Chapter 7

Geothermal Energy

7.1 Summary

KEY MESSAGES

- Geothermal energy is a major resource and potential source of low emissions renewable energy suitable for base-load electricity generation and direct-use applications.
- Australia has significant potential geothermal resources associated with buried high heat-producing granites and lower temperature geothermal resources associated with naturally-circulating waters in aquifers deep in sedimentary basins.
- Most current geothermal projects in Australia are still at proof-of-concept or early commercial demonstration stage.
- Demonstration of the commercial viability of geothermal energy in Australia will assist in attracting the capital investment required for geothermal energy development. The development of some remote geothermal resources will require additional transmission infrastructure.
- Geothermal energy is projected to produce around 6 TWh in 2029–30. Electricity supply is likely to be from demonstration plants initially but commercial-scale geothermal energy production is expected by 2030.

7.1.1 World geothermal resources and market

- Electricity has been produced commercially from geothermal resources for over 100 years. Conventional geothermal resources are based on hydrothermal systems associated with active volcanism, which Australia lacks.
- Significant geothermal resources can also be associated with basement rocks heated by natural radioactive decay of elements (such as uranium, thorium and potassium) and in naturally-circulating waters deep in sedimentary basins.
- Geothermal energy is used in many countries for electricity generation and heat production (91 per cent) and in direct-use applications (9 per cent), but accounted for only 0.4 per cent of total primary energy consumption in 2007.
- Geothermal energy has the potential to sustainably provide large amounts of low-emission base-load electricity generation, and can also be used to power industrial processes via direct-use applications (including desalination distillation, district heating and cooling), and for ground source heat pumps.
- Government policies, energy prices and falling investment costs and risks are projected to be the main factors underpinning future growth in world geothermal energy use.
- World electricity generation from geothermal energy is projected by the IEA in its reference case to increase at an average annual rate of 4.6 per cent between 2007 and 2030 to reach 173 TWh or around 0.5 per cent of total electricity generation. Most of this increase is projected to come from projects in the United States and non-OECD Asia.

7.1.2 Australia's geothermal resources

- Australia has considerable Hot Rock geothermal energy potential. This results from the widespread occurrence of basement rocks (granites in particular) in which heat is generated by natural radioactive decay. Where high heat-producing rocks occur beneath thick blankets of thermally insulating strata, the thermal energy is retained in the basement rocks and overlying strata causing elevated temperatures at relatively shallow depths. There are extensive areas where temperatures are estimated to reach at least 200°C at around 5 km depth (figure 7.1).
- There is also potential for lower temperature geothermal resources associated with naturally-circulating waters in aquifers deep in a number of sedimentary basins (Hot Sedimentary Aquifer geothermal). These are potentially suitable for electricity generation and direct use.

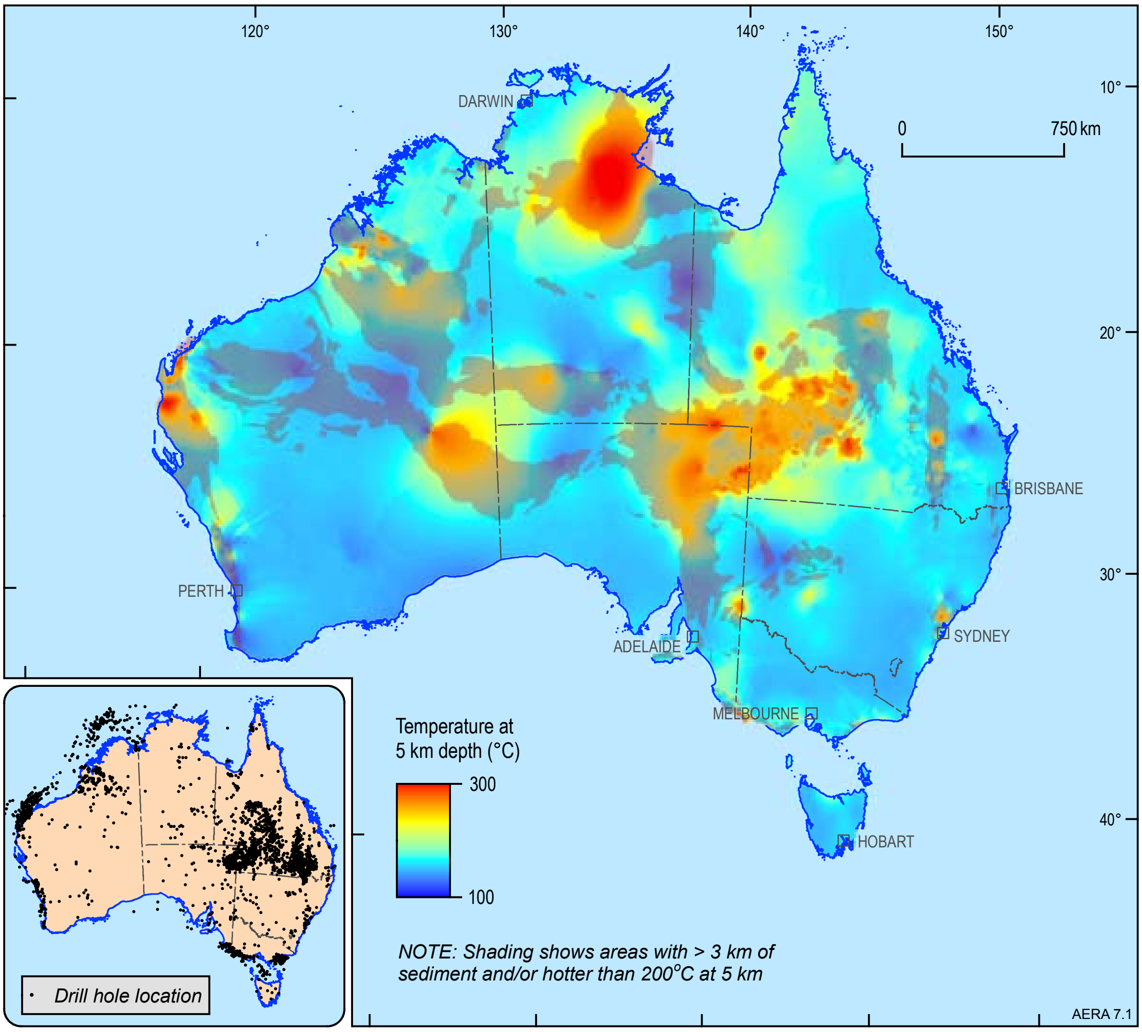

Figure 7.1 Predicted temperature at 5 km depth based mostly on bottom-hole temperature measurements in more than 5000 petroleum and water boreholes

Source: Data from Earth Energy Pty Ltd; AUSTHERM database; Geoscience Australia

- A geothermal power plant has been periodically in operation at Birdsville, Queensland, since 1992. It uses a bore that produces water from the Great Artesian Basin at 98°C at surface to generate approximately 80 kW net, supplying about 30 per cent of the total plant output with the remainder being fuelled by diesel and LPG.
- Australia's overall geothermal potential has only recently been appreciated. Consequently, there are significant gaps in the information required to adequately assess potential. It is likely that additional new data will lead to increases in the geothermal resource base.
- As of July 2009 eight companies have declared identified geothermal resources totalling 2.6 million PJ of heat in place.

7.1.3 Key factors in utilising Australia's geothermal resources

- Government policies relating to geothermal energy research, development and demonstration (RD&D) are critical to the outlook for electricity generation from geothermal energy. The Australian Government's Renewable Energy Demonstration Program and Geothermal Drilling Program are key contributors.
- The demonstration of the economic viability of the extraction and use of geothermal energy both for electricity generation and direct use is critical to attract the capital investment required.
- Improved information on geothermal energy potential in many parts of Australia – especially new geoscientific data designed to locate regions with temperature anomalies at relatively shallow depths (1-4 km) – would aid definition of geothermal resources and reduce exploration costs.
- There is significant potential for energy savings through greater use of ground source heat pumps in heating and cooling buildings in many regions of Australia.

7.1.4 Australia's geothermal energy market

- There are uncertainties in the outlook for geothermal power over the next two decades. A major uncertainty is the cost of electricity production as the technology has yet to be proven commercially viable. Present estimates show a wide range in the cost of geothermal electricity generation, reflecting the current pre-commercial stage of the industry, as the cost of electricity generation is highly dependent on future technology developments and grid connection issues.
- The geothermal industry in Australia is progressing, with proof-of-concept having been attained in one project and expected to be achieved in at least two others within one to two years. Several pilot projects are expected to be completed within five years.
- Progress is being assisted by government grants to developing geothermal projects. Two geothermal projects were awarded grants in November 2009 totalling $153 million under the Australian Government's Renewable Energy Demonstration Program; the Australian Government Geothermal Drilling Program has announced $49 million in grants to support seven proof-of-concept projects; and the Victorian Government has announced $25 million to support a demonstration project.
- 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, geothermal electricity generation in Australia is projected to increase by 18.4 per cent per year, to reach around 6 TWh in 2029–30 and account for around 1.5 per cent of total electricity generation.

7.2 Background information and world market

7.2.1 Definitions

Geothermal energy is heat (thermal) derived from the Earth (geo). Geothermal energy is an abundant, clean (effectively no greenhouse gas emissions) and reliable (renewable or sustainable) natural resource. There is a steady flow of heat from the centre of the Earth (where temperatures are above 5000°C) through the surface of the Earth (-30 to +40°C) into space (-273°C): heat flows from hot to cold. The heat is generated by the natural decay over millions of years of radiogenic elements including uranium, thorium and potassium.

Geothermal resources that have been utilised, or are prospective for development, range from shallow ground to hot water and rock several kilometres below the Earth's surface (Energy and Geoscience Institute 2001).

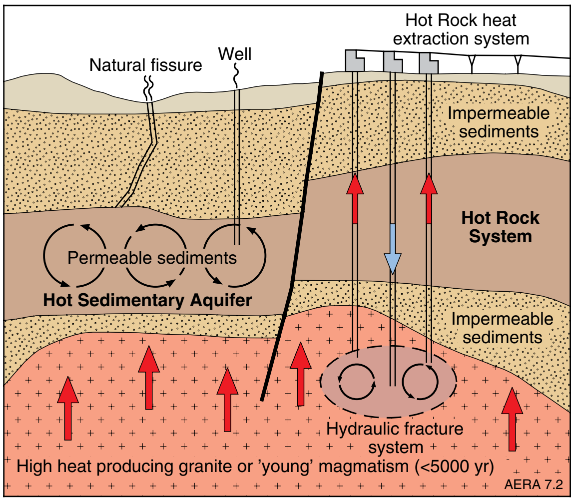

Figure 7.2 Hot Rock and Hot Sedimentary Aquifer systems

Source: Ayling et al. 2007a

It is useful to distinguish between hydrothermal and other geothermal resources:

- **Hydrothermal resources** use naturally occurring hot water or steam circulating through permeable rock – these conventional geothermal systems are usually based on hydrothermal aquifers commonly associated with active or young volcanic systems. Hydrothermal resources have been used in a range of applications (discussed further later). Australia lacks hydrothermal resources as it has no active volcanism on the mainland.
- **Hot Rock** and **Hot Sedimentary Aquifer** geothermal resources are of particular interest to Australia (figure 7.2). Research over the past 30 years has demonstrated that non-volcanic areas may have potential for Hot Rock resources (also known as enhanced geothermal systems); that produce super-heated water or steam by artificially circulating fluid through the rock. Hot Sedimentary Aquifers are found in areas where high temperatures are reached at depths shallow enough for natural porosity and permeability in sedimentary rocks to be preserved so that fluid circulation can occur without artificial enhancement. It is now evident that Australia has good Hot Rock geothermal energy potential, as well as a significant potential for Hot Sedimentary Aquifer resources. Geothermal systems that are similar to Australia's Hot Sedimentary Aquifer systems have been used elsewhere in the world for electricity generation and direct-use applications for over 20 years.

