THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Coal and the Commonwealth

The Greatness of an Australian Resource

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The University of Queensland, Brisbane, Australia

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The University of Queensland

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Note: all monetary units are expressed in Australian dollars.

Executive Summary

This study, by a multi-disciplinary panel of experts from The University of Queensland, adopts a plain language approach to present the findings on the past and future uses of coal and the role that this fuel has played and will continue to play, in Australia and globally. Coal currently attracts negative press because of the concern that this particular fossil fuel may have on the changing global climate. This study accepts the dominant role that greenhouse gases are playing in global climate change. Further, it acknowledges that most of these greenhouse gases are produced from the burning of fossil fuels. An often unconsidered reaction to these positions – one sometimes seen in the popular press – is to call for the abandonment of coal and other fossil fuels as an energy source. This report shows that this is a totally unrealistic position for Australia and for the world.

A starting point is to recognise that access to energy, mainly in the form of electricity at affordable prices, is a key factor that lifts people out of poverty. This first occurred in the Industrial Revolution in England in the 18th century but is continuing to occur on an unprecedented scale today in countries with huge populations, such as China and India. Any attempts by countries that have already enriched themselves through the use of cheap fossil fuels to prevent developing countries from raising the living standards of its populations are likely to be met with understandable resistance.

A second point is to recognise that today almost all (80%+) of the world's energy is generated by fossil fuels – dominantly oil (34.4%) and coal (26%) – with the latter being the main fuel used to generate electricity globally. Currently, 41% of the world's electricity is generated using coal and this fraction is continuing to increase. In capital-intensive industries, such as power generation, it is not technologically feasible to achieve rapid change. Therefore, if there was to be a move away from the use of coal because of climate change concerns (and there are no indications that this is likely to happen as the trend is towards increasing the use of coal) such a transition would take decades.

This study argues that coal will be just as important an energy source in the future as it was in the past and it is today. Coal is the world's most abundant fossil fuel. Coal resources are widely dispersed geographically around the world. This overcomes the concerns about energy security that are often expressed about oil and gas where the global resources are concentrated in the politically unstable Middle East and Russia. Undoubtedly renewable energy and nuclear energy will play increasing roles in the global energy mix. Today the former, outside of hydroelectricity (which accounts for 2.2%) is insignificant (0.6%) and the latter, at 9%, is small. Both will grow significantly, but because the world's population is growing, and because the world's poor have the right to a higher standard of living, the demand for energy will increase substantially. Hence the use of all fuels, including coal will continue to increase globally.

For this to be the case, technologies need to be developed that allow the consumption of coal without causing atmospheric pollution, including greenhouse gas emissions. This study describes a range of low emission technologies in various stages of development. Some or all of these will achieve this required goal.

Carbon capture and storage (CCS) takes the carbon dioxide emitted from power plants and reinjects it into suitable rock formations underground. This technology is already used on a modest scale in a few locations around the world. When it is exploited on larger scales it will allow existing power plants to operate in a pollution free manner. This study describes CCS and a range of other technologies, including coal seam gas (CSG), currently the source of a large and rapidly growing industry. The study also describes underground coal gasification, and coal gasification and coal-to-liquids conversion in surface plants.

EXECUTIVE SUMMARY

Australia is blessed with very large reserves of extremely high-quality coal, both thermal coal – used for making steam and generating electricity, and metallurgical (coking) coal – used for steel making. Australia is the world's largest exporter of coal. Over one fifth of Australia's mineral wealth comes from coal. Coal exports generated $55 billion in export revenues during 2008-09. In addition to Federal Government taxation income derived from coal, Queensland and New South Wales State coal royalties and taxes are expected to exceed $4 billion during the same period. Coal currently provides 81% of Australia's electrical generation requirements with black coal supplying 57% and brown coal the remaining 24%.

This study reviews the effects that this bountiful resource has on employment and wealth in Australia. In 2006-07 the Queensland and NSW coal industries directly employed over 32,000 people. Traditionally, "multipliers" of 1:4 have been used to estimate the number of indirect employees generated by the mining industry. A macroeconomic model developed by Monash University – the same one used by Professor Ross Garnaut and his team to model the effects of climate change – was used to estimate that in 2008 household disposable income grew by nearly 7% in Queensland and 6% in NSW as a result of coal mining.

The study also examines the benefits realised by Australia's major trading partners from our coal exports. Japan is the main destination for these exports, however China and India are expected to become major customers in the near future. Although both of these last two countries have large coal reserves of their own, these reserves are not likely to be sufficient to meet their growing energy requirements. Australian coal is typically cleaner than the indigenous coals as it has a higher energy content and lower contaminants, such as ash and sulphur. The higher quality coal produces lower emissions than inferior coal.

The concept of a 'cleaner coal' is shifting in Australia towards low emission coal technologies. This shift also aligns itself with the new initiatives of the Australian Government via the National Low Emission Coal Council (NLECC), a partnership between the Commonwealth and State Governments, the coal and the power industries and research providers.

Australia is at the forefront of research, development and demonstration of technologies for capturing and storing carbon dioxide emissions from coal power stations. Twelve CCS demonstration programs costing more than $1 billion are currently underway in NSW, Queensland and Victoria. These projects range in maturity from Australia's first storage project (CO_2CRC Otway Project) and the CSIRO Loy Yang PCC Pilot Project that are already underway, to projects which are under feasibility assessment. China is currently the largest emitter of carbon dioxide in the world. In the short term, CCS demonstration plants are likely to be deployed in China as demand for new power station developments continue.

The rise of the CSG industry in Queensland is also examined in the study. Proven, probable and possible reserves of CSG now exceed 800 Mt – larger than the liquefied natural gas (LNG) reserves off the north and west coasts of Australia. With over $18 billion of projects in the planning, the CSG industry has the potential to be the next great industry for Australia.

In summary, the Coal and the Commonwealth study makes the case that coal will be a principal energy source for the world for the foreseeable future. Coal is far more abundant and far more geographically dispersed than any other fossil fuel. The way coal is used today is more challenging than many of the other fuels, but technologies to change this are well underway. Australia, because of its vested interest in continuing to reap the economic benefits from its plentiful coal resources and its heavy reliance on coal as an energy resource, is among the world leaders in the development of these low emissions technologies.

Prologue

Australian coal, has played, and will continue to play a vital role in the development and progress of Australia as a nation. Coal is the most abundant fossil fuel on the planet. Coal will outlast oil and natural gas reserves by centuries, with suggestions that coal reserves could possibly last for over 500 years. Coal has two main uses; it is used to power thermal power stations for the generation of electricity or as a metallurgical agent in the production of steel. Australia is blessed with great reserves of black (or hard) coal located close to the eastern seaboard, predominately in New South Wales and Queensland. This, combined with favourable geology, has facilitated the extraction and export of hard coal by bulk carriers to countries such as Japan, India, Korea, Taiwan and China. Over one fifth of Australia's mineral wealth comes from coal. Coal exports generated $55 billion in export revenues during 2008-09. Black and brown coal currently provide 81% of Australia's electrical generation requirements.

Coal has two main uses; thermal coal is used to generate electrical power and metallurgical (coking) coal is used to produce steel.

Despite this, in recent times, the coal mining and coal power generation industries have been subject to considerable negative press, principally because of their association with greenhouse gas emissions. At the extreme end of the political spectrum, there are voices calling for an end to coal mining and coal-fuelled power stations. Alternative energy sources are being sought to reduce Australia's dependence on fossil fuels, however renewable energy sources such as wind and solar power produce energy at significantly higher life cycle costs than coal fired power stations. The current government target is for Australia to meet 20% of its electricity needs from renewable sources by 2020. While nuclear power generation remains politically unacceptable within Australia, our base load electricity needs will continue to be met by fossil fuel sources (coal and gas) for the foreseeable future.

Coal is the most abundant fossil fuel on the planet. Coal will outlast oil and natural gas reserves by centuries, with suggestions that coal reserves could possibly last for over 500 years.

In order to provide an alternative viewpoint in the current debate over the future of coal, this study sets out to explore the positive externalities associated with Australian coal. Coal has delivered a multitude of socio-economic benefits to Australians, as well as citizens of other nations, through low-cost energy generation and steel production. This study consists of eight chapters, each drafted by a subject matter expert at The University of Queensland. The study is multi-disciplinary in nature, linking the disciplines of history, economics, social sciences and engineering. The study does not necessarily reflect the views of The University of Queensland: each chapter is the sole responsibility of the contributing author(s).

PROLOGUE

Chapter 1 examines coal in the history of the development of the world; it makes the point that world living standards remained unchanged for thousand of years until the Industrial Revolution. A number of factors coincided to bring about the Industrial Revolution, but chief among these was the substitution of machines for human labour. This was made possible by the Newcomen's invention of the steam pump, and Watt's subsequent refinement of the steam engine, with coal as the fuel that produced the steam. Even before this, Britain became a nation fuelled by coal. Because the richest coal reserves were found around Newcastle upon Tyne in the northeast, a maritime industry developed revolving around the transport of coal to London. A fleet of coal haulers was constructed that became an important part of Britain's naval strength. In times of conflict, ships and sailors were commandeered to help defend the nation. Captain James Cook received his training sailing colliers, and indeed, his ship "Endeavour" began its life as a coal hauler. The chapter concludes that coal continues to power the industrial revolutions being experienced by many developing countries, with China and India having the largest influence on coal consumption.

Chapter 2 follows the historical developments surrounding coal in Australia. It traces the discovery of coal at Coal River, now known as the Hunter River in NSW and the development of the town of Newcastle, named after its British counterpart. It examines the early use of convict labour to mine coal, as well as the early colony's dependence on scarce mining expertise. In 1824 the Australian Agricultural Company (which still exists today) was granted land rights north and west of Newcastle. It went on to monopolise coal production until the late 1840s, around which time important coal reserves were discovered in the Moreton Bay district near Brisbane, at Ipswich and Redbank. Meanwhile the Australian Gas and Light Company (AGL), formed in 1836, began supplying reticulated coal gas (formed by heating coal and capturing its gaseous emissions) for street lighting and wider domestic purposes in the Sydney area. The great coal deposits west of Rockhampton, including Blair Athol in the Bowen Basin, were discovered in the 1860s. However because of the lack of rail infrastructure they were not commercially significant. The introduction of steam powered ships and the development of railways from the late 1840s onwards, broke the "tyranny of distance" in Australia and opened up new trade routes with the world. In the Asia-Pacific region Britain developed key ports such as Singapore, Colombo and Suva as coal storage and refuelling stations for steam ships. Steam ships also transformed internal transport in Australia, with paddle steamers operating along the Murray-Darling river system taking wool downstream to Adelaide and supplies back inland.

The history of coal mining in Australia is also intimately linked with the history of unionism and the growth of the labour movement in Australia. During the early twentieth century, conflicts surrounding working conditions and health and safety were not uncommon in the coal industry. With the revival of the Japanese steel industry following the Second World War, a market for metallurgical (coking) coal was created. In 1959 Thiess Bros discovered reserves of hard coking coal at Moura in Queensland. The family firm needed help to develop the reserves and so turned to Peabody Coal of America and Mitsui of Japan. Thiess Peabody Mitsui became the largest corporate entity in coal until the arrival of the Utah Development Company in 1968. Together they made the Bowen Basin the centre of coking coal production in Australia. In the early twentieth century oil began to displace coal as the primary fuel source for shipping. Railways continued to use coal until the early 1950s, but eventually converted to diesel. Subsequent electrification of the most important railway lines in Australia has seen a renewed dependence on coal as a significant source of energy for transportation.

Chapter 3 details the contribution of coal to the Australian economy: Australia really was built on the miner's back. Queensland and NSW account for 99% of Australia's black coal production. Coal provides a substantial and consistent revenue stream to governments at both Federal and State levels in the form of taxes, natural resource royalties and payment of rail freights. In 2006-07 taxes were in excess of $8 billion and natural resources royalties amounted to a further $1.6 billion. The surplus built up by the Australian Government as a result of the minerals – and specifically coal – boom was almost certainly, an important factor in Australia avoiding a technical recession during the global financial crisis of 2008-09.

Coal also directly and indirectly contributes to the economic prosperity of individual households through the payment of wages and salaries, and the provision of low-cost electrical power. In Australia, residential energy use per capita has increased 35% from 1976 to 2006 as houses have increased in size and the number of persons per household has decreased. Australians enjoy a more energy-intensive lifestyle: modern technologies make it possible for us to live in the comfort provided by climate control systems, enjoy entertainment beamed to us on plasma TV screens, and keep a second "beer" fridge for refreshments. Coal also supports the development of physical and social infrastructure, particularly in rural areas. Black coal projects worth $2 billion were completed in 2007, with further projects requiring a capital investment of $7 billion scheduled for completion in the short to medium term. Coal provides Australia with energy security and independence: two thirds of the world's conventional oil supplies are in the Middle East, an area that has proved to be politically unstable.

Coal on the Yangtze River 2008

Chapter 4 explores the direct and indirect employment and socioeconomic development provided by exploiting our coal reserves. In 2006-07 the Queensland and New South Wales coal industries directly employed over 32,000 people. However this grossly underestimates the jobs created by coal mining. Coal mining activities cannot function without a network of suppliers and service providers. In addition, direct employees spend a portion of their incomes, generating additional employment. Traditionally, "multipliers" of 1:4 have been used to estimate the number indirect employees generated by the mining industry. In this chapter, a macroeconomic model developed by Monash University – the same one used by Professor Ross Garnaut and his team to model the effects of climate change – is used to estimate the flow-on benefits of the coal industry. The model shows that in 2008 household disposable income grew by nearly 7% in Queensland and 6% in New South Wales as a result of coal mining. Employment in the finance, banking and insurance sector grew by around 5,000 people between 2004-07. The mining technology and services industry in Queensland is estimated to be worth around $1 billion, with over 300 firms – most of these being small to medium enterprises – located in the Brisbane area. Coal also contributes to improve the overall standard and quality of life, through the provision of services such as safe drinking water, lighting and treatment of wastewater made possible by low-cost, reliable electricity. Average life expectancy in Australia is shown to have a high correlation with the availability of electricity.

Chapter 5 looks at global production and consumption of hard coking (metallurgical) coal. Australia is the largest exporter of hard coking coal by volume, with Indonesia a close second and Russia third. The three biggest customers of Australian metallurgical coal are: Japan, India and Korea. The three biggest customers of Australian thermal coal are: Japan, Korea and Taiwan. China and India presently occupy sixth and seventh place respectively, but are expected to grow in importance as export destinations. China, for example, is currently building the equivalent of two new 500MW coal-fuelled power stations each week. China is by far the largest producer and consumer of coal; however reserves of high quality coal are predominately located in the north. Australian thermal coal exports are primarily used to fuel thermal power stations located in the south of China.

In the event that the cost and availability of Australian thermal coal exports were affected by carbon taxes and environmental concerns, China would most likely turn to Indonesia and Russia to supply its thermal coal needs in the southern provinces. However the ability of these countries to sustain supply to China is questionable. At current production rates Indonesian coal reserves are likely to be depleted in 30 years. The largest reserves of Russian coal are land-locked in central Russia complicating transport logistics. In the event of volatility in supply China could revert to exploiting reserves of inferior quality coals located in its central and southern provinces. This coal has inferior heat content, higher ash and sulphur content than the high quality Australian thermal coals. It is therefore in the world's best interests to continue to make low emission Australian coal available at competitive world prices.

Chapter 5 also examines how economic growth of our major trading partners is intimately linked to Australian coal. The growth of GDP per capita for Japan, Korea, India, Taiwan and China is strongly correlated to installed electricity generation capacity. Japan is dependent on coal for 26% of its electrical energy needs, Korea for 38% and China for 82% respectively. Life expectancy in these countries has increased as a function of energy consumption per capita, an example of the vital role that Australian thermal coal exports have played in elevating living standards. In India, the percentage of population having access to sanitation facilities and health expenditure per capita have increased. This coincides with rapid urbanisation, which requires the construction of infrastructure (buildings, bridges, sanitation facilities etc) dependent on the availability of low-cost steel for which Australian metallurgical coal is an essential ingredient.

Chapter 6 considers issues of health, safety, environmental management and community engagement related to coal mining. These issues deal with the workforce and the local and broader community. Native title is included in the community issues, and a case study is provided of Peabody Energy Australia's management of the Wilpinjong Coal Project. Health, safety, environmental management and native title are framed in the context of legislation and how the industry responds to directives and encouragement from the Government. The most significant development is that the coal mining industry is moving towards risk management systems processes. This approach focuses on hazard identification, risk assessment, risk control, competency of key people, monitoring of system effectiveness and review and systems modification. One benefit of the systems approach is that it has the capacity to rapidly change as circumstances evolve. Advanced technology is an integral part of safety and environmental management systems in modern coal mining. An example is provided of the coal industry's support of the development of the Smartcap™, an instrumented baseball cap capable of measuring and monitoring operator fatigue.

With over $18 billion of projects in the planning, the CSG industry has the potential to be the next great industry for Australia.

Chapter 7 reviews current and potential advanced technologies for capturing and storing carbon dioxide emissions from coal-fuelled power stations. Australia has sufficient carbon storage capacity to outlast its reserves of coal. The Australian Government, the Australian Coal Association and the coal industry is providing significant support for the development of carbon capture and storage (CCS) technologies. Twelve CCS demonstration programs worth in excess of $1 billion are currently underway in Australia. These projects range in maturity from Australia's first storage project (the CO_2CRC Otway Project) and the CSIRO Loy Yang PCC Pilot Project, to projects which are under feasibility assessment.

First generation carbon capture demonstration plants are adopting energy intensive technologies, which reduce power efficiency and increase the cost per kW of power generated. China is currently the largest emitter of carbon dioxide in the world and is undertaking a remarkable expansion of its energy program to the extent where it may host 50% of the world's coal power generation capacity. India has relatively old and inefficient coal power production plants. In the short term, CCS demonstration plants are likely to be developed in China rather than India because of the ability to integrate CCS facilities into its new coal-fuelled power stations.

Chapter 8 looks at coal's new frontiers. It chronicles the rise of the coal seam gas (CSG) industry in Queensland. Proven, probable and possible reserves of CSG now exceed 800 Mt - larger than the LNG reserves off the north and west coasts of Australia. With over $18 billion of projects in the planning, the CSG industry has the potential to be the next great industry for Australia. The chapter also looks at developments to exploit coal without mining it, by reacting it in-situ with oxygen, steam and or hydrogen in order to recover synthesis gas. This syngas can be used directly for power generation or as the base material from which other transport fuels and chemicals can be made. There are several in-situ coal gasification trials currently underway in Australia. Alternatively, coal can be gasified in plants on the surface after it has been mined. There are no surface coal gasification plants in Australia yet, although one, the ZeroGen project, which will produce power, is well advanced in terms of planning and design.

The eight chapters in this study provide evidence from which to conclude that, in addition to its vital importance as the critical ingredient in the production of steel, fertilisers and cement, coal is not just a fuel of the past, but very much a fuel of today. Of crucial importance - coal is a major fuel for the future.

Coal truly is a Great Resource for Australia.

Professor Peter Knights
Brisbane, Oct 2009

Introduction

1

Professor Michael Hood – Chief Executive Officer
of the Cooperative Research Centre for Mining (CRCMining)

1.1 COAL POWERS THE WORLD

Members of the general public, because they buy fuel for their automobiles on a regular basis, have a keen appreciation of the role that oil plays in their household and in the national economy. The public, however, has little or no such appreciation of the vital role that coal plays in their everyday lives. This report sets out to change that appreciation.

Most people, if they think about coal at all, regard it as an old fuel, one that was once used to heat houses and drive steam engines. This perception is only partly incorrect. Coal, indeed, was the fuel that, 250 years ago, changed the world forever. It started the process of lifting the standard of living of an average person from a subsistence level to what we now call middle-income. The misperception is that coal's role lies in the past. In fact coal plays an ever increasing role in supplying the world's energy needs. As shown in Figure 1.1, there is a direct relationship between the standard of living in a country (as measured by Gross Domestic Product per person) and the amount of energy or power consumed per person in that country. All countries in the emerging world - those that lie in the bottom left hand corner of Figure 1.1 - appropriately aspire to the standard of living enjoyed by countries in the developed world - those in the middle and upper regions of this plot. For those developing countries to realise this goal their energy consumption will need to rise significantly. As this report explains, coal will provide a substantial part of this energy need.

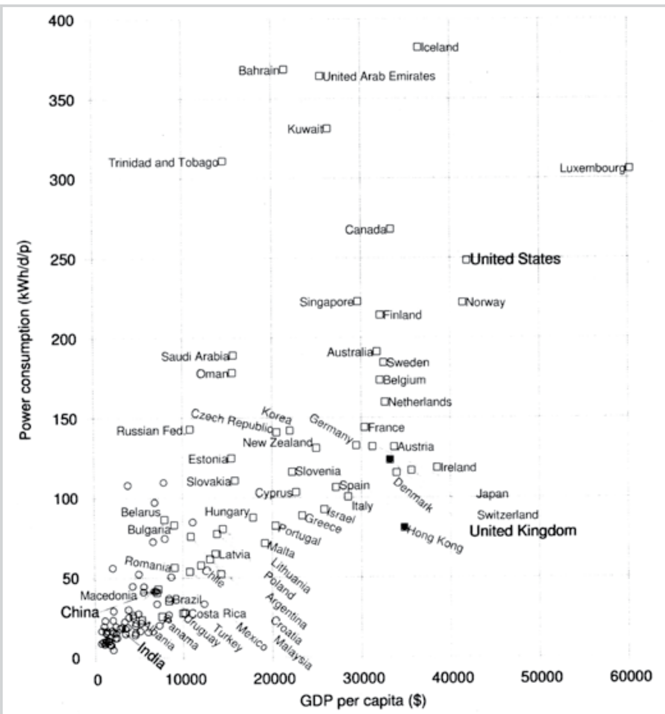

Figure 1.1 The relationship between the power consumed per person and that person's standard of living for different countries (from MacKay, 2009 - Fig 18.4).

Coal was the fuel that, 250 years ago, changed the world forever.

Coal plays an ever increasing role in supplying the world's energy needs.

All countries in the emerging world appropriately aspire to the standard of living enjoyed by countries in the developed world.

To realise this goal their energy consumption will need to rise significantly. Coal will provide a substantial part of this energy need.

Coal currently supplies 26% of the world's energy and this is expected to increase to 29% by 2025.

The International Energy Agency (IEA) implements an international energy program under the auspices of the Organisation for Economic Cooperation and Development (OECD). In a recent publication (World Energy Outlook, 2008) the IEA makes the point that coal today is the world's second most important fuel, after oil. Coal currently supplies more than one quarter (26%) of the world's energy and this is expected to increase to 29% by 2025.

The two plots below (from the IEA, 2008) highlight some very interesting points. First, the world's energy production has almost doubled (from 6,115 to 11,741 million tons of oil equivalent) in 33 years from 1973 to 2006. (As might be expected from Figure 1.1, this has helped to lift hundreds of millions of people in India, East Asia - particularly China - and elsewhere in the developing world from a state of abject poverty to a higher standard of living). Second, fossil fuels account for more than 80% of fuel production globally. Third, nuclear and gas both increased substantially over this period. And, fourth, while the relative contribution of oil has declined over this period (from 46.1% to 34.4%), the relative contribution by coal has increased, albeit slightly (from 24.5% to 26%).

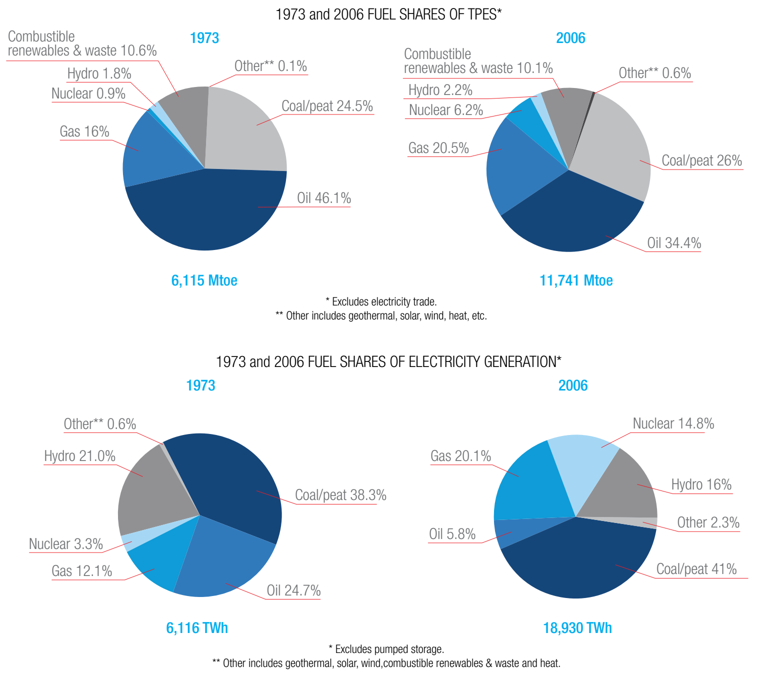

Figure 1.2 The world's increasing use of energy, and particularly electricity and the important role still played by coal (TPES is the Total Primary Energy Supply; Mtoe is a million tons of oil equivalent; TWh is a terrawatt hour) (International Energy Agency, 2008).

During this same period the production of hard coal has more than doubled, from 2.235 billion tonnes to 5.543 billion tonnes and electricity generation has more than tripled, from 6,116 TWh to 18,930 TWh. It is important to note that coal is the major primary fuel used for generating electricity and that its role is increasing, from 38.3% in 1973 to 41% in 2006.

1.2 WHERE IT ALL BEGAN

The Industrial Revolution

We begin the story on the importance of Australian coal and what this resource has meant and continues to mean, not just to Australians but also to our trading partners and neighbours, by reviewing the role that coal has played in world history.

The Industrial Revolution that took place in England at the end of the 18th and first part of the 19th century changed the world in a manner that is so fundamental and so dramatic that, from today's perspective, it is hard to believe how constant and unchanging life was during the millennia before this event.

Those of us fortunate enough to live in the developed world take our lifestyle for granted. The vast majority of us enjoy food and clothing that is plentiful and, relative to the average income, inexpensive. We have access to clean water and sanitation. We live in accommodation which generally has heating and, in warmer climates, cooling; consequently we can remain comfortable regardless of the weather conditions. We own an array of entertainment devices: televisions, radios, CD players, MP3 players. Many of us have a car which gives us the ability to live some distance from where we work and the freedom to travel when and where we like for recreation.

Our standard of living is better than that of our parents and significantly better than that of our grandparents. In fact our expectation is that the standard of living increases with each succeeding generation. We have this expectation because this is the situation that has existed throughout modern history. But, as shown in Figure 1.3, it is a very new phenomenon. For the vast majority of human history living standards did not change from one generation to the next; and, for most people, these living standards were spartan.

Professor Geoffrey Blainey in his 2007 book, *A Very Short History of the World*, notes:

"In Europe and Asia, the typical family lived close to the breadline. Whether in 1500 or 1800, in France or in China, most families either owned no land or such a small holding that it could barely feed them even in a prolific year... Scavenging and foraging were almost a way of life. A peasant owning one cow and a tiny pocket of land might send his children out each day in summer to cut grass on the roadside, some of which was preserved as hay to feed the cow in winter. In forests mushrooms and wild berries were sought... Daily life, in every part of the world centred on the production of food.

The failure or half-failure of a harvest was frequent all the way from Sudan to China. In Finland in the early 1690s a long famine killed one-third of the people. France... suffered a nationwide famine in 16 of the 100 years after 1700.

Health suffered as the inland cities became larger. No large city had a system for the disposal of sewage. The river was the favourite outlet and someone's sewage, after floating 200m downstream, became some-one else's washing water or drinking water.

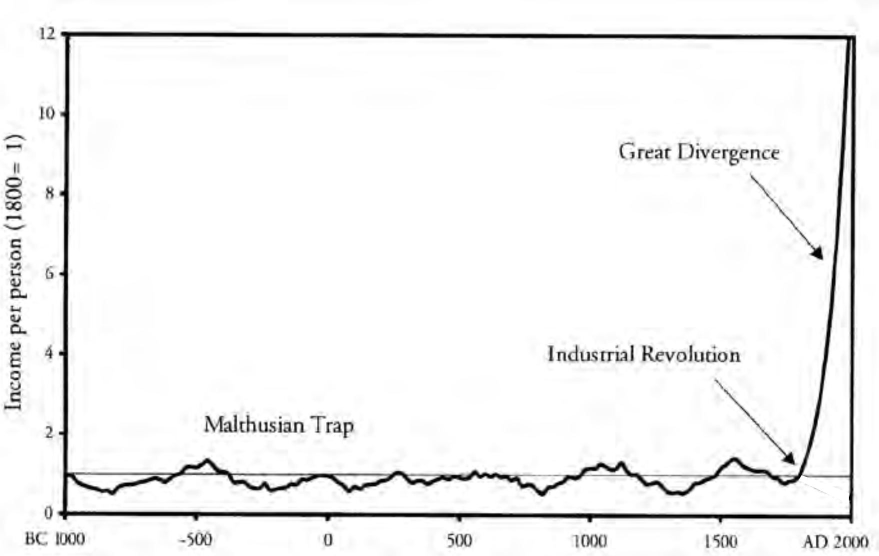

Figure 1.3 World economic history in one picture. World living standards remain unchanged for thousands of years until the Industrial Revolution (from Clark, 2007)

While the population of Europe was usually rising, it was cut back by occasional disasters. Thus, during the Thirty Years War which raged in the years 1618 to 1648, Germany lost perhaps one-third of its population. While the war was raging, Italy was hit by plague. In 1630 one million people died on the plains of Lombardy, with Bologna and Parma and Verona losing half their population in a year.

In the year 1800 most people in Europe did not buy even one item of new clothing from shops or fairs. They made clothes at home, inherited them from the dead, or bought them second-hand. It was an enormous effort for Europe and Asia and Africa to produce enough food and clothing to keep people alive and well. Sometimes the effort failed and millions of people had empty bellies and threadbare clothes.

Houses (on these three continents) were of the simplest: most would now be called slums. In Europe and China the shared bed was normal... Sometimes the whole family slept together on a homemade mattress filled with straw... In winter the house was usually cold - the bed was warmer... In large towns many people living together in the one room generated heat. Even if a fire was burning in that room in the depths of winter it radiated scant heat, partly because firewood had to be used frugally... Sometimes there was no forest nearby and so fuel was very *scarce for poor people....There were limits almost everywhere on cities growing beyond a certain size. A city could not grow too large simply because it could not secure in its neighbourhood the food and firewood it needed.*

The need to spend much time and devote much land to growing fuel for heating and lighting, and the raw materials for warm clothing, was a perpetual curb on the standard of living of much of Europe....For maybe 4,000 years the standard of living of the average person in Europe, Africa and Asia had risen little, if at all. There had been abundant years and terrible years, minor rises and falls in people's material wellbeing and an increase in the luxuries available to the rich; but for two-thirds of the population living on the lower rungs of the economic ladder, daily life was a struggle."

This dispiriting picture of life for the average person over the centuries was recognised by Malthus, an early practitioner of the field that we now call economics. Writing in 1798, Malthus made the case that the natural rate of population increase exceeds the rate of food production. This lead to famines and outbreaks of disease or war, which in turn caused the population to decrease. As Professor Gregory Clark notes in his excellent 2007 book, *A Farewell to Alms - A Brief Economic History of the World*, perversely, in pre-Industrial Revolution society, factors that caused reductions in population such as war, harvest failures and poor sanitation, resulted in a higher standard of living for those that survived. Factors that lead to an increase in population, such as peace, public health, or technology that improved food production, caused living standards to decrease because the available resources, including food resources, had to be shared by this larger number of people. In Malthus' words:

"The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race. The vices of mankind are active and able ministers of depopulation. They are the precursors in the great army of destruction, and often finish the dreadful work themselves. But should they fail in this war of extermination, sickly seasons, epidemics, pestilence, and plague advance in terrific array, and sweep off their thousands and tens of thousands. Should success be still incomplete, gigantic, inevitable, famine stalks in the rear, and with one mighty blow levels the population with the food of the world."

Malthus understood that this situation, where the population size is in balance with land area and available food supply, is the natural state of affairs, not just for humans but for the whole animal kingdom. As Blainey (2007) describes, this balance meant the population of the world prior to 1800 typically increased only slowly over long periods of time (centuries). However, there were periods when, because of famine or disease, the population declined on a scale

The thing that changed the world forever was the increased rate of technological change that began with the Industrial Revolution. This higher rate of technological progress allowed the population to increase dramatically while, at the same time, and for the first time in all of human history, allowed the standard of living of the average person to increase.

The Industrial Revolution was a series of "revolutions" in a number of industries that occurred at much the same time in England.

unimaginable today. For example the plague, or Black Death, reduced the population of England from six million in 1316 to just over two million in 1450 (Figure 1.4). As Clark (2007), points out that it was not just that the standard of living of the average person in 1800 was no better than that of the average person tens of thousands of years earlier (see Figure 1.3), the quality of their life was not improved either. Average life expectancy of 30-35 years was no higher in 1800 than it had been for hunter gathers, and human stature, a measure of the quality of diet and children's exposure to disease, was higher in the Stone Age than it was in 1800.

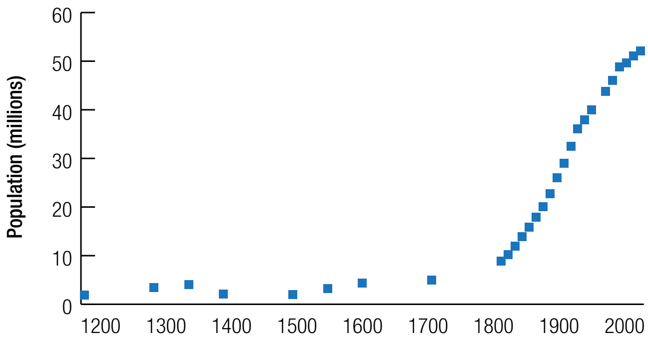

Figure 1.4 The relatively stable population of England from 1200 until the late 18th century followed by an unprecedented population explosion in the 19th and 20th Centuries.

The thing that changed the world forever was the increased rate of technological change that began with the Industrial Revolution. This higher rate of technological progress allowed the population to increase dramatically (Figure 1.4) while, at the same time, and for the first time in all of human history, allowed the standard of living of the average person to increase (Figure 1.3).

What we now term the Industrial Revolution was a series of "revolutions" in a number of industries that occurred at much the same time in England. One was the transformation of textile making using the new factory method for manufacturing. Another was the sequence of developments that took place in iron and steel-making, including the use of coke as a replacement for charcoal in these processes. A third was in agriculture where new, productive techniques allowed a minority of people to produce enough food to satisfy the needs of the entire population, freeing the majority up to work in other industries. A fourth was in transportation where an extensive canal system was developed to transport goods and roads were improved. Later, and the real revolutions in transport, were the development of the railroads and, yet later, steam ships. Geoffrey Blainey (2007) describes steam trains as "probably the most important invention (in land transportation) since the Roman road."

The key development, that made possible all of these step-change improvements across this range of industries, was the steam engine. Powered systems, notably waterwheels and windmills, had been used to drive machines for centuries. These, obviously, were fixed plants. Steam provided a mobile power source, or alternatively, a fixed power source in locations remote from water courses or windy areas. Steam was a replacement for animal power, notably horses and oxen, providing orders of magnitude more power at lower cost. Coal was the fuel used to generate the required steam and England was fortunate to have abundant coal reserves.

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The wave of innovation that took place in England during the Industrial Revolution is classified by Professor Landes in his 1998 book *The Wealth and Poverty of Nations* into three areas:

1. The substitution of machines – rapid, regular, precise, tireless – for human skill and effort.
2. The substitution of inanimate for animate sources of power, in particular, the invention of engines for converting heat into work, thereby opening an almost unlimited supply of energy.
3. The use of new and far more abundant raw materials, in particular the substitution of mineral, and eventually artificial, materials for vegetable or animal substances.

These areas were brought together in the new factory system of production, particularly for textile manufacture. Prior to the Industrial Revolution, in the early 18th century, England had a thriving cottage industry producing textiles. A cloth merchant would purchase wool from a sheep farm and distribute it to several families. Women washed and carded (combed between two pads of nails to align the fibres) the wool. They then used a spinning wheel to spin it and wind it on to a bobbin. Men performed the physically-demanding job of weaving the thread into cloth using a hand loom (http://industrialrevolution.sea.ca/causes.html).

In the 100 years from 1760, the introduction of the radically-new factory production of textiles replaced this cottage industry and resulted in a 14 fold increase in the efficiency of converting raw cotton into cloth (Clark, 2007). Landes (1998) notes:

"It took power machinery to make the factory competitive. Power made it possible to drive larger and more efficient machines, thus underselling the cottage industry by ever bigger margins.

The first device to use steam to create a vacuum and work a pump was patented in England by Thomas Savery in 1698; the first steam engine proper (with piston) by Thomas Newcomen in 1705. Newcomen's atmospheric engine (so called because it relied simply on atmospheric pressure) in turn was grossly wasteful of energy because the cylinder cooled and had to

The Industrial Revolution was a key turning point in human history. It signified the moment when the pace of technological innovation increased, setting a trajectory that has been followed ever since causing the wealth of the average person to increase while, at the same time, allowing the population to rise.

be reheated with every stroke. The machine therefore worked best pumping water out of coal mines, where fuel was almost a free good. A long time – sixty years – passed before James Watt invented an engine with separate condenser (1768) whose fuel efficiency was good enough to make steam profitable away from the mines, in the new industrial cities; and it took another 15 years to adapt the machine to rotary motion, so that it could drive the wheels of industry. Another line remained to be explored: high pressure engines (more than atmospheric), which could be built more compact and used to drive ships and land vehicles. This took another quarter century......Nor was that the end of it. The size and power of steam engines were limited by the piston's inertia. Driving back and forth it required enormous energy to reverse direction. The solution was found (Charles A. Persons, 1884) in converting from reciprocating to rotary motion, by replacing the piston with a steam turbine. These were introduced into central power plants at the very end of the 19th century; into ships shortly after."

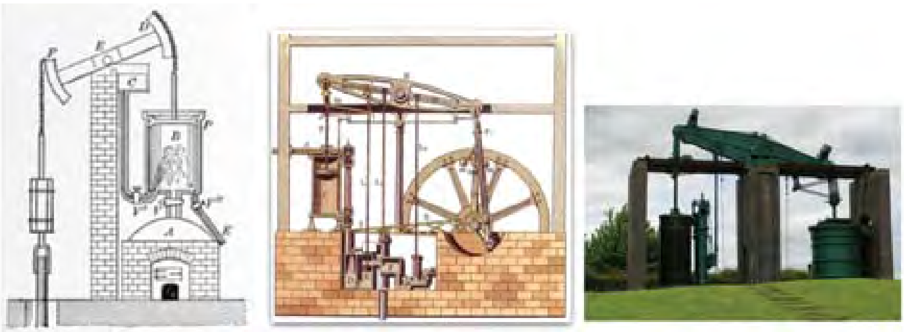

Figure 1.5 Newcomen engine on left (http://en.wikipedia.org/wiki/File:Newcomen6325.png) was inefficient because cold water was injected directly into the cylinder filled with steam, meaning the cylinder had to be reheated on each cycle. Watt's engine, in centre (http://www.eoht.info/photo/2480735/Watt+steam+engine+(c.+1788)) and on right (http://www.flickr.com/photos/tim_ellis/155142093/) employed a separate condenser to increase the fuel efficiency by at least a factor of four.

There are two take-home messages from this section. One, is the Industrial Revolution was a key turning point in human history. It signified the moment when the pace of technological innovation increased, setting a trajectory that has been followed ever since causing the wealth of the average person to increase while, at the same time, allowing the population to rise. The other is that there were many things that came together at the same time that resulted in the Industrial Revolution. But, the key factor was the development of steam power, with coal as the fuel that produced the steam.

1.3 COAL - THE FUEL THAT MADE BRITAIN A MARITIME NATION AND MADE THE INDUSTRIAL REVOLUTION POSSIBLE

The story begins in Britain centuries before the Industrial Revolution. In the mid 16th century England had a thriving wool industry. The need for pastoral land for sheep encouraged the clearing of forests in this small island nation. Wood was also being used to produce charcoal for the iron industry, in the manufacture of ships, and to produce other goods, such as furniture. In addition, wood was used to heat houses and for cooking. This resulted in the deforestation of the regions around the cities. Blainey (2007) makes the point that one of the key constraints on the size of a city was the availability of firewood. He notes that one large ironworks might use 2,000 hectares of forest each year and that a town of 30,000 people in England needed 600 to 1,000 horse-drawn carts of firewood each week.

Coal was the solution. It was mined in the north-east of the country in the area around Newcastle upon Tyne and transported by sea to London. This allowed the city to grow and by 1,600 it had a population of 200,000; by 1750 it was the largest city in Europe; by 1800 its population exceeded one million and by 1860 it was three million, the largest city the world had known. By the late 1740s, London was consuming a million tons of coal a year, requiring an enormous fleet of 1,000 ships with each ship making ten return trips along the east coast of the country, weather permitting.

Barbara Freese, in an entertaining book *"Coal: A Human History"* (2006), makes the point that these sturdy coal ships were an important part of Britain's naval strength. They played a significant role in one of the nation's most important naval victories, the defeat of the Spanish Armada in 1588 and, for more than a century, they served as a training ground for seamen, including the young James Cook (later Captain Cook) who learned his seafaring skills conveying coal from the port of Whitby in his native Yorkshire to London in the late 1740s.

Before the Industrial Revolution, wood was being used to produce charcoal for the iron industry, in the manufacture of ships and to produce other goods, such as furniture. In addition, wood was used to heat houses and for cooking.

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One large ironworks might use 2,000 hectares of forest each year and a town of 30,000 people in England needed 600 to1,000 horse-drawn carts of firewood each week. Coal was the solution.

As the demand for coal grew, mines progressed deeper, requiring access via vertical shafts. Groundwater was encountered which needed to be removed before the coal could be taken.

Newcomen's steam piston engine, first installed in a coal mine in 1712, was the answer. This innovation, made in response to a market need, was one of the key steps in a process that would transform the world's economy.

As the demand for coal grew the mines progressed deeper. The close-to-surface seams had been mined by digging pits or driving adits (nearly horizontal tunnels) into the sides of hills. The deeper mines required vertical shafts. In these mines groundwater was encountered which needed to be removed before the coal could be taken. Methods for draining water from these shafts included chain of bucket mechanisms. The large mines needed more power than humans could provide to drive these pieces of apparatus. Generally this was provided by horses. As many as 50-60 horses could be required to keep the pumping system working day and night. Feeding these horses and hiring workers to look after them was expensive. Newcomen's steam piston engine, first installed in a coal mine in 1712, was the answer with one engine performing the work of 50 horses. By the 1760s, hundreds of Newcomen engines were in use at mines in England and Scotland. Although cheaper than horses, this engine's poor efficiency meant it was a voracious consumer of coal. Consequently, it rarely found a market other than that for dewatering coal mines. Nevertheless, this innovation, made in response to a market need, was one of the key steps in a process that would transform the world's economy.

It took James Watts' improvements to cause steam engines to become the motive power for the Industrial Revolution. Steam engines drove the machinery in the burgeoning factories, they powered the locomotives that allowed the development of the new railway industry, and later they powered the steam ships that would revolutionise sea transport.

In order to manufacture these new machines and transport systems, iron production needed to increase dramatically. At the beginning of the Industrial Revolution, iron was made by smelting the ore with charcoal which, as discussed above, required huge volumes of wood; a commodity in short supply in England. Attempts to replace wood with coal in these processes proved difficult because the impurities in the coal would contaminate the iron. The answer, which took until the mid-1780s to develop, was to heat the coal without the presence of air to drive off the volatile products and turn the coal into coke. Because coke, when made from the appropriate type of coal, is stronger than charcoal, the blast furnaces could be made larger. This development, with the resultant ability to produce cast iron in large quantities, was a key factor in driving the Industrial Revolution. It also created a new market for coal. Then, as now, there are two distinct coal markets; thermal coal, used for heating and for steam generation, and metallurgical coal, used for iron and steel making.

This is the big picture. Of course, as is well known, all was not beer and skittles. What was good for the average individual has resulted in casualties along the way. Life for the workers in the coal mines and factories during this time was horrendous. Emile Zola's classic novel *Germinal* (1885) describes the horrific conditions of a coal miner's life in northern France. Barbara Freese described the environmental and working conditions in Manchester during the 1840s. She accurately describes this city as the centre of (steam-driven) cotton milling and "as a dual symbol of industrial might and misery". The burning of all that coal during the Industrial Revolution caused enormous air pollution problems. She quotes an 1840s government report noting the smoke density in the northern English city of Manchester had:

"...risen to an intolerable pitch....the air is rendered visibly impure, and no doubt unhealthy, abounding in soot, soiling the clothes and furniture of the inhabitants.....The lives of factory workers in Manchester, and in other new industrial cities rising up around Britain, were shaped by the burning of coal just as the coal miners' lives were shaped by the digging of it. Coal made the iron that built the machines that the workers operated as well as the factories they worked in, and then it provided the power that made the machines and factories run. Coal gas provided the lights that the factories toiled under, letting their work day start before dawn and end after dusk. When they left the factory doors, they would walk through a city made of coal-fuelled bricks, now stained black with the same coal soot that was soiling their skin and clothes. Looking up, they would see a sky darkened by coal smoke; looking down, a ground blackened by coal dust. When they went home, they would eat food cooked over a coal fire and often tainted with a coal flavor, and with each breath, they would inhale some of the densest coal smoke on the planet. In short, their world was constructed, animated, illuminated, colored, scented, flavored, and generally saturated by coal and the fruits of its combustion."

However, Barbara Freese goes on to write:

"The (steam) engine was also hailed as a boon to humanity as a whole. There was reason to think that, by lifting the yoke of grueling physical labor, the steam engine would help the poor most of all. Arguably, this is what happened in the very long run."

History shows this is what indeed did happen. The comfortable life most of us in the developed world enjoy today is attributable to our use of power sources that relieve us of the "yoke of grueling physical labor".

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China's economic growth over the past 30 years has made it the second largest economy in the world after the United States, on a purchasing power parity (PPP) basis.

India's economy has grown at an average rate of more than 7% in the decade from 1997; this has helped to reduce poverty by more than 10%.

1.4 COAL - TODAY IS POWERING THE INDUSTRIAL REVOLUTIONS IN MANY EMERGING COUNTRIES AND IS A KEY FUEL FOR MANY DEVELOPING COUNTRIES

Some of the large emerging countries, notably China and India, are going through their own industrial revolutions today. The World Resources Institute reports that over the past quarter century China's economic growth has lifted 50 million people out of poverty and tripled energy demand (http://earthtrends.wri.org/updates/node/274).

China's economic growth over the past 30 years, shown in Figure 1.6, has made China the second largest economy in the world (after the United States) on a purchasing-power-parity (PPP) basis. The per capita income, or the standard of living of the average person living in China, has also risen at an average annual rate of 8% over this period to an estimated US$6,000, on a PPP basis (http://en.wikipedia.org/wiki/Economy_of_the_People's_Republic_of_China; https://www.cia.gov/library/publications/the-world-factbook/geos/ch.html).

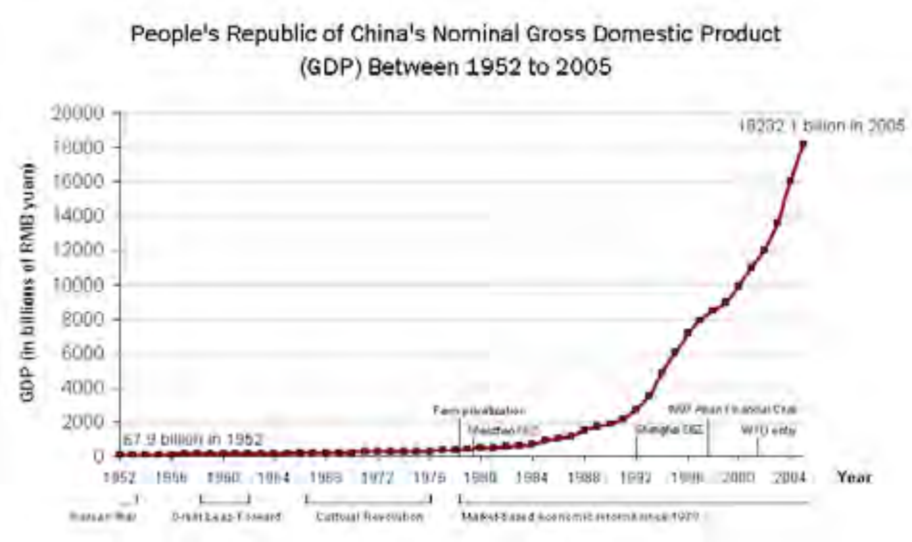


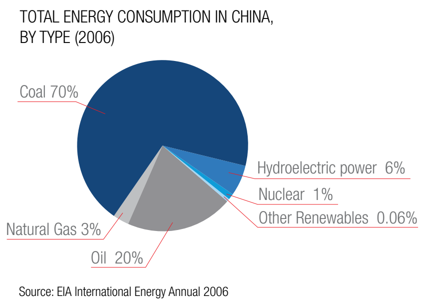
Figure 1.6 China's industrialisation over the past 30 years has resulted in a dramatic increase in the nation's wealth (http://en.wikipedia.org/wiki/File:Prc1952-2005gdp.gif).

India's economy has grown at an average rate of more than 7% in the decade from 1997; this has helped to reduce poverty by more than 10%. In 2008 the standard of living per person (measured as GDP per capita on a PPP basis) was US$2,900; up from $2,500 in 2006 (https://www.cia.gov/library/publications/the-world-factbook/geos/in.html).

These current industrial revolutions are largely fuelled using coal (see Figure 1.7). China, for example, is currently building the equivalent of two new, 500MW coal-fuelled power stations each week; a rate equivalent to Australia's entire coal-fuelled power sector every four months. It plans to continue to do this for the next 10 years! In 2007, China's electricity generating capacity was 624 Gigawatts (GW). This capacity has increased by 100% since 2000 and is likely to add a further 80 GW capacity in 2009 alone (http://www.eia.doe.gov/cabs/China/Full.html).

About half of China's coal production is used for electricity generation. The other half is mainly consumed by industry (http://www.eia.doe.gov/cabs/China/Full.html). China is the world's largest producer and consumer of coal and its rate of consumption continues to increase. In 2006 China consumed an estimated 3 billion short tonnes of coal, representing nearly 40% of the world total; a 129% increase since 2000.

India, by contrast, with only a slightly smaller population (China 1.339 billion; India 1.166 billion), had an electricity generating capacity of 144 GW in 2006 with a goal to add a further 90 GW of capacity by 2012. 70% of India's electricity is generated from coal. India is the world's third largest producer and consumer of coal (2007 consumption 579 million short tonnes).



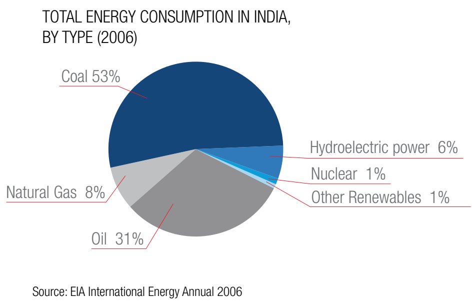


Figure 1.7 China's and India's energy use by fuel type

(http://www.eia.doe.gov/cabs/China/Background.html)

This widespread use of coal is not confined to rapidly emerging countries. The United States operates the equivalent of more than 500, 500MW coal-fuelled power stations. Figure 1.8 (http://www.eia.doe.gov/aer/pecss_diagram.html) shows that 23% of the energy consumed in the United States today is produced from coal and that 91% of this is used for generating electricity. This means that coal accounts for almost 50% of the electricity generated in the US.

