Sustaining Australia’s wealth—economic growth from a stable base

Despite continuing global supercontinent cycles, the Precambrian core of the Australian continent has endured. Most of the continent is now remote from active plate boundaries, and this, together with its core strength, has ensured relative geological stability over the last 200 million years (Myr). Much of the continent is deeply weathered. The relative stability, however, has ensured that the vast mineral and energy resources of Australia have been preserved and, indeed, created. These resources include the bulk commodities of iron ore, bauxite, coal and natural gas, which now generate much of the wealth for the Australian people. The resources sector, to which these bulk commodities contribute the majority of the value, is worth over $206 billion per year to Australia in export earnings. Increasing demand from our Asian neighbours is driving further growth in the sector. Demand for Australia’s natural resources, coupled with sound financial management and governance, ensured that Australia largely avoided the ravages of the 2008 global financial crisis (GFC).
Resources from a stable base

Australia is one of the most stable and strongest economies in the world. A major factor in this has been the unprecedented boom in demand for Australia’s high-quality bulk resources—in particular, from the rapidly developing Asian economies (Figure 9.1). In 2011, Australia was the 11th largest economy in gross domestic product (GDP) per head and 18th largest in total GDP. According to the International Monetary Fund, Australia’s GDP at purchasing power parity was US$919 billion (B) or US$40,836 per person in that year.

Stemming from its size and long geological history, Australia has a rich endowment of geological resources. Australia is a top-five producer of the world’s key resource commodities, including:

- world’s leading producer of bauxite, alumina, rutile, zircon and tantalum
- second largest producer of lead, ilmenite and lithium
- third largest producer of iron ore, uranium and zinc
- fourth largest supplier of LNG (liquefied natural gas)
- fourth largest producer of black coal, gold, manganese and nickel
- fifth largest producer of aluminium, brown coal, diamonds, silver and copper.

This impressive list of resource endowment for Australia is dominated economically by the main bulk commodities. These are high-volume/tonnage resources that require massive infrastructure and capital to develop. The Bureau of Resources and Energy Economics documented the key resources exports in 2011 as iron ore ($58.4 B), coal ($47 B), gold ($14.6 B), LNG ($11.1 B) and bauxite/aluminium products ($9.3 B), forming a pivotal (44%) share of the nation’s export trade. Each commodity attracts around $10 B or more in export income annually, and collectively they have had a unique influence on Australian society. The four bulk commodities of coal, iron ore, LNG and bauxite products make up 40% of the nation’s exports. They provide raw materials supporting the industrial development of modern economies in Asia, while delivering substantial economic and social benefits to the Australian people.

The favourable geological endowment of these resources is complemented by Australia’s stable democratic political system and a transparent regulatory environment. These factors have enabled commercial entities to invest the necessary billions of dollars in project development. This chapter presents a short history of the Australian economy and the major role of resources in shaping it. We discuss the main drivers of demand and the benefits in jobs, the development and economic achievement that rides on the back of the resources industry. We also consider some of the costs to society and the environment and the balance reached by sound governance. A summary of the geology of the main bulk commodities—iron ore, bauxite, coal and gas—is given, and the unique conditions that have led to this resource endowment are explained.
Figure 9.2: Locality map including place names mentioned in the text.
A brief economic history of Australia

Resources and the evolution of Australia’s economy

For thousands of years, the different regions of Australia had an economy based on the trade of goods rather than money. Aboriginal and Torres Strait Islander people exchanged prized stone implements, shells, ochres and pigments, along trade routes extending across many parts of the country (Chapter 1). Following British settlement of New South Wales in 1788, an Australian economy began to evolve. This evolution can be viewed in seven periods of time.

The early years: colonial expansion (1788–1820)

The economic development of Australia during the colonial expansion period depended upon the influx of convict labour, which was financed by capital from Britain. The early financial history of the colony of New South Wales was marked by a shortage of money. The Bank of New South Wales (today known as Westpac) was established in 1817 to bring some order to the finances of the colony and to act as a bank of issue. Competitor banks soon followed and, with capital structures in place, the colony developed rapidly once large areas of arable land were identified.

Wealth from the sheep’s back (1821–50)

In the first decades, the arable land to the west of the Blue Mountains of New South Wales (Figure 9.2) was an unknown. The first crossing of the mountains in 1813 led to a number of access routes to the arable grasslands, and the official seal of approval from Governor Macquarie for expansion was secured in 1820. A rapidly evolving worldwide wool industry was pivotal in the expansion. Wool was cemented as a key primary product of Australia at that time and, by 1820, Australia had a GDP per capita of $1528, the second highest in the world after the Netherlands.

Putting Australia on the map: the golden years (1851–90)

The public announcement of gold discoveries created a nexus with past development, particularly in the remarkable goldfields of central Victoria.
No previous mineral discovery in Australia was comparable with the new alluvial gold finds. Gold attracted labour from overseas and drew Australian workers from their jobs (Chapters 1 and 8). For the 10 years from 1851 to 1861, Victoria produced 750 tonnes of gold, some 40% of the world's output in that period. As the gold rushes ended, miners were absorbed into the Australian economy, resulting in increased availability of casual labour, much of which went into further developing the agricultural sector and other activities such as railroad building.

Despite these changes in the rural parts of Australia, the country remained predominantly urban. Only in Victoria (due to the rush to the goldfields) did the urban population fall relative to that in rural areas. Later mineral discoveries of the period, such as Mount Lyell (1881), Mount Morgan (1882) and Broken Hill (1883) led to new development, but this could not entirely offset the decline of the Victorian gold industry.

Arrested expansion (1891–1900)

An intense economic depression during the early 1890s led to a precipitous trough in activity by 1893, with 12 banks defaulting, taking two-thirds of Australia's bank assets with them. Falling export prices, ongoing drought, a cessation of capital inflow and land boom collapses led to a general decline in each of the Australian colonies. In contrast with most of Australian history since 1788, emigration from Australia occurred during this period. The discovery of gold in the supremely rich Eastern Goldfields (Chapter 8) saw a flood of easterners move to the west, and the expansion of the economy and population of the colony of Western Australia. These people took with them the values of a united eastern and western Australia, and it was their yes-vote in the Federation Referendum that ensured that Western Australia joined the Commonwealth.
New expansion and contraction (1901–39)

The strength of Australian balance of payments in the early 20th century made it possible to liquidate most of the commitments made to overseas creditors generated during the down-time of the 1890s. Australia also once again became an attractive destination for migrants, many of whom were subsidised by governments. At federation in 1901, Australia’s GDP included agriculture (20%) and mining (10%), together accounting for 95% of exports and more than 30% of the labour force. The GDP per capita at this time was $4299, second only to New Zealand in world standards.

The impact of World War I (1914–18) was widespread, with a decline in the flow of capital for long-term investment. However, one earlier theme continued strongly, that of increased metropolitan concentration based economically on rural development, a theme that continues today.

In 1910, some 40% of the Australian population resided in the six capital cities. The Commonwealth Bank of Australia was founded in 1911, issuing notes backed by the nation’s mineral resources. Following a pause after the 1929 depression and three bank failures in 1931, the growth in output of Australia continued.

The beginnings of the bulk commodity industry (1940–75)

By the end of the 1930s and into the 1940s, Australia had developed a rising manufacturing output, much of it initially to serve the war effort. From the end of the 1940s to the late 1960s, this manufacturing growth continued, representing a break with the largely agricultural or at least rural past. Australia’s prosperity was improving, and simultaneously mineral exploration companies increased activity. In 1950, Australia’s GDP per capita was $7218, or fifth in the world, led now by the powerful United States of America.
Following exploration successes, a highly capital-intensive mining sector developed, but it did not add to the total workforce in the same way as manufacturing or agriculture. The emergence of large markets in Japan, in particular, together with rapidly improving geological knowledge acquired by government geological surveys and measures taken to improve the efficiency of mining, fuelled this resurgence. Apart from Japan’s economic growth, the general expansion of the world economy in the 1950s and 1960s meant an ever-increasing demand for minerals. Australia, with its established industry, had the framework in place that enabled the development of new deposits to meet this demand. A major expansion of Australia’s aluminium industry followed the decision to mine bauxite in the Darling Ranges, Western Australia, in the early 1960s. The perception that high-grade iron ore resources were limited in Australia was turned around with the discovery of vast resources in the Pilbara in the 1960s. The economics of working some previously uneconomic deposits changed remarkably because of technological advances, which lowered the cost of mining and transporting huge quantities of material. These advances would not have been decisive without the emergence of Japan as a major buyer of coal, iron ore, bauxite and, later, LNG. Around 1964, a pivotal crossover occurred, with Australia’s growing exports to Japan exceeded the falling exports to the United Kingdom. In 1973, the GDP per capita in Australia was $12,485, or 10th in the world.

The Mineral Securities Australia Ltd (Minsec) collapse of 1971 sparked the most serious money panic in Australia since 1893. A poor call on the value of Poseidon shares during the nickel boom (Did you know? 9.1) culminated in the failure of some financial institutions. Exacerbating the Australian situation was the 1974 international oil shock and associated impacts on the global economy.

Shaping the economy and the people: bulk commodities (1975 to present)

The brief history detailed above highlights the uncertainty of economic security. Australia has moved, or by some measures lurched, from one means of sustaining itself to another. By the late 1970s, the rate of growth of the mining industry in Australia, which had been maintained for more than 15 years, began to slow. New mines had been developed around the world to meet a forecast demand for minerals, which turned out to be overly optimistic. The Australian industry’s costs had increased but mineral prices generally had not. The industry was largely dependent on exports and had to compete for sales with an increasing number of mines in other countries; some of these mines were less affected by cost increases, or were assisted in various ways by their governments. New coal mines were established in Australia after the second oil shock in 1979, but world demand slowed, leaving Australia with surplus capacity for a time.

Between 1983 and 1985, the then Treasurer Paul Keating deregulated the banking system by floating the Australian dollar (1983), granting 40 new

---

**Did you know?**

9.1: Fallout from the Poseidon crash

A small nickel (Ni) deposit at Windarra, Western Australia, was the subject of one of the most spectacular stock market ‘bubbles’ in Australian history: the Poseidon crash of 1970. Speculators drove the 80-cent stock to $280 before its inevitable crash. Many investors suffered losses and these, together with the negative media coverage, soured investment in the mining industry.

The government established the Rae Committee (1974), which recommended a number of changes to stock market regulation. The Poseidon bubble also led to the development of codes for the reporting of ore reserves, which were the forerunners of the present-day Joint Ore Reserves Committee (JORC) code, which has (along with the Canadian NI 43–101) become an international standard for reporting ore reserves.

Following exploration successes, a highly capital-intensive mining sector developed, but it did not add to the total workforce in the same way as manufacturing or agriculture. The emergence of large markets in Japan, in particular, together with rapidly improving geological knowledge acquired by government geological surveys and measures taken to improve the efficiency of mining, fuelled this resurgence. Apart from Japan’s economic growth, the general expansion of the world economy in the 1950s and 1960s meant an ever-increasing demand for minerals.