There are three basic requirements for a geothermal resource:

1. a persistent heat source (or sink);
2. a heat transfer and transport medium (usually water and/or steam); and
3. sufficient permeability/transportability within the buried geothermal reservoir for the fluid to be able to pass through and gain (or lose) heat.

To some degree, the natural conditions can be modified. There is a large range of heat conversion technologies available, so that geothermal resources of almost any temperature can be utilised. If insufficient volumes of water exist naturally, this can be added. Permeability can be artificially enhanced, or pipes can be used in shallow systems.

Geothermal resources (excluding ground source heat pumps) may be classified broadly according to temperature – high temperature (greater than 170°C), moderate temperature (90°C to 170°C) and low temperature (less than 90°C) – which influences the uses to which they may be applied (Geothermal Resources Council 2009). High temperature systems are often exploited for electricity generation, while low temperature systems are more suited to direct-use applications (figure 7.3). High and moderate temperature systems may be used for both electricity generation and direct-use applications in a cascading fashion.

Electricity generation – hydrothermal systems are currently utilised in several countries for electricity generation. Geothermal power plants can provide base-load capacity 24 hours a day and have very high long-term capacity and availability factors. Current technologies (Box 7.1) include dry steam plants (uses steam at greater than 235°C through production wells), flash steam plants (use hot water at temperatures in the range 150°C to 300°C) and binary-cycle plants (used for moderate temperature geothermal reservoirs between 100°C and 180°C). Temperature is only one parameter used to determine which conversion technology is utilised for any geothermal reserve (box 7.1). Electricity generation from geothermal water was pioneered at Larderello, Italy in 1904, and this steam field has been in continuous production since that time. The Wairakei geothermal power plant, located in New Zealand, built in 1958 – the second geothermal power station built in the world and the first to use hot pressurised water

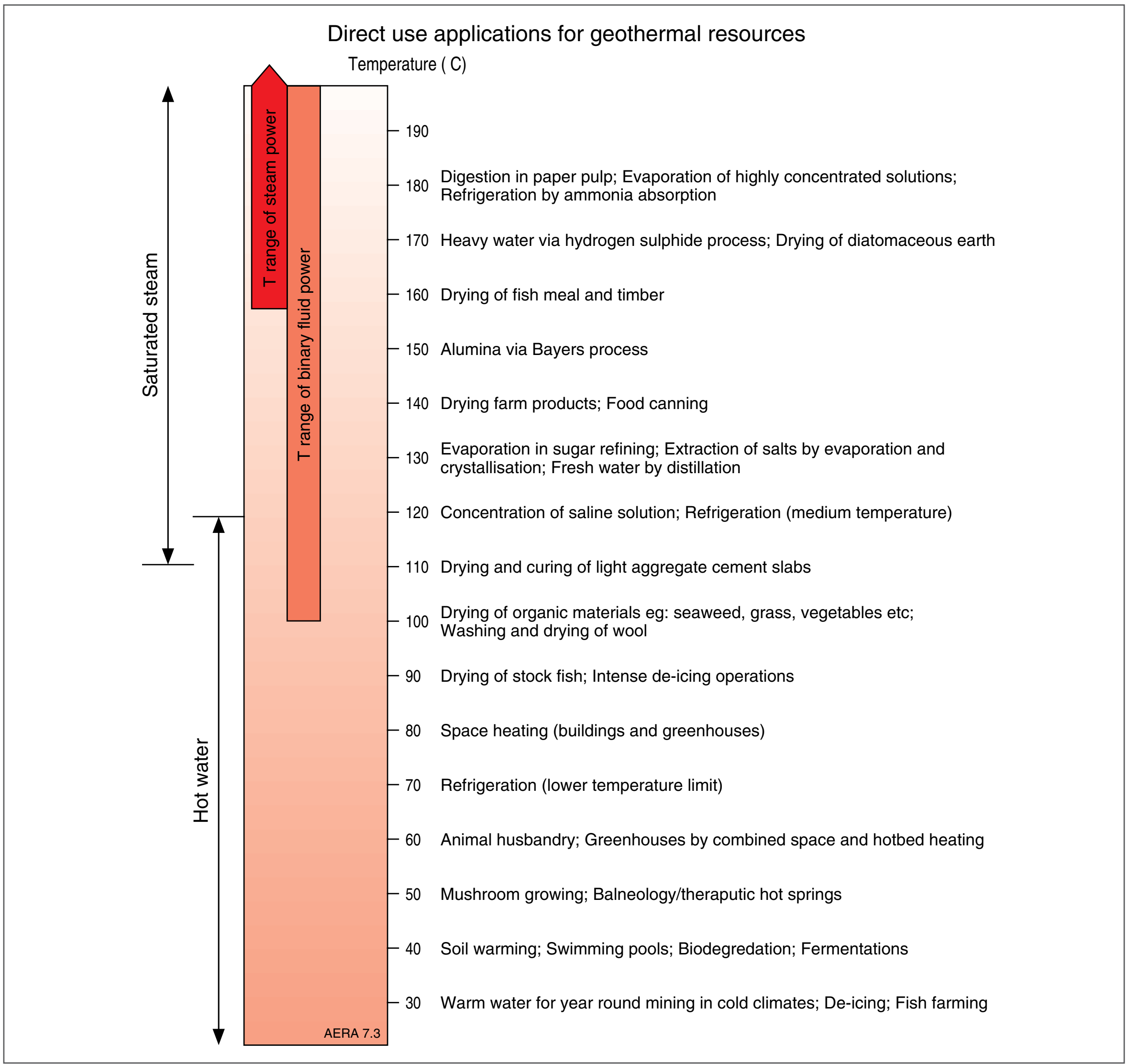

Figure 7.3 Direct-use applications of geothermal energy
Source: Geoscience Australia modified after Lindal 1973; Ayling et al. 2007b

– has generated electricity for more than 50 years. The largest geothermal development in the world at The Geysers in California, United States, has an output capacity of 750 MW based on 22 separate power plants, some of which have been in operation for nearly 50 years.

Direct-heat uses for geothermal waters – hot water may be piped directly into facilities for use in a range of applications such as district (and large commercial buildings) heating and greenhouses, heating water for fish farming (aquaculture), drying crops and building materials, and for use in resorts and spas (figure 7.3). The heat may be used directly in industrial processes including drying, for absorption chillers (including airconditioning), and in desalination of sea water by distillation. People have traditionally used hot water from geothermal springs for bathing, cooking and heating; for example, the Romans used geothermal waters at Bath in England.

Ground source heat pumps (GSHP) that utilise the ground as a heat source/sink – these systems are a direct-use technology that use the ground as a heat source or sink rather than natural hot water (i.e. they do not use 'geothermal resources') and are used to heat and cool buildings. Heat is extracted from the ground and delivered to the building in winter (heating mode) and heat is removed from the building and delivered for storage into the ground in summer (cooling mode). The GSHP is electric powered to circulate heat-carrying fluid, but energy consumption is significantly reduced compared with conventional heating and cooling systems.

7.2.2 Geothermal energy supply chain

Figure 7.5 is a schematic representation of the potential geothermal energy market in Australia. At present geothermal energy resources are used only in limited local-scale applications in Australia. High and moderate temperature geothermal energy resources (Hot Rock and Hot Sedimentary Aquifer) may be utilised to produce base-load electricity for distribution through the transmission grid. In addition, lower temperature geothermal energy resources, particularly those found in shallow sedimentary aquifers, could be used for direct-use applications. Ground source heat pumps could be

BOX 7.1 GEOTHERMAL ENERGY TECHNOLOGIES FOR ELECTRICITY GENERATION

Current geothermal technologies for electricity generation are:

- **Flash steam plants** are used where abundant high temperature water or vapour is available. Hot water is removed from the production well and sprayed into a separator (tank) held at a much lower pressure, causing some of the water to flash to steam (vaporise). The steam is used to drive the turbine and then condensed back to water and injected back into the reservoir.
- **Dry steam plants** use steam resources at temperatures of about 250°C. The steam goes directly to a turbine which drives a generator that produces electricity. This was originally used in Larderello, Italy, and is the technology used at the world's largest geothermal power field, at The Geysers in California, United States.
- **Binary power plants** (figure 7.4) use a heat exchanger to transfer energy from the geothermally-heated fluid to a secondary fluid ('working fluid', e.g. iso-pentane or ammonia-water mix) that has a lower boiling point and higher vapour pressure than steam at the same temperature. The working fluid is vaporised as it passes through the heat exchanger, and then expanded through a turbine to generate electricity. It is then cooled and condensed to begin the cycle again. The cooled geothermal fluid is also recirculated into the ground: the system comprises two closed loops.

Australia's geothermal systems are neither hot enough nor under sufficient pressure to sustainably produce large amounts of steam. Most Australian geothermal resources will be exploited using binary power generation systems, even those with temperatures of over 200°C.

Electricity generation costs are strongly influenced by the temperature and flow rate of the geothermal fluid produced, which dictates the size of the turbine, heat exchangers and cooling system. Access to the electricity grid is also an important cost consideration for electricity generation projects.

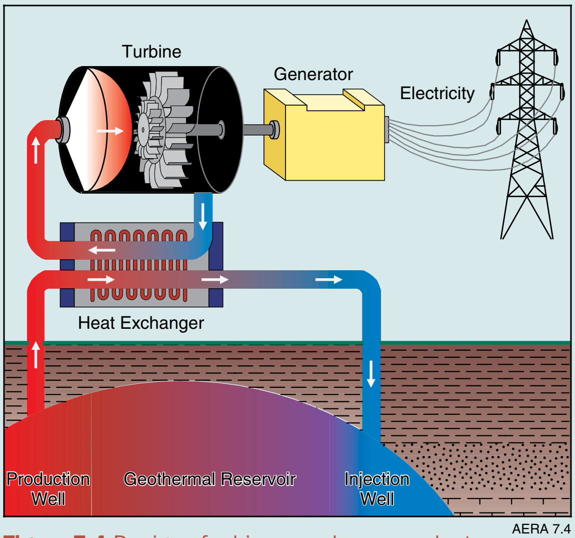

Figure 7.4 Design of a binary cycle power plant

Source: Geoscience Australia

employed almost anywhere and on a range of scales to provide building heating and cooling.

Key stages in the geothermal energy supply chain are discussed further in Box 7.2.

