Solar energy

Malcolm Keay asks whether solar power will find its place in the sun

> "In an 1878 letter, Ericsson concluded that 'the fact is … that although the heat is obtained for nothing, so extensive, costly, and complex is the concentration apparatus that solar steam is many times more costly than steam produced by burning coal.'"
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> Wilson Clark, *Energy for Survival: The Alternative to Extinction* (Garden City, NY: Anchor Books, 1974), p. 364.

For more than a century, solar power has faced the problem highlighted above – that despite the almost universal availability of solar power, the cost of transforming it into useful energy has prevented it from playing any significant part in the world's energy supplies. The purpose of this article is to explore whether this might now be changing – could solar power be the energy of the future, or at least a significant component of future energy systems?

Solar Power Comes in Many Varieties

In fact, the comments in the paragraph above need to be qualified almost immediately. Just as renewable energy is not one source, but many, so there are many varieties of solar power – too many to be covered in a short article. It is possible only to identify certain broad categories of solar power, each of which in its turn embraces many technologies and approaches.

The first, and most important (but usually ignored as an energy source) is **passive solar** power (referring essentially to building design and orientation to make the maximum use of natural sunlight for heating and cooling). This is of course something which has been practised for millennia and remains probably the main use of solar power in this country (it is estimated that it provides 15–20 percent of the heating in an average home during the heating season – a proportion which can be increased to perhaps 40 percent by careful design and better insulation). However, it is of its nature difficult to measure and is normally classed as energy efficiency rather than supply.

The second broad class is of **solar thermal** applications which use sunlight to heat water or some other liquid, which is then circulated to provide hot water or heating (or even cooling) to a building (the heat is normally at too low a temperature for process use). This technology is also fairly widespread. The country making most use of it is (perhaps surprisingly) China, which has over half of global capacity of the technology, with some 50 million square metres of collecting panels.

Both the above technologies will continue to be of importance in the future but for a step change in the penetration of solar power, we probably need to look at solar electricity generation, which in turn comes in various different forms. The best known is probably **solar photovoltaics** which uses solar power to generate electricity directly via photoelectric cells. The technology has been developing rapidly. Traditionally, crystalline silicon cells were used; newer 'thin film' technologies are lighter and cheaper and offer greater flexibility (in a literal as well as a metaphorical sense – some varieties can be folded and shaped at will).

A second class of solar-based electricity generating technologies, which is now receiving increasing attention, is **concentrated solar power** (CSP). Once again, this comes in a variety of forms, including parabolic troughs (using curved mirrors, sometimes raised) or Fresnel lenses to concentrate the rays of the sun onto a target, usually on the ground, where electricity is generated, using a conventional steam turbine, sometimes with a heat carrying fluid such as oil as an intermediate stage. An alternative, now being investigated more intensively, is the 'power tower' which normally uses flat mirrors to focus the sun onto a raised generating system on a tower. There are some advantages to this approach (discussed further in the accompanying article on the prospects for the so-called Desertec project): for instance, the mirrors are generally easier to manufacture and maintain than curved mirrors or lenses, less pipework is required and the need for water cooling is reduced – an important feature in the hot desert areas where solar systems are generally most effective.

A different approach is the use of Stirling engines – a form of external combustion engine that uses a closed internal circulation system. Although invented as long ago as 1816, Stirling engines have so far failed to find a significant place in energy or industry but they may nonetheless have potential – they can use almost any heat source and do not require water for steam raising.

Recent Developments

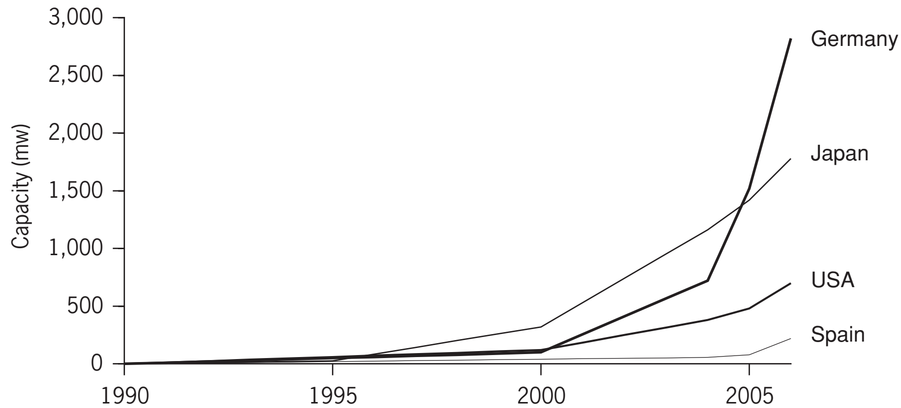
The recent growth of solar power is primarily driven by policy support, which has been substantial. For instance, in Germany the 'feed-in' tariffs offer prices of 30–40 €cents per kWh, about eight times the normal wholesale electricity price and much higher than the price on offer for other renewable sources (e.g. wind and biomass get about 9c; hydro 6–7c). Germany has probably had the world's most ambitious solar programme, despite not being the world's sunniest country – best known perhaps is the so-called 100,000 roofs programme which offered grants and low interest loans for installing solar photovoltaic panels on household roofs (and over-achieved its target – well over 100,000 roofs were equipped with solar panels during the currency of the programme).