Australia, with its established industry, had the framework in place that enabled the development of new deposits to meet this demand. A major expansion of Australia’s aluminium industry followed the decision to mine bauxite in the Darling Ranges, Western Australia, in the early 1960s. The perception that high-grade iron ore resources were limited in Australia was turned around with the discovery of vast resources in the Pilbara in the 1960s. The economics of working some previously uneconomic deposits changed remarkably because of technological advances, which lowered the cost of mining and transporting huge quantities of material. These advances would not have been decisive without the emergence of Japan as a major buyer of coal, iron ore, bauxite and, later, LNG. Around 1964, a pivotal crossover occurred, with Australia’s growing exports to Japan exceeded the falling exports to the United Kingdom. In 1973, the GDP per capita in Australia was $12,485, or 10th in the world.

The Mineral Securities Australia Ltd (Minsec) collapse of 1971 sparked the most serious money panic in Australia since 1893. A poor call on the value of Poseidon shares during the nickel boom (Did you know? 9.1) culminated in the failure of some financial institutions. Exacerbating the Australian situation was the 1974 international oil shock and associated impacts on the global economy.

Shaping the economy and the people: bulk commodities (1975 to present)

The brief history detailed above highlights the uncertainty of economic security. Australia has moved, or by some measures lurched, from one means of sustaining itself to another. By the late 1970s, the rate of growth of the mining industry in Australia, which had been maintained for more than 15 years, began to slow. New mines had been developed around the world to meet a forecast demand for minerals, which turned out to be overly optimistic. The Australian industry’s costs had increased but mineral prices generally had not. The industry was largely dependent on exports and had to compete for sales with an increasing number of mines in other countries; some of these mines were less affected by cost increases, or were assisted in various ways by their governments. New coal mines were established in Australia after the second oil shock in 1979, but world demand slowed, leaving Australia with surplus capacity for a time.

Between 1983 and 1985, the then Treasurer Paul Keating deregulated the banking system by floating the Australian dollar (1983), granting 40 new

---

**Figure DYK 9.1:** The share price for Poseidon from late 1969 to 1970. The nickel boom saw an 80-cent stock rise to $280 in a matter of months. Some made fortunes, but many investors lost their money from the inevitable crash from these dizzy heights. (Source: Simon, 2003)
foreign exchange licences (1984), and granting banking licences to 16 foreign banks (1985). Despite slow global growth, exports to Japan continued to expand. In the late 20th century, massive new industrialising markets emerged in China and, to a lesser extent, India. In 2000, GDP per capita was US$20,866 or 23rd in the world. By 2006, however, it was US$37,433 and 15th in the world, the increase a function of the high prices paid for Australia’s quality resources. The trend has continued to 2011 at US$40,836 or 18th in the world.

One aspect of the ongoing economic development of Australia is the impact on the quality of life of Australian people. Australia’s population is increasing at 1.4% per year, which is leading to increasing impacts on the resident population. These effects are not limited to economic matters, but include environmental, employment and social costs (including housing shortages and rising house prices). The prevailing circumstances mean that some of these costs can be ameliorated by financial means, such as higher wages and lower taxes, which are largely funded through ‘dividends’ from the resources export industry.

The most important difference from previous booms is the driver, the industrialisation of the BRICK group of countries—Brazil, Russia, India, South Korea and, particularly, China. Other mining booms can be linked to the industrialisation of economies—Japan in the 1960s and 1970s, for instance—but the size of the population in the BRICK group has made the current boom larger and longer than previous booms. Over the past two decades, real growth in China has averaged 9.4%. By 2025, China’s cities are expected to grow by more than 200 million people, which equates to creating three Sydney
As a consequence of this growth, China has become a net importer of many commodities, thereby driving up their global price, and China is now the largest destination for Australian exports. One of the reasons that Australia did not feel the full effects of the GFC is that Australian exports, particularly of minerals, were tied to China, which continued to grow (Figure 9.3).

The demands of China and India for raw materials have also affected, and will continue to affect, the ownership of Australia’s mining industry. Traditionally, the funding and resulting equity in Australian mining houses came from Britain, Europe and North America, but in the current boom much of the capital invested in Australian mining has come from China. This reality will continue to affect government policy on overseas investment.

A final difference between this and previous booms may be its longevity (Figure 9.1). Many analysts argue that the present boom looks set to continue at breakneck speed for the foreseeable future—although, no doubt, the same was said for each of the previous booms. The industrialisation of the BRICK group of countries will eventually bring 2 billion people to developed-world living standards. The resources required to achieve this may continue to fuel Australia’s current mining boom for years to come, provided that investment continues for projects and Australia maintains a competitive edge in minerals geoscience.

**Living in contemporary Australia**

Most Australians in the early 21st century have an enviable quality of life. Although not without its societal and environmental problems and issues, Australia is fortunate today to have one of the best-performing economies in the developed world. Australia is a middle-sized power, but exerts an influence on the world beyond what one would expect from the 22.7 million people who live ‘down under’. The contemporary economic dynamic that has positioned Australia is underpinned by geology, especially by the big four bulk commodities of coal, iron ore, bauxite products and LNG.

These bulk commodity drivers are feeding the demand of our neighbours in Asia, and this has led to a post-2000 world where the economic

---

*Figure 9.3: Growth of GDP in selected countries. Note that Australia endured a much smaller drop in growth rate following the global financial crisis than did equivalent developed economies (such as the European Union and Organisation for Economic Cooperation and Development). Australia’s growth mirrored more closely that of India and China, as a result of their ongoing demand for Australia’s bulk commodities. (Source: World Economic Outlook Database from IMF)*
realistic is no longer predictable, as seen in Figure 9.1. China is Australia's largest merchandise export market, accounting for $46.5 B in 2009–10. This is followed in order by Japan ($37.1 B), South Korea ($16.5 B), India ($16.2 B) and the United States ($9.5 B).

Strong domestic demand can readily constrain a country’s capacity to export. For example, the United States, with around 27% of global coal resources compared with Australia’s 9%, has not developed its export industry for coal to the same degree (Figure 9.4; Table 9.1). This is a direct result of the need for the United States to first satisfy its domestic market and only export the surplus. There is a contrast between the two nations in domestic and export consumption; for Australia, domestic demand is less than 70% of production. Limited domestic demand has facilitated Australia’s role as the world’s largest exporter of coal and iron ore.

Australia does not have a ‘top 10’ LNG resource, nor the largest known resources of bauxite, but it is the world leader in bauxite production and a prominent and growing producer of LNG (Table 9.1). Whether resources are developed and

<table>
<thead>
<tr>
<th>World rank</th>
<th>Resources</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Coal</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Iron</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>LNG</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Rutile&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Zircon&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ilmenite&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Uranium</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

(Sources: Geoscience Australia, 2011; US Energy Information Administration, 2011; DRET, 2011)

<sup>a</sup>Rutile, zircon and ilmenite are derived from mineral-sands deposits.

Figure 9.4: Share of proven global coal reserve (2010). Australia holds a relatively small coal resource compared with its dominance of the global export market. (Source: BP Statistical Review of World Energy, 2011)
exported depends on a myriad factors, including the domestic market, location of resources, political stability, educated workforce and established legal structures. Although Australia does have a strong resource base, it is these external factors that have spearheaded development and led to an extensive export industry. Access to land and funding for exploration remain key factors for the industry's future because new deposits provide the opportunity to expand resources.

Australia has earned a well-deserved reputation as a reliable and competitive supplier of a wide range of high-quality mineral and energy products (Figures 9.5 and 9.6). Prevailing conditions in the global marketplace constrain Australia to the role of ‘price taker’, rather than setting prices according to the cost of production. The peaks and troughs of demand reflect economic cycles (Figure 9.3) and further reinforce Australia's role as a price taker.

Historically, industrialisation and growing incomes have led to shifts in the composition of economic activity to encompass higher shares of consumption and services, at the expense of other sectors such as investment, construction, manufacturing and mining commodity industries. Although China and India are likely to follow this path, the vast size of their population means that this transition could be expected to take years, possibly decades. Given this, it is likely that growth in their consumption of raw materials will remain robust for some time yet.

The rapid industrialisation of China, in particular, has led to an unprecedented market for Australia. China is the most rapidly mobile population in history, with hundreds of millions of people leaving rural areas for the eastern cities in a matter of decades. Cities require resources, such as steel, concrete, energy, water and food. This process of industrialisation, and the requirement particularly for coking coal and iron ore, repeat the industrial ‘revolution’ that occurred in the west some 200 years ago.

Contrary to some expectations, there does not appear to be a long-run tendency for the prices of mined commodities to fall relative to the price of manufactured goods. Mineral prices have remained very strong in recent years. Most notably, increased demand from steel producers, especially in China, has driven up the prices of iron ore and coal. Australian mining houses are trying to ramp up supply in response, as are producers elsewhere in the world. The efforts of mining companies to increase production can be hampered by large fixed costs, the capital-intensive nature of
modern mining, the lack of critical infrastructure and competing sectors for investment return. Consequently, new production may lag the initial investment decision by a number of years. A result of this lag is that prices run up excessively, and this can be followed by periods of weakening as global supply expands, with prices falling in absolute terms during recessions. Past experience suggests that the projected increase in demand will underpin current prices for the medium term, but beyond that prospects are less certain.

The depletion of higher quality resources could, in time, make commodities more expensive to mine. Furthermore, declining grades and the requirement for more complex levels of processing could lead to increased environmental impacts and higher production costs. Hence, there is an ongoing imperative to discover and delineate new resources to sustain future production.

Societal benefits

Jobs and services for Australians

The early 21st century has seen Australia’s capital cities thrive. Restaurants and cafes work to capacity, traffic is frustratingly busy and employment is strong, all indications that the economy is providing positive outcomes. The minerals sector directly employs only a small proportion of the Australian workforce, around 130,000, representing only about 1% of the total labour force. The intense activity in the bulk commodities sector is characterised by materials handling and technical/professional support based at largely static locations, thus having some parallels with the manufacturing sector.

The social effects of the cycles in the minerals and energy sectors can be profound. During boom times, workers are drawn to remote areas for high wages. In 2010, the Australian Bureau of Statistics calculated average mineral industry wages at around $103,000 compared with hospitality at $46,000 or construction at $65,000. Often the communities these workers are drawn from find the remaining labour pool inadequate to fill necessary jobs. At the same time, the remote towns rapidly increase in population, straining physical and social infrastructure. Underwriting the development of regional infrastructure, including railways and roads, manufacturing and information technology, the Australian minerals industry also contributes to
the economy in multiplier effect. There is a saying: ‘for every job in the resources sector, another four jobs are created’. While the precise ratio is debatable, it is significant that the reverse situation also occurs after the booms, with attendant social implications.

The benefits of the minerals industry to the Australian community extend far beyond direct labour and exports (Figures 9.5 and 9.6). The Australian minerals industry provides the greatest value adding of any sector to the Australian GDP per person employed. The wealth generated by the bulk commodities industry has contributed substantially to the support of community services such as social equity payments, hospitals, police, infrastructure and other government services. Australia is a developed country with a highly educated workforce and is generally an early adopter of new technology. In effect, the bulk commodities, along with other resources exports, allow Australia to fit the mould of a developed first-world country, without a large manufacturing sector that traditionally characterises such economies.

Regional infrastructure and economic development of regional Australia

Large areas of Australia have been opened up by developments associated with the bulk commodity export industry, despite the limited area actually required for the mining operations. Towns, community facilities, transport and communications infrastructure, including roads, ports, airports and railways, have been built almost entirely by resource development, funded by private capital.