These current industrial revolutions are largely fuelled using coal.

China is the world's largest producer and consumer of coal and its rate of consumption continues to increase.

70% of India's electricity is generated from coal. India is the world's third largest producer and consumer of coal.

Globally, coal accounts for 26% of energy consumed and about half of the fuel used for power generation.

There are two reasons for this. One is coal is the most abundant, lowest cost fuel, providing useful energy at a cost of US$1 to 2 per GJ compared with oil and natural gas at US$6 to 12 per GJ.

Coal is not just a fuel of the past, it is very much a fuel of today and of crucial importance, a major fuel of the future.

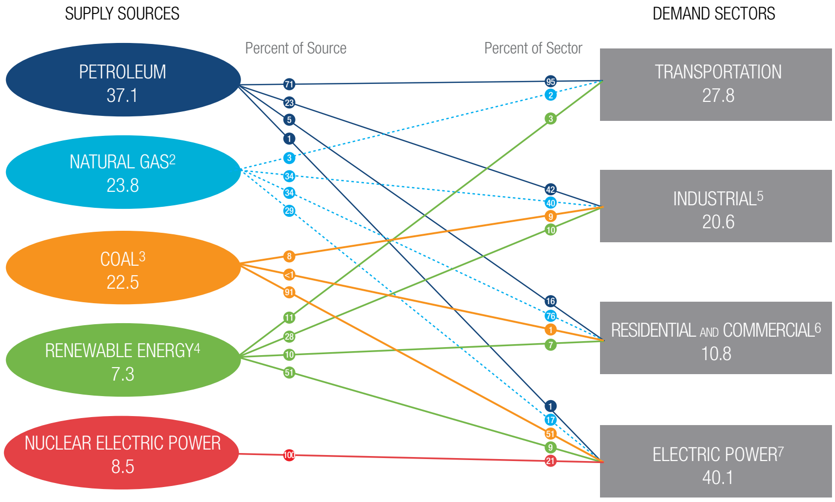


Figure 1.8 Energy consumption by source and consuming sector in the United States in 2008 (units are quadrillion Btu) (MIT study, 2007)

80% of Australia's electricity today is generated by burning coal. Globally, coal accounts for 26% of energy consumed (Figure 1.2) and about half of the fuel used for power generation (International Energy Agency (IEA), 2008). There are two reasons for this. One is that coal is the most abundant, lowest cost fuel, providing useful energy at a cost of US$1 to 2 per GJ compared with oil and natural gas at US$6 to 12 per GJ (MIT Study, 2007). The other is that coal deposits are widely dispersed around the globe, unlike oil and natural gas which are concentrated in unstable regions such as the Middle East and Russia. Specifically the US, China and India have very large coal reserves. For reasons of energy security as well as cost, therefore, a recent (2007) study by MIT on the Future of Coal concluded that:

"Coal use will increase (globally) under any foreseeable scenario (of carbon tax or carbon trading scheme)... "coal, in significant quantities, will remain indispensable (as a global energy source)."

The point we are trying to make here is coal is not just a fuel of the past, it is very much a fuel of today and, of crucial importance, a major fuel of the future. World demand for coal has increased more than any other fuel, by about 4.9% per year from 2000 to 2006, and the IEA projects its rate of growth will continue to increase faster than the total energy demand, at about 2% per year to 2030.

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Coal in Australian History

2

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This chapter reviews the role of coal in Australian history. It looks at the first discovery of coal in convict times, the development early industry around Coal River (now the Hunter River), railway and steam ship transport and the growth of the labour movement. It also reviews the growth of the Queensland coal export industry over the last fifty years.

2.1 CAPTAIN COOK TO CONVICTS

The first inhabitants of Australia used fire for many purposes, for cooking and hunting, in fire-stick farming to encourage particular types of grazing animals, to make charcoal for decorative and ritual purposes. But they had no use for coal. With an abundance of wood available, there was no need for coal-fuelled burning.

The history of coal in Australia goes back to the first arrival of Lieutenant James Cook in HMS Endeavour in 1770. Both man and ship had a history of involvement in the coal trade. Yorkshire-born Cook served his apprenticeship under a Whitby shipowner whose ships worked in the North Sea coal trade, and the Endeavour began life as a Whitby collier, the Earl of Pembroke, before – possibly on Cook's advice – the Royal Navy bought her, refitted her for exploration, and renamed her Endeavour.

Fig 2.1 **Black and brown coal resources** (Camm and McQuilton, 1987)

> The history of coal in Australia goes back to the first arrival of Lieutenant James Cook in HMS Endeavour in 1770.

Notes:

1. 1797 (Newcastle) Lt. John Shortland discovered coal on the banks of the Hunter. A government pit worked by convicts opened in 1801 but failed. Mining recommenced in 1804 and in 1817 the first shaft was sunk by convict labour to a seam 33 metres below the surface. Mining spread slowly. Mines were in operation at East Maitland by 1851, and after discoveries in 1864, the development of the Greta and Cessnock coalfield to the south west of Newcastle started. The numerous small 'pit villages' established now form part of the urban area of Greater Newcastle.
2. 1797 (Wollongong) Coal seams were discovered but it was not until 1857 that the Mt Keira mine tunnel was opened. In 1858 the Bellambi colliery was opened.
3. 1850s (Lithgow) A small pit was opened but the lack of a railway to Sydney retarded development. Expansion started in the 1880s. In 1932 the first open cut mine in Australia was opened near Wallerawang.
4. 1827 (Ipswich) Coal was discovered at Limestone near Ipswich but it was not until 1843 that it was mined.
5. 1863 (Burrum) Coal discovered but regular production did not start until 1883 following the completion of the railway from Maryborough.
6. 1864 (Blair Athol) Coal discovered during the sinking of a well but it was not mined until 1892. The extension of the railway from Clermont led to the development of new mine in the 1910s.
7. 1860s (Bowen Basin) The presence of coal was known but little development took place until the 20th century. Since 1960 the Bowen basin has become a leading producer of black coal.
8. 1890s (Darling Downs) Developed to supply the local markets. Recent discoveries, near Milmerran south west of Toowoomba show coal deposits suitable for liquefaction.
9. 1860s (Upper Hunter) Small mines have operated in the district since the nineteenth century. Since 1960 large open cut mines have been developed to supply electricity generating stations and export markets.
10. 1825 (Wonthaggi) Black coal was discovered near Westernport but it was the 1890s before production increased to more than 100 000 tonnes per year. In 1909 the State-owned mine at Wonthaggi was opened. This mine produced nearly all of Victoria's black coal reaching a peak annual production of 700 000 tonnes in the 1920s. The mine closed in 1968.
11. 1873 (Latrobe Valley) Brown coal was discovered but until the opening of the Morwell open cut mine, in 1916, production was small. The Yallourn deposits were first mined in 1924.
12. 1888 (Leigh Creek) Low grade coal discovered and the first shaft was sunk in 1892. In 1943 open cut mining of low grade steaming coal started. The deposits are still mined for the production of electricity.

13 1834 (Port Arthur) Tasmania's first coal mine where convicts from Port Arthur dug 58 tonnes of coal. Production reached a peak in 1840 when 10 000 tonnes of coal was mined but ceased in 1843.

14 1880s (Fingal) Tasmania's major coalfield was opened in the Fingal valley.

15 1846 (Irwin River) Coal was discovered at Irwin River but it proved to be of no commercial value.

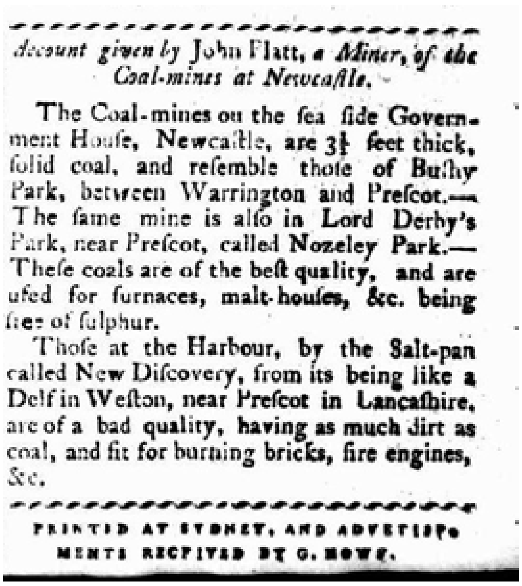
16 1883 (Collie) Workable deposits discovered and mining started in 1898. Coal is still mined and is used for electricity generation.

Coal deposits were found in New South Wales in 1797 and coal mining began on a small scale the following year, 1798, when two government ships came to the newly discovered river and loaded 45 tonnes of coal for the settlement at Port Jackson.

Coal was an important source of fuel in England. Coal was used for domestic purposes such as cooking and heating; it was used for traditional metallurgical activities, such as blacksmithing; and with the development of the process of coking coal, it was used more widely in iron smelting.

Above all, it was used to heat steam for the new steam engines that gradually took over from wind and water power towards the end of the 18th century. Coal is distributed widely across northern England and Wales, but Newcastle-on-Tyne was the centre of the trade from medieval times, hence the phrase ‘taking coals to Newcastle’.

In 1788, the British established the colony of New South Wales, at first no more than a thousand or so convicts and soldiers camped on the edge of Port Jackson (Sydney) Harbour. These first settlers had little use for coal since, unlike in Britain, there was little industrial activity, and plenty of wood available for cooking and heating. Where necessary for rudimentary industrial processes such as grinding corn, wind and water mills were built. With a large convict labour force, there was little need for labour saving devices, and at times convicts did the work of machinery. In early Brisbane, for instance, convicts were punished by working a treadmill to grind corn. In Van Diemen’s Land (Tasmania), they pulled truckloads of cargo along railway tracks. While such labour was to hand, there was little need for steam engines.



Account given by John Flatt, *a Miner, of the Coal-mines at Newcaſtle.*

The Coal-mines on the ſea ſide Government Houſe, Newcaſtle, are 3½ feet thick, ſolid coal, and reſemble thoſe of Buſhy Park, between Warrington and Preſcot.—The ſame mine is alſo in Lord Derby’s Park, near Preſcot, called Nozeley Park.—Theſe coals are of the beſt quality, and are uſed for furnaces, malt-houſes, &c. being free of ſulphur.

Thoſe at the Harbour, by the Salt-pan called New Diſcovery, from its being like a Delf in Weſton, near Preſcot in Lancaſhire, are of a bad quality, having as much dirt as coal, and fit for burning bricks, fire engines, &c.

PRINTED AT SYDNEY, AND ADVERTISE-MENTS RECEIVED BY G. HOWE.

Fug 2.2 Sydney Gazette, 5 May 1805

However some coal was needed to provide the greater heat required for metal work, particularly blacksmithing. Ships also needed a more energy dense fuel than wood, and as Sydney began to develop as a port, coal was sold to visiting ships, thus becoming Australia's oldest export trade. Whaling ships in particular needed coal to fuel the boilers that operated 24 hours a day during the hunting season, boiling down blubber into whale oil.

Coal deposits were found in New South Wales in 1797. On their journey back from circumnavigating Tasmania, Bass and Flinders saw what they thought were coal deposits along the coast south of Sydney, in the area that would eventually become Wollongong. Meanwhile, in early September, a group of convicts escaped from Port Jackson by boat, and Lieutenant Shortland was sent north to bring them back. He never found the convicts, but during his search, he found an outcrop of coal at a river he named 'the Coal River'. He chipped off a few samples, and reported back to the government that 'In this harbour was found a very considerable quantity of coal of a very good sort, and laying so near the water side as to be conveniently shipped.' (Windsor and Ralston, 1897)

Coal mining began on a small scale the following year, 1798, when two government ships came to the newly discovered river and loaded 45 tons of coal for the settlement at Port Jackson (Windsor and Ralston, 1897). In 1804, a permanent convict settlement began on the Coal River, now renamed the Hunter River after Governor Hunter. This new settlement was called Newcastle, after Britain's foremost coal city. In Australia, as in Britain, mining at this time was dirty and often dangerous work, so it was natural that the Newcastle settlement became a place of secondary punishment, a destination for convicts who had reoffended in New South Wales.

At first, coal was mined from the seam that Shortland had seen from the sea: a seam three foot one inch wide – known as the Yard Seam – which extruded from the sandstone, on the side of the hill now called Fort Scratchley. Later a pit was dug that eventually reached 111 feet below the surface. These early mines were primitive affairs, not least because neither soldiers nor convicts knew anything about mining, so it was a godsend when Benjamin Grainger, a miner from Sedgely, Staffordshire, was transported for life in 1807. Grainger was sent immediately to Newcastle, where he became the Superintendent of Coal Mines; by 1813, though still a convict, he was on the payroll.

In 1819 Grainger described the mining operations to Commissioner Bigge. In all, 27 men were employed. Eight men – the hewers – descended the pit by ladder or windlass, and then crawled 100 yards to the coal face. The rest of the crew bailed out water, wheeled the coal to the shaft in barrows, raised it by windlass, and carried it by bullock wagon to the wharf. They worked a 10 hour day, and the hewers received a double food ration for their efforts. Mining

In 1804, a permanent convict settlement began on the Coal River, now renamed the Hunter River after Governor Hunter. This new settlement was called Newcastle, after Britain's foremost coal city.

affected the men's health. They worked in wet conditions, without a change of clothing. One of the miners, John Allen, told Bigge that coal mining had given him asthma, and Surgeon Evans criticised the poor air quality (Turner, 1973).

Grainger claimed that the hewers could produce 2.5 tons of coal per man, per day. However export figures suggest this level of production was very rarely met:

	Tons raised	Government vessels tons	Value (in £ s d)	Private vessels tons	Value (in £ s d)
1805	150	20	10-0-0	64	32-0-0
1806	420	121	60-10-0	253	126-10-0
1807	400	66	33-0-0	237	118-10-0
1808	500	160	80-0-0	233	116-10-0
1809	800	357	178-10-0	308	154-0-0
1810	800	380	190-0-0	328	164-0-0
1811	1,400	641	320-10-0	700	350-0-0
1812	1,400	493	246-10-0	632	316-0-0
1813	1,800	922	461-0-0	647	323-10-0
1814	–	455	227-10-0	1,738	869-0-0
1815	1,750	750	375-0-0	727	363-10-0
1816	1,450	917	458-10-0	340	170-0-0
1817	1,500	836	418-0-0	479	239-10-0
1818	1,300	947	473-10-0	95	59-7-6
1819	2,250	1,887	943-10-0	125	72-2-6
1820	3,915	2,903	1,451-10-0	150	93-15-6

Fig 2.3 Return of coal raised at and exported from Newcastle to Sydney from January 1805 to December 1820 inclusive. (Historical Records of Newcastle, p. 278) Coals 10 shillings per ton until 1818, then 12/6 to private vessels 'in consequence of being loaded by government gangs'

By 1812, three small sailing vessels were trading with coal to Sydney. Nearly all the coal produced was burned locally in Newcastle, or in Sydney, but gradually an export trade developed. In 1824 an American schooner took 250 tons of coal to Rio de Janeiro, and some coal was exported to Mauritius, Batavia (Jakarta) and Bombay, often as ballast, (Windsor and Ralston, 1897) but the quality was low, and Asian markets were unenthusiastic. Even in New South Wales, the demand for coal was limited, especially at the high price of 10 shillings at the pit, and in 1822 the convict settlement was disbanded.

Governor Brisbane explained that 'Newcastle could afford but inadequate supply of work, as the demand for coal was limited' (Windsor and Ralston, 1897). A small number of convicts – 'the New Gang' – remained behind to mine coal, but in 1826, the government abandoned coal mining altogether, deciding that convicts could be better employed in road building.

2.2 INDUSTRY AND DEVELOPMENT

In 1824, the first two incorporated companies were created by the British Parliament to invest in New South Wales: the Australian Agricultural Company (AAC, which still exists) and the Van Diemen's Land Company. The directors were well connected, and generous in their gifts to politicians, and they were well rewarded. Both companies received large land grants and allocations of convict labour; in return, they were expected to bring capital to invest in the colony. The AAC was granted one million acres of land (400,000 hectares) north and west from Newcastle, between Port Stephens and the Peel River, containing most of the known coal reserves of NSW. A feature of this land grant was that land title was not limited to the surface of the land, as is true of Australian freehold title today; instead, pre-1825 land grants included mineral rights.

The AAC moved into coal mining, leased the government mines in Newcastle, and gained a monopoly on the sale of coal in New South Wales. For the next twenty years, the AAC supplied all coal to the colony. At first, coal was not particularly profitable, for demand remained limited, however tonnages gradually rose: 974 tons in 1828, 780 tons in 1829, and 4000 tons in 1830 In 1831, a change of policy in Britain meant that free immigrants began to come to New South Wales; once these immigrants were unloaded in Sydney, some of the immigrant vessels headed north to Newcastle to take on coal as freight to another port. By 1840 the AAC's superintendent, P. P. King, reported that 'There are between 2,000 and 3,000 tons of shipping in Newcastle harbour waiting for coals.' In 1841, the AAC sold 34,841 tons of coal at 12 shillings a ton, for a total of £20,905 (Windsor and Ralston, 1897).

Although the mines were still worked by convicts, the AAC invested in some improvements, so that coal mining became more efficient. On 31 December 1831, the Sydney Gazette described some of these improvements; a steam engine was imported from Newcastle-on-Tyne to pump out water and rails were laid to help transport coal to the wharves. In 1840, as convict transportation was coming to an end in New South Wales, the company sponsored the immigration of 'a few practical miners' from England (Windsor and Ralston, 1897).

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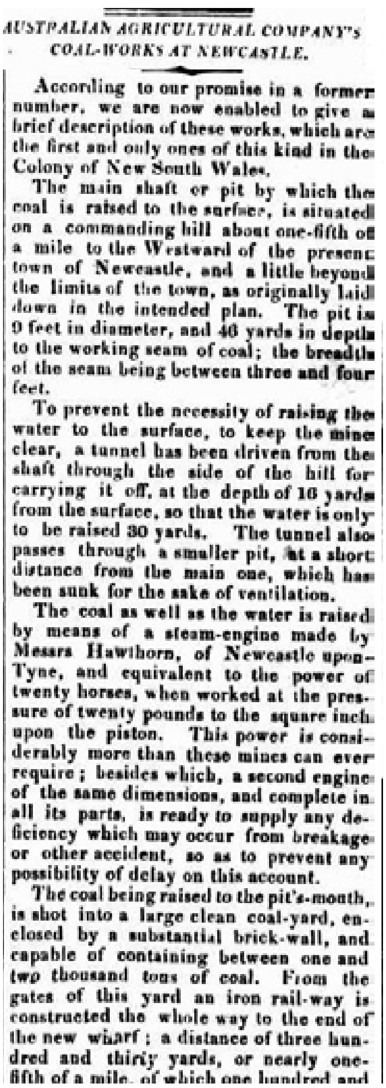
Coal production went hand-in-hand with industrial development and Newcastle consequently became Australia's first industrial town.

Demand for coal expanded from the 1830s because of the growth of population, but also because from 1831, steam ships began to operate in Australian waters. The first locally built steam ship, William the Fourth, ran between Newcastle and the Clarence River, while the Sophia Jane was imported from London for the Newcastle-Sydney run. By 1840, the ships of the Hunter River Steam Navigation Company could sail between Newcastle and Sydney in six or six and a half hours (Windsor and Ralston, 1897). Increasing numbers of steam ships meant a growing demand for coal.

Coal production went hand-in-hand with industrial development and Newcastle consequently became Australia's first industrial town. Salt and lime production began in convict times; later industrial products included sulphuric acid, iron (1840), copper (1853) and brass (1866) foundries, soap and candle works (1866), cloth (1840) and flour mills (1844) and more (Windsor and Ralston, 1897)[1]. Newcastle exported coal to other centres in Australia, and in return, imported raw materials for processing, such as copper ore from the South Australian mines.

By the late 1840s, the AAC's monopoly on coal mining in New South Wales had become a problem, restricting supply at a time of growing demand to meet new uses. New sources of coal had been discovered, both in the Newcastle region and elsewhere, and the company found it difficult to enforce its monopoly. Small amounts of coal were discovered soon after settlement in Tasmania (then Van Diemen's Land). In 1833, the Commandant at Port Arthur examined a seam of coal at Norfolk Bay, and a coal mine was opened, using convict labour, and brought to Hobart where it sold well 'though tending to crack and throw out burning pieces when in the grate'. Zephaniah Williams, a mineral surveyor and coal merchant from Wales transported for his Chartist politics, became the Superintendent at the Port Arthur coal mines. He later started his own company and began the Denison Colliery in 1853. He imported skilled miners from England, built a tramway and deep-water jetty, but the enterprise failed, and Williams spent the rest of his life as a publican (Robson, 1990). In general, the colony stagnated economically, its coal reserves were small and locally consumed, and Tasmania remained a net importer of coal.



AUSTRALIAN AGRICULTURAL COMPANY'S COAL-WORKS AT NEWCASTLE.

According to our promise in a former number, we are now enabled to give a brief description of these works, which are the first and only ones of this kind in the Colony of New South Wales.

The main shaft or pit by which the coal is raised to the surface, is situated on a commanding hill about one-fifth of a mile to the Westward of the present town of Newcastle, and a little beyond the limits of the town, as originally laid down in the intended plan. The pit is 9 feet in diameter, and 40 yards in depth to the working seam of coal; the breadth of the seam being between three and four feet.

To prevent the necessity of raising the water to the surface, to keep the mine clear, a tunnel has been driven from the shaft through the side of the hill for carrying it off, at the depth of 10 yards from the surface, so that the water is only to be raised 30 yards. The tunnel also passes through a smaller pit, at a short distance from the main one, which has been sunk for the sake of ventilation.

The coal as well as the water is raised by means of a steam-engine made by Messrs Hawthorn, of Newcastle upon-Tyne, and equivalent to the power of twenty horses, when worked at the pressure of twenty pounds to the square inch upon the piston. This power is considerably more than these mines can ever require; besides which, a second engine of the same dimensions, and complete in all its parts, is ready to supply any deficiency which may occur from breakage or other accident, so as to prevent any possibility of delay on this account.

The coal being raised to the pit's-mouth, is shot into a large clean coal-yard, enclosed by a substantial brick-wall, and capable of containing between one and two thousand tons of coal. From the gates of this yard an iron rail-way is constructed the whole way to the end of the new wharf; a distance of three hundred and thirty yards, or nearly one-fifth of a mile, of which one hundred and

Fig 2.4 Sydney Gazette, 31 December 1831

Similarly coal seams were discovered near Ipswich in the Moreton Bay District (later Queensland) while mining for limestone during convict times. When the region was opened to free settlement in 1842, the demand for coal rose, and the first recorded coal mine opened at Redbank in 1843. The coal on the Bremer River was easily accessible by water, and during the 1840s, small steamers on the Brisbane and Bremer rivers used local coal. But the river channel below Brisbane was too shallow for ocean-going steamers, and the West Moreton coal reserves were limited to local use for steamships until the 1860s, when the river mouth was dredged. Outside the Brisbane area coal was discovered west of Rockhampton in 1862, in Laidley and at Burrum in 1863, at Blair Athol in 1864 and on the Bowen River in 1867. For the time being, none of these areas was commercially significant (Whitmore, 1981).

Ipswich, like Newcastle, became an important industrial town in the second half of the 19th century. Queensland's railway workshops were based there, together with the bulk of the colony's coal mines, and Ipswich therefore became a centre of engineering expertise. Easy access to coal meant that Ipswich, like Newcastle, became a centre for industries such as steam driven saw mills, flour mills, woollen mills, and blacksmithing. Ipswich was also potentially radical. The coal-mining electorate of Bundamba was the first in Queensland to elect a Labour member, Thomas Glassey, in 1888 (Bowden, 1997).

In the Port Phillip district, later Victoria, coal was discovered at Western Port by the explorer William Hovell in 1827, and rediscovered by Robert Massie in 1837 (Shaw, 1996). However coal production did not begin in earnest until the 1860s. Victoria has some of the largest reserves of lignite coal in the world, but brown coal could not compete with the black coal available in New South Wales, particularly at a time when the efficiency of steam engines was poor. Newcastle coal remained the preferred option until after the gold rushes (1851-60), when the Victorian Government embarked on a policy of import replacement behind high tariff barriers. Local coal was given preferential treatment, despite its inferior quality, especially when strikes in Newcastle in 1861 made the Victorians question the dependability of supply from NSW.

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[1] These are the dates for the establishment of companies. Unincorporated industrial developments existed much earlier, especially in the case of low capital industries such as flour milling, but leave little record behind.

The coal-mining electorate of Bundamba was the first in Queensland to elect a Labour member, Thomas Glassey, in 1888.

A further new use for coal came with the development of coal gas, firstly for street lighting, and later for wider domestic purposes.

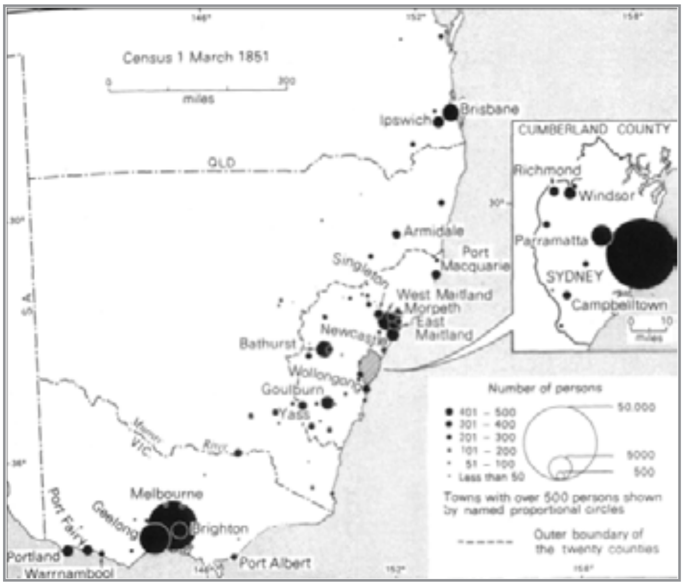

Fig 2.5 Population recorded in census 1851 (Linge, 1979)

2.3 GAS AND LIGHTING

A further new use for coal came with the development of coal gas, firstly for street lighting, and later for wider domestic purposes. In 1836, a group of Sydney businessmen formed the Australian Gas and Light Company (AGL) to supply reticulated gas in Sydney, the first private company designed to invest in a public utility: urban street lighting. It took five years before the company achieved its plan, but on 24 May 1841 – Queen Victoria's birthday – a crowd of over 2,000 people watched the ascent of a gas filled balloon, followed by illuminations including a 30 foot structure with 'a large crown with the letter V on one side and R on the other' above the company's headquarters (Broomham, 1987).

The AGL began operations with one engineer supervising the work of two stokers who worked 12 hour shifts, day and night, for a weekly wage of 45 shillings. By the end of the decade, the workforce had risen from two to eight stokers. Coal was shovelled from the ship's hold into baskets, heaved onto the jetty at the Company wharf on Darling Harbour, and wheeled to a stockpile within shovel reach of the retorts, where the coal was heated, the gas released and bubbled through limewater. The stored gas was distributed through pipes to the street lamps, which were lit each night by a lamplighter employed by the AGL. Part of the engineer's job was to patrol the streets on horseback, checking that the lamplighter was doing his job (Broomham, 1987).

As Sydney grew, so did the demand for gas lighting, and other towns followed suit. Newcastle got gas street lighting in 1856 (Windsor and Ralston, 1897). The new industry produced by-products; coke was sold for a shilling a bushel, and coal tar at a shilling a gallon was 'found useful as an asphalt mixture with sand or gravel' for footpaths and garden paths (Ellis, 1969).

Demand for coal for gas lights, steamships and industry made it increasingly difficult for the AAC to sustain its monopoly on coal production. Then, in 1846, businessmen in Sydney began to talk about building a railway line to Goulburn. In 1847, following an inquiry into the coal monopoly by the New South Wales Legislative Council (Select Committee, 1847), the AAC bowed to the inevitable and agreed to abandon its monopoly on coal production, although their Newcastle mines continued to dominate production for many years.

2.4 STEAMSHIPS AND COALING STATIONS

With the introduction of steamships, the tyranny of distance which had isolated Australia from the rest of the world, and the ports of Australia from one another, began to diminish. Since steam ships did not depend on wind conditions, they were much more reliable, for they could sail whether the wind was blowing or not, and they could sail direct from port to port, rather than tacking according to the direction of the wind. Shipping timetables became commonplace. However steamships were more expensive to operate, and were used for high-value cargo, in particular passengers and mail, while sailing ships continued to transport bulky freight such as wheat, wool and – ironically – coal. Coal had to be deposited at coaling stations where steamships would refuel, and within the Asia-Pacific region, much of that coal came from Australian sources. In 1862, the British Admiralty conducted tests on coal from Newcastle, and reported favourably on its quality.

Coal had to be deposited at coaling stations where steamships would refuel and within the Asia-Pacific region, much of that coal came from Australian sources.

By 1870, one third of Newcastle's coal production was exported, much of it for coaling stations in the Asia-Pacific region such as Singapore, Colombo and Suva, key ports linking Australia to the world.

'We have already despatched our coals to China, Batavia, India, California, and South America', the *Sydney Morning Herald* reported on 28 August 1861. 'But this is a mere fragment of the probable demand, as the mining interest becomes stable and reliable.'

By 1870, one third of Newcastle's coal production was exported, much of it for coaling stations in the Asia-Pacific region such as Singapore and Colombo and Suva, key ports linking Australia to the wider world. Coal was also exported to India for use in the Indian railways *(Moreton Bay Courier, 3 January 1861).*

Coastal shipping had always been important in Australia, but from the 1840s regular steam traffic became commonplace. The Hunter River Steam Navigation Company was formed in 1839 with a capital of £40,000; in 1851 it became the Australasian Steam Navigation Company (Ellis, 1969). Such companies were able to develop reliable passenger services from port to port. 'The steamer Breadalbane made an extraordinarily fast passage to Ipswich and back on Thursday last,' announced the *Moreton Bay Courier* in November 1859. 'Leaving McCabe's Wharf [Brisbane] at 6 am, she stopped at Redbank for coal, then went on to Ipswich and discharged about 10 tons of cargo, reloaded with wool and returned to Brisbane (notwithstanding several stoppages), by 1.45 pm, thus accomplishing the journey of 110 miles in 8 hours 45 mins inclusive of various detentions.'

As technology improved, these steamers used coal more efficiently. The low-pressure side-lever marine engines of the 1840s were replaced by engines using high-pressure steam. The rectangular boilers were replaced by fire-tube types with improved heat exchange, while jet condensers gave way to surface condensers which allowed the boilers to run on recirculated water (particularly important for ocean-going steamers, which had previously used salt water). Thus the 75 kw engines of the *Shamrock*, which sank in Moreton Bay in 1847, consumed coal at a rate of some 4.8 kg/kW/hour, the *Diamantina* which came into service in Brisbane in 1861, had a fuel consumption of about half this figure (Whitmore, 1981).

Steamships also transformed internal transport in Australia, allowing cargo and passengers to move more quickly and reliably along the inland waterways. From the 1850s, paddle steamers operated along the Murray-Darling river system, and the port of Echuca on the Murray River became Australia's largest inland port, taking wool downstream to Adelaide and returning with supplies for the pastoral industry. In 1863, H. S. Chapman reported that there were 'ten steam boats and as many barges' operating on the Murray[2].

[2] Chapman was Victoria's attorney general in 1858.

By the mid-1870s, that number had risen to 23 steamers and 25 barges based in Echuca, and another 16 barges and 19 barges of South Australian origin based in Goolwa. Some of these steamers were wood fired, but as the timber along the Murray was consumed, they relied increasingly on coal for fuel, especially after 1864, when the Victorian Government built a railway linking Echuca to Melbourne, making it easier to access coal from Victoria (Gunn, 1989).

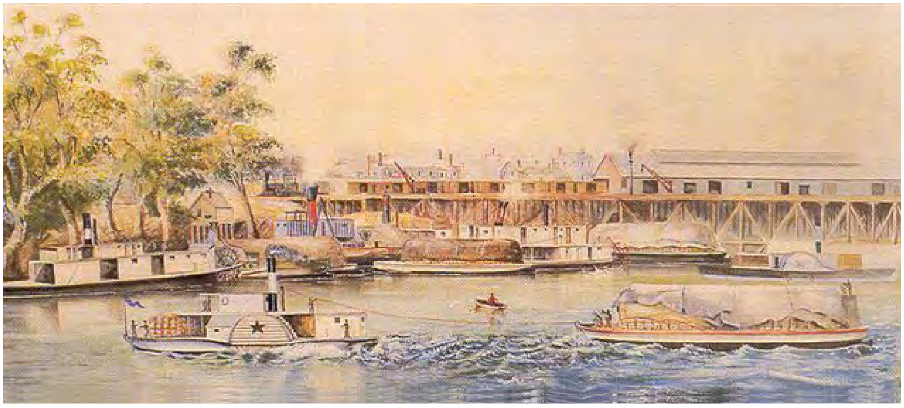

Fig 2.6 Watercolour by an unknown artist, c. 1880.' In Graeme Aplin, S.G. Foster, Michael McKernan (eds.), Australians: Events and Places (Sydney, 1987)

2.5 RAILWAYS

The first private railway company in Australia was floated in 1848, the Australian, Southern and Western Railway Company, which planned in the first instance to build a line from Sydney west to Goulburn. The Governor's daughter turned the first sod at Redfern in 1850, but this, and other, companies, came to grief. The population was too small, and the distances too great, for any private company to make a profit from rail, and it was only from the 1860s that railways took off, built and operated by colonial governments rather than private companies. To begin with, the steam engines that drew the trains were powered by wood, but in 1861, John Whitton, the engineer-in-chief for NSW Railways, undertook trials using coal on the Campbelltown line. These trials were successful, and coal replaced wood as the standard fuel on all lines.

The relationship between rail and coal was symbiotic: coal fuelled the railways, but railways also moved coal. In 1861 the Wallsend Coal Mine opened in Newcastle and shipped 5420 tons of coal by rail that year, and between 1866 and 1870, the Northern Line made a profit of £110,000 for the carriage of 2,341,500 tons of coal, while a private branch line carried another million tons from the AAC and Waratah mines. As the railway networks grew, they linked into the river network, supplying coal for the river steamers at key river ports: the Victorian railway reached Echuca in 1864; Bourke (NSW) and Goolwa (SA) followed (Gunn, 1989).

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Between 1875 and 1900, the mining regions were connected to the railway system and exporting facilities.

Railways allowed coal to be transported much more cheaply than ever before, often at subsidised rates. The NSW and Victorian colonial governments used competing freight rates to entice trade from one side of the Murray to the other. Elsewhere, government subsidies on railway construction opened new opportunities by providing cheap freight rates. The Lithgow line, for instance, was particularly expensive to build, travelling through hilly terrain, including the famous 'Lithgow Zigzag' which in its day was an engineering masterpiece. Yet the arrival of the railway in the Lithgow valley in 1869 made it possible to open the Lithgow coal mine, and led to rapid industrialisation in the valley (Patmore, 2000). In 1883 coal from Lithgow was transported to Sydney for only a penny per ton per mile (Gunn, 1989).

Meanwhile in Queensland, railway construction began in 1865, with the first line linking Ipswich to Warwick and Toowoomba. The first locomotives burned wood, but from 1870 coal began to replace wood as fuel. By the 1880s, serious efforts were underway to transfer coal from the Ipswich mines to Brisbane by rail. Between 1875 and 1900, the mining regions were connected to the railway system and exporting facilities (Whitmore, 1981).

Until the development of road transport in the 1920s, railways dominated land transport in Australia (and they would continue to handle most freight until the trucking industry began to develop in the 1950s). Beyond the rivers and the railways, products such as wool moved slowly by bullock wagon to the nearest railhead. Railways facilitated the export of raw materials from rural Australia and the import into rural Australia of finished product from colonial cities and beyond. Rail tied everyone to the same clock, too, for with railway timetables, for the first time each small town had to keep to the same time as the metropolis (Davison, 1993). Everywhere, in Henry Lawson's words, 'With iron bands, the mighty bush is tethered to the world.' (Lawson, 1901).

2.6 THE ELECTRIC TELEGRAPH AND ELECTRICITY GENERATION

The first use of electricity in Australia came in the form of the 'electric telegraph'. Telegraph wires rolled out across the land from the 1850s, and had an immediate impact on the speed of communication between city and country, and eventually between Australia and the rest of the world. But the telegraph did not involve the generation of power from coal. The telegraph used 'galvanic batteries' and repeater stations along the route, with a team of operators manually interrupting the current to send messages in Morse code.

Between 1851 and 1860 the population of NSW trebled, mainly through immigration, and the Victorian population rose sevenfold. Once the gold rush ended, miners and others had to look for work elsewhere; many, perhaps most, of these new immigrants found work in factories. Between 1860 and the end of the century industrial development took place across Australia, but most particularly in Victoria. Most of the gold miners and their families had gone to Victoria, and the Victorian colonial government responded to the end of the gold rush by pinning its hopes on industrialisation.

These new factories needed cheap fuel. To begin with, they relied on black coal imported by colliers from Newcastle, but supplies could be occasionally disrupted by strikes in the mines, or on the wharves or ships. By the end of the 19th century, Victoria was attempting to establish a coal supply based on its own mines. A state owned coal mine was established at Wonthaggi in 1909, which supplied 'inferior black coal' to the Victorian railways for nearly 60 years (Blainey, 1984).

There were isolated efforts to use electricity for lighting in the late 19th century; electric light was installed in Sydney's General Post Office in 1878 (Broomham, 1987), and electric street lighting began to replace gas from the 1890s. However gas remained the fuel of choice for domestic purposes, while coal (or wood) was widely used to generate steam power in factories. Large scale electricity generation with a distributive power network did not really take off until after the First World War.

In 1919, the Victorian Government created the State Electricity Commission and appointed General Sir John Monash as general manager and chairman in 1920. Monash had been an engineer before he became a general. The child of German Jewish parents, he spoke German (Serle, 1982), and this may have helped him to apply German technology to the problems associated with utilising the brown coal reserves of Gippsland for electricity generation. The first open cut coal mine in Australia was established at Yallourn under Monash's supervision, and electricity from Yallourn was turned on in 1924. That year, Monash gave a Presidential Address to the Australasian Association for the Advancement of Science, in which he said:

Large scale electricity generation with a distributive power network did not really take off until after the First World War.

"Electrical energy has become the servitor of humanity…In the course of a single generation, we have witnessed the almost complete obliteration of the social and economic condition which was thought to have been the acme of progress. Factories, industrial plants and workshops belching forth pollution through forests of chimney stacks are almost a thing of the past. The horse-drawn tram, only very recently thought to be an indispensable public utility, has become a relic of the past. The days of the steam railway locomotive are numbered (Monash, 1924)."

This enthusiasm for progress was reflected in the development of Yallourn itself. The town was designed by the SEC as a 'garden city', a 'model town where workers lived in contentment, and industrial unrest would be minimised through the employer's control of domestic spaces.'[3] It was not to be.

2.7 STEEL CITIES: NEWCASTLE AND PORT KEMBLA

By the early 20th century, coal production in New South Wales was concentrated in three regions, all of them on parts of the same great reserve of black coal, and each with a principal city that had become a hub of industry based on access to coal: Newcastle to the north, Lithgow to the west, and Port Kembla to the south of Sydney. Copper smelting was important in Newcastle and Port Kembla, using copper ore imported from South Australia, and other metallurgical industries developed such as the Electrolytic Refining and Smelting Co of Australia which processed zinc at Port Kembla from 1907 (Eklund, 1994).

Iron smelting began at Lithgow in the 1870s. The town developed as an industrial centre around coal and iron, a blast furnace was built in 1907, employing one hundred men, and in 1911 the American company Pratt and Whitney won a government contract to establish the Lithgow Small Arms Factory. (Eklund, 2002) However the inland city suffered from its dependence on rail and its distance from a port, and in 1926, the Hoskins family, who were the main steel producers in Lithgow, formed the Australian Iron and Steel Company, and moved their operations to Port Kembla, where they built new and more efficient plant. (Eklund, 2002)

3 Instead, ironically, the open cut mine on which this model town depended for its rationale, eventually expanded to absorb the town itself, and Yallourn's population was moved to other locations.

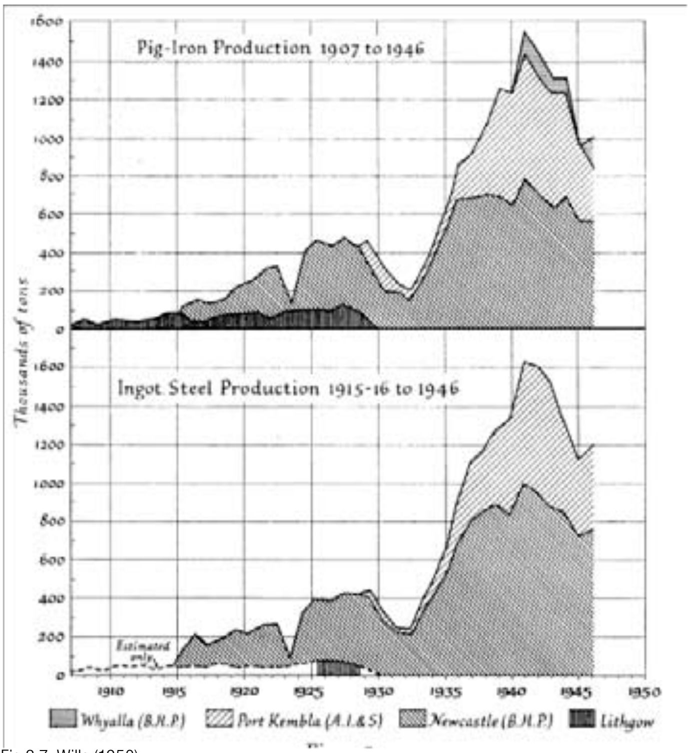

Fig 2.7 Wills (1950)

Despite Australia's large resources of iron ore, only a small amount of steel was produced before the First World War. With the outbreak of war, however, Australians became concerned with import replacement of strategic commodities such as iron and steel. There were also new opportunities to profit from the shortages brought about by a lack of shipping. Broken Hill Proprietary Company (BHP) had been involved with silver, lead and zinc production at Broken Hill since 1880; in 1915, they established BHP Steelworks in Newcastle. The war did not cause BHP to move to steel production. The NSW Government had already granted the company a site in Newcastle in 1912, and plans were well underway when war broke out, but it did influence the direction that BHP took. By the early twentieth century, both Germany and the United States had more advanced technology in steel production than Britain. BHP chose American engineering technology since alternative German technology was not available at that time.

The key man behind BHP's initiatives was the engineer Guillaume Delprat. Delprat came from a Basque family, was born in the Netherlands, and had trained as an engineer in Scotland – as an apprentice on the ill-fated Tay Bridge – and later worked in America and Mexico, before he was recruited by BHP as a manager, and arrived in Australia in 1898. He spoke several European languages, and made good use of visits to Krupps steelworks in the Ruhr Valley in 1911 and to US Steel in 1912 to investigate the newest available technology. (Jay, 1999)

Despite Australia's large resources of iron ore, only a small amount of steel was produced before the First World War. With the outbreak of war, however, Australians became concerned with import replacement of strategic commodities such as iron and steel.

Work in early Australian coal mines was hard.

Getting coal from the coalface was difficult. As a result, even in convict times various working patterns emerged that were designed to protect the rights of the worker (however minimal those might be in convict times).

Miners were drawn to unionism.

The first wartime years of steel production at Newcastle gave the company an early boost in a market artificially protected by lack of imports. Once the war ended, however, imports flooded back in, and the Commonwealth Government responded by introducing high tariffs to protect the fledgling industry from overseas competition. Behind this protective barrier, steel production increased gradually during the interwar years.

During the depression, steel production was consolidated, first when Australian Iron and Steel moved from Lithgow to Port Kembla, and then, in 1935, BHP bought out AIS and effectively established a monopoly in steel production, in Port Kembla and Newcastle. BHP's superior technology gave it an advantage: its blast furnaces were electrified by 1927, while those at Port Kembla were still steam powered, though in both cases, ultimately reliant on coal. (Eklund, 2002) When BHP took over Port Kembla, they invested in new plant: a coke oven in 1937, a new blast furnace in 1938, new port facilities and the transformation of the factory from steam to electricity. (Cochrane, 1989)

The timing was important. In September 1939 war broke out, and Australia's ability to produce steel for military purposes became of critical importance. Steel from Newcastle went into the production of combat vessels, rifle barrels, bayonets, machetes, link strip for machine gun cartridge belts, high tensile bolt steel for aircraft, gas bottles and much more. During the war, 30,000 tons of coal was used weekly to make blast furnace coke, which also yielded, as by-product, coal tar, benzol, naphthalene, ammonia and other products, including 12m gallons of tar that went to build strategic roads and airfields. Since Australia was cut off by war from normal imports of oil, bitumen and fertilisers, these products were particularly valuable substitutes. (Jay, 1999)

2.8 LABOUR RELATIONS AND UNIONISM

Work in early Australian coal mines was hard. In convict times, being sent to Newcastle was a punishment, above and beyond ordinary transportation, and the early Newcastle mines were dangerous places, with poor ventilation and inadequate drainage. Getting coal from the coalface was difficult. As a result, even in convict times various working patterns emerged that were designed to protect the rights of the worker (however minimal those might be in convict times). Miners in NSW imported from England the idea of the darg, or normal day's work, the cavil, designed to equalise opportunities by rotating access to the best parts of the seam amongst all the miners, and other time-honoured working practices. These became more entrenched after convict times, when miners were often English or Welsh immigrants, drawn into close knit communities in mining towns (Gollan, 1963).

Miners were drawn to unionism. During the gold rush many men left other jobs to seek their fortune in the gold fields. This made it difficult for mining companies to retain workers, demand for labour was high, and wages rose in consequence. But the labour shortage was short lived. Between 1851 and 1860 the population of NSW trebled, mainly through immigration, and the Victorian population rose sevenfold. Once the gold rush ended, miners and others had to look for work elsewhere. Consequently the AAC and other Hunter Valley companies tried to reduce wages to pre-rush levels. In retaliation, serious conflict broke out in Newcastle in 1861 and again in 1862. The details of these disputes are complex and contentious, and will not be dealt with here, but they illustrate a number of constantly repeated themes.

One feature of Newcastle – as of other mining towns subsequently – was that industrial disputes involved everybody: men and women, small businesses, the press, with reverberations throughout the community. On this occasion, the Newcastle Herald was 'declared black' by unionists, who refused to patronise 'any store or public-house that took in the paper' (Ellis, 1969). Intransigence by labour was met by intransigence by the companies, and miners were locked out of the AAC mines while the company tried to arrange the importation of coal miners from Britain to replace them. And the details of the dispute, here as elsewhere, depended on specific geological and technological issues: miners were paid on piece rates, so the question of how much coal could be taken by any individual worker was crucial, and required a degree of local knowledge unlikely to be available to a member of the London Board of the AAC.

Another constant theme of strikes in the coal industry is that the consumers of coal require certainty of supply. By the 1860s, coal underpinned essential public utilities – gas, shipping and railways – as well as a great variety of factories.

Another constant theme of strikes in the coal industry is that the consumers of coal require certainty of supply. By the 1860s, coal underpinned essential public utilities – gas, shipping and railways – as well as a great variety of factories. If Newcastle's coal supplies dried up, the rest of the economy was immediately affected, and the impact on employment was severe. There were therefore political implications to any serious disruption of the coal industry, not least because coal fuelled the transport of exports to the coast, and onwards from Australia to the rest of the world.

Industrial disputes were therefore often bitter affairs, sometimes violent, and often political. Perhaps the most notorious episode of violence within the context of coal mining was the death of a miner from a ricocheting police bullet at Rothbury in December 1929. The incident occurred during a bitter lockout in the coal mines. In February 1929, the Northern Collieries Association, representing forty of the largest coal mines in the Newcastle-Maitland with nearly ten thousand workers, gave their men fourteen days notice that they would be sacked unless they accepted a drop of 12.5% in their wages. The subsequent lockout lasted fifteen months, until June 1930, when the miners finally accepted the conditions on offer. In the middle of the

Great Depression there was little choice. The death of Norman Brown was almost certainly an accident. Forty years later, the historian Miriam Dixson investigated the incident in detail, interviewing some of the men who remembered the events, to reconstruct the affair (Dixson, 1969).

Fig 2.8 Norman Brown's funeral (Jim Comerford's collection of photographs, in Cultural Collections, University of Newcastle)

At this distance, what comes through most clearly is the strength of community affiliation to the union movement that kept men out of work and running down their savings, growing vegetables and catching rabbits, for over a year. Small mining towns were isolated, close knit places, with abundant community connections: Norman Brown was a member of the Masonic Brethren of Excelsior Mine, he worshipped at the Anglican Church where his stepfather was churchwarden, he had a local girlfriend. Today's term is 'social capital', and mining communities had this in abundance. The drawback of this situation was a lack of social or geographical mobility. In 1940, a sociological study of Cessnock by Alan Walker reported that of 70 marriages in the town, 47 of the bridegrooms and all of the brides came from the town itself. 'And what else is there for a girl to do in Cessnock save marry? And this she does, earlier than elsewhere in the State, and the parents approve.' Walker also interviewed Cessnock schoolchildren. Asked 'Would you like to work in the pits when you grow up?', only 17 out of 380 said 'yes' (Walker, 1945).

2.9 HEALTH AND COAL MINING

This was a much bleaker vision than the optimism that characterised the 'garden city' of Yallourn in the 1920s, and reflected the impact of the depression. However it also reflected the differences in health and safety between an open cut mine (Yallourn) and the older, deep mines of the Hunter region. 'To work underground,' said Walker, 'means darkness, dampness, constant peril and bad ventilation. For many it involves much walking, sometimes three to four miles each way, from the bottom of the mine-shaft to the coal-face. This itself imposes its physical strain without actual labour. Modern methods have reduced the effects of the dust-laden atmosphere, but many an older miner suffers from his long breathing of the coal dust.'(Walker, 1945) Walker was only partly right about the 'modern methods'; in fact, two technological improvements in the late nineteenth century, pneumatic drills and dynamite, increased the amount of coal dust in the atmosphere, leading to many pulmonary complaints usually lumped under the generic term of 'black lung'.

Then there were the accidents. Spasmodic accidents killed and injured miners on a regular basis, but it was the occasional catastrophic disaster that reverberated through a mining community: Bulli in 1881 (83 dead), Mount Kembla in 1902 (95 dead), Mount Mulligan in 1921 (70 dead). These disasters became a part of Australian folklore, and seared themselves on the collective memory of individual communities. In 1923, an explosion occurred in the Bellbird Colliery at Cessnock. Twenty men were trapped below ground, and their bodies had to be left there when the mine was sealed; according to someone who was there at the time, 'if only the bodies could have been recovered, and buried in due form, the emotional tension would have been released in the normal way. But this could not be. The effect was the addition of a strong emotional tone to the demand for safety measures, and to the readiness to stop work at any sign of danger.'(Elkin, 1945)[4] In this way, health and safety issues became significant industrial matters, with the Miners' Federation taking up the cause of improved conditions in underground mines.

2.10 POST WORLD WAR II AND QUEENSLAND COAL EXPORTS

Conflict broke out again in the coal mines in the closing months of World War II, and continued intermittently thereafter. Conflict reached a peak in 1949, when a seven week strike ended when the Chifley Labor Government sent troops into the mines (Deery, 1995). Chifley took the action for political as well as economic reasons, but it shows how essential it was to keep the coal mines open. By the 1940s, coal was a commodity of such strategic importance to the Australian economy that a loss of supply would be catastrophic in its impact. Coal, and coalminers, could make or break governments – and sure enough, Chifley's government was defeated later that year.