Globally, photovoltaics have been growing particularly fast, as shown in Figure 1, particularly in Europe, where about 4GW was installed in 2008, making this the third largest source of new capacity (behind wind and natural gas, but ahead of coal and nuclear). Photovoltaic capacity has doubled every few years this decade, though total capacity, at around 15GW, remains a small proportion of global electricity supply.

This exponential growth has, however, recently faced a setback. Excess capacity has emerged in Europe, because of a combination of over-rapid expansion in production, lower growth in demand for electricity as a result of the recession, and the impact of the credit crunch on a capital-intensive industry. In addition, as in many other sectors, Asian companies are now able to produce at much lower cost than their European counterparts – many of which are now contracting production out to Asia. China alone is thought to have around 8 GW a year of production capacity – as compared with global demand currently standing at around 7 GW.

Photovoltaics are not of course the only version of the technology receiving support in Europe. Solar thermal is supported in many countries and concentrated solar power has been under development for some years, particularly in Spain, which opened the world's first commercial CSP plant near Seville in 2007.

Figure 1: Cumulative Installed PV Capacity by Country, 1990–2006



Japan and the USA have also been active in installing various forms of solar power. In the USA, unsurprisingly, it is the Western states, particularly California and Nevada, which have the most capacity, aided by their high levels of sunshine and land availability. Solar capacity in US utilities grew about 25 percent in 2008 – to 882MW – driven by renewable portfolio standards and expectations of future carbon regulation. A range of technologies is being developed, including Stirling engines. Stirling Energy Systems of Phoenix, Arizona has two large projects in planning – a 750MW plant in the Imperial Valley to sell electricity to San Diego and a huge 850MW project in the Mojave Desert destined for Southern California Edison.

Resource Availability and Economics

As regards longer-term potential, solar power is of course ubiquitous and abundant. Indeed it is the most abundant permanent energy resource in the world; the question is how much of it can be captured for human use and how efficiently. The constraint is unlikely to be the resource itself. For instance, the World Energy Council estimates that 'Even if only 0.1% of this energy could be converted at an efficiency of only 10% it would be four times the world's total generating capacity of about 3,000 GW. Looking at it another way, the total annual solar radiation falling on the earth is more than 7,500 times the world's total annual primary energy consumption of 450 EJ.' Even taking account of such issues as land availability and efficiency, the IEA suggests that the potential could be 3 to 100 times current world energy consumption.

Question marks over the future of solar arise not from issues of availability but from economics. Solar power remains expensive, even as compared with other renewables, as the figures above from Germany indicate. The capital costs for most forms of solar start at about $5,000 per kW or more (about ten times the cost of a combined cycle gas turbine plant) and installation and land costs are high. Efficiencies are also currently fairly low (typically below 20 percent, though best available technology achieves higher efficiencies and prototypes with efficiencies of over 40 percent have been developed).

However, the capital costs are coming down and efficiencies increasing; costs are also lower in areas such as North Africa and the Middle East (where solar resources are high and land often has few alternative uses), than they are in Europe or Japan, where most existing plants are located. Overall, the cost of photovoltaics has been declining at 3–4 percent p.a. for many years and the cost of solar thermal plant is also falling fast – the IEA thinks it could fall to around $1,250 per kW in 2030, which would bring generating costs on suitable sites to about 5c per kWh. This would be competitive with gas at $6.5 per MBtu or above; it should also be broadly competitive with nuclear or other renewables.

Characteristics of Solar Power

Assuming that the cost can be brought down as suggested above, solar power would have a number of additional attractions, which could well make it the renewable source of choice:

Generation pattern: With many renewable sources, such as wind, generation is variable, unpredictable (except in the very short term) and not well matched with demand. Solar power by contrast is stable and predictable. In the hot countries where it is likely to be sited and where air conditioning is the main component of electricity load, generation coincides fairly well with demand. Back-up of some sort would of course be needed for the hours of darkness. Cloudiness can also be a problem in northern Europe, but it can largely be avoided at sites in desert areas away from the coast and in any event it reduces output only partially (unlike, say, the absence of wind for a wind farm). Furthermore, concentrated solar systems can, at least in principle, store solar power in the form of a hot liquid, which is easier than storing electricity.

Siting: For many of the new renewables, siting is a problem. Good resources of wind and hydropower are only available at suitable sites, which may be remote or environmentally sensitive. Solar power by contrast tends to be relatively homogeneous over a country or even a whole region, so sites can be chosen with fewer constraints.

