Chapter 10
Solar Energy

10.1 Summary

KEY MESSAGES

- Solar energy is a vast and largely untapped resource. Australia has the highest average solar radiation per square metre of any continent in the world.
- Solar energy is used mainly in small direct-use applications such as water heating. It accounts for only 0.1 per cent of total primary energy consumption, in Australia as well as globally.
- Solar energy use in Australia is projected to increase by 5.9 per cent per year to 24 PJ in 2029–30.
- The outlook for electricity generation from solar energy depends critically on the commercialisation of large-scale solar energy technologies that will reduce investment costs and risks.
- Government policy settings will continue to be an important factor in the solar energy market outlook. Research, development and demonstration by both the public and private sectors will be crucial in accelerating the development and commercialisation of solar energy in Australia, especially large-scale solar power stations.

10.1.1 World solar energy resources and market

- The world's overall solar energy resource potential is around 5.6 gigajoules (GJ) (1.6 megawatt-hours (MWh)) per square metre per year. The highest solar resource potential is in the Red Sea area, including Egypt and Saudi Arabia.
- Solar energy accounted for 0.1 per cent of world total primary energy consumption in 2007, although its use has increased significantly in recent years.
- Government policies and falling investment costs and risks are projected to be the main factors underpinning future growth in world solar energy use.
- The International Energy Agency (IEA) in its reference case projects the share of solar energy in total electricity generation will increase to 1.2 per cent in 2030 – 1.7 per cent in OECD countries and 0.9 per cent in non-OECD countries.

10.1.2 Australia's solar energy resources

- The annual solar radiation falling on Australia is approximately 58 million petajoules (PJ), approximately 10 000 times Australia's annual energy consumption.
- Solar energy resources are greater in the northwest and centre of Australia, in areas that do not have access to the national electricity grid. Accessing solar energy resources in these areas is likely to require investment in transmission infrastructure (figure 10.1).
- There are also significant solar energy resources in areas with access to the electricity grid. The solar energy resource (annual solar radiation) in areas of flat topography within 25 km of existing transmission lines (excluding National Parks), is nearly 500 times greater than the annual energy consumption of Australia.

10.1.3 Key factors in utilising Australia's solar resources

- Solar radiation is intermittent because of daily and seasonal variations. However, the correlation between solar radiation and daytime peak electricity demand means that solar energy has the potential to provide electricity during peak demand times.
- Solar thermal technologies can also operate in hybrid systems with fossil fuel power plants, and, with appropriate storage, have the potential to provide base load electricity generation. Solar thermal technologies can also potentially provide electricity to remote townships and mining centres where the cost of alternative electricity sources is high.
- Photovoltaic systems are well suited to off-grid electricity generation applications, and where costs of electricity generation from other sources are high (such as in remote communities).

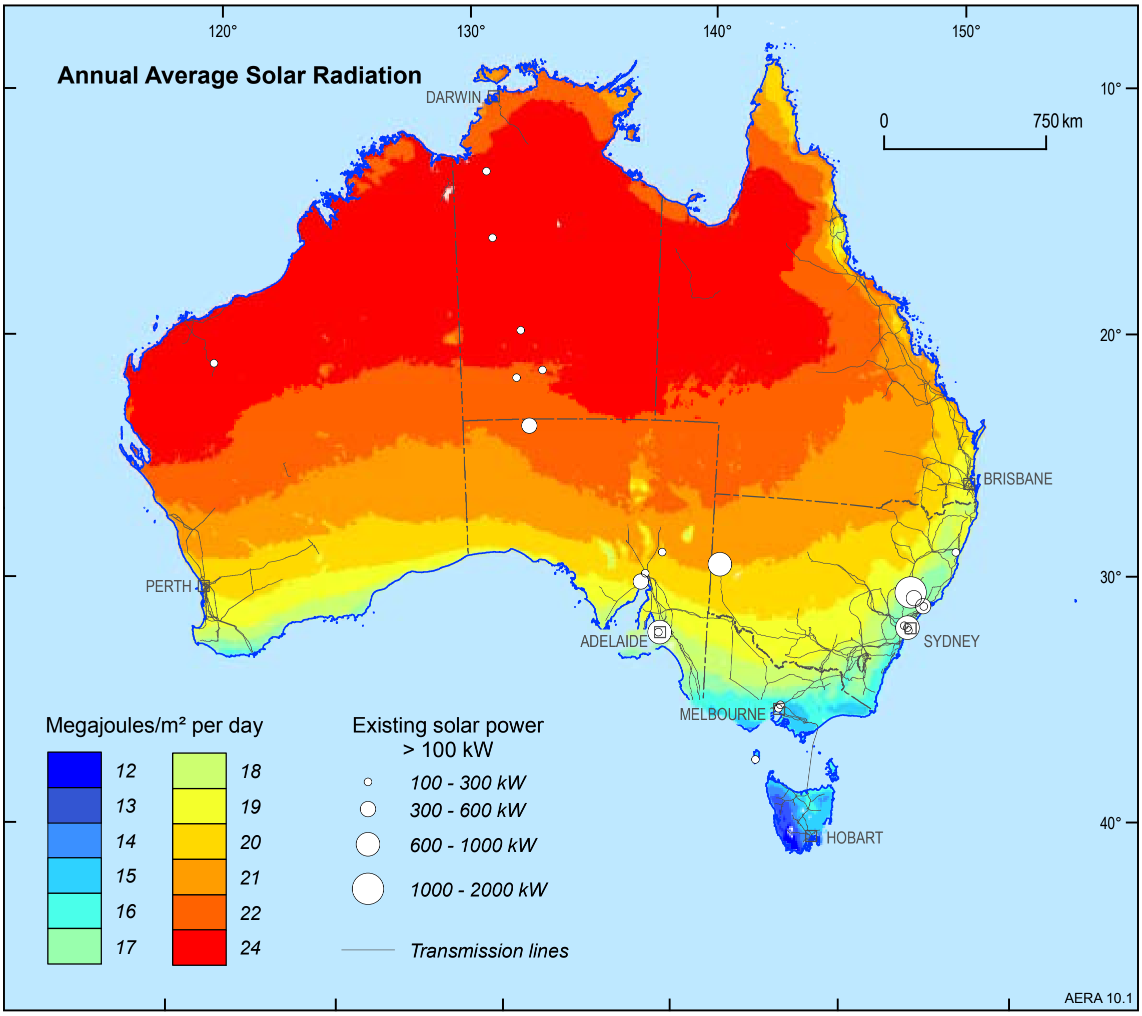

Figure 10.1 Annual average solar radiation (in MJ/m^2) and currently installed solar power stations with a capacity of more than 10 kW

Source: Bureau of Meteorology 2009; Geoscience Australia

- Relatively high capital costs and risks remain the primary limitation to more widespread use of solar energy. Government climate change policies, and research, development and demonstration (RD&D) by both the public and private sectors will be critical in the future commercialisation of large scale solar energy systems for electricity generation.
- The Australian Government has established a Solar Flagships Program at a cost of $1.5 billion as part of its Clean Energy Initiative to support the construction and demonstration of large scale (up to 1000 MW) solar power stations in Australia.

10.1.4 Australia's solar energy market

- In 2007–08, Australia's solar energy use represented 0.1 per cent of Australia's total primary energy consumption. Solar thermal water heating has been the predominant form of solar energy use to date, but electricity generation is increasing through the deployment of photovoltaic and concentrating solar thermal technologies.
- In ABARE's latest long-term energy projections, which include the Renewable Energy Target, a 5 per cent emissions reduction target, and other government policies, solar energy use in Australia is projected to increase from 7 PJ in 2007–08 to 24 PJ in 2029–30 (figure 10.2). Electricity generation from solar energy is projected to increase from 0.1 TWh in 2007–08 to 4 TWh in 2029–30 (figure 10.3).

10.2 Background information and world market

10.2.1 Definitions

Solar power is generated when energy from the sun (sunlight) is converted into electricity or used to heat air, water, or other fluids. As illustrated in figure 10.4, there are two main types of solar energy technologies:

- **Solar thermal** is the conversion of solar radiation into thermal energy (heat). Thermal energy carried by air, water, or other fluid is commonly used directly, for space heating, or to generate electricity using steam and turbines. Solar thermal is commonly used for hot water systems. Solar thermal electricity, also known as concentrating solar power, is typically designed for large scale power generation.
- **Solar photovoltaic (PV)** converts sunlight directly into electricity using photovoltaic cells. PV systems can be installed on rooftops, integrated into building designs and vehicles, or scaled up to megawatt scale power plants. PV systems can also be used in conjunction with concentrating mirrors or lenses for large scale centralised power.

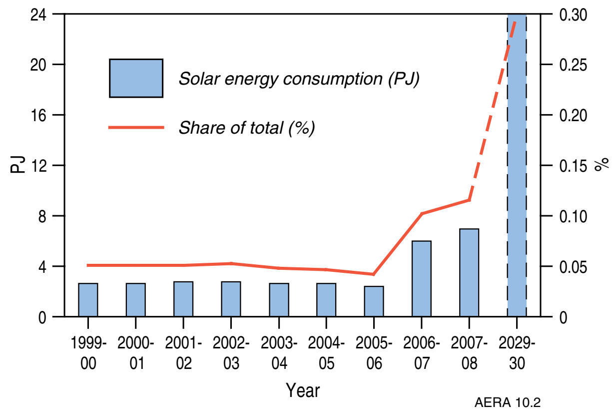

Figure 10.2 Projected primary consumption of solar energy in Australia

Source: ABARE 2009a, 2010

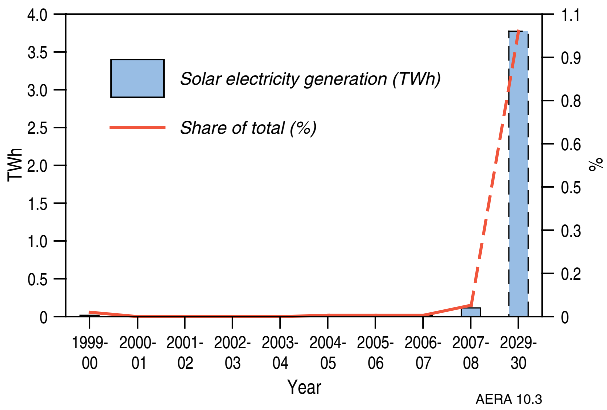

Figure 10.3 Projected electricity generation from solar energy in Australia

Source: ABARE 2009a, 2010

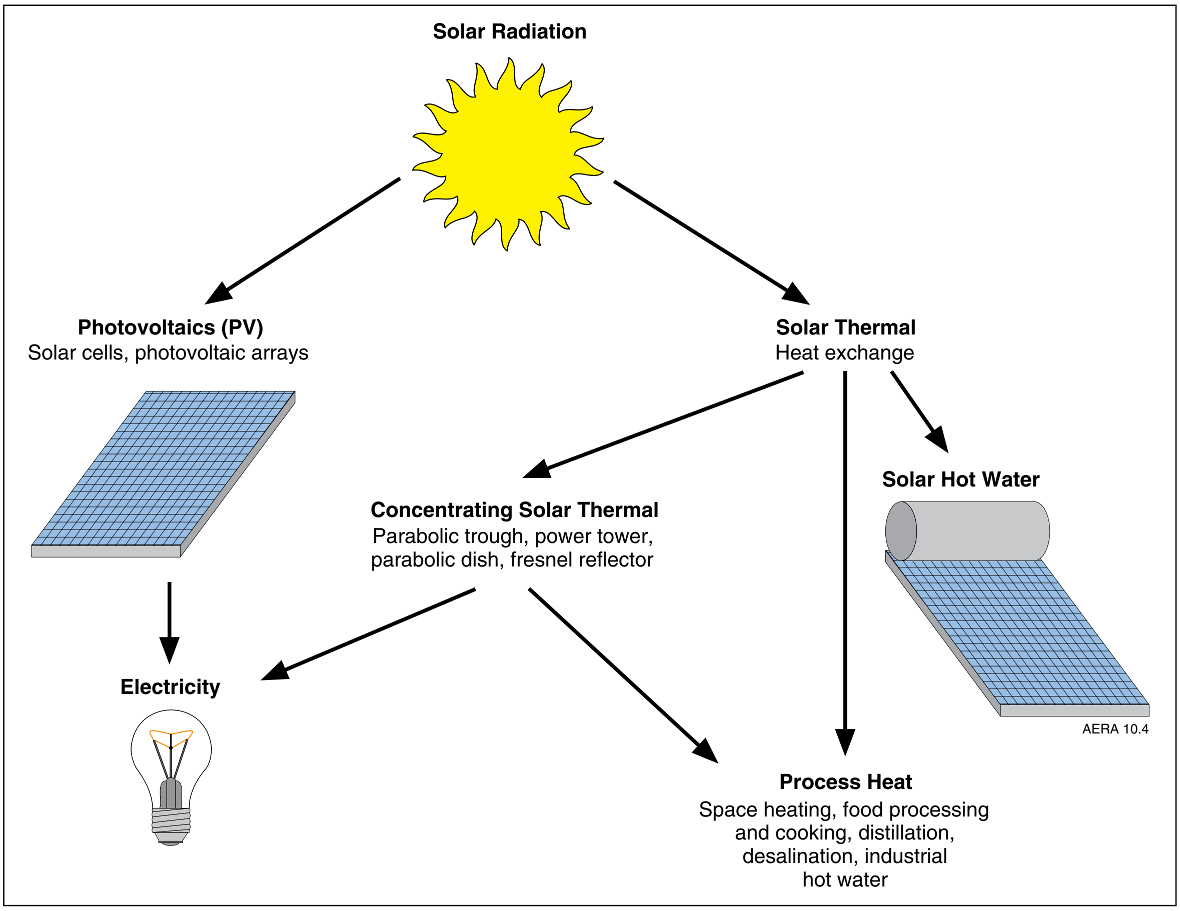

Figure 10.4 Solar energy flows

Source: ABARE and Geoscience Australia

Solar thermal and PV technology can also be combined into a single system that generates both heat and electricity. Further information on solar thermal and PV technologies is provided in boxes 10.2 and 10.3 in section 10.4.

