SOLAR ENERGY

Andrew Blakers
Director, Centre for Sustainable Energy Systems
Australian National University
Ph 02 6125 5905
Andrew.blakers@anu.edu.au
Web: http://solar.anu.edu.au
26th March 2009

Summary

Solar energy is special. It is vast, ubiquitous and indefinitely sustainable.

The solar resource utilised by photovoltaics and solar heat is hundreds of times larger than all other energy resources combined, including fossil, nuclear fission and geothermal.

Solar energy:

- is indefinitely sustainable;
- utilises only very common materials;
- uses a resource that is far larger than required to provide all of the world's energy;
- has minimal security and military risks;
- is available nearly everywhere in vast quantities; and
- has minimal environmental impact over unlimited time scales.

No other energy source can make claims that come anywhere near these. Solar energy is a complete long term sustainable solution.

Australia receives 30,000 times more solar energy each year than all fossil fuel use combined. Australia has a significant presence in the worldwide solar energy industry, which can be built upon to create a major export-oriented technology-rich industry.

Energy supply options

There are five potentially available energy sources. These are energy from the sun (in its various forms), nuclear energy (fission and fusion), fossil energy (coal, oil and gas), tidal energy and geothermal energy.

Solar energy is available on a massive scale. Collection and conversion methods usually entail few environmental problems. Solar energy includes both direct radiation (photovoltaics and solar heat) and indirect forms such as biomass, wind, hydro, ocean thermal and waves. The direct solar energy resource is far larger than the indirect solar energy resource.

Nuclear energy from fission has substantial problems relating to nuclear weapons proliferation, nuclear terrorism, uranium and thorium deposit limitations, and waste disposal. Nuclear fusion is still several decades away from commercial utilisation, but may make a major contribution to sustainable energy supply in the future.

Fossil fuels are the principal cause of the enhanced greenhouse effect and are subject to resource depletion. Other problems include oil spills, oil-related warfare (for example, the Gulf wars) and pollution from acid rain, particulates and photochemical smog.

Tidal energy can be collected using what amounts to a coastal hydroelectric system. Geothermal energy in volcanic regions or from hot dry rocks can be used to generate steam for district heating or to drive a steam turbine to produce electricity. Tidal and geothermal energy are restricted to a few geographic localities.

Photovoltaics

Photovoltaics (PV) is an elegant technology for the direct production of electricity from sunlight. Most of the world PV market is serviced by crystalline silicon solar cells. Sunlight causes electrons to become detached from their host silicon atoms. Near the upper surface is a “one way membrane” called a pn-junction. When an electron crosses this junction it cannot easily return, causing a negative voltage to appear on the sunward surface (and a positive voltage on the rear surface). The sunward and rear surfaces can be connected together via an external circuit containing a battery or a load in order to extract current, voltage and power from the solar cell.

PV has widespread use in niche markets such as consumer electronics, remote area power supplies and satellites. Now, as costs decline, millions of PV systems have been installed on house roofs in cities. The worldwide PV industry is doubling every 20 months. Production is currently 8 gigawatts per year. Mass production is causing rapid reductions in cost. A solar revolution is brewing.

Most PV systems are mounted on fixed support structures. Some PV systems are mounted on sun-tracking systems to maximise output. Others use sun-tracking concentrators to concentrator light by 10-1000 times onto a small number of highly efficient solar cells.

PV systems mounted on house roofs can be used to achieve household carbon neutrality. A collector area of about $25m^2$ is needed to carbon-neutralise a 5 star (energy rating) house with gas space heating, solar/gas water heating and efficient electrical appliances. Such a house exports more electricity to the grid during the day than it imports at night. An additional $10m^2$ of PV panel is required to offset the annual greenhouse gas emissions of an efficient car.

Hybrid PV/thermal micro concentrator systems on building roofs are being developed to provide solar PV electricity, solar water heating, solar air heating, and solar air conditioning – a complete building energy solution.

PV panels on building roofs compete with retail electricity prices, which are three times higher than wholesale electricity prices. When the cost of rooftop PV generation falls below the daytime retail electricity price (“grid parity”) then the PV industry will enjoy explosive growth as hundreds of millions of home owners adopt the technology. Grid parity is expected to be achieved in many countries within a few years, due to falling PV costs, rising fossil fuel costs, the introduction of carbon pricing and the introduction of time-of-use tariffs. Time-of-use tariffs properly reward PV systems for generating during sunny summer afternoons when peak loads caused by air conditioning, commerce and industry lead to high energy prices.

The efficiency of PV is eventually likely to rise above 60%, compared with the current world record efficiency of 42%. The cost of PV systems can be confidently expected to continue to decline for decades – as has happened with the related integrated circuit industry.

Solar thermal

Good building design, which allows the use of natural solar heat and light, together with good insulation, minimises the requirement for space heating. Solar water heaters are directly competitive with electricity or gas in most parts of the world. Solar air heaters will allow a large reduction in the heating load in many parts of the world, while solar driven air conditioning is a rapidly developing industry.

Solar thermal electricity technologies use sun-tracking mirrors to concentrate sunlight onto a receiver. The resulting heat is ultimately used to generate steam, which passes through a turbine to produce electricity. Concentrator methods are equally applicable to concentrating PV systems. The usual ways of concentrating sunlight are point focus concentrators (dishes), line focus concentrators (troughs, both reflective and refractive) and central receivers (heliostats and power towers).

There is a large crossover between the technology of solar thermal and PV solar concentrators. The concentrating systems are quite similar, with the major technical difference being the solar receiver mounted at the focus: a black solar absorber in one case, and a PV array in the other. Since current efficiencies are similar, then the cost of energy produced by the two types of system is also similar.