The Pilbara and surrounding areas in Western Australia provide a contemporary illustration of the development impact of resources. Prior to the iron ore discovery, there was a small population and limited infrastructure in this remote region. Today, there are significant communities at Newman, Port Hedland and Karratha, towns largely based in mineral extraction and shipping, with purpose-built railways and ports, along with supporting infrastructure such as airports. The heavy-duty railways of the Pilbara region have pushed the limits of wheel-to-rail interface technology, adding useful knowledge to railways worldwide. Rio Tinto plans to further expand iron ore production capacity on the railway line linking its mines to the port at Dampier. Without the development of the Pilbara’s iron ore and the North West Shelf gas, the region would probably have remained largely underdeveloped.

Late 19th and early 20th century mineral sector development saw new mines planned as large-scale operations, with the construction of adjoining residential areas from the very beginning. Large workforces needed to be housed, and provided with community services and transport facilities developed to handle millions of tonnes of product each year. Rather than provide these facilities, governments in Australia made it a condition of many new mining leases that the companies did so, with major financial investments not only in the mining operation but in social infrastructure, such as streets, houses, schools, hospitals and recreation facilities.
National and regional economic benefits

The minerals sector contributed 9% of Australia’s GDP in 2011, being the second largest sector after finance and insurance, according to the Reserve Bank of Australia. Only in economies such as Canada, Norway and the Middle Eastern gulf states does the production of minerals and energy play as significant a role. In most developed economies, mining represents less than 2% of GDP.

The benefits of the minerals industry to the Australian community extend far beyond export profits, with economy-wide impacts made through the multiplier effect. Put simply, the demands of the resources sector support a myriad other activities, such as services, manufacturing and technical and intellectual development. Despite the remote location of the resources, the cities around Australia are dependent upon the resources industry to varying degrees. Perth is the support and supply base for numerous Western Australian petroleum and mineral operations. The city’s economy strongly reflects this dependence on prevailing circumstances in the resources sector. The Western Australian Government alone has a ‘Royalties for Regions’ program that aims to spend around 25% of the royalty revenue in the regional areas that created the wealth. In 2009–10, an additional $619 million to the regular Budget programs was provided for regional communities. Projects are wide ranging and include health, education and infrastructure, as well as significant spending ($80 million over five years) on acquiring new geological knowledge of the state.

Societal impacts

The success and opportunities brought to Australia by the bulk commodity trade have not been without issues for society. Around 0.02% of the land area of Australia is physically affected by mining and resource development. This is about the same sized area as the citizens’ residential driveways. Although this area of mining disturbance is small compared with that caused by other activities such as real estate development, farming and grazing, road construction and urban growth, the minerals industry must responsibly manage the environment in which it operates.

The risks of higher inflation, acute skill shortages and potentially some symptoms of what economists know as ‘Dutch Disease’ have been at least partial consequences. Dutch Disease was first identified in the natural gas export boom years of the Netherlands. One effect of Dutch Disease is that a currency is strengthened in its price parity with other currencies. It can have a negative effect on the competitiveness of other industries and activities in those regions not benefiting from the resource trade. A current example in Australia is the high price of the Australian dollar (above parity with the US dollar through much of 2011), which makes Australia an expensive destination for inbound tourists and overseas destinations cheap for Australian travellers. Australia had been able to avoid more severe impacts, but the phenomena associated with a ‘two-speed’ economy have influenced the policy considerations of government and other authorities. To avoid negative impacts of inflation the Reserve Bank of Australia was raising interest rates, while comparable economies were lowering theirs.
The resources sector is cyclical in nature. Rapidly increasing production and export levels of the previous five years stalled during the 2008 GFC, following significant falls in metal prices. This downturn brought reductions in capital spending, exploration and workforce in Australia and internationally. Viewed in hindsight, this may appear as a small negative deviation; however, the effect on industry and individuals at the time was dramatic.

The rise of fly-in/fly-out (FIFO) mining, whereby personnel are flown to and from capital cities on charter flights direct to the mines, may also present societal challenges. Rosters are variable, but nine on-days days and five off-days are common. Life at the mine is based around a generally well-equipped camp, with a canteen, wet mess (bar), internet access, gym and other recreational facilities. Although the majority of the workforce is male, women are well represented in some areas, particularly as truck drivers and geologists. FIFO has not been a major part of the bulk commodities workforce to date, due to the existence of well-established residential towns. However, it has seen significant growth from a small base. People are drawn by higher potential wages from the trades and professional jobs in the southern cities of Australia to work in remote regions at the mines and other support services to the minerals industry. Many employees, however, view the FIFO lifestyle as a transient phase. Once they have achieved a financial or career goal, many workers move onto a more traditional job environment, perhaps in the company’s urban headquarters or with another employer.

The environment and social licence to operate

We have stressed that many bulk commodity operations are located in areas remote from major metropolitan centres. Even so, the industry increasingly finds that it is required to justify its activities in competition with other potential land users. From the 1960s onwards, the mining industry became increasingly influenced by public concern for the quality of the environment—leading to what is known as a social licence to operate. With the rising awareness that preservation of natural features such as scenery, plant and animal habitats, cultural and even geoheritage had a value to society, governments increased controls, for instance, on discharge of potentially polluting emissions, such as water containing sediments or chemicals, and noxious gases.

Initially based on the more densely populated coastal strip, particularly ocean beaches, the mineral sands industry was early to face difficulties in their social licence to operate. Although Australia
Sustaining Australia's wealth—economic growth from a stable base
continues to play a major role in the global output of commodities mined from mineral sands, especially heavy minerals such as rutile, zircon and ilmenite (Table 9.1), some proposed mines have been mothballed and are under threat of closure due to community objections. From a revenue base of $1.15 B in 2005–06, mineral sands fell to $1.08 B in 2010–11. This is despite Australia’s prominent position as a supplier and the rapidly increasing global demand for commodities. The media profile and community awareness of the mineral sands industry reflects the proximity of the resource to areas recognised as high value to the Australian population for tourism and conservation purposes, as opposed to the experience of the coal, iron ore, aluminium and natural gas industries, in general. Significant new issues have arisen in recent years that may lead to consequences for the other bulk commodity industries that have been faced by minerals sands project proponents for many years. The suite of conflicts associated with competing land use, such as at Liverpool Plains in New South Wales for the Caroona coal mine proposal, proposed coal-seam gas projects in southeast Queensland or conventional gas at James Price Point in the Kimberley region of Western Australia, will be dealt with on a case-by-case basis.

Recent coal-seam gas proposals in the eastern states have experienced objections paralleling those that arose earlier over sand-mining proposals. The physical location of the wells and associated infrastructure can impact upon a significant area of arable land (e.g. Bowen and Surat basins in Queensland) (Figure 2.9). One company even has plans for drilling for coal-seam gas in an inner Sydney suburb. The recovery process—called ‘fracking’—uses a chemical mixture injected under pressure to improve the permeability structure of the gas-bearing coal seams. There are community concerns about the safety of the groundwater due to pollution from these chemicals, some of which may be carcinogens.

The dewatering of coal seams may impact on existing groundwater users (Chapter 7). Brackish water is also produced during dewatering. Disposal of this saline production water can present an environmental issue. Utilising a series of evaporation ponds to reduce the water volume takes up land area, and the resulting highly saline brine must be disposed of sensitively. Recent approvals have required the implementation of other technologies to treat production water and dispose of associated...
waste streams. Coal-seam gas operators are required to treat and dispose of the wastewater to maintain groundwater pressure as a first priority, and in some cases to allow other beneficial use of the extracted and treated water. Reinjection of treated water to repressurise artesian aquifers and the use of saline water for local coal-wash plants are options being actively explored.

Prior to the advent of commercial coal-seam gas operations, natural gas accumulations were usually vented to the atmosphere. As methane is a highly intensive greenhouse gas, with a global warming potential significantly higher than carbon dioxide (CO$_2$), this represented not only a wasted resource, but also an emission source for greenhouse gases. Exploration and mining leases are now required by law to be rehabilitated; some rehabilitation involves reshaping and revegetating the surface, often resulting in a significant increase in land quality. Most interesting is that resource companies are the largest sector employing Australian environmental scientists and, increasingly, Indigenous workers. Companies are often able to draw upon the knowledge of local Indigenous people to ensure the best results for rehabilitation.

Environmental and social concerns in relation to the mining industry have also become global. Widespread uptake of new communication technologies occurred around the same time as the Australian mining industry grew from a large national sector into a world player. This increasing globalisation has led to an increased consciousness regarding the environmental consequences of exports once they have left Australia’s shores. For example, there have been concerns over CO$_2$ emissions resulting from the burning of exported Australian coal, although many studies have shown that mixing the coal with lower quality local resources can result in large environmental benefits. The low sulfur and ash content of Australian coal has led to marketing efforts to ‘package’ it with local coal for more efficient use in developing nations. Gujarat NRE Coking Coal Ltd exports Australian coal to India, where it uses the ash by-product in the company’s cement works, thereby maximising resource utilisation. The low sulfur content of Australia’s coal resources presents a number of environmental and engineering advantages globally over many other coal resources.

The market recognises this relative advantage with regard to sulfur content, and Australian coal commands a market premium as a consequence (Figure 9.7). About 40% of the world’s electricity is generated using coal, and this proportion is steadily increasing. By comparison, nearly 80% of electricity in Australia is generated by coal-fired power stations. In capital-intensive industries, such as power generation, it is technologically difficult to achieve rapid change. Therefore, if there were to be a global move to restrict the use of coal because of climate change concerns, such a transition would likely take decades.

Production of bulk commodities inevitably results in emissions of CO$_2$; however, significant advances have been made in reducing the impact through the incorporation of newer technologies.

Australian industries have long argued that they operate in a world market and that, if similar environmental operating conditions are not placed on all producers, they will be at a competitive
disadvantage. Australian and international law on climate change remains in a state of flux, and pressure is mounting in the domestic and international arenas. It is conceivable that developments in international law could force changes in the way that Australia’s greenhouse emissions and trade impacts on global emissions are calculated.

**Technology and innovation: keeping ahead of the game**

Contrary to the perception in some parts of society that the resources sector is a ‘sunset’ industry, the sector has consistently exhibited a high degree of innovation and technical advancement. Contemporary examples are the development and use of software, remote-controlled operations and advanced geoscience expertise; historical examples include initiatives such as mineral flotation and electrolytic smelting. Australian companies are major developers, users and exporters of computer software used to improve and increase the efficiency of mining operations. To lessen its exposure to external forces, Australian industry operators have long been at the forefront of implementing technologies of scale in both coal and iron ore operations, driving down costs and improving productivity. These are important attributes to keep Australian mining operations price competitive and thus major suppliers of the world’s mineral commodities.

A more recent phenomenon is the increasing number of mine personnel who are able to operate equipment remotely from the capital cities. For example, Rio Tinto has satellite links with its Australian mines that allow workers some 1200 km away to operate drill rigs, load cargo, use robots to place explosives and perform production blasts. Robotic machines monitored by electronic eyes in the Pilbara region transmit images and data to the Perth operations centre, dig out the broken ore, move it to automated
conveyor belts and activate water sprays to remove fines and reduce dust. These remote-controlled operations not only reduce direct financial costs, but also importantly reduce exposure of workers to potentially hazardous situations. The West Angelas iron ore mine in the southern Pilbara is an example of technological development, with an autonomous haul-system fleet accessing the Marra Mamba iron ore deposit, using a FIFO roster for on-site staff. The company’s Perth data centre employs 300 personnel; engineers are able to monitor large screens to set movement commands for the remotely automated machines. Ore haulage using driverless trucks has been trialled at Rio Tinto’s West Angelas iron ore mine in the Pilbara. A fleet of 160 automated trucks, which will be run from the company’s Perth operations centre, is scheduled for 2015.