Important elements of Hot Rock (and, to a lesser extent, Hot Sedimentary Aquifer) geothermal energy developments are the definition of the geothermal resource by deep drilling and establishing a geothermal reservoir in the geothermally-heated rocks. The artificial creation of geothermal reservoirs in the hot rocks for water to flow through is commonly called 'engineered or enhanced geothermal systems' (EGS) and involves fracturing the hot rock in a process known as 'hydrofracturing'. Once the reservoir in the hot rock is created and the flow of water established in a closed loop, the geothermal resource can be used to generate electricity using the technologies described in Box 7.1 and the electricity connected to the transmission grid for distribution.

7.2.3 World geothermal energy market

The world has vast, largely unutilised geothermal energy resources. Geothermal energy currently accounts for only a small share of world primary

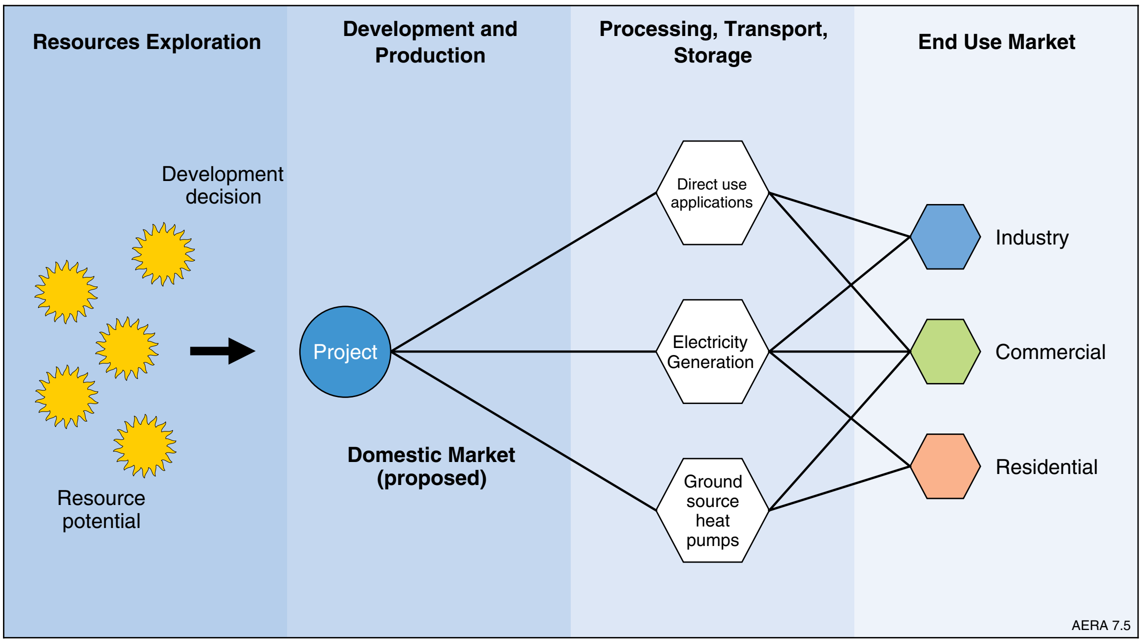

Figure 7.5 Australia's geothermal energy supply chain
Source: ABARE and Geoscience Australia

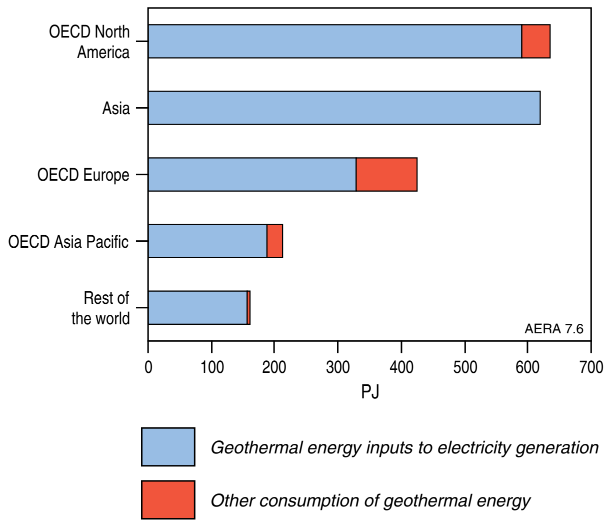

Figure 7.6 Primary consumption of geothermal energy, by region and use, 2007
Source: IEA 2009a

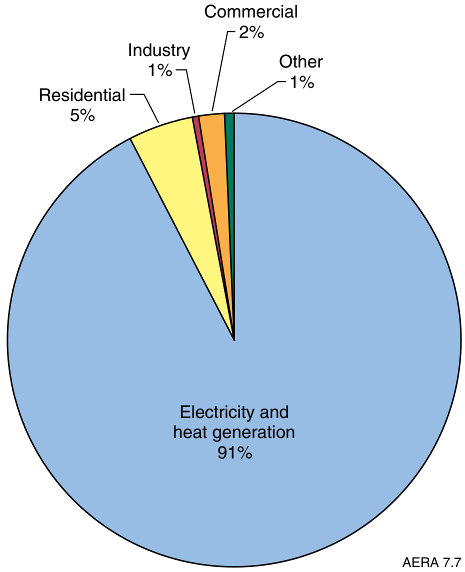

Figure 7.7 World geothermal energy consumption, by sector, 2007
Source: IEA 2009a

energy consumption. Geothermal resources are mainly utilised for electricity generation, although direct-use applications are also significant. Globally, geothermal energy use is projected to more than double over the outlook period to 2030 (IEA 2009b).

Resources

Until recently, geothermal energy was considered to have significant economic potential only in areas with hydrothermal systems; that is, in countries with active volcanoes. Countries that have identified and are utilising significant amounts of these hydrothermal energy resources include the United States, the Philippines, Indonesia, Mexico, Italy, Iceland, New Zealand and Japan.

Many countries have identified lower temperature geothermal resources and these are increasingly used for district heating and ground source heat pump systems (WEC 2007).

Consumption

Geothermal energy consumption is equal to geothermal energy production as geothermal energy is not traded in its primary form. Most geothermal plants are built close to the resource because it is generally not efficient to transport high temperature steam or water over distances of more than 10 km by pipeline due to heat losses (or 60 km in thermally insulated pipelines; IGA 2004).

Table 7.1 Key statistics for the geothermal energy market

	unit	Australia 2006[b]	OECD 2008	World 2007
Primary energy consumption[a]	PJ	-	1316	2053
Share of total	%	-	0.6	0.4
Average annual growth, since 2000	%	-	0.4	0.6
Electricity generation				
Electricity output	TWh	0.0007	40.0	61.8
Share of total	%	-	0.4	0.3
Average annual growth, since 2000	%		2.4	2.5
Electricity capacity	MW	0.08	5364	10 300[c]

a Energy production and primary energy consumption are identical. **b** Goldstein et al. 2008. **c** World data are 2008 Australian Geothermal Energy Group unpublished data

Source: IEA 2009a

BOX 7.2 STAGES IN DEVELOPMENT OF GEOTHERMAL ENERGY

- **Resources and exploration** – usually involves site assessment, leasing and land acquisition, exploratory drilling, and well testing. Notably, exploratory drilling and reservoir assessment, as in oil and gas fields, are high-risk activities and an entire project may be cancelled if an adequate resource is not found (IEA 2003). Improvement in Hot Rock geothermal resource exploration and assessment will reduce costs.
- **Development and production** – following successful exploration activity, a company will seek to confirm the energy potential of the resource. The costs associated with drilling and well testing play a major role in determining the economic feasibility of producing energy from geothermal resources. Hot Rock geothermal resources require the creation of a geothermal reservoir by hydrofracturing. Depending on the orientation of stresses in the earth, fractures can be horizontal, vertical, or at an angle. A horizontal fracture network is considered optimal, as it reduces water loss to the surrounding rock and increases the efficiency of the system. The hydrofracturing process can last for several weeks, depending on the degree of fracturing required. Hydrofracturing can induce local seismic activity but the risks associated with this are considered to be very low. Hot Sedimentary Aquifer geothermal resources generally have sufficient naturally-occurring water and permeability that most systems do not need to be enhanced including by hydrofracturing.
- **Processing and distribution to end use applications** – once the amount of recoverable heat from the reservoir has been estimated, it needs to be converted to usable energy, either by generating electricity or by direct use of the heat energy in (industrial) processes. Activities that bring a power plant on line include: drilling, project permitting, liquid and steam gathering system, and power plant design and construction (Kagel 2006). Information on geothermal electricity generation technologies is provided in Box 7.1. The type of geothermal resource and its location are important from a commercialisation viewpoint. Access to the electricity grid (whether short or long distance) is important for electricity generation. Location adjacent to infrastructure is important for retro-fitting or development of new direct-use applications.

In 2007, geothermal energy accounted for around 0.4 per cent of world primary energy consumption (table 7.1). World geothermal energy consumption has increased slowly in recent years, at an average rate of 0.6 per cent per year between 2000 and 2007. In the OECD region, geothermal energy accounts for a relatively small share of total primary energy consumption (0.6 per cent in 2008) and growth in recent years has also been very slow (0.4 per cent per year between 2000 and 2008).

Geothermal resources are mainly utilised in the energy markets of OECD North America (31 per cent of world geothermal energy consumption in 2007), Asia (30 per cent), OECD Europe (21 per cent) and the OECD Asia Pacific (10 per cent) (figure 7.6). The main geothermal energy consumers are the United States, the Philippines, Mexico, Indonesia, Italy, Iceland, New Zealand and Japan (IEA 2009a).

Figure 7.7 provides information on the world use of geothermal energy as a fuel input to the transformation (or conversion) sector and a fuel input to other industries in direct-use applications, all measured in PJ. In 2007, 91 per cent of world geothermal energy consumption was used as a fuel input to the transformation sector (of which electricity plants accounted for 97.5 per cent, combined heat and power plants for 2.2 per cent, and heat plants for 0.3 per cent). The remaining 9 per cent was used in direct-use applications (for district heating, agriculture and greenhouses) including, most importantly, 5 per cent in the residential sector and 2 per cent in the commercial sector (IEA 2009a). Most direct-use applications of geothermal energy occur in the OECD Europe, North America and Asia Pacific regions (figure 7.6).

Electricity generation

The utilisation of geothermal energy for electricity generation has increased markedly since the 1970s (figure 7.8). World geothermal electricity generation increased from 4.5 TWh in 1971 to 61.8 TWh in 2007, which represents an average annual growth rate of 7.5 per cent. In recent years, however, this growth rate has been much slower, at 2.5 per cent per year between 2000 and 2007. Geothermal energy accounted for 0.3 per cent of world electricity generation in 2007 (IEA 2009a).

Electricity generation from geothermal energy has a low heat-to-electricity conversion efficiency compared with many other sources of electricity generation. For example, in 2007, geothermal inputs of 1884 PJ to electricity generation yielded 61.8 TWh (223 PJ), showing a 12 per cent aggregate conversion efficiency. Regional conversion efficiencies in 2007 ranged from 11.8 per cent to 14.7 per cent for those regions that provided data – the IEA assumes a 10 per cent conversion efficiency for countries that do not supply data. Technological advances in the geothermal energy industry have resulted in efficiency gains which has increased the conversion ratio and decreased the fuel inputs required for a unit of electricity generation.