During the 1950s, coal continued to be essential to the Australian economy, but changes were taking place both in coal mining and in Australia's place in the world. Coal mining changed with the expansion of open cut mining, which required greater initial capital investment, but also produced a much safer environment for miners.

[4] Elkin, later Professor of Anthropology at the University of Sydney, was an exception to the general rule of social and geographical immobility in coal towns. He was born in West Maitland, educated at Maitland East Boys' High School, and became was Anglican Minister at Wollombi (1922-5) and Morpeth (1929-30), before taking a lectureship at Sydney University in 1932. (Wise, 1985)

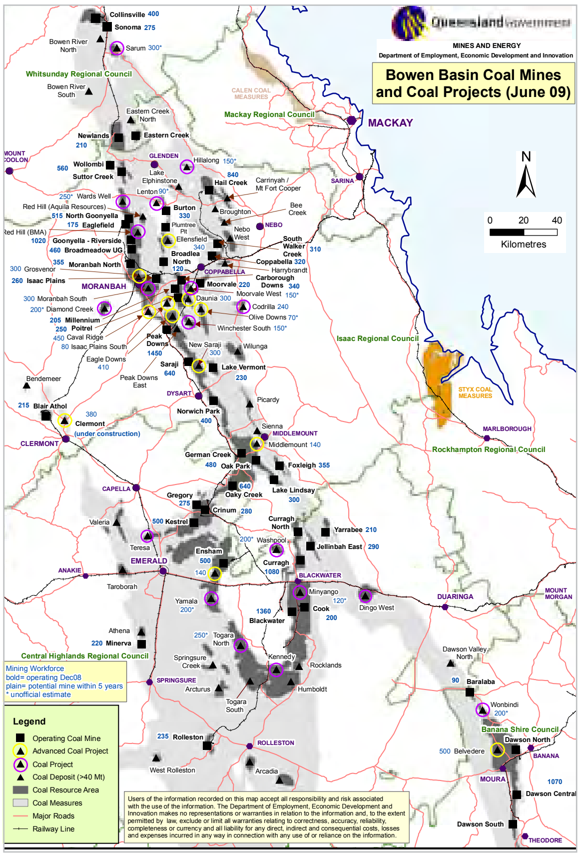

Fig 2.9 Map of Bowen Basin Coal Mines

During the 1950s, coal continued to be essential to the Australian economy, but changes were taking place both in coal mining and in Australia's place in the world. Coal mining changed with the expansion of open cut mining, which required greater initial capital investment, but also produced a much safer environment for miners. Australia was changing too, looking for new Asian trading partners to replace her previous reliance on the imperial link with Britain. In 1957 Australia signed a trade agreement with Japan.

The revival of the Japanese steel industry during the 1960s created a market for coking coal. One Australian company with the foresight to recognise this potential was Thiess Brothers. They began in the 1920s as sub-contractors in the Darling Downs. They went into coal in the 1940s, as contract open-cut miners for Blair Athol Coal and the Muswellbrook Coal Company. By the early 1950s, they were supplying Victoria with steaming coal from their open-cut mine at Callide, in the Bowen Basin.

During 1957 Les Thiess visited Japan for the first time and met representatives of the Japanese steel industry. Two years later, in 1959, Thiess Bros. discovered reserves of hard coking coal at Moura. The first 12,000 tons of Kianga-Moura coal were exported to Japan in 1961, and in 1962 a contract was finalised with eight Japanese companies to export 2.4 million tons of coal over five years. The family firm needed help, and Thiess Bros. joined forces with Peabody Coal of America and Mitsui of Japan. TPM became the largest corporate entity in the coal industry until a new arrival – Utah – in 1968 (Barry, Bowden and Brosnen, 1998). Between them, these companies transformed coal production in Australia. With the support of the Queensland Government, they made the Bowen Basin the centre of coking coal production in Australia, with dedicated railways and ports such as Gladstone designed to facilitate the export of coal to new markets.

Life for coalminers has also undergone a transformation. The new coal mines were mostly open cut mines, and the work of miners under this regime is very different from the traditional experience underground. For companies, the value of their investment is such that the cost of the labour force is a relatively minor factor, but greater mechanisation means that workers are more highly trained, and once trained, worth retaining. Wages and conditions have been transformed by the logic of this new industrial relationship. At the same time, the old, bleak immobility of the labour force in the pre-war coal mining towns of the Hunter has given way to new towns with the social challenges and prospects of all recent immigrant communities, though in this case the immigration is largely internal, from the industrial south to the mining north of Australia.

2.11 REPLACING THE TRADITIONAL USES OF COAL

Meanwhile the traditional uses of coal were changing. The first move away from coal as a fuel came in the early twentieth century, when steam ships converted from coal to oil. Loading coal on to ships was a dirty, laborious business, and it was slow. Oil could be pumped on board much quicker, allowing a faster turnaround time in port. The British Navy and the major passenger lines converted to oil just before the First World War – and consequently gave new strategic importance to the Middle East, for while coal is found in many locations, oil fields are fewer.

Railways continued to use coal as their fuel source for much longer, but they too eventually converted to diesel from the 1950s onwards. On the most important lines, particularly on urban networks, electricity has since replaced diesel – and thus effectively returned railways to their original reliance on coal. Domestic use of coal gas continued into the 1950s, but the discovery of large natural gas deposits from the 1960s, and the development of pipeline technology, led to the replacement of coal gas by safer natural gas for cooking, while the innumerable domestic appliances that complicate our lives today operate on electricity.

Most electricity in Australia today is generated by coal. Today, most Australians have no direct experience of coal; they have never lifted a lump of coal, smelt it burning, or breathed the smoky residues that polluted nineteenth century towns. Yet through electricity, coal plays a larger part in their lives than ever before.

Meanwhile the traditional uses of coal were changing. The first move away from coal as a fuel came in the early twentieth century, when steamships converted from coal to oil.

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Coal and the Australian Economy 3

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> Coal was the first commodity to be discovered and mined in Australia. After three centuries, it still maintains its position as the most important mineral in the country in terms of domestic consumption and international trade.

> The growth of Sydney, as well as other major centres in the 18th and early 19th centuries, may be attributed to the exploitation of coal deposits.

This chapter reviews the significance of coal in the Australian economy. It looks at the contribution of black coal to taxes, royalties and rail freight incomes, as well as its role in supporting infastructure and other capital development

Finally, it reviews the important role of coal in Australia's energy security and independence".

3.1 AUSTRALIA: BUILT ON THE MINER'S BACK

Coal was the first commodity to be discovered and mined in Australia. After three centuries, it still maintains its position as the most important fuel in the country in terms of domestic consumption and international trade. According to Branagan (1990), coal was first discovered in a creek near what is now Newcastle in March 1791 by convicts escaping north. A subsequent discovery was made in 1797 at the mouth of the Hunter (or Coal) River (ABS, 2009a), leading to the establishment of a township which is now Newcastle. The progressive spread of settlement, initially along the coastline, led to further discoveries. In Tasmania, coal was discovered after the first settlement of Hobart in 1803 and was used for heating purposes as early as 1805. The first discovery of coal in Queensland was in 1825 near Ipswich, upstream from the first settlement on the Brisbane River (Hargraves, 1993). The first discoveries of coal occurred in Victoria in 1826 and in Western Australia in 1846 (Stedman, 1988).

The growth of Sydney, as well as other major centres in the 18th and early 19th Centuries may be attributed to the exploitation of coal deposits. In those days, as is the case now, many towns were built in order to open up coal deposits. Infrastructure built included hotels, shopping centres, hospitals, police stations, post offices and swimming pools. Coal mining, therefore, made a substantial contribution to the progress of settlement in remote and inhospitable areas. Coal not only provided a reliable source of energy for domestic purposes, but it was also a vital source of power for steam locomotives and steamships in the early years of settlement.

The first recorded export of coal from Australia was in 1798 (Ellis, 1798). By 1865, production in the Newcastle Coalfields was 368,000 tons and exports overseas were 68,400 tons. Total coal production in New South Wales by 1881 was 1,769,597 tons with a value of £603,248 (Table 3.1a). In contrast, Queensland's production was 65,612 tons with a value of £29,033. By the end of 1908, over 10 million tons of coal valued at about £3.8 million tons were being produced in Australia.

While Queensland now surpasses NSW in coal production, it was not until the early 1960s, with the opening up of the Central Bowen Basin, that the surge in coal production began to occur. Queensland became Australia's leading coal producer in the early 1990s. The discovery of gold in the mid 19th century resulted in a rapid growth of the population and industry, thus setting the stage for Australia's tradition as a mineral-based economy.

By the 1860s, gold had taken over from coal as the leading export (ABS, 2005). However, by the early 1960s the situation had been reversed. The net value of gold production in 1962-63 was £10.3 million, compared to £45.6 million for black coal (ABS, 1965). This development was caused by a rapid growth in export trade mainly for coking coal, initially with Japan, and subsequently with a number of European countries.

Table 3.1a Quantity and Value of Coal Production in Australia, 1881-1908

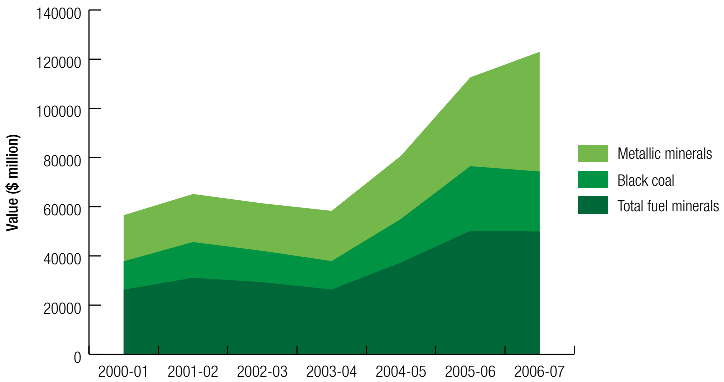
	N.S.W.	Victoria	Q'land	S. Aust.	W. Aust.	Tas.	Total
QUANTITY							
Year	Tons	Tons	Tons	Tons	Tons	Tons	Tons
1881	1,769,597		65,612	-	-	11,163	1,846,372
1891	4,037,929	22,834	271,603	-	-	43,256	4,375,622
1901	5,968,426	209,329	539,472	-	117,836	45,438	6,880,501
1902	5,942,011	225,164	501,531	-	140,884	48,863	6,858,453
1903	6,354,846	69,861	507,801	-	133,427	49,069	7,115,004
1904	6,019,809	121,742	512,015	-	138,550	61,109	6,853,225
1905	6,632,138	155,136	529,326	-	127,364	51,993	7,495,957
1906	7,626,362	160,631	606,772	-	149,755	52,896	8,596,416
1907	8,657,924	138,635	683,272	-	142,373	58,891	9,681,095
1908	9,147,025	113,962	696,332	-	175,248	61,068	10,193,635
VALUE							
	£	£	£	£	£	£	£
1881	603,248	-	29,033	-	-	4,465	636,746
1891	1,742,796	19,731	128,198	-	-	17,303	1,908,028
1901	2,178,929	147,228	180,877	-	68,561	18,175	2,602,770
1902	2,206,598	155,850	172,286	-	86,188	19,546	2,640,469
1903	2,319,660	43,645	164,798	-	69,128	19,628	2,616,859
1904	1,994,952	70,208	166,536	-	67,174	24,444	2,323,314
1905	2,003,461	79,060	155,477	-	55,312	20,797	2,314,107
1906	2,337,227	80,283	173,282	-	57,998	21,158	2,669,948
1907	2,922,419	79,706	222,135	-	55,158	23,556	3,302,974
1908	3,353,093	64,778	244,922	-	75,694	24,427	3,762,914

Source: ABS (2009a)

Black coal currently contributes to a fifth of the total value of minerals produced in Australia and to nearly half the value of fuel minerals.

Queensland and NSW are the major producers of black coal. Together, the two States account for over 99% of Australia's black coal production.

Figure 3.1 Value of Metallic and Fuel Minerals Produced, 2000/01-2006/07



Source: ABS (2008a)

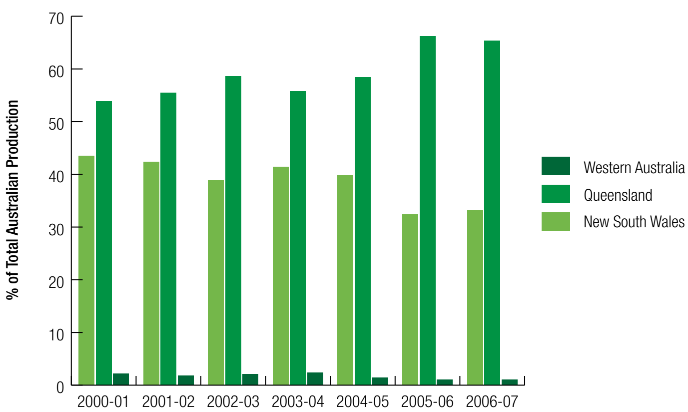
Black coal contributes to one-fifth the value of all minerals produced in Australia, and to half the value of all fuel minerals.

Black coal currently contributes to a fifth of the total value of minerals produced in Australia, and to nearly half the value of fuel minerals. Black coal's share in Australia's total mineral production has been growing strongly since 2003-04 (Figure 3.1). Queensland and New South Wales are the major producers of black coal[1].

Between 2001-02 and 2006-07, Queensland's share of the total value of black coal output increased from 55 per cent to 66 per cent, while New South Wales's contribution declined from 42 per cent to 33 per cent (Figure 3.2).

Together, the two States account for over 99% of Australia's black coal production. With more than 30 billion tonnes of identified resources of black coal in Queensland, the coal industry is a major contributor to Queensland's economy and the largest exporter of seaborne coal in the world[2]. In New South Wales, coal production also plays a major economic role, accounting for over 70 per cent of the total value of mineral production in the State[3].

Figure 3.2 State's Contribution to Australian Black Coal Production, 2001-07



Source: ABS (2008a)

Queensland and NSW account for over 99 per cent of Australia's output of black coal. The coal industry is a major contributor to Queensland's economy and the largest exporter of seaborne coal in the world.

[1] Victoria produces a small amount of brown coal.

[2] Queensland Government (2009) Coal Statistics, Queensland Department of Employment, Economic Development, Innovation, Mines and Energy, accessed on May 5 2009 at http://www.dme.qld.gov.au/mines/coal_statistics.cfm

[3] New South Wales Department of Primary Industries (2009) New South Wales Coal Industry Profile 2008, accessed on May 5 2009 at http://www.dpi.nsw.gov.au/minerals/resources/coal/nsw-coal-industry-profile

The mining industry, in general, and coal mining, in particular, has not had a glowing public image throughout history. In Australia, factors such as the use of convict labour in the coal mines, blackened miners returning from work, dust around coal mines, and strikes painted a 'dirty' picture of the industry in the early years (Hargraves, 1993). These days, safety and environmental incidents highlighted by media publicity and some green groups have contributed in tarnishing the industry's image. However, the fact of the matter is that the industry over time has made strenuous efforts to improve its safety record and address environmental issues. For example, in Queensland, fatalities in underground mines over the 20-year period from 1987-88 to 2007-08 averaged one per year and there were seven years over this period in which no fatalities were recorded (Queensland Government, 2009). Australian coal mines operate under stringent environmental and safety conditions, including strict requirements for mine land rehabilitation.

We show in the following sections, various ways in which the coal industry has contributed to Australia's economic development and current prosperity. One can imagine an alternative development path the country could have taken in the absence of coal. It is highly likely that the rate of settlement, industrialisation, and economic progress would have been much slower. Also, the rate of deforestation in Australia could have been much faster in the absence of the abundant and relatively more fuel efficient coal resource.

3.2 OVERALL ECONOMIC IMPACT

Coal has been a key driver of Australia's economic growth by not only providing valuable foreign income from exports (discussed below) but also by providing a reliable and affordable source of energy to power domestic production activities.

Figure 3.3 Coal's Contribution to Australia's Economic Growth

Sources: ABS (2009b, 2009c)

There is a very close correlation between growth in Australia's total black coal output and Real GDP growth, pointing to coal as a key driver of economic growth in Australia.

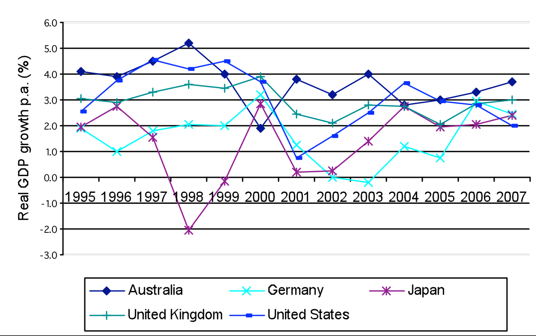
Industry over time has made strenuous efforts to improve its safety record and address environmental issues.

Australian coal mines operate under stringent environmental and safety conditions, including strict requirements for mine land rehabilitation. The rate of deforestation in Australia could have been much faster in the absence of the abundant and more fuel efficient coal resource.

Coal has been a key driver of Australia's economic growth by not only providing valuable foreign income from exports but also by providing a reliable and affordable source of energy to power domestic production activities.

Figure 3.3 shows a very close correlation between growth in Australia's total black coal output and real Gross Domestic Product (GDP) growth for the period 1991-92 through 2007-08.[4] Both have risen consistently since 1991-92. In general, coal is cheaper per energy unit compared to other fuels, and therefore it continues to be the fuel of choice for electricity generation not only in Australia, but also globally.[5] Although coal prices have risen over time, they are still relatively lower than other energy fuels, thus making coal an attractive energy source. The current global demand for coal is driven by strong demand from developing countries such as India and China. Consequently, world coal demand is projected to rise by 60 per cent between 2006 and 2030, with 90 per cent of this coming from developing countries (IEA, 2008).

Figure 3.4 Real GDP Growth for Selected OECD Countries, 1995-2007



Source: OECD (2009)

Australia has been among the fastest growing countries in the OECD. During the global financial crisis, it was the only one to avoid a recession due to strong coal and iron ore exports.

Australia's strong economic growth powered by coal and other mineral exports is evident in Figure 3.4. Here, it can be seen that within the last seven years, Australia has been among the strongest growing countries in the OECD. With the exception of South Korea, Australia was the fastest growing economy for the period 2005-2007, with annual growth rates of 3 per cent or more. The current global financial crisis has plunged the economies of the industrialised world into recession. However, Australia is the only country to have avoided a recession, technically speaking.[6] While a number of factors are responsible for this remarkable performance, there can be little doubt that the strong surplus built up on the back of the mining boom helped to cushion Australia from the effects of the crisis.

[4] A statistical measure of the association between coal output and Real GDP growth is given by the correlation coefficient, r. Absolute values of r greater than 0.7 indicates a strong association. In this case, $r = 0.98$.

[5] Coal is the main source of energy for electricity generation in the US, Germany, China, India, South Africa and most of Central Europe.

[6] A recession is defined as a decline in economic activity (GDP) that persists for at least two quarters.

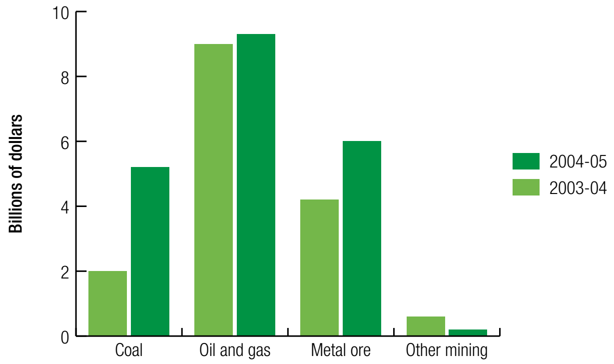
3.3 COAL'S CONTRIBUTION TO AUSTRALIA'S ECONOMIC PROSPERITY

Coal provides a substantial and consistent revenue stream to governments at both the Federal and State levels in the form of taxes, natural resource royalties, and payment of rail freights. In addition, billions of dollars are generated from general economic activity and export income. Natural resource royalties are defined to include payments under mineral lease arrangements, resource rent taxes and royalties. These payments are made to State/Territory and the Federal Governments and can be based on the value of production at mine site, sales value, gross proceeds or profit. In 2004–05, the coal mining industry paid natural resource royalties amounting to about $1 billion, while royalty payments by the metal ore mining and the oil and gas industries were $0.9 billion and $1.7 billion, respectively (ABS, 2008). Royalties paid by the coal industry rose to $1.6 billion in 2006-07, with Queensland contributing $1.05 billion and NSW contributing $412 million.

Figure 3.5 shows ABS estimates for mining industry operating profits before taxes (OPBT) for the period 2003-04 to 2004-05. In 2003-04, the oil and gas industry declared before tax profits of over $8 billion, while before tax profits for the metal ore and coal industries were $4.2 and $2 billion, respectively.[7] From 2003–04 to 2004–05, OPBT for the mining industry increased by $4.7 billion or 30 per cent. The coal mining industry was the driving force behind this rise, accounting for $3 billion of this increase.

Coal also directly and indirectly contributes to the economic prosperity of individuals and households through the payment of wages and salaries. We show in Chapter 4 the positive externalities generated by coal through the flow-on effects of jobs created by other industries as a result of growth in coal mining.

Figure 3.5 Mining Industry Operataing Profit Before Tax, 2003-04 to 2004-05



Sources: ABS (2009b, 2009c)

There is a very close correlation between growth in Australia's total black coal output and Real GDP growth, pointing to coal as a key driver of economic growth in Australia.

Coal provides a substantial and consistent revenue stream to governments at both the Federal and State levels in the form of taxes, natural resource royalties, and payment of rail freights.

The coal industry's operating profits before taxes increased from $2 billion in 2003–04 to $5 billion in 2004–05. It has been the driving force behind the mining industry's profit growth.

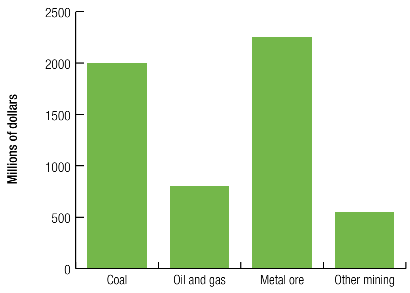
[7] Operating tax before profit is net profit before the deduction of income tax and dividends.

Investment in physical and social infrastructure is a vital element in the development of a nation.

In this respect, the coal industry has played a significant role in Australia's development, not only by investing in physical infrastructure within the mining industry, but also by contributing to infrastructure development in regional areas.

The highest level of commitment in terms of investment in 2004-05 was by the oil and gas industry with $4.3 billion, followed by the coal industry with $3.3 billion.

Figure 3.6 Payment of Wages and Salaries by the Mining Industry, 2004-05



Source: ABS (2008)

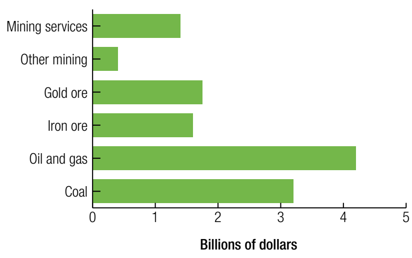
The coal industry pays out over $2 billion in wages and salaries per year. This figure would be considerably more if we consider wages and salaries from jobs created indirectly by the industry.

Figure 3.6 shows ABS figures for wages and salaries paid by the mining industry in 2004-05. The coal and metal ore mining industries each pays out over $2 billion per annum in wages and salaries, while the oil and gas industry pays out about $0.9 billion per annum. These amounts are just the earnings of those directly employed by the industry. If we consider earnings from jobs indirectly created, the figures are considerably more. We introduce the concept of the multiplier effect in the next chapter in terms of job creation.

3.4 SUPPORTING INFRASTRUCTURE AND OTHER CAPITAL INVESTMENT

Investment in physical and social infrastructure is a vital element in the development of a nation. In most cases, the onus falls on government to provide this much needed investment. The process of development can be speeded up with significant private sector contributions. In this respect, the coal industry has played a significant role in Australia's development, not only by investing in physical infrastructure within the mining industry, but also by contributing to infrastructure development in the regional areas. Coal mining companies have provided facilities such as roads and other facilities not only for their workforce but also for communities living around the mines. In many cases, provision of these facilities has relieved local authorities of obligations they would otherwise incur in the growth a town. Infrastructure development and production activities (e.g., manufacturing and building construction) rely heavily on materials such as steel and concrete that require a lot of energy to produce. As a cheap source of energy, coal significantly lowers the cost of production and therefore helps the nation to accumulate capital assets.

Figure 3.7 Net Capital Expenditure in the Mining Industry, 2004-05



Source: ABS (2008)

The highest level of commitment in terms of investment in 2004-05 was by the oil and gas industry with $4.3 billion, followed by the coal industry with $3.3 billion.

New and planned investments in new projects are important in ensuring the creation of jobs and inflow of revenues into government coffers. Figure 3.7 shows the net capital expenditure in the mining industry for the year 2004-05. The highest commitment was by the oil and gas industry with $4.3 billion worth of investments, followed by the coal industry with $3.3 worth of investments. In 2007, 16 new black coal projects with a total value of around $2 billion were completed in the country, while another 19 projects with an estimated capital cost of around $7 billion were scheduled for completion in the short to medium term (ACA, 2008a). Another 50 projects with an estimated capital value of more than $14.5 billion were at a less advanced stage of planning. In addition to payment of natural resource royalties, the mining industry contributes to capital investment and government revenues through expenditures on mineral exploration. In 2006-07, private expenditure on mineral exploration was estimated at $193 million, which was almost four times that in 2001-02 (ABS, 2008).

3.5 DEVELOPMENT OF AUSTRALIA'S COAL EXPORT MARKETS

Given its vast mineral wealth but relatively small population, Australia has no choice but to rely on exports to generate revenues for its development needs. Australia is the world's leading coal exporter, accounting for about 30 per cent of total global trade and 4.6 per cent of global consumption. Black coal is the leading mineral export with 261 metric tonnes of exports valued at $55 billion. This was equivalent to about a fifth of Australia's total commodity exports in that year (ABARE, 2009). Exports were equally divided between metallurgical (coking) coal for steel production and thermal (steaming) coal for power generation. Japan has been the key destination for Australian coal at the beginning of the boom in coal exports in the mid-sixties and it still remains the preferred destination. Figures 3.8a and 3.8b indicate that Japan was the leading destination for both types of coal, with 25%and 59% of coking and thermal coal, respectively, in 2006-07. Other poplar destinations include South Korea, the EU, Taiwan and India.

Fast growing economies such as India and China are likely to be increasing consumers of Australian coal. Due to their strong economic growth, these countries are projected to account for just over half of the increase in world primary energy demand between 2006 and 2030. Overall, world demand for coal is projected to increase by 2%a year on average, and coal's share of global energy demand will rise from 26% in 2006 to 29% by 2030 (IEA, 2008).

Australia is the world's leading exporter of coal, accounting for about 30% of global trade. Japan is the leading destination for both coking and thermal coal. However, China and India are likely to increase consumption due to their strong projected growth. These countries are projected to account for just over half of the increase in world primary energy demand between 2006 and 2030.

Overall, world demand for coal is projected to increase by 2% a year on average, and coal's share of global energy demand will rise from 26% in 2006 to 29% by 2030.

Two-thirds of the world's proven conventional oil reserves are located in the Middle East. By 2030, OPEC will control 60% of global conventional oil supplies compared to 40% in 2000.

Figure 3.8a Australian Coking Coal Exports, 2006-07

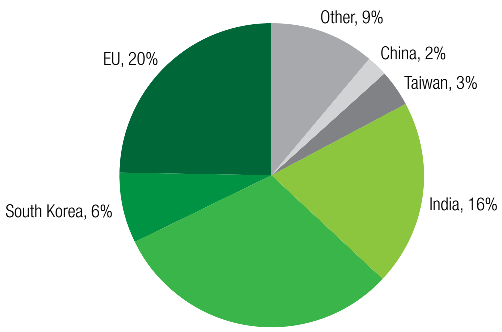
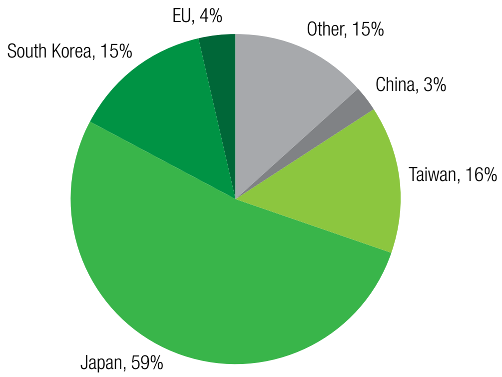


Figure 3.8b Australian Thermal Coal Exports, 2006-07



Sources: ABARE (2009)

Australia is the world's leading exporter of coal, accounting for about 30 per cent of global trade. Japan is the leading destination for both coking and thermal coal. However, China and India are likely to be increasing consumers due to projected strong growth.

3.6 ENERGY SECURITY AND INDEPENDENCE

There is no clear consensus on the precise definitions of energy security and independence. For the purposes of this volume, we define energy security as a goal to ensure the supply of energy from all possible sources, while energy independence is a goal to become self-sufficient in the production of energy. Both issues are relevant to Australia and other countries as we progress into the next millennium. Global demand for energy is increasing and is expected to rise by about 60 per cent by 2030. Global oil consumption has increased by 20 per cent since 1994, and it is projected to grow at a rate of 1.6 per cent per annum (IEA, 2008). The worrying aspect of this trend is that about two-thirds of the world's proven conventional oil reserves are in the Middle East (see Figure 3.9), which has proven to be an unstable part of the world. By 2030, OPEC will account for 60 per cent of the world's conventional oil supply, compared to 40 per cent in 2000. An even more worrisome fact is the finiteness of global oil and gas reserves. Estimates of remaining proven global reserves are about 1.2 trillion barrels of conventional oil and 6,400 trillion cubic feet of gas. At the current rates of consumption, the conventional oil reserves will run out in about 40 years and the gas reserves will run out in about 100 years (IEA, 2008). The world has over 3 trillion barrels of shale oil, with much of it (about 1.8 trillion barrels) located in the Green River region of Colorado, Utah and Wyoming (Badiali, 2006). However, it is not currently recoverable with current technology due to the high cost. Another major source of non-conventional oil can be found in Canada's Athabasca oil tar sands located in northeastern Alberta. The size of these reserves is thought to be second only to Saudi Arabia's reserves. Output of marketable oil sands production is projected to reach 3 million barrels per day by 2020 and possibly even 5 million barrels per day by 2030 (Government of Alberta, 2009).

In Australia, economic demonstrated resources (EDR)[8] of conventional oil and gas were about 4.2 billion barrels of oil and 91 trillion cubic feet of gas by the end of 2005 (Geoscience Australia, 2005). Australia has 28 million barrels of shale oil EDR. At the current production rate of 202 million barrels per year, the conventional oil reserves will run out in 20 years in the absence of significant new discoveries. Currently, consumption is about 50 per cent higher than domestic production. Figure 3.9 shows that Australia's net imports of oil will increase from 508 petajoules (PJ) in 2005-06 to 794 PJ by 2030. On the other hand, Australia has 39.6 gigatonnes of coal EDR (ABS, 2008), estimated to last over 200 years at the current consumption rate. Australia's black coal production is projected to increase from 175 PJ in 2005-06 to 193 PJ by 2030, while net production will reach 10,989 PJ by 2030 (Figure 3.10). Thus, coal clearly has a significant contribution to make in ensuring energy independence.

Up until around mid 2008, energy prices had been trending upwards, led by crude oil prices. However, there was a sudden dip in prices in July 2008, and the downward trend continued to December 2008. Crude oil prices began to rise in December 2008 and there is every reason

Australia has 39.6 gigatonnes of coal estimated to last over 200 years at the current consumption rate.

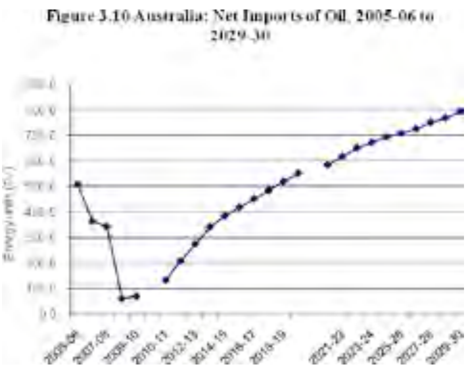
Coal clearly has a significant contribution to make in ensuring energy independence.

Figure 3.9 Location of the World's Main Fossil Fuel Reserves (Gt of coal equiv.)

Source: World Coal Institute (2009)

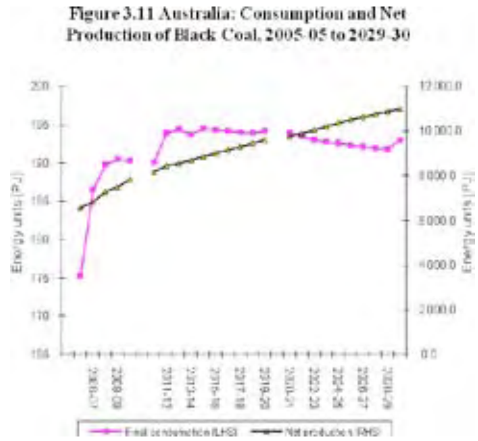
Two-thirds of the world's proven conventional oil reserves are located in the Middle East. By 2030, OPEC will control 60 per cent of global conventional oil supplies.

8 EDR is a measure of the resources that are established, analytically demonstrated or assumed with reasonable certainty to be profitable for extraction or production under defined investment assumptions (ABS, 2008).



Source: ABARE (2009)

Australia's net imports of oil will increase to 704 petajoules by 2030.



Source: ABARE (2009)

Net production of black coal is projected to reach 10,989 petajoules by 2030.

Coal has an important role to play not only in ensuring energy security in Australia, but also in boosting economic growth and reducing variability in future energy prices.

to believe that the upward trend will continue as global demand starts to pick up. Higher oil import prices are a drain on the economy and impose a tax on the citizens. Rising oil prices have the potential to depress economic output, reduce household incomes and fuel inflation.

According to modelling carried out by ABARE (2005), a sustained 60 per cent increase in oil prices could have reduced Australian economic growth by 0.6 per cent in 2006. Therefore, coal has an important role to play not only in ensuring energy security in Australia, but also in boosting economic growth and reducing variability in future energy prices. It is relatively cheap and plentiful, and offers a pragmatic alternative while other sources of energy are being developed.

It is important to address the challenge of CO_2 emissions associated with coal consumption. Chapter 7 discusses the emerging technology of Carbon Capture and Storage (CCS), which can be used to sequester CO_2 underground. There are also good prospects for utilising proven technologies such as coal gasification technology, which can be used to produce synthetic fuel or syngas. Syngas can be used to generate heat and power, as well as gasoline and diesel fuel with zero sulphur, very low NOx, and low aromatics. Other by products of syngas include ammonia, which can be used to produce fertilisers; and chemicals such as methanol which can be used to produce formaldehyde, acetic acid, and other chemical products. Coal gasification also offers the possibility of point of production capture of CO_2 emissions.

3.7 GROWTH OF RAILWAYS AND PORTS

The development of mining in Australia has been closely intertwined with the growth of railways and ports. The earliest railway lines in the country were built to haul coal from mines and these were horse-drawn; one of the earliest ports, Newcastle, was built to facilitate the shipment of coal to overseas markets. By the second half of the 19th century, horse-drawn railways had been replaced by steam-powered trains, which utilised coal as a fuel source. The first railways for public use were built by private companies in the colonies of Victoria and New South Wales in 1854, but were soon taken over by the respective governments because they were not financially viable (GOA, 2008). South Australia's railways were constructed by the government and consisted of a horse-drawn line which opened in 1854, followed by a steam-powered line in 1856. The railways provided the relatively cheap and efficient transport needed to develop agricultural industries and to exploit newly discovered mineral fields. For example, railways were built to open up the Broken Hill mineral field in New South Wales and mineral fields in North Queensland. While railways provided isolated communities with a link to the outside world, they also served to transport produce and wealth back to the capital cities and ports. Steam-powered railways continued to play a significant role in transportation before the introduction of diesel locomotives in the 1950s.

The early railways were developed as disjointed networks with different gauges (i.e. width) between the rails.[9] The first standard gauge Trans-Australian railway was constructed between Kalgoorlie and Port Augusta in 1917, which was later extended to Port Pirie in 1937 (ARTC, 2009). A standard gauge line connecting Brisbane to the NSW system was completed in 1930. Between 1951 and 1965, successive Federal Governments embarked on efforts to standard railway gauges between the capital cities (except Darwin) and this program was finally completed in June 1995, with the conversion of the Adelaide to Melbourne broad gauge track to standard gauge (ARTC, 2009).

Within the last three decades, the mining sector has continued to play a leading role in the development of railways and ports in the country. For example, in 2008, Fortescue Metals Group, the largest holder of iron-ore tenements in the Pilbara region of Western Australia, completed a $3.2 billion project comprising a mining and processing facility, a new 520km open access railway between the Pilbara and Port Hedland, and a dedicated iron-ore loading and berthing facilities at Port Hedland (Clout and Rawley, 2009). In 2008, Rio Tinto announced a $65 million contract to extend its Robe River heavy-haul railway in the Pilbara region of Western Australia (International Railway Journal, 2008). Construction began in 2005 on the $240 million 110km Bauhinia Regional Rail Project in Central Queensland, the longest railway to be built in the state since the mid-1980s (Hammond, 2005). The ABS reports that between 1967 and 1999, mining industries built at least 25 new towns, 12 new ports, 20 airfields and 1,900 kilometres of rail line within Australia (ABS, 1999). The construction of railways and associated infrastructure provides a significant boost to engineering businesses for manufacture of rolling stock and other railway equipment and contributes to the prosperity of industry at various levels.

Please refer to references at the end of Chapter 4.

Within the last three decades, the mining sector has continued to play a leading role in the development of railways and ports in the country.

The ABS reports that between 1967 and 1999, mining industries built at least 25 new towns, 12 new ports, 20 airfields and 1,900 kilometres of rail line within Australia.

[9] For example, railways in Queensland, Tasmania and Western Australia were built on the 3’6” (1,067 mm) narrow gauge, while railways in NSW were built on the 4’8½” (1,435 mm) standard gauge.

Economic and Socioeconomic Development 4

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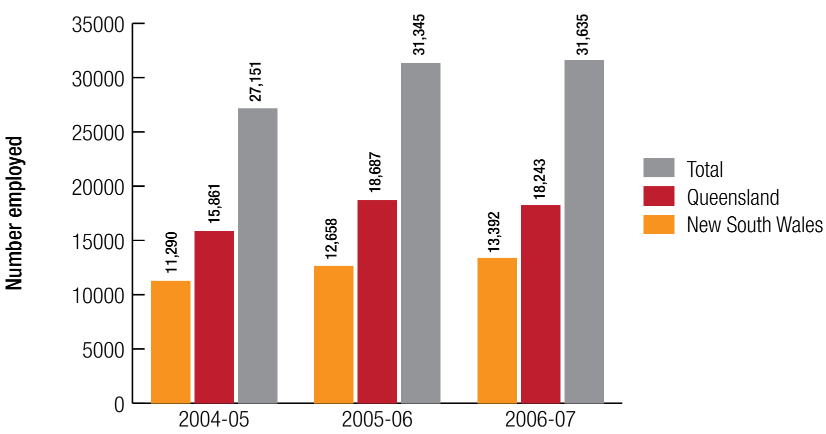
The coal industry directly employs over 32,000 people a year, with over 18,000 in Queensland and about 13,000 in NSW. Indirect employment for both states is around 126,500 people.

4.1 INTRODUCTION

This chapter discusses coal's role in employment creation and sustainable economic development in general. The next two sections discuss coal's contribution to the nation's socioeconomic development by providing jobs directly and indirectly. The direct jobs created by the coal industry are relatively easy to report since these are published regularly by the Australian Bureau of Statistics (ABS). However, the indirect jobs created are more difficult to arrive at and need to be estimated. Here, we provide estimates of indirect employment in two different ways. The first is through the use of what is referred to as multiplier analysis. The second set of estimates is provided with the aid of a macroeconomic model that is able to predict the flow-on effects of coal mining through the different sectors of the economy. Coal mining not only provides jobs but also plays a key role in regional development. In the following section, we highlight this aspect using a case study of Moranbah, a coal mining community in Queensland. The section concludes with a discussion of coal mining's contribution to national development in general.

Figure 4.1 Direct Employment in the Queensland and New South Wales Coal Industries, 2004-05 to 2006-07



Sources: NSW DPI (2009); Queensland Government (2009)

4.2 DIRECT EMPLOYMENT

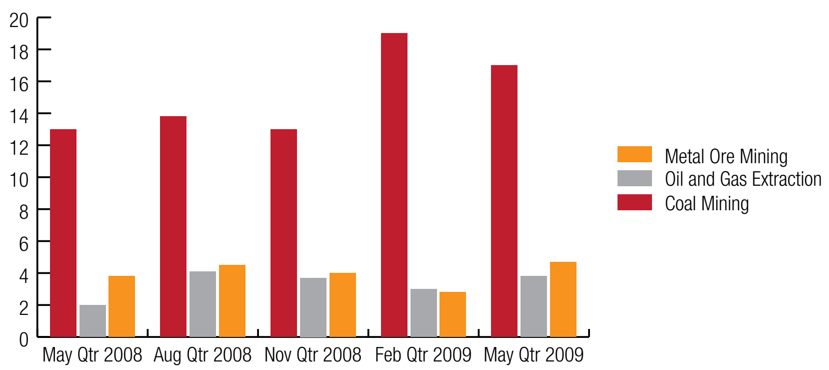
Figure 4.1 shows direct employment created by the coal industry in Queensland and New South Wales (NSW) for the period 2004-05 to 2006-07. The industry directly employs over 32,000 people per year on average, with 60% of these (over 18,000) in Queensland and the remainder in NSW. Total employment rose sharply from 27,151 in 2004-05 to 31,345 in 2005-06 (an increase of 13%), followed by a much slower increase to 31,635 in 2006-07. Coal mining's crucial role in providing direct employment is underlined by the fact that it provides over 80% of the jobs in the mining sector in both Queensland and NSW.

The global financial crisis threatened sharp falls in demand for Australia's two most valuable exports – iron ore and coking coal, stoking fears of job losses in the industry. However, the latest job figures indicate that these fears were unfounded. Although there were some job losses at the onset of the crisis, Figure 4.2 shows that direct employment in Queensland's mining industry (coal, oil and gas, metal ore) increased by over 20% between the May quarter 2008 and the May quarter 2009. This trend can be attributed to strong recovery in China and India. The Queensland Government has announced early in 2008 that it would go ahead with large infrastructure projects in the sector, including coal terminal expansions. The Newcastle Coal Infrastructure Group (NCIG) terminal will provide an additional 20Mt export capacity to NSW. These will place the States in a more competitive positions in the market after the expected recovery occurs.

Coal mining's crucial role in providing direct employment is underlined by the fact that it provides over 80% of the jobs in the mining sector in both Queensland and NSW.

Direct employment in Queensland's mining industry (coal, oil and gas, metal ore) increased by over 20% between the May quarter 2008 and the May quarter 2009.

Figure 4.2 Direct Employment in Queensland Mining, May 2008 - May 2009



Source: ABS (2009c)

Although the direct employment benefits of coal mining are significant in their own right, of equal significance is the industry's ability to generate additional employment in the local communities indirectly as a result of the flow-on or 'multiplier' effect on the non-coal sectors.

4.3 INDIRECT EMPLOYMENT

Although the direct employment benefits of coal mining are significant in their own right, of equal significance is the industry's ability to generate additional employment in the local communities indirectly as a result of the flow-on or 'multiplier' effect on the non-coal sectors. Coal mining projects generate wages and profits for their employees and investors who then pay taxes and spend out of their income, stimulating production in other sectors, which in turn leads to the creation of additional jobs. We present estimates of indirect employment created by coal mining using two different approaches - multiplier (impact) analysis and macroeconomic modelling.

4.3.1 Multiplier Estimates

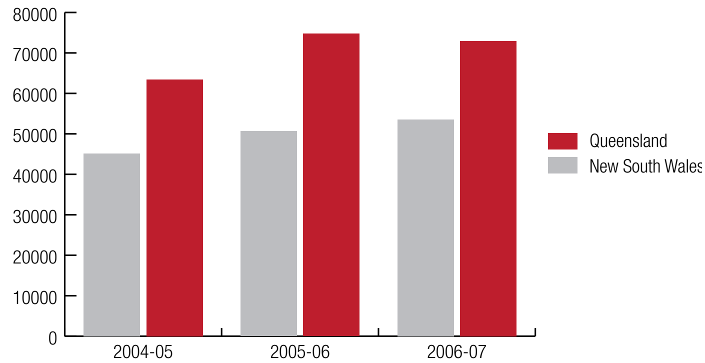
Multipliers are used to measure the impact of a change in output or the value added of an industry on key economic aggregates such as gross state product or the number of persons employed. Here we employ a multiplier of 1:4 (i.e. one mining job creates 4 non-mining jobs) for the mining sector to estimate indirect employment created by the coal industry. Aislabie and Moira (1990) have shown from disaggregated analysis that a multiplier of 1.4 is a reasonable estimate for the mining sector employment in regional Australia. Johnson (2001, 2004) found mining sector multipliers in the Gascoyne and Kimberly regions of Western Australia to be 1.34 and 1.295 respectively; while Rolfe et al. (2003) found employment multipliers to be 1:4 in the Nebo Shire in the Mackay region of Queensland.

Our estimates suggest that 63,444 jobs were indirectly dependent on the coal industry in Queensland in 2004-05, and this figure rose to 72,972 in 2006-07 (Figure 4.3). In New South Wales, 45,160 jobs were indirectly supported in 2004-05, rising to 53,568 in 2006-07. In total, about 126,540 were created indirectly in the two coal producing states. We estimate that the total number of people employed (directly and indirectly) by the coal industry in the two states is over 158,000.

4.3.2 Macroeconomic Model Estimates

Although multipliers are simple to understand and can provide useful information on the impacts of industrial activity and government policies, the input-output (I-O) modelling approach, from which they are derived, has a number of limitations. Among other things, I-O models do not sufficiently take into account the behaviour of consumers and producers. Furthermore, they are based on some unrealistic assumptions including the absence of prices which are very important in shaping the decisions of economic agents. Another limitation of multipliers is that they are fairly broad estimates and are not able to determine the impacts on specific industries in the economy.

Figure 4.3 Indirect Employment in Queensland and New South Wales using Multipliers, 2004-05 to 2006-07



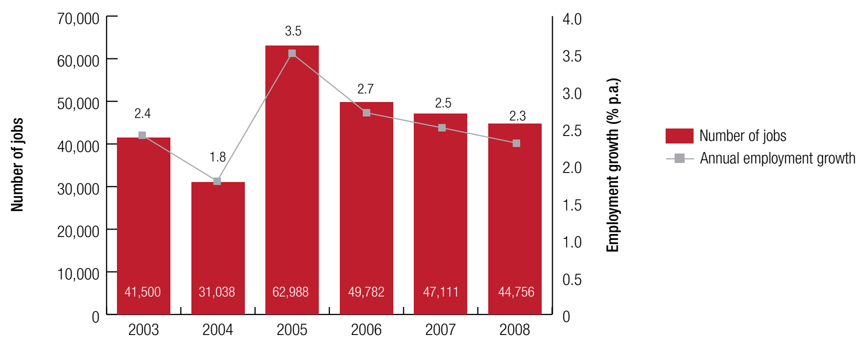
Source: Author's estimates

Multiplier models are based on unrealistic assumptions including the absence of prices which are very important in shaping the decisions of economic agents.

The macroeconomic model we have used to estimate the indirect impacts of coal mining in Australia is the Monash Multi-Regional Forecasting (MMRF) model. MMRF is a multi-regional Computable General Equilibrium (CGE) model of Australia's eight regional economies — the six states and two territories. Each region is modelled as an economy in its own right, with region-specific prices, region-specific consumers, region-specific industries, and so on (COPS, 2008). There are four types of economic agents: industries, households, governments and foreigners. This model has been used extensively in policy analysis in Australia, including analysis of the Federal Government's Emissions Trading Scheme (ETS). The version used here is aggregated into 34 industrial sectors producing 34 products. We first present indirect impacts of coal mining on employment growth in Queensland and New South Wales, next we consider the indirect impacts in terms of contribution to household income through the jobs that are created by coal.

The macroeconomic model we have employed has been used extensively in policy analysis in Australia, including analysis of the Federal Government's Emissions Trading Scheme (ETS).

Figure 4.4 Coal's Contribution to Employment Growth in Queensland

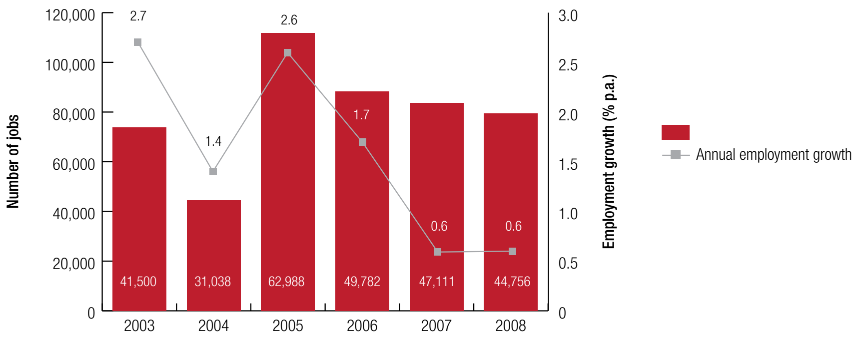


Source: Model estimates

[10] One major limitation of the I-O model is the assumption that an industrial structure remains unchanged by an economic event. It is also assumed that the marginal response of industries as a result of some policy action is equivalent to the average relationships observed in the base year – the year in which the I-O the tables are compiled.

In Queensland and NSW, the sectors in which indirect job growth occurred include agriculture, forestry, manufacturing (metal products and other), machinery and equipment, transport and services.

Figure 4.5 Coal's Contribution to Employment Growth in New South Wales



Source: Model estimates

Figure 4.4 shows the coal industry's contribution to employment creation in Queensland in the period 2003 through 2008. The right hand side scale shows the annual percentage change in the number of jobs, while the left hand side column shows the total number of jobs in that period. This scenario was simulated by feeding the historical rate of growth in coal production (domestic production and exports) into the model and allowing the model to calculate the overall change in employment in the overall economy.[11] The figures show that, on average, coal mining has increased total employment by 2.5 per cent per annum over this period. However, from a high of 3.5% annual growth in 2005, the rate of growth declined to 2.2 per cent in 2008. Between 2004 and 2006, for example, employment increased from 31,038 to 49,782, an increase of 18,744 jobs.

A similar situation can be observed in New South Wales (Figure 4.5). The average increase in employment generated by coal mining is 1.6% per annum over the same period. The highest rate of job growth was 2.7% in 2003, which subsequently declined to 0.6% in 2008. Nevertheless, the coal industry has made a steady contribution to employment creation in the state. Between 2004 and 2006, for example, employment increased from 44,586 to 88,340, an increase of 43,754 jobs. In Queensland and NSW, the sectors in which indirect job growth occurred include agriculture, forestry manufacturing (metal products and other), machinery and equipment, transport and services.

To provide a check on the plausibility of the model's employment projections, we compared our estimates of total employment in the economy with ABS employment data. For Queensland, the model consistently under predicts employment (Figure 4.6a). But the mean absolute percentage error is only 5%. In the case of NSW, the model over predicts employment (Figure 4.6b), but the mean absolute percentage error is lower at 2%.

[11] Technically minded readers are referred to COPS (2008) for the key model assumptions and solution method.