New technology can compensate for declining quality of ore, such as the carbon-in-pulp technique for gold extraction (Chapter 8). The development of new technology has largely been driven by necessity as easy and more accessible mineral resources have been exploited, leaving remaining resources in more remote locations that are more difficult to develop. The shift to more technologically advanced operations, through the use of remote operators, has the potential to help resource companies attract and retain skilled and valuable employees who wish to minimise the time they spend in remote locations.

**Governance: getting the balance right**

One romantic view of mining in the 19th century gold rushes is the individual prospector who pegged his claim and worked the ground by hand. In contrast, the mining of bulk commodities is underpinned by massive economies of scale, organised labour, complex technologies and substantial infrastructure investment. Commercial entities developing these projects take substantial financial risks, which governments can mitigate by providing high degrees of regulatory certainty. A stable society, stable political system and well-established legal environment with an adherence to the ‘rule of law’ have provided the necessary framework for investment that encouraged developers to proceed with large-scale export projects in Australia.

Australia’s federal system of government is enshrined in its constitution of 1901. The Australian people live in a country that is divided into six states and three territories (including Norfolk Island), further subdivided into around...
Did you know?

9.2: Community ties in Weipa

Weipa in western Cape York is a small coastal community of about 2000 people, with a unique Aboriginal heritage. Local traditional owner groups include the Alngith and a number of others, including the Aboriginal communities of Napranum, Aurukun, Mapoon, Injinoo and New Mapoon.

Weipa’s history is predominantly linked with Rio Tinto–Comalco Aluminium’s bauxite mine, which has been operating since the early 1960s. Mining predominates in Weipa, although tourism, especially fishing and ecotourism, is growing rapidly.

The traditional owners, Comalco Aluminium Limited and the Queensland Government, signed on the 14th March 2001, the Western Cape Communities Co-Existence Agreement (WCCCA), making a commitment to focus on Aboriginal economy, culture, education, employment and training. Already there have been improved educational attendance, academic performance and employment outcomes for the local people. Traineeships for local Aboriginal people have increased, and the company has worked with the community to preserve sites of cultural significance and supported cultural activities.

700 shire or city councils (local government). Broad economic policy settings are a federal responsibility and, with the exception of the offshore regime, the regulation of the resources sector is a state or territory responsibility. The monitoring of foreign investment and, where necessary in the national interest, its control is an Australian Government responsibility. Recognising the need for capital inflows to sustain regional growth, Australia’s foreign investment policy is designed to encourage investment consistent with the interests of the community. One formal mechanism to ensure consistency is the assessment of foreign investment proposals, with approval subject to their not being considered contrary to the national interest.

Governments in Australia do not seek to participate directly in resource developments; however, there is a historical legacy of some state government involvement in the mining of coal for power generation. State governments, by virtue of their wide powers to regulate matters within their own boundaries, are more directly involved in the day-to-day administration and regulation of mining operations. The granting of exploration rights and mining leases, the approval of mining operations, and the levying of royalties and other like charges is a state responsibility. State governments also consider environmental protection and rehabilitation aspects of development proposals. The cost for all of the environmental works associated with a project is borne by the proponent. State and Australian governments carry out precompetitive ‘exploration’ and geoscientific mapping in onshore and offshore Australia (Chapter 2). However, the Australian Government has a responsibility in terms of investment attraction, derived through its national economic management role and maintains overriding responsibility for petroleum activities in Commonwealth waters (Chapter 4).

The majority of Australia is arid, and subterranean groundwater in many areas is a scarce, valuable resource (Chapter 7). However, once regulatory requirements are met, groundwater supply can usually be secured where surface water is not available, but this comes at a cost. The large distances between significant sites and settlements in Australia are an overriding aspect. Government support for the resources sector has assisted in the development of rail, road and port infrastructure in some of the more populated regions. Private investment has usually facilitated infrastructure development in the more remote parts of the country, such as the Hamersley iron ore province and the bauxite mines in the tropical north.

A wide range of issues concerning development and sustainability face the minerals sector. Companies need to sustain a high level of community acceptance, and this has been recognised publicly through the triple-bottom-line reporting of social, economic and environmental performance under the Code for Environmental Management developed by the Australian minerals industry. Almost without exception, the majority of Australian mining and petroleum companies prepare and issue sustainability reports. The finite nature of mineral resources and the strong potential for rapid decline in demand represent other challenges. Resources companies and Australian governments work to ensure that these issues are minimised; however, declining grades do raise the potential for increased environmental impacts.
Native title—Indigenous Australians gain a right

The High Court of Australia’s landmark decision in 1992 to extinguish the colonial concept of *terra nullius* and recognise native title of the traditional owners was an important step in Australia’s social development. By developing regulatory systems that take into account the requirements of government and the capacity of industry, and engaging affected people, especially Indigenous people, in the process, a community licence to mine is sought and often achieved.

The 1992 *Mabo v Queensland* (No. 2) High Court decision finally recognised that Australia’s Aboriginal and Torres Strait Islander people held legally responsible rights to land. The High Court proclaimed that ‘the common law of this country recognises a form of Native Title which, in the cases where it has not been extinguished, reflects the entitlements of indigenous inhabitants, in accordance with the laws and customs, to their traditional lands’.

The *Native Title Act 1993* commenced on 1 January 1994. In 1998, the Federal Parliament passed a comprehensive package of amendments, which commenced on 30 September 1998. Under the Act (or approved state/territory legislation), applicants for onshore mining or petroleum titles are required to undertake formal negotiations or consultations with native title holders or registered native title claimants who have registered a claim over the area prior to the grant of the titles.

The recognition of native title has significantly enhanced the position of many Indigenous communities in rural and regional Australia. These
communities have become integral stakeholders in mineral and petroleum resource development. The use of Indigenous land use agreements between Indigenous groups and mining and exploration companies has proven a win–win in a number of cases. Indigenous people have secured cultural support, training and work, while companies have been able to more readily attract workers already living in remote areas such as Cape York or the Pilbara (Did you know? 9.2).

Partnership programs reflect the aspirations of Indigenous communities for training and employment and for establishing commercial enterprises. Commercial arrangements are also expanding, under which traditional owners take on ownership of mining ventures and support organisations. For example, the Alice Springs-based CDE Group, which provides mining and civil works services to industry, is 51% owned by Lhere Artepea and 33% owned by the Rusca family, making its Indigenous ownership 84%. The success of the CDE Group was recognised formally when the company won the Contract Miner of the Year award at the 2008 Australian Mining Prospect awards.

The carbon wealth of Australia: coal and the Australian people

The early discovery of coal in Australia stands apart from the more recent, technical or geological discoveries of bauxite, iron ore and gas (LNG). A group of escaped convicts, led by William and Mary Bryant in March 1791, found coal when they beached their vessel south of Newcastle near the entrance to Lake Macquarie. From the ship's record ‘we picked with an axe as good coals as any in England … they burned exceedingly well’. For the Newcastle area, this discovery initiated a sequence of pivotal developments that continue to influence the social and cultural fabric of the Hunter region today.

In the years following the Bryant discovery, coal occurrences were reported at many other centres to the north and south of Sydney. The coal industry began in 1798 when ship owners gathered surface coal at Newcastle and brought it to Sydney for sale. Export of Newcastle coal began in 1799 with a shipment to Bengal in India. Coal was discovered in Tasmania by the French near Recherche Bay in 1793; after settlement, coal was mined there from 1803 onwards on a small scale.

Coal is now mined in all Australian states (Figure 9.8). The location and high quality of Australia’s coal resources have led to a heavy domestic reliance on this fuel source for power generation. Queensland and New South Wales have the largest black coal resources and production. Victoria hosts the largest resources and only production of brown coal. The coal industry is one of the mineral industry’s largest employers, Queensland having more than 88 225 and New South Wales more than 19 000 direct employees at the start of 2011. In that year, Queenslanders produced more than 9500 tonnes of coal per employee from 52 operating mines.
Geological setting of Australia’s coal

Australian coal of economic significance occurs in Permian, Triassic, Jurassic, Cretaceous and Cenozoic sedimentary basins. The most economically significant coal accumulations are in the Permian and Cenozoic; however, minor but important measures exist in the Mesozoic.

Generally, the Permian coals are hard, with a coal rank between high-volatile bituminous and anthracite. The Mesozoic coals are high-volatile bituminous, relatively hydrogen-rich and carbon-poor (perhydrous) coals. The Cenozoic coals are low-rank lignite.

The Carboniferous was the main coal-forming period for the Northern Hemisphere. In contrast, Australia’s Carboniferous coals are poorly developed, with only thin coals known from the Coen region in Cape York Peninsula of Queensland, and also along the northern margin of the Sydney Basin in New South Wales. Australia lay in close proximity to the South Pole during the Carboniferous (Chapter 2). Although climatic conditions for plant growth were suitable, as evidenced by the abundant plant remains in the fossil record, it was relatively dry (Chapter 3). Ice sheets and local valley glaciers extended across the Australian land mass during the Late Carboniferous to Permian (Chapter 2). Formation of peat, and hence coal, was limited, with some minor occurrences in the Cooper and Arafura basins in central and northern Australia.

Permian coal is widely distributed throughout Australia, from the Collie Basin in Western Australia, the Arckaringa Basin in central Australia, the Sydney Basin in New South Wales and the Bowen, Cooper and Galilee basins in Queensland (Figures 2.9 and 9.8). The main Permian coal-producing basins in eastern Australia were formed in the foreland of the convergent Gondwana margin, to the west of a volcanic arc system. The foreland basins and associated arc developed on the early Paleozoic Lachlan Orogen of the Tasman Element (Chapter 2).

Figure 9.8: Map of the main black coal resources in Australia. Note the dominance of the resources near the east coast, adjacent to the main population centres of the country. Not surprisingly these resources have shaped the energy choice of the Australian people. Nearly 80% of Australia’s electricity is generated from burning coal. (Source: Geoscience Australia & Australian Bureau of Agricultural and Resource Economics, 2010)

EDR = economic demonstrated resources; PJ = petajoule;
SDR = sub-economic demonstrated resources
Why do Australia’s Permian coals command such a high price?

Australia’s Permian coals are prized around the world; they command high prices on markets and are known for their exceptional thickness, quality and rank. For both coking (metallurgical) and power generation (thermal), these coals have outstanding qualities.

Australia does have other coals, but the Late Permian Sydney and Bowen basins form the bulk of the export coal from Australia. These basins host abundant, relatively easily mined, vitrinite-rich coals, with a sulfur content of less than 1% and a low ash content, generally less than 10% (Figure 9.7).

The main controls on the formation of the Permian coal appear to be a combination of palaeoclimate and palaeotectonic setting. To form thick coal seams, a steady and ongoing creation of suitable accommodation space is needed to allow the initial peat deposits to accumulate. Each of the 30 m (or more) thick seams of coal at Blair Athol in Queensland would have originated from a layer of peat that was more than 400 m thick.