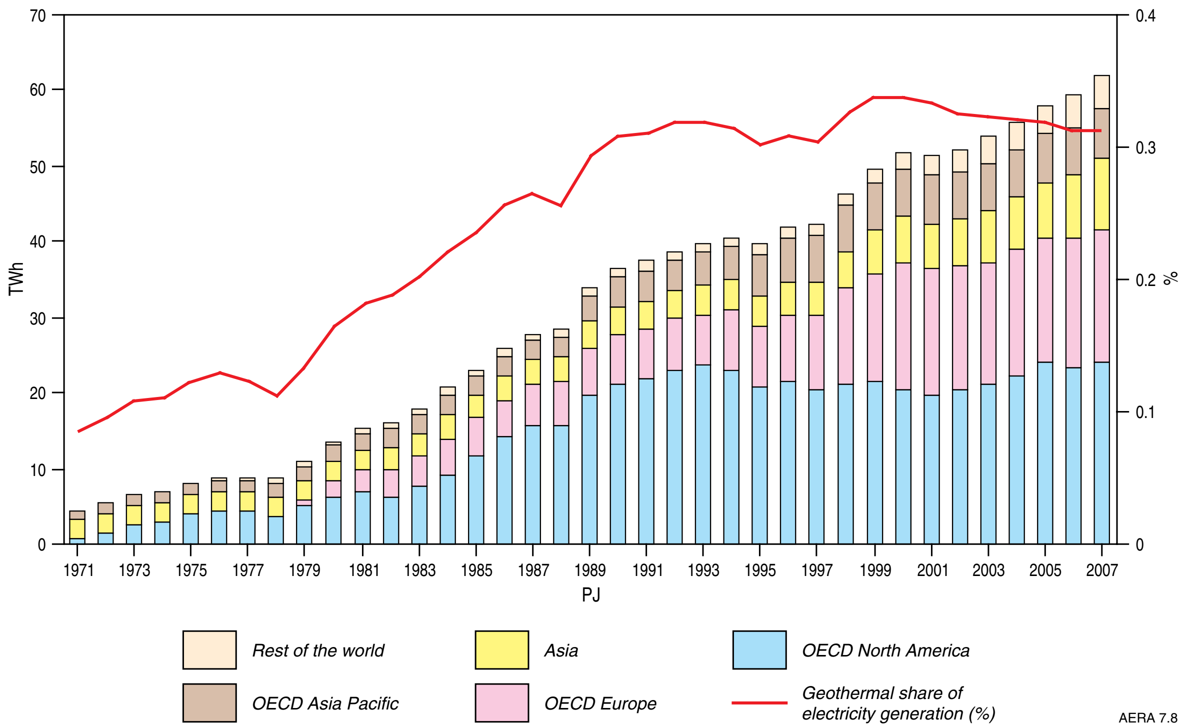

Figure 7.8 World geothermal electricity generation, by region

Source: IEA 2009a

In 2007, 17 countries were generating electricity from geothermal energy (IEA 2009a). The United States was the largest geothermal electricity generator, with output of 17 TWh. Other major producers include the Philippines, Mexico, Indonesia, Italy, Iceland, New Zealand and Japan (figure 7.9a).

Geothermal electricity generation represents a significant share of the total electricity requirements in some countries. In 2007, the three countries most dependent on geothermal energy for electricity generation were Iceland (30 per cent of total electricity generation), El Salvador (24 per cent) and the Philippines (17 per cent) (figure 7.9b).

Direct-use applications

The largest direct applications of geothermal energy are in ground source heat pumps and industrial applications and space heating: together these accounted for more than 80 per cent of direct-use applications in 2004 (WEC 2007). In 2007, the United States was the largest consumer of direct geothermal energy (43 PJ), followed by Turkey, Iceland and New Zealand (figure 7.10). Ground source heat pumps are mainly used in areas with noticeable seasonal temperature fluctuations such as North America and Europe.

World market outlook to 2030

IEA reference case projections for primary consumption of geothermal energy are not available; therefore, the outlook for the world geothermal energy market will focus on electricity generation. However, the increased global demand for renewable energy is expected to increase demand for geothermal energy both for electricity generation and for direct use. The strong growth in use of ground source heat pumps established over the past decade is expected to continue, supported by increased demand for renewable energy and increasing cost-effectiveness of direct-use geothermal energy. Improvements in drilling technologies, improved reservoir management, and reduced operating and maintenance costs, coupled with further exploration, are likely to promote increased utilisation of geothermal resources, and hydrothermal resources in particular.

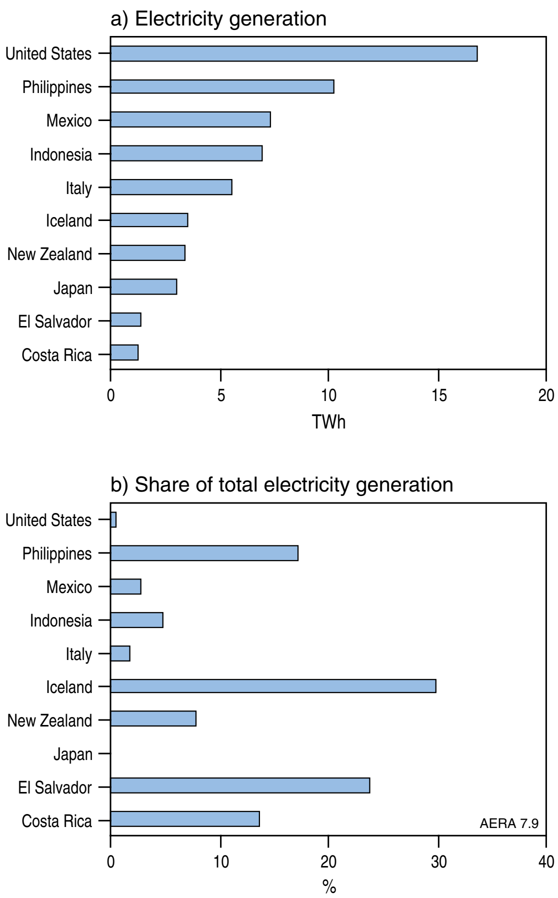

Figure 7.9 World geothermal electricity generation, major countries, 2007

Source: IEA 2009a

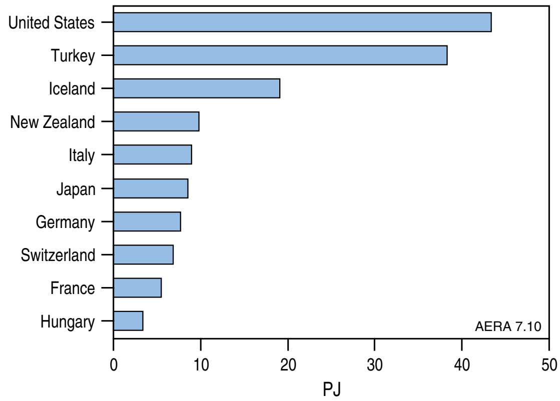

Figure 7.10 World direct use of geothermal energy, major countries, 2007

Source: IEA 2009a

Table 7.2 IEA reference case projections for world geothermal electricity generation

	unit	2007	2030
OECD	TWh	40	92
Share of total	%	0.4	0.7
Average annual growth	%	-	3.7
Non-OECD	TWh	22	81
Share of total	%	0.2	0.4
Average annual growth	%	-	5.8
World	TWh	62	173
Share of total	%	0.3	0.5
Average annual growth	%	-	4.6

Source: IEA 2009b

Geothermal electricity generation is projected to double its share of total electricity generation by 2030 to reach 0.5 per cent. World electricity generation from geothermal energy is projected to nearly triple to 173 TWh by 2030, growing at an average rate of nearly 5 per cent per year (table 7.2). Most of the growth in geothermal electricity generation is expected to come from the United States and non-OECD Asia (IEA 2009b).

7.3 Australia's geothermal resources and market

7.3.1 Geothermal resources

As there are no active volcanoes on the Australian continent (there are active volcanoes on Heard and McDonald Islands), Australia lacks conventional hydrothermal resources. However, Australia has substantial potential for Hot Rock and Hot Sedimentary Aquifer resources.

The factors which combine to give Australia an excellent Hot Rock geothermal potential are:

- Widespread occurrence of basement rocks, especially granites, with unusually high heat generating capacities because of abundances of the radioactive elements uranium, thorium and potassium which over hundreds of millions of years, decay and produce heat. In particular, granites of Proterozoic age which occur throughout northern and central Australia are generally high heat producing because of unusually high abundances of uranium, potassium and thorium, but some occurrences of older Archean and younger Paleozoic granites are also high heat-producing (Budd 2007). Where these high heat-producing granites are buried beneath thick blankets of thermally insulating sediments or metamorphic rocks, the heat energy is retained in the basement rocks and overlying strata.
- The Australian plate is moving northwards and colliding with the Pacific plate, resulting in a general horizontal stress orientation in the Australian crust, which is favourable for the development during hydrofracturing of sub-horizontal fracture networks that can connect adjacent wells at a similar depth (box 7.2; Hillis and Reynolds 2000). Geodynamics Ltd (2009) estimate that they are able to create an underground heat exchanger at Habanero (in the Cooper Basin of far north-east South Australia) four times larger than has previously been attained elsewhere in the world.

There is also potential for Hot Sedimentary Aquifer geothermal resources in a number of sedimentary basins where circulating groundwater systems may allow a high flow rate of high, moderate and low temperature water. Although commonly at a lower temperature, the high flow rate allows significant energy delivery to the surface. Water temperatures, permeability and the depth at which useful geothermal waters can be tapped will depend on a number of factors, particularly the nature of the basement rocks underlying the basin and the local hydrology of the basin.

Australia's geothermal potential has only recently been appreciated (box 7.3). As a consequence, there is incomplete knowledge of where geothermal potential exists. It is likely that further data acquisition will lead to increases in the geothermal resource base as already geothermal resources have been identified by company exploration programs in areas outside of those predicted to have geothermal potential in national-scale compilations (figure 7.11).

Current knowledge is based on a database of temperatures recorded at the bottom of more than 5700 deep drill holes, most of which were drilled for petroleum exploration (figure 7.11) supported by more detailed local investigations by companies (box 7.3). National-scale maps published by Geoscience Australia showing the distribution of high heat-producing granites and sedimentary basins, together with other information such as basin depth, provide a national framework and basis for identifying areas likely to have the greatest hot rock potential (Budd 2007).

In addition to the national database, maps and assessments of a number of regional and local assessments have been undertaken. For example, an assessment of the geothermal potential of Victoria (SKM 2005) concluded that while the temperatures of geothermal water found within the top 2000 m of the surface of the state were not sufficiently high for generating electricity, there was abundant and readily accessible geothermal water suitable for direct heating purposes.

The Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (2008) has been developed to provide a common framework for categorising geothermal resources and reserves for the information of potential investors (available at www.agea.org.au). The various categories of the Code describe the development process, which broadly consists of reducing geological uncertainty and completing technical (e.g. energy conversion), economic and regulatory requirements.