10.2.2 Solar energy supply chain

A representation of the Australian solar industry is given in figure 10.5. The potential for using solar energy at a given location depends largely on the solar radiation, the proximity to electricity load centres, and the availability of suitable sites. Large scale solar power plants require approximately 2 hectares of land per MW of power. Small scale technologies (solar water heaters, PV modules and small-scale solar concentrators) can be installed on existing structures, such as rooftops. Once a solar project is developed, the energy is captured by heating a fluid or gas or by using photovoltaic cells. This energy can be used directly as hot water supply, converted to electricity, used as process heat, or stored by various means, such as thermal storage, batteries, pumped hydro or synthesised fuels.

10.2.3 World solar energy market

The world has large solar energy resources which have not been greatly utilised to date. Solar energy currently accounts for a very small share of world primary energy consumption, but its use is projected to increase strongly over the outlook period to 2030.

The highest solar resource potential per unit land area is in the Red Sea area. Australia also has higher incident solar energy per unit land area than any other continent in the world. However, the distribution of solar energy use amongst countries reflects government policy settings that encourage its use, rather than resource availability.

World solar resources

The amount of solar energy incident on the world's land area far exceeds total world energy demand. Solar energy thus has the potential to make a major contribution to the world's energy needs. However, large scale solar energy production is currently limited by its high capital cost.

The annual solar resource varies considerably around the world. These variations depend on several factors, including proximity to the equator, cloud cover, and other atmospheric effects. Figure 10.6 illustrates the variations in solar energy availability.

The Earth's surface, on average, has the potential to capture around 5.4 GJ (1.5 MWh) of solar energy per square metre a year (WEC 2007). The highest resource potential is in the Red Sea area, including Egypt and Saudi Arabia (figure 10.6). Australia and the United States also have a greater solar resource potential than the world average. Much of this potential can be explained by proximity to the equator and average annual weather patterns.

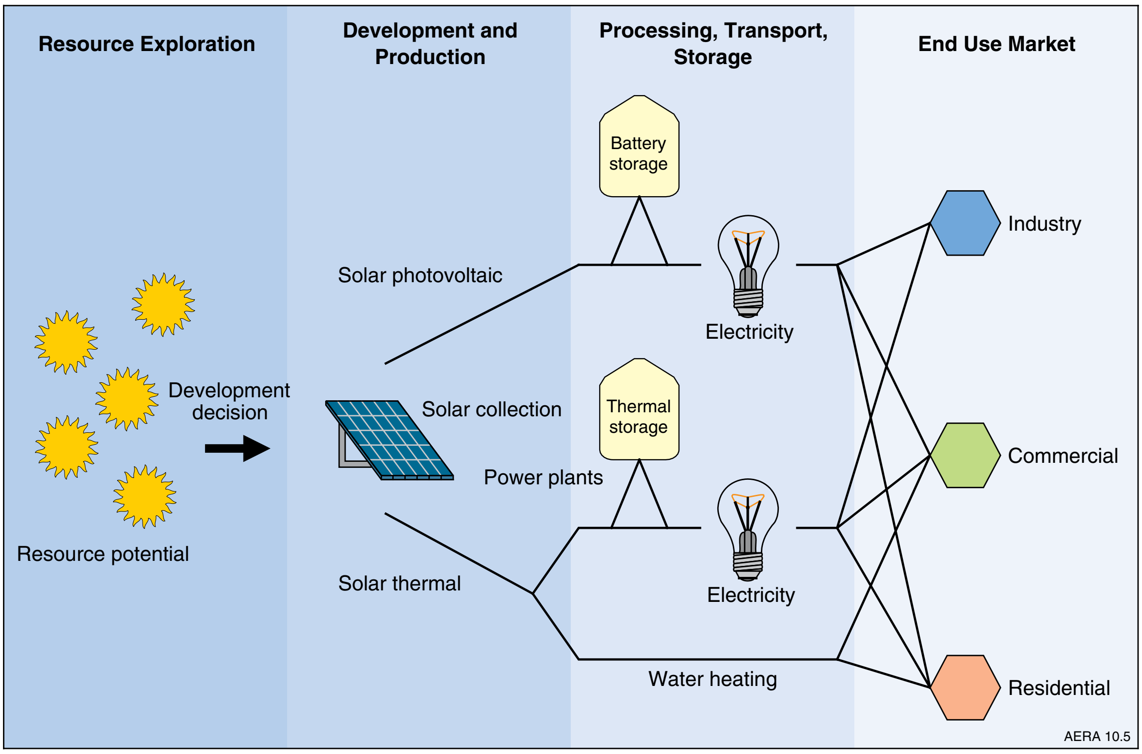

Figure 10.5 Australia's solar energy supply chain

Source: ABARE and Geoscience Australia

Primary energy consumption

Since solar energy cannot currently be stored for more than several hours, nor traded in its primary form, solar energy consumption is equal to solar energy production. Long term storage of solar energy is currently undergoing research and development, but has not yet reached commercial status.

Solar energy contributes only a small proportion to Australia's primary energy needs, although its share is comparable to the world average. While solar energy accounts for only around 0.1 per cent of world primary energy consumption, its use has been increasing at an average rate of 10 per cent per year from 2000 to 2007 (table 10.1). Increased concern with environmental issues surrounding fossil fuels, coupled with government policies that encourage solar energy use, have driven increased uptake of solar technologies, especially PV.

From 1985 to 1989, world solar energy consumption increased at an average rate of 19 per cent per year (figure 10.7). From 1990 to 1998, the rate of growth in solar energy consumption decreased to 5 per cent per year, before increasing strongly again from 1999 to 2007 (figure 10.7).

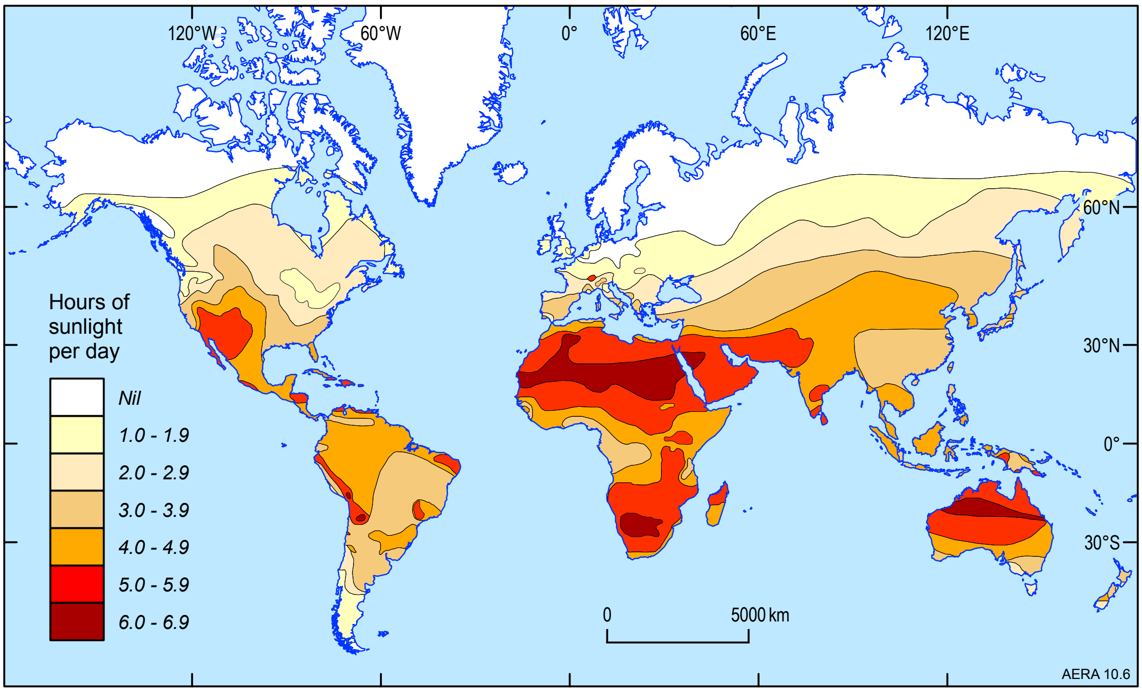

Figure 10.6 Hours of sunlight per day, during the worst month of the year on an optimally tilted surface

Source: Sunwize Technologies 2008

Table 10.1 Key statistics for the solar energy market

	unit	Australia 2007–08	OECD 2008	World 2007
Primary energy consumption[a]	PJ	6.9	189.4	401.8
Share of total	%	0.12	0.09	0.08
Average annual growth, from 2000	%	7.2	4.3	9.6
Electricity generation				
Electricity output	TWh	0.1	8.2	4.8
Share of total	%	0.04	0.08	0.02
Average annual growth, from 2000	%	26.1	36.3	30.8
Electricity capacity	GW	0.1	8.3	14.7

a Energy production and primary energy consumption are identical

Source: IEA 2009b; ABARE 2009a; Watt 2009; EPIA 2009

The majority of solar energy is produced using solar thermal technology; solar thermal comprised 96 per cent of total solar energy production in 2007 (figure 10.7). Around half is used for water heating in the residential sector. Most of the remainder is used for space heating either residentially or commercially, and for heating swimming pools. All of the energy used for these purposes is collected using solar thermal technology.

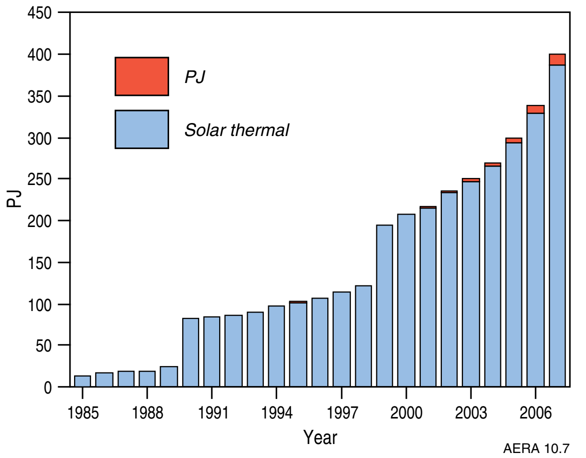

Figure 10.7 World primary solar energy consumption, by technology

Source: IEA 2009b

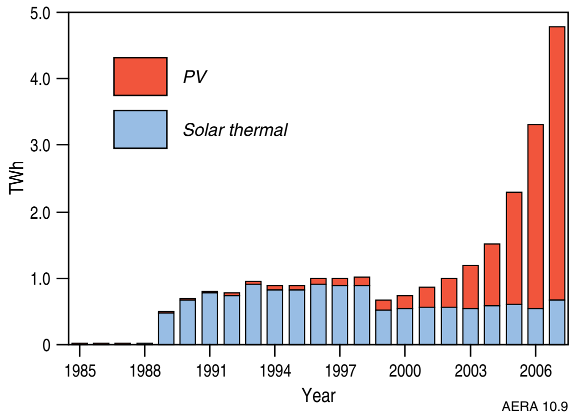

Figure 10.9 World electricity generation from solar energy, by technology

Source: IEA 2009b

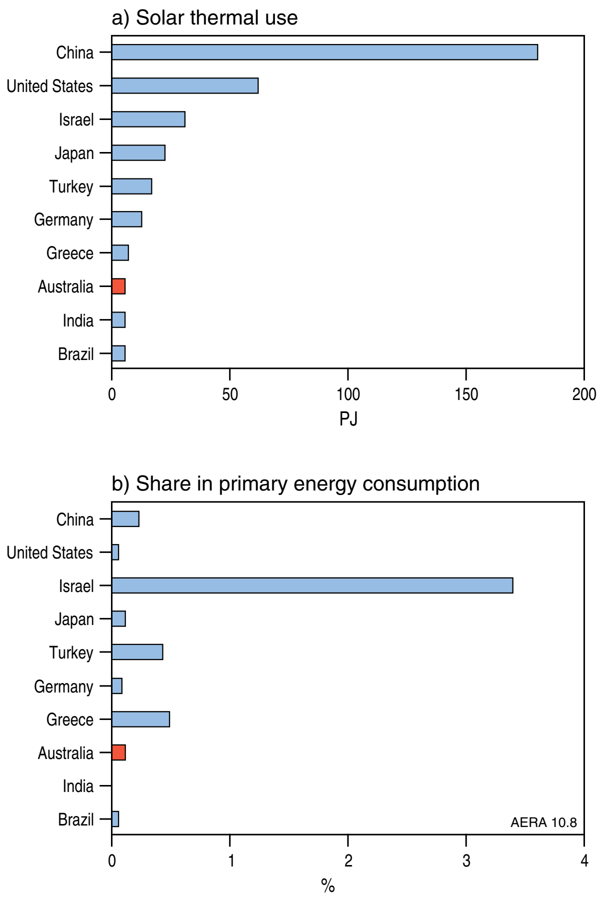

Figure 10.8 Direct use of solar thermal energy, by country, 2007

Source: IEA 2009b

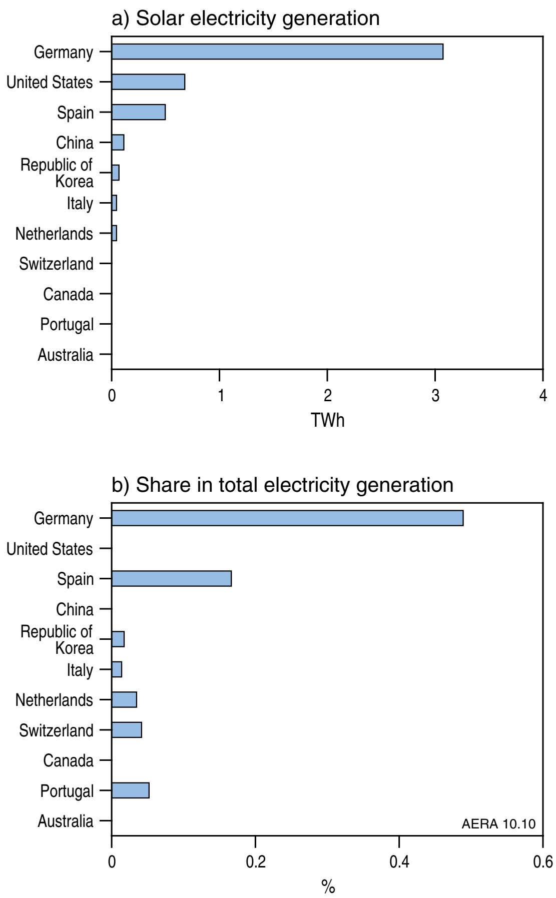

Figure 10.10 Electricity generation from solar energy, major countries, 2007

Source: IEA 2009b

Solar thermal energy consumption

The largest users of solar thermal energy in 2007 were China (180 PJ), the United States (62 PJ), Israel (31 PJ) and Japan (23 PJ). However, Israel has a significantly larger share of solar thermal in its total primary energy consumption than any other country (figure 10.8). Growth in solar thermal energy use in these countries has been largely driven by government policies.