The foreland setting of the basins tended to remain at sea-level, ensuring that the accommodation space was balanced by sediment supply—an ideal situation for peat accumulation. The high-latitude palaeogeography was moist and temperate in the Permian, which resulted in limited decomposition of the accumulating organic matter. This played a key role in peat accumulation and preservation, and is analogous to the modern peatland environment of northern Canada.

Volcanism to the east of the present deposits contributed volcanic detritus, now represented by tuff horizons. Locally, tuffs are interlayered with the coals, such as in the Wollombi Coal Measures from the Newcastle area. An eruption analogous to that at Mount St Helens in 1980 flattened a peat forest in a west-southwest direction from a laterally directed volcanic blast. A thick blanket of volcanic ash from that event overwhelmed the peat swamps in which trees were still growing.

The virtual absence of pyrite (FeS₂) and other sulfur-bearing minerals in most Australian coal resources (Figure 9.7) reflects the fact that these terrestrial successions were flushed by freshwater with low sulfate content. Higher sulfur levels accompanied by high boron levels occur locally in the central eastern area of the basins, reflecting Late Permian marine incursions. Hydrogen sulfide (H₂S), produced by bacterial reduction of the sulfate and combined with dissolved iron in the seawater, only permeated through the peat following these marine transgressions. Pyrite is most abundant in the Greta seam of the Sydney Basin and the Garrick seam of the Bowen Basin. In both cases, the coal seams are overlain by a marine succession.

Coal is a complex organic-rich rock produced by the low-temperature metamorphism of peat, the effects of which are known as rank. The carbon content increases and the water content decreases with increasing rank. The coal rank in the Sydney–Gunnedah–Bowen basins decreases markedly from east to west and appears to be controlled mainly through burial depth, although magmatic intrusions do locally increase coal rank. The
highest coal rank occurs in the northeast Bowen Basin. High-rank coals emit their volatiles at high temperatures; low-rank coals tend to produce a crumbly, powdery residue. Medium-rank coals emit volatiles at the same temperature at which they become fluid, causing the coal to froth. The weakly resistive liquid coal material fills with bubbles to form an expanded, carbon-rich material with a large surface area and strong resilient framework, known as ‘coke’, which is used predominantly for the smelting of iron.

The Sydney Basin is geologically contemporaneous with the Bowen Basin and covers an area of some 35 000 km$^2$ (Figure 9.8). The Sydney Basin coal successions are covered by a thick and, relative to the Bowen Basin, continuously preserved cover of Triassic sediments. As a consequence, development of coal resources has concentrated on deposits near the basin margins where the cover is thinner. The Sydney Basin passes into the Gunnedah Basin to the northwest, which is a source of both metallurgical and thermal coal and a region of coal-seam gas (CSG) exploration.

The process of coalification in the Bowen Basin took place largely during the Triassic under a relatively high-heat-flow regime, when the highest temperatures developed in the northern and eastern parts of the basin. Low-volatile bituminous or anthracite coals were formed in the north and east as a consequence. Whereas the coals from across the basin are suitable for thermal purposes, only in the northeast was the temperature optimal for forming the moderately volatile coals suitable for coking—an extremely high-value coal resource.

High-quality thermal coal can be derived from much of the Sydney–Gunnedah–Bowen basins, with the high quality due to a generally low ash and sulfur content. This coal is ideal for the production of electricity or other uses that require a high heat with few environmental effects, except the generation of CO$_2$. Metallurgical or coking coal has a set of characteristics that make it of high value and greatly in demand for industrial development requiring large quantities of iron and steel. Coking coals are found in other basins, but only in the Sydney–Gunnedah–Bowen basins where the coal seams have been uplifted and preserved at shallow depths are they amenable for economic shallow-underground and open-cut mining techniques.
Another favourable factor in the preservation of eastern Australia’s Permian coal measures is the limited amount of later deformation due to the 350–220 Ma Hunter Bowen Orogeny (Chapter 2). Many of Australia’s coal beds are gently dipping, making them relatively easy to mine, whether using open-cut or underground mining techniques. In contrast, the Hercynian and Alleghanian orogenies deformed the European and North American coal measures, producing bituminous anthracites, such as in the coal fields of South Wales and the Appalachians.

**Black sunlight: power and industrialisation of a nation**

Mining of coal occurs in every state of Australia, but quality varies. The eastern states of New South Wales and Queensland produce more than 96% of all black coal (Figure 9.8), and Victoria produces most of Australia’s brown coal. Domestic coal is used to generate nearly 80% of the total electricity, which amounted to 266 TWh in 2008–09. Around 75% of coal mined is exported, mainly to Asia. Brown coal (lignite) is younger and less matured, with a low heating value. Used widely for power generation, it is also made into briquettes and can be converted to liquid or gaseous fuels. The extensive Cenozoic brown coal deposits equate to hundreds of years of reserves in the southeast of Victoria, in the Gippsland Basin and especially in the Latrobe Valley, with the coal used in adjacent power stations. Australian brown coal is not exported. The onshore coal deposits correlate to the coaly sediments offshore that are the source rocks for oil and gas—for example, in the Gippsland Basin (Chapter 4).
From the red centre to greenbacks: Australia’s iron ore and steel

Red, the iconic colour of Australia’s outback, reflects a landscape rich in iron oxides (Chapter 5). To Australians, this richness of iron extends from the past, with the red ochre, much valued by Aboriginal people, being hematite. The Pilbara region of northwest Western Australia is prized for its hematite, with a world-class export industry feeding the steel mills of a growing Asia.

Iron ore deposits were first discovered in Tasmania in 1822. By the late 19th century, iron ore had been identified in all of the colonies. Low-grade iron ore provided feed for Australia’s first blast furnace at Mittagong, New South Wales, in 1848. High-grade iron ore mining commenced in South Australia’s Middleback Ranges in 1900. Prior to a government ban on exports (see later), specialist resources such as the magnetite of Savage River in Tasmania and the pisolitic iron ore of the Cobar region of New South Wales provided limited-scale iron exports.

Although prospector Lang Hancock is generally credited for discovering the Hamersley iron ore province in 1952, the potential of this area had been recognised more than six decades earlier by Western Australian Government geologist Harvey Page Woodward. Hancock, however, did set in train political changes necessary to develop the province (Box 9.1). Since the 1960s, Australia’s iron ore industry has grown remarkably. Australian exports of iron ore rose from virtually zero in 1965 to 80 Mtpa in 1974 and further expanding to more than 293 Mtpa in 2009. In 2011, $59 B worth of exports were generated, making it the largest export industry in Australia after coal ($47 B). In terms of people, the Pilbara region has grown from a sleepy backwater to having a resident population of more than 51 000 people in 2011, although many workers are transient, preferring a FIFO roster. Growth of iron ore production in the Pilbara region has not been confined to the larger global corporations. Fortescue Metals Group, for example, started to mine the Cloudbreak, Christmas Creek and Marra Mamba Iron Formation deposits in the Fortescue Valley between Newman and Nullagine. Furthermore, development of the Christmas Creek to Port Hedland railway line has added significantly to the region’s infrastructure.

Hancock’s prize: the Hamersley iron ore province

High-grade iron ore deposits, particularly microplaty hematite ores, generally require multiple stages for their formation. The first stage involves deposition of banded iron-formation, and the second (and later) stage(s) involves upgrading of this iron-bearing deposit by dissolution of deleterious material during moderate-temperature hydrothermal fluid flow and supergene processes.

Banded iron-formation, particularly the type that dominates the Hamersley iron ore province, formed on Earth before the ca 2.46 Ga Great Oxidation Event. This early Proterozoic event saw a rapid and dramatic increase in atmospheric oxygen, driven by an increase in oxygen-producing life forms (Chapter 3) and/or the escape of hydrogen into space. During the late Archean, the
deposition of sedimentary rocks in the Hamersley Basin occurred with little free atmospheric oxygen. The oceans were overall reduced, although they were probably stratified with a more oxidised upper layer. Interaction between the deep, reduced oceanic waters and mafic crust resulted in bottom waters that were highly enriched (to hundreds of parts per million) in reduced iron.

The Hamersley iron ore province is hosted by rocks of the Fortescue and Hamersley groups (Figure 9.9), or their weathered/eroded derivatives. They formed between 2.78 Ga and 2.41 Ga, and consist of the basal mafic–volcanic–dominated Fortescue Group and the conformably overlying sediment-dominated Hamersley Group. The latter contains four banded iron-formations, the ca 2.60 Ga Marra Mamba Iron Formation, the ca 2.52 Ga Mount Sylvia Formation, the ca 2.46 Ga Brockman Iron Formation and the ca 2.45 Ga Boolgeeda Iron Formation. The Marra Mamba and Brockman iron-formations contain all major primary iron ore deposits currently being mined in the Hamersley Province (Figure 9.9).

The Hamersley Group was deposited upon a relatively shallow-water platform formed by the Fortescue Group and the older granite–greenstone
Large iron ore resources were known as early as 1890 from the Pilbara region, with research by the Western Australian Government geologist Harvey Page Woodward. He wrote that:

> this is essentially an iron ore country. There is enough iron ore to supply the whole world, should the present sources be worked out.

Despite this earlier report, the Australian Government was under the impression that the country had only limited resources of iron and, with war looming in the late 1930s, an export embargo on iron ore was enacted in 1938. In support of the national government, the Government of Western Australia also banned the pegging of claims for iron ore prospects.

In the midst of these constraints on development, prospector Lang Hancock in 1952 ‘rediscovered’ the iron ore in the Pilbara. He lobbied for a decade to get the bans lifted, which they finally were in 1961; he then revealed his discovery and staked his claim. Hancock and his partner Ken McCamey entered into a deal with the Rio Tinto Group to develop the find.

Hancock was born in 1909 in Perth to one of Western Australia’s oldest land-owning families, and the story of his iron ore discovery in the Pilbara has entered Australian mining folklore.

The initial discovery was made on 16 November 1952 while Hancock was flying south to Perth with his second wife, when they were forced by bad weather to fly low. He described his discovery as follows:

> I was flying down south with my wife Hope, and we left a bit later than usual and by the time we got over the Hamersley Ranges, the clouds had formed and the ceiling got lower and lower. I got into the Turner River, knowing full well if I followed it through, I would come out into the Ashburton. On going through a gorge in the Turner River, I noticed that the walls looked to me to be solid iron and was particularly alerted by the rusty looking colour of it, it showed to me to be oxidised iron.

Once government reluctance with the mining of iron ore was overcome, development of the Pilbara iron ore region began. The industry grew with gathering momentum; ports, railways, mines and support towns were constructed in what was once one of the most remote parts of the world. Aided by information from the Bureau of Mineral Resources (now Geoscience Australia) and the Geological Survey of Western Australia, the pace of exploration was stepped up. Australia became a major raw materials exporter, especially to Japan and Europe. The exploration boom led to mining operations at Mount Tom Price and at Paraburdoo in the following decade (Figure 9.9a). From a zero base in 1961, the industry has grown so that it is now the largest export industry in dollar terms in Australia. There has been a 10-fold expansion in exploration expenditure for iron ore since 1994. This has led to the identification of more than 60 new iron ore deposits, mostly in Western Australia. Despite massive increases in production in recent years (e.g. 488 Mt in 2011), the resource life for iron ore in Australia has been maintained.
Deposition of iron-formation occurred during the upwelling of reduced, iron-rich waters from the adjacent deep oceanic basins onto the shallow, and relatively oxidised, Hamersley Basin shelf. Reduced Fe\(^{2+}\) was oxidised during upwelling, becoming insoluble Fe\(^{3+}\) and depositing as ferric hydroxides. Silica was also precipitated during this upwelling, along with phosphate and carbonate. Background sedimentation introduced some aluminium, resulting in an iron- and silica-rich rock with significant levels of phosphate and carbonate, and with variable amounts of aluminium. Such rocks have been mined elsewhere in the world as iron ore, but are less economic than hematite-rich ores, which are formed through hydrothermal and supergene upgrading of banded iron-formation, as discussed below.