Figure 4.6a Estimates of Persons Employed in Queensland, 2003-07

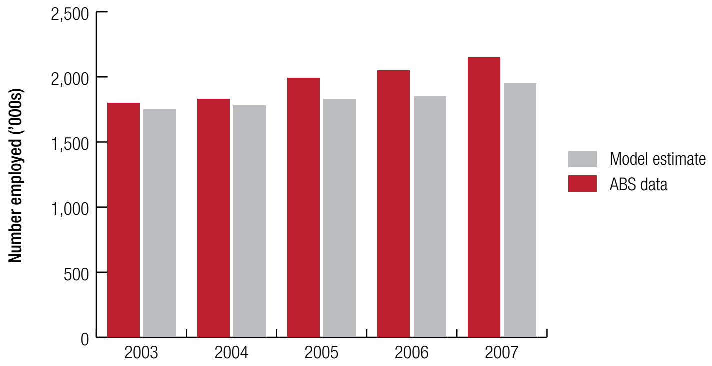
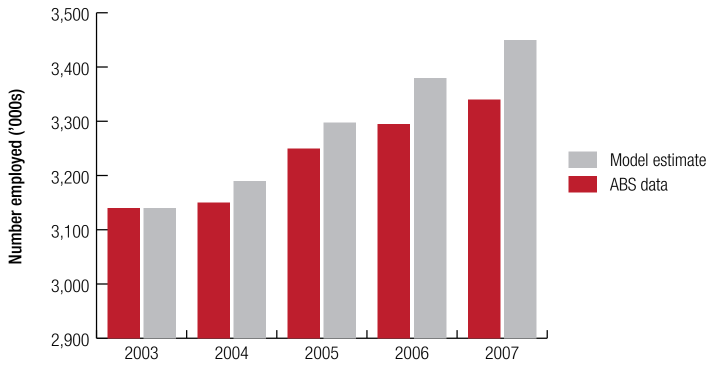


Figure 4.6b Estimates of Persons Employed in New South Wales, 2003-07



We also compared the model's growth rates with growth rates calculated from the 2001 and 2006 Census. The annual average increase in employment between 2001 and 2006, based on the census data is 2.7%. The model predicts an average annual growth rate of employment of 2.6% between 2003 and 2006 for Queensland, and 2% for NSW in the same period. Based on these comparisons, we conclude that the model's projections are realistic.

Finally, we compared estimates of indirect employment generated from the multiplier analysis with those generated by the model (Table 4.1). Estimates from the two methods for Queensland were very close in 2004-05; the multiplier analysis predicted 63,444 jobs, versus 62,988 by the model. However, the model estimates were lower for 2005-06 to 2006-07. An opposite trend can be observed for NSW, where the model estimates were consistently higher than those predicted by the multiplier. On average, the model implies a multiplier effect of 1.3 for Queensland and 1.8 for NSW. The difference between the two estimates could be due to the larger size of the NSW economy and the greater degree of market integration.

We estimate that in 2008 household disposable income grew by nearly 7% in Queensland and by nearly 6% in NSW as a result of coal mining.

Table 4.1 Comparison of Multiplier and Model Estimates of Indirect Employment

	2004-05	2005-06	2006-07
Queensland			
Multiplier	63,444	74,748	72,972
Model	62,988	49,782	47,111
New South Wales			
Multiplier	45,160	50,632	53,568
Model	111,775	88,340	83,599

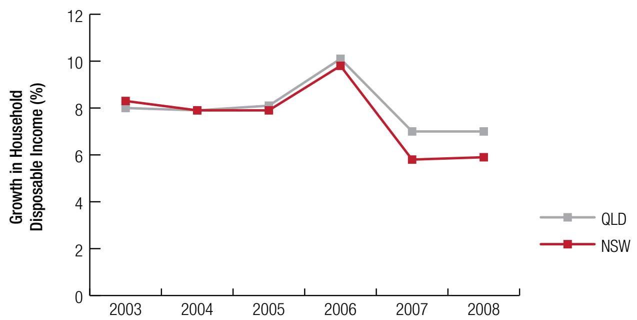
4.4 OTHER ECONOMIC IMPACTS

In addition to employment, the indirect economic impacts are caused in a variety of ways. First, as indicated earlier, wages and salaries paid to people directly employed in the industry are spent in the economy, which increases the demand for more goods and services, resulting in the creation of more jobs as aggregate demand increases. State and Federal Governments also enjoy a dividend in the form of increased taxes (personal and company income tax) and charges. Some of this money is spent in the local communities in the form of provision of infrastructure (e.g., roads, bridges, schools and hospitals) and services. Following we present the additional economic impacts of coal mining.

4.4.1 Real Household Disposable Income

Figure 4.7 shows trends in changes in real household disposable incomes as a result of coal mining in Queensland and NSW. In the last few years, the growth rate in Queensland has been higher than in NSW. The highest growth was in 2006 after the peak in production in 2005, followed by a decline in 2007 and 2008. Nevertheless, we estimate that in 2008, household disposable incomes grew by nearly 7% in Queensland and by nearly 6% in NSW as a result of coal mining.

Figure 4.7 Coal's Contribution to Household Disposable Income

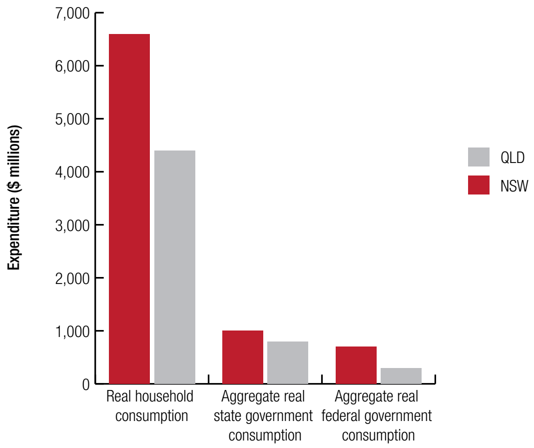


Source: Model estimates

4.4.2 Household and Government Consumption Expenditure

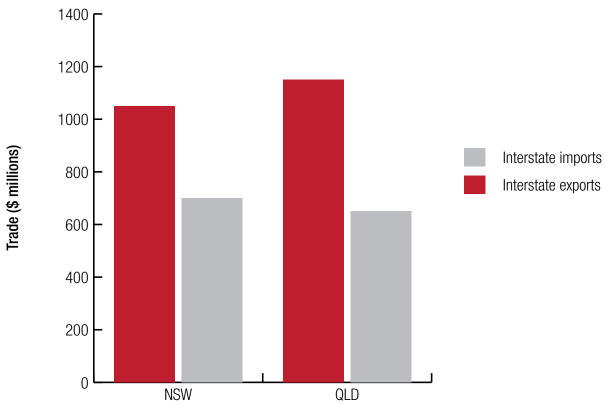
In terms of expenditure, we estimate that households in Queensland spent $4.3 billion in 2008, while households in NSW spent $6.7 billion (Figure 4.8). We were also able to estimate how much government at both the State and Federal Governments spent in 2008 due solely to the changes in coal output. At the State level, $694 million was spent in Queensland, while $975 million was spent in NSW. On the other hand, the Federal Government spent $312 million in Queensland and $565 million in NSW.

Figure 4.8 Impacts on Real Household and Government Consumption



Source: Model estimates

Figure 4.9 Impacts on Interstate Trade in 2008



Source: Model estimates

4.4.3 Interstate Trade

The increase in economic activity arising from the indirect impacts of coal mining can also be measured in terms of the changes in inter-state trade (i.e. changes in inter-state exports and imports). In Queensland, inter-state exports increased by $1.2 billion, while inter-state imports increased by $619 million. In NSW, inter-state exports increased by $1.0 billion, while inter-state imports increased by $705 million (Figure 4.9).

4.4.4 Gross State Product and Gross Domestic Product

Finally, we can also measure coal's contribution to Gross State Product (GSP) and Gross Domestic Product (GDP) for the period 2003 through 2008. In both states, coal's contribution to GSP has declined since 2003. The current estimate for 2008 is about 7% for Queensland and 5% for NSW (Figure 4.10). However, over this period, average annual GSP grew by 9% for Queensland and by 7% for NSW. In line with the trends at the state level, coal's contribution to the national level has been declining.

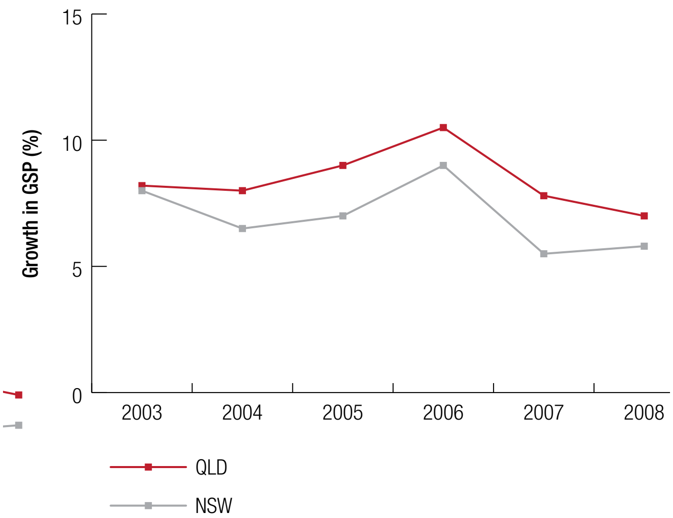
This contribution is significant in terms of job creation and generation of export revenue and taxes.

Real GDP growth declined from a high of 3.7% in 2003 to 2.0% in 2008, but average growth over this period was 3% per annum (Table 4.11). This contribution is significant in terms of job creation and generation of export revenue and taxes.

4.5 REGIONAL DEVELOPMENT

Mining in general and coal mining in particular, has played a crucial role in the development of regional areas in Australia. In addition to the provision of jobs, both directly and indirectly, the coal industry has been instrumental in infrastructure development. Examples of this type of development can be seen in the growth of new townships, construction of ports, airports, and dams, development of regional road networks and rail lines. Alongside the development of new towns has been the provision of social infrastructure such as schools, hospitals, and community leisure facilities. Coal mining can be credited with the development of many remote and inhospitable areas in Queensland and NSW. We highlight coal's contribution to regional development by presenting the case of Moranbah, a typical coal mining town in Queensland (see Box 4.1).

Figure 4.10 Coal's Contribution to Gross State Product



Source: Model estimates

Figure 4.11 Coal's Contribution to Gross Domestic Product Growth

Source: Model estimates

4.5.1 CASE STUDY: MORANBAH

Moranbah is a bustling modern coal mining town located about 200m above sea level, and is 194km south-west of Mackay, 208km north-east of Emerald and 1117km from Brisbane via Emerald. Moranbah is situated in the northern part of the Isaac Local Government Area (LGA). The town used to be part of the Belyando Shire Council which in 2008 merged with the Nebo and Broadsound Shire Councils to form the Isaac LGA. The area was settled in the 1850s by some famous Queensland pastoralists, including Andrew Scott who called his cattle station 'Moranbah', and the Archer family who moved into the Peak Downs area.

Moranbah is part of the "Coal to Coast" area of North Queensland, incorporating towns such as Clermont, Dysart, St Lawrence, Carmila, Middlemount and Nebo. It was established in 1970 as a dormitory town to service large open-cut mines at Goonyella and Peak Downs. The Goonyella mine lies 24km north of the town and the Peak Downs mine is 38km to the south. The town expanded considerably in the early 1980s owing to the discovery of huge coal reserves and the opening of the Riverside coal mine to the north of the town. The coal is transported by rail (constructed in 1972) to the sea near Mackay.

Since 2006 there has been a marked increase in the population of the area due to an upsurge in construction activity associated with the development of further coal mines and other industrial facilities such as an ammonium nitrate plant. According to the Isaac Region Council the current population of Moranbah is in excess of 10,500, an increase of over 80% in less than two years. They anticipate the population to reach 13,000. Most of this growth is made up of transient construction workers. The communities in and around Moranbah rely on rural-based activities such as cattle, grain and oil-seed farming.

At the time of the discovery of good quality metallurgical coal at Goonyella, it was a remote area. Exploitation of this resource required the development of a whole new set of infrastructure including sealed roads, rail and port facilities, electricity, water supply and housing and facilities for a workforce.

In the 2006 Census, 3,807 persons (98% of the labour force) were employed in Moranbah. Forty-three percent of the workforce was employed by the coal mine and the remainder were employed in services such as education, health, cafes/restaurants, supermarkets and grocery stores. Clearly, the coal mine has contributed significantly both directly and indirectly to incomes in the town. In 2006, the median weekly individual income for residents aged 15 years and over was $948, compared with $466 for Australia. The median weekly household income was $2,479, compared with $1,027 in Australia.

Coal mining continues to be a significant driver of not only the local economy, but also the Isaac LGA as a whole. For example coal mining accounted for 76.1% of total Gross Regional Product (GRP) in 2007–08. The second largest contributor to the regional economy was the construction sector, accounting for 2.7% of the region's GRP. This was followed by the agriculture, forestry and fishing industry, which contributed to 1.6% of regional GRP.

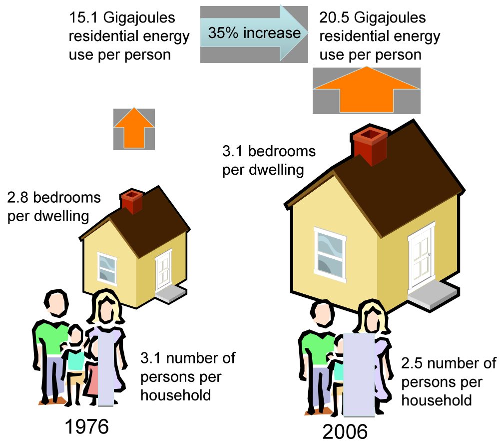
Coal's contribution to the development of Moranbah and the region in general may also be seen in terms of community and social development. The town can boast of modern amenities such as an airport, schools, library, health and dental facilities, shopping facilities, restaurants, a cinema complex, golf club, and off-road racing. The Moranbah Arts Council has been active in the town since 1972 and mounts regular exhibitions.

Sources: Isaac LGA (2008); Sydney Morning Herald (2004); Royal Geographical Society of Queensland (2009); Encyclopaedia Britannica (2009)

Coal provides affordable and reliable energy services. It can be considered to be a significant contributor to national development and improvement in the quality of life.

Coal's contribution in the early years of industrialisation was as a principal source of energy to power these manufacturing industries.

Figure 4.12 Australia Residential Energy Use per Capita, 1976-2006



Source: ABS (2008b)

4.6 NATIONAL DEVELOPMENT

Energy services are a crucial input to development in terms of the provision of basic human needs such as cooked food, a comfortable living temperature, lighting, the use of appliances, water supply, sewerage, essential health care (refrigerated vaccines, emergency and intensive care), educational aids, communication (radio, television, email, the internet), and transport. Energy also fuels productive activities, including agriculture, commerce, manufacturing, industry, mining, and services. Figure 4.12 suggests that Australians are increasingly adopting an energy intensive lifestyle. Energy use per person has increased 35% from 15.1GJ in 1976 to 20.5GJ in 2006. Although the average family size per household has declined from 3.1 to 2.5 persons during this period, Australians are choosing to live in bigger houses. The average number of bedrooms per house has increased from 2.8 to 3.1.

To the extent that coal provides affordable and reliable energy services, it can be said to be a significant contributor to national development and improvement in the quality of life. This section takes a closer look at coal's contribution to national development, with specific attention to economic and social development. Under economic development, we consider coal's contributions to economic growth and development via industrialisation and growth of businesses. Under social development, we consider indirect contributions in terms of health indicators such as life expectancy and infant mortality. We conclude with a note on technologies underpinning the mining services industry.

4.6.1 Economic Growth and Development

In the early days of Federation, Australian industry was led by the pastoral industry which at that time supplied more than half of the British wool market. This led to the establishment of various manufacturing industries. Coal's contribution in the early years of industrialisation was as a principal source of energy to power these manufacturing industries.

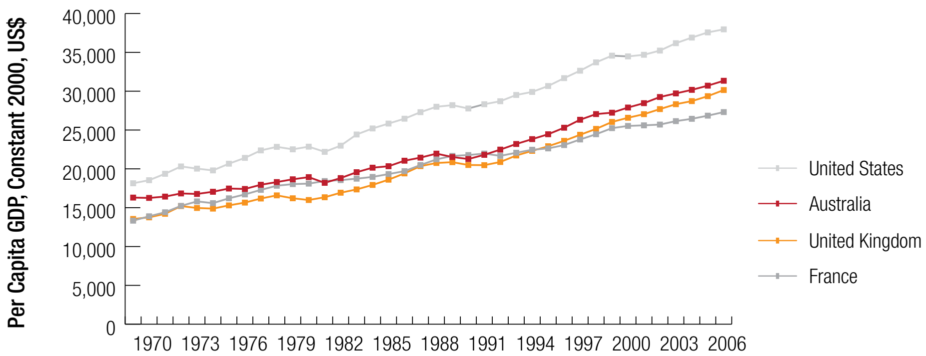
The growth of manufacturing industries increased exponentially before and during World War II in response to the increased demand for war related material and equipment. However, since 1960/61, manufacturing's share of national output has declined to about 10%, whereas the services and export sectors have increased. Coal is a key source of energy for steel and cement manufacturing in Australia. Even in steel plants that utilise electric arc furnaces, electric power is generated from coal-fuelled power plants.

4.6.2 Social development

As indicated earlier, by providing reliable and affordable electricity supply, coal contributes to social development by improving public health outcomes and enhancing the productivity of human capital. Each of these aspects is briefly discussed here.

Revenues from minerals such as coal and gold have enabled Governments to provide goods and services which have enhanced the standard of living of Australian's over a long period of time. Coal, directly and indirectly (through the flow-on effects) has increased the income and wealth of the people and has been instrumental in promoting Australia's current status as an advanced country. Australia's per capita income in 1970 was US$16,302. By 2007, this had almost doubled to US$31,342 (Figure 4.13), well above the OECD average of US$27,323. In 2007, Australia was ranked 12th, in per capita GDP terms, out of a total membership of 30. By contrast, per capita income growth for the United Kingdom, France, and other European countries have been below Australia's. Of the top 15 OECD countries, Australia's annual rate of per capita GDP growth has been among the highest since the early 1990s.

Figure 4.13 GDP Per Capita for Selected OECD Countries, 1970-2007



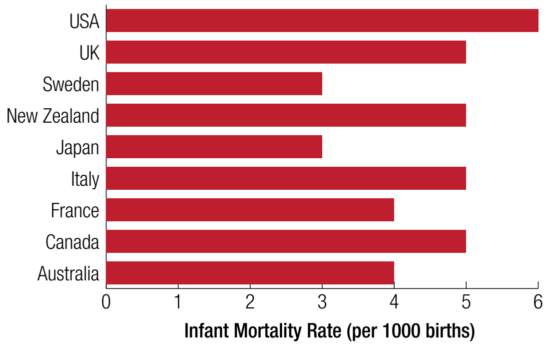
Source: OECD (2009)

Coal, directly and indirectly (through the flow-on effects) has increased the income and wealth of the people and has been instrumental in promoting Australia's current status as an advanced country.

Of the top 15 OECD countries, Australia's annual rate of per capita GDP growth has been among the highest since the early 1990s.

These benefits combine to improve the overall standard and quality of life, which enhance the life expectancy of citizens.

Figure 4.14 International Comparison of Infant Mortality Rates

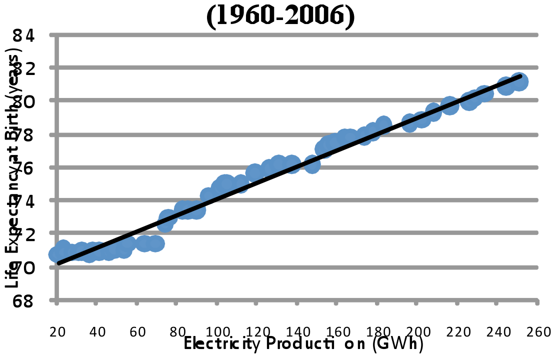


Source: ABS (2008b)

The lighting, refrigeration and power services made possible by electricity facilitates the delivery of better health care, provision of safe drinking water and treatment of sewage. These benefits combine to improve the overall standard and quality of life, which enhance the life expectancy of citizens. Figure 4.14 shows a comparison of infant mortality rates (per 1,000 life births) for selected OECD countries using 2005-2010 as the reference year. It can be seen that Australia's infant mortality rate is lower than that of the UK, US, Canada, New Zealand and Italy.

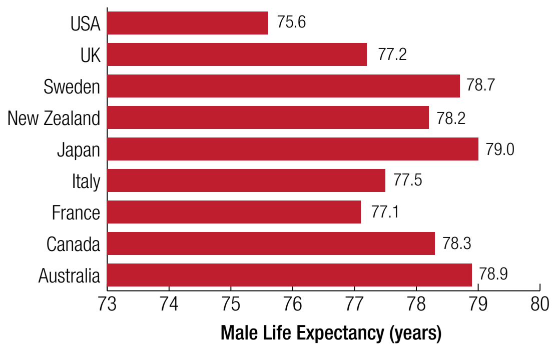
Figure 4.15 shows the relationship between electricity production and life expectancy in Australia for the period 1960 through 2006. It can be seen that there is a very high correlation between the two variables. Figure 4.16 shows comparisons of male life expectancy for selected OECD countries, with a reference year of 2005-2010. It can be seen here that Australia's male life expectancy of 78.9 years is only surpassed by Japan's 79 years.

Figure 4.15 Electricity Production and Life Expectancy in Australia (1960-2006)



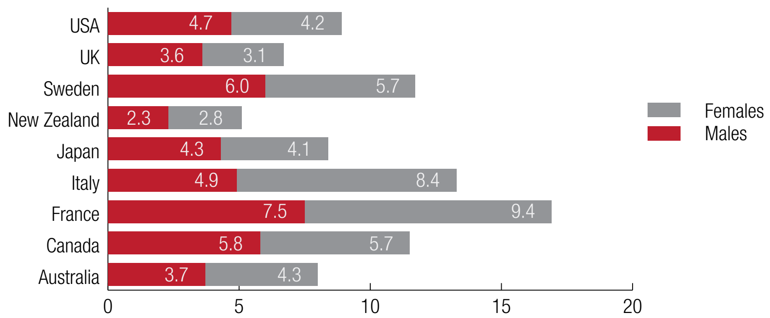
Source: ABS (2008b)

Figure 4.16 International Comparison of Male Life Expectancy



Source: ABS (2008b)

Figure 4.17 International Comparisons of Unemployment Ratios in 2005



Source: ABS (2008b)

Australia has the third lowest unemployment ratios among the selected OECD countries.

Although the mining industry tends to be capital intensive, it has been shown to have a huge impact on the economy in terms of the number of jobs created indirectly from the flow-on effects. At the aggregate level, the impact of mining can be assessed by comparing Australia's unemployment ratios with other OECD countries. Australia has one of the lowest unemployment ratios for both males and females in the OECD. Figure 4.17 shows that only the UK and New Zealand have lower rates of unemployment.

The relatively cheap and high quality electricity provided by coal also enhances the productivity of education. This happens through the provision of high quality lighting which is required for a comfortable and effective study environment. Reliable electricity is required for the operation of computers, laboratory equipment and teaching aids. Improvement in education provision generally leads to an increase in the productivity of human capital. This translates into an improvement in labour productivity which leads to an increase in income and wealth in the long run. Another important dimension of the productivity increase associated with affordable and reliable electricity supply is that it frees up time for families and individuals, which can be used for leisure, resulting in an enhanced quality of life.

Reliable and high quality electricity supply promotes business growth through lowering the cost of communications and information as well as transportation. The provision of reliable electricity in itself is a huge benefit to business and the economy in terms of cost savings.

Australia's mining technology and services (MTS) exports are comparable to its wine exports.

4.7 GROWTH OF BUSINESSES

Coal contributes to the growth of businesses mainly by lowering the costs of energy services. Reliable and high quality electricity supply promotes business growth in a number of ways. Firstly, it lowers the cost of communications and information, which in turn greatly enhances the productivity of labour and capital. The resulting increase in business profitability leads to expansion in business activities and therefore a greater level of employment. Secondly, the affordable and reliable energy services provided by coal lower the cost of transportation. This generates a number of positive externalities, including expanding the geographic scale and competitiveness of business operations. Thirdly, provision of reliable electricity, in itself, is a huge benefit to businesses and the economy at large in terms of cost savings. For example, it has been determined that the costs of electricity supply interruptions per lost megawatt hour far exceed the cost of base load or peak electricity supply costs (OTA, 1991). These costs arise from maintaining backup generators that could have been put to more productive use. Reliable supply of electricity also represents cost savings to businesses in terms of avoiding down time costs associated with repairing or replacing sensitive electronic and electrical equipment.

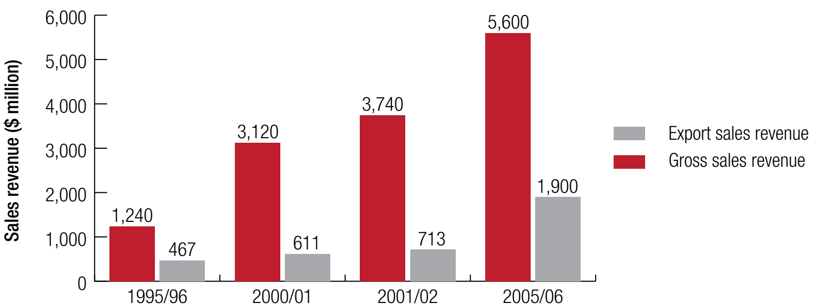
4.8 CONTRIBUTIONS OF THE MINING SERVICES INDUSTRY

One of the contributions that mining in general, and coal mining, in particular, makes to the economy is through its linkages with the business and financial services sectors. In this section, we discuss contributions by mining technology and services (MTS) sector, followed by the banking, finance and insurance services sector.

4.8.1 Mining Technology and Services

The MTS industry includes companies providing technology services to the mining industry, excluding petroleum. The MTS industry in Queensland is estimated to be worth $1 billion, which is equivalent to 26% of the total industry value in Australia (Invest Brisbane, 2009). There are over 300 MTS firms operating in Queensland, the majority of which are small and medium-sized enterprises (SMEs). Most of these SMEs are located in Brisbane and they service regional mining areas and the Asia-Pacific region. Services provided include equipment design, technology applications, engineering construction and maintenance and contract mining and consultancy services. Queensland is the second largest provider of mining services in Australia and supplies 60% of global demand for mining software (Invest Brisbane, 2009).

Figure 4.18 Sales Revenue and Exports for the Australian MTS Sector, 1995/96 - 2005/06



Source: ABARE (2002)

The innovation framework within the MTS sector has been credited with the rapid growth in the mining sector's productivity and increase in international competitiveness over the past two decades.

Nationally, the MTS sector comprises over 500 companies and more than 10 research organisations. A 2000-01 survey by the Australian Bureau of Resource and Agricultural Economics ((ABARE) indicated that the MTS sector in Australia generated gross sales revenue of over $3.1 billion, including exports of $610 million, and employed 17,329 persons (ABARE, 2002). Figure 4.18 shows trends in sales revenue and exports for the MTS sector for the period 1995-96 to 2005-06. Between 1995-96 and 2005-06, total revenues increased from $1.24 billion to $5.6 billion, which translates to an annual growth rate of 32%. Export sales revenue in the industry is around $2 billion per annum and is projected to reach $6 billion by 2010 (MacFarlane, 2003). Australia's MTS exports are comparable to its wine exports. In 2006-07, for example, 787 million litres of wine were exported at a value of $2.8 billion (ABS, 2009e).

The innovation framework within the MTS sector has been credited with the rapid growth in the mining sector's productivity and increase in international competitiveness over the past two decades.

4.8.2 Banking, Finance and Insurance Services Sector

The banking, financial and insurance services sector has strong links to the mining sector due to the fact that modern mines are highly capital intensive. Consequently, in moving financial resources to pay for both their capital and operational requirements, mining companies make heavy use of banking and financial services, leading to additional job creation in this sector. According to the 2006 Australian census, there were 24,408 persons working in the banking and finance sector in Queensland and 70,212 persons in NSW (ABS, 2007). While it is difficult to know exactly how many jobs in this sector were created as a result of the activities of coal mining industry, we used the macro model to estimate the change in jobs in this sector based on historical growth of coal output. The results indicate that 5,000 jobs were dependent on the coal industry in Queensland and 2,600 in NSW in 2007.

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Australian Coal Driving International Development 5

Dr Shahriar Shafiee and Professor Peter Knights –
School of Mechanical and Mining Engineering, The University of Queensland.

5.1 INTRODUCTION

This chapter examines Australian coal from an international perspective. It begins by looking at global supply and demand trends for hard coal (which includes coking coal, anthracite, bituminous and, in Australia and US, sub-bitumous coals). It then analyses known economic reserves of hard coal and where these reserves are located around the world. Australia has the fifth largest reserves of hard coal, but it is the leading coal exporter. In part this is explained by the proximity of Australian coal mines to deep water ports, but it is also due to the high quality of Australian export coals.

The latter part of the chapter examines how Australian coal has contributed to the quality of life enjoyed by inhabitants of our principal export partners, Japan, Korea, Chinese Taipei (Taiwan), India and China. In particular, it examines growth in GDP per capita as a function of energy use per capita for these countries. In China and India, 82% and 68% respectively of total electricity needs are generated from coal. In both counries, growth in GDP/capita has improved quality of life as measured by improvements in per capita health expenditure and access to sanitation facilities.

Australia has the fifth largest reserves of hard coal, but it is the leading coal exporter. In part, this is explained by the proximity of Australian coal mines to deep water ports, but it is also due to the high quality of Australian export coals.

Figure 5.1 2008 World hard coal production and consumption (Mt).

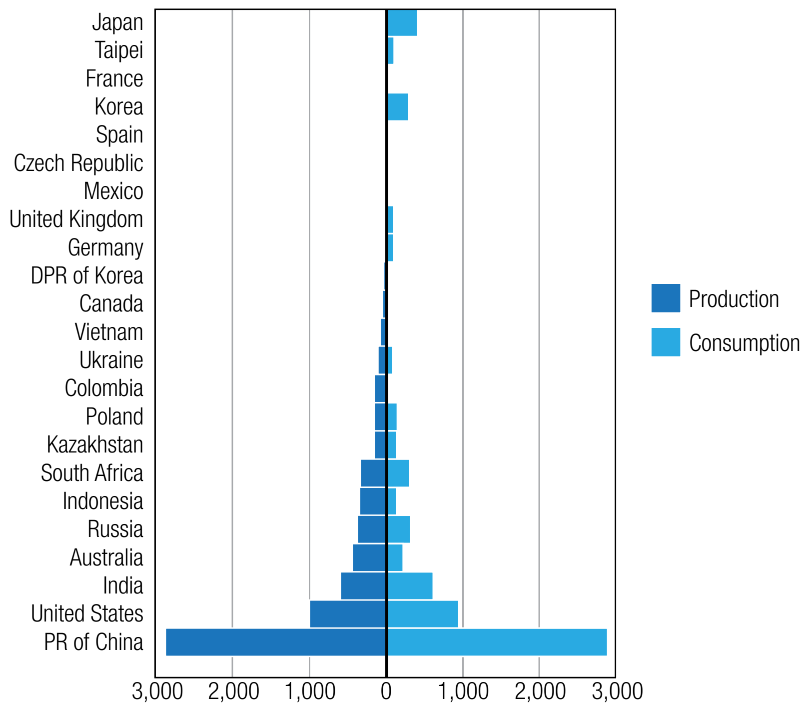

Figure 5-1: 2008 World hard coal production and consumption (Mt).

Data sources: (IEA 2008, 2009)

The top three coal producing countries are: China, the United States and India.

Australia consumes only 22% of the hard coal that it produces and is the largest exporter of hard coal.

Japan, Korea and Chinese Taipei (Taiwan), the United Kingdom and Germany are dependent on hard coal imports for their steel and energy needs.

5.2 GLOBAL COAL PRODUCTION AND CONSUMPTION

Figure 5-1 shows world hard coal production and consumption in selected countries. The top three coal producing countries are: China, the United States and India. In 2008, China produced approximately 2.7 billion tonnes of coal, or 40% of world coal production. Australia is the fourth largest coal producer, producing less than one eighth that of China.

In 2008, China consumed almost all of the coal that it produced. The US is a net exporter, as it consumed less than it produced and India had to import 59 Mt of coal in order to satisfy steel production requirements.

Australia consumes only 22% of the hard coal that it produces, and is the largest exporter of hard coal. Indonesia is the second largest exporter of hard coals, with Russia and South Africa in third and fourth place respectively.

Japan, Korea and Chinese Taipei (Taiwan), the United Kingdom and Germany are dependent on hard coal imports for their steel and energy needs.

Figure 5.2 2008 World hard coal production (Mt) and reserves (100Mt)

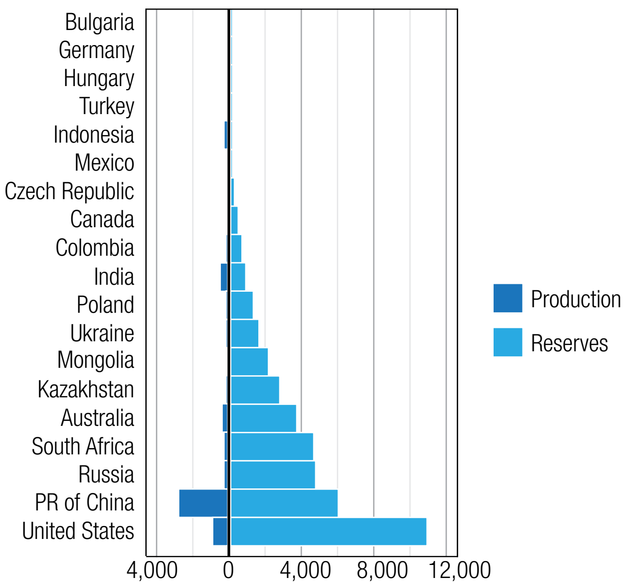

Figure 5-2: 2008 World hard coal production (Mt) and reserves (100Mt) .

Data sources: (BP 2009; IEA 2009; Methane to Markets 2009)

5.3 GLOBAL COAL RESERVES AND PRODUCTION

Coal reserves account for approximately 65% of total fossil fuel reserves in the world, with the remaining 35% being oil and gas (Shafiee and Topal 2008). While most of reserves of oil and gas are located in the politically unstable Middle East and Russia, coal remains abundant and broadly distributed around the world. 'Economically recoverable reserves of coal are available in more than 70 countries worldwide, and in each major world region'(WEC 2007b). Figure 5-2 shows the top twenty countries with proven coal reserves in 2008. The United States holds that largest economically proven coal reserves, followed by China, Russia, South Africa and Australia.

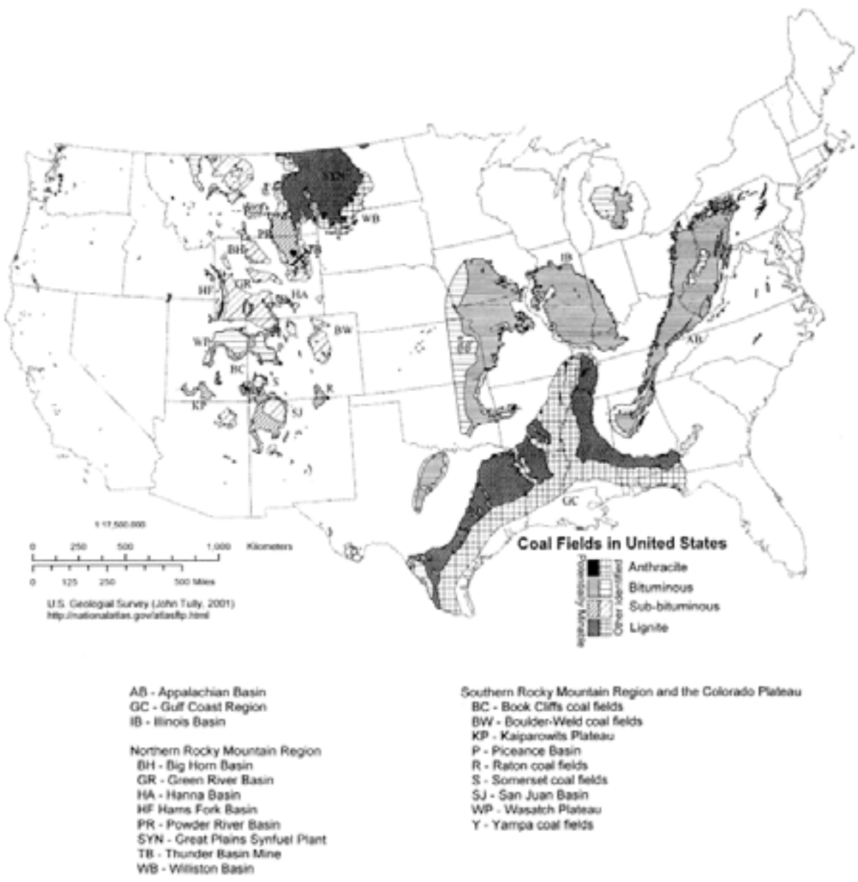

Figure 5-3: Coal fields in United States (CostMine 2009).

In 2007, the United States had around 612 active underground coal mines and 812 surface coal mines (Methane to Markets, 2009). Figure 5-3 shows a map of coal fields in the United States, based on coal type.

Coal reserves account for approximately 65% of total fossil fuel reserves in the world, with the remaining 35% being oil and gas.

Economically recoverable reserves of coal are available in more than 70 countries worldwide, and in each major world region.

The United States holds that largest economically proven coal reserves, followed by China, Russia, South Africa and Australia.

China is by far the largest coal producer and consumer in the world. At the current rate of consumption, China may experience difficulty in meeting domestic coal demand beyond the next 30 years. As a result, the global coal market may experience a shortage of supply, increasing coal prices in the near future.

Figure 5-4: Coal fields in China (ABARE 2003).

Figure 5-4 illustrates the distribution of China's coal fields according to official resources. There are an estimated 27,500 mines in China, most of which are operated by local authorities. Most (83%) of the high quality coal reserves in China are concentrated in the north and northwest; Shanxi, Inner Mongolia and Xinjiang provinces. Coal reserves are relatively scarce in the south-eastern provinces of Shanghai, Zhejiang, Fujia, Guangdong, Hainan, Guangxi, Hunan and Jiangxi. For this reason, Australian thermal coal exports are primarily used to supply thermal power stations located in these provinces.

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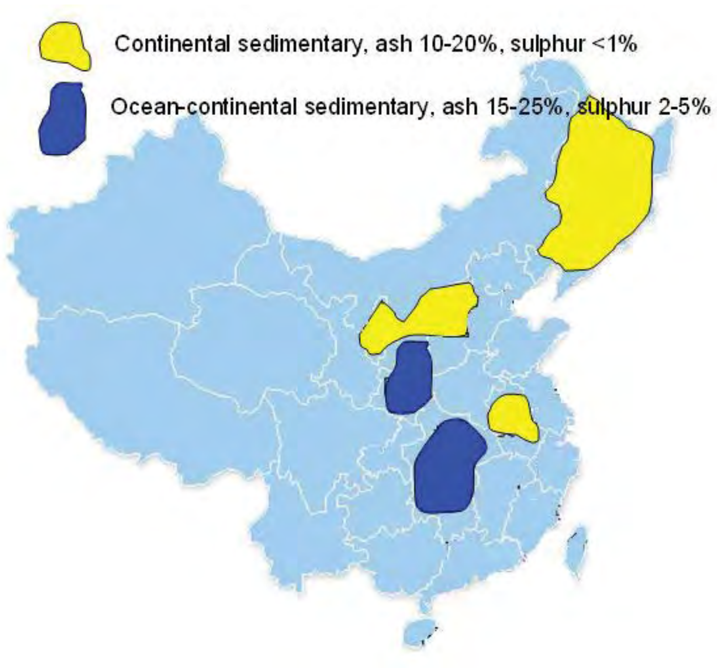

Figure 5-5 Coal quality distribution in China (source www.coalchina.org.cn, 2009 accessed 19/07/2009)

Coal quality varies across China (see Figure 5-5). Two important coal quality parametres are ash content and sulphur content. The North-Eastern and Northern provinces (Shanxi, Shaanxi, Ningxia, Henan and Anhui) host continental sedimentary deposits of coal that has an ash content of between 10-20% and low sulphur content (less than 1%). The southern provinces of Hunan and Hubei host ocean-continental alternative sedimentary deposits, with ash contents of between 15% and 25% and sulphur content between 2-5%.

In the event that the cost and availability of Australian thermal coal exports are affected by carbon taxes and environmental concerns, China will most likely turn to Indonesia and Russia to supply its thermal coal needs in the southern provinces. However the ability of these countries to sustain supply to China is questionable. At current production rates, Indonesian coal reserves are likely to be depleted in 30 years and the largest reserves of Russian coal are land-locked in central Russia complicating the costs of transport. In the event of any volatility in supply, China could revert to exploiting reserves of inferior quality coals located in the central and southern provinces. This coal has inferior heat content, higher ash and sulphur content than the high quality Australian thermal coals. It is therefore in the world's best interest to continue to make clean Australian coal available at competitive world prices.

In the event that the cost and availability of Australian thermal coal exports are affected by carbon taxes and environmental concerns, China will most likely turn to Indonesia and Russia to supply its thermal coal needs in the southern provinces. However the ability of these countries to sustain supply to China is questionable.

China could revert to exploiting reserves of inferior quality coals located in the central and southern provinces. This coal has inferior heat content, higher ash and sulphur content than the high quality Australian thermal coals.

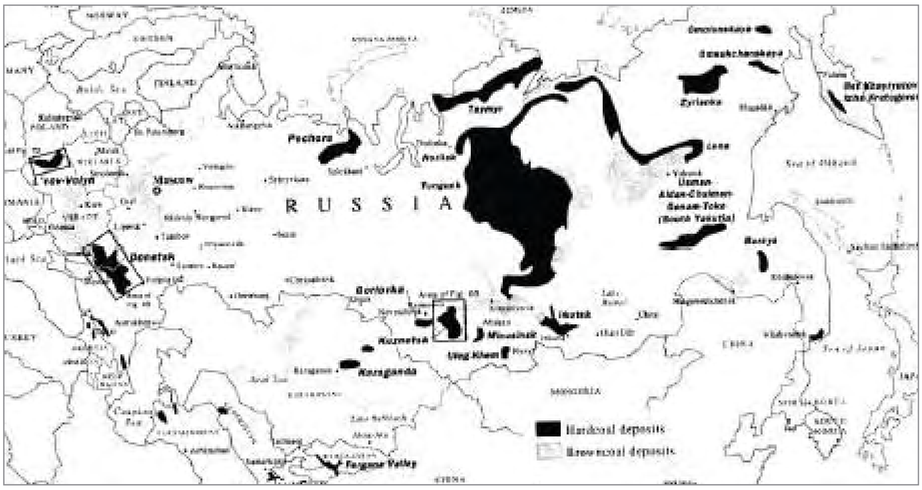

Figure 5-6: Coal fields in Russia (Methane to Markets 2009).

Russia has the third largest coal reserves with approximately 157 billion tonne. In 2003, Russia had 92 underground and 119 surface coal mines. The rate of coal production and coal reserves in Russia indicate that Russia has the potential to become a dominant coal supplier over the next century. Figure 5-6 maps the black and brown coal reserves in Russia. Coal is found in the Kuzbass, Kansko Achinsky, Pechora, Irkutsk and South Yakutia basins (Tailakov 2005).

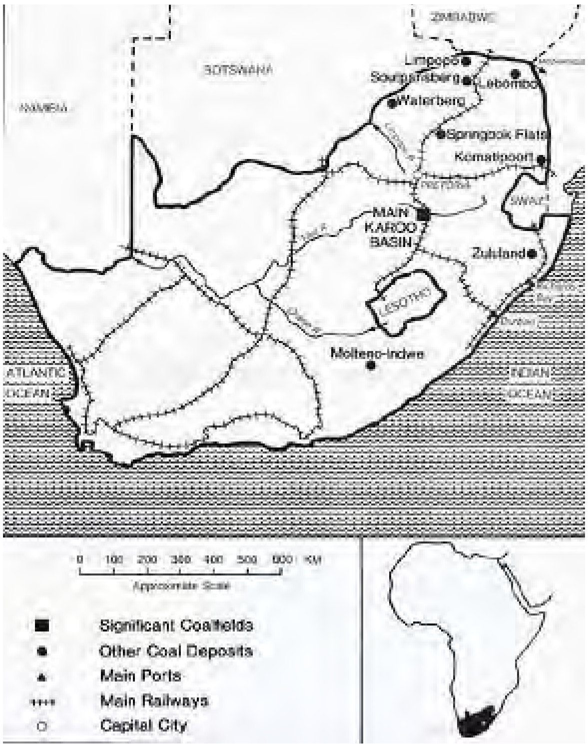

Figure 5-7: Coal fields in South Africa (Methane to Markets 2009).

South Africa's coal resources are estimated at about 110 billion tonnes with half of that in the reserve category (Methane to Markets 2009). South Africa has dominated the African coal industry over the last century and is likely to do so for the foreseeable future. Figure 5-7 depicts South Africa's coal fields. There are about 70 coal mines in South Africa with 44 of them underground and the rest surface operations. More than 70% of South Africa's coal reserves lie in the Highveld, Waterberg and Witbank fields (EIA 2008c). The main Karoo basin is the biggest coal reserve in South Africa: in 2006 Witbank coal field and Highveld coal field produced more than 80% of the total country's output (Methane to Markets 2009).

There are 118 privately owned mines located across Australia, 74 of which are surface pit mines and 44 are underground operations. Black coal reserves in Australia are high quality, high energy content and low in sulfur, ash and other contaminants.

Figure 5-8: Coal fields in Australia (Methane to Markets 2009).

Australia has just under 9% of proven global coal reserves, and has been the largest exporter of hard coal since 1984. Comparison of coal reserves and coal production indicates that Australia has the potential to be the biggest coal exporter for the foreseeable future despite the fact that Indonesia and Mongolia are expanding their coal exports. The vast majority of black coal is sourced from the east coast of Australia: Queensland (53%) and New South Wales (42%). The largest black coal reserves and mines are located in the Bowen Basin in Queensland and the Sydney-Gunnedeh Basin in New South Wales. These basins contain large deposits of near-surface, bituminous coals and are located close to deepwater ports. There are 118 privately owned mines located across Australia, 74 of which are surface mines and 44 are underground operations (ACA 2006). Black coal reserves in Australia are high quality, high energy content and low in sulfur, ash and other contaminants.

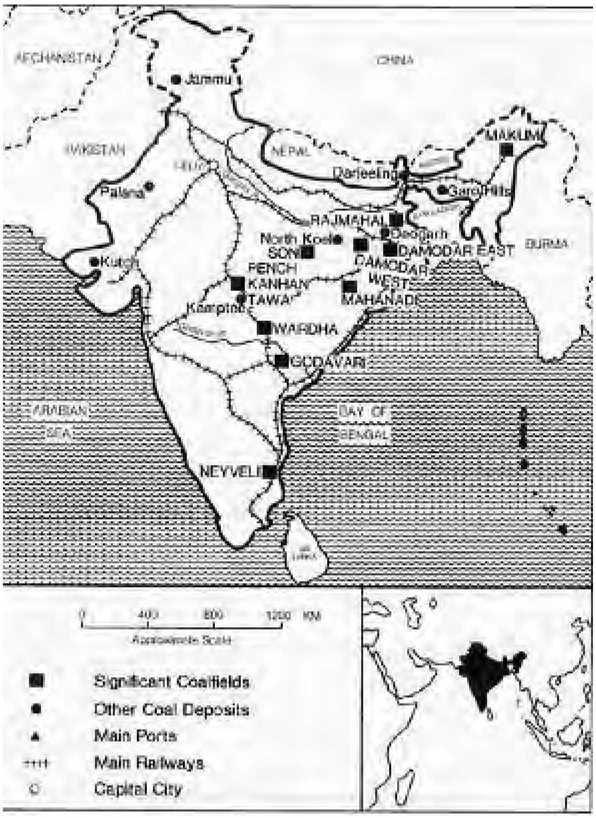

Figure 5-9: Coal fields in India (Methane to Markets 2009).

Figure 5-9 depicts the significant coal fields in India. The number of active underground and surface coal mines in India is estimated at 359 and 170 respectively (Methane to Markets 2009). The main deposits of hard coal in India are located in the eastern part. More than 85% of Indian coal reserves are located in five states: Jharkhand, Orissa, West Bengal, Chhattisgarh and Andhra Pradesh (Coal India 2008). India has sufficient coal reserves for the next century but the quality of India's coal is relatively low.

5.4 GLOBAL COAL TRADE

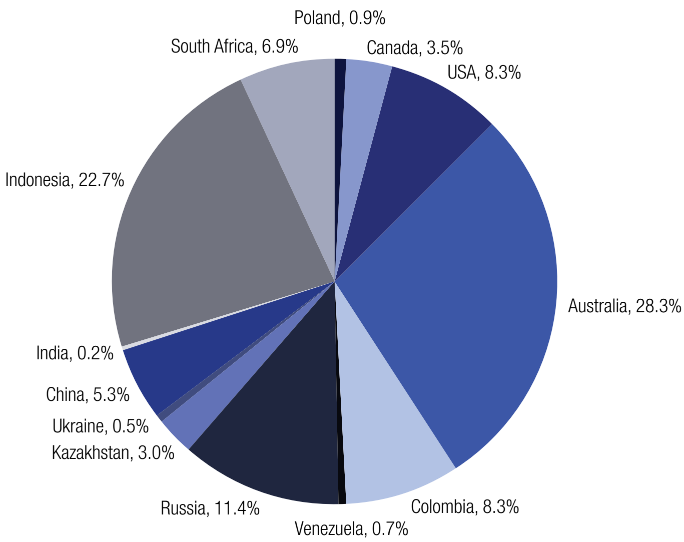

Figure 5-10: The main world hard coal exporter in 2008. Data sources: (IEA 2009)

Figure 5-10 shows the world's major coal exporters in 2008. Australia accounted for more than 28% of total international hard coal trade, followed by Indonesia (22.7%), Russia (11.4%), Colombia (8.3%), United States (8.3%) and South Africa (6.9%). The United States traded about 24% of worldwide hard coal in 1985, but this decreased to 8.3% in 2008. China, Poland, Canada, Kazakhstan and South Africa decreased their hard coal exports. Indonesian coal exports have increased 20 fold over the last 20 years. In 2007 Indonesia overtook Australia as the world's largest exporter of thermal coal.

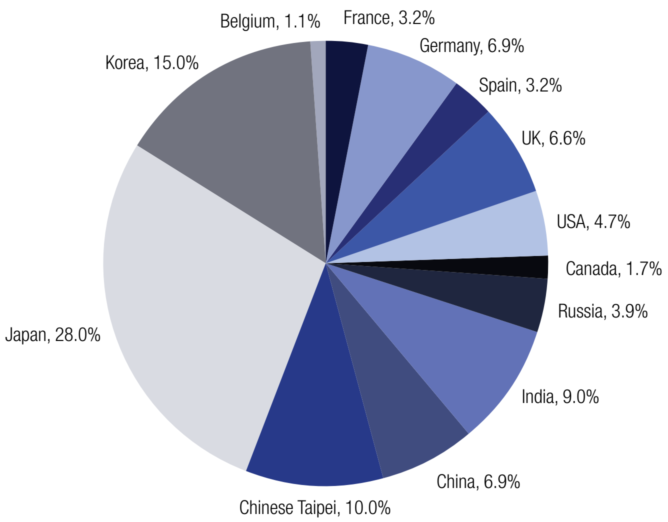

Figure 5-11: Main hard coal importers in 2008. Data sources: (IEA 2009)

Figure 5-11 shows the major coal importing countries in 2008. Japan and Korea are the major importers of hard coal at about 28% and 15% respectively. These two countries import coal from Australia and Indonesia. Japan was the largest importer of hard coal. Korea has increased its hard coal imports by approximately 5% since 1985. China, India and the United States, increased their imports slightly from 1985 to 2009.