Table 7.3 Australia's reported geothermal resources as at July 2009[a]

	PJ
Identified geothermal resources (sub-economic)	2 572 280

a Includes measured, indicated and inferred resources. Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves. www.agea.org.au
Source: Geoscience Australia

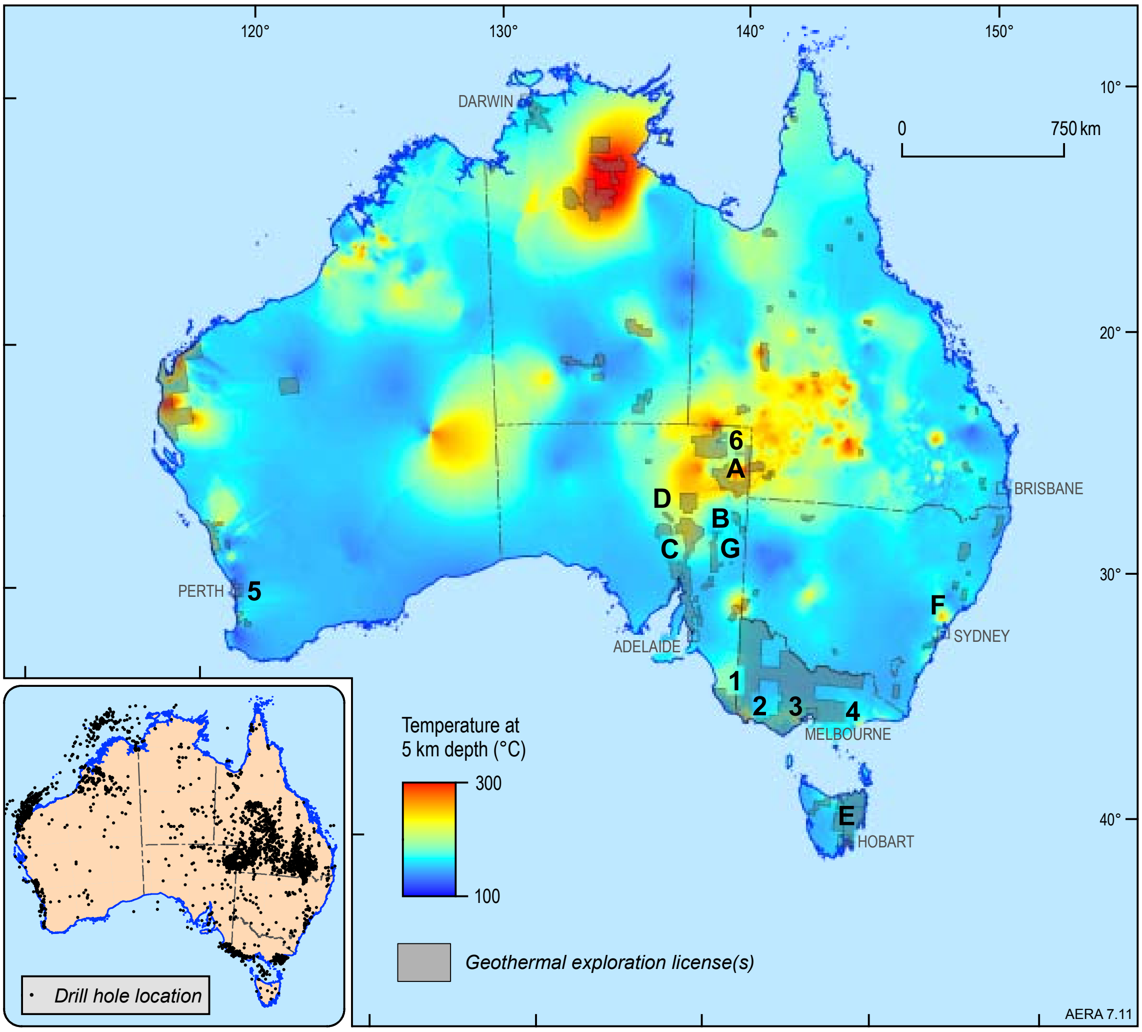

Figure 7.11 Predicted temperature at 5 km depth based mostly on bottom-hole temperature measurements in more than 5000 petroleum and water boreholes. Areas of current exploration discussed in the chapter are shown as overlaid letters (box 7.4) and numbers (box 7.5)

Note: Inset map shows the distribution of data points used to construct the map and the paucity of data points over most of the continent

Source: Data from Earth Energy Pty Ltd; AUSTHERM database; Geoscience Australia

Eight companies have declared identified geothermal resources in 28 leases across four States totalling 2.6 million PJ of heat in place (table 7.3).

Other than at Birdsville, Australia's reported geothermal resources are currently all sub-economic because the commercial viability of utilising geothermal energy for large-scale electricity generation connected to the National Electricity Market has not yet been demonstrated in Australia. Australia's geothermal industry is still in the RD&D phase of the technology innovation process. It is not expected that any technological breakthroughs are needed. Rather there is a need for progression of projects through all stages from resource definition to production and marketing. Project economics is the main factor that has potential to impede the development of the industry.

Compilations of predicted temperature at 5 km depth (figure 7.11) suggest that there are substantial areas of the continent where temperatures exceed 200°C at this depth, which is considered feasible for geothermal energy exploitation. This implies that Australia has world class potential for Hot Rock geothermal power.

A simple calculation suggests that if just 1 per cent of Australia's geothermal energy above a minimum temperature of 150°C and at a maximum depth of 5 km were accessible, the total resource is of the order of 190 million PJ, which is roughly 25 000 times Australia's primary energy use (Budd et al. 2008). This calculation ignores the renewable nature of the resource, that it can be utilised at temperatures of less than 150°C, and that improvements in drilling technology will mean that depths of greater than 5 km will be accessible.

The distribution of data points in the small inset map shows that there are extensive areas of the continent with little or no data. New geological data

BOX 7.3 GEOTHERMAL EXPLORATION ACTIVITY AND DATA ISSUES IN AUSTRALIA

It has only become evident in the last decade that Australia has considerable geothermal potential. This is because of a perception that geothermal resources are found only in regions of active volcanism, which excludes Australia. The Hot Dry Rock concept originated at Fenton Hill, New Mexico, from the work by the Los Alamos Scientific Laboratories in the early 1970s. The concept was to replicate conventional geothermal systems in dry, un-fractured rock by creating the required permeability and introducing the required fluid.

The Australian Bureau of Mineral Resources (BMR) first drew attention to Australia's Hot Rock potential in the Cooper Basin, other sub-basins beneath the Eromanga Basin (Queensland, New South Wales, South Australia); the McArthur Basin (Queensland/Northern Territory); the Otway Basin (Victoria, South Australia); the Carnarvon, Canning and Perth basins (Western Australia); areas in east Queensland; and the Sydney Basin north-west of Newcastle (Somerville et al. 1994). In the Cooper Basin, they reported extrapolated temperatures in excess of 300°C at 5 km depth, and estimated the heat energy available in rocks at temperatures above 195°C at 7.8 million PJ. This work was based largely on a compiled database of temperatures recorded at the bottom of deep drill holes, most of which were drilled for petroleum exploration. This GEOTHERM database has evolved through work at the Australian National University and Earth Energy Pty Ltd to become the AUSTHERM database, maintained and updated by Geoscience Australia. Until recently, this has been the only database of significant use to geothermal explorers, and exploration in Australia was initially limited to areas of petroleum exploration activity because this was the only available relevant dataset. However, this dataset has a number of inadequacies and does not fully represent Australia's geothermal potential.

More recently, explorers have gained a better understanding of the geology of Hot Rock systems, and have expanded the range of geothermal exploration 'plays' by using a greater range of geoscience information. This, together with the acquisition of new data specifically for geothermal exploration, most notably heat-flow measurements, has increased the exploration search area.

Exploration models being implemented in Australia now cover a range of targeted temperatures from as low as 60°C for direct-use applications, to as high as 250°C. Reservoirs being targeted include granite and metasedimentary rocks requiring fracture enhancement for Hot Rock developments, and deep natural aquifers for Hot Sedimentary Aquifer systems. Most explorers are aiming to achieve suitable temperatures within 4 km depth from surface, but some explorers are considering depths of 5.5 km and greater. These geological systems are being targeted for electricity generation or for direct-use applications, or both via cascading arrangements that enable multiple uses of the same fluid at successively lower temperatures.

Exploration for geothermal resources is rapidly gaining momentum and new geological opportunities are being recognised. The first geothermal exploration licence in Australia was granted in 2000 and by January 2010, 54 companies held 409 leases over an area of 432 000 km^2. Committed exploration work programs, to be undertaken in every State, amount to more than $1 billion for the period 2002–2014 (Long et al. 2010).

are needed to provide a better understanding of Australia's geothermal energy potential, particularly near potential major markets.

Geothermal exploration

With the great variety of geological systems and end-use applications now being considered, there are not many areas in Australia where geothermal potential has been ruled out.

Figure 7.11 shows areas of active exploration and development. It is important to note that many of the areas under exploration do not appear to be of high temperature on the map: this underscores the fact that bottom hole temperatures used alone are an insufficient geological dataset.

There are numerous explorers in each of the Cooper Basin, the Mount Painter Inlier–Frome Embayment, and the Otway Basin, and many of these companies have announced inferred geothermal resources. Other areas where resources have been announced include: the Perth Basin (Western Australia); the broad area around Olympic Dam and Lake Torrens, Port Augusta (all South Australia); central Tasmania; the Gippsland Basin, Mildura (Victoria); the area south east of Mount Isa, near Nagoorin (Queensland); and the upper Hunter Valley (New South Wales). Exploration projects listed in boxes 7.4 and 7.5 illustrate the range of geothermal targets.

Hot Rock geothermal resources

Exploration has been largely focused on the high temperature Hot Rock geothermal resources of South Australia (Cooper Basin, Adelaide Fold Belt, Mount Painter Inlier–Frome Embayment (box 7.4). Each of these areas has an underlying basement that includes high heat-producing granites of Proterozoic age. The depth of sedimentary cover varies from relatively shallow along the margins of the Mount Painter Inlier to more than 5 km in the Cooper Basin.

BOX 7.4 HOT ROCK GEOTHERMAL EXPLORATION AND RESOURCES IN AUSTRALIA

This box summarises the Hot Rock exploration projects shown on figure 7.11 as letters A to G.

Area A: Geodynamics Ltd – Cooper Basin area. Geodynamics Ltd have shown temperatures in excess of 270°C at 4911 m depth in granite buried beneath approximately 3800 m of sediment. Geodynamics Ltd achieved proof-of-concept of sustained fluid flow between an injector and production well couplet and the surface in March 2009. The company has announced plans for a 25 MW commercial demonstration plant to be operational by December 2013 and this is being supported by a grant of $90 million through the Australian Government's Renewable Energy Demonstration Program. The estimated thermal resource in the 1962 km^2 of lease area in the Cooper Basin is approximately 400 000 PJ, with an estimated energy resource to support power development of between 5000 and 10 000 MW (www. geodynamics.com.au).