The intensity of deformation increases from north to south across the Hamersley Basin, which was affected by five contractional deformation events, including the ca 2.14 Ga Ophthalmia and the ca 1.77 Ma Capricorn orogenies, the latter the consequence of collision between the Pilbara and Yilgarn cratons (Chapter 2). In the northern part of the basin, the strata are generally flat lying and undeformed, but in the south the rocks were strongly folded during these orogenies about west-northwest-trending axes. Along the southern margin, fold vergence and reverse fault movements suggest tectonic transport to the north. Most major deposits are localised in the more deformed southern part of the basin (Figure 9.9a).

In addition to the contractional events, the Hamersley Basin was also affected by events that formed younger extensional basins, at ca 2.03 Ga
and also at ca 2.00 Ga. The basal unit of the older basin contains clasts only of banded iron-formation, whereas the basal unit of the younger basin contains clasts of hematite, suggesting that upgrading of the ores took place between 2.03 Ga and 2.00 Ga. The best constraint on the timing of the upgrade comes from an altered mafic dyke that intruded along iron ore–related normal faults at the Paraburdoo deposit. This dyke gives an age of ca 2.01 Ga, which is the most likely age of mineralisation.

In detail, the Hamersley Basin iron ore deposits are lithologically and mineralogically complex, the result of a series of both hydrothermal and supergene events (Figure 9.10). Three discrete mineral assemblages are present: (1) magnetite–carbonate–apatite, (2) hematite–martite–apatite, and (3) hematite–martite, with each stage adding value to the iron ore.

- The earliest assemblage to overprint the banded iron-formation was a magnetite–carbonate–apatite assemblage, which formed by the reaction of moderate-temperature (150–250°C) reduced fluids that altered the pre-existing iron-formation adjacent to normal faults. These fluids are interpreted to be basinal brines that were expelled upwards from deeper in the Hamersley Basin and migrated along normal faults during extensional uplift. This event was associated with the intrusion of the ca 2.01 Ga mafic dykes and might have been related to early extension associated with the ca 2.00 Ga basin (Figure 9.10). Interaction of fluids and iron-formation resulted in the removal of silica and the addition of carbonate.

- Continued erosion associated with extensional uplift allowed ingress of deeply circulating meteoric fluids; upward movement of basinal brines stopped (Figure 9.10). This resulted not only in a change in the direction of fluid flow from upward to downward but also in a change in the characteristics of the mineralising fluids. Meteoric fluids after the Great Oxidation Event were oxidised, had low salinity and were relatively low temperature (ca 100°C). These fluids altered the early magnetite–carbonate–apatite assemblage to a microplaty hematite–martite–apatite–(ankerite) assemblage and then to a hematite–martite–apatite assemblage. Not only did meteoric fluids oxidise ferric to ferrous iron, but they also continued to dissolve the remaining silica and carbonate, thus removing these deleterious components from the ores. Hematite-rich clasts present at the base of the younger extensional basins indicate that these processes were likely complete by ca 1.95 Ga, the most likely age of deposition.

- The best-quality iron ore produced in the Hamersley Basin comes from a low-phosphorus hematite–martite assemblage. This assemblage only overprints the earlier assemblages above the present-day base of weathering. This suggests that the final upgrading of ores through dissolution of apatite occurred as a consequence of relatively recent, probably Cenozoic, weathering (Figure 9.10).

Much younger Cenozoic landscape evolution was superimposed on the older Hamersley Basin landscape, and was controlled by basement lithology, structure and landscape position.

Before the Cenozoic, the region was mantled by a deeply weathered regolith (Chapter 5). Erosion of this material occurred in the upland areas, with deposition into lowland and valley areas. This eroded and weathered regolith is in itself part of the mineral system, with the channel-iron deposits such as Robe River palaeovalley and the alluvial fans forming significant iron ore resources (Figure 9.9a).

The Hamersley iron ore province: keys to geological beneficiation

The process of ore formation in the Hamersley iron ore province is not a typical process of metal concentration but, in effect, a process of contaminant removal and geological ore beneficiation. Even so, contaminant removal has surprising commonalities with other mineral-systems (Chapter 8). These include a relationship with extensional faults, and an association with a thermal anomaly, as indicated by the presence of syn-ore mafic dykes. Extensional faults were fluid conduits for both early upward-migrating and later deeply circulating meteoric fluids.

Another important control on mineralisation, as noted above, was the relationship to the Great Oxidation Event at ca 2.46 Ga (Chapter 3). Because of the prevailing reducing conditions of seawater prior to this event, high concentrations of iron were able to be deposited as banded iron-formation. The subsequent upgrading, when iron became, in effect, insoluble in oxidised surficial fluids, prevented iron mobility but beneficially allowed for removal of silica, carbonate and apatite. These contaminants reduce iron ore quality, with apatite contributing undesirable phosphorus (Figure 9.10).
Further benefit came from the stripping of silica from the high-grade hematite ore, with concomitant removal of asbestos and asbestiform minerals, which are known for their negative health impacts, especially cancer. Some magnetite ores, even in the Pilbara region, do contain the asbestiform amphibole riebeckite, a low- to moderate-grade metamorphic mineral, which consists of hydrated sodium iron–magnesium silicate.

Bauxite: a legacy of Australia’s deeply weathered past

Aluminium and hence bauxite are a vital resource for modern life. In just over 150 years since its first commercial production, aluminium has become the world’s second most used metal, after steel. Its strength and low density make it ideal for transport and packaging applications. Aluminium is a unique metal: strong, durable, flexible, impermeable, lightweight, corrosion resistant, readily recyclable and a good conductor of electricity. A unit of aluminium cable carries twice as much electricity as a unit of copper, and most overhead and many underground transmission lines are now made of aluminium.

Bauxite is not just a tropical weathering material. In Australia, bauxite is known from the tip of Cape York Peninsula in Queensland to Tasmania and is mined in three localities: Weipa (Queensland), Gove (Northern Territory) and Pinjarra (Western Australia) (Figure 9.2). Bauxite forms by weathering in well-drained areas over extended time periods, with the original parent rock playing a critical role. Most weathering profiles in Australia have lost their major elements in the following order: Ca, Mg, Na, K, Fe$^{3+}$, Si, Fe$^{2+}$ and finally Al. This process is why much of the Australian regolith is dominated by silcrete, ferricrete and, in places, bauxite, and why it is red coloured (Chapter 5).

Why is Weipa the world’s largest bauxite deposit?

Weipa, on the western side of Cape York Peninsula is the largest bauxite deposit in the world (Box 9.2; Figure 9.11). The ore resource covers an area of 11 000 km$^2$, of which 520 km$^2$ is ore grade. Why is it so large and located where it is? Using a modification of the mineral-systems approach (Chapter 8), we can help to answer this question. Modification to the approach is needed because bauxite is formed by successive removal of other minerals and material to form bauxite ore, rather than the concentration of a desired element into an ore resource.

The bauxite must form where the regolith is well drained and permeable in nature, to allow the dissolving fluid and solutes to be removed, leaving the bauxite as a residue. Following the mid-Cretaceous marine regression from the western part of Cape York Peninsula, the region has been subjected to weathering and erosion, seasonally high rainfall, a fluctuating watertable, and efficient leaching. The relative tectonic stability of western Cape York Peninsula has helped to protect the resource from the erosion that would occur in uplifted areas. The original source of aluminium is the extensive successions of arkosic sandstone that crop out along western Cape York Peninsula. The feldspars, micas and hornblende in these parent rocks weather into kaolinite, goethite and...
hematite, with silicic acid being mobilised. Quartz in the sediments eventually dissolves, further concentrating residual aluminium.

The Weipa bauxite formed on rocks of the Carpentaria and Karumba basins (Figure 2.8)—in particular, highly siliceous Cretaceous marine volcanolithic sediments and Paleogene quartzose terrestrial gravels, sands and muds. The bauxite ranges in thickness from 3 m to 12 m at elevations ranging from sea-level to about 80 m asl. The weathering of the source rock results in a varied loss of thickness and, at Andoom, just north of Weipa, it appears that a 40 m thick profile of the Cretaceous Rolling Downs Group has been reduced to 25 m, which now contains a 3–5 m thick layer of high-grade bauxite. Alluvial fans and rivers filled with quartzose sediments incise the plateau, and no marine sediments have been identified since the Cretaceous. The bauxite is underlain by a lateritic profile. In areas of low topography, ‘red soil’ sourced from local sediments overlies the resource, while the whole sequence is overlain by soils.

There is a high degree of mineralogical variability in the various mining areas around Weipa, particularly with regard to quartz, hematite, kaolinite and some aspects of trace element chemistry. From this chemistry, it appears that the typical bauxite pisoliths (pea-sized concretions) were derived from weathered source rock of essentially the same composition as the substrate under their current location. The isotopic chemistry (oxygen and
Willem Janszoon, captain of the *Duyfken*, made the first recorded sighting of the Australian coast at the Pennefather River, some 40 km northeast of Weipa, in 1606. Captain Matthew Flinders sailed the *Investigator* into Albatross Bay and named Duyfken Point in 1802, noting in the ship’s log the sighting of ‘some reddish cliffs’ south of the bay at Pera Head.

Remoteness from markets, poor soils, a monsoonal tropical climate and the rough terrain of the northwest Cape York Peninsula discouraged overlanders and settlers for most of the 19th century, although attempts to settle commenced as early the 1840s. Weipa was later established as a mission and CFV Jackson, Assistant Queensland Government Geologist, referred to the presence of ‘brown pisolitic ironstone’ between Mission and Embley rivers, but follow-up investigations were not carried out. Jackson wrote at the time:

*I think it probable that if these deposits were systematically examined and sampled, they would be found to include masses of higher-grade ores; and, if such were the case, they might ultimately prove of some value, especially on account of their ready accessibility from the sea.*

In 1947, FW Whitehouse collected samples of bauxite at the mouth of the Archer River, to the south of Weipa. As a result, a field survey was considered, but the samples sent were low grade.

It was not until 1955 that the significance of Weipa’s reddish cliffs was recognised by geologist Harry J Evans. Leading a field party on a reconnaissance of possible oil-bearing structures, Evans skirted the west coast of the Cape towards the end of his expedition ‘just to see what the country looked like’. He discovered a large outcrop of bauxite near Weipa on 16 July and continued
to collect ore samples over a large area. When analysis revealed the ore to be high grade, Evans returned to continue exploration, guided by a local Aboriginal elder, Matthew. He examined 84 km of coast in a 3 m dinghy. Realising the significance of the deposit he noted in his diary:

"As the journey down the coast revealed miles of bauxite cliffs, I kept thinking that, if all this was bauxite, then there must be something the matter with it, otherwise it would have been discovered and appreciated long ago."