Electricity generation

Electricity generation accounts for around 5 per cent of primary consumption of solar energy. All solar photovoltaic energy is electricity, while around 3 per cent of solar thermal energy is converted to electricity. Until 2003, more solar thermal energy was used to generate electricity than solar photovoltaic energy (figure 10.9).

The largest producers of electricity from solar energy in 2007 were Germany (3.1 TWh), the United States (0.7 TWh) and Spain (0.5 TWh), with all other countries each producing 0.1 TWh or less (figure 10.10). Germany had the largest share of solar energy in electricity generation, at 0.5 per cent. It is important to note that these electricity generation data do not include off-grid PV installations, which represent a large part of PV use in some countries.

Table 10.2 IEA reference case projections for world solar electricity generation

	unit	2007	2030
OECD	TWh	4.60	220
Share of total	%	0.05	1.66
Average annual growth, 2007–2030	%	-	18
Non-OECD	TWh	0.18	182
Share of total	%	0.00	0.86
Average annual growth, 2007–2030	%	-	35
World	TWh	4.79	402
Share of total	%	0.02	1.17
Average annual growth, 2007–2030	%	-	21

Source: IEA 2009a

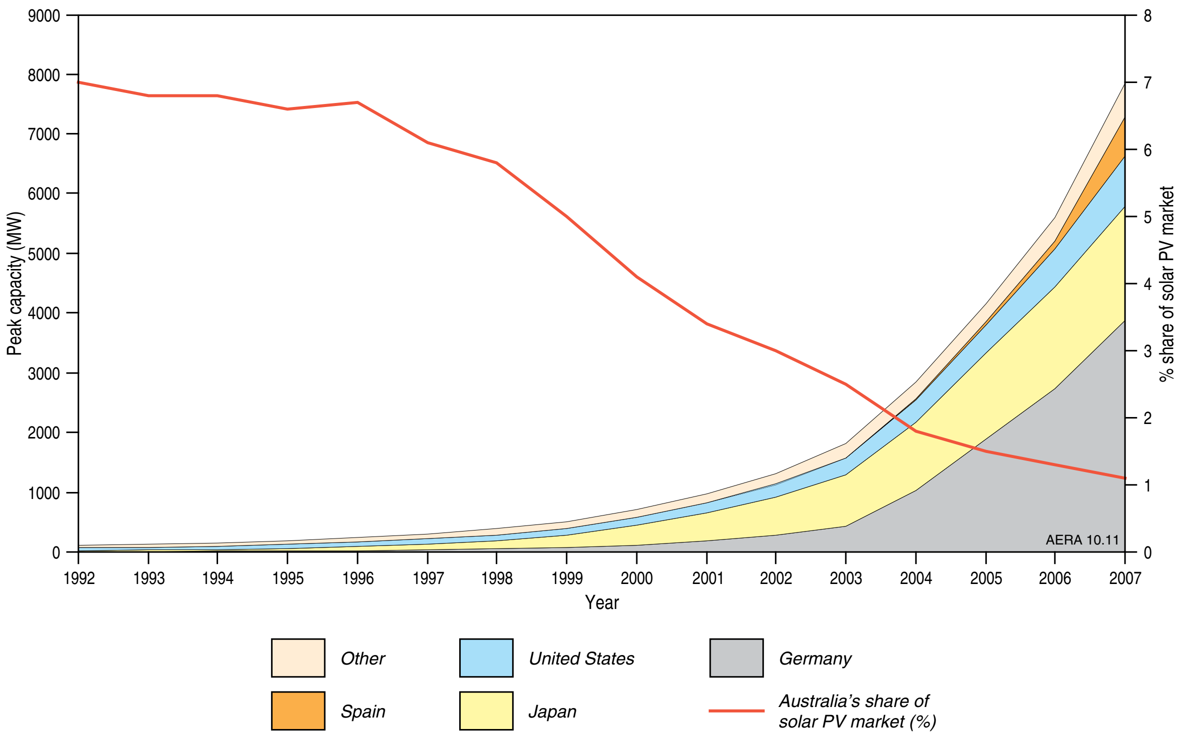

Figure 10.11 World PV Capacity, 1992–2007, including off-grid installations

Source: IEA-PVPS 2008

Installed PV generation capacity

The IEA's estimates of total PV electricity generation capacity (including off-grid generation) show that Japan (1.9 GW) and the United States (0.8 GW) had the second and third largest PV capacity in 2007, following Germany with 3.9 GW (figure 10.11). Over 90 per cent of this capacity was connected to grids (WEC 2009).

World market outlook

Government incentives, falling production costs and rising electricity generation prices are projected to result in increases in solar electricity generation. Electricity generation from solar energy is projected to increase to 402 TWh by 2030, growing at an average rate of 21 per cent per year to account for 1.2 per cent of total generation (table 10.2). Solar electricity is projected to increase more significantly in non-OECD countries than in OECD countries, albeit from a much smaller base.

PV systems installed in buildings are projected to be the main source of growth in solar electricity generation to 2030. PV electricity is projected to increase to almost 280 TWh in 2030, while electricity generated from concentrating solar power systems is projected to increase to almost 124 TWh by 2030 (IEA 2009a).

10.3 Australia's solar energy resources and market

10.3.1 Solar resources

As already noted, the Australian continent has the highest solar radiation per square metre of any continent (IEA 2003); however, the regions with the highest radiation are deserts in the northwest and centre of the continent (figure 10.12).

Australia receives an average of 58 million PJ of solar radiation per year (BoM 2009), approximately 10 000 times larger than its total energy consumption of 5772 PJ in 2007–08 (ABARE 2009a). Theoretically, then, if only 0.1 per cent of the incoming radiation could be converted into usable energy at an efficiency of 10 per cent, all of Australia's energy needs could be supplied by solar energy. Similarly, the energy falling on a solar

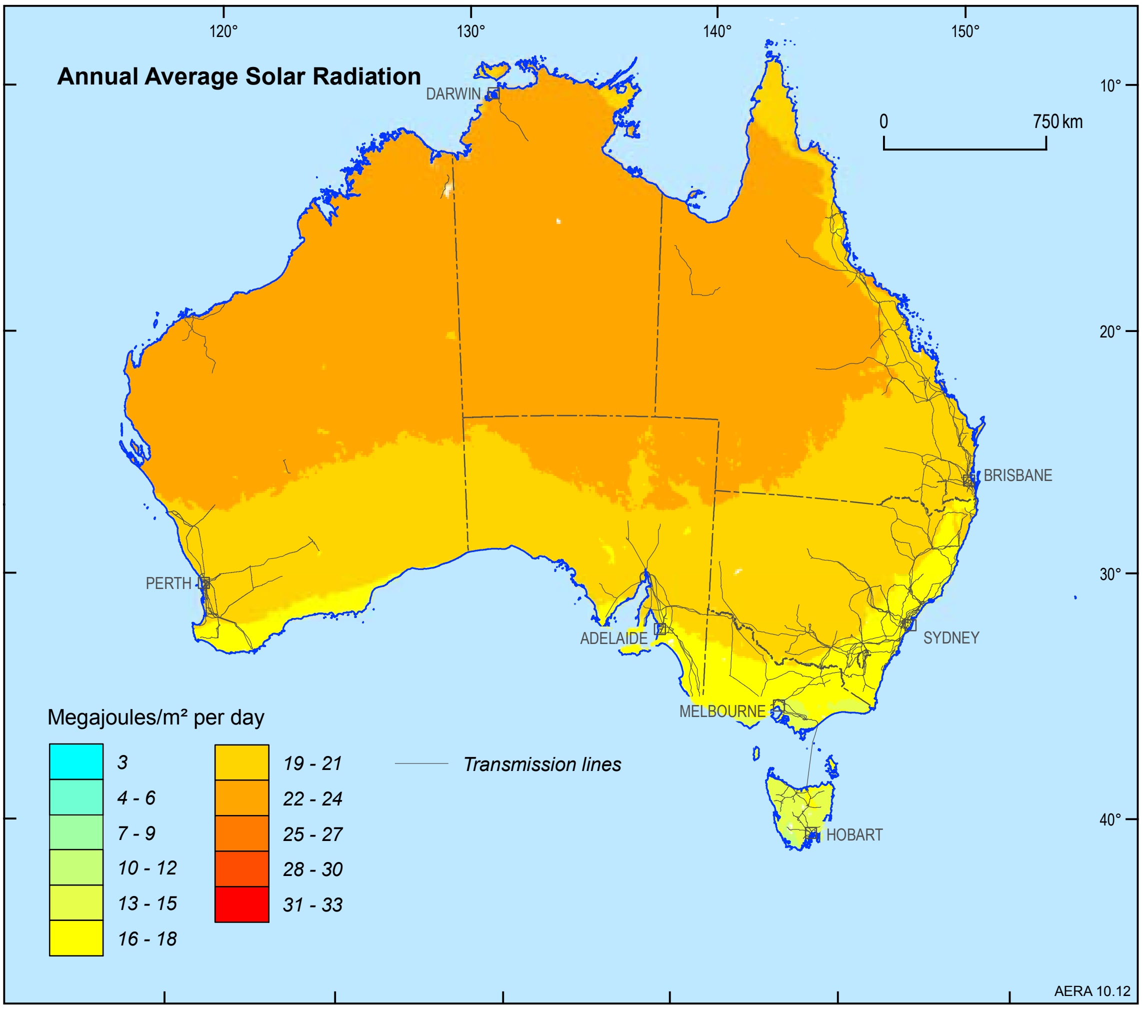

Figure 10.12 Annual average solar radiation

Source: Bureau of Meteorology 2009

farm covering 50 km by 50 km would be sufficient to meet all of Australia's electricity needs (Stein 2009a). Given this vast and largely untapped resource, the challenge is to find effective and acceptable ways of exploiting it.

While the areas of highest solar radiation in Australia are typically located inland, there are some grid-connected areas that have relatively high solar radiation. Wyld Group and MMA (2008) identified a number of locations that are suitable for solar thermal power plants, based on high solar radiation levels, proximity to local loads, and high electricity costs from alternative sources. Within the National Electricity Market (NEM) grid catchment area, they identified the Port Augusta region in South Australia, north-west Victoria, and central and north-west New South Wales as regions of high potential for solar thermal power. They also nominated Kalbarri, near Geraldton, Western Australia, on the South-West Interconnected System, the Darwin-Katherine Interconnected System, and Alice Springs-Tennant Creek as locations of high potential for solar thermal power.

Concentrating solar power

Figure 10.12 shows the radiation falling on a flat plane. This is the appropriate measure of radiation for flat plate PV and solar thermal heating systems, but not for concentrating systems. For concentrating solar power, including both solar thermal power and concentrating PV, the Direct Normal Irradiance (DNI) is a more relevant measure of the solar resource. This is because concentrating solar technologies can only focus sunlight coming from one direction, and use tracking mechanisms to align their collectors with the direction of the sun. The only dataset currently available for DNI that covers all of Australia is from the Surface Meteorology and Solar Energy dataset from the National Aeronautics and Space Administration (NASA). This dataset provides DNI at a coarse resolution of 1 degree, equating to a grid length of approximately 100 km. The annual average DNI from this dataset is shown in figure 10.13.