Area B: Petratherm Ltd – Paralana project area. Petratherm Ltd have partnered with Beach Petroleum and TRUenergy on the Paralana Hot Rock project in the Mount Painter–Frome Embayment area of South Australia. The geological model here is a significant variant on the 'normal' Hot Rock model, and Petratherm intend to create a 'Heat Exchanger Within Insulator' meaning fracturing within the metasedimentary insulating rocks rather than the heat-producing granite. The project received a $7 million grant through the Australian Government's Geothermal Drilling Program, and completed the Paralana 2 well to a depth of 4 km in November 2009. An independent assessment has estimated a total inferred geothermal resource of 230 000 ± 40 000 PJ. The Project's immediate plan is for a 30 MW commercial demonstration project to provide power to local consumers (particularly uranium mines) and this is being supported by a grant of $63 million through the Renewable Energy Demonstration Program. Petratherm has a long term development plan to deliver a minimum of 260 MW of base-load power into the National Electricity Market (NEM) Grid from the Paralana site (www.petratherm.com.au).

Area C: Torrens Energy Ltd – Parachilna project area. Torrens Energy Ltd considers that the general area of the Adelaide Fold Belt and the Torrens Hinge Zone has the right components for Hot Rock potential, including high heat flow, good potential for high heat-producing basement including granites, and thick insulating layers. The AUSTHERM map of predicted temperature at 5 km depth (figure 7.11) did not show this area to be hot due to a lack of temperature data.

Torrens Energy received an Australian Government Renewable Energy Development Initiative grant of approximately $3 million to conduct exploration via heat flow measurements and to build a 3 dimensional Thermal Field Model. The Treebeard 1A well was drilled to 1807 m and confirmed high heat flow with modelled temperatures in excess of 200°C at 4500 m, and seismic surveying in the area indicates sediment thicknesses of between 3000 to 4500 m. A basement (i.e. granite) hosted reservoir is the primary target and preferred model for geothermal development at Parachilna, and the Company has estimated an Inferred Geothermal Resource of 150 000 PJ within the basement. Torrens Energy plans to drill a 4 km confirmation well at Parachilna. This project is being supported by a $7 million Geothermal Drilling Program grant.

Torrens Energy entered into a Geothermal Alliance Agreement with AGL Energy Ltd in 2008, which provides for the joint development and commercialisation of base-load geothermal projects close to the NEM grid (www.torrensenergy.com.au).

Torrens Energy have also conducted exploration in the immediate vicinity of the Port Augusta power plant where they have demonstrated high heat flow.

Area D: Green Rock Energy Ltd – Olympic Dam project area. Green Rock Energy Ltd have drilled one deep (approximately 2000 m) exploration well, Blanche No. 1, only 10 km away from the BHP Billiton Ltd Olympic Dam Special Mining Lease and 5 km from a 275 kV and 132 kV transmission line connected to the NEM grid. The well provides good information on subsurface temperatures and an indication of the temperature gradient within the Roxby Downs Batholith granite body. The inferred temperature at 5500 m is 190°C. Green Rock have discussed plans for drilling to the east of Blanche 1 where the sediment cover is interpreted to be thicker.

Green Rock have conducted mini-hydrofracturing experiments within Blanche No. 1 and successfully demonstrated the ability to enhance fractures within the granite, and to do so at multiple levels using removable packers. This demonstrated the ability to create sub-horizontal fracture networks including at deeper levels, and is an important step in testing expected reservoir conditions prior to more expensive drill testing.

Green Rock have plans to ultimately develop a 400 MWe power plant with an operation life of at least 30 years (www.greenrock.com.au).

Area E: KUTh Energy Ltd – Central Tasmania project area. The map of predicted temperature at 5 km based on bottom hole temperature data (figure 7.11) suggests Tasmania has only limited geothermal potential. However, several old measurements show high heat flow values. KUTh Energy Ltd have undertaken an extensive drilling program and confirmed areas of anomalously high heat flows. They have also conducted other surveys, including seismic and extensive thermal conductivity measurements, to indicate that there is a considerable thickness of low-to-moderate thermal conductivity units above what is interpreted to be deeply buried granites. KUTh have announced an Inferred Geothermal Resource of 260 000 PJ at Charlton-Lemont (central Tasmania) (www.kuthenergy.com).

Area F: Geodynamics Ltd – Hunter Valley project area. The Somerville et al. (1994) report highlighted an area of high temperature in the upper Hunter Valley area. This was targeted by Australia's first geothermal company (now Geodynamics Ltd). Although there is little information publicly available about the project, Geodynamics Ltd have reported thermal gradients similar to those found in the Cooper Basin project. Geodynamics Ltd is targeting a high heat-producing Paleozoic granite buried beneath more than 3500 m of Sydney Basin sediments including coal measures (www.geodynamics.com.au). This project is being supported by a $7 million Geothermal Drilling Program grant.

Area G: Geothermal Resources Ltd – Frome project area. The Frome project comprises buried Cambrian basins known as the Moorowie and Yalkalpo sub-basins that are underlain by relatively radiogenic Precambrian volcanics and granites rocks of the Curnamona Craton. Frome 12 was drilled to a depth of 1761 m in the centre of a heat anomaly identified from earlier shallow drilling. A bottom of hole temperature of 93.5°C was recorded shortly after drilling ceased. This can be extrapolated to a temperature of 200°C at 4080 m. Geothermal Resources Ltd plan further drilling to intersect granite at about 3 km depth (www.geothermal-resources.com.au).

Hot Sedimentary Aquifer geothermal resources

There are several sedimentary basins in Australia where high geothermal gradients are known, including the Otway Basin (South Australia, Victoria), Gippsland Basin (Victoria), Perth Basin (Western Australia), Carnarvon Basin (Western Australia) and the Great Artesian Basin (Queensland, New South Wales, South Australia, Northern Territory). These basins have porous and permeable aquifers, which means that hot water circulating naturally at depth within them can be readily extracted. However, some fracture enhancement may be necessary to increase flow rates, especially in deeper parts of basins.

This potential has stimulated significant interest in exploration for Hot Sedimentary Aquifer geothermal resources in a number of basins, notably the Otway, Gippsland and Perth basins (box 7.5). For example, shallow groundwater systems in the Perth Basin are being investigated as a potential source of low temperature energy that could be used for direct heating and other applications. The Otway Basin differs from the other areas in that there is also potential for heat input from dormant volcanic activity that occurred some 5000 years ago. However, previous regional heat-flow data showed no evidence of abnormal heat-flow in the region, including around Mount Gambier – the youngest volcano in the Newer Volcanics group in the south-west Victoria–south-east South Australia region. More detailed heat flow measurements identified a 40 km long zone of elevated heat flow of uncertain origin (including potentially buried granite) along the northern margin of the Otway Basin (Matthews and Beardsmore 2009), and highlighted the need for higher resolution data to identify finer scale variations in heat flow.

Direct Heat geothermal resources

Direct-use applications generally require access to low to moderate geothermal resources with at least moderate flow rates. Direct-use applications such as air conditioning for commercial and office buildings via absorption chillers or making fresh water via seawater distillation desalination will generally require access to Hot Sedimentary Aquifer geothermal resources.

Ground source heat pumps have potential in Australia, although this technology is most cost effective in geographic locations that have marked seasonal temperature fluctuations. Estimating the full resource potential is somewhat difficult – this technology can be applied anywhere, but local conditions and the cost competitiveness of the technology are important factors in influencing its uptake.

7.3.2 Geothermal energy market

Electricity generation

To date, two geothermal energy projects have been undertaken in Australia that demonstrated geothermal electricity generation technologies in the Great Artesian Basin (table 7.4).

In 1986, Mulka Station in South Australia used a hot artesian bore to produce a maximum 0.02 MW of power. However, as the project utilised a working fluid on the power plant side that was subsequently banned, it has since ceased operation.

Electricity generation from geothermal energy in Australia is currently limited to one pilot power plant producing 80 kW net at Birdsville in south west

Table 7.4 Geothermal energy projects in Australia

Project	Company	State	Start up	Capacity
Mulka Station	Mulka Station	SA	1986 (ceased operations)	0.02 MW
Birdsville	Ergon Energy	QLD	1992	0.08 MW

Source: Compiled from publically available reports by Geoscience Australia

Queensland. The plant uses a binary-cycle power system, and sources hot (98°C) waters at relatively shallow depths from the Great Artesian Basin. The water comes from the town's water supply bore, which was not drilled specifically as a geothermal bore. Total electricity generation in 2006 was 1.8 MWh, of which 0.5 MWh was provided by the geothermal power plant with the remainder provided by auxiliary LPG and diesel powered generators (Ergon Energy 2009). The plant operator, Ergon Energy, has commenced a feasibility study into whether it can provide Birdsville's entire power requirements and relegate the existing LPG and diesel-powered generators to be used only as a back-up to meet peaks in electricity demand.

Direct-use applications

There is a number of small direct-use applications of geothermal energy resources in Australia. At Portland in Victoria, water from a single well was used for heating several council-operated buildings including council offices, library and hospital for several years.

Numerous spas and baths operate in several parts of Australia using warm spring waters. These include spa developments (Mornington Peninsula, Victoria

BOX 7.5 EXPLORATION FOR HOT SEDIMENTARY AQUIFER RESOURCES IN AUSTRALIA

This box summarises exploration for Hot Sedimentary Aquifer geothermal resources shown as numbers 1–6 on figure 7.11.

In the *Otway Basin*, three companies have projects underway: Panax Geothermal Ltd at the Penola project (1 on figure 7.11), Hot Rocks Ltd at Koroit (2) and Greenearth Energy Ltd at Geelong (3). All projects are Hot Sedimentary Aquifer-style, and have as targets a sequence of sandstone aquifers within early Cretaceous sediments expected to contain water at temperatures in the range 140–180°C at depths of between 2500 to 3500 m. Panax Geothermal Ltd received a $7 million grant from Round 1 of the Australian Government's Geothermal Drilling Program, and commenced drilling their first deep production well in early 2010. The company has been in discussion with owners of nearby petroleum companies regarding the use of existing otherwise unused wells as an injection well. Panax Geothermal Ltd has a development plan to build a 59 MW (net) generator within a project timeframe of 24 months once proof-of-concept is complete (www.panaxgeothermal.com.au). Hot Rocks Ltd has been awarded a $7 million Geothermal Drilling Program grant for the Koroit proof of concept project (www.hotrockltd.com). The Greenearth Energy Ltd project at Geelong has also been awarded a $7 million Geothermal Drilling Program grant, and also a $25 million Victorian Government Energy Technology Innovation Strategy grant.

In the *Gippsland Basin*, Greenearth Energy Ltd have a project in the LaTrobe Valley, and a principal aim of this Hot Sedimentary Aquifer and direct-use project is to assist in decreasing the carbon intensity of this brown-coal region (www.greenearthenergy.com.au) (4 on figure 7.11). The target aquifer is the Rintouls Creek Formation where temperatures greater than 150°C are expected between 3250–4000 m depth.