A subsidiary of the American company Consolidated Zinc, Enterprise Exploration Pty Ltd commenced proving operations in June 1956, using the coastal vessel Wewak. A camp was developed east of today’s Napranum township on the banks of the Embley River. By 1957, Consolidated Zinc had formed a new company called Commonwealth Aluminium Corporation Ltd to develop the Weipa deposits. The acronym Comalco is derived from the initial letters of the company.

Exploration and planning for the Weipa deposit progressed well, with the first trial shipment of 9849 tonnes of bauxite being sent to Japan in April 1961. A new town was built at Rocky Point, and bauxite processing and shipping facilities were constructed at Lorim Point. The first shipment of 10 000 tonnes of bauxite to the Gladstone alumina refinery in December 1966 marked the second significant step towards establishing a fully integrated aluminium industry in Queensland. The development of the readily accessible high-quality coal resources of the Bowen Basin provided an important catalyst for establishing the energy-hungry smelting component of an integrated industry.

Comalco and partners commenced aluminium production at the Gladstone smelter in 1984. Operations at Weipa include the mining, crushing and washing of bauxite, and ore handling through port facilities for transport to alumina refineries. Weipa has become one of the largest bauxite mining sites in the world and is a major contributor to Rio Tinto’s bottom line. Development of the south of the Embley Project, which will replace production from the depleted East Weipa reserves, is expected to extend the life of the operation by 40 years and lift annual production.

The location of further deposits at Gove in the Northern Territory and the Darling Ranges east of Perth has led to the identification in Australia of more than 6200 Mt in economically demonstrated bauxite resources. The bauxite deposits generally occur as pisolitic residuals of Cenozoic laterite, developed on several rock types including sedimentary rocks, basalt and schist.

In 2011, the Bureau of Resources and Energy Economics reported that the export value of bauxite was $300 M. For the same period, the export value of alumina was nearly $5.5 B and that of aluminium ingots was $4 B. The transformation of ore (bauxite) to more refined products (alumina and aluminium) clearly adds significant value to Australia’s bulk resources.
deuterium) of the present-day groundwater is the same as the pisoliths, which are thought to have started to form in the mid-Cenozoic (ca. 50 Ma). This suggests that monsoonal conditions encountered today were prevalent when the pisoliths formed, but that this likely occurred when Weipa was at latitudes 1000–2000 km further south than today (Chapter 2). In contrast, the bauxites of Brazil have differing isotopes, suggesting that conditions for bauxite formation there were different from the trade wind–dominated rainfall encountered today. In this way, bauxites are a measure of ancient climatic conditions.

The possibility of a biological role in the formation of bauxite has been raised. In some cases, it appears that beetles might have influenced the formation of the marble-sized pisoliths. Other possible bio-agents are microbes such as Bacillus. The bauxite at Weipa is almost unique in the world, in that it is made up of free-running pisoliths with limited matrix material. These have a consistent size distribution, sphericity, roundness, density, total Al₂O₃ and major element chemistry, despite their varied complex interiors. One possibility is that the pisoliths formed further up slope than their current position, and were transported and deposited down to their present location.

The science case for reworking is strong, and offers an explanation for why the ore body is not as large as the areal extent of the parent rock and equivalent climatic conditions. The Weipa bauxite lies directly to the west and down gradient of the highest elevations in the Coen Inlier, which is up to almost 800 m asl (Figure 9.11). The elevated hinterland centred along the Great Divide (Chapter 5) could have been the topographic driver for enhanced fluid flow in this region, hence controlling the location and extent of the Weipa ore resource.

**Gas, the ‘greener’ hydrocarbon**

Australia was self-sufficient in energy before the arrival of the internal combustion engine, after which the country became an importer of petroleum (Chapter 4). The discovery of oil in Victoria’s Bass Strait in the 1960s provided relief from imports for a time. Production of Australian oil peaked in 2000–01, and has since declined by 5% per year. Australia now imports oil, which cost the country $20 B in 2010–11. Globally, around 50% of annual oil production is consumed by the transport industry; however, in Australia, this sector uses 70% of about 1 million barrels per day total. The disproportionate use in Australia probably reflects the nature of commerce (no trade barriers over a large area) and the large distances between population centres (Chapter 1).

In contrast to oil, Australia has significant natural gas endowment provided by the giant gas fields of the North West Shelf (Box 9.3). The US Energy Information Administration rates Australia 29th in global resources with known conventional reserves at 164 trillion cubic feet (tcf), equivalent to 25 billion barrels of oil. The natural gas industry has shown remarkable growth in both the domestic and export sectors over the past few decades, and this is projected to continue. More recently, natural gas is being produced from Australia’s coal fields as coal-seam gas. These significant resources are being progressively developed in eastern Australia, with Queensland currently 80% reliant on coal-seam gas for its domestic gas supply. The addition of coal-seam gas’s known resources of 42 tcf (Chapter 4) gives a total resource of 206 tcf.

Unconventional resources include tight gas, shale gas and gas hydrates. No definitive gas hydrates have been identified in Australian waters. The reservoirs of tight gas and shale gas resources tend to be deeper (1.5–3.5 km) than the typical coal-seam gas resources, so their development is less contentious with respect to their impact on groundwater. These unconventional resources are not currently being produced in Australia, although there are tight gas projects in the planning stage.

**What is natural gas?**

Natural gas is composed of simple hydrocarbons, mainly methane (CH₄). Pure methane gas is colourless, odourless and lighter than air. Depending on the source of the gas, it may contain minor quantities of heavier C₃–C₄ hydrocarbons: ethane (C₂H₆), propane (C₃H₈), butane (C₄H₁₀) and pentane (C₅H₁₂). Natural gas with a high concentration of methane is known as a ‘dry’ gas (e.g. coal-seam gas) and that with a high proportion of C₃–C₄ hydrocarbons is known as a ‘wet’ gas. A ‘lean’ gas falls between the two. Other constituents may or may not be present, such as the more complex liquid hydrocarbons (C₅₋₅), in addition to nitrogen (N₂), carbon dioxide (CO₂) and hydrogen sulfide (H₂S). A ‘sour’ gas contains more than four parts per million H₂S and is
characterised by an increasingly foul or rotten-egg smell. Australian natural gas is generally ‘sweet’ due to its low H₂S content.

Inorganic and organic sources have been inferred for non-hydrocarbon gases such as CO₂. A mantle and/or igneous origin for the CO₂ is likely where the natural gas has CO₂ content of 5% or higher. Low levels of helium are generally found (less than 0.5%); however, if the natural gas reserve is large enough, helium can be extracted economically—as happened in 2010 with Australia’s first helium extraction plant in Darwin.

Liquid hydrocarbons, if present in high enough concentrations, may separate as ‘condensate’ from the natural gas when the gas is brought to lower pressures and temperatures at the surface. The remaining natural gas can itself be turned into a liquid, mainly through cooling to lower temperatures. LNG contains mainly methane and occupies about 1/600th the volume of natural gas in the gaseous state. Therefore, LNG is more convenient for transportation over long distances using cryogenic sea vessels or cryogenic road tankers. Liquefied petroleum gas (LPG) comprises mainly propane and butane, and ethane is widely used as a petrochemical feedstock.

Natural gas as an energy source has significant environmental benefits over both coal and oil in terms of its lower greenhouse gas and other emissions. This aspect is of considerable advantage in the further promotion of natural gas use and Australia’s energy future. Natural gas remains a cheap energy source in Australia compared with North Asia and Europe. However, wholesale gas prices have generally trended upwards in the past few years, especially in Western Australia as Australia becomes increasingly engaged in the global LNG market.
Formation and distribution of gas

Australia’s conventional gas reserves and resources are distributed unevenly around the continent. More than 90% of the reserves and resources are located offshore from northwest Western Australia (Carnarvon and Browse basins) and in the Timor Sea to the north of Australia (Bonaparte Basin), remote from population centres in the south or east of the country. The largest onshore accumulation of conventional gas reserves and resources occurs in the Cooper and Eromanga basins in northeast South Australia and southwest Queensland. It is this source that currently supplies the bulk of the domestic eastern Australian gas market (SA, ACT, NSW and Qld). Victoria and the emerging Tasmanian market are dominantly supplied from the Gippsland Basin, offshore from southeast Victoria.

The source rocks for Australia’s gas range from the Ordovician in the Amadeus Basin to the late Cretaceous–early Cenozoic in the Bass and Gippsland basins. The major source rocks were derived predominantly from land plants and were deposited in intracratonic or passive margin settings (Chapter 4).

Although source and maturity are the primary control on the composition of the natural gas, secondary alteration processes are also important and can affect the economic value of the resource. If the reservoir depths are shallow (<1500 m), such as in the Gippsland Basin, the Carnarvon and Browse basins of the North West Shelf and the onshore Bowen Basin in Queensland, in-reservoir biodegradation of the gas by microbes can increase the dryness. The microbes can flourish because temperatures are low enough and groundwater flow is sufficient at these reservoir depths. Natural gas can also show differential fractionation along the migration path, or within the reservoir. The bias towards methane leakage relative to longer chain hydrocarbons has resulted in stacked reservoirs, where the shallowest reservoir tends to have the drier gas.

Unlike coal resources, most of Australia’s largest conventional gas resources are inconveniently located with respect to the nation’s population and therefore demand centres (Figure 9.12). However, the ‘stranded’ nature of these resources has led to the development of a significant new export industry for Australia, LNG, with Australia rapidly racing towards being one of the world’s largest exporters (Box 9.3). Furthermore, the limits of conventional gas in the more populous eastern states are being
Traditionally, Australian reserves of gas have been far in excess of what has been needed for domestic usage. Much of the gas discovered in Australia's exploration history was discovered during the search for oil, including a string of giant gas fields discovered along the North West Shelf in the 1970s and 1980s. Many of these fields were considered to be 'stranded', being located in areas where the gas could not easily be developed at that time because of remoteness and water depth. The discovery of gas was viewed as an exploration failure or a very poor second prize, at best. The development of the LNG industry has changed that picture, linking the gas resources of northwest Australia with the energy-hungry markets of north Asia.

The industry is now in a period of rapid growth—in addition to the two currently operating projects (North West Shelf project and Darwin), another five are under construction or committed for development (Gorgon, Pluto, Wheatstone, Ichthys and Prelude, the world's first floating LNG project). These projects will help triple Australia's existing LNG export capacity and will mean that by 2016 Australia could rival Qatar for the top spot as the world's largest exporter of LNG.

The innovation of floating LNG technology will further unlock the smaller and more remote gas resources on the North West Shelf. Furthermore, gas is favoured in the global energy mix for its flexibility and its potential, when replacing other fossil fuels, to lower emissions of greenhouse gases and local pollutants.
overcome by the identification of large, readily extracted coal-seam gas resources close to major cities (Figure 9.12).