Since the grid cell size is around 10 000 km^2, this dataset provides only a first order indication of the DNI across broad regions of Australia. However, it is adequate to demonstrate that the spatial distribution

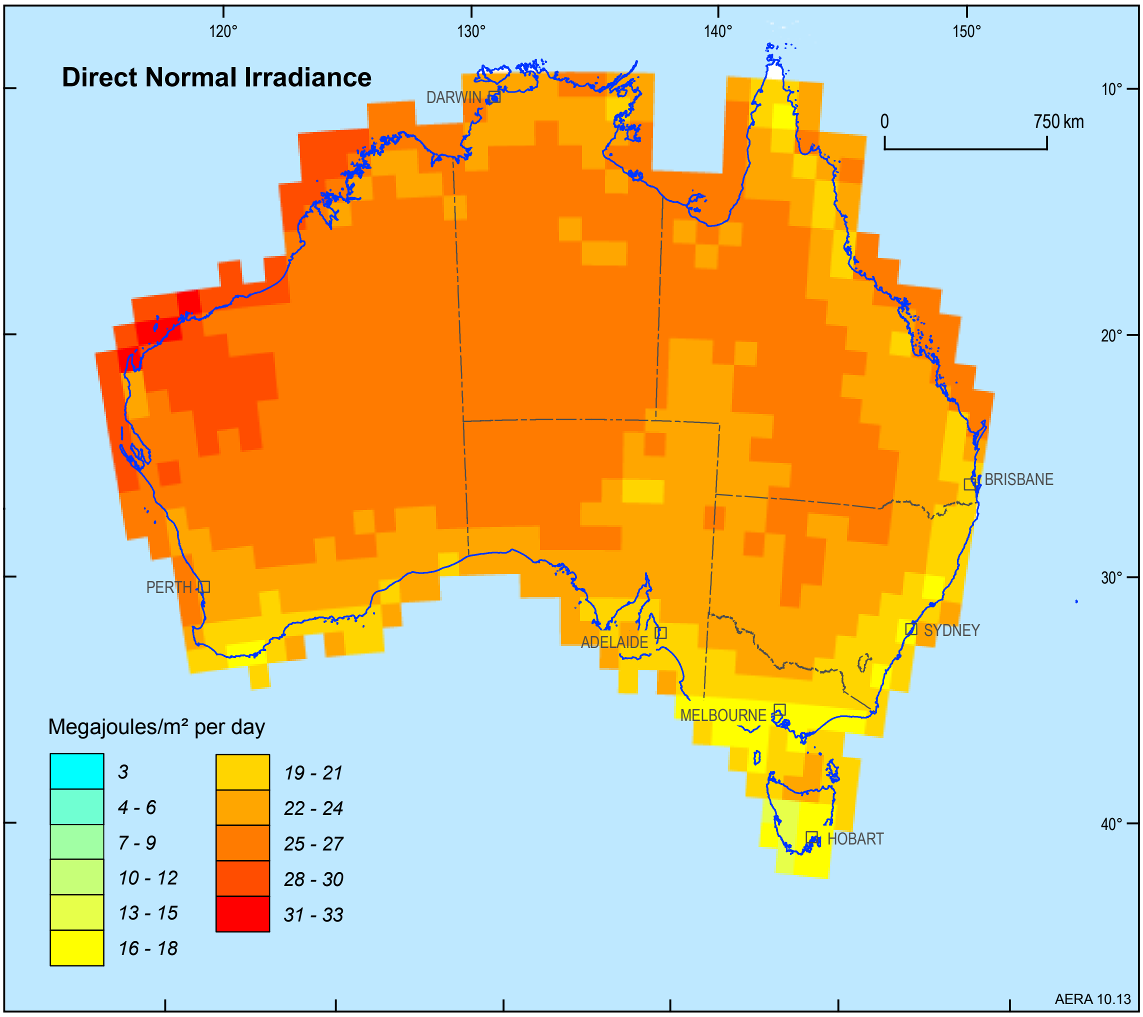

Figure 10.13 Direct Normal Solar Irradiance

Source: NASA 2009

of DNI differs from that of the total radiation shown in figure 10.12. In particular, there are areas of high DNI in central New South Wales and coastal regions of Western Australia that are less evident in the total radiation. More detailed mapping of DNI across Australia is needed to assess the potential for concentrating solar power at a local scale.

Some types of solar thermal power plants, including parabolic troughs and Fresnel reflectors, need to be constructed on flat land. It is estimated that about 2 hectares of land are required per MW of power produced (Stein 2009a). Figure 10.14 shows solar radiation, where land with a slope of greater than 1 per cent, and land further than 25 km from existing transmission lines has been excluded. Land within National Parks has also been excluded. These exclusion thresholds of slope and distance to grid are not precise limits but intended to be indicative only. Even with these limits, the annual radiation falling on the coloured areas in figure 10.14 is 2.7 million PJ, which amounts to nearly 500 times the annual energy demand of Australia. Moreover, power towers, dishes and PV systems are not restricted to flat land, which renders even this figure a conservative estimate.

Seasonal variations in resource availability

There are also significant seasonal variations in the amount of solar radiation reaching Australia. While summer radiation levels are generally very high across all of inland Australia, winter radiation has a much stronger dependence on latitude. Figures 10.15 and 10.16 show a comparison of the December and June average daily solar radiation. The same colour scheme has been used throughout figures 10.12 to 10.16 to allow visual comparison of the amount of radiation in each figure.

In some states, such as Victoria, South Australia and Queensland, the seasonal variation in solar radiation correlates with a seasonal variation in electricity demand. These summer peak demand periods – caused by air-conditioning loads – coincide with the hours that the solar resource is at its most abundant. However, the total demand across the National Electricity Market (comprising all of the

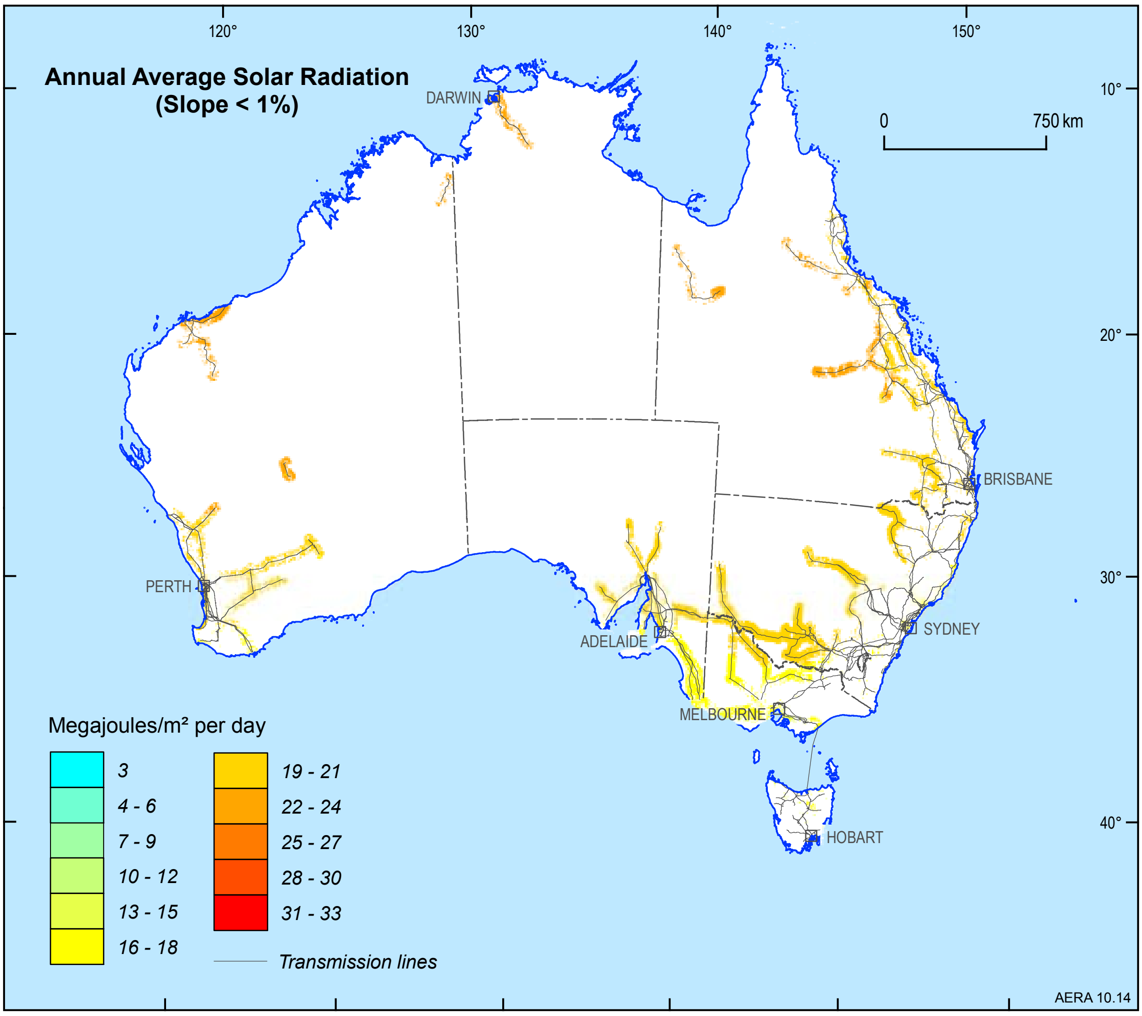

Figure 10.14 Annual solar radiation, excluding land with a slope of greater than 1 per cent and areas further than 25 km from existing transmission lines

Source: Bureau of Meteorology 2009; Geoscience Australia eastern states, South Australia and Tasmania) is relatively constant throughout the year, and occasionally peaks in winter due to heating loads (AER 2009).

10.3.2 Solar energy market

Australia's modest production and use of solar energy is focussed on off-grid and residential installations. While solar thermal water heating has been the predominant form of solar energy use to date, production of electricity from PV and concentrating solar thermal technologies is increasing.

Primary energy consumption

Australia's primary energy consumption of solar energy accounted for 2.4 per cent of all renewable energy use and around 0.1 per cent of primary energy consumption in 2007–08 (ABARE 2009a). Production and consumption of solar energy are the same, because solar energy can only be stored for several hours at present.

Over the period from 1999–2000 to 2007–08, Australia's solar energy use increased at an average rate of 7.2 per cent per year. However, as illustrated in figure 10.17, the growth rate was not constant; there was considerable variation from year to year. The bulk of growth over this period was in the form of solar thermal systems used for domestic water heating. PV is also used to produce a small amount of electricity. In total, Australia's solar energy consumption in 2007–08 was 6.9 PJ (1.9 TWh), of which 6.5 PJ (1.8 TWh) were used for water heating (ABARE 2009a).

Consumption of solar thermal energy, by state

Statistics on PV energy consumption by state are not available. However, PV represents only 5.8 per cent of total solar energy consumption; on that basis, statistics on solar thermal consumption by state provide a reasonable approximation of the distribution of total solar energy consumption.

Western Australia has the highest solar energy consumption in Australia, contributing 40 per cent of Australia's total solar thermal use in 2007–08 (figure 10.18). New South Wales and Queensland contributed another 26 per cent and 15 per cent respectively. The rate of growth of solar energy use