The *Perth Basin* (5 in figure 7.11) is a 1000 km long geological rift containing sediments up to 15 km thick. It contains thick sequences of permeable aquifers containing hot geothermal water with sufficient temperature and water flow capacity at depths considered to be economic for electricity generation. Green Rock Energy Ltd, in conjunction with the University of Western Australia, is preparing for the development of Australia's first commercial geothermal powered heating and air-conditioning unit, in a commercial building in the Perth Metropolitan area. The geothermal energy will be the direct heat source which will replace conventional air-conditioners and their associated large scale electrical and natural gas consumption. The company was working towards the drilling of the geothermal wells in late 2009 with the commissioning of the commercial unit in 2011. By replacing a Conventional Chiller that uses electric energy with an Absorption Chiller using geothermal energy, large commercial buildings, including universities, hospitals, hotels, airports, data centres and shopping centres, can be air-conditioned using hot geothermal water as the principal power source. The project will need to drill two wells to approximately 2500 m depth to extract water at temperatures greater than 75°C. This project is being supported by a $7 million Geothermal Drilling Program grant (www.greenrock.com.au).

The *Great Artesian Basin (GAB)* is the largest artesian basin in the world covering about 22 per cent of the Australian continent and has ground waters of 30–100°C at the well head. Australia's only operating geothermal power plant at Birdsville uses water at 98°C drawn from the GAB. The temperature of the water varies across the Basin, and is understood to be hottest in northeastern South Australia (6 on figure 7.11). Several companies have exploration leases in this area. The maximum water temperature is thought to be less than 140°C, which is at the lower limit for generating electricity at a large commercial scale. The added cost of transmission infrastructure is likely to make electricity generation for supply into the NEM uneconomic in the near future, however local supply is likely to be competitive against power generated by diesel or gas generators (as is the case at Birdsville).

and Mataranka, Northern Territory), artesian baths (Moree, Lightning Ridge artesian baths, and Pilliga Hot Artesian bore, inland New South Wales) and swimming pool heating (Challenge Stadium, Western Australia). Ground source heat pumps are used in several public buildings, including the Geoscience Australia building in Canberra.

7.4 Outlook to 2030 for Australia's geothermal resources and market

Australia's considerable high-temperature (above 180°C) geothermal energy potential associated with deep Hot Rock resources and lower temperature resources associated with hot waters circulating in aquifers in sedimentary basins (Hot Sedimentary Aquifer resources), have potential for electricity production and direct use. The requirements for development of geothermal electricity generation include significant investment, firstly in demonstration projects to prove viable generation, and then in commercialisation. Government policy and direct support for research, development and demonstration are likely to continue to play a significant role in this process until commercial viability can be established.

Geothermal power has significant benefits. It is environmentally benign, renewable (temperature is renewed by conduction from adjacent hot rocks, and heat is generated by natural radiogenic decay), and able to provide base-load power and heat for industrial processes. Ground source heat pumps have been proven to be viable in various parts of Australia, and widespread implementation could provide a significant energy efficiency and carbon reduction benefit.

7.4.1 Key factors influencing the future development of Australia's geothermal energy resources

Australia's existing indicated geothermal resources are sufficient to meet projected domestic demand over the period to 2030. There is also scope for Australia's geothermal resources to expand substantially, based on further predicted temperature at 5 km data, heat flow measurements and enhanced general geological knowledge. This in turn could affect the market outlook as several expected proof-of-concept projects demonstrate the suitability of the technology to Australia and commercial demonstration projects are established. However, some of Australia's geothermal resources lie remote from the existing electricity transmission grid.

BOX 7.6 AUSTRALIAN GEOTHERMAL INDUSTRY DEVELOPMENT FRAMEWORK

The Australian Geothermal Industry Development Framework and the associated Australian Geothermal Industry Technology Roadmap were released in December 2008 (see Australian Government Department of Resources, Energy and Tourism 2008a, b). The framework recognised that Australia's geothermal industry is at a very early stage of development and identified major challenges for the future of the industry including the development of:

- an attractive investment environment in which early stage ventures are able to mature to a level sufficient to attract private finance;
- accurate and reliable information on geothermal energy resources in Australia;
- networks that encourage sharing of information and experience between stakeholders including companies, researchers and governments in Australia and overseas;
- geothermal technologies suited to Australian conditions;
- a skilled geothermal workforce;
- community understanding and support of the economic, environmental and social benefits of geothermal energy;
- a geothermal sector which understands and can contribute to the institutional environment within which it operates; and
- a consistent, effective and efficient regulatory framework for geothermal energy.

Several recommendations have been significantly advanced already. For example, three key outcomes are:

- The first edition of the *Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves*.
- The Australian Government's $435 million Renewable Energy Demonstration Program in November 2009 awarded $90 million to Geodynamics Ltd's Cooper Basin Commercial Demonstration Program, and $63 million to Petratherm Ltd's Paralana project.
- The Australian Government's $50 million Geothermal Drilling Program, administered by the Department of Resources, Energy and Tourism, has provided seven grants of each of $7 million for proof-of-concept projects in Hot Rock and Hot Sedimentary Aquifer settings for both electricity generation and direct-use applications.
- In addition, the Victorian Energy Technology Incentive Scheme has awarded $25 million to a geothermal project out of a total of $72 million of grants.

Government support for geothermal energy research, development and demonstration (RD&D)

Government policies relating to geothermal energy research, development and demonstration (RD&D) are critical to the outlook for electricity generation from geothermal energy in Australia. Actions to accelerate the development of the geothermal industry include completion of the Australian Geothermal Industry Development Framework and the associated Australian Geothermal Industry Technology Roadmap (box 7.6). Direct assistance includes the Australian Government's $50 million Geothermal Drilling Program, administered by the Department of Resources, Energy and Tourism, which has provided grants of $7 million for seven proof-of-concept projects in Hot Rock and Hot Sedimentary Aquifer settings. The Australian Government has also provided funding to assist two geothermal projects to a total of $153 million to progress from proof-of-concept to commercial demonstration stage from its $435 million Renewable Energy Demonstration Program. These programs, which provide funding to projects on a merit-basis, will accelerate the development of the geothermal industry by helping to address the key impediment to development of insufficient market investment. It is expected that the funding will not only assist companies to finance their respective stages of activity in the projects and reduce financial risk to investors but have the longer term effect of lowering the technical risk of both stages of geothermal developments, and therefore increasing investor confidence.

Better definition of geothermal resources – improved basic geoscientific data to enhance development prospects for geothermal energy

The AUSTHERM database of bottom hole temperatures is largely populated by petroleum drilling results. Of necessity, this dataset is biased towards particular geological settings, i.e. basins. Geothermal resources are not limited to the same geological settings as petroleum resources. Not only is the geographical distribution of this data uneven and inadequate, measurements of bottom hole temperatures are not robust for predicting temperature at depth.

Heat flow measurements are normally significantly more robust indicators of temperature at depth. However, in addition to the gradient and conductivity data necessary, other geological data, including lithologies at depth are very important to make confident temperature extrapolations. Both the number and distribution of publicly-available heat flow measurements, and the knowledge of geology at depth, are inadequate for efficient geothermal exploration in Australia.

Given the potential for geothermal to be a significant energy source in the future, there is support for government programs to increase the collection and dissemination of basic pre-competitive geoscientific data to guide future geothermal exploration (see, for example, Hogan 2003). Government investment in a geothermal resources database will also complement private sector activity in the geothermal industry and enhance prospects for future geothermal energy development in Australia. The priorities are summarised in Box 7.7.

Geothermal RD&D and technology development

Further research in the exploration and enhancement of reservoirs and in drilling and power generation technology, particularly for the exploitation of low temperature geothermal resources, will be important in realising potential in this area (IEA 2008; box 7.3). Technology developments in oil and gas production and carbon storage, such as horizontal wells, expandable solid tube technology, rock fracturing and improved seismic technology, will also benefit geothermal electricity generation (IEA 2006).

It is important to note that the development of the geothermal industry in Australia is not dependent on major technology breakthroughs – all of the required technology exists from the conventional geothermal and petroleum industries, and to a large degree it is a matter of a trial-and-error learning process in adapting this technology. The challenges in Australian geothermal systems are more about making exploitation more economically viable (for example through cheaper drilling), requiring incremental technological adaptation and development rather than major technological breakthroughs.

As many other countries around the world (especially the United States) have very large untapped Hot Rock geothermal resources there is a technology development push worldwide. Geothermal resources in Hot Sedimentary Aquifer systems are also being brought into production in a number of countries, providing another source of experience and technology developments internationally.

Ground source heat pumps have already been demonstrated to be economically and environmentally beneficial in numerous installations in Australia.

As a consequence of the geothermal industry being new to Australia, only limited research has been conducted to date but this is now developing quickly and it is expected that Australian research capability will continue to grow. Several research centres have been established, including:

- The University of Queensland has a $15 million program mostly investigating power conversion technologies;

BOX 7.7 IMPROVING KNOWLEDGE OF AUSTRALIA'S GEOTHERMAL POTENTIAL

Because of the inadequate geoscience data available to the industry in Australia, exploration has only been undertaken in those areas having useful data. A good understanding of geology is a prerequisite for developing geothermal resources and the knowledge required is scale-dependent.

In selecting tenement areas for more detailed exploration for geothermal resources in Australia companies rely on publicly available, pre-competitive regional scale geological data, as companies only have the right to collect information on ground that they have under lease. Once a company has taken out a lease area, it then explores in increasing detail for the small volume of rock that will produce the most profitable geothermal resource.

Publicly available geoscience data that is sought for evaluation by the geothermal exploration companies comes from:

- seismic reflection, gravity, magnetic and magneto-telluric surveys;
- stratigraphic drilling in key locations and thermal conductivity measurements for key stratigraphic units throughout the country;
- accurate depth to conductive basement maps based on the activities above;
- downhole temperature measurements;
- granite geochemistry, particularly of buried units; and
- assessments of risks posed by geothermal developments (including radiation/radon, induced seismicity).

Many of these data types are already being collected to varying degrees by Geoscience Australia and State geological surveys, but this has not been done in a systematic manner with geothermal energy in mind. Some database development is required to incorporate new data types (such as thermal conductivity) and to make existing data more accessible. Also data generated by companies and reported as part of lease requirements needs to be captured and made available.

Companies conduct more detailed studies in their exploration leases, such as:

- in-situ porosity and permeability measurements or their proxies;
- detailed measurements of crustal stress distribution, including down-hole stress measurements;
- enhanced seismic monitoring, including temporary deployment of detailed monitors during hydrofracturing;
- fluid chemistry and rock mineralogy to predict the effects of scaling (mineral deposition that may inhibit fluid flow either in the rock fracture network or in the piping or power plant); and
- fluid chemistry for use as a geothermometer in exploration, and for studies of fluid-rock interaction to predict and develop mitigation strategies for scaling and corrosion during production.

- The Western Australian Geothermal Centre of Excellence has $2.3 million to investigate direct-use applications of geothermal energy including absorption chillers;
- The University of Adelaide is receiving a smaller amount of funding mostly for research into exploration and fracturing techniques; and
- The University of Newcastle has a small program researching power cycle technology.

The demonstration of the economic viability of the extraction and use of geothermal energy in the domestic Australian energy market is required for the future development of the industry. Several pilot projects are expected to be advanced within the next few years.

