper. It has a conversion factor of between 5 and 10 per cent. The theoretical maximum efficiency is 86 per cent, while 40.5 per cent is the best so far achieved in the laboratory”.

Solar Power

Solar power, or solar energy, comes from solar radiation emitted by the sun. For centuries, man has captured solar radiation, and converted it into useful power using a number of technologies. This conversion can be direct or indirect. Indirect solar power involves multiple transformations of sunlight, which result in a usable form of energy. Examples of indirect solar power are photosynthesis, wind, or wave energy. Direct solar power involves a single transformation of sunlight using a range of different conversion techniques and technologies – photovoltaics, concentrating solar power (CSP) or solar thermal – to produce a usable form of energy.

Photoconversion is a generic term describing the capture of light energy by a biological, chemical or electrochemical system for subsequent use as a fuel, a chemical or electricity. These technologies could be based on photosynthesis, plants algae or bacteria producing sugar or direct conversion in semiconductors: photovoltaic devices.

Concentrating solar power (CSP). There are three main types of concentrating solar technologies: trough systems, dish/engine systems, and power towers. Each uses a different configuration of mirrors to convert the sun's energy into high-temperature heat. The heat energy is then used to generate electricity in a steam generator. A key advantage of CSP is that the solar energy can be stored as heat before it is converted into power, which means that power can be generated outside daylight hours and dispatched when it is needed. CSP needs large-scale installations and thus competes in wholesale electricity markets at favorable peak daytime rates. The use of concentrated solar energy to generate higher temperature heat for industrial purposes is still in its infancy.

The ability of non-concentrating solar collectors to generate heat is relatively low (50 to 100 °C) and so is only suitable for use in low-temperature applications such as space heating in homes and greenhouses, hot water generation and pool heating. ■

"First and second-generation PV panels are here now, and third generation is in the lab. The option is either to increase efficiency by capturing and converting more wavelengths or to drive down the cost. The cost is now close to comparable with retail electricity. Lab efficiency is now around 45 per cent. There could be cells with 30 per cent conversion efficiency this year or soon after."

"The Holy Grail is a printed roll-up sheet. To drive development we need greedy investors, low interest rates and subsidies as in Japan and Germany."

But intermittency of supply remains the problem; when the sun goes in, the electrical output goes down.

"Variations in solar supply will really matter if 20 per cent of grid electricity is coming from solar panels."

Photovoltaics

A photovoltaic cell is a device that converts light energy into electrical energy. Sometimes the term solar cell is reserved for devices intended specifically to capture energy from sunlight, while the term photovoltaic cell is used when the light source is unspecified.

Compared to energy conversions for hydrocarbons and biomass, photovoltaics have a much higher information technology content, as the two primary components of PV cells are the solar panel (which converts energy from the sun into DC electricity) and the solar inverters (which convert DC to AC electricity for wider use).

At present, photovoltaic panels typically convert about 15 per cent of incident sunlight into electricity. Therefore, a solar panel typically delivers 100 to 150 watts per square metre at peak sunshine or 100 to 150 kilo watt-hours per square metre per year.

Electricity generated by PV panels currently costs more than retail power generated by large-scale plants. In addition to the cost of the PV panels themselves, there are additional costs associated with installing the equipment and purchasing equipment to convert the electricity produced from direct current (DC) – used in the home – to the alternating current (AC) used in the grid.

Fully installed rooftop PV systems, which directly compete with retail electricity rates (10 to 25 cents/kWh), currently produce electricity for between 5 and 10 cents per kWh, depending on annual sunshine and orientation of the panels. Adding upfront costs leads to a current full operating cost range of 30 to 80 cents/kWh.