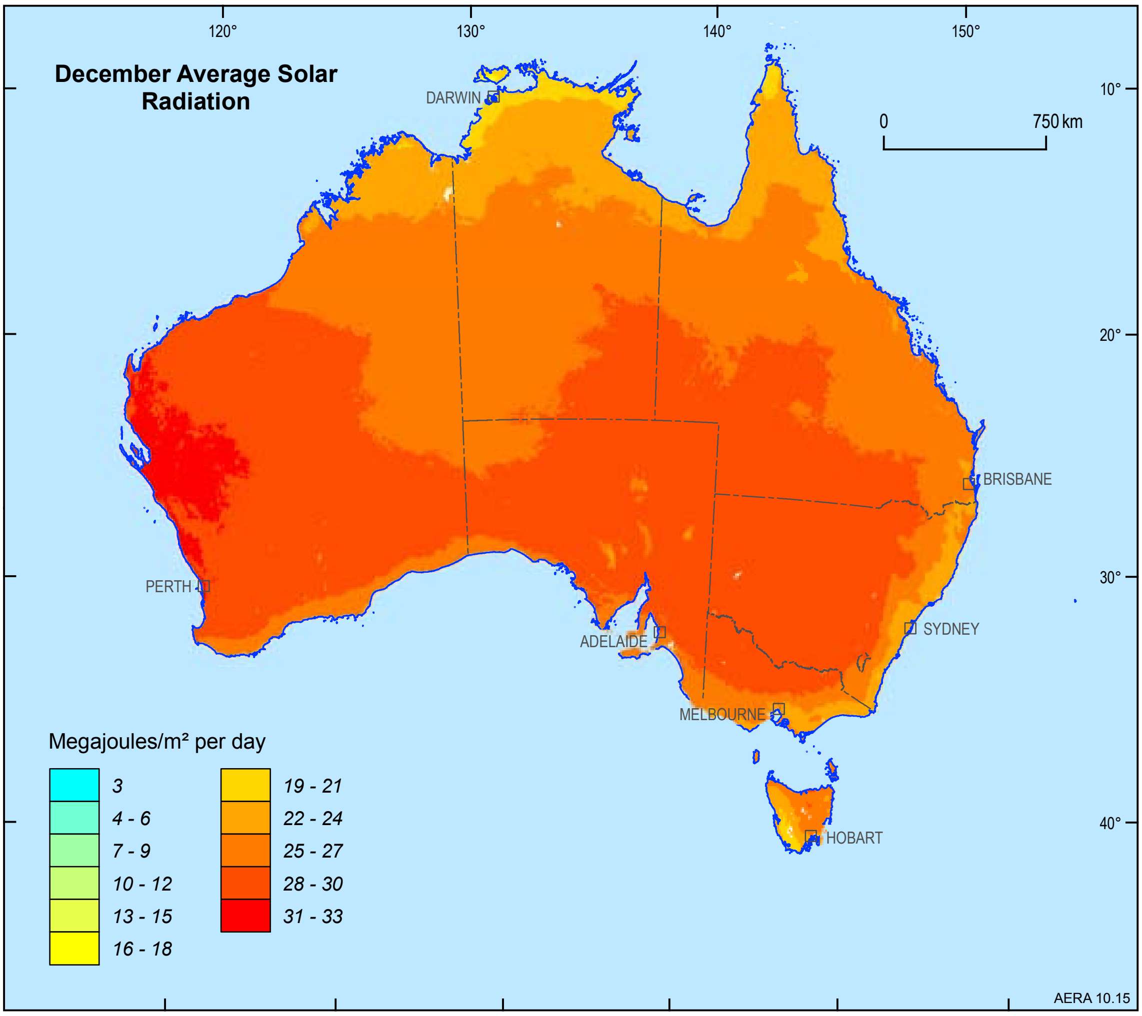

Figure 10.15 December average solar radiation

Source: Bureau of Meteorology 2009

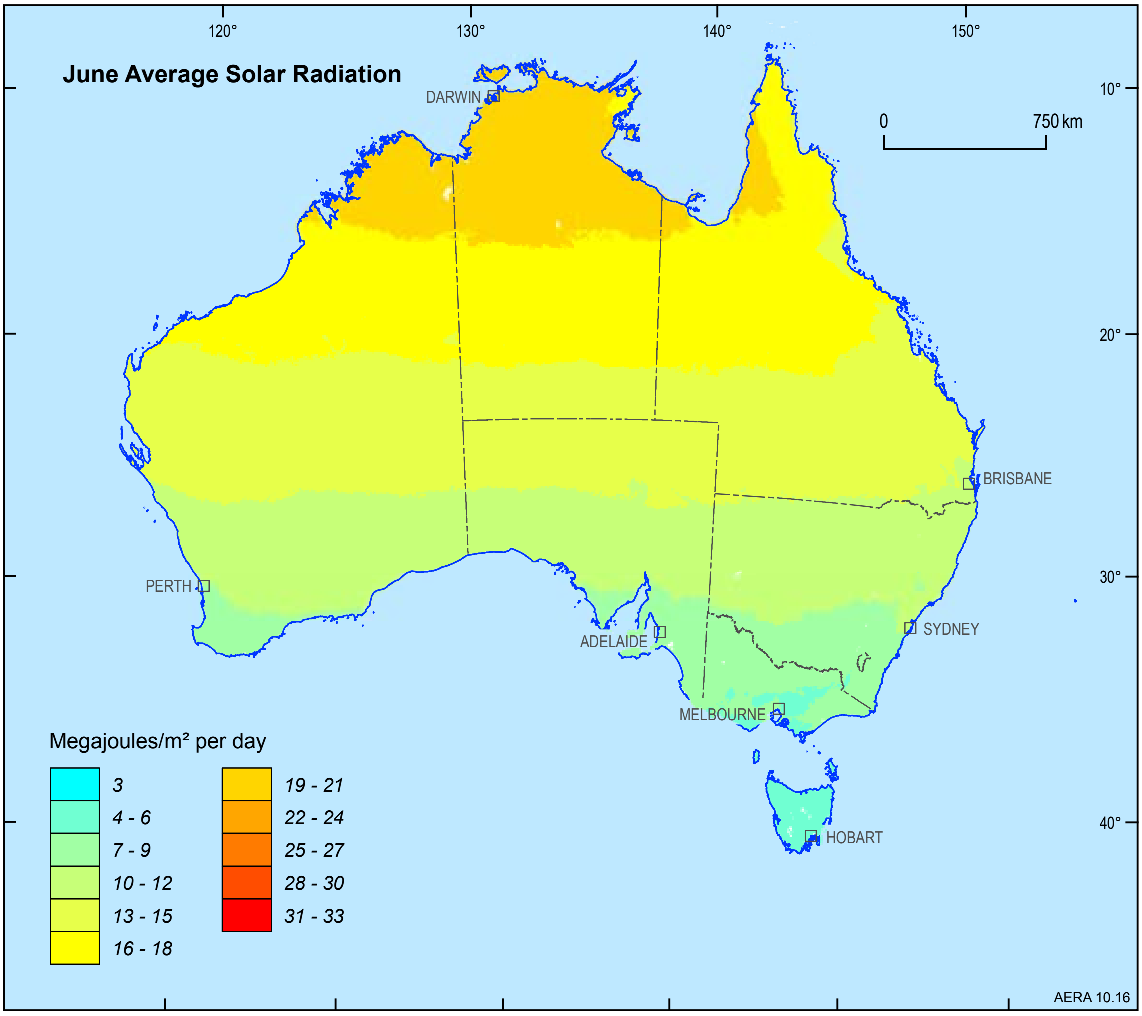

Figure 10.16 June average solar radiation

Source: Bureau of Meteorology 2009

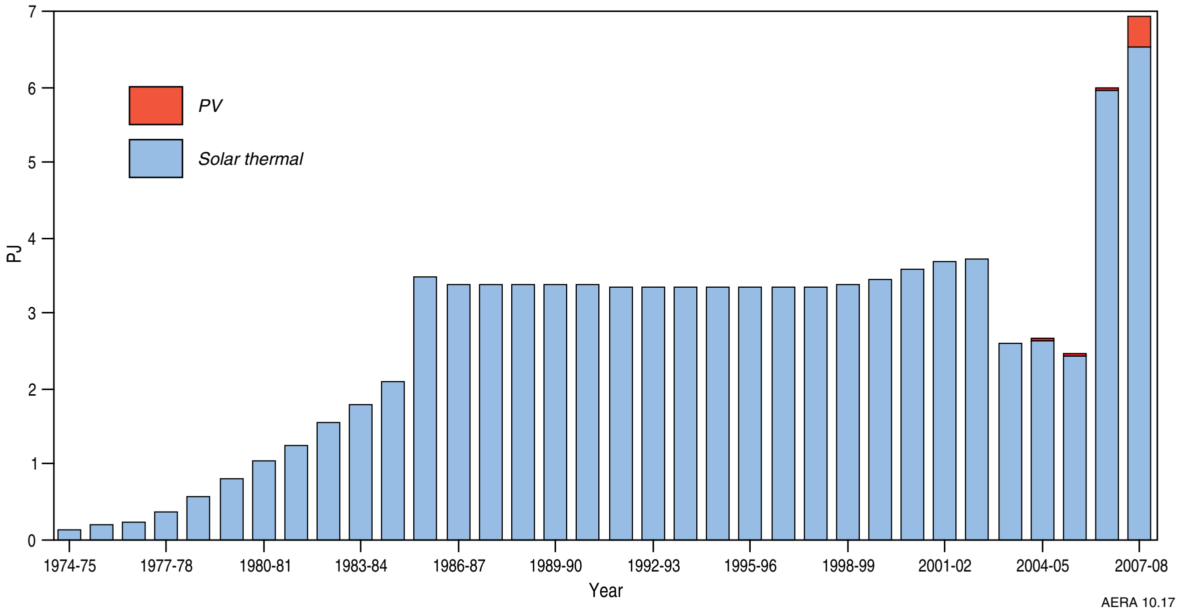

Figure 10.17 Australia's primary consumption of solar energy, by technology

Source: IEA 2009b; ABARE 2009a

over the past decade has been similar in all states and territories, ranging from an average annual growth of 7 per cent in the Northern Territory and Victoria, to an average annual growth of 11 per cent in New South Wales.

A range of government policy settings from both Australian and State governments have resulted in a significant increase in the uptake of small-scale solar hot water systems in Australia. The combination of drivers, including the solar hot water rebate, state building codes, the inclusion of solar hot water under the Renewable Energy Target and the mandated phase-out of electric hot water by 2012, have all contributed to the increased uptake of solar hot water systems from 7 per cent of total hot water system installations in 2007 to 13 per cent in 2008 (BIS Shrapnel 2008; ABARE 2009a).

Electricity generation

Electricity generation from solar energy in Australia is currently almost entirely sourced from PV installations, primarily from small off-grid systems. Electricity generation from solar thermal systems is currently limited to small pilot projects, although interest in solar thermal systems for large scale electricity generation is increasing.

Some care in analysis of generation data in energy statistics is warranted. For energy accounting purposes, the fuel inputs to a solar energy system are assumed to equal the energy generated by the solar system. Thus, the solar electricity fuel inputs in energy statistics represent the solar energy captured by solar energy systems, rather than the significantly larger measure of total solar radiation falling on solar energy systems; however this radiation is not measured in energy statistics. Fossil fuels such as gas and coal are measured in terms of both their thermal fuel input, and their electrical output. The result of this difference between fuel inputs and energy output for fossil fuels is that solar represents a larger share of electricity generation output than of fuel inputs to electricity generation.

In 2007–08, 0.11 TWh (0.4 PJ) of electricity were generated from solar energy, representing 0.04 per cent of Australian electricity generation (figure 10.19). Despite its small share, solar electricity generation has increased rapidly in recent years.

Installed electricity generation capacity

Australia's total PV capacity has increased significantly over the last decade (figure 10.20), and in particular over the last two years. This has been driven primarily by the Solar Homes and Communities Plan for on-grid applications and the Remote Renewable Power Generation Program for off-grid applications. Over the last two years, there has been a dramatic increase in the take-up of small scale PV, with more than 40 MW installed in 2009 (figures 10.20, 10.23). This is due to a combination of factors: support provided through the Solar Homes and Communities program, greater public awareness of solar PV, a drop in the price of PV systems, attributable both to greater international competition among an increased number of suppliers and a decrease in worldwide demand as a result of the global financial crisis, a strong Australian dollar, and highly effective marketing by PV retailers.

Most Australian states and territories have in place, or are planning to implement, feed-in tariffs. While there is some correlation of their introduction with increased consumer uptake, it is too early to suggest that these tariffs have been significant contributors to it. The combination of government policies, associated public and private investment in RD&D measures and broader market conditions are likely to be the main influences.

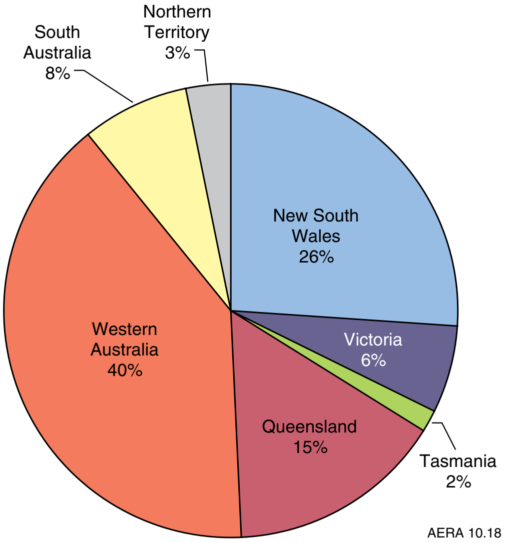

Figure 10.18 Solar thermal energy consumption, by state, 2007–08

Source: ABARE 2009a

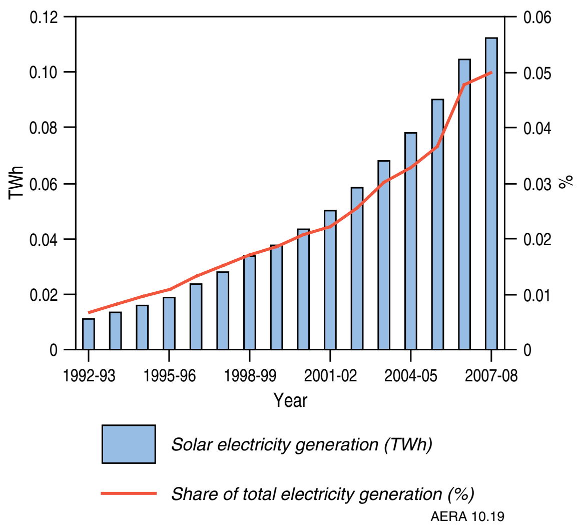

Figure 10.19 Australian electricity generation from solar energy

Source: ABARE

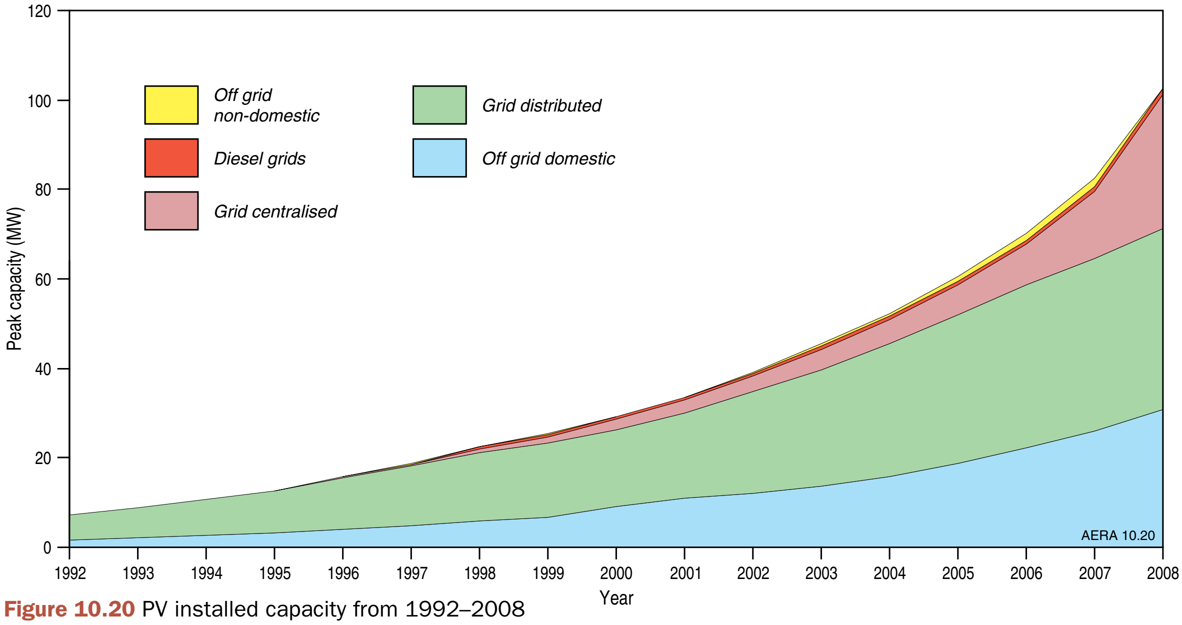

Figure 10.20 PV installed capacity from 1992–2008

Note: These estimates represent the peak power output of PV systems. They do not represent the average power output over a year, as solar radiation varies according to factors such as the time of day, the number of daylight hours, the angle of the sun and the cloud cover. These capacity estimates are consistent with the PV production data presented in this report

Source: Watt 2009

The largest component of installed solar electricity capacity is used for off-grid industrial and agricultural purposes (41 MW), with significant contributions coming from off-grid residential systems (31 MW), and grid connected distributed systems (30 MW). This large off-grid usage reflects the capacity of PV systems to be used as stand-alone generating systems, particularly for small scale applications. There have also been several commercial solar projects that provide electricity to the grid.

Recently completed solar projects

Five commercial-scale solar projects with a combined capacity of around 5 MW have been commissioned in Australia since 1998 (table 10.3). All of these projects are located in New South Wales. Commissioned solar projects to date have had small capacities with four of the five projects commissioned having a capacity of less than or equal to 1 MW. The only project to have a capacity of more than 1 MW is Ausra's 2008 solar thermal attachment to Liddell power plant, which has a peak electric power capacity of 2 MW (Ausra 2009). While somewhat larger than the more common domestic or commercial installations, these are modestly-sized plants. However, there are plans for construction of several large scale solar power plants under the Australian Government's Solar Flagships Program, which will use both solar thermal and PV technologies.