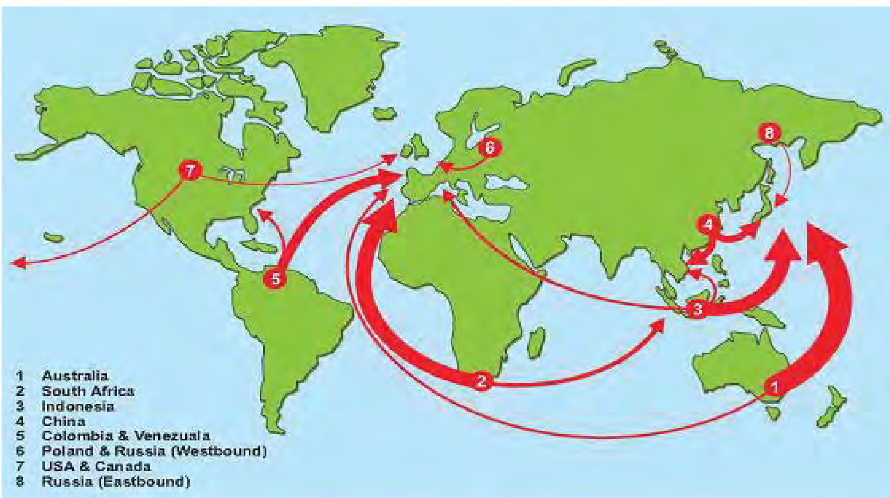

Figure 5-12: Global coal trade routes and volume (ACA 2003)RTS

Figure 5-12 shows the major global trade routes for hard coal weighted by volume of trade.

Black coal in Australia is the largest mineral commodity export, valued at $55 billion in 2008–09.

In addition, the Australian coal industry pays over $4 billion in royalties to State Governments.

5.5 AUSTRALIA AND THE GLOBAL COAL MARKET

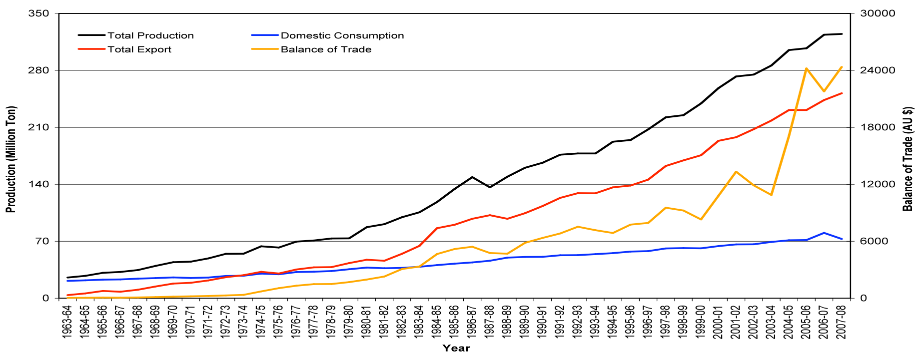

Figure 5-13: Historical trend of total black coal production, export, domestic consumption and balance of trade in Australia from 1963 to 2008. Source of data: (ABARE 2009).

Black coal in Australia is the largest mineral commodity export, valued at $55 billion in 2008–09. In addition, the Australian coal industry pays over $4 billion in royalties to State Governments. Figure 5-13 shows the historical trend of total black coal production, exports, domestic consumption and balance of trade from 1963 to 2008. From 2008 to 2009, the value of coal exports (balance of trade) doubled due mainly to increasing coal prices, not volume of production.

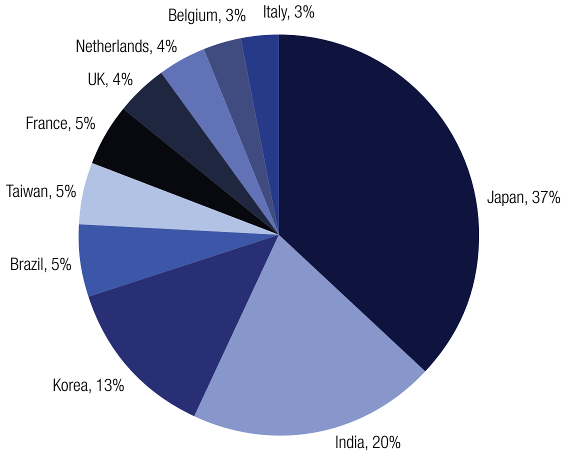

Figure 5-14: Top ten importers of coking coal from Australia in 2008.

Source of data: (The Department of Mines and Energy 2008)

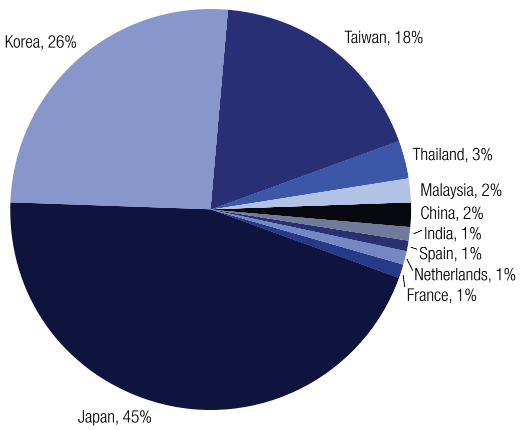

Figure 5-15: Top ten importers of thermal coal from Australia in 2008

Source of data: (The Department of Mines and Energy 2008)

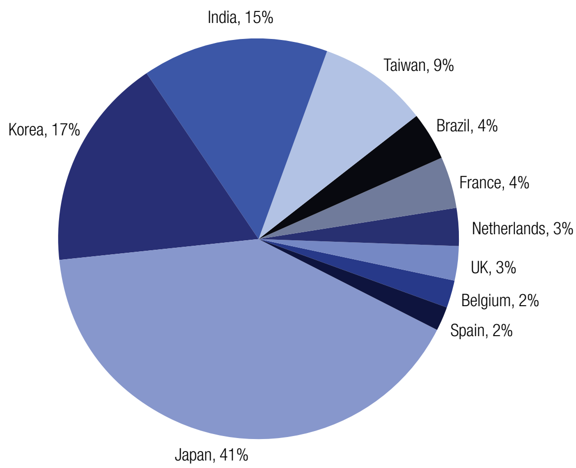

Figure 5-16: Top ten importers of coal (both types) from Australia in 2008.

Source of data: (The Department of Mines and Energy 2008)

Japan, India and Korea are the major importers of Australian metallurgical coal.

Japan, Korea and Chinese Taipei (Taiwan) are the major importers of Australian thermal coal.

Japan is the largest importer of Australian coal, purchasing more than 40%, followed by Korea at 17%, India at 15% and Chinese Taipei at 9%.

Japan, India and Korea are the major importers of Australian metallurgical coal accounting for 37%, 20% and 13% respectively (Figure 5-14).

Thermal coal is exported to Japan, Korea and Chinese Taipei (Taiwan) accounting for 45%, 26% and 18% respectively (Figure 5-15).

Overall, Japan is the largest importer of Australian coal, purchasing more than 40%, followed by Korea at 17%, India at 15% and Chinese Taipei at 9% (Figure 5-16).

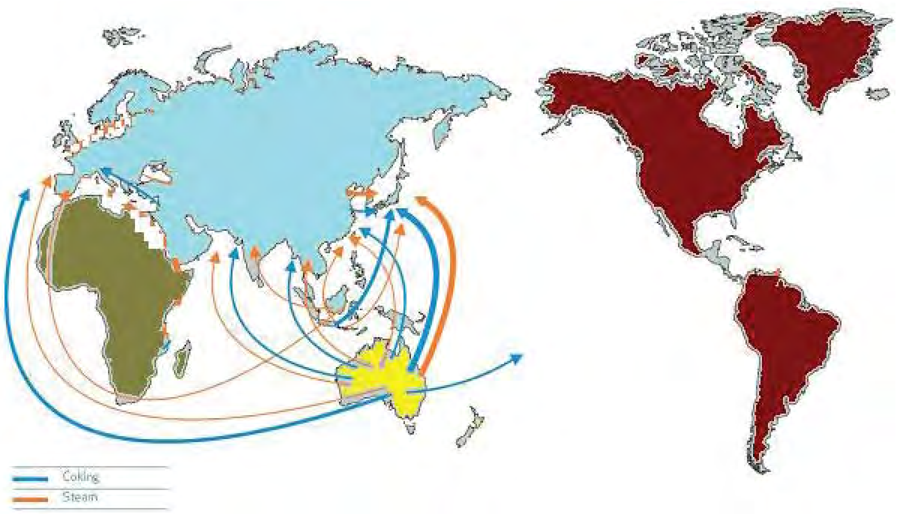

Figure 5-17: Main Australian coal export flow (WCI 2006)

Figure 5-17 shows the flow of coking and thermal coal export from Australia to other countries. As can be seen, the largest proportion of Australian coal goes to East Asian countries. The seaborne trade for coal from Australia has significantly increased over the past 30 years. This is due to the low costs of seaborne transportation and competitive prices made possible by efficient production (Ellerman 1995). Accordingly, Australia has the potential to continue to supply Japan, Korea, India and Chinese Taipei (Taiwan) for the foreseeable future.

5.6 AUSTRALIAN COAL POWERING JAPAN

Japan is by far the world's largest importer of coal, mainly for power generation, paper plants, the steel industry and cement production (Methane to Markets 2009). Japan does not have significant fossil fuel reserves, and so imports coal and gas to satisfy its electrical generation requirements. Japan is the fourth largest energy consuming country in the world and it is expected to move to third position in the next couple of years following the United States and Russia (IEA 2008). Coal accounts for a little over one quarter (26%) of Japan's primary energy supply. Japan has no active coal mines, and so imports 100% of its coal requirements (Methane to Markets 2009).

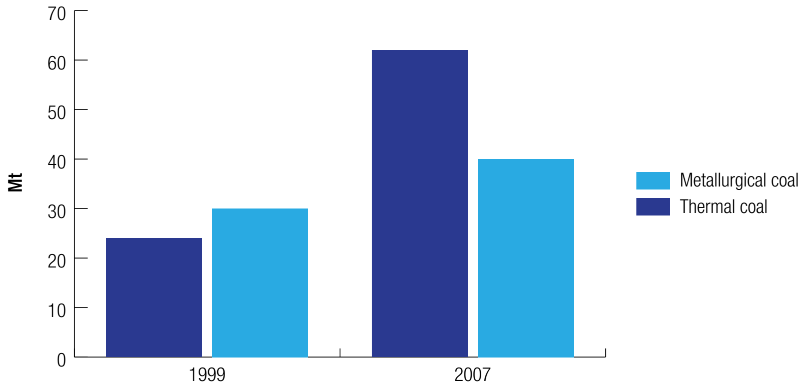

Figure 5-18: Volume of Japanese thermal and metallurgical coal imports from Australia. Source of data: (ABARE 2008)

Australia has been the major coal supplier to Japan since 1988. Japan imported more than 60% of its total thermal coal requirements from Australia in 2007. Australia is also the principal exporter of metallurgical coal to Japan, accounting for 40% of Japan's metallurgical coal imports.

Figure 5-18 shows the volume of imported Australian thermal and metallurgical coal in Japan. Australia has been the major coal supplier to Japan since 1988 (ABARE 2009). In 2007, Japan imported more than 60% of its total thermal coal requirements from Australia. Australia is also the principal exporter of metallurgical coal to Japan, accounting for 40% of Japan's metallurgical coal imports. Indonesia has grown to become the second largest exporter of metallurgical coal to Japan.

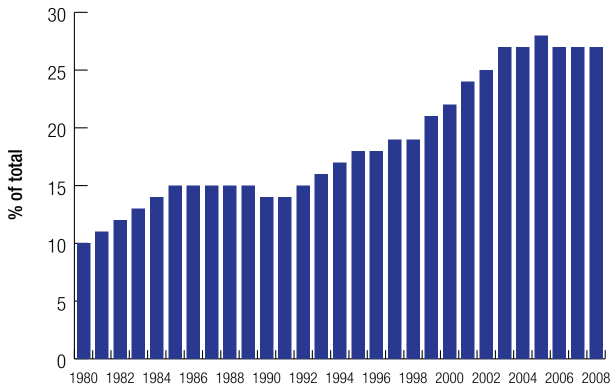

Figure 5-19: Historical trend Electricity production from coal sources in Japan from 1980 to 2008. Source of data: (World Bank 2009).

Figure 5-19 illustrates the proportion of electricity production from coal sources over the last thirty years. Coal supplies over one quarter (26%) of Japan's electrical energy needs. While net energy imports decreased over the period, dependence on coal as an energy source grew. Australian thermal coal exports to Japan have grown at a faster rate than for competing suppliers, which indicates that Japan is become increasingly dependent on Australia as a reliable supplier of high quality thermal coal.

In 2008, Korea was the second largest importer of Australian coal.

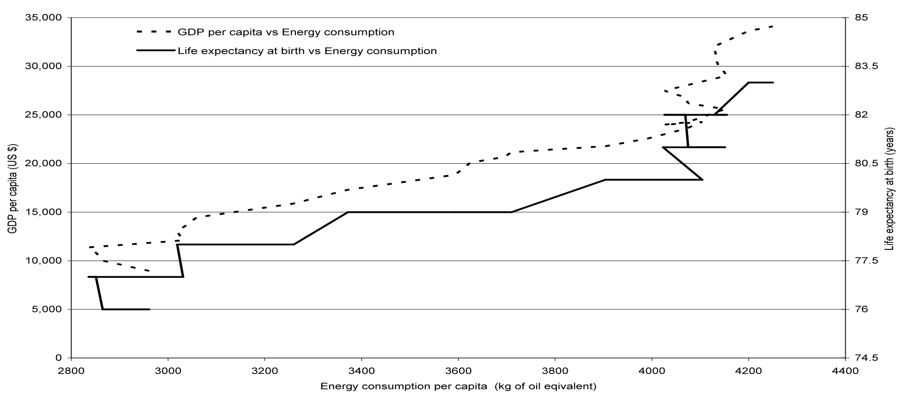

Figure 5-20: Historical trend of GDP per capita and Life expectancy versus Energy consumption in Japan from 1980 to 2008. Source of data: (World Bank 2009).

Figure 5-20 illustrates how both GDP per capita and life expectancy in Japan have increased as a function of energy consumption per capita.

Consequently, Japan's economy depends on consuming fossil fuel and imported Australian coal.

5.7 AUSTRALIAN COAL POWERING KOREA

In 2008, Korea was the second largest importer of Australian coal. Korea, like Japan has limited mineral resources. Korea currently generates more than one third (38%) of its electricity needs from coal. In 2005, Korea imported more than 97% of its coal, principally from Australia, China, Russia and Canada (Methane to Markets 2009). Korea has some small coal mines north and south of Chugcheong, however after 1988 Korea reduced its production from 25 Mt to less than 5 Mt per year. Coal production costs in Korea are high because of thin coal seams located in mountainous areas and poor labor productivity (Methane to Markets 2009). Nowadays, the Korean government is encouraging investments in foreign coal mining ventures. Korea had a total of 19 overseas projects in 2003 with several of these in the Australian coal mines (WTO 2004).

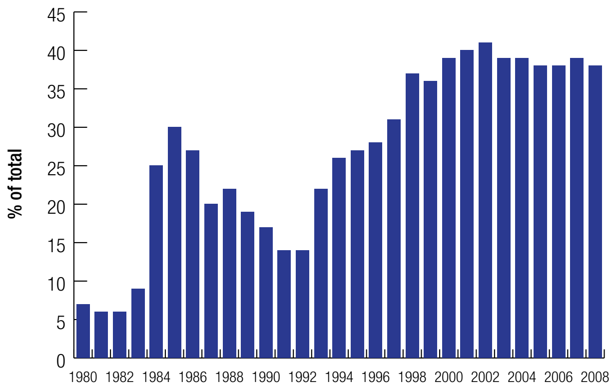

Figure 5-21: Historical trend of Electricity production from coal sources in Korea from 1980 to 2008. Source of data: (World Bank 2009).

Figure 5-21 shows the historical trend of electricity production from coal sources in Korea from 1980 to 2008. Electricity production from coal dipped in the 1980s, but overall dependence on coal has grown.

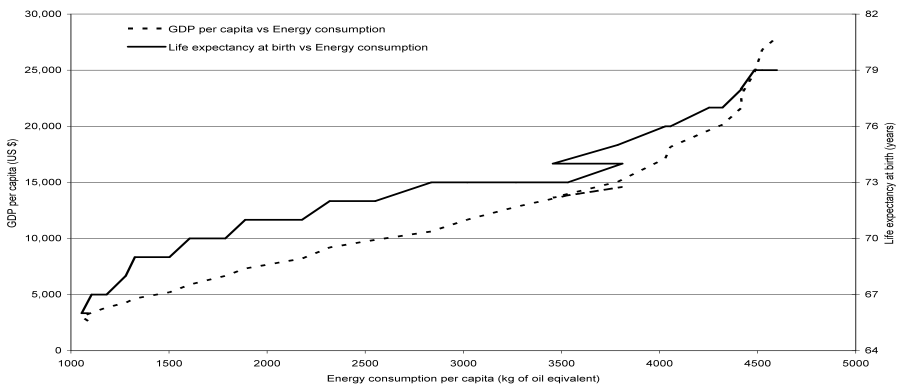

Figure 5-22: Historical trend of GDP per capita and Life expectancy versus Energy consumption in Korea from 1980 to 2008. Source of data: (World Bank 2009).

Figure 5-22 depicts GDP per capita and life expectancy in Korea versus energy consumption per capita. Once again, both factors have increased with energy availability. Australian coal has played an important role in elevating living standards in Korea.

5.8 AUSTRALIAN COAL AND INDIAN STEEL PRODUCTION

India is the third largest coal consumer in the world. Coal is the main source of energy usage and more than 70% of India's coal production is used to generate electricity (IEA 2007). India has a strong economy based on heavy coal consuming industries such as steel, cement, fertilizers, chemicals, paper and industrial plants. In India, coal has largely been phased out from the rail transport sector (Methane to Markets 2009). India is a net importer of coking and steaming coal needs (20 Mt and 17 Mt respectively, or around 10.8% of total coal consumption in 2005). Its domestic coal is of low quality (high-ash, low-calorific value), making it unsuitable for coking coal (WEC 2007a).

Australian coal has played an important role in elevating living standards in Korea.

India is the third largest coal consumer in the world. Coal is the main source of energy usage and more than 70% of India's coal production is used to generate electricity.

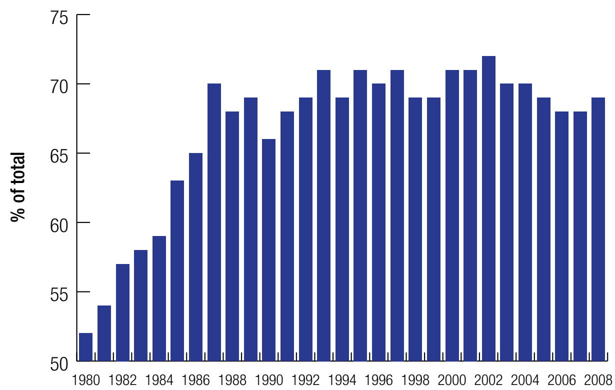

Figure 5-23: Electricity production from coal sources in India from 1980 to 2008.

Source of data: (World Bank 2009).

The structure of Indian economy differs from that of Japan and Korea. Figure 5-23 shows that the percentage of electricity production from coal has been relatively constant since 1986. India uses more coal imports for steel and industrial plants than it does for generating electricity.

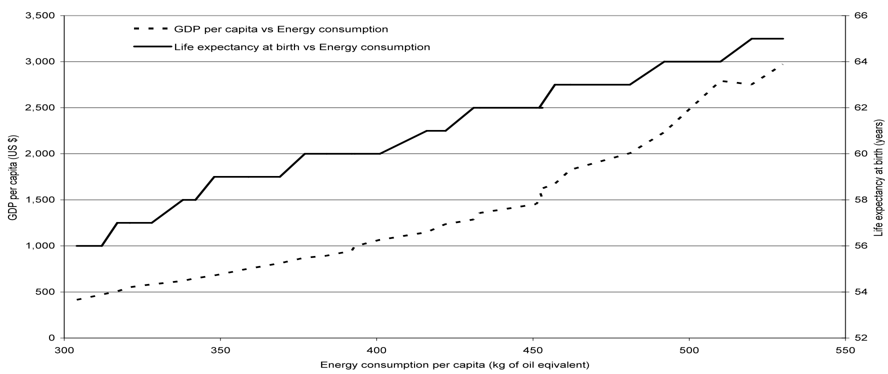

Figure 5-24: Historical trend of GDP per capita and Life expectancy versus Energy consumption in India from 1980 to 2008. Source of data: (World Bank 2009).

Figure 5-24 shows that GDP per capita and life expectancy have increased as a function of energy consumption per capita during the period 1980 to 2008.

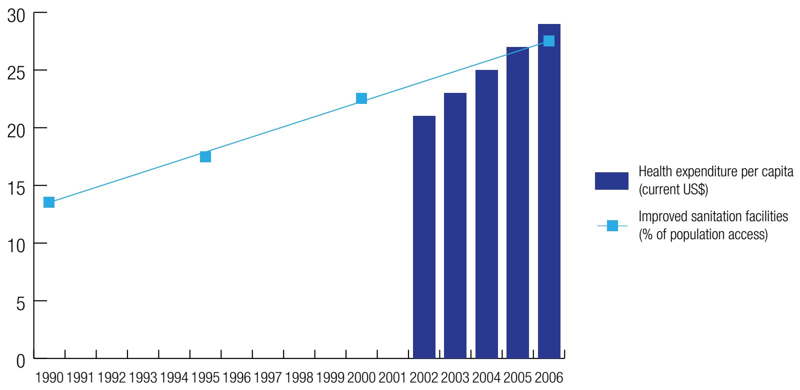

Figure 5-25: Historical trend of Health expenditure per capita and Improved sanitation facilities in India from 1990 to 2006.
Source of data: (World Bank 2009).

Figure 5-25 illustrates the gradual increase in per capita health expenditure and access to sanitation facilities in India. These indicators of quality of life are driven by growth in GDP per capita and, correspondingly, energy availability. The percentage of population having access to sanitation facilities has grown from 14 to 28% over the sixteen year period 1990-2005. This coincides with the increase in urbanisation in India, rising steadily from 18% of the population in 1960 to 30% in 2006 (World Bank, 2009). Rapid urbanisation requires the construction of infrastructure (buildings, bridges, sanitation facilities etc.) which depend on the availability of low cost steel and cement for which coal and ash from coal-fuelled power plants are essential ingredients. Australian metallurgical coal exports are thus helping to elevate the standard of life of the Indian population.

In India, quality of life has increased as a result of growth in GDP per capita and energy availability. Health expenditure per capita has increased, and the percentage of population having sanitation facilities has grown from 14 to 28% over the sixteen year period 1990-2005. This coincides with the increase in urbanisation in India, rising steadily from 18% of the population in 1960 to 30% in 2006.

China, for example, is currently building the equivalent of two new 500MW coal-fuelled power stations each week; a rate that is equivalent to Australia's entire coal-fuelled power sector every 4 months. It plans to continue to do this for the next 10 years.

5.9 AUSTRALIAN COAL POWERING THE FUTURE OF CHINA

China is ranked first in the world in production and consumption of coal. As Figure 5-26 indicates, coal accounts for 82% of China's electricity production, up from 55% in 1980 (EIA 2008a). China is currently the sixth largest importer of Australian thermal coals. As described in Chapter 1, China is currently building the equivalent of two new, 500MW coal-fuelled power stations each week; a rate that is equivalent to Australia's entire coal-fuelled power sector every four months. It plans to continue to do this for the next 10 years (http://www.eia.doe.gov/cabs/China/Full.html). This rate of expansion, combined with declining reserves, means that China has the potential to become a major export destination for Australian thermal coal.

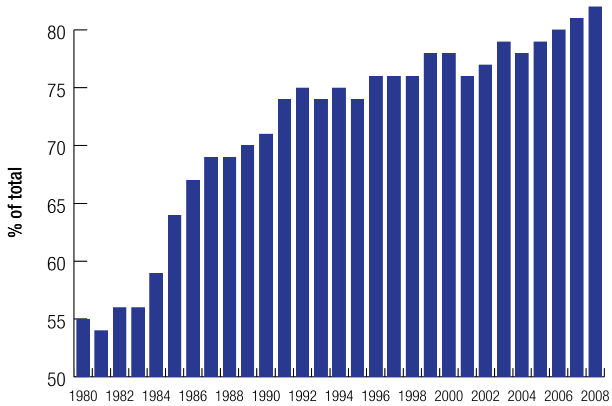

Figure 5-26: Electricity production from coal sources in China from 1980 to 2008.
Source of data: (World Bank 2009).

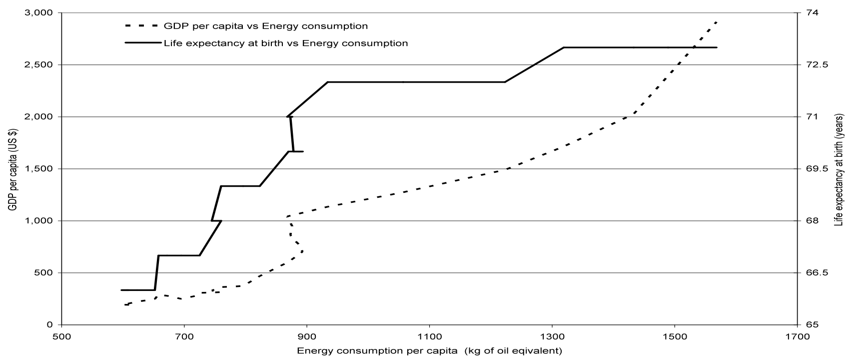

Figure 5-27: Historical trend of GDP per capita and Life expectancy versus Energy consumption in India from 1980 to 2008. Source of data: (World Bank 2009).

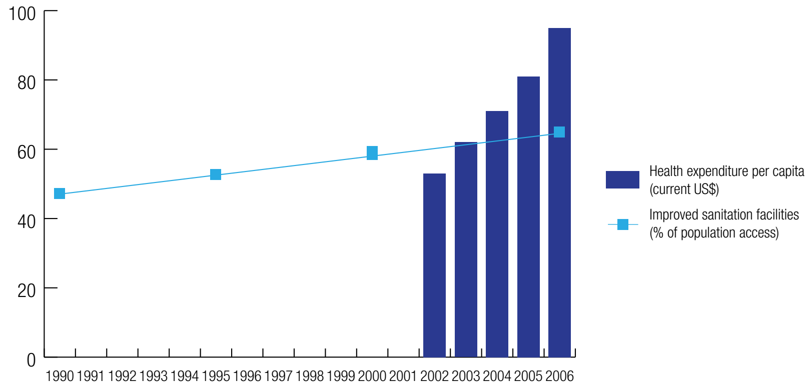

Figure 5-28: Historical trend of Health expenditure per capita and Improved sanitation facilities in China from 1990 to 2006. Source of data: (World Bank 2009).

Figure 5-28 illustrates the increase in per capita health expenditure and access to sanitation facilities in India. Again, these indicators of quality of life are driven by growth in GDP per capita and, correspondingly, energy availability. The percentage of population having access to santitation facilities has grown from 48% to 65% over the sixteen year period 1990-2005.

However, China faces significant challenges to curtail its emissions in the face of growing world concern. China is currently reponsible for 22% of world greenhouse gas emission. Air pollution in the large urban centres is linked to respiratory diseases in at-risk sectors of the population, particularly young children and the aged. Coal-fuelled power stations are partly reponsible for these emissions. Carbon capture and storage (CCS) technologies (see Chapter 7) for coal-fuelled power stations offer great potential for improving air quality in the urban environments of China. China is investing heavily in CCS technologies.

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Carbon capture and storage (CCS) technologies for coal-fuelled power stations offer great potential for improving air quality in the urban environments of China.

5.10 AUSTRALIAN COAL AND THE FUTURE

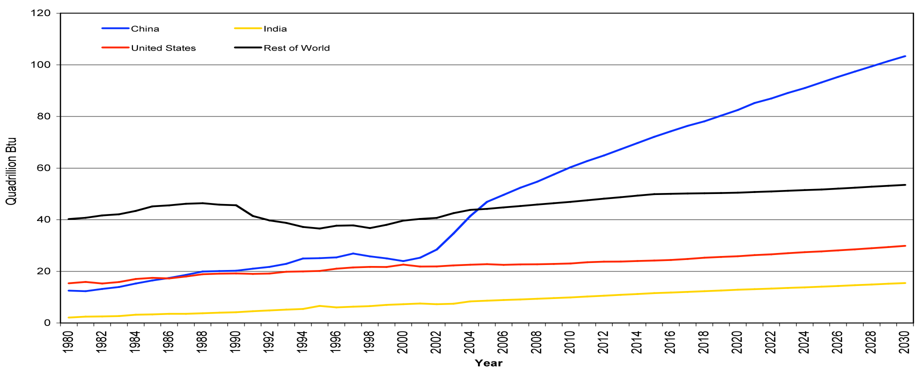

Figure 5-29: Coal consumption in selected world regions from 1980 to 2030. Source of data: (EIA 2008b).

Figure 5-29 shows projected coal consumption for China, India and the United States, which will continue be the major consumers of coal in the future.

Australian coal enjoys a number of advantages over competitor countries. Chief amongst these are low cost production and the availability of a skilled workforce. Australian coal will continue to play a vital role in the socio-economic development of Australia and Australia's major trading partners.

China will increase its coal consumption by 2030 to be twice that of the United States. BHP Billiton believes that steel production in China could double between now and 2025 to more than 1 billion tonnes by 2025 (Jacoby 2009). As its domestic coal reserves decline over the next 30 years, China will need to import increasing amounts of coal.

Table 5-1: The main advantages of Australian export coal

No	Advantage	Reason
1	Strategic Location	Close to Japan and Korea
		Mines located close to the coast
2	Low Cost	Generally thick deposit and near surface
		Relatively low stripping ratio
		Low cost electricity supplies
3	Efficient Mine	Skilled workforce and experienced management
		Highly mechanized and modern mines
4	Low Transport	Efficient transport links to the ports
		Deepwater access for large ships
		Efficient terminals/bulk loading facilities
		High capacity rail lines
5	High Quality	High quality, high energy-content coal
		Low sulphur, low ash content coal
6	Spread Resources	Large quantities of accessible coal
		Excellent environmental credentials

Source: (ACA 2003)

As Table 5-1 shows, Australian coal enjoys a number of advantages over competitor countries. Chief amongst these are low cost production and the availability of a skilled workforce. Australian coal will continue to play a vital role in the socio-economic development of Australia and Australia's major trading partners.

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Coal Mining and Sustainability

Mr Bruce Ham – mining engineer, independent health and safety adviser to the mining industry.

6

6.1 WORKING TOWARDS A ZERO INCIDENT WORKPLACE

In this section, the evolution of health and safety is described. As a starting point, basic health and safety statistics are examined to provide a reference point for the development of safety management systems and the resulting expectations for change. While trends in some health and safety outcomes are evident, it is useful to monitor the new types of data that are being reported as the government and industry move towards a systems approach for health and safety management. These data sets are important to understanding why and how changes in the approach to health and safety management are evolving.

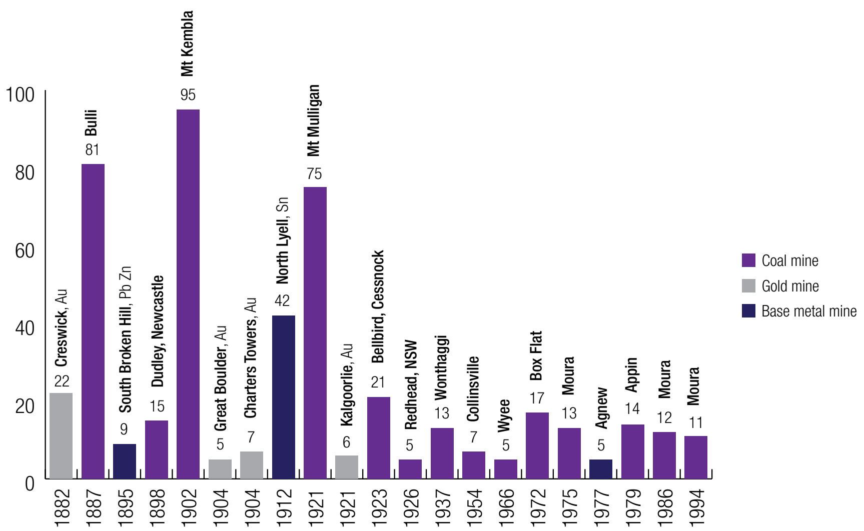


Figure 6.1.0 Major mining incidents resulting in multiple fatalities (Laurence, 2007)

Figure 6.1.0 shows that a positive feature is that coal mining incidents resulting in multiple fatalities such as Appin (14 fatalities in 1979) Moura No 2 (12 Fatalities in 1986) Moura No 4 (11 Fatalities in 1994) and Gretley (4 fatalities in 1998), have declined in frequency and severity due to improved risk management systems and the development of gas monitoring, gas drainage and inertisation technology that better control the risk of underground fires and explosions.

Table 6.1 Surface Coal Mining Employment and Fatalities (compiled from NSW - DPI and QLD DME Data)

	State	Year				
		01/02	02/03	03/04	04/05	05/06
Employment	NSW	4 392	4 749	4 914	5 221	5 966
	Qld	7 496	10 027	11 559	13 207	17 081
Fatalities	NSW	0	0	1	0	0
	Qld	1	0	0	0	2

Table 6.2 Underground Coal Mining Employment and Fatalities (from NSW - DPI and QLD DME Data)

	State	Year				
		01/02	02/03	03/04	04/05	05/06
Employment	NSW	1 895	1 798	1 895	1 929	2 057
	Qld	2 551	2 667	3 712	3 579	4 319
Fatalities	NSW	1	0	2	0	0
	Qld	0	0	0	0	0

Tables 6.1 and 6.2 show growth in employment as well as the number of mining-relate fatalities in Queensland and New South Wales between 2001/02 and 2005/06 as compiled from published data from the Department of Mines and Energy (DME,2009) in Queensland. Despite the growth in employment numbers, fatalities have remained relatively steady ranging from 0 to 2 per year. The number of reported injuries have also been relatively stable across all sectors. The Lost Time Injury Frequency Rate (LTIFR) has decreased in recent years in both underground and surface coal mines in Queensland and New South Wales as shown in Figures 6.1.1 and 6.1.2. LTIFRs are higher in New South Wales mines than in Queensland mines.

Figure 6.1.1 Lost Time Injury Frequency Rate (LTIFR) in surface coal mines

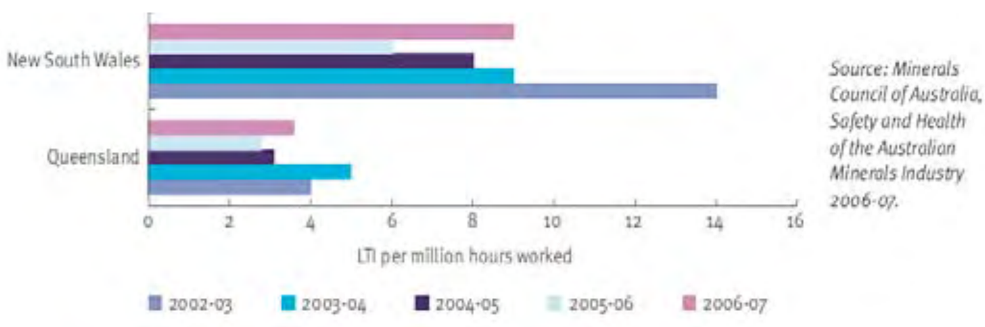
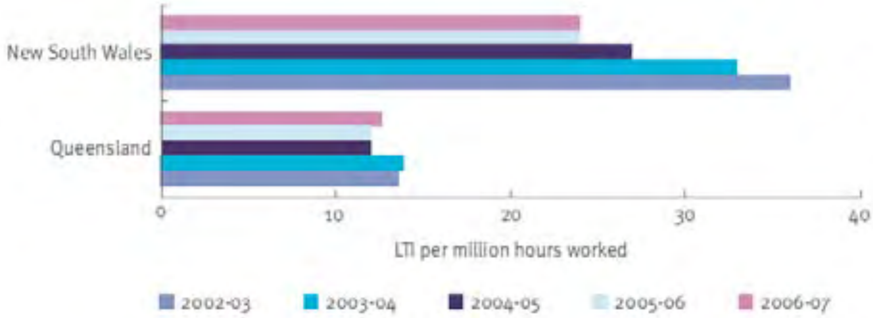


Figure 6.1.2 Lost Time Injury Frequency Rate (LTIFR) in underground coal mines



Source: Minerals Council of Australia, Safety and Health Performance Report of the Australian Minerals Industry 2006-07.

Fatality and injury data alone do not provide a comprehensive overview of the status of health and safety management systems in the coal mining industry. A third measure is the workers compensation data that includes both injury and occupational related disorders and disease. In Queensland, the compensation information is provided by WorkCover Queensland and the self-insurers. When the 2007-2008 data (DME, 2008) is aggregated for the surface and underground coal mining operations, it shows the coal mining sector incurred 966 claims costing $6.6 million. It should be noted that this compares with 170 lost time injuries for the same period.

In recent years, both the Department of Mines and Energy in Queensland (recently absorbed into the Department of Employment, Economic Development and Innovation) and the Department of Primary Industries (NSW) have taken additional interest in publishing analysis of incident data. The logic behind this is that, while the Departments are encouraging the coal industry to comply with legislation based around risk analysis and safety management systems, the mine operators need evidence-based risk data in formulating their risk management strategies. The challenge is how to analyse incident reports. For the purpose of an annual report, the government authorities report on single incidents of significant (or potentially significant) impact, total number of reported incidents and then breakdown the incidents into various categories as shown in figures 6.1.3 and 6.1.4.

As an immediate response, the Departments issue Safety Alerts, Safety Bulletins and Safety Incident Reports for various hazards as they come to the attention of the Departments and subsequently get fully investigated (DME 2009).

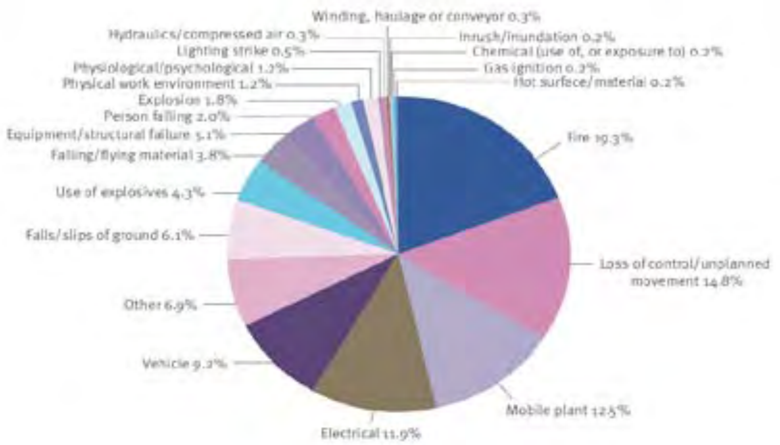


Figure 6.1.3 High potential incident types for surface mines

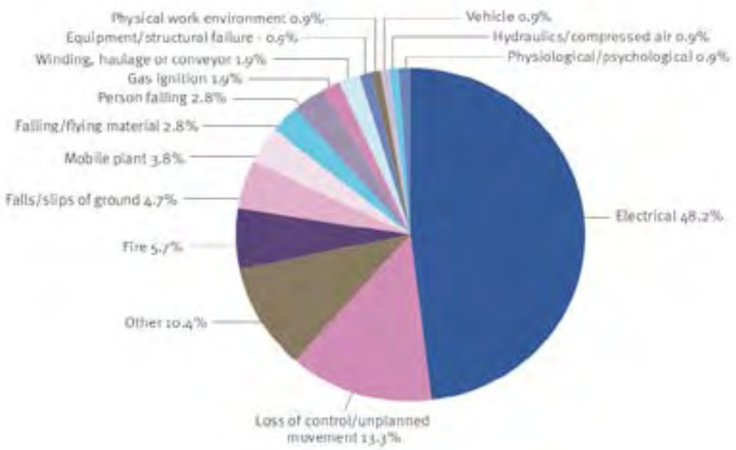


Figure 6.1.4 High potential incident types for underground mines

Historically, health and safety in the coal industry was largely driven by the need to comply with legislation. Through a series of mining disasters from the 1970s to the 1990s, the industry and various other stakeholders, realised that leading practice in coal mining health and safety had to evolve within the industry. The role of government regulators was to establish a framework providing some minimum standards but importantly it compelled and enabled the industry to develop new systems to identify hazards and identify and manage risk in an environment of uncertainty and evolving technology.

This evolution in improving health and safety is partly marked by reporting of injury and incident statistics, but is more accurately reflected in the emergence of leading practice systems that seek to identify emerging hazards and establish systems to control the risk to acceptable levels.

Historically, health and safety in the coal industry was largely driven by the need to comply with legislation. Through a series of mining disasters from the 1970s to the 1990s, the industry and various other stakeholders, realised that leading practice in coal mining health and safety had to evolve within the industry.

Coal mine safety is regulated under separate coal mining health and safety legislation in both NSW and Queensland.

With the advent of the 1994 Moura Mine accident in Queensland and the 1998 Gretley accident in NSW, a new style of regulation was introduced based on obligations of care and a risk management systems approach.

Coal mine safety is regulated under separate coal mining health and safety legislation in both New South Wales and Queensland. The legislation is administered by an inspectorate. These programs lie within the Department of Primary Industries in New South Wales and the Department of Employment, Economic Development and Innovation (previously in a separate Department of Mines and Energy) in Queensland. The Inspectorates inspect mines, investigate serious injuries and incidents and compile data on injury statistics. In NSW the mining legislation is subordinate to the Workplace Occupational Health and Safety Act. In Queensland, it is not subordinate to general workplace health and safety legislation. With the advent of the 1994 Moura Mine accident in Queensland and the 1998 Gretley accident in New South Wales, a new style of regulation was introduced based on obligations of care and a risk management systems approach as outlined in the New South Wales risk management standard MDG1010 (Department of Mineral Resources, 1997).

In New South Wales, Wran (2005) identified a series of issues that represented a significant barrier to improving coal industry health and safety outcomes as the industry moved from a regulatory to a management systems approach. The report identified an underlying theme across the industry - the need to get the basics of OHS management right. The Platinum Rules codified the fundamental steps the industry should take to more effectively manage OHS. They are as follows;

- 'Remember you are working with people
- Listen to and talk with your people
- Fix things promptly
- Make sure your paperwork is worth having
- Improve competence in OHS
- Encourage people to give you bad news
- Fix your workplace first
- Measure and monitor risks that people are exposed to
- Keep checking that what you are doing is working effectively
- Apply adequate resources in time and money .'

The NSW government through the Department of Primary Industries charged the Mine Safety Advisory Council, (2008) to develop the 'Digging Deeper Action Plan' and oversee industry's implementation of the action plan through educative assistance programs. In reviewing the status of the industry the Council found 'Up to 30% of mine sites were pro-actively working towards best practice in OHS. A further 43% of sites were identified as being in a transitional stage and about 27% were reactive to OHS issues.

6.1.1 CASE STUDY: THE COAL INDUSTRY ADDRESSING OPERATOR FATIGUE

With 12 hours shifts commonly in use across the Australian mining industry, operator fatigue has become a leading cause for concern. Fatigue has been linked as a contributing factor to several accidents and near misses. A number of commercial products have been developed over the past decade to tackle the operator fatigue concern. The majority of these use either eye/head behaviour or operator response time to determine the level of fatigue. A limitation common to these technologies is the inability to cope with driver-to-driver variations, which results from the fact that they infer fatigue levels based on individuals' response/behaviour rather than the direct, physiological measurement of fatigue.

Over the past few years, the coal industry, through the Australian Coal Association Research Program (ACARP) and Anglo Coal, has supported the development of the SmartCap™ fatigue measurement and management system that overcomes these limitations. The SmartCap™, developed by the Cooperative Research Centre for Mining (CRCMining), uses sophisticated sensors concealed in the lining of a baseball cap to measure an operator's brain wave (EEG) information to calculate a measure of drowsiness. This information is then wirelessly communicated to a display in-cab or to a PDA or mobile telephone. With the look and feel of a typical baseball cap, it is expected that the SmartCap™ will overcome the operator acceptance problems experienced by sites that in the past have implemented camera or response based technologies.

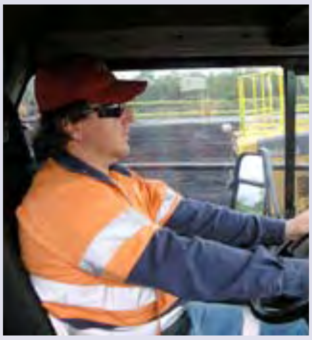


Figure 6-1.5 The CRCMining SmartCap™

Two field trials have been conducted to date using this prototype, which provided encouraging results in terms of both fatigue measurement accuracy and repeatability, and operator acceptance. More than fifty operators were involved in the trials, accumulating over 600hours of collected data and prototype use; each operator was surveyed as to the comfort and usefulness of the SmartCap™ prototype and the displayed data.

The commercial SmartCap™ system will be completed in mid-November 2009 and has some advantages over the trialed version. The principal difference is the separation of the core (higher cost) electronics from the electronics permanently contained in the cap. The core electronics will be contained in a card-like package that may be inserted in a connector on the underside of the brim, or docked in a recharging display. This separation significantly reduces the complexity and cost of the caps, allowing for occasional disposal (likely life is 2-6 months). Drivers keep their own cap with them (as with their hardhat), and insert a card into the brim of their cap once inside the truck. The in-cab display will have an allowance to hold and recharge three cards.

A major milestone of this final development work is the independent certification of the fatigue algorithm. This will be unique to the SmartCap™ system, and will provide documented evidence of the performance of the system as tested on multiple individuals by independent sleep specialists.

6.2 COMPARISONS WITH OTHER INDUSTRIES

The most recent statistics on work-related traumatic injury fatalities in Australia was compiled by the Australian Safety and Compensation Council (ASCC, 2008). This work was based on the 2005–06 data. This data is shown in Figure 6.2.1. The analysis by the ASCC groups all mining together. Information extracted from the reported departmental fatality data has been included to show relative fatality incident rate data in open-cut and underground coal mining. The higher figure related to underground coal mining is a reflection of the considerably higher level of hazards in underground coal mining.

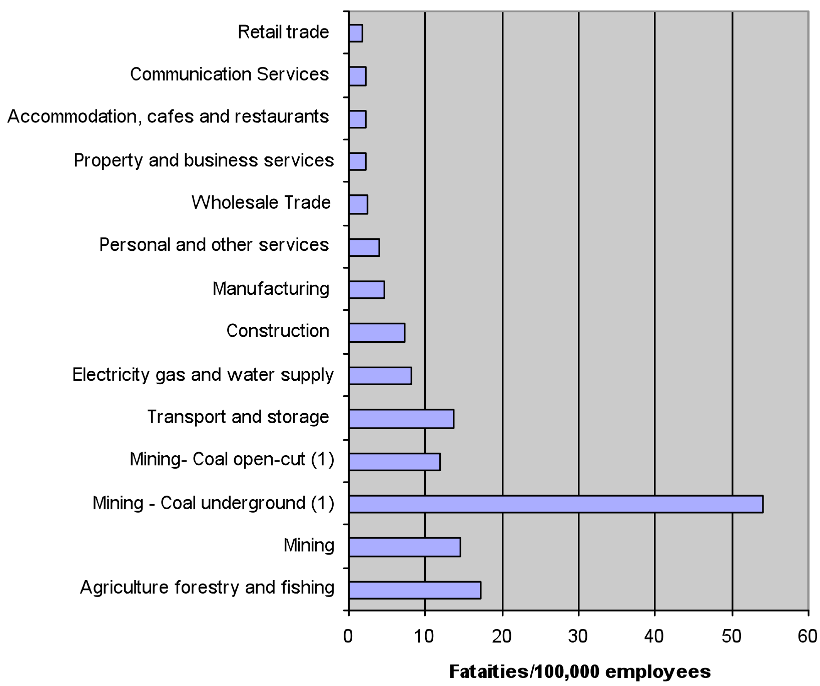


Figure 6.2.1 Australian Fatality Incidence Data

Agriculture, forestry and fishing (17.3) has a higher fatality incidence rate than mining (14.5) but is considerably less than underground coal mining (54). The fatality risk in transport (13.6) is similar to mining. Other industrial activities such as electricity, gas and water supply (8.2), construction (7.2) and manufacturing (4.6) have about half the fatality incidence rate as mining. Mining is six times more hazardous than wholesale trade, property and business services, accommodation, cafes and restaurants and communication services.

A feature of the ASCC analysis is that it captures data on commuting and bystander fatalities. The report makes a point that the fatality incidence rate for mining commuting (2.3) is the highest of all industries. The report also noted that there were no bystander fatalities for mining. This is a reflection of the generally good security arrangements on mining operations.

In a previous study on 'Work-related Traumatic Fatalities in Australia (1986 to 1992)', the National Occupational Health and Safety Commission (NOHSC, 1998), recorded that the fatality incidence rate from mining was 36 which compared favourably to forestry and logging (93) and fishing and hunting (86). Mining had a higher fatality incidence rate than transport and storage (23 and agriculture (20)

A comparison with coal mining sectors in other countries was undertaken by MacNeill (2008) who reported on an 'International Mining Fatality Database Project'. To compare the fatality risk, the fatality incidence rate (fatalities per 100,000 employees) is shown in Figure 6.2.2

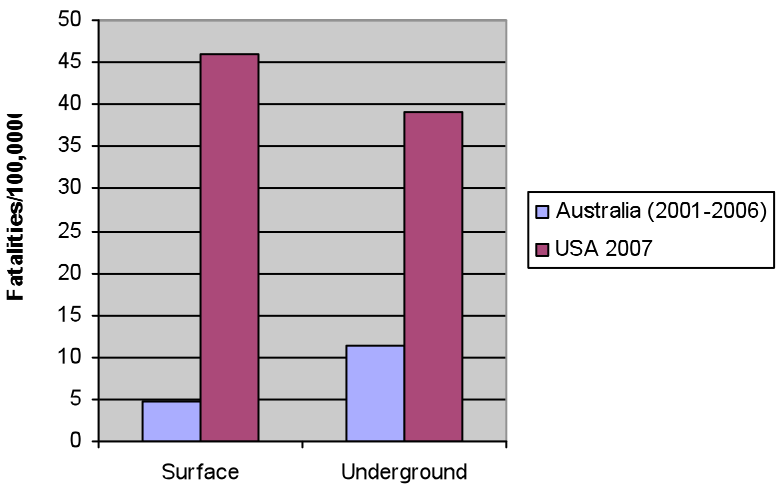
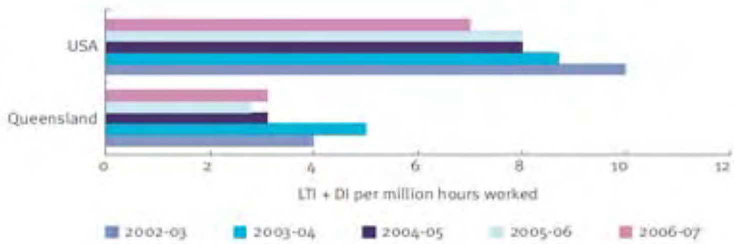


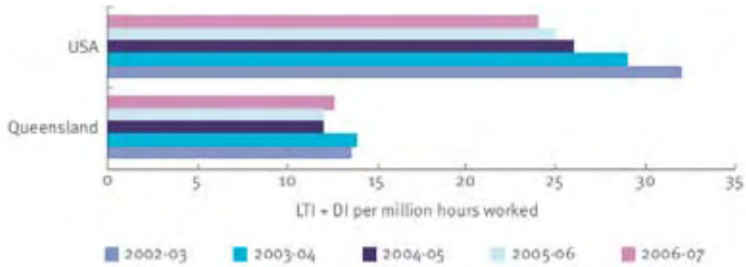
Figure 6.2.2 Coal Mining Fatality Incidence Rates in Australia and the United States

Comparisons of injury frequency rates between Queensland and the United States were published in the Safety Performance and Health Report (DME, 2008) and are shown in figure 6.2.3 and figure 6.2.4 for open cut mines and underground mines respectively.