Over the past five years the PV industry has grown at a rate of over 45 per cent a year, largely thanks to policies designed to promote their growth in Japan and Germany. Similar support systems are now in place in many countries, and the industry can expect continued rapid expansion. Growth might accelerate further when costs in the most favorable locations – where there is high sunshine, low interest rates and high retail electricity prices – fall to a level where they become cost-competitive with retail electricity. The opening of unsubsidised markets will lead to further growth and thus further cost reductions along the learning curve, accelerating the deployment and uptake of solar energy in an increasing number of countries. ■

So efficient, cost-effective storage is another key requirement for PV to take off in a big way. Power can be stored in many forms. For example, excess power can be used to pump water from a lower to a higher hydroelectric reservoir, ready to be released to drive hydro turbines at a later time, releasing energy once again. Such schemes are still in their infancy, though.

"A house could use the electricity from its panels to convert water to hydrogen when the sun is shining – and then use the hydrogen in a fuel cell."

An easier option is to store the electricity where it is generated, in a battery. Batteries are bulky and expensive, but every car already has some kind of battery.

"So you could use your car for storage. A photo-voltaic panel charges the battery while the sun shines."

For many years it has been possible to buy a small PV panel that sits on a car dashboard, trickling twelve volts into the car battery through the lighter socket. This keeps the battery topped up against the constant drain from security electronics. An electric car with much bigger batteries would make a far more efficient store for PV power.

The most attractive option, though, is to feed excess domestic and locally produced electricity into the grid and use the grid as a giant virtual battery. The power supply company then gives cash credits – so-called "feed in" tariffs – for power injected into the grid instead of drawn from the grid.

"We will need a smarter grid."

The power supply companies will also need to make grid storage easier to set up and more rewarding financially.

Building design is another part of the PV jigsaw.

"We have so much untapped surface area. PV could become just another aspect of facades. But building orientation is a big factor. Street patterning is a major issue. Hundreds of years of relatively cheap energy have given us street patterns that don't let us orient correctly."

Whether locally generated power is stored on site in batteries or fed back into the grid will depend on the cost and efficiency curves for batteries, and how easy it is for homes and offices to inject power into the grid and get economic benefit. There is not yet a simple DIY kit for homeowners to install, and amateur tinkering with

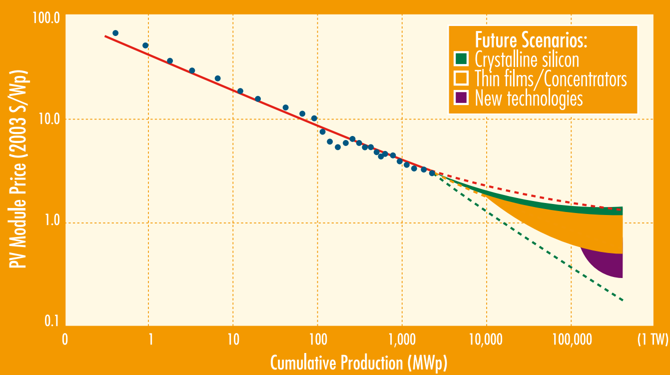
Photovoltaics - First, Second and Third Generation

First-generation PV technology is based on single or multi-crystalline silicon (xSi) with an optically thick single semiconductor junction, where the practical efficiency limit is currently around 20 per cent. This is the classic p-n junction photovoltaic cell where silicon is doped with other elements to make the material preferentially positive (p) or negative (n) with respect to electronic charge carriers. At present first generation PV modules typically cost $4 per watt, mainly due to a supply shortage. Meanwhile manufacturing costs have continued to follow the learning curve (see figure below) leading to very healthy industry margins. A realistic long-term cost target for xSi PV modules is in the order of $1 to 1.5 per watt peak (watt peak: nominal output at peak sunshine for a standardised solar spectrum and intensity).

The second-generation technology, developed to replace the high cost xSi cells, is based on thin film materials – Copper Indium Di-Selenide (CIS), Cadmium Telluride (CdTe) and Amorphous or Micro-Crystalline Silicon (aSi, mSi) thin films are the key technologies – deposited on molybdenum and stainless steel substrates. The efficiency of these modules is only of the order of 6 to 12 per cent. Costs are still close to xSi due to the low production volumes and the relative immaturity of the technology but, given the greatly reduced amount of semi-conductor material, thin film solar cells hold the promise of greatly reduced costs, with a realistic target well below $1 per watt peak.