The cost of geothermal energy is expected to continue to fall over the outlook period

The costs of hydrothermal energy have dropped substantially since the 1970s and 1980s – overall, costs fell by almost 50 per cent from the mid 1980s to 2000. Upfront costs, comprising mainly of exploration, well-drilling and plant construction, can comprise up to 70–80 per cent of the overall costs of geothermal electricity, depending on the technology. For example, drilling costs can account for as much as one third to one half of the total cost of a geothermal project (IEA 2008). Operation and maintenance costs account for a very small percentage of total costs, but can vary depending upon the location of the plant. Geothermal drilling costs tend to rise exponentially with drilling depth (figure 7.12). Company reports indicate that the cost of drilling to a well depth of 5 km in Australia is in the order of $10–15 million.

Hot Rock geothermal energy has only been deployed commercially in one location (Landau, Germany, a hybrid project that uses hydrofracturing) but is being tested and developed at a number of locations. Like conventional geothermal power systems, Hot Rock geothermal systems have high up front costs, up to 70–80 per cent of total costs, in developing the well

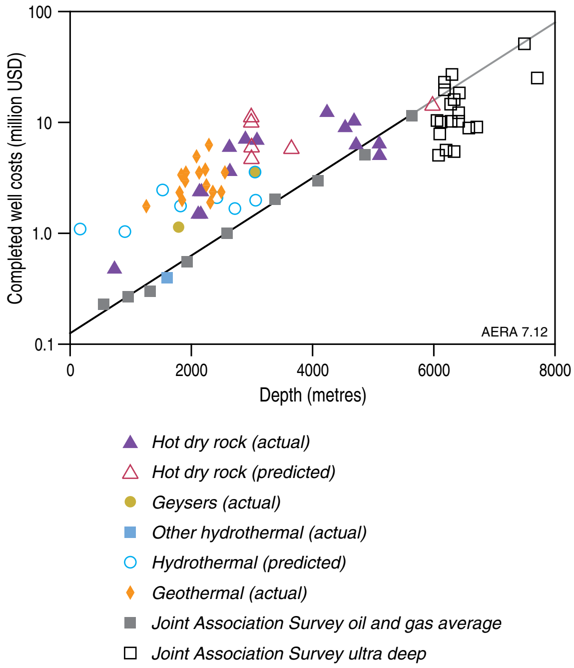

Figure 7.12 Completed well costs as a function of depth

Source: Augustine, Tester and Anderson 2006

field at the geothermal resource. Hot Sedimentary Aquifer geothermal technology is considered to be of lower risk and cheaper than Hot Rock technology because it generally involves shallower drilling and generally does not require reservoir stimulation through hydrofracturing. However, high flow rates are required.

The cost of electricity produced from geothermal energy sources, both Hot Sedimentary Aquifer and Hot Rock, are expected to fall over the next 10–20 years as the technologies mature. A considerable advantage that geothermal electricity generation has over other renewable energy generators is that it is base load with high capacity and availability factors (each greater than 90 per cent). It will classify as a 'scheduled generator' under the Australian Electricity Market rules in the eastern half of Australia.

Cost of access to the grid

A potential impediment to the development of some of Australia's geothermal resources for geothermal electricity generation is the distance of some of the resources from existing transmission lines or consumption centres. Most geothermal plants are built at the site of the reservoir since it is not practical to transport geothermal resources over long distances. High-voltage direct current transmission lines are used because for a given carrying power capacity they have less line loss (MIT 2006).

Additional power lines must be built if transmission infrastructure does not exist where a geothermal resource is located. Some of Australia's known geothermal resources are located in areas remote from the existing electricity transmission grid. Geothermal developers pay the direct costs to connect their plant to the grid, and may incur additional transmission related costs, including the construction of new lines, upgrades to existing lines, or new transformers and substations (Kagel 2006).

This impediment may be lessened by the proposed changes to the National Electricity Market rules by the Australian Energy Market Commission (AEMC) that include the introduction of a new framework for the connection of generation clusters in the same location over a period of time. The recommended model overcomes the lack of commercial incentives for network businesses to bear the risk of building assets to an efficient scale (AEMC 2009). This is called Scale Efficient Network Extension (SENE) and will assist geothermal (and other renewable energy) projects to overcome the relatively high cost of accessing the electricity grid. The geothermal industry is investigating the cost impacts of transmission connection to the National Electricity Market. One study focussing on connection from the Cooper Basin to Port Augusta via the Arrowie Basin suggests benefits to both generators and customers if the transmission network is built to coincide with the onset of geothermal production (MMA 2009).

There is scope for some industries to co-locate to new geothermal generators. For example, Geodynamics Ltd has been investigating the establishment of a large data centre at Innamincka in the Cooper Basin. In this case it is cheaper to lay fibre optic cable than power lines to the major centres.

Environmental considerations

Geothermal energy is generally regarded as one of the most environmentally-benign sources of electricity generation.

- **Air emissions** – geothermal fields in Australia will generally utilise groundwater systems, and will have very few air emissions especially if using a double closed loop system. Some concerns have been raised over radon release; however these are projected to be well within Australian occupational health and safety guidelines (PIRSA 2009). The only emissions created are in building infrastructure (well completion, plant, power lines) which is necessary for all generation technologies. There are no emissions associated with the 'fuel'. Some volcanic systems used in other parts of the world emit CO_2 as a natural part of magma outgassing: this is a natural process that happens whether used for geothermal power production or not; and Australia has no such active volcanism.
- **Noise pollution** – geothermal plants produce noise during the exploration drilling and construction phases. With direct-heat applications, noise is usually negligible during

operation. Noise from normal operation of power plants generally comes from the cooling tower fans, steam ejector and turbine.

- **Water usage** – geothermal systems in Australia are generally expected to be operated as closed-loop systems for a number of reasons, including water conservation. For **Hot Rock** developments, the loss of water injected into the artificial reservoir would result in operational inefficiencies through higher pumping costs and lower energy returns than optimal and are therefore to be avoided. In **Hot Sedimentary Aquifer** systems, water needs to be returned to the originating aquifer otherwise the reservoir pressure will be depleted and water returns will be reduced. In Hot Rock systems requiring hydrofracturing to enhance the reservoir permeability, water will need to be introduced from the surface during the fracturing process. This is in the order of tens of megalitres to create a reservoir volume of up to 10 cubic kilometres. As it is a one-off use, this water will generally continue to serve as the circulation fluid during production. As they will generally be working in areas of very low rainfall, Australian geothermal developers are mostly planning to use air-cooled power stations. Some research is being conducted into using ground-loop cooling or novel air-cooled systems to assist power plant efficiency during peak daytime temperatures, and also to using solar energy to boost input water temperatures to increase power plant efficiencies. Other generators of power may also benefit from this technology.
- **Subsidence** – this was found to be a problem during some early conventional geothermal developments overseas. Reinjection of groundwaters became a common practice to prevent this. Geothermal reservoirs in Australia are considerably deeper than conventional reservoirs overseas, and this combined with reinjection mean that subsidence is most unlikely to be of concern.
- **Induced seismicity** – this term is used to describe earth movements generated by human activities. Induced earth movements are associated with the movement of material into or out of the earth, for example during water reservoir filling, underground mining, oil and gas extraction, compressed carbon dioxide injection, and development of Hot Rock reservoirs. The hydrofracturing process employed in the creation of Hot Rock reservoirs can induce seismic activity, which can be detected by sensitive seismological instruments (Lewis 2008). In over thirty years of hydrofracturing in Hot Rock developments overseas and more recently in Australia, there have been no instances of damage caused by earthquakes directly attributed to hydrofracturing. Substantial knowledge is being gained about controlling the incidence of microfracturing by varying the rates and pressures of fluid injection. Ultimately this will lead to better reservoir development with minimal risk from unwanted seismicity. Earthquakes are commonly reported using a 'Magnitude' scale, and this describes the intensity of the earthquake at its origin: it does not provide information on the effects at surface, which can be many kilometres above and away from the point of origin. Ground motion sensors provide information about the extent of movement at a point on the surface and are a significantly better way of monitoring the surface effects of induced seismicity.

7.4.2 Outlook for geothermal energy market

The major geothermal energy developments occurring in Australia are focused on electricity generation. Several companies have plans for pilot and demonstration plants, and some for commercial generation. Given the major investment in geothermal energy RD&D by both government and industry in Australia, it is considered likely that geothermal power will be produced on a commercial scale over the period to 2030.

There is considerable uncertainty surrounding projections of geothermal energy in the period to 2030. The commercial development of the industry is dependent on the demonstration in Australia of commercial viability to show an acceptable investment risk, and this includes grid connection issues. No technology breakthroughs are needed,

Table 7.5 Geothermal projects under development, as of October 2009

Project	Company	Location	Status	Start up	Capacity	Capital Expenditure
Moomba stage 2	Geodynamics Ltd	Moomba, SA	Demonstration plant under construction	2013	25 MW	na
Paralana	Petratherm Pty Ltd	Mount Painter, SA	First well completed, feasibility underway	na	30 MW	$200 m
Penola	Panax Geothermal Ltd	Limestone Coast, SA	Commenced first well	na	59 MW	$340 m

Source: ABARE 2009; Geodynamics Ltd 2009, Panax Geothermal Ltd 2009 but advances in technologies that reduce costs will potentially lead to greater market penetration by geothermal energy.

In the latest ABARE long-term energy projections which incorporate the Renewable Energy Target, a 5 per cent emissions reduction target and other government policies, geothermal electricity generation is projected to increase to annual production of around 6 TWh in 2029–30 (ABARE 2010). This represents around 1.5 per cent of Australia's projected electricity generation in that year. Geothermal energy is projected to be the fastest growing source of electricity to 2030, albeit from a near zero base. Electricity is projected to be supplied initially by demonstration plants but commercial scale plants are expected to be in operation by 2030.

Proposed development projects

The Geodynamics Ltd project in the Cooper Basin in South Australia is the most advanced Hot Rock geothermal project in Australia. Geodynamics Ltd completed proof-of-concept at their Habanero prospect in early 2009. It has also started drilling two other prospects (Savina and Jolokia). Geodynamics Ltd's tenements in the Cooper Basin have been shown to contain more than 400 000 PJ of high-grade thermal energy.

Geodynamics Ltd have begun development of a 25 MW Commercial Demonstration Project for completion by 2013 (table 7.5). In November 2009 Geodynamics Ltd was awarded a $90 million Renewable Energy Demonstration Program grant to assist the commercial demonstration project.

Petratherm Ltd have completed drilling well Paralana 2 at their Paralana Hot Rock Heat Exchanger Within Insulator project. Together with Joint Venture partners Beach Petroleum and TRUenergy, the project aims to build a 7.5 MW pilot plant to supply power to nearby uranium mines and to then scale up to a 30 MW demonstration plant connected to the NEM grid (table 7.5). In April 2009 Petratherm Ltd was awarded a $7 million Geothermal Drilling Program grant, and in November 2009 was awarded a $62.75 million Renewable Energy Demonstration Program grant to assist development of their demonstration project.

Panax Geothermal Ltd started drilling the Salamander 1 well at the Penola Hot Sedimentary Aquifer project having received a $7 million grant from Round 1 of the Geothermal Drilling Program. Panax Geothermal Ltd has announced plans for the rapid development of a 59 MW (net) commercial plant at their Penola project in the Limestone Coast area of South Australia (Panax Geothermal Ltd 2009).

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