Coal-seam gas: getting a bigger bang for the coal buck

Coal-seam gas is naturally occurring methane (with or without CO₂) that has been absorbed onto the grain faces and micropores of coal or held within fractures or joints (called cleats) with water. The gas is generated by both microbial digestion of the coal and by the thermal maturation process of coalification. Unlike conventional gas, where the source rock generates the gas that then migrates upwards to a reservoir, coal-seam gas remains bound up in the coal seams. Conventional gas trapped in a reservoir generally flows to the surface under pressure. Coal-seam gas requires dewatering of the coal seams to reduce the pressure and allow the gas to flow or be forced to the surface. The permeability of coal seams is very low, and the fracture/joint network controls the fluid flow and recovery of the gas. The flow rate depends on many factors and changes with time, as the ongoing development and recovery of gas (and water) can alter the permeability framework of the coal seams.

Since the start of the 21st century, there has been a rapid commercial rush to develop Australia’s unconventional coal-seam gas resources, which are located relatively close to major population centres in eastern Australia and the associated infrastructure (Figure 9.12). The development of these gas sources has alleviated the need for gas to be piped or transported as LNG from western and northern Australia to meet growing domestic demand. Indeed, the coal-seam gas resource is large enough to support a new export industry. Whereas production began in the United States in the 1970s,
exploration for coal-seam gas in Australia only started in 1976. The first commercial coal-mine methane operation commenced at Moura in Queensland in 1996, largely for hazard reduction in underground coal-mining operations. There are two LNG processing facilities under construction near Gladstone, based on coal-seam gas resources, which will require a significant infrastructure investment in excess of $30 B.

**The economics of gas**

Natural gas is converted to LNG for transportation in speciality ships destined for overseas markets—currently Japan, South Korea, China and Taiwan, with other shipments to single spot markets including Spain, Turkey, India and the United States. Although only 14th in the world for resources, Australia is 4th largest exporter of LNG (Table 9.1). Global LNG trade is characterised by two distinct import markets, the Asia-Pacific and the Atlantic. The vast majority of Australia's LNG exports are delivered to economies in the Asia-Pacific, and these countries account for more than half of world LNG trade. As with the other bulk commodities, circumstances in China will play an increasingly important role in the development of Australian markets. China imported around 5.5 Mt of LNG in 2009, which was 64% higher than imports in 2008. The Bureau of Resources and Energy Economics predicts that China will import 13 Mt of LNG in 2012! This continued growth is a direct result of increased capacity for

![Image](https://example.com/image.jpg)
The fall in LNG prices has also encouraged China to purchase additional spot cargoes, with an immediate impact on prices.

The North Rankin gas field on the North West Shelf is located in moderately deep water some 135 km offshore and 1500 km from the nearest major domestic gas market. Exporting the LNG was considered as the key commercial option for the developers. The North West Shelf project is Australia’s largest resources project to date, involving some $25 B of capital expenditure and operated by Woodside Petroleum Ltd and its international consortium partners. Substantial capital investment is required for LNG, which is sometimes beyond the financial resources of local developers.

The first LNG deliveries from the North West Shelf to Japanese buyers were made in 1989. From that time to 2004, production was around 7.5 Mtpa. Export LNG volumes increased to around 11.7 Mtpa following the commissioning of the fourth processing train in 2004. With the completion of a fifth LNG processing train, production capacity increased to 15.9 Mtpa.

The $43 B Gorgon project is coming to fruition more than 30 years after its discovery (Box 9.3). The scale of Gorgon means that it will become Australia’s biggest resources project, a modern Snowy Mountains Hydroelectric Scheme, which will add an estimated $64 B to Australia’s GDP and employ around 10 000 workers.

Additional LNG export volumes are expected in the near future from a number of new ventures, including Greater Gorgon, Pluto, Pilbara and the Browse, all in Western Australia. The Greater Gorgon fields include the expansive Jansz field, and currently represent 25% of Australia’s total conventional gas resource. The project partners, Chevron, Shell and ExxonMobil, will construct a 5 Mtpa LNG production plant on Barrow Island, to the east of the resource.
Marriage of the giants: adding value to the bulk commodities

Many of Australia’s large bulk commodities are located within a few hundred kilometres of the coast. This relative proximity of resources to ports has driven the development of infrastructure (rail and port) to handle the vast tonnages of these bulk resources. Newcastle is the world’s largest export port for coal. The trains running from the Hamersley iron ore province in the southern Pilbara are some of the longest in the world, delivering their wares to the adjacent coast in the north. In many instances, however, the different resources (iron ore, bauxite, coal, gas) are separated from one another by half a continent—such as iron ore in South Australia and coal in New South Wales. In this example, bringing the resources together has relied on shipping, using Australia’s coastal waters and ports (Chapter 6).

There has been ongoing political discussion supporting the concept that Australia, as a developed country, should add more value to its raw materials. It was recognised more than 100 years ago that new industries could develop where metalliferous resources could be further refined and transformed by marrying them with energy. Examples include iron ore and coal for steel, iron ore and gas for hot briquettes, and bauxite and coal/gas for aluminium.

Despite its many positive aspects, significant hurdles exist that constrain value adding. Many of the resources companies are not geared up to produce elaborately transformed manufactures and, even if they were, Australia would face high input tariffs in many countries. Implementing newer technologies to upgrade raw materials is not always straightforward, especially on the vast scale required by these industries.

Bauxite + energy (coal or gas) = aluminium

Bauxite is a mixture of hydrated aluminium oxide minerals, including gibbsite, Al[OH]₃, boehmite, γ-AlO[OH] and diaspore, α-AlO[OH], together with variable impurities such as silica, iron oxide and titanium-bearing minerals. The Hall–Héroult Process, invented in 1886 to turn bauxite to aluminium, is very energy intensive. It uses around 15.7 kWh of electricity per kilogram of recovered metal. A source of relatively cheap electricity was therefore critical for growing the industry in Australia (Did you know? 9.3).

A relative newcomer to the aluminium industry, Australia has secured a prominent position as the world leader in mining and refining of bauxite, alumina and aluminium. From an initial capacity of 20 000 tpa in 1955, at the Bell Bay alumina plant, Australia’s production developed quickly. Australia’s 6.2 Bt economically demonstrated resource base of bauxite provides a world-class resource for the industry, which consists of 5 bauxite mines, 7 alumina refineries, 6 primary aluminium smelters, 12 extrusion mills and 2 rolled product (sheet, plate and foil) mills. The Australian aluminium industry alone directly employs more than 12 000 people. Bauxite, alumina and aluminium exports were worth nearly $10 B in 2011 (Figure 9.6).
Most of the export income from this resource is derived from the refined product—alumina or aluminium metal—rather than the raw bauxite from the mines. This was made possible due to Australia’s capacity to supply relatively cheap energy from its enormous coal resources. The Gladstone refinery in central-east Queensland uses the bauxite from Weipa and the coal from the inland Bowen Basin. These factors have led to Australia leading the world in bauxite refining and being fourth largest producer of primary aluminium.

Growth in refining has slowed in recent years, partly due to uncertainty in the future cost of energy. For the future, this presents an irony, as aluminium is such a light metal that the ongoing energy savings from its use in transport infrastructure create a strong demand.

Iron + energy (coal or gas) + other constituents = steel

Steel is an alloy of iron and carbon, with other metals added to meet different functional needs. Steel making is also energy intensive, and Australia has a lot of iron and a lot of energy. Australia’s steel making was built on the marriage of the vast coal resources with the iron ore.

In 1915, iron ore from the Middleback Ranges in South Australia became the raw material for the integrated Broken Hill Proprietary Company Limited (BHP) iron and steel industry at Newcastle, New South Wales. The iron ore was shipped to the Newcastle coalfields (Chapter 6). The development of the steel industry was facilitated by BHP metallurgists and chemical analysts who relocated from the Broken Hill lead and zinc operations, with technical assistance from the United States. The transfer of these scientific skills was crucial to the rapid development of sound operating practices for open-hearth steel making under local conditions.

Integrated steelworks were developed at Port Kembla, New South Wales, in 1928, then Whyalla, South Australia, in 1941 and later at Kwinana in Western Australia in 1968. In each case, the steel making was different because of the wide variety of cokes and ferruginous feeds. The result was an industry that adapted its practices to suit the input conditions. Australia also mines metals such as nickel, manganese, chromium and tungsten (Appendix 8.1), which are used in specialist steel manufacture by alloying or galvanising with zinc, or electroplating with tin.

The steel industry is a major employer, and the scale of operations means that steel firms are often a dominant influence in the community in which they are located, such as Port Kembla and formerly Newcastle. This can make communities vulnerable to the vagaries of the market, such as tariffs and exchange rates. There have been major job losses in the industry in Australia, and around the world (except in South Korea and China).

Iron ore + gas = hot-briquette iron

BHP Billiton Ltd attempted to upgrade iron ore to hot-briquette iron by marrying the vast Hamersley Basin iron ore resources with the gas from the adjacent North West Shelf. The Boodarie hot-briquette iron plant located 7.5 km southwest of Port Hedland on the Pilbara coast was completed in 1999 and was planned to produce 2.3 Mt of briquettes per year. The energy-intensive process used hydrogen and carbon monoxide to remove oxygen from the ore, leaving a more than 90% iron briquette for export. A pipeline brought the gas from the west, and the railway brought the iron ore from the south, meeting at Boodarie. The finished briquettes were loaded onto ships at Port Hedland via a vast conveyor-belt network. However, the operation was not financially viable and the plant was closed in 2004, having cost more than $2.5 B.

Unearthing our past and future

The bulk commodities of coal, iron, aluminium and LNG account for more than 40% of Australia’s export earnings ($126 B in 2011), sustaining the nation’s economic success and the lifestyle of the Australian people. A cornerstone of the Australian economy since the gold rushes, mining was pivotal in shaping mid-19th century Australia. The importance of the resources sector has increased markedly since the mid 20th century, with accelerating export income from the bulk commodities (Figure 9.1). The industrialisation of Asia has provided the demand, driving infrastructure investment in remote regions of Australia. Advances in technology, combined with massive economies of scale and sound policy, have enabled access to the resource and helped to satiate the growing market to which Australia is well located geographically.

Australia’s long geological history, fringing passive margins, overall landscape stability and relatively limited amount of deformation in the
past 200 Myr have formed and preserved a vast quantity of high-quality resources that are the physical basis for the bulk commodity industry. Competition from other bulk commodity suppliers with a similar Gondwana geological heritage—for example, southern Africa and South America—has not prevented Australian exports from growing rapidly. Australia's educated workforce, system of government and legal framework have provided a sound, stable administrative foundation that allows the geological legacy to be utilised for societal and national benefit. The relatively small domestic population relative to the size of the resource wealth has meant that local demand is readily met, allowing the surplus to be exported.

Commentators talk of Australia’s boom period of the early part of the 21st century as being unprecedented in its longevity. What to do with this windfall is a vital question to be answered by the Australian people. In the next chapter, we will look at another of Australia’s energy resources, deep heat.
Bibliography and further reading

Resources from a stable base


Centre for Social Responsibility in Mining 2010. *Indigenous employment in the Australian minerals industry*, Centre for Social Responsibility in Mining, University of Queensland, Brisbane.


Roarty M 2011. The Australian resources sector—its contribution to the nation, and a brief review of issues and impacts, Parliamentary Library background note, Parliament of Australia, Canberra.


**Coal and gas**


Campbell I 2009. An overview of tight gas resources in Australia. PESA News 100, 95–100.


**Iron ore**


**Bauxite**


Geoscience Australia 2012. Australian mines atlas, Geoscience Australia, Canberra.


**Marriage of the giants**