Table 10.3 Recently completed solar projects

Project	Company	State	Start up	Capacity
Singleton	Energy Australia	NSW	1998	0.4 MW
Newington	Private	NSW	2000	0.7 MW
Broken Hill	Australian Inland Energy	NSW	2000	1 MW
Newcastle	CSIRO	NSW	2005	0.6 MW
Liddell	Ausra	NSW	Late 2008	2 MW

Source: Geoscience Australia 2009

10.4 Outlook to 2030 for Australia's resources and market

Solar energy is a renewable resource: increased use of the resource does not affect resource availability. However, the quantity of the resource that can be economically captured changes over time through technological developments.

The outlook for the Australian solar market depends on the cost of solar energy relative to other energy resources. At present, solar energy is more expensive for electricity generation than other currently used renewable energy sources, such as hydro, wind, biomass and biogas. Therefore, the outlook for increased solar energy uptake depends on factors that will reduce its costs relative to other renewable fuels. The competitiveness of solar energy and renewable energy sources generally will also depend on government policies aimed at reducing greenhouse gas emissions.

Solar energy is likely to be an economically attractive option for remote off-grid electricity generation. The long-term competitiveness of solar energy in large-scale grid-connected applications depends in large measure on technological developments that enhance the efficiency of energy conversion and reduce the capital and operating cost of solar energy systems and componentry. The Australian Government's $1.5 billion Solar Flagships program, announced as part of the Clean Energy Initiative, will support the construction and demonstration of large scale (up to 1000 MW) solar power stations in Australia. It will accelerate development solar technology and help position Australia as a world leader in that field.

10.4.1 Key factors influencing the future development of Australia's solar energy resources

Australia is a world leader in developing solar technologies (Lovegrove and Dennis 2006), but uptake of these technologies within Australia has been relatively low, principally because of their high cost. A number of factors affect the economic viability of solar installations.

Solar energy technologies and costs

Research into both solar PV and solar thermal technologies is largely focussed on reducing costs and increasing the efficiency of the systems.

- **Electricity generation** – commercial-scale generation projects have been demonstrated to be possible but the cost of the technology is still relatively high, making solar less attractive and higher risk for investors. Small-scale solar PV arrays are currently best suited to remote and off-grid applications, with other applications largely dependent on research or government funding to make them viable. Information on solar energy technologies for electricity generation is presented in box 10.1.
- **Direct-use applications** – solar thermal hot water systems for domestic use represent the most widely commercialised solar energy technology. Solar water heaters are continuing to be developed further, and can also be integrated with PV arrays. Other direct uses include passive solar heating, and solar air conditioning. Information on solar energy technologies for direct-use applications is presented in box 10.2.

With both solar PV and solar thermal generation, the majority of costs are borne in the capital installation phase, irrespective of the scale or size of the project (figure 10.21). The largest cost components of PV installations are the cells or panels and the associated components required to install and connect the panels as a power source. In addition, the inverter that converts the direct current to alternating current needs to be replaced at least once every 10 years (Borenstein 2008). However, there are no fuel costs – once the system is installed, apart from replacing the inverter, there should be no costs associated with running the system until the end of its useful life (20 to 25 years). The major challenge, therefore, is initial outlay, with somewhat more modest periodic component replacement, and payback period for the investment.

Currently, the cost of solar energy is higher than other technologies in most countries. The minimum cost for solar PV in areas with high solar radiation is around US 23 cents per kWh (EIA 2009).

Solar thermal systems have a similar profile to PV, depending on the scale and type of installation. The cost of electricity production from solar energy is expected to decline as new technologies are developed and economies of scale improve in the production processes.

The cost of installing solar capacity has generally been decreasing. Both PV and solar thermal technologies currently have substantial research and development funds directed toward them, and new production processes are expected to result in a continuation of this trend (figure 10.22). In the United

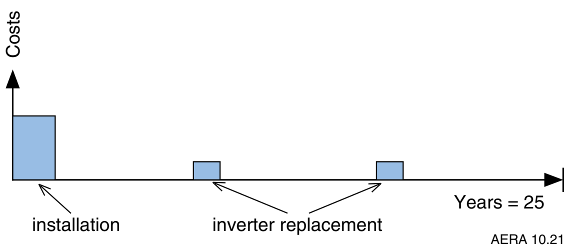

Figure 10.21 Indicative solar PV production profile and costs

Source: ABARE

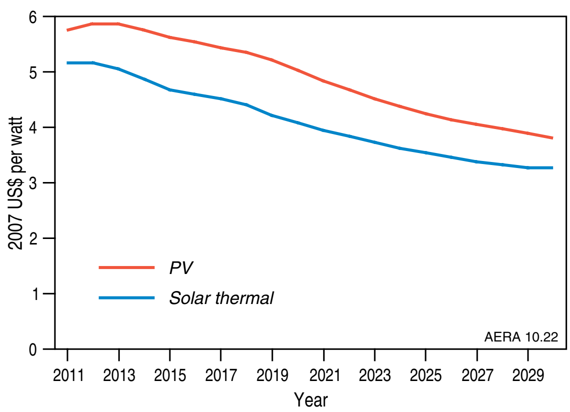

Figure 10.22 Projected average capital costs for new electricity generation plants using solar energy, 2011 to 2030

Source: EIA 2009

States, the capital cost of new PV plants is projected to fall by 37 per cent (in real terms) from 2009 to 2030 (EIA 2009).

The Electric Power Research Institute (EPRI) has developed estimates of the levelised cost of technology[a], including a range of solar technologies, to enable the comparison of technologies at different levels of maturity (Chapter 2, figures 2.18, 2.19). The solar technologies considered are parabolic troughs, central receiver systems, fixed PV systems and tracking PV systems. Central receiver solar systems with storage are forecast to have the lowest costs of technology in 2015. Adding storage to the central receiver systems or to parabolic troughs is estimated to decrease the cost per KWh produced, as it allows the system to produce a higher electricity output. Tracking PV systems are forecast to have the lowest cost of the options that do not incorporate storage. The EPRI technology status data in figures 2.18 and 2.19 show that, although solar technologies remain relatively high cost options throughout the outlook period, significant reductions in cost are anticipated by 2030. The substantial global RD&D (by governments and the private sector) into solar technologies, including the Australian Government's $1.5 billion Solar Flagships Program to support the construction and demonstration of large scale solar power stations in Australia, is expected to play a key role in accelerating the development and deployment of solar energy.

The time taken to install or develop a solar system is highly dependent on the size and scale of the project. Solar hot water systems can be installed in around four hours. Small-scale PV systems can similarly be installed quite rapidly. However, commercial scale developments take considerably longer, depending on the type of installation and other factors, including broader location or environmental considerations.

Location of the resource

In Australia, the best solar resources are commonly distant from the national electricity market (NEM), especially the major urban centres on the eastern seaboard. This poses a challenge for developing new solar power plants, as there needs to be a balance between maximising the solar radiation and minimising the costs of connectivity to the electricity grid. However, there is potential for solar thermal energy application to provide base and intermediate load electricity with fossil-fuel plants (such as gas turbine power stations) in areas with isolated grid systems and good insolation resources. The report by the Wyld Group and MMA (2008) identified Mount Isa, Alice Springs, Tennant Creek and the Pilbara region as areas with these characteristics. Access to Australia's major solar energy resources – as with other remote renewable energy sources – is likely to require investment to extend the electricity grid.

Stand-alone PV systems can be located close to customers (for example on roof areas of residential buildings), which reduces the costs of electricity transmission and distribution. However, concentrating solar thermal technologies require more specific conditions and large areas of land (Lorenz, Pinner and Seitz 2008) which are often only available long distances from the customers needing the energy. In Australia, installing small-scale residential or medium scale commercial systems (both PV and thermal) can be highly attractive options for remote areas where electricity infrastructure is difficult or costly to access, and alternative local sources of electricity are expensive.

Government policies

Government policies have been implemented at several stages of the solar energy production chain in Australia. Rebates provided for solar water heating systems and residential PV installations reduce the cost of these technologies for consumers and encourage their uptake.

The Solar Homes and Communities Plan (2000 to June 2009) provided rebates for the installation of solar PV systems. The capacity of PV systems installed by Australian households increased significantly under this program (figure 10.23). The expanded RET scheme includes the *Solar Credits* initiative, which provides a multiplied credit for electricity generated by small solar PV systems. *Solar Credits* provides an up-front capital subsidy towards the installation of small solar PV systems.

The Australian Government has also announced $1.5 billion of new funding for its Solar Flagships program. This program aims to install up to four new solar power plants, with a combined power output of up to 1000 MW, made up of both PV and solar thermal power plants, with the locations and technologies to be determined by a competitive tender process. The program aims to demonstrate new solar technologies at a commercial scale, thereby accelerating uptake of solar energy in general and providing the opportunity for Australia to develop leadership in solar energy technology (RET 2009b).

The Australian Government has also allocated funding to establish the Australian Solar Institute (ASI), which will be based in Newcastle. It will have strong collaborative links with CSIRO and Universities undertaking R&D in solar technologies. The institute will aim to drive development of solar thermal and PV technologies in Australia, including the areas of efficiency and cost effectiveness (RET 2009a).

Other government policies, including feed-in tariffs, which are proposed or already in place in most Australian states and territories, may also encourage the uptake of solar energy.

a This EPRI technology status data enables the comparison of technologies at different levels of maturity. It should not be used to forecast market and investment outcomes.

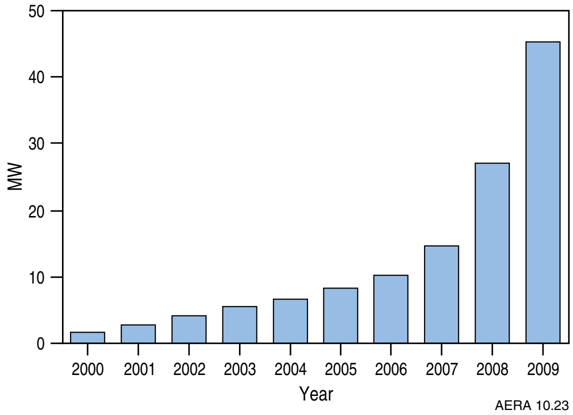

Figure 10.23 Residential PV capacity installed under the Solar Homes and Communities Plan (as of October 2009)
Source: DEWHA 2009

Infrastructure issues

The location of large scale solar power plants in Australia will be influenced by the cost of connection to the electricity grid. In the short term, developments are likely to focus on isolated grid systems or nodes to the existing electricity grid, since this minimises infrastructure costs.

In the longer term, the extension of the grid to access remote solar energy resources in desert regions may require building long distance transmission lines. The technology needed to achieve this exists: high voltage direct current (HVDC) transmission lines are able to transfer electricity over thousands of kilometres, with minimal losses. Some HVDC lines are already in use in Australia, and are being used to form interstate grid connections; the longest example being the HVDC link between Tasmania and Victoria. However, building a HVDC link to a solar power station in desert areas would require a large up-front investment.

The idea of generating large scale solar energy in remote desert regions has been proposed on a much larger scale internationally. In June 2009 the DESERTEC Foundation outlined a proposal to build large scale solar farms in the sun-rich regions of the Middle East and Northern Africa, and export their power to Europe using long distance HVDC lines. More recently, an Asia Pacific Sunbelt Development Project has been established with the aim of moving solar energy by way of fuel rather than electricity from regions such as Australia to those Asian countries who import energy, such as Japan and Korea. These projects illustrate the growing international interest in utilising large scale solar power from remote and inhospitable areas, despite the infrastructure challenges in transmitting or transporting energy over long distances.

Environmental issues

A roof-mounted, grid-connected solar system in Australia is estimated to yield more than seven times the energy required to produce it over a 20 year system lifespan (MacKay 2009). In areas with less solar radiation, such as Central-Northern Europe, the energy yield ratio is estimated to be around four. This positive energy yield ratio also means that greenhouse gas emissions generated from the production of solar energy systems are more than offset over the systems' life cycle, as there are no greenhouse gas emissions generated from their operation.

Most solar thermal electricity generation systems require water for steam production and this water use affects the efficiency of the system. The majority of this water is consumed in 'wet cooling' towers, which use evaporative cooling to condense the steam after it has passed through the turbine. In addition, solar thermal systems require water to wash the mirrors, to maintain their reflectivity (Jones 2008). It is possible to use 'dry cooling' towers, which eliminate most of the water consumption, but this reduces the efficiency of the steam cycle by approximately 10 per cent (Stein 2009b).

A further option under development is the use of high temperature Brayton cycles, which do not use steam turbines and thus do not consume water. Brayton cycles are more efficient than conventional Rankine (steam) cycles, but they can only be achieved by point-focussing solar thermal technologies (power towers and dishes).

10.4.2 Outlook for solar energy market

Although solar energy is more abundant in Australia than other renewable energy sources, plans for expanding solar energy in Australia generally rely on subsidies to be economically viable. There are currently only a small number of proposed commercial solar energy projects, mostly of small scale. Solar energy is currently more expensive to produce than other forms of renewable energy, such as hydro, wind and biomass (Wyld Group and MMA 2008). In the short term, therefore, solar energy will find it difficult to compete commercially with other forms of clean energy for electricity generation in the NEM. However, as global deployment of solar energy technologies increases, the cost of the technologies is likely to decrease. Moreover, technological developments and greenhouse gas emission reduction policies are expected to drive increased use of solar energy in the medium and long term.

Key projections to 2029–30

ABARE's latest (2010) Australian energy projections include the RET, a 5 per cent emissions reduction target, and other government policies. Solar energy use in Australia is projected to more than triple, from 7 PJ in 2007–08 to 24 PJ in 2029–30, growing at an average rate of 5.9 per cent a year (figure 10.27, table 10.4). While solar water heating is projected to remain the predominant use for solar energy, the share of PV in total solar energy use is projected to increase.