Good environmental management aims to minimise the environmental impact of mining operations or the community during mining operations and leave the site in such a condition that subsequent land users find the land in as good as or better than condition as it would have been in the case that mining had not been undertaken.



Source: Minerals Council of Australia, Safety and Health Performance Report of the Australian Minerals Industry 2006-07.



Source: Minerals Council of Australia, Safety and Health Performance Report of the Australian Minerals Industry 2006-07.

6.3 ENVIRONMENTAL MANAGEMENT AND SUSTAINABILITY

Good environmental management aims to minimise the environmental impact of mining operations on the community during mining operations and leave the site in such a condition that subsequent land users find the land in as good as or better than condition as it would have been in the case that mining had not been undertaken. Over time, the expectations of the community in relation to environmental impacts from mining have continued to rise. This rise is reflected in the media, the environmental and planning legislation and environmental standards and technical guidelines. The coal industry has developed strategies to identify emerging issues and is working with a number of universities to develop solutions and transfer the new knowledge to the various stakeholders.

Prior to the 1970s, mining was seen as a cornerstone of the Australian economy and a few adverse environmental impacts were an acceptable price for the significant development that mining brought to the community. In general, mining leases granted prior to the 1970s had few if any environmental conditions. Evidence of this can be seen in some of the old mining areas around Bundamba west of Brisbane. While the land was left derelict, other industrial users are seeing the potential for this land and re-development is progressing.

From the 1970s, there has been a series of environmental regulations implemented by State Governments around Australia. The geographical and geological differences in the major coal mining states of New South Wales and Queensland have led to different strategies and processes in environmental management.

In Queensland, coal mining is now predominantly undertaken in surface mines, in areas of low agricultural value and at distances remote from populated centres. In this context mining operations are monitored by the Department of Mines and Energy with technical environmental assistance from the Department of the Environment

In New South Wales, coal mining occurs in close proximity to urban and semi-rural areas, high value agricultural land, metropolitan water storages and national parks with sensitive land features. New South Wales has a considerable number of underground coal mines which have less impact than surface mines, but do have issues related to mining subsidence.

One of the challenges of environmental management in general, and mine site rehabilitation in particular, is that each site has unique characteristics. To deal with this diversity, there has been a need to develop a body of knowledge and expertise in mine site rehabilitation.

The management of water is a key issue with short and long term impacts. While the challenges are slightly different at each site, there is a need to pool industry knowledge and experience. This is achieved by the Australasian Institute of Mining and Metallurgy through its series of 'Water in Mining Conferences' (AusIMM, 2005, 2007 and 2009)

For surface coal mines, the critical environmental management issues are to operate with minimal disruption to the local community and to implement a rehabilitation program that progressively re-establishes natural contours, native vegetation and re-develops the natural eco-systems so the post-mining landscape leaves a minimal mining footprint. There is a strong push from government and leading practitioners for site rehabilitation to progress with mining operations so that after mining is completed, only a minor final site clean-up is required before relinquishment of the lease is undertaken. Government (EPA,2004) has introduced a rehabilitation bond system such that there are financial incentives for rehabilitating land as soon its mining activity has been completed. The basis of costing for bond estimation in New South Wales is provided on the DPI (2009) website.

From the 1970s, there has been a series of environmental regulations implemented by State Governments around Australia.

The Queensland Environmental Protection Agency (EPA, 2009) has outlined key environmental issues that need to be considered for surface coal mining. These are:

- Determination of Post-Mining Land Use
- Land Suitability Assessment Techniques
- Good Relations With Landowners
- Community Consultation
- Air Pollution Control
- Noise Management
- Exploration and Mining in Watercourses
- Identification of Suitable Mine Environmental Management Expertise
- Progressive Rehabilitation
- Assessment and Management of Acid Drainage
- Assessment and Management of Saline/Sodic Wastes
- Water Management Guidelines
    - Water supply
    - Site Water Management
    - Water Discharge Management
    - Tailings Management
    - Water Monitoring
- Rehabilitation Guidelines
    - Rehabilitation of Areas Containing Shafts, Boreholes or Adits
    - Open Pit Rehabilitation
    - Rehabilitation of Spontaneous Combustion Areas
    - Rehabilitation of Land Subsidence Areas

By way of providing a standard as to what represents leading practice, the Department of Resources, Energy and Tourism (RET, 2009) implemented a Sustainable Development in Mining Program to work cooperatively with industry experts to generate a series of 'Handbooks on Leading Practice in Sustainable Development'. The following handbooks have been completed:

- Overview Handbook - provides a summary of the Leading Practice Sustainable Development Program.
- Stewardship Handbook - outlines the main principles of stewardship. Stewardship involves the care and management of a commodity through its life cycle partnerships. The handbook discusses materials stewardship, resources stewardship, process stewardship and product stewardship.
- Mine Rehabilitation Handbook - outlines the principles and practices of mine rehabilitation. Rehabilitation is the process used to repair the impacts of mining on the environment.
- Mine Closure and Completion Handbook - examines planning for mine closure and completion after a mine has reached the end of its life. It describes the business case for planned, structured and systematic mine closure and completion of mines in the context of sustainable development.
- Community Engagement and Development Handbook - addresses some of the key issues surrounding community engagement and development and offers insights, approaches and practical discussion about the challenges that companies may encounter as they engage with local communities and seek to contribute to their long term development.
- Working With Indigenous Communities Handbook - addresses issues relating to working with indigenous communities, including issues such as cultural heritage and land rights.
- Biodiversity Management Handbook - addresses the broad issue of biodiversity management for mining operations, including environment protection and conservation legislation, flora and fauna management, landscape level planning and environmental offsets.
- Managing Acid and Metalliferous Drainage Handbook - addresses issues related to the social and environmental impacts and remediation of acid and metalliferous drainage in the mining industry.

- Tailings Management Handbook - addresses tailings management through the life of the project (including planning, design, operation and closure of tailings storage facilities).
- Water Management Handbook - addresses issues relating to water management within the mining industry.
- Cyanide Management Handbook - addresses the principle and procedures for effective and safe cyanide management.
- Risk Assessment and Management Handbook - addresses issues relating to identifying, assessing and managing risk in the mining industry.

In relation to mine closure, the Mine Closure and Completion Handbook (Australian Government, 2006a) reports:

'Poorly closed and derelict (orphaned and abandoned) mines provide a difficult legacy issue for governments, communities and companies and ultimately tarnish the mining industry as a whole. Increasingly, as access to resources becomes tied to industry and corporate reputation, effective closure processes and satisfactory mine completion becomes critical to a company's ability to develop new projects. Taking a more integrated approach to mine closure planning, and doing it earlier, can achieve effective mine closure and completion.

Mine completion ultimately determines what is left behind as a benefit or legacy for future generations. If mine closure and completion are not undertaken in a planned and effective manner, a site may continue to be hazardous and a source of pollution for many years to come. The overall objective of mine completion is to prevent or minimise adverse long-term environmental, physical, social and economic impacts and create a stable landform suitable for some agreed subsequent land use.'

To the west of Brisbane, the Ipswich community is acutely aware of mining subsidence problems through high profile events such as the subsidence at Collingwood Park on the south-western outskirts of Brisbane. There have also been significant mining subsidence issues around Newcastle and around the lakes to the south of Newcastle. Mining subsidence can cause vertical ground movements of up to 2 metres and horizontal movement that can leave surface cracks of up to 200mm.

The nature of subsidence relates to the type of mining. With bord and pillar mining there may be no subsidence or little subsidence depending on the area extracted and the stability of pillars remaining. Where workings are shallow or the pillar stability is marginal, movements can take many decades before surface effects are evident and the movement can progress for many more decades as stress on pillars is re-distributed and further pillars fail. Bord and pillar mining was the dominant form of underground coal mining up until the late 1980s. There are extensive areas between Redbank and Ipswich in Queensland that will continue to suffer occasional mining subsidence problems for many decades to come. Similar areas exist around the old coal mining areas in New South Wales, particularly in the area from Newcastle to Cessnock. Building on land that may be subject to mining subsidence is permitted provided the design of the building is such that it can withstand mining subsidence should it occur some time into the future.

Since the 1990s, underground coal mining has predominantly utilised the longwall method in mines located in central Queensland from Blackwater up through Emerald to Glenden. In New South Wales, the longwall method is used extensively in the underground mining districts of the Illawarra (south of Sydney), western district and the Newcastle / Hunter. Using this method, blocks of coal 200m wide by 2000m long are extracted over periods of approximately 12 months. The ground above subsides shortly after mining and thereafter becomes stable. This permits effective long term planning of the post mining land use. Where surface cracking is evident, deep ripping using a bulldozer effectively fills the cracks which are generally shallow in nature.

In a few cases where aquifers are 40 to 60 metres above the seam being mined, there may be risk of creating pathways that cause the water to leak from the aquifer into the mine workings. This causes potential problems of loss of water from the aquifer and flooding of mine workings. This risk needs to be identified during mine planning and assessed with geotechnical and geohydrological studies.

Mining subsidence does not prevent post mining land use, but a number of issues need to be considered in planning for post mining land use. Where there is a major concern that the stability of pre-existing major infrastructure facilities such as dams, buildings and railways might be compromised, underground coal mining may proceed provided that the mine design provides stable pillars of coal that prevent significant surface movement.

Mining subsidence creates issues for holders of high value agricultural land where crops are grown using irrigation or contour banks for erosion control. In both these cases, the land cannot be used for cropping during the subsidence cycle. The land is best put to grasses and grazed until the final profile is established, when re-contouring can be undertaken to re-establish the cropping system.

An emerging sensitive socio-environmental issue is whether mining (and potentially other development) should proceed on high value agricultural land.

An emerging sensitive socio-environmental issue is whether mining (and potentially other development) should proceed on high value agricultural land. This is a sensitive issue for mining developments in the Hunter Valley and also in the Darling Downs west of Brisbane.

The Queensland State Government is approaching this issue by forming a special 'Social Impact Unit' within the Department of Infrastructure and Planning.

6.4 OLD PERCEPTIONS VERSUS TODAY'S REALITY

Since the gold rush of the 1850s, Australia's economic wealth has been tied to mining. Coal has been the principal source of energy for industry and power since the Illawarra and Newcastle coal-fields were opened up in the early 1800s. With the development of bulk marine transport of coal in the 1970s, Australian export coal has been a major contributor to the Australian economy and particularly to the balance of trade. While this may be the economic truth, the perception of the identity by the general public is largely shaped by the attention that the media give to the mining industry. This can best be described as sensationalist and inconsistent, as a case study of the articles relating to mining in the Brisbane major daily newspaper demonstrates.

6.4.1 CASE STUDY - BRISBANE COURIER MAIL NEWSPAPER - SATURDAY 19TH SEPTEMBER 2009.

Headline	Page	Story	Comment
The Herd stampeded from music festival	7	A music group pulled out because the event was sponsored by the coal industry. Three other groups will continue.	Radical activists scorn coal mining which is seen as an unsustainable industry. The mining company supports regional youth cultural events.
Mining boom is back - employment hits pre-crisis proportions	13	As a result of the of the financial crisis, 5000 people in the coal industry lost their job. The ABS reported on job growth from August 2008 to August 2009. Mining employment increased by 6990 to 45,795.	Over the period, most sectors showed little or negative growth. The biggest growth was in utilities which is supported by government spending. Mining growth is very much export oriented with China being the key customer.
Cost of living leaves some out in the cold	13	In the western Darling Downs towns of Miles and Chinchilla, rent and house values have climbed steeply as demand related to new mining projects grows strongly.	The coal mining industry creates demand for housing. High rents and housing shortages have been a feature of Queensland coal mining centres for decades
Miners Memorial Day	42	The government is hosting the second Miners Memorial Day to commemorate over 1450 miners who have died in mining tragedies.	The event has the effect of refreshing the public's and the mining industry's awareness of the hazards of mining and the need to be mindful of the need to effectively manage the risks.
Notification of Public Consultation - domestic gas market security of supply Qld Govt Ad	48	Department of Employment, Economic Development and Innovation is seeking comment on policy options. Should a proportion of production be put aside for domestic demand or should areas be set as reserves.	Coal bed methane production is growing strongly with several plants being constructed to supply gas for export. Drainage of methane is a key consideration in reducing the risk of fires and explosion in underground coal operations.
Cheap Qatar gas threat looms over state's suppliers	78	The growth in Queensland coal bed methane production may be curtailed by lower cost gas from Qatar being sold into the market.	Changing technology and high gas prices resulted in strong growth. Weakening prices and supply from other sources would slow growth and stop some projects.

The mining industry with its strong presence in rural and remote Australia has an opportunity to demonstrate its social responsibility by supporting Indigenous Australians.

In order to counter negative perceptions, mining industry associations such as the Queensland Resources Council (QRC), the Minerals Council of New South Wales and the Minerals Council of Australia regularly issue media releases outlining mining industry investments and commitments to community engagement.

6.5 INDIGENOUS AUSTRALIANS AND MINING

The mining industry with its strong presence in rural and remote Australia has an opportunity to demonstrate its social responsibility by supporting Indigenous Australians. For mining companies, key issues in relation to Indigenous Australians are native title, cultural heritage, indigenous employment and indigenous enterprises. In the coal sector, the Minerals Council of Australia, the Queensland Resources Council and the New South Wales Minerals Council assist their constituent mining companies with policy development and coordination in dealing with indigenous groups, the various levels of government and the justice system. The Federal Government and the Minerals Industry Council have signed a Memorandum of Understanding to work cooperatively to promote opportunities and welfare of Indigenous Australians by a wide range of employment, training and business development initiatives led by minerals companies (Minerals Council of Australia 2009).

For the most part, Indigenous Australians had been disenfranchised by the rural community long before the coal industry started seeking rights to extract coal. In 1992, the High Court of Australia recognised that, subject to conditions, Indigenous Australians may have a form of entitlements over their traditional lands. 'Native title is the legal recognition of Indigenous Australians' rights and interests in land and waters according to their own traditional laws and customs. Unlike land rights, native title is not a grant or a right that is created by governments. The High Court recognised native title for the first time in 1992, in what is known as the Mabo case. Native title is recognised and protected in Australian law by the Native Title Act 1993' (Department of Aboriginal Affairs 2009).

The development of effective systems to establish native title and resolve land access for exploration and mining has taken some time to evolve. The Federal Court has a role in resolving the extent to which a Native Title Group has title over a particular tract of land for which a claim is made. When title is established, processes have been established for mining companies to access land for exploration and mining purposes.

In the case of exploration and other temporary land uses, mining companies can seek to have 'Native title protective conditions' applied to gain speedy access to land for evaluation purposes. Where the feasibility study indicates that a mining lease should be sought to facilitate a mining operation, a more comprehensive Native Title Agreement may need to be negotiated with the Native Title group.

In Queensland, the lead agency that assists with Native Title compliance in the process of granting leases is the Department of Employment, Economic Development and Innovation which incorporates what was previously the Department of Mines and Energy. In New South Wales, the lead agency is the Department of Planning with support from the Department of Primary Industries and the Department of Aboriginal Affairs. The Department of Aboriginal Affairs monitors the development of native title policy in NSW, including the effectiveness of NSW Government agencies in their development and delivery of native title policy and services.

Mining companies also need to work with various groups of Indigenous Australians in ensuring compliance with the Cultural Heritage legislation was enacted by the Federal Government. A variety of Cultural Heritage legislation which has been enacted by most of the states including Queensland and New South Wales. Essentially, the legislation calls for cultural heritage monitoring systems that identify sites of significance and monitor that they are not adversely affected by mining operations or other related activity.

The importance of the cultural heritage legislation is that it obliges mining companies to develop a sensitivity to indigenous cultural issues and establishes a regular dialogue that is very important in gaining respect and trust that may be needed if more challenging issues arise in the future. This program is less likely to deliver employment opportunities and business partnerships than Native Title Agreements.

The publication 'Working with Indigenous Communities' warns that in dealing with Indigenous Australians, negotiating parties should not presume that Indigenous Australian have a western set of economic and social values. They are a society that has survived sustainably 'on their country' for 40,000 years. They had no written language, no complex numerical systems. Wisdom was passed down from generation to generation by word, song and dance undertaken with reference to 'their country'. They have not measured their wealth in terms of assets, but rather in the sustainable interaction of their extended family groups and the natural ecology of 'their country'.

6.5.1 CASE STUDY - WILPINJONG COAL PROJECT

The following case study is drawn from a paper presented by Robyn Williams at the 2008 Environment and Community conference of the New South Wales Minerals Council. Wilpinjong Coal Proprietary Limited (WCPL), a subsidiary of Peabody Energy Australia, announced that it wanted to mine a large reserve of thermal coal in the Wilpinjong area of the Upper Hunter Valley of NSW. Native title was lodged by an aboriginal party consisting of several clans, as the identified area contained a significant amount of Aboriginal Cultural Heritage, including 40,000 artifacts and 250 areas. This led to the negotiation to extract the coal resource with minimal impact to Aboriginal cultural heritage in the designated project area and the provision of tangible benefits to the North East Wiradjuri to compensate for suspension of Native Title over the affected land for the duration of the mining lease.

The Native Title Agreement was negotiated within 3 months to meet Wilpinjong Coal's (WCPL) obligations in accordance with Native Title Act 1992 and the NPWS Act 1973.

Free and open discussion was encouraged from the beginning leading to a spirit of mutual respect and friendship between Wilpinjong and Native Title groups. This mutual respect and a collective aim to achieve shared goals allowed both parties to work closely together to go beyond compliance of their individual obligations. Peabody, through WCPL, and the North East Wiradjuri representatives are working closely to achieve lasting outcomes that build capacity and improve living standards for members of North East Wiradjuri community and their descendants. WCPL assisted North East Wiradjuri community to establish corporate governance and best practice methodologies, including: business planning; legal advice; communication; infrastructure and execution of plans.

The Relationship was described as: "It's like a marriage – we have to make it work for at least 20 years". Another interested party commented: "We rarely refer to the Agreement to manage the partnership and build relationships. Genuine friendships have developed between the people involved".

The Aboriginal Cultural Heritage Management Plan formulated consists of: a protocol for consultation with local Aboriginal groups, a salvage program; provision of a keeping place for artifacts; a monitoring and management protocol; a schedule for a survey of the escarpment; baseline recording of Aboriginal rock art sites; general land management measures to protect Aboriginal cultural heritage, and details of Aboriginal cultural heritage training for project employees.

Community and company benefits of the Agreement include; training (TAFE, clerical, on-site operations); employment; business opportunities (such as Ulan house, an accommodation business) and transfer of land to the North East Wiradjuri post mining.

Signing Native Title Agreements, 12 December 2005.

6.6 COMMUNITY ENGAGEMENT

In a subtle way, the coal industry had a large number of cultural impacts in the Queensland and New South Wales communities. While most of the impacts have been positive, there is a recognition of a number of negative impacts. The general community and the coal mining industry in particular are starting to recognise the negative impacts and programs to address these negative impacts are identified.

From the very early days of coal mining, up until the development of the major transport systems developed in the 1970s for bulk coal handling, industrial towns were built around the coal fields with access to marine transport. Such industrial towns included Wollongong, Newcastle, Ipswich and Maryborough. While coal resources have been depleted around Ipswich and Maryborough, heavy industry is a key element of the Newcastle and Wollongong economies. These towns were centres for migration which initially featured migrants from Great Britain, followed in the 1950s by migrants from Europe and more recently migrants from Asia and Africa. The immigrants have brought with them, the rich cultural elements of their countries of origin and added significantly to the diversity of Australian cuisine.

With the 1970s construction of the major coal transport systems and bulk-handling ports, the Queensland Bowen Basin coal fields were developed to supply the international coal markets. The bulk coal terminals of Gladstone, Hay Point, Dalrymple Bay and Abbott Point were developed. These developments resulted in major expansions in the small rural Queensland towns of Moura, Biloela, Blackwater, Emerald and Collinsville as well as the purpose built mining towns of Moranbah, Dysart, Tieri and Glenden. The towns of Biloela and Emerald already had substantial populations that serviced the extensive regional rural activities. The development of coal mines caused land and house prices to rise sharply. Local business found access to workers difficult as the mines drew potential employees away with more attractive salaries.

In the purpose built mining towns, social conditions were more difficult for both the population and the mine management who effectively were responsible for the town operations. The narrow profile of the population caused the personal issues at the mine to flow into community and the personal issues of the community to flow into the work environment.

With the changing industrial landscape of the 1990s, there was wider spread of growth in the employment of contractors and an increase in the extent of 12 hour shifts and night work. These work arrangements also led to a growth of drive-in / drive-out operations where mine workers resided in camp style accommodation while working days-on and they could then have a coastal residence where they could stay on their days-off. The majority of mine workers found this arrangement very attractive and this led to a housing boom around Mackay and the Capricorn Coast east of Rockhampton.

From the very early days of coal mining, up until the development of the major transport systems developed in the 1970s for bulk coal handling, industrial towns were built around the coal fields with access to marine transport.

Mining companies are aware of the limited cultural diversity in the rural and remote areas and provide strong support for community activities. This support is reported in either cultural development reports or sustainability reports published by the mining company subsidiaries that operate in the various mining districts. Table 6.5 shows support provided by BHP Illawarra Coal for a range of sporting, cultural, wildlife and community activities.

Table 6.5 Case Study - Community Partnership Projects funded by BHP Illawarra Coal in 2007-2008 (BHP Illawarra Coal, 2008)

Organisation	Project	$ Funding committed
NSW Rail Transport Museum Rail Heritage Centre	Thirlmere upgrade	28,930
Appin Chamber of Commerce	Heritage signs in Appin	3,200
Wollondilly Rural Fire Service	Training defibrillator	1,500
Picton Public School	Outdoor classroom	1,507
Wollondilly Communication Brigade (Rural Fire Service)	Fireground repeater project	10,238
First Picton Scouts	Funding for Picton Scout hall	5,000
Life Education Australia	Sponsorship of Wollondilly Schools to visit mobile van	22,600
The Oaks Historical Society	Digital computer package	2,750
Appin United Soccer Club	Disabled toilet and awning at Appin AIS Sportsground	18,975
NSW Steam Preservation Co-op	Multimedia recording and artefact restoration	23,060
Wildlife Health and Conservation Centre	Koala tracking collars	8,910
Mt Kembla Translator Association	Contribution costs	11,500
Mt Kembla Mining Heritage	Event Coordinator for the Heritage Festival	16,000
Smiths Hill High School	Rock Eisteddfod	1,000
Figtree High School	Digital project equipment	7,000
Mt Kembla Scouts	Construction of a storage shed	3,935
Mt Kembla Mining Heritage	Studio 100 (Heritage Centre lease payments)	50,410
Total 2007 -2008		216,524

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7

Carbon Capture and Storage

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7.1 TOWARDS A CLEANER COAL

Coal currently attracts negative press because of the concern that this particular fossil fuel may have on the changing global climate. The emphasis is therefore on reducing carbon emissions. The concept of a “cleaner coal” is shifting in Australia towards “low emission coal technologies”. This shift also aligns itself with the new initiatives of the Australian Government via the National Low Emission Coal Council (NLECC), a partnership of the Commonwealth and State Governments, the coal and power industries and research providers. Carbon capture and storage (CCS) is considered as an essential aspect of meeting the low emission coal targets. This chapter addresses the efforts of the Australian community towards the development of CCS.

7.2 COAL POWER PRODUCTION IN AUSTRALIA

Australian energy production is heavily dependent on coal. Coal is the most abundant fossil fuel on the planet, with current estimates at 261 years recoverable reserves in Australia at current usage rates[1]. Coal will outlast oil and natural gas reserves by centuries, with suggestions that coal reserves will possibly last for over 500 years. Currently coal contributes about 40% of Australia’s energy requirements and predominantly as fuel for electricity generation, with approximately 81% produced from coal[2]. In terms of infrastructure, the coal extraction, transportation and power generation industry in Australia is well established. Coal reserves are located within 200 km of the eastern Australian capitals (Brisbane, Sydney, Melbourne) where large economic activity take place. In addition, Australia is a minerals processing based economy, thus requiring significant electrical power, in particular for the aluminium production sector. Therefore, the case for coal as the fuel of choice for base load electricity production in Australia is strong and it is envisaged to continue for the long haul.

The three major processes that can be utilised for coal power generation are air blown coal combustion, oxyfuel coal combustion and air and oxygen blown coal gasification. Air blown coal combustion is the most conventional coal power generation process and is predominant in Australia. In this process, coal as a pulverized fuel is injected into a boiler and combusted in excess air generating a flue gas stream containing ~15% CO_2 and ~84% NO_X. Oxyfuel coal combustion (Figure 7.2.1) is essentially the same process as conventional air blown coal combustion. The major difference is that an air separation unit is required in the front end of the plant to produce pure O_2 for coal combustion instead of an air blower. In principle, oxyfuel combustion generates in excess of 90% CO_2, which may need to be subsequently purified. Oxyfuel combustion generates excessive temperatures, so the flue gas stream is recycled back to the boiler, typically at a 70% rate to oxygen feed, to control the boiler temperature. Coal gasification (Figure 7.2.2), also called integrated gasification combined cycle (IGCC), is a process in which coal is gasified under pressure with air or O_2 and steam to make syngas (H_2 and CO). IGCC departs from the conventional power generation paradigm, as the plant can deliver, in addition to electricity, high value added products such as syngas for gas to liquids (see Chapter 8) for the production of fuels, and H_2 production for energy and transportation fuel cell systems.

The concept of a “cleaner coal” is shifting in Australia towards low emission coal technologies.

Carbon capture and storage (CCS) is considered as an essential aspect of meeting the low emission coal targets.

The three major processes that can be utilised for coal power generation are air blown coal combustion, oxyfuel coal combustion and air and oxygen blown coal gasification.

[1] British Petroleum (2002). BP statistical review of world energy, http://www.bp.com/centres/energy.

[2] Australian Government (2009) Energy in Australia 2009, Department of Resources, Energy and Tourism www.abare.gov.au.

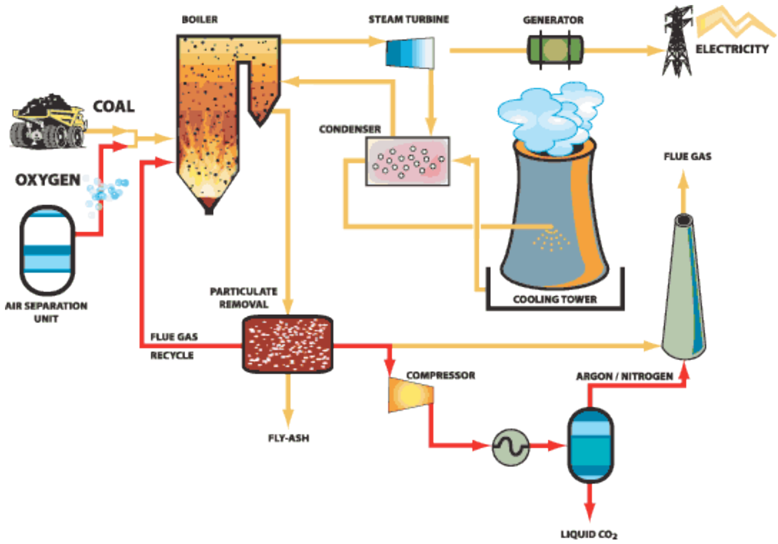


Figure 7.2.1 - Schematics of an Oxyfuel coal power plant[3].

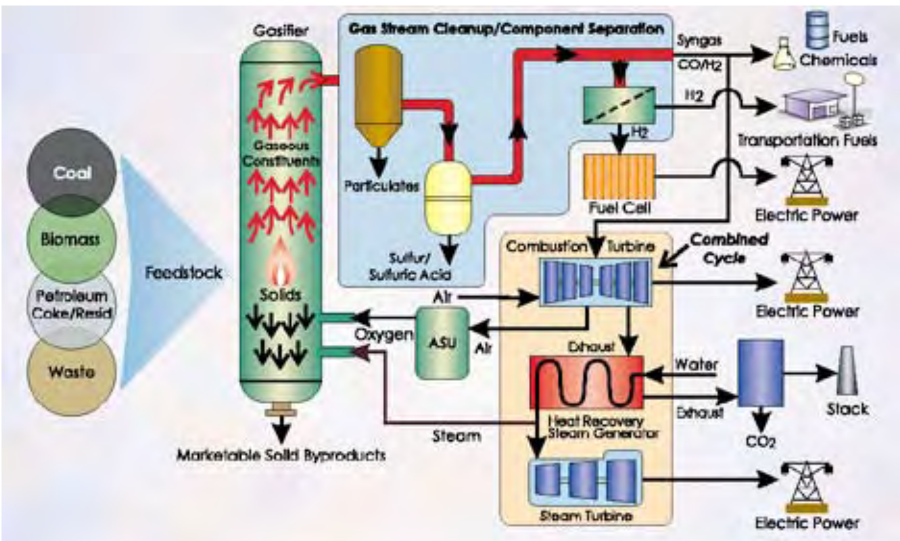


Figure 7.2.2 Schematic of an Integrated Gasification Combine Cycle (IGCC) power) IGCC plant[4].

[3] CCSC (2008) Factsheets: Oxyfuel combustion, www.ccsd.biz/factsheets/oxyfuel.cfm

[4] Source unknown but generally used by academics in Australia and in other countries.

7.3 CARBON CAPTURE TECHNOLOGIES

There are a number of low emission carbon technologies that can be integrated in the coal power processes described in section 7.3.1. The general thinking at the moment is to adapt current technologies to be retrofitted to coal power plants. An example is showed in Figure 7.3.2, where a carbon capture train based on chemical absorption technology is built at the back end of a coal power plant, generally called post carbon capture (PCC). This is an example of adopting a mature technology extensively utilised by the chemical and oil industries for over 60 years[5] and involves the employment of a regenerable solvent, generally mono-ethanolamine (MEA). The CO_2 absorbs to the solvent in a scrubbing tower and is subsequently stripped from the chemical solution by steam, thus releasing CO_2 of very high purity. There are also physical solvents such as the Rectisol, Selexol and Fluor solvent processes which have better deployment to capture CO_2 in pressurised syngas streams from IGCC processes.

There are a number of low emission carbon technologies that can be integrated in the coal power processes. The general thinking at the moment is to adapt current technologies to retrofit coal power plants.

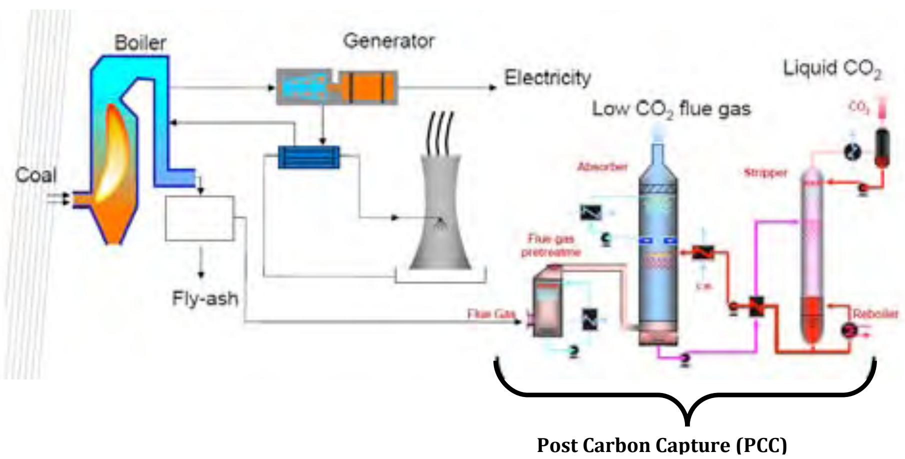


Figure 7.3.1 – Diagram[6] of a conventional coal power plant with a PCC train to capture CO_2.

Table 7.3.1 lists a number of technologies under consideration for coal low emission technologies. Although it is beyond the scope of this chapter to provide an in-depth analysis of these technologies, it is important to point out some general issues. The general principles of operation of these technologies are based on thermodynamic laws, which imply that heat and pressure are key operating principles. Therefore, many of these technologies are energy intensive and will reduce the efficiencies of coal power plants. They require processing gases at low or very low temperatures, or very high temperatures. As a consequence, energy will be used to cool down or heat up gas streams, or to compress or decompress gas streams. Some technologies will require adaptation to process flue gas, in particular flue gas that contains

[5] DTI (2003). Review of the feasibility of carbon dioxide capture and storage in the UK. IN: UK Department of Trade and Industry, Report DTI/ Pub URN 03/1261, pps 1-33.

[6] P. Feron, Post combustions CO2 capture R&D at CSIRO, APEC Clean Fossil Fuel Seminar, 15-17 October 2007, Xian, China.

deleterious substances such as mercury or sulphur oxides under certain conditions, which may be detrimental for the efficient operation of these technologies. Many of these technologies will have to process extremely large volume of gases, much larger than any industrial processes available. As a result, very large capture trains will have to be built which will potentially impact on capital and operating costs. There are other potential technologies that could also be employed as carbon capture systems. One example is biological fixation (e.g. algae) which is not considered in this chapter, as size estimates for a 500MWe power station are in the order of up to 100 km^2 and is considered too complex to manage.[7]

Table 7.3.1 – Potential low emission technologies for carbon capture.

Technology	Operating Conditions	Application		
Chemical Solvent	~40 to 120°C, at 1 bar.	PCC	Oxy	IGCC
Physical Solvent	-20°C, and pressurised CO_2 flue gas			
Chemical Looping	400 to 900°C, at 1 bar or higher.			
Pressure Swing Adsorption	<50°C at 1 bar or higher			
Polymeric Membranes	<50°C at 1 bar or higher			
Silica and Metal Membranes	500 to 600°C at high pressures.			
Perovskite Membranes	Up to 950°C at 1 bar or higher			
Cryogenics	<-50°C at low pressures.			

[7] IEA (2002). Solutions for the 21st century – zero emissions technologies for fossil fuels: technology status report. In: International Energy Agency, pp.12.

7.4 CARBON STORAGE

Australia was one of the first countries to initiate a continent-wide program to determine the potential use of geological storage for mitigation of emissions[8]. The GEODISC research program was set up via the Australian Petroleum CRC, which later become the CO_2CRC. By 1998, the GEODISK had considered 48 basins as viable sites for carbon storage study (out of > 300). In total, 102 sites were analysed and 65 were proved viable while 22 sites were not viable. Figure 7.4.1 shows that potential basins for carbon storage sites which are generally well spread around Australia. As a matter of fortuity, many of these basins are located around the coast in Australia and closer to major population areas and coal power stations. Current work shows that Australia has significant carbon storage capacity, of the order of 800 gigatonnes[9], and possibly in excess of 1600 years of Australia's total current emissions[10]. In other words, there is an excess carbon capture storage capacity by at least 1000 years, as coal resources are in the order of 261-500 years. Figure 7.4.2 shows the options for carbon storage in Australia. Apart from conventional storage, one option that is receiving a great deal of attention is carbon storage in unmineable deep coal seams. This option is very attractive in Queensland where coal seams contain more than 90% methane. Methane can be displaced from the coal seam by CO_2 injection, which preferentially adsorbs on carbon. There is a major advantage here, as carbon storage in deep seam coal unlocks methane, a valuable energy product. Hence, the economic case is very attractive for the CCS industry, and carbon storage as enhanced coal bed methane recovery can potentially realise an extra $20 billion[11] to the Australian economy (see chapter 8). There have been intense and aggressive take-overs of companies operating in methane recovery from shallow coal reserves in Queensland in 2008/9. It is likely that financial take-overs will intensify in the future once carbon storage becomes a reality.

Australia was one of the first countries to initiate a continent-wide program to determine the potential use of geological storage for mitigation of emissions.

Current work shows that Australia has significant carbon storage capacity, of the order of 800 gigatonnes and possibly in excess of 1600 years of Australia's total current emissions.

One option that is receiving a great deal of attention is carbon storage in unmineable deep coal seams.

[8] Peter Cook, Demonstration and Deployment of CCS and Storage in Australia, Energy Procedia 1 (2009) 3859-3866.

[9] J. Bradshaw, G Allinson, B.E. Bradshaw, V. Nguyen, A.J. Rigg, L. Spencer and P. Wilson, Australia's CO2 Geological Storage Potential and Matching of Emission Sources to Potential Sinks. GHGT-6, 6 (2002).

[10] www.apcrc.com.au/Programs/geodisc_res.html

[11] Massarotto, P., Rudolph, R., Golding, S.D., "Preliminary Feasibility Economics and Risks of CO2 Geosequestration in Coal Seams of the Bowen Basin, Australia"; GHGT-8, Trondheim, Norway (2006).

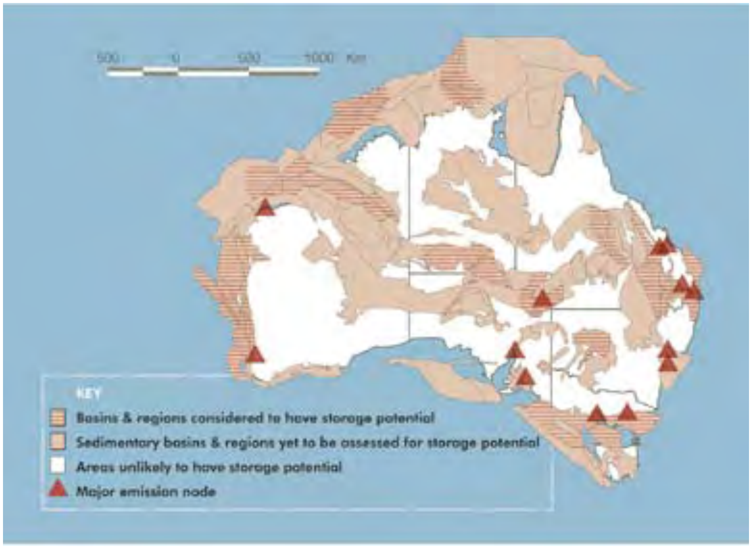


Figure 7.4.1– Potential carbon storage sites in Australia (source CO_2CRC)

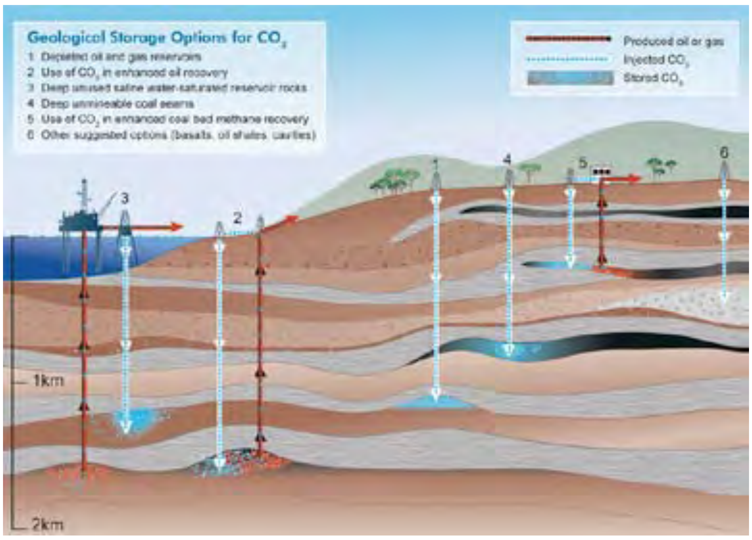


Figure 7.4.2 - Options for carbon storage in Australia (source CO_2CRC)

7.5 TECHNOLOGY PATH TOWARDS MEETING EMISSIONS GOALS

It Is currently possible to build a carbon capture-ready plant by using mature and aging technologies such as cryogenic, pressure swing adsorption (PSA), chemical and physical solvents and low temperature polymeric membranes. These technologies can be bought off the shelf and there is relatively large know-how for integration into coal power systems. In addition, the risk for industrial applications is low as these technologies have been fully developed to maturity for the last 15-30 years. However, these technologies operate at low temperatures, preferably below 50°C for chemical solvents and PSA, or mild sub zero to extremely low (<0 to -170°C) temperatures for cryogenic processes and are thus subject to significant energy penalties.

Another cluster of technologies include those at an embryonic or growth stage where the focus is on high temperature and high pressure applications. Many of these technologies have achieved laboratory proof-of-concept and scale-up work is in progress for perovskites, metal and silica membranes. The gaps for technology improvement are enormous as any one of these solutions or combinations thereof can provide technological breakthroughs. These technologies are therefore attracting worldwide governmental research and industrial R&D funds as the potential for technological advancement is high.

The Australian industry is currently seeking demonstration projects in order to meet carbon emission reductions. In this sub-section, potential carbon capture technologies are matched against coal power processes and the analysis takes into consideration four key factors:

- R&D phase: the technology is still being developed in the laboratory.
- Second generation: the technology is ready for scale-up and initial engineering design.
- Pilot trials: the technology has been tested at a pilot scale for at least 3000 hours.
- First generation: the technology is ready for demonstration as first of a kind (FOAK).

7.5.1 Air Blown Coal Combustion

Solvent extraction is likely to be the “first generation” technology ready for scale-up and power plant integrated demonstration. This is clearly shown by the three post carbon combustion (PCC) demonstration trains based on mono-ethanolamine (MEA) solvent scrubbing built by the CSIRO and currently being tested in Australian coal power plants. These technologies are energy intensive and it is likely that plant efficiencies will be reduced from the current best of 40% down to 30% of power plant output efficiency with carbon capture. Processing large volumes of flue gas having excess air will also be energy intensive for pressure swing adsorption (PSA) systems due to low temperature operating requirements (<40°C).

The Australian industry is currently seeking demonstration projects in order to meet carbon emission reductions.

Solvent extraction is likely to be the “first generation” technology ready for scale-up and power plant integrated demonstration.

In the case of polymeric membranes, the flue gas will have to be compressed or the permeate stream operated under vacuum to provide a driving force for the capture of CO_2.

Table 7.5.1 - Low emission technologies for air blown coal combustion process.

R&D Phase	Second Generation	Pilot Trials	First Generation
Novel solvents and novel solid sorbents	PSA and TSA, polymeric membranes, and polymeric + solvent membranes	Solvent extraction	Solvent extraction

All these modifications attract energy penalties. As these are mature technologies, the technical gaps are currently being directed to the development of novel solvents or solid sorbents tailor made to the flue gas properties and conditions. For instance, amine based solvents suffer degradation caused by high temperature (>120°C) in oxidising environments, like flue gas conditions and contaminants (SO_x and NO_x) generally need to be reduced to less than 10ppmv to minimise losses. Similarly high CO_2 sorption sorbents such as zeolite are significantly affected by water vapour which is a component of flue gas, while polymeric membranes undergo plasticisation and performance degradation.

7.5.2 Oxyfuel Coal Combustion

Cryogenic air separation is an energy intensive and aging technology, and is the "first generation" technology choice for demonstration. This is shown by CS Energy's oxyfuel coal power plant (30MW) currently under trial in Australia. The cryogenic process for air separation is expensive and energy intensive because it operates at very low temperatures (down to minus 200°C) and at elevated pressures. Coupling a cryogenic air separation unit at the front end of an oxyfuel coal power plant is likely to reduce power generation efficiencies from current best practice of around 40 to 30% points. In order to minimise these losses, ceramic membranes offer the potential to achieve energy savings and reduce O_2 production costs by 35% or more[12]. There is major support by the US Department of Energy for the development of perovskite membranes with Air Products and in the European community via the EU Seventh Framework (FP7) R&D program. Chemical looping combustion has been proposed though the development of stable metal oxides and is at an early stage of laboratory research.

Table 7.5.2 Low emission technologies for oxyfuel coal combustion.

R&D Phase	Second Generation	Pilot Trials	First Generation
Novel perovskite materials, chemical looping combustion	Perovskite membranes	PSA	Cryogenics

[12] R. Stiegel, "UD DOE-Important advances in gas separations for gasification applications", in: Separations Technology VI: New perspectives on very large scale operations, Oct. 3-8, 2004, Fraser Island, Australia.

7.5.3 Coal Gasification

Similarly to the previous coal power processes, coal gasification is likely to employ mature and aging technologies as first generation demonstration plants with CO_2 capture. Cryogenics will supply pure O_2 at the front end while physical solvent extraction will separate CO_2 from H_2 at the back end of the plant. The issues with energy penalties remain the same. As coal gasification operates at high pressures (~32 bar) and high temperatures (>400°C), these operating conditions favour the employment of embryonic technologies such as metal silica and palladium alloy membranes. In addition, syngas shifting and separation at the same time can be carried out in a membrane reactor as a single operating unit. Again perovskite membranes are an enabling technology of great interest for reducing energy use penalties and cost to supply tonnage O_2 to an oxygen blown coal gasifier. The technological gaps are related to developing novel materials, their fabrication and scale-up.

Table 7.5.3 Low emission technologies for coal gasification.

R&D Phase	Second Generation	Pilot Trials	First Generation
Metal membranes, novel metal alloys, novel perovskite materials, and chemical looping.	Pd alloy membranes, metal silica membranes, membrane reactors, perovskite membranes		Cryogenics and solvent extraction.

Currently a range of CCS technological options exist for the coal mining and coal power industries. There is no single best technology. The best CCS technology and power match will depend on the circumstances of each coal power generator.

7.6 TECHNOLOGICAL OPTIONS

Currently a range of CCS technological options exist for the coal mining and coal power industries. As a matter of fact, there is no single best technology, and the best CCS technology and power match will depend on the circumstances of each coal power generator. It is likely that mature and aging technology (e.g. chemical/physical absorption and cryogenics) will be employed as first generation carbon capture processes, though these technologies will attract incremental benefits only. There are several reasons for this approach. First, the risk for first generation technologies is low, thus making it easier for retrofitting to current plants. Second, coal power plants are major and expensive assets and power generators are likely to prefer the retrofitting option rather than building a new plant. Third, this follows a well known "learning by doing" strategy which provides the coal power generators with a pathway to technological improvements while reducing financial liabilities. However, first generation technologies are likely to attract large energy penalties, thus reducing coal power plant efficiencies from 40% down to 30%. This means that a coal power plant will have to burn 25% more coal per kW hour of power delivered. As a consequence and in addition to higher capital and operating costs of plant, the electricity cost may increase from around 53 US$/MWh to 93 US$/MWh[13] from a coal power plant with and without CCS, respectively.

In terms of industrial deployment, technologies must overcome the “hump cost” or sometimes called the “mountain of death” during demonstration.

The most logical option is to employ new and more efficient process to counter balance efficiency losses such as “ultra-supercritical coal power plants” or coal gasification Integrated Gasification Combine Cycle (IGCC) plants which can reach efficiencies up to 50%. To make the case economically feasible, cost estimates for generic plants[14] indicate that IGCC plants with carbon capture have lower costs than coal power plants with carbon capture and that IGCC has a greater potential for cost improvements with accumulated experience. In comparison to an oxyfuel coal power plant of the same output, an air separation plant required for IGCC will be three times smaller in its output, thus reducing major energy penalties associated with air separation. Coal gasification operates at high pressures (~32 bar) and high temperatures (>400ºC). These operating conditions favour the employment of embryonic technologies such as metal silica and palladium alloy membranes, which are currently the subject of much research.

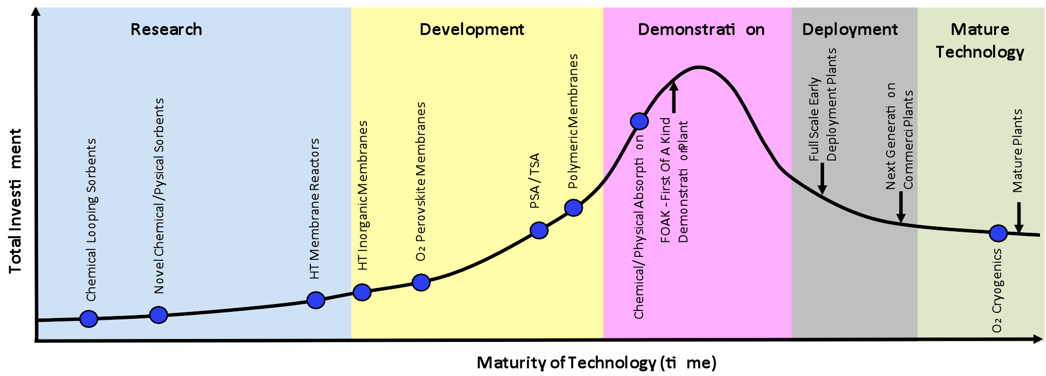


Figure 7.6.1 - Maturity vs. total investment for technologies[15].

Technology development is driven by the promise of increased performance of a system, usually through efficiency improvements, which reasonably balances benefits against costs. For early stage or novel technologies, there is a significant risk associated with the probability of a technology successfully maturing toward an operational state as a function of time. The progress of each CCS technology towards maturity for industrial carbon capture versus total investment is displayed in Figure 7.6.1. In terms of industrial deployment, technologies must overcome the “hump cost” or sometimes called the “mountain of death” during demonstration. This means that costs of technology will increase since conception at the research stage, and will escalate during demonstration. From there, learning by doing will bring the cost down until the technology reaches maturity. In our opinion, chemical/physical absorption processes are the closest technology for deployment as CCS systems, though not yet over the hump cost.

[13] Davison, J., Thambimuthu, K., An overview of technologies and costs of carbon dioxide capture in power generation, Journal of Power and Energy, 223 (2009) 201-212.

[14] Rubin,E. S.,Yeh, S., Antes, M.,Berkenpas, M., and Davison, J. Use of experience curves to estimate the future cost of power plants with CO2 capture. International Journal of Greenhouse Gas Control, 1 (2007) 188–197.

[15] Adapted from: M. C. Duke, B. Ladewig, S. Smart, V. Rudolph, J. C. Diniz da Costa, Assessment of Post Combustion Carbon Capture Technologies for Power Generation, Frontiers of Chemical Engineering in China, - DOI 10.1007/s11705-009-0234-1.

7.7 AUSTRALIA AT THE FOREFRONT OF CCS

Australia has a strong tradition in CCS research, and the work championed by the CO_2CRC has been recognised by the CCS community in International Greenhouse Gas conferences and other meetings to be in the forefront of carbon storage research. This does not mean that Australia holds excellence in all CCS areas, but the concerted effort of the Australian CCS community in the areas discussed below are well recognised indeed. One of the major vehicles that allowed Australia to progress very well in CCS research was the creation of Cooperative Research Centres (CRC) programs by the Australian Government. The CRC programs' coal and CCS technologies have attracted over $250 million in research funding while other initiatives by the Australian Government and industry are leading expenditure in excess of $1 billion. The most relevant CCS research and industrial projects are addressed below.