Third-generation technologies are aiming for either ultra-low costs per m^2 or for very high efficiencies. Both pathways are pursued with the goal to develop cells costing tens of cents per watt peak. The main methods being explored include dye-sensitized cells, organic (polymer-fullerene) cells, and ETA cells (Extremely Thin Absorber). Further third-generation PV concepts are based on quantum dots as a way to increase the part of the solar spectrum that can be captured (e.g. through intermediate bandgaps, hot carrier capture and multiple electron generation). Further on from third-generation technologies, research programmes are focusing on developing advanced multi-junction PV cells from elements of the III/V groups of elements (e.g. GaInP / Ga(In)As / Ge), as currently used in space applications, with the goal of further reducing costs to enable their wider use in terrestrial applications. These highly efficient cells are often used in concentrated solar PV, where mirrors or lenses are used to concentrate solar light onto a small PV cell. ■

Learning Curve for PV Production



The present learning curve rate is 80% (20% cost reduction for every doubling of cumulative production); projected rates of 90% and 70% are shown for years beyond 2003.

Source: Surek 2005

mains voltages can kill. A safe easy-to-fit kit could be a money-spinner with green credentials.

There are, however, still other constraints that limit the growth of solar energy.

"The biggest practical problem is that the panels don't work in the dark. So there is no heating at night when it's cold, which is when you most want it. Storing heat is difficult. Storing electricity is much easier."

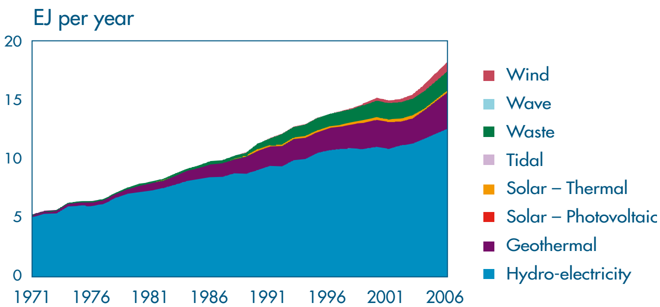
Heating water to produce steam and drive a generator to produce the electricity is clumsy and inefficient, especially for small home-scale installations. PV panels convert light directly into electricity, which can then be used for much more than heating water, and can be stored in a variety of ways. Recent developments in PV technology have made solar power a serious proposition for homeowners.

"When you want to run your lights at night-time you'll be able to run it off batteries. Will this be the source of the majority of electricity in twenty years? No. But it will be able to contribute significantly to the overall energy mix and also make a significant contribution to reducing greenhouse gases and climate change."

"Today solar electricity is very expensive but that price continues to come down by about 4 to 5 per cent per year. In expensive electricity markets like Japan, solar electricity is already cost competitive with the retail grid. In California in about ten years it will also be competitive with the retail grid. Eventually solar electricity is going to be competitive with the whole grid, though that's maybe more a 20 year time horizon."

"No. I say that advanced photo-voltaics will be competitive with the grid within ten years. Where the curves cross depends mainly on the cost of grid electricity."

Renewables



Wind Power

As much as 3 per cent of energy from the Sun that hits the earth is converted into wind energy, according to some estimations. This is roughly 100 times more than is converted through photosynthesis into biomass by all the plants on Earth. Wind energy is plentiful, renewable, widely distributed and clean, and reduces toxic atmospheric and greenhouse gas emissions if used to replace electricity made from fossil fuel.

Wind energy is converted into power by wind turbines. The rotation of turbine blades generates electrical current. In windmills, still part of the energy mix in many third-world countries, wind energy is used to turn mechanical machinery to do physical work, such as crushing grain or pumping water.

At the end of 2006, the worldwide capacity of wind-powered generators was 74,223 megawatts – less than 1 per cent of electricity used worldwide. Nevertheless, it is more popular in some places than others and accounts for approximately 20 per cent of electricity use in Denmark, 9 per cent in Spain, and 7 per cent in Germany.