BOX 10.1 SOLAR ENERGY TECHNOLOGIES FOR ELECTRICITY GENERATION

Sunlight has been used for heating by generating fire for hundreds of years, but commercial technologies specifically to use solar energy to directly heat water or generate power were not developed until the 1800s. Solar water heaters developed and installed between 1910 and 1920 were the first commercial application of solar energy. The first PV cells capable of converting enough energy into power to run electrical equipment were not developed until the 1950s and the first solar power stations (thermal and PV) with capacity of at least 1 megawatt started operating in the 1980s.

Solar thermal electricity

Solar thermal electricity is produced by converting sunlight into heat, and then using the heat to drive a generator. The sunlight is concentrated using mirrors, and focussed onto a solar receiver. This receiver contains a working fluid that absorbs the concentrated sunlight, and can be heated up to very high temperatures. Heat is transferred from the working fluid to a steam turbine, similar to those used in fossil fuel and nuclear power stations. Alternatively, the heat can be stored for later use (see below).

There are four main types of concentrating solar receivers, shown in figure 10.24. Two of these types are line-focussing (parabolic trough and Linear Fresnel reflector); the other two are point-focussing (paraboloidal dish and power tower). Each of these types is designed to concentrate a large area of sunlight onto a small receiver, which enables fluid to be heated to high temperatures. There are trade-offs between efficiency, land coverage, and costs of each type.

The most widely used solar concentrator is the parabolic trough. Parabolic troughs focus light in one axis only, which means that they need only a single axis tracking mechanism to follow the direction of the sun. The linear Fresnel reflector achieves a similar line-focus, but instead uses an array of almost flat mirrors. Linear Fresnel reflectors achieve a weaker focus (therefore lower temperatures and efficiencies) than parabolic troughs. However, linear Fresnel reflectors have cost-saving features that compensate for lower energy efficiencies, including a greater yield per unit land, and simpler construction requirements.

The paraboloidal dish is an alternate design which focuses sunlight onto a single point. This design is able to produce a much higher temperature at the

Figure 10.24 The four types of solar thermal concentrators: **(a)** parabolic trough, **(b)** compact linear Fresnel reflector, **(c)** paraboloidal dish, and **(d)** power tower

Source: Wikimedia Commons, photograph by kjkolb; Wikimedia Commons, original uploader was Lkruijsw at en.wikipedia; Australian National University 2009a; CSIRO receiver, which increases the efficiency of energy conversion. The paraboloidal dish has the greatest potential to be used in modular form, which may give this design an advantage in off-grid and remote applications. However, to focus the sunlight onto a single point, paraboloidal dishes need to track the direction of sunlight on two axes. This requires a more complex tracking mechanism, and is more expensive to build. The other point focusing design is the 'power tower', which uses a series of ground-based mirrors to focus onto an elevated central receiver. Power tower mirrors also require two-axis tracking mechanisms; however the use of smaller, flat mirrors can reduce costs.

The parabolic trough has the most widespread commercial use. An array of nine parabolic trough plants producing a combined 354 MW have operated in California since the 1980s. Several new ones have been built in Spain and Nevada in the last few years at around a 50–60 MW scale, and there are many parabolic trough plants either in the construction or planning phase. While parabolic troughs have the majority of the current market share, all four designs are gaining renewed commercial interest. There is an 11 MW solar power tower plant operating in Spain, and a similar 20 MW plant has recently begun operating at the same location. The linear Fresnel reflector has been demonstrated on a small scale (5 MW), and a 177 MW plant is planned for construction in California. The paraboloidal dish has also been demonstrated on a small scale, and there are plans for large scale dish plants.

Methods of power conversion and thermal storage vary from type to type. While solar thermal plants are generally suited to large scale plants (greater than 50 MW), the paraboloidal dish has the potential to be used in modular form. This may give dish systems an advantage in remote and off-grid applications.

Efficiency of solar thermal

The conversion efficiency of solar thermal power plants depends on the type of concentrator used, and the amount of sunlight. In general, the point-focusing concentrators (paraboloidal dish and power tower) can achieve higher efficiencies than line focussing technologies (parabolic trough and Fresnel reflector). This is possible because the point-focussing technologies achieve higher temperatures for higher thermodynamic limits.

The highest value of solar-to-electric efficiency ever recorded for a solar thermal system was 31.25 per cent, using a solar dish in peak sunlight conditions (Sandia 2009). Parabolic troughs can achieve a peak solar-to-electric efficiency of over 20 per cent (SEGS 2009). However, the conversion efficiency drops significantly when the radiation drops in intensity, so the annual average efficiencies are significantly lower. According to Begay-Campbell (2008), the annual solar-to-electric efficiency is approximately 12–14 per cent for parabolic troughs, 12 per cent for power towers (although emerging technologies can achieve 18–20 per cent), and 22–25 per cent for paraboloidal dishes. Linear Fresnel reflectors achieve a similar efficiency to parabolic troughs, with an annual solar-to-electric efficiency of approximately 12 per cent (Mills et al. 2002).

Energy storage

Solar thermal electricity systems have the potential to store energy over several hours. The working fluid used in the system can be used to temporarily store heat, and can be converted into electricity after the sun has stopped shining. This means that solar thermal plants have the potential to dispatch power at peak demand times. It should be noted, however, that periods of sustained cloudy weather cut the productive capacity of solar thermal power. The seasonality of sunshine also reduces power output in winter.

Thermal storage is one of the key advantages of solar thermal power, and creates the potential for intermediate or base-load power generation. Although thermal storage technology is relatively new, several recently constructed solar thermal power plants have included thermal storage of approximately 7 hours' power generation. In addition, there are new power tower designs that incorporate up to 16 hours of thermal storage, allowing 24 hour power generation in appropriate conditions. The development of cost effective storage technologies may enable a much higher uptake of solar thermal power in the future (Wyld Group and MMA 2008).

Current research is developing alternative energy storage methods, including chemical storage, and phase-change materials. Chemical storage options include dissociated ammonia and solar-enhanced natural gas. These new storage methods have the potential to provide seasonal storage of solar energy, or to convert solar energy into portable fuels. In future, it may be possible for solar fuels to be used in the transport sector, or even for exporting solar energy.

Hybrid operation with fossil fuel plants

Solar thermal power plants can make use of existing turbine technologies that have been developed and refined over many decades in fossil fuel technologies. Using this mature technology can reduce manufacturing costs and increase the efficiency of power generation. In addition, solar thermal heat collectors can be used in hybrid operation with fossil fuel burners. A number of existing solar thermal power plants use gas burners to boost power supply during low levels of sunlight.

Combining solar thermal power with gas can provide a hedge against the intermittency of sunlight.

Solar thermal heat collectors can be attached to existing coal or gas power stations to pre-heat the water used in these plants. This is possible since solar thermal heat collectors perform a very similar function to fossil fuel burners. In this way, solar thermal power can make use of existing infrastructure. This option is not affected by intermittency of sunlight, since the fossil fuel burners provide firm capacity of production. Internationally, there are several new integrated solar combined cycle (ISCC) plants planned for construction. ISCC plants are similar to combined cycle gas plants (using both a gas turbine, and a steam turbine), but use solar thermal heat collectors to boost the steam turbine production.

Solar updraft towers

An alternative solar thermal power technology is the solar updraft tower, also known as a solar chimney. The updraft tower captures solar energy using a large greenhouse, which heats air beneath a transparent roof. A very tall chimney is placed at the centre of the greenhouse, and the heated air creates pressure differences that drive air flow up the chimney. Electricity is generated from the air flow using wind turbines at the base of the chimney.

Solar updraft towers have been tested at a relatively small scale, with a 50 kW plant in Spain being the only working prototype at present. There are plans to upscale this technology, including a proposed 200 MW plant in Buronga, NSW. The main disadvantage of solar updraft towers is that they deliver significantly less power per unit area than concentrating solar thermal and PV systems (Enviromission 2009).

Photovoltaic systems

The costs of producing PV cells has declined rapidly in recent years as uptake has increased (Fthenakis et al. 2009) and a number of PV technologies have been developed. The cost of modules can be reduced in four main ways:

- making thinner layers – reducing material and processing costs;
- integrating PV panels with building elements such as glass and roofs – reducing overall system costs;
- making adhesive on site – reducing materials costs; and
- improving decisions about making or buying inputs, increasing economies of scale, and improving the design of PV modules.

There are three main types of PV technology: crystalline silicon, thin-film and concentrating PV. Crystalline silicon is the oldest and most widespread technology. These cells are becoming more efficient over time, and costs have fallen steadily.

Thin-film PV is an emerging group of technologies, targeted at reducing costs of PV cells. Thin-film PV is at an earlier stage of development, and currently delivers a lower efficiency than crystalline silicon, estimated at around 10 per cent, although many of the newer varieties still deliver efficiencies of less than this (Prowse 2009). However, this is compensated by lower costs, and there are strong prospects for efficiency improvements in the future. Thin-film PV can be installed on many different substrates, giving it great flexibility in its applications.

Concentrating PV systems use either mirrors or lenses to focus a large area of sunlight onto a central receiver (figure 10.25). This increases the intensity of the light, and allows a greater percentage of its energy to be converted into electricity. These systems are designed primarily for large scale centralised

Figure 10.25 (a) Example of a rooftop PV system. **(b)** A schematic concentrating PV system, where a large number of mirrors focus sunlight onto central PV receivers

Source: CERP, Wikimedia Commons; Energy Innovations Inc. under Wikipedia licence cc-by-sa-2.5

power, due to the complexities of the receivers. Concentrating PV is the most efficient form of PV, delivering a typical system efficiency of around 20 per cent, and has achieved efficiencies of just over 40 per cent in ideal laboratory conditions (NREL 2008).

An advantage of using concentrating PV is that it reduces the area of solar cells needed to capture the sunlight. PV cells are often expensive to produce, and the mirrors or lenses used to concentrate the light are generally cheaper than the cells. However, the use of solar concentrators generally requires a larger system that cannot be scaled down as easily as flat-plate PV cells.

A relatively recent area of growth for PV applications is in Building-integrated PV (BIPV) systems. BIPV systems incorporate PV technology into many different components of a new building. These components include rooftops, walls and windows, where PV cells can either replace, or be integrated with existing materials. BIPV has the potential to reduce costs of PV systems, and to increase the surface area available for capturing solar energy within a building (NREL 2009b).

Efficiency of photovoltaic systems

Currently, the maximum efficiency of commercially available PV modules is around 20 to 25 per cent, with efficiencies of around 40 per cent achieved in laboratories. Most commercially available PV systems have an average conversion efficiency of around 10 per cent. New developments (such as multi-junction tandem cells) suggest solar cells with conversion efficiencies of greater than 40 per cent could become commercially available in the future. Fthenakis et al. (2009) posit that increases in efficiency of PV modules will come from further technology improvements.

BOX 10.2 SOLAR ENERGY TECHNOLOGIES FOR DIRECT-USE APPLICATIONS

Solar thermal heating

Solar thermal heating uses direct heat from sunlight, without the need to convert the energy into electricity. The simplest form of solar thermal heating is achieved simply by pumping water through a system of light-absorbing tubes, usually mounted on a rooftop. The tubes absorb sunlight, and heat the water flowing within them. The most common use for solar thermal heating is hot water systems, but they are also used for swimming pool heating or space heating.

There are two main types of solar water heaters: flat-plate and evacuated tube systems (figure 10.26). Flat-plate systems are the most widespread and mature technology. They use an array of very small tubes, covered by a transparent glazing for insulation. Evacuated tubes consist of a sunlight absorbing metal tube, inside two concentric transparent glass tubes. The space between the two glass tubes is evacuated to prevent losses due to convection. Evacuated tubes have lower heat losses than flat plate collectors, giving them an advantage in winter conditions. However, flat-plate systems are generally cheaper, due to their relative commercial maturity.

Solar thermal heating is a mature technology and relatively inexpensive compared to other solar technologies. This cost advantage has meant that solar thermal heating has the largest energy production of any solar technology. In some countries with favourable sunlight conditions, solar water heaters have gained a substantial market share of water heaters. For example, the proportion of households with solar water heaters in the Northern Territory was 54 per cent in 2008 (CEC 2009) whereas in Israel this proportion is approximately 90 per cent (CSIRO 2010).

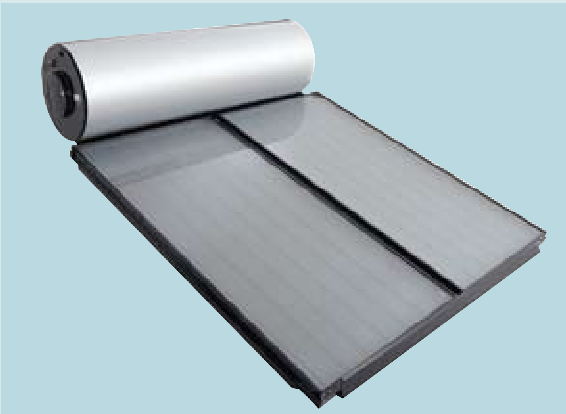
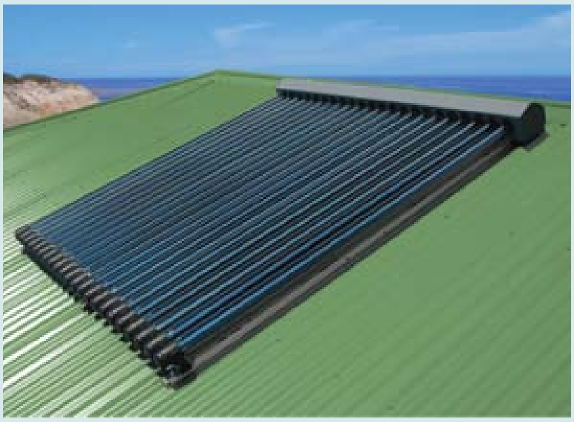

Figure 10.26 (a) Flat-plate solar water heater. **(b)** Evacuated tube solar water heater

Source: Western Australian Sustainable Energy Development Office 2009; Hills Solar (Solar Solutions for Life) 2009

Solar air conditioning

Solar thermal energy can also be used to drive air-conditioning systems. Sorption cooling uses a heat source to drive a refrigeration cycle, and can be integrated with solar thermal heat collectors to provide solar air-conditioning. Since sunlight is generally strong when air-conditioning is most needed, solar air-conditioning can be used to balance peak summer electricity loads. However, a number of developments are required before solar air-conditioning becomes cost competitive in Australia (CSIRO 2010).