The CRC programs' coal and CCS technologies have attracted over $250 million in research funding while other initiatives by the Australian Government and industry are leading expenditure in excess of $1 billion.

7.7.1 CCSD – CRC for Coal in Sustainable Development

The CCSD CRC started its life as the CRC Black Coal and was funded to the total amount of $100 million[16], but closed its operation mid 2008 after 14 years of operation. The initial focus was on specific technical aspects common to black coal power generation, with a strong focus on combustion, coal properties and coal gasification. The CCSD alliance partners are listed in Table 7.7.1. Upon renewal, the new CCSD incorporated new programs to bridge its mission towards environmental protection and sustainable utilisation of resources. These included more fundamental studies on environmental mercury measurement, wet pound fly ash leaching and cleaner production. In the later operating years, the CCSD focussed on oxyfuel coal combustion, a research project which was fully supported by CS Energy's Callide oxyfuel coal power plant (30 MW) trial program.

Table 7.7.1 – CCSD alliance partners.

Government	Industry	Research Providers
CRC Australia, Australian Government, Queensland Government (Natural Resources and Mines)	BHP Billiton, Rio Tinto, Xstrata, Coal & Allied, Premier Coal, ACARP, Delta Electricity, Western Power, CS Energy, Stanwell Corporation and Tarong Power.	The Universities of: Queensland, Newcastle, New South Wales, Curtin University of Technology, Macquarie University and CSIRO.

[16] CCSD (2008), Achievement s 2001-2009 Report, CRC for Coal in Sustainable Development, Brisbane, Qld, Australia.

7.7.2 CO_2CRC – Greenhouse Gas Technologies CRC

The CO_2CRC has established an international reputation in the area of carbon storage. It started its life as the CRC for Petroleum (first 7 years), where it carried out a large assessment of potential carbon storage sites in Australia via the GeoDisc programs. This work was further expanded via the newly formed CO_2CRC in 2003 with $100 million funding through new programs investigating geological modelling, CO_2 mineralisation modelling and risk analysis of CO_2 storage among many other research projects. In addition, the CO_2CRC included a new stream in carbon capture research including projects in polymeric membranes and contactors, carbon capture adsorbents, novel PSA systems and modelling, hydrates and CCS costing. The latter involved the development of capex and opex costs for carbon capture, transportation and storage. In 2009, the CO_2CRC re-bid was successful for a third, seven year term. Although the new programs will be known in due course, it is likely that chemical looping and carbon storage in deep coal seams will be part of the new research projects.

Table 7.7.2 – CO_2CRC alliance partners

Government	Industry	Research Providers
CRC Australia Australian Government, Geoscience Australia, Australian Greenhouse Office, Department of Industry, Tourism and Resources	BHP Billiton, Rio Tinto, Xstrata, ACARP, Stanwell Corporation, NZ Resource Consortium, Shell, BP, Chevron Texaco, Schlumberger, Woodside Petroleum	The Universities of Melbourne, Monash, New South Wales, Queensland, Curtin University of Technology, Adelaide University and CSIRO.

7.7.3 cLET – Centre for Low Emission Technology

The cLET operated from 2005 to July 2009. The research program was specifically designed to focus on enabling technologies for coal gasification and funded for a total of $15 million. Of particular attention, the cLET program focussed on the development of high temperature and high pressure syngas separation (membranes for H_2 separation), syngas processing (catalysts and membrane reactors for the water gas shift reaction), gas cleaning (high temperature particle and mercury capture), coal gasification (coal properties), and coal gasification design and costing. The cLET also had an interesting side research program, in particular surveying the attitudes of the Australian community on carbon capture, a non-technical area that warrants attention due to the transient views of society.

Table 7.7.3 – cLET alliance partners

Government	Industry	Research Providers
Queensland Government	ACARP, Tarong Power and Stanwell Corporation.	University of Queensland and CSIRO.

7.7.4 Global Carbon Capture and Storage Institute

The Global Carbon Capture and Storage Institute (GCCSI) was established in 2009 by the Australian Government as an independent entity whose key mandate is to accelerate the deployment of commercial scale CCS solutions around the world. Still in its infancy, the GCCSI has more than 100 foundation members including national governments, corporations, NGOs, trade organisations and research institutes. The Australian government has pledged annual funding of up to $100 million. Its major contributions will be through accelerating CCS demonstration projects and working with NGOs to support and promote capture, transport and storage projects in addition to raising community awareness. The GCCSI was supported by governments of Britain and Norway and major multinational companies signed up as founding members: Peabody Energy, Xstrata Coal (Australia), Shell International Petroleum (UK), Rio Tinto Ltd (Australia), Mitsubishi Corporation (Japan), Anglo American (South Africa), Services Petroliers Schlumberger (France), Alstom (France), and The Climate Group.[17]

7.7.5 Low Emission Technology Demonstration Fund (LETDF)

In 2005, the Australian Government announced the LETDF funding of $500 million, while matching funds of at least two dollars for every LETDF dollar was expected by the government. For instance, the coal industry also announced a levy on every tonne of coal produced, which provided a fund of $100 million a year for ten years for demonstration of “clean coal” technologies. The LETDF round of applications closed on 31st march 2006. A total of $340 million of public funds were granted to four projects in CCS, triggering an accumulated investment of just over $2 billion[18] as follows:

- Chevron’s Gorgon CO_2 Injection Project. Public funding is $60 million of a total project cost of $841.3million.
- CS Energy: Oxy-firing demonstration and carbon sequestration project. Public funding is $50 million of a total project cost of $188 million.
- HRL Limited: 400 MW Integrated Drying Gasification Combined Cycle (IDCC) Clean Coal Demonstration Project. Public funding is $150 million of a total project cost of $750 million.

The Global Carbon Capture and Storage Institute (GCCSI) was established in 2009 by the Australian Government as an independent entity whose key mandate is to accelerate the deployment of commercial scale CCS solutions around the world.

To date, there are more than 100 founding members including national Governments, corporations, industry NGOs, trade organisations and research institutes.

[17] International CCS Technology Survey, Australia Governmental Programs and Strategies, Issue 4, December 2008.

[18] International CCS Technology Survey, Australia Governmental Programs and Strategies, Issue 4, December 2008.

The COAL21 partnership was formed by an initiative of the Australian Coal Association with the coal and electricity industries, unions, Australian and State Governments and the research community.

The COAL21 initiative clearly demonstrates the seriousness of the coal and power industries to fund major CCS projects to achieve lower emissions.

- International Power: Hazelwood 2030 (Lignite Drying with Post Combustion Capture). Public funding is $80 million of a total project cost of $369 million.

7.7.6 Coal21

The COAL21 partnership was formed by an initiative of the Australian Coal Association (ACA) with the coal and electricity industries, unions, Australian and state governments, and the research community. The Coal 21 Action Plan was launched in 2004, as a blueprint for accelerating the demonstration and deployment of low emission technologies.[19] The action plan roadmap is shown in Figure 7.7.1, where the status of CCS technologies and know-how were considered from evaluation through pilot, demonstration and commercial plants. The delivery timeframe for these projects has been revised by at least 5 years.

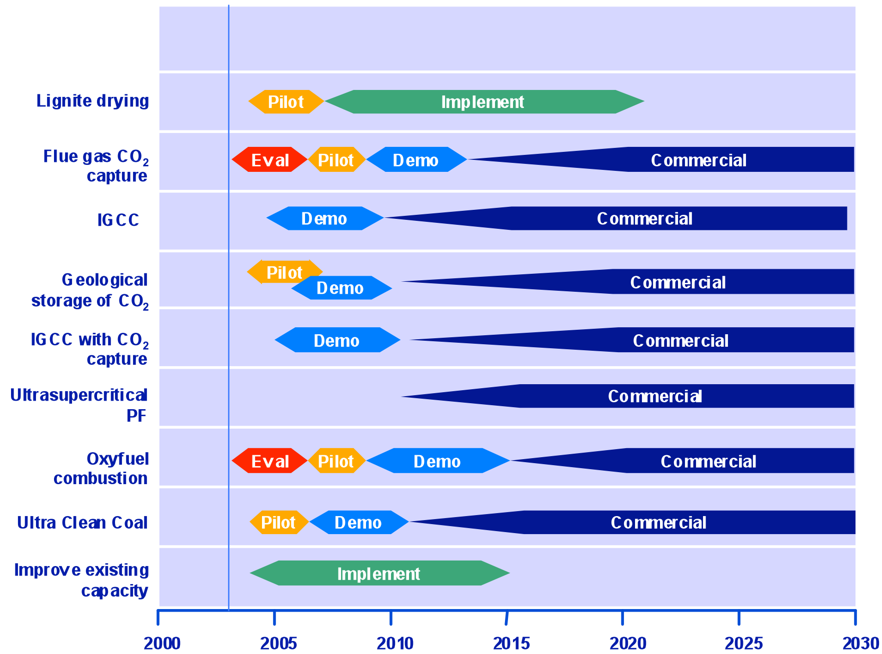


Figure 7.7.1 – Coal 21 Action Plan Roadmap 2004.

To support this initiative, a voluntary levy $0.20 per tonne of coal on its members was set up. The original levy of A$300 million has now increased to A$1 billion to develop CCS over the next 10 years . Over the last two years, Coal 21 have provided funds of just over $500 million for support of LETDF approved projects such as the Callide Oxyfuel Plant and the IGCC project in Queensland, in addition to Queensland geosequestration initiatives, PCC demonstrations in New South Wales, and the newly formed National Low Emission Coal Council (NLECC). The Coal 21 initiative clearly demonstrates the seriousness of the coal and coal power industries to fund major CCS projects to avert climate change.

[19] Coal 21 - www.australiancoal.com.au/coal21

[20] www.coal21.com.au/Media/COAL21%20Fund%20Announcement.pdf

7.7.7 National Low Emission Coal Council (NLECC)

The NLECC was set up by the Australian Government with a mandate to support R&D for commercial demonstrations by 2015. This initiative is to support a possible reduction of CO_2 emissions by 60% by 2050. The Australian Government is providing $75 million for a period of 5 years, with the expectation of another $2 from the industry and state governments for every LECC $1, making a total funding of $225 million. The Coal 21 initiative is providing $75 million to the NLECC. The R&D programs will be aimed at accelerating demonstrations and early commercial demonstrations, thus targeting near term deployment of CCS technologies. The industry is particularly looking at technologies called "First of a Kind", defined as pre-commercial demonstration. These are likely to be first generation technologies. The major driver of the R&D program to be considered will be focussed in reducing technical and commercial risks.

The final R&D model has yet to be approved. However, a preliminary model has been put forward where the proposed funding for the R&D programs are: Economic modelling and review (10%), Alternative & Fundamental (10%), Brown Coal (10%), Capture – PCC (10%), Oxyfuels (10%), Coal Gasification (10%), Storage (30%) with additional funding for Administration (5%) and Contingency (5%). It is expected that the NLECC will be fully operation late 2009 or early 2010.

7.7.8 Research Providers

There is significant research activity in Australia supporting the commitments of the Australian Government to reduce the emission of greenhouse gases. The most relevant and best equipped research providers are the CSIRO and the Universities Low Emission Coal Consortium (ULECC) which is an alliance between the Universities of Queensland, Melbourne, Monash, Newcastle, New South Wales, Western Australia and Curtin. These research providers have been major players in the CRC programs, and also are members of the new NLECC. They have considerable expertise in all areas of coal characterisation, air and oxy combustion, gasification, gas cleaning, gas separation, reaction, control, modelling, control and diagnostics, carbon storage, geological formation, geo-chemistry, economics, optimisation and intensification, among many other areas relevant in CCS processes. In addition, these research providers have a strong international network of collaborators in Europe, North America and Asia. This provides an ideal platform to work on common CCS problems.

The industry is particularly looking at technologies called "First of a Kind", defined as pre-commercial demonstration.

The major driver of the R&D program to be considered will be focussed in reducing technical and commercial risks.

There is significant research activity in Australia supporting the commitments of the Australian Government to reduce the emission of greenhouse gases.

Twelve CCS projects involving the capture and/or storage of carbon dioxide in Australia are currently proposed or underway.

The deployment of carbon storage projects appears to be more advanced then carbon capture projects.

7.7.9 Current Demonstration

Twelve CCS projects involving the capture and/or storage of carbon dioxide in Australia are currently proposed or underway[21]. Many of these projects are funded by the Australian and state governments, and the Australian Coal Association. Also, very importantly, there is a strong alliance mainly in CO_2 storage with international oil companies such as Chevron, BP and Shell, and oil consultants such as Schlumberger. In addition, the deployment of carbon storage projects appears to be more advanced then carbon capture projects. Table 7.7.3 presents a list and bred description of the major CCS projects currently underway in Australia[22].

Table 7.7.3 Major CCS projects currently underway in Australia

Project	Description
Callide Oxyfuel Coal Power Plant, by CS Energy in Queensland	30MW oxyfuel coal plant for power generation and CCS of approximately 30,000 tonnes of captured CO_2. The project is expected to cost A$206 million and involves an international collaboration between partners CS Energy, IHI, Schlumberger, Mitsui, J-Power, and Xstrata, with extra funding from the ACA and the Australian and Queensland Governments.
CO_2CRC Otway Project, Victoria:	Injection of 150 tpd CO_2 from a nearby gas well into a depleted gas field at began in April 2008, with an injection target of up to 100,000 tonnes of CO_2 over two years. A major program of monitoring and verification has been implemented. The A$40 million project, which is supported by 15 companies and 7 government agencies, involves researchers from Australia, New Zealand, Canada, Korea and the US. CO_2CRC Pilot Project Ltd, the operating company, includes AngloCoal, BHP Billiton, BP, Chevron, Schlumberger, Shell, RioTinto Solid Energy, Woodside and Xstrata. Additional financial support is provided by the Australian Government, the Victorian Government and the US Department of Energy.
Coolimba Power Project, Western Australia	A feasibility study is underway by Aviva Corporation Ltd into the possible construction of 2 x200MW coal power capture ready plants. Sequestration sites are being sought for the storage of about 3Mtpa of CO_2 for up to 30 years.
FutureGas Project, South Australia	Gasification of lignite to syngas for the production of synfuels, including a CO_2 captured post-gasification to be stored in the Otway Basin. A feasibility study and an environmental impact study will be completed by 2011.

[21] P. Cook, Demonstration and Deployment of CCS in Australia, Energy Procedia 1 (2009) 3859-3866.

[22] Adapted from Cook (2008) and International CCS Technology Survey (2008)

Project	Description
Gorgon Project, Western Australia	Chevron (operator), Shell and Exxon are planning a major sequestration project linked to the Gorgon LNG Project. A total of 125 million tonnes of CO_2 will be injected over the life of the project, at a rate of 3.3 million tpa. The total cost of the project is estimated of the order of $15-20 billion with the storage component being of the order of $1 billion.
Loy Yang CSIRO Project, Victoria	The Loy Yang CSIRO project involves retrofitting a pilot-scale mobile PCC facility, capturing up to 1000 tpa CO_2 using an amine-based solvent
CO_2CRC H3 Capture Project and Hazelwood Capture Project, Victoria	Hazelwood power station will capture and chemically sequester CO_2 at a rate of 10,000 – 20,000 tpa of CO_2 using solvent technology.
Mulgrave Pre-combustion Capture Project, Victoria	CO_2 emissions will be captured from HRL's research gasifier at Mulgrave in a pilot-scale capture project. Partners include CO_2CRC and HRL with funding from the Victorian Government.
Monash CTL Project, Victoria	A multibillion dollar project proposal designed to exploit the source-sink match involving the brown coal resource of the Latrobe Valley (Victoria) and the CO_2 storage potential of the off-shore Gippsland Basin. The proposal involves gasification of brown coal to produce syngas to be converted into a range of liquid products. Excess CO_2 extracted and injected into storage of approximately 15 million tpa. Monash Energy is a joint development of Anglo American and Shell Gas and Power.
Moomba Carbon Storage Project, South Australia	Capture of CO_2 from existing gas processing facilities and injection of one million tonnes of CO_2 to re-pressurise oil reservoirs for enhanced oil recovery. Partners in this project include Santos and Origin.
Tarong PCC Project, Queensland	A research scale retrofit PCC pilot project using ammonia absorption process to capture up to 4000 tonnes of CO_2. Partners involved in this project are Delta Electricity, CSIRO and the ACA.
ZeroGen Project, Queensland	The Queensland Government, ACA and industry partners (Shell was the previous partner, but possibly Mitsubishi at the moment) and Zerogen propose 'ZeroGen Mark II', a two stage coal gasification and CCS project. Stage 1 (demonstration) will be a 80 MW net plant. The CO_2 will be captured and transported approximately 220km by pipeline for storage in the Denison Trough. For stage 2, a 300 MW net coal gasification plant is planned.

The Otway CO2 capture and storage project at Cape Otway, Victoria. (CO2CRC)

China is now believed to be the world's largest CO_2 emitter with more than 3 billion ton CO_2 per year, surpassing the United States in 2007. In order to maintain strong economic growth, China is building a significant number of coal power plants, equivalent to 24.3 GW per year, or almost 50% of the world's new coal power plant capacity. These reasons makes a strong case that there will be no carbon management goals achievable without CCS technology. It is therefore important that China and India are included in the carbon management goals.

7.8 CCS TECHNOLOGY IS KEY TO EMISSIONS CONTROL IN CHINA AND INDIA

China and India are the two most populous countries in the world and currently facing development unprecedented to their economies. As a result, people are becoming affluent requiring more resources and energy. China has built within the last 20 years an enviable industrial structure becoming one of the world's industrial powerhouse. India is also showing similar sign of aspirations.

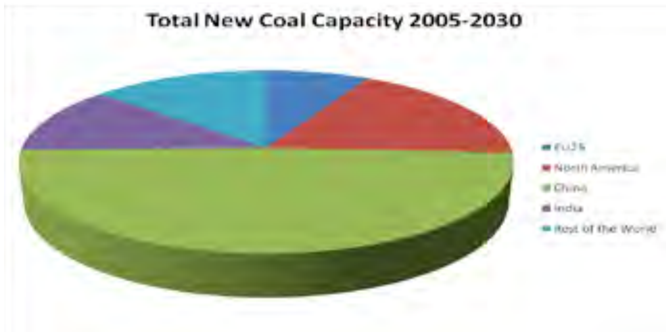


Figure 7.8.1 -New coal plant capacity projected to be built 2005-2030 (GW).[23]

A further point is that capital has no frontiers, and world's multinationals have moved production plants to China to take advantage of lower-cost, efficient labour, while environmental regulations are arguably less restrictive than those in the Western world. China is now believed to be the world's largest CO_2 emitter with more than 3 billion ton CO_2 per year, surpassing the United States in 2007.[24] In order to maintain strong economic growth, China is building a significant number of coal power plants, equivalent to 24.3 GW [25] per year, or almost 50% of the world's new coal power plant capacity as shown in Figure 7.8.1. Although in a small scale, India's new coal power plant capacity are nonetheless significant, equivalent to 5.8 GW per year or 12.5% of the world's new coal power plant capacity. These make a strong case that there will be no carbon management goals achievable without CCS technology. It is therefore important that China and India are included in the carbon management goals.

Although there are parallels between China and India, there are also some significant differences. Worldwide, the cost of constructing a power plant is cheapest in China because of the low-cost Chinese steel in addition to low-cost labor[26]. Therefore, it is more cost effective to develop CCS demonstration plants in China. The European Commission (EU) has been supporting research, development and demonstration of CCS projects in China through initiatives such as the EU-China Near Zero Emissions Coal (NZEC). The EU has supported the demonstration of CCS in China "to exploit the economies of scale and ensure that, once demonstration is completed, deployment could happen at scale, if all challenges of deployment are adequately addressed."[27]

[23] Same as reference 22.

[24] International CCS (Carbon Capture and Storage) Technology Survey. Report prepared for Gassnova by Innovation Norway Issue 3 July 2008.

[25] Future of Coal Carbon Abatement Technologies to UK Industry URN/738, Final Report to the Department of Energy and Climate Change, December 2008.

[26] Clean Coal Power Generation Technology Review: Worldwide Experience and Implications for India , World Bank 2008, Background paper , India Strategies for Low Carbon Growth.

[27] European Commission, Demonstrating Carbon Capture and Geological Storage (CCS) in emerging developing countries: financing the EU-China Near Zero Emissions Coal Plant project, (2009) Communication from the Commission to the European Parliament.

India has a large portion of old and inefficient coal power plants which will need significant upgrades. Being the 6th largest CO_2 emitter in the world.[28] India needs the assistance of other more developed countries to allow them to develop CCS. Clean Development Mechanism (CDM) Projects have been proposed in developing countries such as India. The World Bank is funding Coal-fuelled Generation Rehabilitation Projects in India to help modernise old and polluting coal power plants so that they can supply cleaner energy[29] and ready them for participation is CCS Schemes. The prices of power plants in India are between OECD and Chinese prices.[30]

Although India has signed the Kyoto Protocol in 2002, it is exempt from the framework of the treaty and therefore not obliged to reduce emissions of greenhouse gases. In the Indian Government's Eleventh Five Year Action Plan (2007-2012)[31] they state "*they would focus on efforts to ensure that the emissions intensity of India's GHG continues to decline.*" One interesting aspect is that many parts of India are seismically active which may hinder the acquisition of suitable storage sites not prone to leakage.[32] Nevertheless, China has also significant seismically active regions, though it is expected that the CCS research development and demonstration plants in the short-term will be mainly concentrated in China rather than India.

7.9 PROJECTION OF NUMBER OF CCS JOBS BY 2020

The number of CCS jobs created in Australia or overseas by 2020 is difficult to predict. First one must define what is a 'carbon capture and storage job'? Will it be different from the jobs currently available in the coal industry? What training will be required to re-skill or upgrade the current workforce in the coal industry in Australia. However, one point that it is certain is that CCS will reduce plant efficiencies in the short term from 40 to 30% as discussed above. This means that to maintain the same base power load, up to 25% additional coal will have to be burnt. Hence, this will at least add extra jobs for the coal mining sector.

One important aspect of CCS implementation is the support of the working unions in Australia. For example, the Construction Forestry Mining Energy Union (CFMEU) National President Tony Maher says that rapid demonstration of CCS in Australia is essential to securing employment prospects in regional Australia and jobs in coal mining and jobs in new high-tech CCS power plants.[33] An example of this is the recently proposed $1.25 billion coal-fuelled power station (Galilee Power) incorporating CCS technologies, where it is anticipated that 1,000 jobs would be created during construction of the power station and more than 60 permanent positions once it was operating. By applying the same investment to employment factor, the current projects supported by the Low Emission Technology Demonstration Fund (LETDF: see section 7.7.5) worth over $2 billion may provide 2000 new jobs.

One important aspect of CCS implementation is the support of the working unions in Australia.

The recently proposed $1.25 billion coal fuelled power station (Galilee Power) incorporating CCS technologies may initially create up to 1000, new jobs and more than 60 permanent jobs when operating.

[28] Helland, Jens and Anantharaman, Rahul (2009) Carbon capture and storage (CCS) options for co-production of electricity and synthetic fuels from indigenous coal in an Indian context; Energy for Sustainable Development 13, 56–63

[29] India Coal Fired Generation Project World Bank, http://www.worldbank.org.in/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/INDIAEXTN/0,,contentMDK:22216279~pagePK:141137~piPK:141127~theSitePK:295584,00.html#f1

[30] Clean Coal Power Generation Technology Review: Worldwide Experience and Implications for India , World Bank 2008, Background paper , India Strategies for Low Carbon Growth ,

[31] Indian Government Planning Commission 2008, Eleventh five year plan 2007-2012. Chapter 9.2 Environment and Climate Change. Page 206 http://planningcommission.nic.in/plans/planrel/fiveyr/welcome.html

[32] Dadhich, Pradeep Kumar , Potential for CCS in India, Opportunities and Barriers. http://www.un.org/esa/sustdev/sdissues/energy/op/ccs_egm/presentations_papers/dadhich_presentation.pdf

[33] http://www.qrc.org.au/_dbase_upl/ACA_Media_Release_160408.pdf

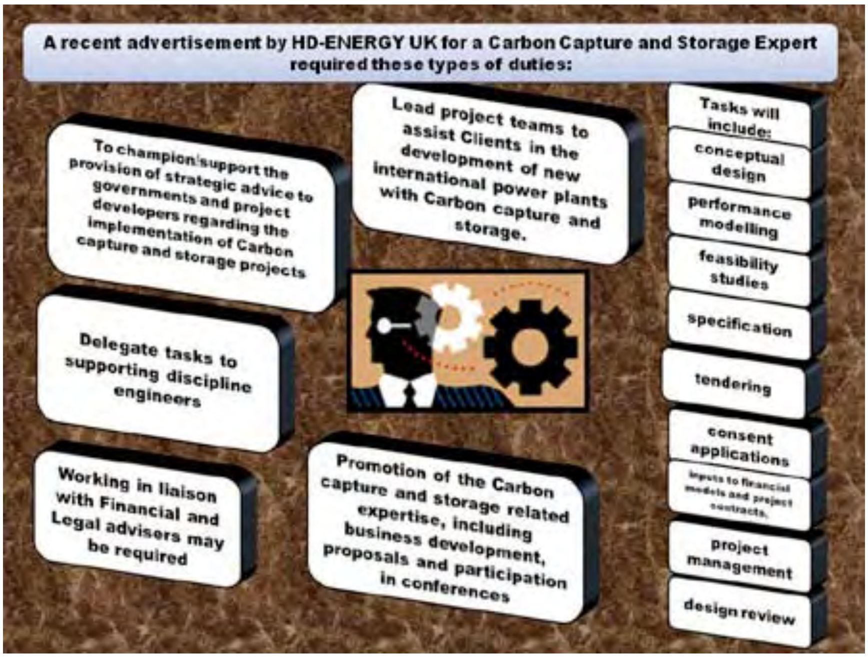
It is possible that the pre-implementation CCS programs in Australia may create up to 5,000 jobs.

These jobs will come from the areas of geology, engineering, management, government and service sectors.

The potential scale of the other non-LETDF funded projects (section 7.4.9) is also immense and very possibly will deliver more than 2,000 new jobs. By taking into account 30% flow on effects due to the creation of indirect jobs, it is possible that the pre-implementation CCS programs in Australia may create up to 5,000 jobs. This figure may increase significantly once CCS becomes a reality. Perhaps the infrastructure and construction sectors will be the biggest beneficiaries in employment creation derived from CCS activities.

It is expected that a large number of jobs will be created in the areas of geology, engineering, management, government and service sectors. This may include project managers, policy advisers, client liaison, conceptual designers, economic modellers, financial and legal advisers, business development among many other expertises as shown in Figure 7.9.1 that will be required by the CCS industry. Currently Australia has no formal training in CCS. However the Universities Low Emission Coal Council (Queensland, Melbourne, Monash, New South Wales, Newcastle, Western Australia and Curtin) are discussing new masters programs as part of the new National Low Emission Coal Council initiatives.

Figure 7.9.1 - What is a CCS Job?



The United Kingdom has a number of postgraduate degrees in CCS. The University of Edinburgh offers a Masters of Carbon Capture and Storage led by the School of Geo Sciences, in which carbon storage is a major component. The Universities of Nottingham, Birmingham and Loughborough (hereinafter called UNBL) consortium offers an Engineering Doctorate (Industrial) in carbon dioxide capture as part of a large capacity building programme awarded by the British Government via the Engineering and Physical Sciences Research Council (EPSRC) with further sponsorship from Industrial and Energy Companies. The program entails the graduation of 50 Engineering Doctorates in the next 7 years.[34]

Similarly, the United States has already taken steps to ensure they have a well trained workforce in carbon capture and storage. In August 2009, the United States Department of Energy announced training programs allocated to US universities worth approximately 8.47 million over 3 years.[35] The training activities will focus on the applied engineering and science of carbon capture and storage for site developers, geologists, engineers, and technicians, providing a technology transfer platform for carbon dioxide (CO_2) sequestration. The selected awards will produce the workforce necessary for the CCS industry with skills and competencies in geology, geophysics, geomechanics, geochemistry and reservoir engineering disciplines.

7.10 CONCLUSIONS

The Australian Government, Australian Coal Association and industry currently provide significant support for the development of CCS technologies. Australian investments in research surpassed $250 million, while 12 CCS demonstration programs are worth in excess of $1 billion to date. Australia has significant carbon storage capacity in excess of the current coal resources of 261-500 years, of the order of 800 gigatonnes or 1600 years. Carbon capture demonstration plants are adopting energy intensive first generation carbon capture technologies. As a result first generation CCS coal power stations will have to burn 25% more coal, possibly doubling the cost per kW of power generated. The upside is that more jobs will be generated, in particular for the mining sector to produce more coal. Although very difficult to predict, employment growth due to CCS investment could be as large as 5,000 new jobs in Australia during demonstration projects. China is currently the biggest CO_2 emitter in the world and is undertaking a remarkable expansion of its energy program, possibly planning to build up to 50% of the worlds new coal power plant capacity. India has old and inefficient coal power production plants and most likely will require world aid to upgrade their energy infrastructure. Although both countries are in seismically unstable regions, in the short-term demonstration plants are likely to be concentrated in China rather than India.

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The United Kingdom currently has a number of postgraduate degrees in CCS.

The United States has also taken steps to ensure they have a well trained workforce in CCS.

[34] J. C. Diniz da Costa (2009), The Landscape of CCSM Education in the UK, International Energy Agency Greenhouse Gas Programme, Report 2009/TR5.

[35] http://www.rdmag.com/News/Feeds/2009/08/energy-department-of-energy-announces-more-than-84-milli/

Coal's New Frontiers

8

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Faculty of Engineering, Architecture and Information Technology, The University of Queensland.

Coal does not have to be mined in order for it to be exploited. One way is to extract the methane gas that is contained in the coal; another is to gasify the coal in its underground location, converting it into a product gas which can be used as a chemical feedstock or fuel for power generation.

8.1 INTRODUCTION

Most energy from coal comes from burning it for heat or to generate electricity. But coal can be transformed quite readily into the other main energy sources that people use: liquid fuels and gas. Since there is much more coal than oil or natural gas, and coal is available in many more countries, converting coal into these products – and the petrochemicals that are made from them - has significant attraction.

Furthermore, coal does not have to be mined in order for it to be exploited. One way is to extract the methane gas that is contained in the coal; another is to gasify the coal in its underground location, converting it into a product gas which can be used as a chemical feedstock or fuel for power generation. The underlying objective is to avoid the cost and environmental impacts of conventional mining, while still accessing the energy value of the coal.

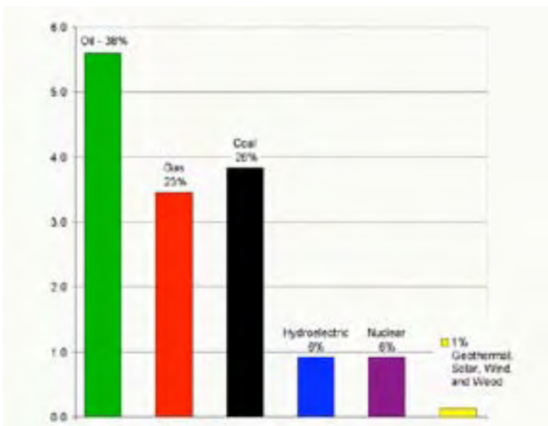
8.2 COAL SEAM GAS

8.2.1 Overview

By far the most abundant hydrocarbon on earth is methane, a molecule made of one carbon atom combined with four hydrogen atoms (CH_4). This important fossil fuel is used as a feed material for energy and chemicals, and is also widely reticulated for domestic heating and cooking. It is a key part of the global energy supply and is one of the cleanest, safest, and most useful of all energy sources. Gas provides about a quarter of the current global energy requirement of around 0.5 ZJ.[1]

Electricity generation from methane, for example using gas turbines, produces less carbon dioxide than other fossil fuels because a high proportion of the released energy comes from the hydrogen contained in the methane, which is turned into water. Also, the energy content of methane (per unit mass) is the highest of all hydrocarbons.

Figure 8.2.1 World energy supply by source (EIA Annual Energy Review)



[1] (1ZJ = one thousand billion billion Joules), 10^{21}J

Currently most natural gas is obtained from conventional gas reservoirs, often associated with oil, but an important emerging source is the methane that is contained in coal seams.

The total amount of methane contained in coal globally has been estimated to be about equal to the conventional natural gas resource, namely around 10ZJ.

The total amount of methane contained in coal globally has been estimated to be about equal to the conventional natural gas resource, namely around 10ZJ.

8.2.2 Origins of coal seam gas

Most methane in natural gas including coal seam gas is a fossil fuel just like oil and coal, and was formed from the remains of ancient life on earth: the plants, animals and micro-organisms that existed many millions of years ago. These were transformed over time into coal, oil or gas, the fossil fuels that we see today. To form methane, this transformation occurred either through chemical reactions (called thermogenic methane) or by the action of micro-organisms which used the organic matter as food and made methane as part of their metabolism (called biogenic methane). It is also more controversially theorised that methane is formed from hydrogen and carbon deep within the earth, predating life (called abiogenic methane) and possibly still occurring.

Thermogenic methane

The thermogenic transformation of organic matter into fossil fuel requires its exposure to high temperatures and pressures over a long time. When the ancient plants and animals died their remains were covered over with mud and silt and became buried. This overburden of material lying on top of the organic matter produced the pressure required for thermogenic breakdown. The temperature is provided either by volcanic action, the higher temperature that exists deep below the surface, or by chemical reactions in the material, for example spontaneous combustion. Some commentators distinguish between "metamorphic" (due mainly to sedimentary burial and spontaneous reactions) and "thermogenic" (heated and transformed by volcanic action). For conventional natural gas (mostly from marine organisms) higher temperatures result in more gas. The deeper in the earth's crust, the higher the temperature, so that most often natural gas is found at greater depths than oil. Higher rank coals, which are formed at higher temperatures, mostly contain thermogenically generated methane.

Coal seam methane usually forms in stages. After dead plant material accumulates any oxygen in the sediments is consumed by aerobic bacteria.

When the oxygen is exhausted anaerobic bacteria start to produce methane.

Biogenic methane

Natural and coal seam gas can also be formed from plants by methane producing micro-organisms as part of their food cycle. These organisms mostly live quite near the earth's surface and although a large proportion of the gas generated is lost by seepage into the atmosphere, the remainder often forms a significant part of the methane that is retained in coal seams. The extent of methanogenisis depends on many factors including the water content of the coal, water salinity, microbe-accessible porosity, and coal permeability. Methane production may occur in all ranks of coal and over many millions of years and there are active microbial communities in present day coals.

Coal seam methane usually forms in stages. After dead plant material accumulates any oxygen in the sediments is consumed by aerobic bacteria (those that use oxygen for respiration). When the oxygen is exhausted anaerobic bacteria start to produce methane. As the coal is buried under further layers of sediment and the temperature increases above 105°C the micro-organisms find the conditions increasingly difficult and thermogenic processes take over from biogenic. As the temperature increases water, carbon dioxide and nitrogen are lost from the coal matter and the rank is increased. At higher temperatures, more methane is evolved, peaking at around 280°C, but still occurring in smaller amounts at much higher temperatures. As erosion and other geological evolution brings the coal nearer to the surface again, it cools off and microbial activity may start again. In general, the methane in lower rank coals is mostly of biogenic origin and in higher rank coals it is thermogenic.

Abiogenic methane

A third way in which methane in natural gas is believed to be formed is through abiogenic processes. According to this hypothesis, hydrogen and carbon occur deep within the earth and may form methane as they move towards the surface. Support for this argument is provided by observations of extra-terrestrial methane (for example on Uranus and its moons) where life is unlikely to have evolved. Also, laboratory tests have shown that the mechanism is possible under conditions that exist inside the earth's crust. The hypothesis of abiogenic hydrocarbon formation is not very widely supported by contemporary petroleum geologists who do not consider this contributes appreciably to normal coal, oil and gas systems, although many natural scientists believe that life evolved from a "primordial soup" which was composed in large part of methane.

8.2.3 CSG in Australia

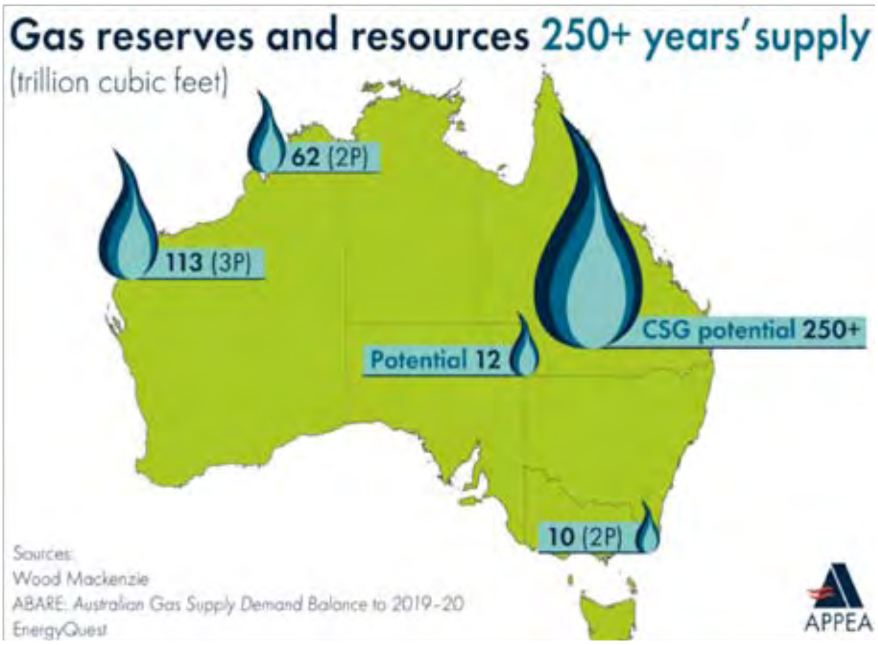


Figure 8.2.2: Gas Reserves and Resources as of June 2009 (Queensland Resources Council, 2009)

Large parts of Australia are known to contain vast amounts of coal, most of which might also be expected to contain methane gas. The Australian coal seam gas (CSG) total resource in place has been estimated to be 12 Gtoe[2], which may turn out to be a very conservative estimate. Reserves already booked, that is explored and mapped, by mid-2009 (at the 3P level of confidence) exceed 800million tonnes (Mt). By any way of counting this represents a huge resource compared with current Australian gas production of about 45Mt/y, used both domestically and for export and mostly sourced from natural gas. The Queensland Resources Council estimates the CSG resource at in excess of 250 years' supply (see Figure 8.2.2). Origin Energy — presently Australia's largest CSG producer — considers producible CSG to be between 300-600 million tonnes, or about ten times Australia's present annual natural gas production.

Before 1996 there was no production of CSG in Australia and even by 2003 there was only 20 PJ[3]. Very rapid growth has followed though, to 75 PJ in 2006, 110PJ in 2007 and the equivalent of 167 PJ/y in the last half of 2008, or more than half of Queensland gas production.

With the recognition of Australian CSG prospects as amongst the best in the world, a significant rationalisation in the CSG industry in Australia has taken place since 2007 as large international gas companies including BG, Conoco-Phillips, Petronas and Shell invested more than $15 billion to acquire access and stakes in Australia's CSG future.

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The Queensland Resources Council estimates the CSG resource at in excess of 250 years' supply.

[2] Gtoe: Gt of oil equivalent. A giga tonne is 1billion tonnes. Since different sources of energy (eg different ranks of coal, gas,oil etc) have different energy contents, it is convenient to quote amounts on a common basis, usually "oil equivalent" to bring the measurements to a common energy content basis.

[3] 1PJ=1 million billion Joules, 10^{15}J

Australia is now widely recognised as having one of the most progressive and innovative CSG industries in the world.

A number of projects to export CSG from Gladstone as liquefied natural gas (LNG) are currently in development, likely to make this one of the major export hubs of LNG in Australia.

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A number of projects to export CSG from Gladstone as liquefied natural gas (LNG) are currently in development, likely to make this one of the major export hubs of LNG in Australia. These could see CSG production increase many fold and rival Queensland thermal coal in terms of export revenues.

8.2.4 History of CSG

The existence of gas associated with coal has been known as long as coal has been mined, mainly because of the explosion, poisoning and suffocation hazards that "damp" (the gas in various forms) posed to miners. Even today, coal mining remains a hazardous occupation in developing countries, with accidents associated with gas outbursts, explosions and suffocation, although these dangers have been mostly eliminated in modern mining in the developed world.

The first attempt to capture and pipe gas from a coal mine was in England in 1773 and from that time until quite recently, interest in coalbed gas production was directed at mining related gas releases. However, the focus switched around 40 years ago with some production testing for methane extraction as a product in the Black Warrior basin in the US, followed by more extensive development by the Gas Research Institute in the US, a decade later. This was largely motivated by concerns at that time regarding security of supply and generous tax incentives from the US government. The enormous reservoirs of gas that were stored in coal were revealed and the outcome was to demonstrate the economic viability of CSG (coalled methane) in the US. This subsequently encouraged commercial CSG development worldwide. CSG is now widely viewed as a reliable and relatively inexpensive source of energy, and is extensively exploited in the US, Australia and many other countries.

Early attempts to exploit CSG in Australia did not meet with success despite considerable investments, due largely to direct use of inappropriate well technologies mimicking US practices, a concentration on coals having high gas content, without appreciating the importance of permeability, and a lack of sufficient understanding of the unique geological conditions in Australia (Riley, 2004). The industry was assisted in Queensland by a State mandate in 2000 that 13% of electricity should come from gas as a greenhouse gas reduction measure.

The initial gas targets were the eastern Bowen and Sydney basins. The discoveries at Comet Ridge on the western side of the Bowen basin, was a significant turning point having the very desirable combination of large gas reserves and good production rates. The Fairview and Spring Gully gas fields exploiting this area are now considered amongst the best CSG prospects in the world. Exploitation in other areas quickly followed, applying many innovative techniques to overcome the issues which had thwarted the earlier attempt, extending into the eastern and northern Bowen basin and then also into the Surat basin where a large region from Roma to Dalby was quickly identified as suitable for CSG production. Other coal basins which have received attention from CSG companies include the Gunnedah, Gloucester, Galilee, Murray and Perth basins, with exploration in more remote areas in central Australia. Even lignite (very young coals in the Otway Basin in Victoria) has become a target for CSG exploration. Lignite coal deposits generally have very low gas content, but this may be compensated by very thick seams and high permeability.

8.2.5 CSG environmental impacts and concerns

CSG developments have a reduced number of environmental impact factors to consider when compared to coal mining. The wells themselves are quite sparse, typically half to one kilometre apart. Drilling is done by light rigs, since the well depth required is not very great, usually 200-1000m. The surface equipment, or headgear, for a well is small (see Figure 8.2.3), and the gas gathering and mains pipes are usually buried. Nevertheless, access requirements by gas companies to explore and develop CSG resources, maintain equipment and for water disposal, may clash with land owners' farming rights.

Figure 8.1.3 CSG wellhead

A large region from Roma to Dalby was quickly identified as suitable for CSG production. Other coal basins which have received attention from CSG companies include the Gunnedah, Gloucester, Galilee, Murray and Perth basins.

Coal seams are attractive targets for sequestration of CO_2 because they have a large storage capacity and the sequestered CO_2 can increase the recovery of coal seam gas by displacing the methane.

The revenue from increased methane production can offset the costs associated with CO_2 capture and storage.

Most CSG wells require dewatering, often producing large amounts of water. This water is generally saline and unsuitable for direct use for livestock or agriculture and represents a significant challenge for the industry. The water is collected in large holding dams, with evaporation and reinjection being the main methods of disposal, both subject to environmental regulation. Small quantities are treated by reverse osmosis, providing drinking quality water, but the cost is prohibitive for large scale deployment.

Minor impacts include gas lost or flared during the well establishment phase and CO_2 that may be scrubbed out and vented to atmosphere for wells that contain CO_2 in significant concentrations. These, along with any gas losses during processing or transport, all represent greenhouse gas loads. Since methane has a warming potential about 21 times greater than CO_2, even small emissions are material. There may also be opportunity for contamination of aquifers by gas-migration through vertical fissures or seepage loss to the surface, but the engineering methods used effectively eliminate this risk.

8.2.6 CO_2 Geosequestration in coal

As described in the previous chapter, one method for sequestering carbon dioxide (CO_2) is to store it in natural geological formations. Coal seams are attractive targets for sequestration of CO_2 because they have a large storage capacity and the sequestered CO_2 can increase the recovery of coal seam gas by displacing the methane (called CO_2 enhanced CSG recovery). A significant advantage is that the revenue from increased methane production can offset the costs associated with CO_2 capture and storage. In normal reservoirs a large proportion of gas is not recovered because it becomes uneconomical when the pressure is too low. By injecting CO_2, the remaining methane is pushed out, while simultaneously, the CO_2 is adsorbed by the coal.

Coal has a large capacity for the CO_2, and most coals can hold five or more times CO_2 compared with the mass of methane recovered. This inherent affinity together with the demonstrated gas-tight character of the reservoir (the CSG has been held there over millions of years) means that the risks associated with long term storage or accidental leakage are minimal. An additional benefit is that the infrastructure for gas recovery for the methane may be used for the CO_2 injection, with some reworking, which reduces the costs, environmental impacts (eg for access ways) and compliance requirements.

Even if the coal is subsequently earmarked for future mining, the CO_2 may simply be drained out again for storage elsewhere, before mining commences. There may be substantial economic advantages to placing CO_2 in such 'temporary' storage depending on the length of time before mining starts and the discount rates that are applied to the time value of money. The large CO_2 emitters, namely power stations, are often in close proximity to the coal areas, reducing the need for long distance pipe networks.

8.2.7 CSG primer

Almost all the methane stored in coal is adsorbed, that is held inside the tiny pores in the coal, like a sponge holding water. Because of adsorption, the coal can hold about six times more methane than a natural gas reservoir of the same volume, and at much lower overall pressure. The coal also contains many small cracks, through which the methane can be extracted and recovered.

To recover the methane, a well, usually about 200mm in diametre, is drilled into the gas bearing coal seam, usually from 100-1000m below the surface (see Figure 8.2.4). Very shallow coal has often lost most of its gas by evaporation to the atmosphere, and deep coal is often too expensive to exploit. The well is lined with a steel pipe for most of the distance to prevent the methane that is removed from the coal dissipating away into porous ground structures, and the steel pipe is cemented into the well. Inside the coal seam, the well is completed, to maximise the methane extraction and recovery.

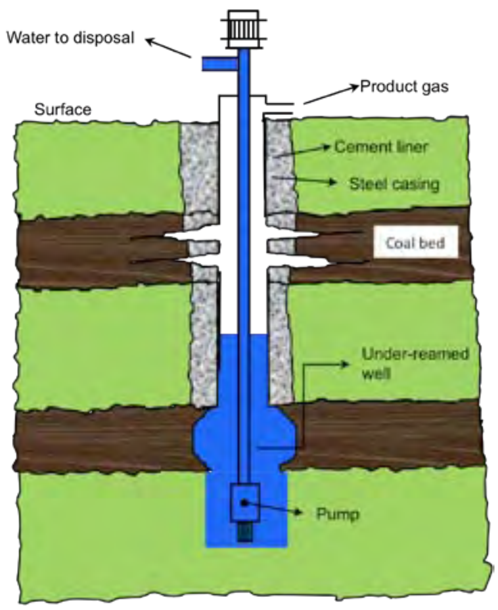

Figure 8.2.4 CSG well arrangement

Horizontal drilling is more expensive than vertical wells, but a single horizontal well accesses a much larger amount of coal and produces more gas since it drains a much larger area.

There are different completion methods, for example most simply just leaving the end part of the well open and exposed to the coal seam (called an open hole completion), by reaming (using a special drilling tool that expands to drill a bigger diametre hole in the coal seal, typically 400mm or more) to increase the active area of the well, or by creating a cavity of 3m or more in diametre at the bottom of the well. The coal may be fractured at the bottom of the well, by pumping in a high pressure fluid like water or air to open up the natural cracks in the coal and improve gas recovery rates. These cracks can extend tens or even hundreds of metres into the coal seam.

A well often penetrates a number of seams of coal separated by rock. These are all produced together using perforated pipe where the well passes through the seams. In some cases vertical wells are drilled into the coal and these drain an area with a radius of several hundred metres around the well. If the coal is very permeable, ten wells can be widely spaced: for less permeable coals they need to be closer together. Often it is advantageous to drill an open hole within the coal seam using steerable drilling, often for hundreds of metres. Horizontal drilling is more expensive than vertical wells, but a single horizontal well accesses a much larger amount of coal and produces more gas since it drains a much larger area (Figure 8.2.5).

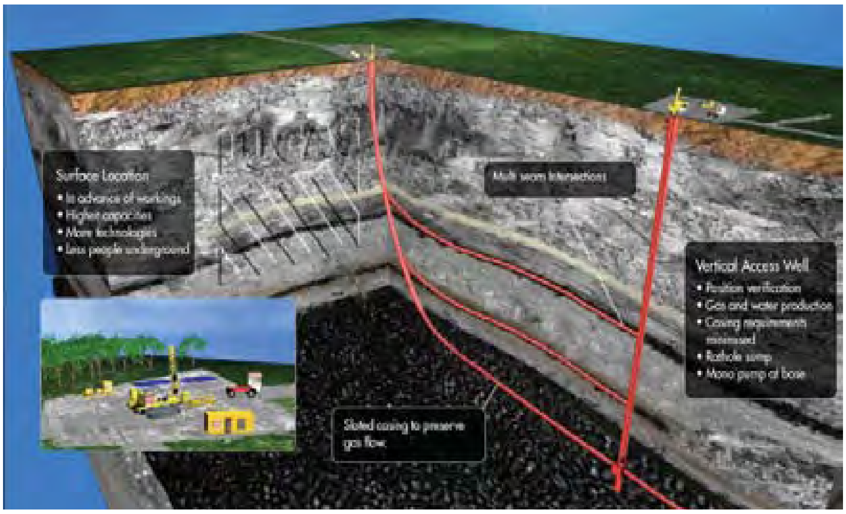

Figure 8.2.5 CSG wellhead

A number of such wells may be drilled from a single position on the surface, in various patterns such as a chevron or wagon wheel, or connected together to a single production well.

The methane is recovered by depressurising the coal seam through the well to the surface, lowering the water table, a process that involves pumping out large amounts of water. As pressure in the seam is reduced the methane is desorbed and recovered out of the well, separated from any water that is carried with it, dried and compressed for sale. There is usually an extensive network of low pressure (eg around 1 atmg) gathering pipes on the surface, connecting the wells to a centralised drying and compression plant.

Producers look for a combination of properties for commercial CSG systems, most importantly:

- High gas content in the coal, with laterally continuous and thick coal seams or a series of seams; in combination these indicate that there is a good total volume of gas available for recovery; and
- High permeability, which means that there are a lot of cleats and cracks though which the gas can flow out of the coal to the well, ensuring that the gas can be recovered easily and at high rates. The permeability affects the number and spacing of the wells that need to be drilled to drain a gas field.

Whereas extraction of CSG simply exploits the methane that is available naturally in coal, the bulk of the coal is left unused. UCG seeks to exploit a greater proportion of the coal without mining it, but rather by reacting it in place into gas.

UCG converts coal in the ground, into syngas which can be used for power generation or the manufacture of hydrogen, synthetic natural gas or transport fuels.

8.3 UNDERGROUND COAL GASIFICATION

8.3.1 Overview

Whereas extraction of CSG simply exploits the methane that is available naturally in coal, the bulk of the coal is left unused. Underground coal gasification (UCG) seeks to exploit a greater proportion of the coal without mining it, but rather by reacting it in place into gas which can then be further transformed into useful products.