An important future application of concentrated sunlight is the generation of thermochemicals and in the storage of heat at high temperature to allow for 24 hour power production. Concentrated solar energy can achieve the same temperatures as fossil and nuclear fuels, either directly (using mirrors) or through the use of chemicals (thermochemicals or bio fuels) created using concentrated solar energy. In the past, heavy industry (e.g. the steel industry) was often located near coalfields, in regions that are relatively poorly endowed with solar energy. Future steel mill could be built in the iron ore and solar energy rich Pilbara region of Western Australia.

Energy efficiency

Hand in hand with the utilisation of solar energy goes energy efficiency. 'Solar energy' and 'energy efficiency' are often the same thing. For example, an energy-efficient building is a building that utilises natural solar light and heat sensibly. Walking rather than driving uses a small amount of solar energy (food) rather than a larger amount of oil energy. A clothesline, solar salt production and putting on extra clothing displaces an electric clothes dryer, fossil-fuel fired kiln drying of salt and electric heating respectively.

Baseload power and storage

It is sometimes claimed, wrongly, that the fact that the absence of sunshine at night means that solar energy cannot dominate energy production.

Options for the provision of stable and continuous solar power include actively shifting loads from night to daytime; wide geographical dispersion of solar systems to minimise the effect of cloud; precisely predicting solar energy output using satellite imagery; diversification of energy supply to include all renewables; the judicious use of small amounts of natural gas; and energy storage. A future large-scale day-night storage option is the batteries of million of electric cars.

Pumped hydro (whereby water is pumped uphill during the day and released through turbines at night to provide energy) is an efficient, economical and commercially available storage option. Lakes covering only 50 km^2 (about 2 m^2 per citizen) utilising either fresh water or seawater, would be sufficient to provide 24 hour storage of Australia’s entire electricity production. In the longer term, intercontinental high voltage DC transmission will further reduce the need for storage.

Environmental impacts

The solar energy industry has minimal environmental impact. About 0.1% of the world’s land area would be required to supply all of the world’s electricity requirements from solar energy. Indeed, the area of roof is sufficient to provide all of Australia’s electricity, using PV panels.

We can never run out of the raw materials for solar energy systems because the principal elements required (silicon, oxygen, hydrogen, carbon, sodium, potassium, calcium, aluminium and iron) are among the most abundant on earth. Old solar energy systems can be recycled without the generation of toxic by-products. Gram for gram, advanced silicon solar cells produce the same amount of electricity over their lifetime as nuclear fuel rods. Per tonne of mined material, solar energy systems have 100-fold better lifetime energy yield than either nuclear or fossil energy systems.

The time required to displace CO_2 equivalent to that invested in construction of a solar energy system is in the range 1-3 years, compared with typical system lifetimes of 30 years. CO_2 payback and price are directly linked (via material consumption), so CO_2 payback times will continue to fall, and will eventually decline to below 1 year.

The future of solar energy

Renewable energy technologies can eliminate fossil fuels.

Roof-mounted solar energy systems can provide photovoltaic electricity, hot water for domestic and industrial use, and thermal energy to heat and cool buildings.

Highly efficient solar cells manufactured from highly engineered materials, and placed at the focus of solar concentrators, can provide much of the world's electricity. High concentration solar thermal can provide electricity, process heat and thermochemicals.

Solar electricity, coupled with a shift to electrically powered cars and public transport, can provide most of the world's transport energy.

Geographical dispersion of solar energy collectors, contributions from many different renewable energy technologies, storage via pumped hydro and other means, and high voltage DC intercontinental transmission, will allow a fully sustainable, zero-carbon future within a few decades.

Grid parity for photovoltaics is likely to be achieved in many countries within 5 years. Direct competitiveness with fossil fuels for wholesale energy supply awaits the implementation of full carbon pricing and the removal of all hidden support for fossil fuels.

Solar energy in Australia

The solar power industry in Australia is constrained by lack of carbon pricing, lack of a time-of-use tariff, and a wide range of built-in (and often hidden) support measures for fossil fuels.

Photovoltaics is an area of real Australian research and commercialisation strength. Photovoltaics is a strong innovation performer, in terms of performance metrics such as research papers, competitive grants and commercialisations. Between them, the solar research groups at the Australian National University and the University of NSW have eight PV commercialisations, including the buried contact, crystalline silicon on glass and SLIVER solar cell designs. Other research groups are also building strength. The solar research groups at the Australian National University, the University of NSW and CSIRO are the core participants in the new $100 million Australian Solar Institute.

The Government has announced a substantial target for the amount of renewable energy to be incorporated into the grid by 2020. Carbon pricing is to be introduced from 2010. These measures have the potential to drive substantial investment in renewable energy. However, the scale of the climate change problem is so large and immediate that further measures will be required to drive very rapid transformation of Australia's energy system to a low carbon future.

It is important for Australia to have a balanced energy portfolio. Greatly increased support is needed for solar energy R&D, commercialisation, manufacturing and market incentives. Solar energy is likely to be a $100 billion per year industry by 2012. Australian Government policy will need to be carefully crafted if Australia is to be a significant player in this vast new industry.

Support for solar energy in Australia should be focused on intellectual property (IP) generation and the export of IP-rich high-value products and services. This strategy would comprise substantial support for R&D, and professional education, coupled with strong incentives for companies to manufacture high value products in Australia for export.

Further reading

Centre for Sustainable Energy Systems, Australian National University, http://solar.anu.edu.au

School of Photovoltaic Engineering, University of NSW, http://www.pv.unsw.edu.au