Passive solar heating

Solar energy can also be used to heat buildings directly, through designing buildings that capture sunlight and store heat that can be used at night. This process is called passive solar heating, and can save energy (electricity and gas) that would otherwise be needed to heat buildings during cold weather. New buildings can be constructed with passive solar heating features at minimal extra cost, providing a reliable source of heating that can greatly reduce energy demands in winter (AZSC 2009).

Passive solar heating usually requires two basic elements: a north-facing (in the Southern Hemisphere) window of transparent material that allows sunlight to enter the building; and a thermal storage material that absorbs and stores heat. Passive solar heating must also be integrated with insulation to provide efficient storage of heat, and roof designs that can maximise exposure in winter, and minimise exposure in summer. Although some of these features can be retrofitted to existing buildings, the best prospects for passive solar heating are in the design of new buildings.

Combined heat and power systems

A technology under development in Australia and overseas is the combined heat and power system, combining solar thermal heating with PV technology (ANU 2009). Typically this consists of a small-scale concentrating parabolic trough system with a central PV receiver, where the receiver is coupled to a cooling fluid. While the PV produces electricity, heat is extracted from the cooling fluid and can be used in the same way as a conventional solar thermal heater. These systems can achieve a greater efficiency of energy conversion, by using the same sunlight for two purposes. These systems are being targeted for small-scale rooftop applications.

Electricity generation from solar energy is projected to increase strongly, from only 0.1 TWh in 2007–08 to 4 TWh in 2029–30, representing an average annual growth rate of 17.4 per cent (figure 10.28). The share of solar energy in electricity generation is also projected to increase, from 0.04 per cent in 2007–08 to 1 per cent in 2029–30.

While high investment costs currently represent a barrier to more widespread use of solar energy, there is considerable scope for the cost of solar technologies to decline significantly over time. The competitiveness of solar energy will also depend on government policies. The RET, the results of RD&D programs and the proposed emissions reduction target are all expected to underpin the growth of solar energy over the outlook period.

Proposed development projects

As at October 2009, there were no solar projects nearing completion in Australia (table 10.5). There are currently five proposed solar projects, with a combined capacity of 116 MW. The largest of these projects is Wizard Power's $355 million Whyalla Solar Oasis, which will be located in South Australia. The project is expected to have a capacity of 80 MW and is scheduled to be completed by 2012.

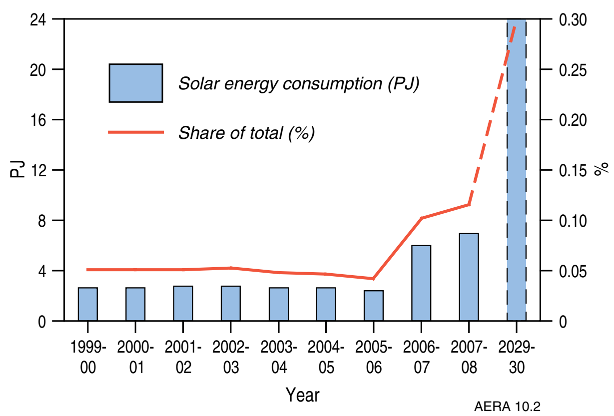

Figure 10.27 Projected primary energy consumption of solar energy

Source: ABARE 2009a, 2010

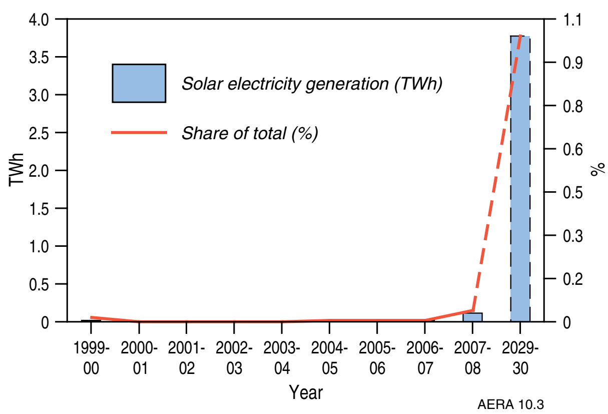

Figure 10.28 Projected electricity generation from solar energy

Source: ABARE 2009a, 2010

Table 10.4 Outlook for Australia's solar market to 2029–30

	unit	2007–08	2029–30
Primary energy consumption	PJ	7	24
Share of total	%	0.1	0.3
Average annual growth, 2007–08 to 20029–30	%		5.9
Electricity generation			
Electricity output	TWh	0.1	4
Share of total	%	0.04	1.0
Average annual growth, 2007–08 to 2029–30	%		17.4

a Energy production and primary energy consumption are identical
Source: ABARE 2009a, 2010

Table 10.5 Proposed solar energy projects

Project	Company	Location	Status	Start up	Capacity	Capital expenditure
SolarGas One	CSIRO and Qld Government	Qld	Government grant received	2012	1MW	na
Lake Cargelligo solar thermal project	Lloyd Energy Systems	Lake Cargelligo, NSW	Government grant received	na	3MW	na
Cloncurry solar thermal power station	Lloyd Energy Systems	Cloncurry, Qld	Government grant received	2010	10MW	$31m
ACT solar power plant	ACT Government	To be determined, ACT	Pre-feasibility study completed	2012	22MW	$141m
Whyalla Solar Oasis	Wizard Power	Whyalla, SA	Feasibility study under way	2012	80MW	$355 m

Source: ABARE 2009c; Lloyd Energy Systems 2007

10.5 References

ABARE (Australian Bureau of Agricultural and Resource Economics), 2010, Australian energy projections to 2029–30, ABARE research report 10.02, prepared for the Department of Resources, Energy and Tourism, Canberra

ABARE, 2009a, Australian Energy Statistics, Canberra, August

ABARE, 2009b, Electricity generation: Major development projects – October 2009 listing, Canberra, November

AER (Australian Energy Regulator), 2008, State of the Energy Market 2008, <http://www.aer.gov.au/content/index.phtml/itemId/723386>

Ausra, 2009, The Liddell Solar Thermal Power Station, <http://www.ausra.com/pdfs/LiddellOverview.pdf>

ANU (Australian National University), 2009a, Solar Thermal Energy Research, <http://solar-thermal.anu.edu.au/pages/DownloadPics.php>

ANU, 2009b, Combined Heat and Power Solar (CHAPS) Concentrator System, <http://solar.anu.edu.au/projects/chaps_proj.php>

AZSC (Arizona Solar Center), 2009, Passive Solar Heating and Cooling, <http://www.azsolarcenter.com/technology/pas-2.html>

Begay-Campbell S, 2008, Concentrating Solar Technologies and Applications: Sandia National Laboratories, <http://apps1.eere.energy.gov/tribalenergy/pdfs/course_tcd0801_ca17ax.pdf>

BIS Shrapnel, 2008, Hot water systems installed in new dwellings in Australia, North Sydney, <http://www.bis.com.au/reports/hot_water_systems_nd_in_aust.html>

Borenstein S, 2008, The Market Value and Cost of Solar Photovoltaic Electricity Production, Centre for the Study of Energy Markets, University of California

Bureau of Meteorology, 2009, Average Daily Solar Exposure, <http://www.bom.gov.au/climate/averages/climatology/solar_radiation/IDCJCM0019_solar_exposure.shtml>

CEC (Clean Energy Council), 2009, Solar Industry Snapshot, <http://www.bcse.or.au/cec/resourcecentre/reports/mainColumnParagraphs/00/text_files/file15/CEC%20Solar%20Sheet_revised_2.pdf>

Climate Action Newcastle, 2009, Newcastle's Going Solar, <http://www.climateaction.org.au/files/images/solar%20panel%20photo_0.jpg>

CSIRO, 2010, Energy technology in Australia: overview and prospects for the future, A report for the Department of Resources, Energy and Tourism, Canberra (forthcoming)

DESERTEC, 2009, Clean Power From Deserts. Whitebook 4th Edition, <http://www.desertec.org/en/concept/whitebook/>

Desertec-UK, 2009, Concentrating Solar Thermal Power, <http://www.trec-uk.org.uk/images/schott_parabolic_trough.jpg>

DEWHA (Department of Environment, Water, Heritage and the Arts), 2009, Solar homes and communities plan website, <http://www.environment.gov.au/settlements/renewable/pv/index.html>

EIA (Energy Information Administration of the United States), 2009, International Energy Outlook 2009, Washington DC

Enviromission, 2009, Technology Overview, <http://www.enviromission.com.au/EVM/content/technology_technologyover.html>

EPIA (European Photovoltaic Industry Association), 2009, Global Market Outlook for Photovoltaics Until 2013, <http://www.epia.org/publications/epia-publications.html>

Fthenakis V, Mason JE and Zweibel K, 2009, The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US, Energy Policy, vol 37, no 2, 387–399

Geoscience Australia, 2009, Renewable Energy Power Stations, <http://www.ga.gov.au/renewable/operating/operating_renewable.xls>

Greenpeace, 2009, Concentrating Solar Power, Global Outlook 09, <http://www.greenpeace.org/international/press/reports/concentrating-solar-power-2009>

IEA (International Energy Agency), 2003, Greenhouse Gas Research and Development Programme – The potential of solar electricity to reduce CO_2 emissions, Paris

IEA, 2009a, World Energy Outlook 2009, Paris

IEA, 2009b, World Energy Balances, 2009, Paris

IEA-PVPS, 2008, Trends in Photovoltaic Applications: Survey report of selected IEA countries between 1992 and 2007, IEA Photovoltaic Power Systems Programme

Jiaxing Dyi Solar Energy Co, 2009, Solar Water Heater-1, <http://jxdiyi.en.made-in-china.com/product/sqdnACbhfQDM/China-Flat-Solar-Water-Heater-1.html>

Jones J, 2008, Concentrating Solar Thermal Power, Renewable Energy World Magazine

Lloyd Energy Systems, 2007, Cloncurry Solar Thermal Storage Project, <http://www.lloydenergy.com/presentations/Cloncurry%20Solar%20Thermal%20Storage%20Project.pdf>

Lorenz P, Pinner D and Seitz T, 2008, The Economics of Solar Power. The McKinsey Quarterly, June 2008

Lovegrove K and Dennis M, 2006, Solar thermal energy systems in Australia. International Journal of Environmental Studies. 63 (6): 791–802

MacKay DJC, 2009, Sustainable Energy – Without the Hot Air. UIT, Cambridge, <http://www.withouthotair.com/>

McKinsey & Company, 2008, The Economics of Solar Power, in McKinsey Quarterly, June 2008, <http://www.mckinseyquarterly.com>

Mills D, Morrison G and Le Lievre P, 2002, Project Proposal for a Compact Linear Fresnel Reflector Solar Thermal Plant in the Hunter Valley, <http://solar1.mech.unsw.edu.au/glm/papers/Mills_projectproposal_newcastle.pdf>

National Aeronautics and Space Administration (NASA), 2009, Surface Meteorology and Solar Energy Dataset, <http://eosweb.larc.nasa.gov/sse>

NREL, 2009a, Photographic Information Exchange, <http://www.nrel.gov/data/pix/searchpix.html>

NREL, 2009b, Photovoltaic Research – Building-Integrated PV, <http://www.nrel.gov/pv/building_integrated_pv.html>

Prowse R, 2009, Personal communication, 5/6/2009. Centre Manager, Centre for Sustainable Energy Systems, Australian National University

RET (Department of Resources, Energy and Tourism), 2009a, Australian Solar Institute Fact Sheet, <http://www.ret.gov.au/energy/Documents/ASI%20Fact%20sheet%2014Jan%20cleared%20by%20MO.pdf>

RET, 2009b, Solar Flagships Program Fact Sheet, <http://www.ret.gov.au/energy/Documents/Solar%20Flagships%20factsheet%20-%20Oct%202009.pdf>

Sandia, 2009, Lab Accomplishments 2009: Sandia National Laboratories, <http://www.sandia.gov/LabNews/labs-accomplish/2009/lab_accomplish-2009.pdf>

SEGS, 2009, Solar Electricity Generating Systems website, <http://www.flagsol.com/SEGS_tech.htm>

Sellsius, 2006, The World's Most Efficient Solar Energy, <http://blog.sellsiusrealestate.com/technology/the-worlds-most-efficient-solar-energy/2006/08/06/>

Solar Systems, 2009, 154 MW Victorian Project, <http://www.solarsystems.com.au/154MWVictorianProject.html>

Solar Tube Company, 2009, Solar Water Heating System, <http://www.solartubecompany.co.uk/solar-water-heating/>

Stein W, 2009a, personal communication, 4/8/2009. Manager, National Solar Energy Centre, CSIRO Division of Energy Technology

Stein W, 2009b, personal communication, 3/11/2009. Manager, National Solar Energy Centre, CSIRO Division of Energy Technology

Sunwize Technologies, 2008, SunWize World Insolation Map, <http://www.sunwize.com/info_center/solar-insolation-map.php>

Watt M, 2009, National Survey Report of PV Power Applications in Australia 2008: Australian PV Association

WEC (World Energy Council), 2007, Survey of Energy Resources 2007, London, September 2007, <http://www.worldenergy.org/pugblications/survey_of_energy_resources_2007/default.asp>

WEC, 2009, Survey of energy resources: Interim update 2009. London, July 2009, <http://www.worldenergy.org/publications/survey_of_energy_resources_interim_update_2009/default.asp>

Wyld Group and MMA, 2008, High Temperature Solar Thermal Technology Roadmap. Prepared for the NSW and Victorian Governments by Wyld Group and McLennan Magasanik Associates, <http://www.coag.gov.au/reports/docs/HTSolar_thermal_roadmap.pdf>