Between 2000 and 2006, wind power generation more than quadrupled. It is used in large-scale wind farms for national electrical grids as well as in small individual turbines for providing electricity to rural residences or grid-isolated locations. The debate continues as to whether to locate wind farms onshore or offshore. The economics of wind power are directly linked to wind speed. Currently, onshore turbines are approximately two megawatts while the largest offshore turbines produce between three and five megawatts. GE (General Electric) predicts that by 2015 this will rise to ten megawatts. And offshore winds are more predictable and stronger than onshore.
However, the capital investment currently needed for offshore wind farms is approximately twice that of onshore installations, and operational costs are three orders of magnitude higher.

Wind and Wave

Building a wind farm with huge propellers near peoples' homes usually triggers a flood of complaints about low frequency noise, interference to TV reception and blotted landscapes. Building the farm in a remote spot, out to sea or in an estuary, involves long cable runs with high electrical resistance and the need for permission to land the cable onshore and connect to the electricity grid. Power is wasted on heating the air, earth or sea.

There are other constraints, too.

"People who like the idea of going green and erecting a wind turbine on their house, forget how much mechanical stress there is on a stormy day. Most houses weren't designed to take the loads.
The turbine can weaken or even destroy the building".

A similar host of constraints came up as soon as wave power was discussed. The idea of using waves to power a generator is surprisingly old. In 1901 a British inventor patented a breakwater with a ramp and floating weight on the end of a rope. The waves pushed the weight up the ramp, and as it fell back down the rope turned the wheels of machine.

Modern systems use huge floating metal snake-like tubes, tethered offshore in the open sea. The waves flex the snake, pumping hydraulic fluid to turn the wheels of a generator.

The obvious problem – common to solar power – is the intermittency of supply: on calm days, the snake stops flexing and the generator slows to a halt.

Less obvious challenges exist too: "Wave machines have to be huge. They need vast quantities of concrete, steel and copper which needs energy to make, and transport."

What's more, the power generated has to be carried ashore, by cables.

"And it may be a lot easier to get permission to tether the machine in the sea than it is to get permission to bring the cables ashore across private land".

Moreover, the longer the cables, the more power that is lost through electrical resistance of the copper.

"A lot of your free energy is wasted as heat which warms the water and is lost to the sea".

©Ocean Power Delivery

Wave Power

Wave power refers to the capture of the energy of ocean surface waves to generate electricity. A number of technologies have been considered over the years.
The oscillating water column is the oldest and most successful of these. It comprises a partly submerged structure that is open to the sea below the water surface so that it contains a column of water. Air is trapped above the surface of the water column and as waves enter and exit the collector, the water column moves up and down acting like a piston on the air, pushing it back and forth. The air is channelled through a turbine coupled to a generator and so produces electricity.

A second technology relies on replacing ocean breaks or sea walls with wave collection systems. By creating a series of layered "reservoirs" up a carefully calculated slope, trapping the water from waves and then releasing it through a turbine, the potential wave energy is converted to kinetic energy and electricity. It is estimated that a 500 metre breakwater would have a 150 kilowatt capacity.

A third approach converts the vertical motion of a marine buoy, bobbing up and down in waves, into an electrical charge that is turned into a direct current and sent to shore. It is estimated that a 10 MW station would occupy one and a half hectares of open ocean and a 100 MW station would be cost-competitive with energy produced from fossil fuels.

Another buoy system is based on a technology called the Pelamis Wave Energy Converter (the name Pelamis comes from a sea-snake). This system comprises a number of large semi-submerged tubular metal sections. The movement of waves makes these sections ripple or bend, rather like a snake. This bending action forces hydraulic pistons in the device to move – causing fluid to flow inside. This movement is then converted into energy. The machine is the world's first commercial-scale floating wave energy converter. It is estimated that a wind farm occupying a square kilometre of ocean could produce 30 megawatts – sufficient power for 20,000 homes. ■