Land use: While solar power is relatively low density in energy terms as compared with fossil fuels, it compares favourably with many other renewables, even those which ultimately also rely on solar energy. For instance, supplying the UK's energy needs with biomass would – according to the calculations of David Mackay, the Government's scientific adviser for climate change and energy – take many times the agricultural land area of the UK. His simple conclusion: 'biofuels can't add up'. Solar power can provide much more energy for a given land area – concentrated solar power production over an area the size of Lake Nasser (the lake behind the Aswan Dam) could produce more energy than the whole of Middle Eastern oil production; an area the size of Austria could provide the whole of the world's energy needs.

Furthermore, solar power is easier to reconcile with existing land uses. Photovoltaics can be installed on the roofs of buildings – even potentially in future on the roofs of vehicles – in crowded developed countries. In many sparsely populated developing countries, like much of North Africa, the Middle East and Southern Africa, there is an ideal combination of abundant solar resource and low pressure on land use.

> "Solar power remains highly attractive in principle: the resource is free and widely available. But the question of cost remains"

Off-grid applications: Because of its ubiquity, solar power is also particularly suitable for off-grid applications. Whereas wind, hydro, geothermal and so on are often found far from any electricity consumption areas, solar power is available everywhere (at least in the developing countries where electricity grids are not yet fully developed) and can be used to provide electricity in places the grid does not yet reach – this is often the cheapest way of providing power for dispersed communities.

Scalability: Finally, solar power should offer scalability – that is, it should be possible to produce it in whatever quantities are required. It is suitable for small-scale applications such as the off-grid uses discussed above or the solar panels on road-side emergency telephones, but can also be scaled up, more or less without limit. This is partly because of the size of the resource, discussed above, but also because of the lack of a major siting problem. Most forms of renewable face two different, and contrasting, cost trends – over time, technical costs tend to go down as the technology improves; however, site costs tend to go up, since the cost of generating, say, wind power, depends very much on the site concerned (wind characteristics; location; closeness to grid connections and so on). As the best sites tend naturally to be used first, the increasing scarcity of good sites pushes up costs over time. (We are currently seeing this in the UK as production is being moved offshore, where it is much more expensive, because of the difficulty of gaining environmental approvals for suitable onshore sites). In addition, with intermittent sources like wind, the costs of integration into the electricity system increase as the proportion of wind on the system increases. These factors tend to cap the maximum contribution feasible from sources like wind.

With solar, these problems should be much less significant. The siting issue is less acute, so should not lead to a rising cost curve; meanwhile, in addition to the technology advances expected, there should be significant economies of scale both in manufacturing the generating equipment and in installation (e.g. in the costs of transmission from a large site). So as solar penetration increases, the costs should tend to go down over time.

The Future – Big Projects?

It is factors such as those discussed above which have led to the elaboration of ambitious plans for solar. The basic idea is simple – Europe wants to increase its use of renewable electricity, mainly for environmental reasons, but is finding it difficult to scale up its own production to match its ambitions – both the UK in particular and the EU in general (and most individual countries in the EU) are falling well short of their renewables targets.

Meanwhile, the countries round the Mediterranean Basin offer one of the most attractive places in the world for solar power development – the combination of a high solar resource; few pressures on land; and closeness to a huge body of demand. For the countries of the Middle East and North Africa, there are additional motivations for an interest in solar.

Many of them face a similar combination of problems:

- a need to diversify their economies away from hydrocarbon revenues which, in many countries, provide virtually all of exports and tax revenues and account for the bulk of GDP;
- rapidly growing populations and economies which are consuming ever larger amounts of domestically produced oil and gas, often at artificially low prices, and therefore limiting quantities available for export – in many cases there are also significant plans for desalination plant required to supply their growing water needs, with additional impact on energy demand;
- the potential decline of their hydrocarbon exports in the future either because of reserve exhaustion or because the world moves away from fossil fuels.

Against this background, developing alternative energy resources of a more sustainable nature, especially if it can be done with outside help, makes good sense.

Plans for cooperation on such projects across the Mediterranean Basin are therefore developing fast. The most prominent is the so-called Desertec project, discussed in more detail in another article in this issue. The project is highly ambitious – it would involve building some 6,500 square miles of concentrated solar power plants in North Africa, along with a super-grid of high voltage transmission lines, to supply countries in Europe and Africa with electricity. Ultimately, the project is expected to cost €400 billon and generate up to 100GW, though in practice it would build up over time. Whether it ever gets off the ground, of course, remains highly uncertain – there are major political and institutional issues to overcome in addition to the basic challenge of economic viability.

Conclusion

Over a century and a quarter have passed since the passage at the head of this article was written, but in many ways not a lot has changed. Solar power remains highly attractive in principle: the resource is free and widely available. But the question of cost remains – can it be converted to useful energy at low enough cost to make it attractive to users? Despite all the technological changes that have taken place, all the innovative new techniques that have been developed, and the increasingly pressing environmental concerns, this fundamental question has not yet been answered. But it is clear that if it can be answered successfully, the future for solar is very positive – of all the renewable energy sources, solar has the strongest claim to be the only one that can potentially form the cornerstone of a post-fossil energy system.