UCG converts coal in the ground, into syngas which can be used for power generation or the manufacture of hydrogen, synthetic natural gas or transport fuels. The syngas can be relatively easily processed to remove environmental contaminants, including importantly the CO_2 contained in it, providing a stream of clean gas and a stream of CO_2 ready for sequestration. UCG may be applied to otherwise unrecoverable coal (eg because the seams are too thin or deep or otherwise unsuitable quality for mining). This would serve to extend useful coal resources by 3-6 fold. For example a demonstration in Australia by Linc Energy showed a 95% recovery of the coal resource, with 75% total energy recovery – a larger amount than can be recovered by mining.

Gasifying coal is the process of reacting the solid coal with oxygen and water to form, predominantly, carbon monoxide, hydrogen, carbon dioxide and methane. This is well established technology and many different gasifiers have been developed and several hundred installed for conducting this reaction using mined coal within vessels on the surface. In underground (or in situ) coal gasification, the reaction is conducted within the coal seam itself (see Figure 8.3.1). A number of wells are drilled into the coal seam, some acting as injection wells and some as production wells. The reactants, typically air or pure oxygen separated from air, are injected into the coal seam to create an underground fire. Water is provided either from the underground formation itself, or injected as steam in order to participate in and also control the reaction, which produces the CO, CO_2 and H_2 product gas. The reaction occurs at high temperatures, around 120^{0}C, and the product gas is extracted through the producing wells. By managing the injection of oxygen and water, the rate of gas production and the progression of the reaction zone are controlled.

The hot zone of coal around the reaction site and the hot gas passing through the coal regions in the wells causes the coal to devolatilise releasing methane and other hydrocarbon gases, which increases the heat value of the gas which is produced.

Another gasification technique, Hydogasification, has been extensively investigated by the Institute of Gas technology in the US under the name HYGAS, and also favoured by, for example, the Japanese after a three-year evaluation study by NEDO (Japan). This process is based on the reaction of coal with hydrogen at high pressures and temperatures. This produces methane directly and has thermal efficiency of close to 80%, but requires additional surface plant to convert some of the methane that is produced to hydrogen for the process. While the development programs were concerned with surface reactors, the method can be adapted to UCG conditions and may provide advantages, but is at a much earlier stage of development than the syngas route. Methane is the product gas, so the process is most suitable when synthetic natural gas is desired. Since the underground hydrogasification reaction requires high pressures, the system generally requires deeper coal seams, eg 800-1000m, than the syngas route, which is typically done at depths of 100-500m. A conceptual scheme is shown in Figure 8.3.2.

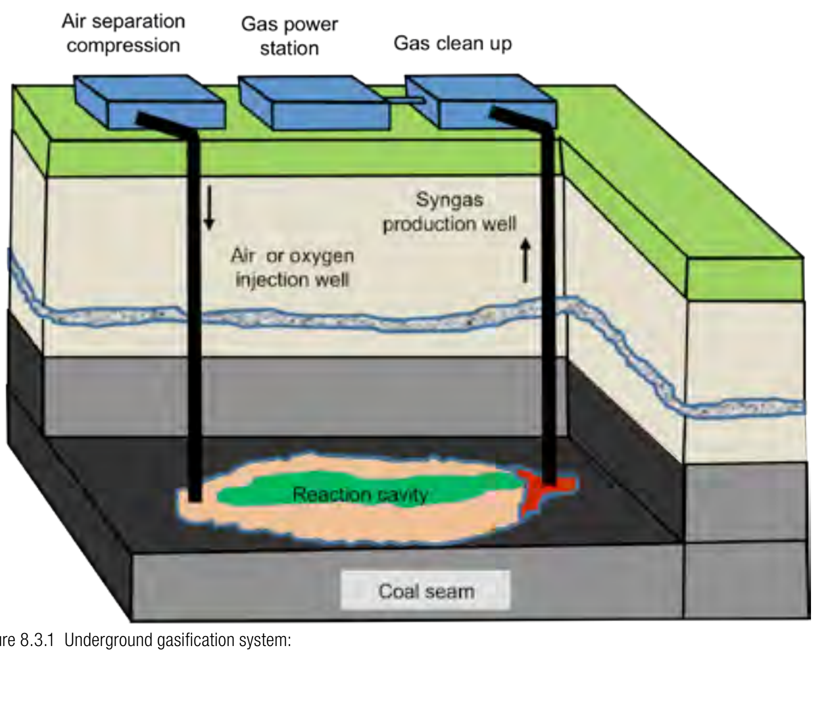

Figure 8.3.1 Underground gasification system:

UCG was used in the former Soviet Union in a number of commercial projects, including an electric power plant in Uzbekistan that has seen nearly 50 years' of operation.

Australia has three pilot trials in progress, all located in Queensland.

In UCG oxygen or air is injected into an underground cavity created in the coal seam and combustion occurs. Water, usually from within the coal seam, or injected in from the surface, partially quenches the combustion and the resulting gases – the syngas – are extracted to the surface for cleanup and use.

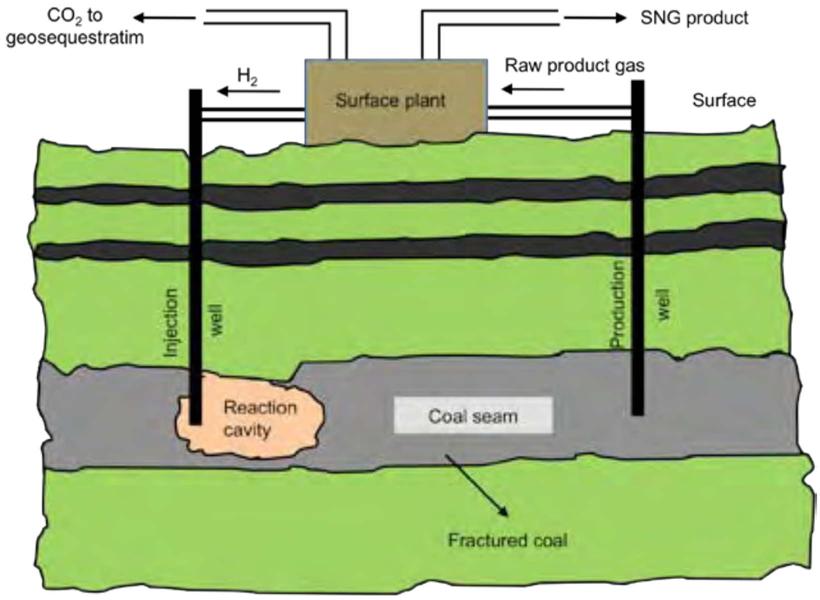

Figure 8.3.2 methane mining (underground hydrogasification)

8.3.2 History of UCG

UCG was used in the Former Soviet Union in a number of commercial projects, including an electric power plant in Uzbekistan that has seen nearly 50 years' of operation.

The US conducted around 30 pilot scale tests between 1975 and 1996, on all kinds of coals including bituminous, sub-bituminous and lignites. It has a number of commercial processes in development. China has conducted many tests also and has several commercial UCG projects for chemical and fertiliser feedstocks, and is building a large facility to make liquid fuels and power. There are a variety of commercial proposals that have been announced in Canada, South Africa, India, New Zealand and Vietnam.

Australia has three pilot trials in progress, all located in Queensland, the number temporarily limited by legislation. One near Chinchilla is operated by Linc Energy and started in 2000. This produced syngas for several years and was cycled through a number of controlled startup and shutdown operations. A Fischer-Tropsch plant has been constructed and has started operation on the site, in order to make liquid fuels including diesel, petrol and aviation gas from the UCG syngas. The UCG process is based on the technology developed in the former Soviet Union. Carbon Energy is conducting a UCG trial at Bloodwood Creek also using air, with a view initially to a 5MW power plant and extension to 20MW. Carbon Energy is using CSIRO developed technology using the knife edge CRIP method (controlled retraction injection point). Cougar Energy has commenced a test burn near Kingaroy as a prelude to a planned 400MW power plant. Its UCG process is a proprietary technology from a Canadian based company, Ergo Exergy. The method is based on and derived from the former Soviet Union experience.

8.3.3 Benefits and challenges with UCG

There is currently a great deal of interest in UCG because of the opportunities to reduce costs. These arise because there is no need to mine or transport the coal or build a surface plant for gasification and ash handling.

The benefits are reported to be:

No need to mine the coal or build a surface plant for gasification.

- Elimination of the safety hazards associated with underground coal mining.
- The syngas product can be used in a variety of industrial processes including power generation, liquid fuel production and chemical manufacture.

Significant environmental benefits, such as

- reduced surface disturbance and land use conflicts (compared with coal mining and oil and gas operations),
- avoidance of greenhouse gas production associated with coal mining,
- a relatively small footprint area for large amounts of energy extraction
- the technology is appropriate for greenhouse gas reductions
- Approximately 25% less greenhouse gas emissions compared with coal fired power stations.
- Potential UCG sites are often suitable for carbon dioxide geosequestration.

These make the process especially attractive for developing countries with quickly expanding energy requirements such as India, China and South Africa where the technology is receiving close attention.

The operation of UCG is complicated by the natural variability of the underground geological conditions and the dynamic changes that accompany the progression of the reaction within the coal seam. Conditions underground need to be deduced from proxy measurements, for example of the syngas composition, and control of the conditions is also indirect or not possible. Within and surrounding the reaction zone there are high temperatures, large thermal and stress gradients, causing cavity collapses and changes in permeability.

Widespread commercialisation requires overcoming a number of real and perceived limitations:

- Environmental: in particular related to potential aquifer contamination and surface subsidence. The main operational issue is controlling the cavity pressure. If the pressure is too high, there is the danger that byproduct volatile organic compounds (VOC) contaminants may be pushed into the groundwater and syngas product lost through surrounding strata, perhaps even to the surface. If the pressure is too low, the cavity will collapse under hydraulic pressure and the reaction will be quenched. Gas cleanup on the surface also results in waste streams, importantly hydrocarbon contaminated water, which need to be treated.
- Local geological features: these can limit the application sites and need to be carefully assessed in each individual case. As the reaction proceeds and the coal is consumed, the resulting cavity is likely to collapse which may result in surface subsidence and provide leakage channels for syngas to be lost into permeable strata above the coal seam or even escape to the surface. This requires careful site selection with correct stratigraphy, geological setting, stress regime and hydrology, since these natural characteristics are difficult or impossible to control or re-engineer.
- Control: of operations is difficult because the many important process variables, such as the rate of water influx, the distribution of reactants in the gasification zone, and the growth rate of the cavity cannot be easily manipulated and indeed can often only be deduced indirectly from measurements of temperatures and product gas quality and quantity. The process is inherently unsteady and the product gas quality changes dynamically as the underground reaction proceeds, requiring surface facilities that can accommodate these changes.

- Process economics: remain untested until sufficient practical experience is gained. In particular, syngas rate and quality will vary over time which creates difficulties for the downstream operations.

Early trials in the US suffered from poor site selection and resulted in unacceptable groundwater contamination, but later tests, most importantly the Linc Energy operation in Australia have demonstrated that these issues can be managed and UCG operated without environmental hazard. This operation has been very extensively monitored by external, independent auditors.

UCG offers good opportunities for CO_2 capture from the product gas stream and presents a natural synergy with CO_2 storage.

8.3.4 CO_2 Geosequestration in UCG

UCG offers good opportunities for CO_2 capture from the product gas stream and presents a natural synergy with CO_2 storage, either in the cavity created during gasification or in neighbouring rocks and coal seams in the local vicinity. Experiments suggest that the CO_2 capacity of systems after stimulation by UCG can hold substantially more gas than before. Since the syngas from the UCG process is quite similar to surface gasifiers, the same technologies can be directly applied. For air blown UCG, CO_2 separation, for example using amine scrubbers could be applied, as being developed for power station flue gas; for oxygen blown systems conventional capture methods such as Selexol or Rectisol, which have long commercial histories, could be used. The UCG cavern, after the coal has been completely or partially consumed, or surrounding coal seams fractured from the UCG cavern subsidence, could also be used for CO_2 storage, although the environmental and risk implication of doing this require additional research and development, including:

- System constraints, such as injection and storage conditions which guarantee the integrity of storage, but are high enough for high density.
- Geomechanical constraints, including consideration of cavity collapse and how injection relates to reservoir dilation and uplift
- Ground-water displacement, considering the reactive mobilisation and fate of flushed materials such as volatile organic compounds (VOCs) or high metal concentrations leeched from the ash.
- CO_2 transport underground leads to the same set of risks commonly considered for conventional CO_2 storage, but with additional features unique to UCG such as thermal induced stresses and shocks of heating and quenching.

8.3.5 UCG primer

Different ways of establishing the underground gasification zone have been developed (see Figure 8.3.3). One method uses vertical wells and a method of reverse combustion to open up the internal pathways in the coal. The process was used in the Soviet Union and more recently it has been tested in Australia by Linc Energy using air and water as the injected gases.

Another method that was largely developed in the US creates dedicated inseam boreholes, using drilling and completion technology adapted from oil and gas production. It has a moveable injection point known as CRIP and generally uses oxygen or enriched air for gasification.

A steeply dipping bed requires a coal seam that is at a steep angle to the surface, and has been the subject of development and use in the former Soviet Union and more recently in China.

The tunnel system is also being trialled in China where there are many abandoned coal mines that still have a great deal of coal left in them (because of wasteful mining methods used in small, private mines).

Parallel inseam wells, also called knife edge CRIP, developed by CSIRO in Australia are being tested by Carbon Energy Ltd.

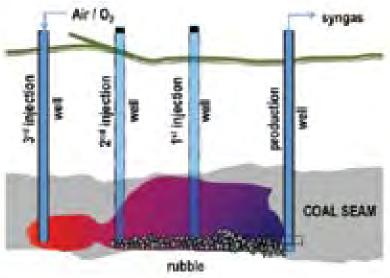

Figure (a)

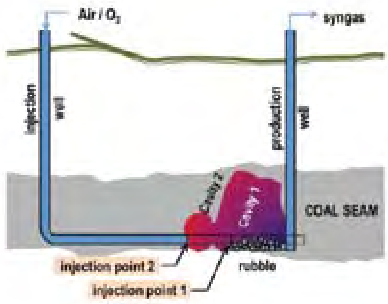

Figure (b)

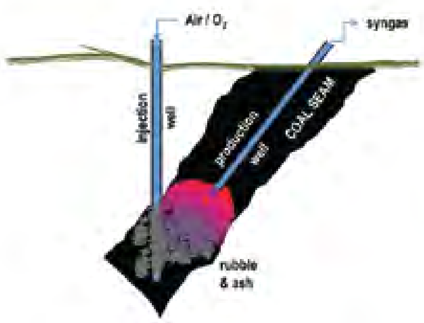

Figure (c)

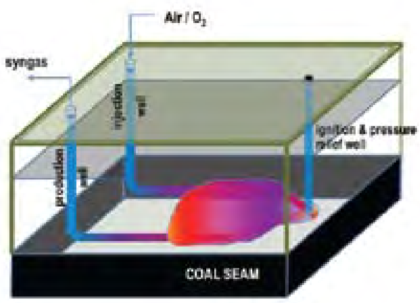

Figure (d)

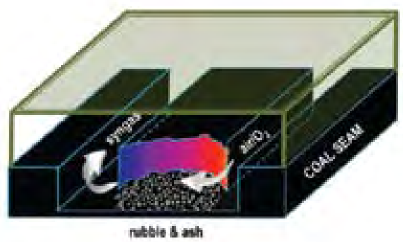

Figure 8(e)

Figure 8.3.3 (a) Vertical wells and reverse combustion (b) Inseam boreholes with Controlled Retraction Injection Point (c) Steeply dipping bed (d) Parallel inseam wells, and (e) Tunnel system being tested in China.

There are nearly 50 coal based gasification plants in the world.

About a quarter (97) of all coal gasifiers are in South Africa making liquid fuels and chemicals and more than 30 are in China.

8.4 COAL CONVERSION

Coal can be used in two ways: burned as a fuel to provide heat or power, or transformed into other products, such as natural gas, transport fuels or chemicals. Gasification involves the transformation of coal into a gas product called synthesis gas, predominantly carbon monoxide and hydrogen, which is then used as feed to downstream processes (see Figure 8.4.1). Gasification can be applied not only to coal but other carbon containing materials like petcoke, biomass, waste and oil refinery residues, although most syngas comes from coal, (Figure 8.4.2).

In a gasifier the coal is reacted with oxygen and steam in a high temperature pressurised reactor, breaking the chemical bonds in the coal and producing the syngas, which besides hydrogen and carbon monoxide, also contains carbon dioxide (CO_2), methane, (CH_4), and possibly higher hydrocarbons. The gas composition depends upon the gasifier conditions, i.e., temperature and pressure. The syngas is normally cleaned up to remove small amounts of entrained ash, any tars and other contaminants such as sulphur and mercury, and also CO_2 if required. The concentration of H_2 in syngas is then adjusted by a step called the water/gas shift reaction. Different products require appropriate amounts of hydrogen and carbon monoxide. The syngas can be further processed to produce chemicals, fertilisers, liquid fuels, hydrogen, and electricity (see Figure 8.4.3).

Synthesis gas can be used for power generation, for example in gas turbines, potentially offering some advantages for CCS. It is also the basis for most of the world's supply of hydrogen, which is used in oil refining. Syngas is the base material from which many other products are made.

There are nearly 50 coal based gasification plants in the world (all having multiple gasifiers), producing transport fuels (49% by syngas throughput) and chemicals (32%), for power generation (11%), and to produce gaseous fuels (8%).

There are three commercially-proven technologies that dominate gasification, each with about a 30% market share: Sasol Lurgi technology is well proven but losing ground to more recently developed gasifiers, Shell which is growing strongly in China, and GE Energy. The remaining commercial capacity representing a 5-8% share is provided by a dozen different technologies. About a quarter (97) of all coal gasifiers are in South Africa making liquid fuels and chemicals and more than 30 are in China.

There are no coal gasification plants in Australia, although one the Zerogen Project – which will produce power based on air blown Mitsubishi gasifier technology – is well advanced in terms of design and planning.

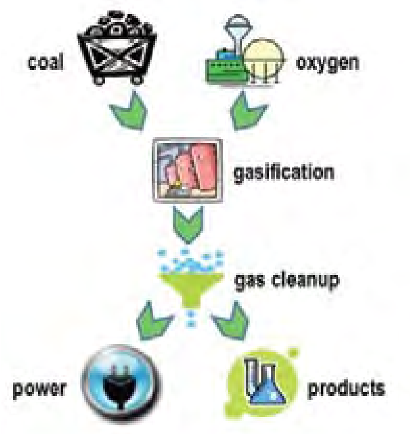

Figure 8.4.1 Gasification overview

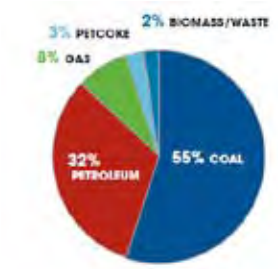

Figure 8.4.2 Feed materials for gasifiers making syngas

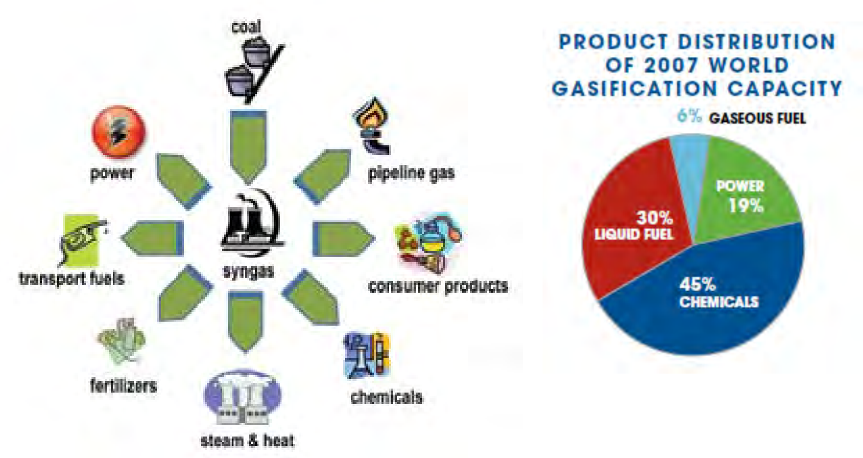

Figure 8.4.3 Gasification products

8.5 TRANSPORT FUELS

There are currently no plants in Australia making liquid fuels from coal or coalbed methane, although there are a number of proposals at various stages of development. In principle, liquids can be obtained from coal by direct liquefaction (hydrogenation), pyrolysis, or through gasification to methane (synthetic natural gas) or to syngas, and then further conversions. Compared with normal transport fuels (petrol, diesel, aviation fuels, bunker fuels), coal is very deficient in hydrogen, which needs to be supplied and represents a significant part of the cost of coal liquefaction.

In principle, liquids can be obtained from coal by direct liquefaction (hydrogenation), pyrolysis, or through gasification to methane (synthetic natural gas) or to syngas, and then further conversions.

The major routes for coal to fuels are through syngas, either by making methanol and then converting the methanol to petrol, or catalytic conversion usually called the Fischer-Tropsch process after its inventors.

The Fischer-Tropsch process was developed in Germany in 1921 and implemented there during WW2 to produce fuel. It is the only route for coal to liquid fuel showing sustained commercial success.

The liquids produced by the direct and syngas routes have different chemical compositions, so the process decision depends on the desired final products. Syngas conversion provides saturated hydrocarbon liquids, suited to high-quality diesel fuel and feedstocks for olefin production. Hydrogenation products are more aromatic and useful for blending to make high-octane petrol and as a basis for aromatic chemicals.

Hydrogenation as a route to fuel liquids, involves reacting the coal in slurry oil and has been known for nearly a century. Although it gained its inventor a Nobel prize, and it provided most of Germany's fuel and oil during WW2, there is currently only one commercial implemention, in Mongolia in 2007, producing about 5mt/y of liquid fuels. Its main disadvantage is that the product requires extensive upgrading to achieve compliance with general transport fuel standards, a necessary requirement for engine manufacturers to provide performance and usage guarantees.

Pyrolysis, or destructive distillation, of coal also provides limited quantities of generally poor quality liquids that would require extensive further processing including hydrogenation to reach normal fuel quality standards. A potential advantage for pyrolysis is that it requires relatively lower energy input (and therefore produces less GHG emissions) than other liquefaction processes. A project to make liquid fuels through pyrolysis of lignite has been proposed in WA.

Converting methane directly to liquids has been developed to pilot scales, but fails to be commercially attractive relative to the indirect route through syngas.

By far the major routes for coal to fuels are through syngas, either by making methanol and then converting the methanol to petrol, or catalytic conversion usually called the Fischer-Tropsch process after its inventors.

The syngas-methanol-petrol route has been commercialised (from natural gas) in one instance: the Methanex plant in New Zealand. This was technically successful, but could only operate with subsidy from the NZ Government and the plant now only makes and sells methanol, being uneconomic to make the further conversion to petrol. A main market for methanol is however for manufacture of methyl tertiary butyl ether, MTBE, a widely used petrol additive which increases the octane number and improves exhaust quality, and is completely compatible with modern petrol engines. MTBE is regulated as an additive in Australia to less than 1% in petrol (under 0.1% in WA) because of water pollution concerns. Methanol could be used as a fuel in its own right and there have been various proposals for blending methanol with petroleum or diesel as an extender, but technical reasons related to engine design and guarantees and distribution difficulties prevent this from being implemented.

The Fischer-Tropsch process was developed in Germany in 1921 and implemented there (as was direct hydrogenation, to a much greater degree) during WW2 to produce fuel. It is the only route for coal to liquid fuel showing sustained commercial success. The Fischer-Tropsch process produces fuels that are mostly superior in quality to oil based petrol and diesel and may be used as premium blend stocks to improve the overall fuel performance. Being fully compatible with and interchangable with existing fuels greatly facilitates distribution and use in the market.

In Australia there are a number of proposals for coal syngas to liquids proposals being developed.

Variants of the technology have been developed by a number of companies and the process may be adjusted to produce the most desired products: petrol, diesel, aviation fuels or waxes. Amongst the major companies that market Fischer-Tropsch processes are ExxonMobile Sasol-Chevron, Shell and Statoil.

In Australia there are a number of proposals for coal syngas to liquids proposals being developed, including from Victorian lignite (a Monash University project, supported by Anglo Coal and Shell) and South Australian lignite (Altona, Syngas). A pilot plant producing liquids from black coal through UCG is operating in Queensland (Linc Energy, Figure 8.5.2). The commercial hurdles are demonstrated by recent past attempts at gas to liquids plants based on natural gas in WA and the NT, by Shell (abandoned), Syntroleum (abandoned), Sasol Chevron (abandoned), Woodside (deferred), Methanex - methanol (abandoned), GTL Resources (abandoned), Mitsubishi – DME (abandoned).

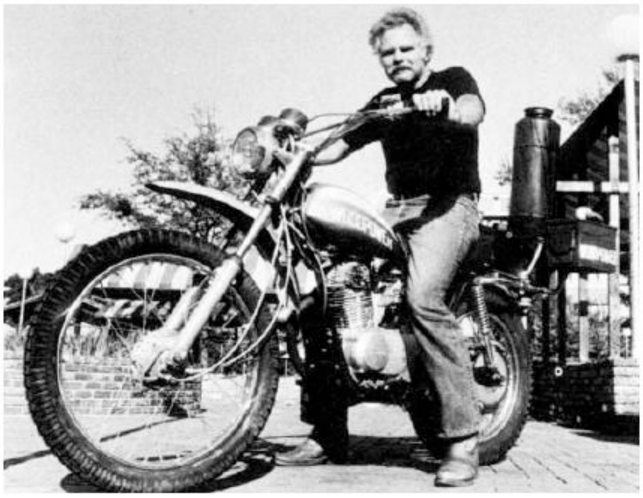

Figure 8.5.1 Old fashioned motor cycle with onboard syngas generator

Figure 8.5.2 Linc Energy FT pilot plant in Queensland

8.5.1 Benefits and challenges with coal to liquids

It is important to get a perspective on the enormous size of the global oil demand. If all thermal coal currently mined (about 3 billion tonnes per year) was to be converted into liquids it would produce the equivalent of, at best, around 5 billion bbl/y of oil. The global oil supply by comparison is over 30 billion bbl/y or six times as large. Consequently, regardless of economic constraints, coal to fuel can realistically only be expected to supply a small part of the energy liquids market, although it could be very important in particular countries or areas.

The main disadvantage of coal to liquids processes are the high capital and operating costs which have kept the technology economically uncompetitive. Those situations where it has been implemented have been driven by strategic considerations (Germany, South Africa), centrally controlled economies or with government underwriting or subsidy. Many studies (eg the recent "Future of Coal" study by MIT) suggest that the technology should be competitive when the oil price is above about US$50/bbl. While this may seem attractive, the extreme volatility of oil prices have made investors very wary, since multi-billion dollar investments in capital plant may be stranded for extended periods if the oil price dips. Half a dozen such projects were written off in the US in the 1980s during a period of low oil prices, with only one making synthetic natural gas surviving. Nevertheless, with many predicting higher oil prices, many projects are now again being proposed all around the world. Once again the size of the oil market needs to be considered, with the capital cost for coal to liquids estimated to require around $1trillion to displace 10% of global oil.

From an environmental perspective, the main criticism of Fischer-Tropsch processes is that they have very high CO_2 emissions. Typically for every tonne of CO_2 emitted from the use of the fuel, the manufacturing process itself would produce 1.5 tonnes of CO_2 (compared with petrol from crude oil which produces only 80kg of CO_2 to extract and refine). However, combining these processes with CCS is much easier than for power plants.

Another environmental concern is the heavy water use that Fischer-Tropsch processes consume: typically 3-6 tonnesof water for every tonne of product. Since in many locations where coal is abundant, water is in short supply – for example in China, parts of the US, Australia, South Africa amongst others – and competition for access to water resources may become an issue.

8.5.2 Fischer-Tropsch primer

The Fischer-Tropsch (FT) process, with coal as a feedstock, was invented in the 1920s, used by Germany during World War II, and has been utilized in South Africa for decades. It is also used in Malaysia and the Middle East with natural gas as the feedstock and there is increasing interest in using it with biomass derived syngas for 'green' fuels.

The Fischer-Tropsch process converts the feed gas into liquid organic compounds, carbon dioxide and water. The conversion takes place in the presence of a catalyst, usually iron or cobalt. The temperature, pressure and catalyst determine whether a light or heavy syncrude is produced. For example at 330^{0}C mostly gasoline and olefins are produced whereas at 180 to 250^{0}C mostly diesel and waxes are produced. Since there is often a surplus of hydrogen from the syngas process, the economics of the process are assisted if this can be used in a petroleum refinery or for the manufacture of ammonia in an adjoining plant.

There are a variety of companies offering the technology, with different reactor setups. An important design consideration is that the reaction produces very large amounts of heat which must be removed so that the temperature can be kept in the correct range without any hotspots.

Fischer-Tropsch reactors may be divided into low temperature and high temperature variants. There are two main setups for low temperature: a tubular, fixed bed reactor and a slurry bed reactor. For high temperature reactions, there are also two systems: conventional and circulating fluidized bed reactors. In all cases the heat that is generated by the reaction is removed through cooling coils where steam is generated for use in the process.

The resulting organic compounds can be purified into many petroleum products including petrol, diesel, aviation fuel and waxes. Most proposals that are being developed seek to produce low sulphur diesel fuel, a premium product with high value that can be blended into crude based diesel to improve quality because of its low sulphur and aromatic content, high cetane number and excellent combustion quality.

The Fischer-Tropsch process converts the feed gas into liquid organic compounds, carbon dioxide and water.

Two Fischer-Tropsch based plants are in construction in China, but approvals for further applications for coal to liquids projects have recently been frozen pending reconsideration of their liquid fuel supply strategy.

The primary chemicals that are made from syngas are methanol, ammonia, oxo-process products.

Methanol production is essentially a variation of the Fischer-Tropsch technology.

The coal to liquids conversion using the Fischer-Tropsch process has quite high capital, operating and maintenance costs, but recent refinements that tailor the products and reduce costs have made it commercially competitive in very large plants which enjoy significant economies of scale. However free capital markets have been reluctant to invest the enormous multi-billion dollar costs for these plants faced with volatile crude oil prices and uncertainty about future CO_2 emissions costs. Two Fischer-Tropsch based plants are in construction in China, but approvals for further applications for coal to liquids projects have recently been frozen pending reconsideration of their liquid fuel supply strategy.

8.6 CHEMICALS AND PRODUCTS

A wide variety of chemicals are made from syngas and it is technically possible, but not commercial to make many more. Figure 8.6.1 shows some of the products that have been commercially developed.

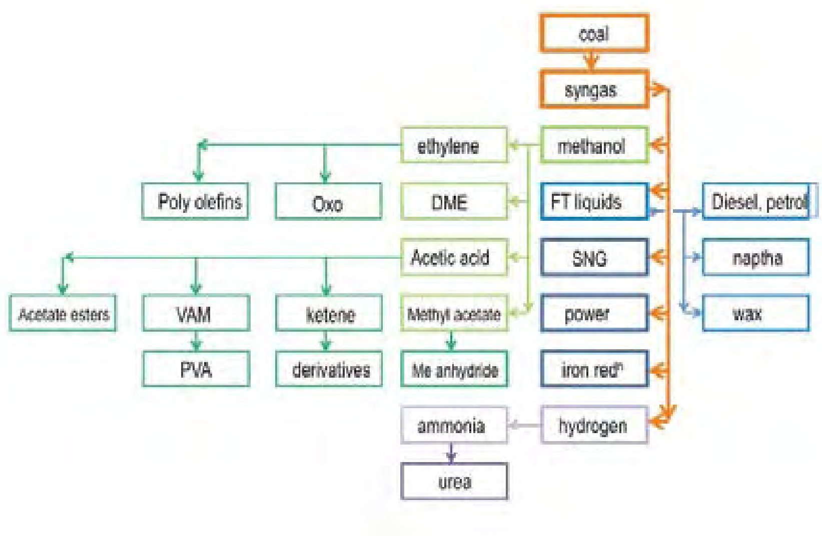

Figure 8.6.1 chemicals from coal based syngas

The main constituents of syngas, carbon monoxide and hydrogen, are both important in their own right. Carbon monoxide is used for the production of acetic acid (by reaction with methanol) and phosgene which is then used to make isocyanates. Hydrogen is widely used in many chemical and refinery operations, and is of interest as a future fuel in the 'hydrogen economy'. It is also used for making ammonia for fertilizer.

The primary chemicals that are made from syngas are methanol, ammonia, oxo-process products.

8.6.1 Methanol

Methanol production is essentially a variation of the Fischer-Tropsch technology. The original process commercialised by BASF in 1923 required high pressures of 300-500 atmospheres. In the mid 1960s a number of lower pressure processes (at 50 atmospheres) were commercialised and captured the market. A liquid phase process is in development in the US.

In Australia, methanol is made from natural gas and almost all is then used to make formaldehyde.

Internationally, methanol is a commodity chemical mostly used for transformation into a large array of secondary chemicals and also transformed into synthetic petrol and olefin products. The main products from methanol are shown in Figure 8.6.2.

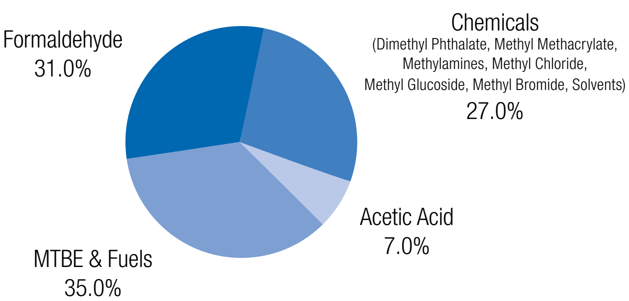

Figure 8.6.2 Distribution of products obtained from methanol.

Formaldehyde is the second largest use of methanol internationally and the largest user in Australia. Formaldehyde is mainly used in the manufacture of plywood and chipboard, but also finds application in paints, explosives, fertilisers, dyestuffs, textiles, paper and cosmetics. Methanol is reacted with oxygen in air over a catalyst and captured in water, making a solution called formalin, which is the most commonly sold form of the product. Reacting methanol with carbon monoxide over a catalyst produces acetic acid.

MTBE is an important product from methanol, discussed in the section dealing with transport fuels. China is also pursuing projects to make methanol to propylene and olefins, but no commercial plants for these products are yet operational.

There are more than 1,000 ammonia plants in the world using a very wide array of production methods. About a quarter of production is in China, a large proportion of which is based on coal derived syngas.

Ammonia is made by the reaction of nitrogen separated from air and hydrogen which is sourced mainly from syngas. The predominant use of ammonia - over 80%, about 100mtpy - is as fertiliser, either liquid ammonia or more commonly as urea or ammonium nitrate. Ammonium nitrate is also used as a blasting explosive in mining. Some ammonia is also used to make cyanide (by reaction with methane) which is used for gold extraction, Perspex and some types of nylon.

The process to synthesise ammonia was invented 100 years ago and first put to industrial use in Germany to supply explosives in WW2, alternative mineral nitrates having been blockaded by the Allies. There are more than 1,000 ammonia plants in the world using a very wide array of production methods. About a quarter of production is in China, a large proportion of which is based on coal derived syngas. India, Russia and the US produce about 10% each mainly from oil or gas although many US producers are looking to lower costs by converting to coal syngas as a hydrogen source, partly because the coal price is low and stable while the gas supply has been constrained and the prices high and volatile. In the US, the Eastman Chemical Company has used coal gasification for over 25 years, producing methanol and acetyl chemicals.

Australia produces (and uses) about a million tonnes of nitrogen (mainly urea) and has the world's largest single train ammonia plant located in WA, based on syngas from natural gas. Perdeman Chemicals have announced plans to build a large ($3.5 billion) ammonia-urea plant in WA based on coal.

Urea is produced by reacting ammonia with CO_2. Since CO_2 is a product of converting the CO in syngas to hydrogen, this is commonly produced at most ammonia plants, providing a convenient solid product. Urea is mainly used as a fertiliser, valued for its high nitrogen content. A smaller proportion is used for urea formaldehyde resin.

Other ammonia based fertilizers are ammonium nitrate and ammonium phosphate.

Syngas is also reacted with olefins to produce plasticisers and biodegradable detergents.

8.7 SYNTHETIC NATURAL GAS

Many countries have gas reticulated to individual homes for heating and cooking. There is also a large trade in gas, mostly by sea. For shipment by sea, natural gas is turned into a liquid called liquefied natural gas (LNG) in order to increase its density and reduce the volume that needs to be moved. LNG is produced by cooling the gas (to $-160^{0}C$) and then storing and transporting it as liquid in insulated containers. A small part of the LNG is allowed to evaporate to maintain the low temperature, but this is used as a fuel on the tankers and is not wasted.

The LNG plants that are to be built at Gladstone will liquefy coal seam gas in this way for export. Another possible source of methane gas is to make it synthetically from coal. This has the advantage that the whole coal resource, not just the adsorbed gas can be provided in the convenient form of gas.

Synthetic Natural Gas (or SNG, also called substitute natural gas) converts syngas obtained from the gasification of coal, including UCG, into the equivalent of pipeline quality natural or coal bed gas.

The low and stable coal price is very appealing, but the distribution of solid fuel as a general source of energy has many drawbacks: the capacity to convert coal into SNG that can be used in an existing natural gas network solves this distribution problem. Also, the advantage of a secure and domestic gas energy supply is attractive in many countries that have no natural gas but do have coal.

Steam-oxygen gasification, hydrogasification, and catalytic steam gasification are the three gasification processes used in coal-to-SNG.

The proven and commercialised method of gasification for the coal-to-SNG process and the only one that has been commercialised is the steam-oxygen gasification process. In principle, UCG can be used as the syngas source – a process which could be attractive if located near to gas pipeline infrastructure. Most of the major international EPC contractors, including for example, Badger, Chevron, Conoco Phillips, Davey, Fluor Daniel, Foster Wheeler GE, Haldor-Topsoe, and Nexant are active in this area, as are many smaller companies and consultants.

The hydrogasification process uses hydrogen or water to gasify coal, making methane as the product. The hydrogen that is required for the reaction may come from an external source or by steam reforming some of the product methane. This process has not yet been commercialized, although extensive studies of the process were conducted from the 1970s to the 1990s. Hydrogasification produces mainly methane and consequently is suited best where SNG is the desired product. An advantage is that the process does not use oxygen and therefore no air separation plant is required.

The advantage of a secure and domestic gas energy supply is attractive in many countries that have no natural gas but do have coal.

There is a substantial level of activity in the area and 15 SNG plant proposals have been identified in the US alone. All are based on mined coal and surface gasification.

Catalytic steam gasification is more energy-efficient than steam-oxygen gasification. The process was initially developed by Exxon in the 1970s using potassium carbonate as a catalyst, but the process was not commercialized. The process, with new catalysts, is currently being developed by a US company with a view to commercial implementation. In this process, gasification and methanation occur in the same reactor in the presence of a catalyst. An advantage is that the energy required for the gasification reaction is supplied by the methanation reaction which produces heat. Methane product is separated from unreacted syngas and carbon dioxide which is a byproduct. The recovered syngas is then recycled to the gasification/methanation reactor. No air separation is required and the use of the catalyst allows the reaction to take place at a relatively low temperature, typically around 7000C. The disadvantages are separation of catalyst from ash/slag and the loss of reactivity of the catalyst.

There is a substantial level of activity in the area and 15 SNG plant proposals have been identified in the US alone, as listed below (see Table 8.7.1). All are based on mined coal and surface gasification.

Table 8.7.1 Planned Synthetic Natural Gas Plants in the US.

Project Name/Owner	Location	status	Cap bcf/y	Capex US$m	completion
Secure Energy Inc.	Illinois	FEED	20	250	2009
Peabody Energy & Arclight	Illinois	proposed	35		
Power Holdings of Illinois	Illinois	preFEED	50	1,000	2009
Taylorville Energy Centre	Illinois	feasibility		2,000	
Global Energy	Indiana	Proposed			
GreatPoint Energy's Pilot	Mass	pre-FEED			
Oswego SNG –TransGas	NY	planned		2,000	2010
South Heart Project	N Dacota	feasibility	36.6	1,400	2012
SES/Consol Coal-to-SNG	Virginia	planned			
GreatPoint SNG Project	Mass	planned			
ConocoPhillips/Peabody Energy	midwest	feasibility	50-70		
Lockwood Project	Texas	concept	65.7		2011
Tondu's Nueces Syngas	Texas	planned			
Peabody Energy	Wyoming	proposed			
Cash Creek LLC/ Davey Eng	Kentucky	feasibility			2012

In Australia there are studies underway regarding opportunities for SNG from UCG as a supplement to the CSG supplies.

Appendix 1 Coal Classification

Coal is a readily combustible black or brown rock normally ocurring in sedimentary rock strata. It is composed of carbon, along with predictable quantities of other elements including sulphur, hydrogen, oxygen and nitrogen (Wikepedia, accessed 12/10/2009). It is formed by the biodegredation of plant remains.

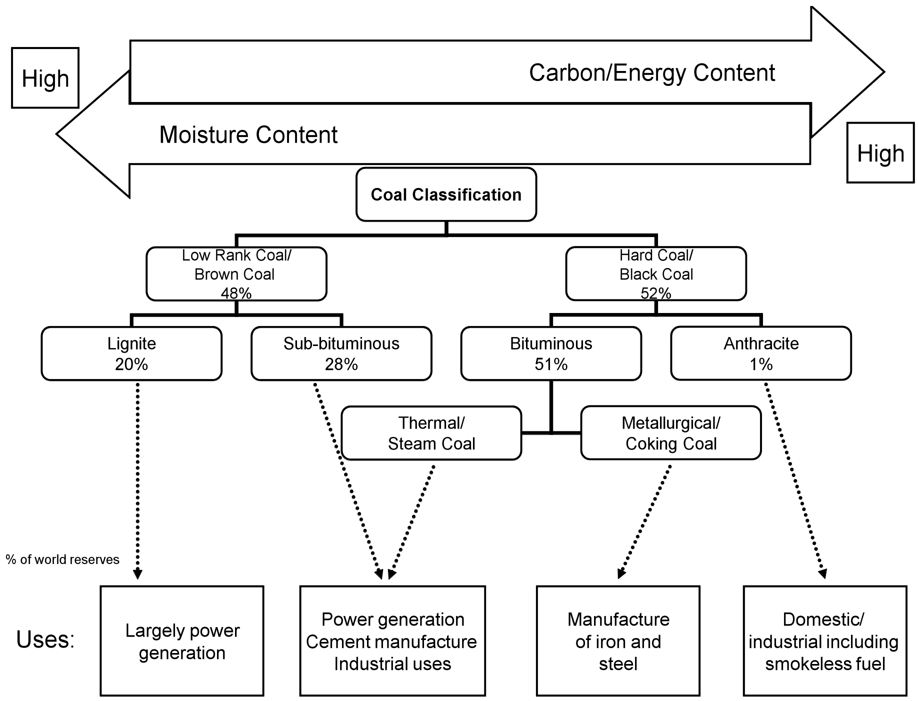

Figure A1-1: Coal classification, uses and world reserves (ACA 2006).

Coal quality is highly variable dependent on its geological formation and the pressures and temperatures to which it has been subjected. The five classical types of coal, ranging from high carbon to low carbon content, are: anthracite, bituminous, sub-bituminous, lignite and peat. Moisture content generally increases as carbon content declines. At the extreme end of the scale, peat is defined as a combustible soft material, porous and easily cut with very low carbon content. In some classification systems peat is ignored and coal is classified by four types (see Figure A1-1). Hard coal includes coking coal, anthracite, bituminous and (in Australia, Mexico and the United States), sub-bituminous coals. Thermal, or steaming black coals includes bituminous and sub-bituminous coals.

Appendix 2 Coal Production, Consumption, Reserves and Trade Statistics

Coal production

Table A2-1: Historical world hard coal* production (thousand tonnes) from 1973 to 2008

Country	1973	1980	1985	1990	1995	2000	2004	2005	2006	2007	2008
Australia	55,483	71,610	122,346	158,572	191,055	239,429	285,854	300,190	299,715	323,770	325,406
Canada	12,337	20,173	34,310	37,673	38,621	33,805	29,262	29,086	29,900	32,811	33,198
Czech Republic	27,780	27,721	26,401	14,383	10,824	8,136	7,316	7,136	7,748	7,674	7,512
France	26,350	20,190	17,055	11,199	8,495	3,804	872	617	452	380	277
Germany	104,407	94,492	88,849	76,553	58,858	37,376	29,151	28,018	23,762	24,185	19,143
Japan	25,090	18,027	16,381	7,979	6,317	2,964					
Korea	13,571	18,625	22,543	17,217	5,720	4,150	3,191	2,832	2,824	2,886	2,773
Mexico	2,578	3,089	5,193	6,933	9,320	11,344	9,882	10,755	11,487	12,514	11,478
Poland	156,630	193,121	191,642	147,736	137,166	103,331	101,230	97,904	95,223	88,312	84,332
Spain	9,991	12,838	16,091	14,612	13,497	11,317	8,911	8,548	8,353	7,873	7,304
United Kingdom	131,985	130,097	94,111	92,762	53,037	31,198	25,096	20,498	18,517	17,007	16,510
United States	530,064	710,178	735,935	853,647	858,627	893,972	943,343	962,440	991,473	981,473	1,006,560
OECD Total	1,117,322	1,335,133	1,385,914	1,447,639	1,397,930	1,387,868	1,454,153	1,476,890	1,499,734	1,510,291	1,525,181
South Africa	62,352	115,120	173,500	174,800	206,211	224,200	242,821	244,986	244,774	247,666	235,750
Colombia	2,834	4,164	8,766	21,375	25,651	38,242	54,184	59,064	65,596	69,902	78,612
India	76,588	111,000	150,468	211,184	268,280	311,428	380,072	404,461	428,247	454,356	489,476
Indonesia	149	304	1,852	6,814	355,547	62,784	118,248	143,601	195,789	230,248	246,159
DPR of Korea	23,198	34,106	40,000	35,693	23,700	22,500	24,371	26,864	27,161	23,861	28,552
Vietnam	2,990	5,200	5,594	4,638	8,350	11,609	25,500	32,396	38,910	42,546	39,940
PR of China	417,000	620,150	837,272	1,050,734	1,343,004	1,231,232	1,955,986	2,158,908	2,320,207	2,466,428	2,761,391
Kazakhstan				128,000	80,754	74,886	83,065	82,788	92,010	93,538	104,417
Russia				237,514	162,411	152,538	189,758	209,213	210,418	217,878	247,082
Ukraine				143,483	74,002	61,601	59,129	60,007	61,439	58,739	59,348
Non-OECD Total	1,117,927	1,465,759	1,811,866	2,041,527	2,249,280	2,213,605	3,156,204	3,447,929	3,709,280	3,931,564	4,320,076
World	2,235,249	2,800,892	3,197,780	3,489,166	3,647,210	3,601,473	4,610,357	4,924,819	5,209,014	5,441,855	5,845,257

Data sources: (IEA 2009)
*Hard coal includes coking coal, anthracite and bituminous coal. In Australia, Mexico and United States sub-bituminous is included in hard coal.

Table A2-2: Historical world brown coal* production (thousand tonnes) from 1973 to 2008

Country	1973	1980	1985	1990	1995	2000	2004	2005	2006	2007	2008
Australia	24,121	32,894	38,380	45,990	50,752	67,293	66,343	67,152	67,737	65,613	72,400
Canada	8,135	16,515	26,543	30,659	36,360	35,358	36,259	36,259	36,104	35,635	34,908
Czech Republic	75,965	89,086	94,636	87,015	64,077	57,026	56,760	54,890	55,164	54,952	52,676
Germany	366,409	389,726	434,037	357,468	192,756	167,691	181,926	177,907	176,321	180,409	175,313
Greece	13,301	23,198	35,888	51,896	57,896	63,887	70,041	69,398	64,787	66,308	65,720
Hungary	25,925	25,142	23,500	17,332	14,772	14,033	11,242	9,570	9,952	9,818	9,404
Poland	39,215	36,866	57,746	67,584	63,547	59,484	61,198	61,636	60,844	57,538	59,570
Turkey	7,754	15,027	36,392	44,683	52,825	60,876	44,431	56,170	61,936	72,902	73,124
United States	12,948	42,783	65,701	79,914	78,471	77,619	75,786	76,151	76,429	71,291	68,659
OECD Total	590,105	699,433	849,185	814,275	632,890	620,841	619,464	622,823	621,820	626,146	617,346
India	3,320	5,110	8,040	14,074	22,146	24,247	30,411	30,228	31,285	33,980	32,242
Indonesia			148	3,672	5,598	13,820	24,335	27,110	30,735	34,516	38,000
DPR of Korea	7,000	10,000	12,000	10,660	7,600	7,243	7,340	7,746	7,946	6,478	8,956
Thailand	361	1,525	5,188	12,421	18,416	17,708	20,060	20,878	19,001	18,239	17,568
Bulgaria	26,459	29,946	30,657	31,532	30,636	26,314	26,452	24,686	25,651	28,418	28,744
Romania	17,679	27,104	37,924	33,737	40,762	29,004	31,792	31,106	34,923	35,780	34,734
Serbia				45,800	40,540	37,006	41,085	35,100	36,780	37,148	37,447
Estonia				22,486	12,433	11,727	13,993	14,591	14,095	16,544	16,193
Russia				134,385	83,317	87,786	69,186	73,668	74,148	71,143	76,044
Non-OECD Total	248,095	286,564	333,355	375,130	293,815	292,687	305,571	307,139	318,286	329,574	334,078
World	838,200	985,997	1,182,540	1,189,405	926,705	913,528	925,035	929,962	940,106	955,720	951,424

Data sources: (IEA 2009)
*Brown coal includes lignite. In Canada, Czech Republic, Hungary and Turkey sub-bituminous is included in brown coal.

APPENDIX

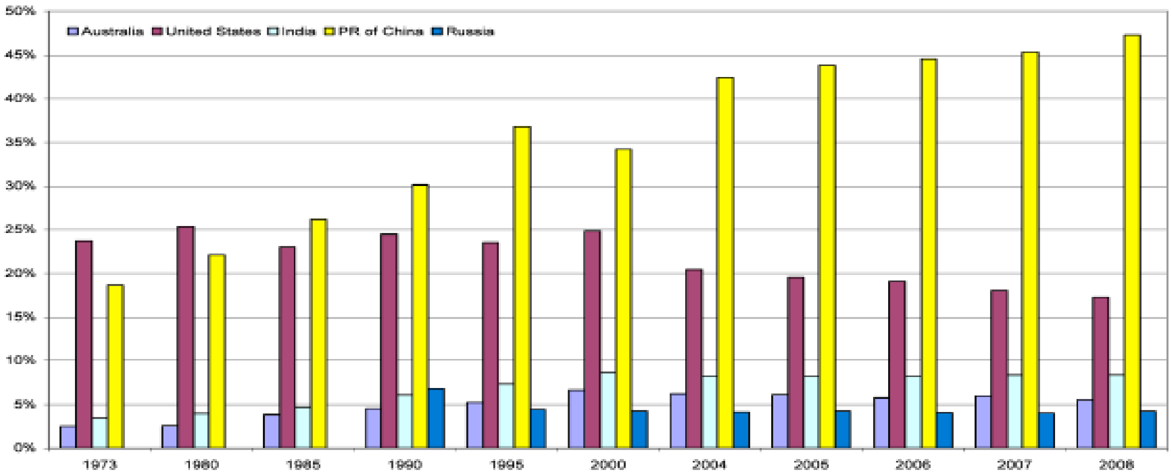

Figure A2-1: Historical trend of world hard coal production in the main producer countries from 1973 – 2008. (IEA 2009)

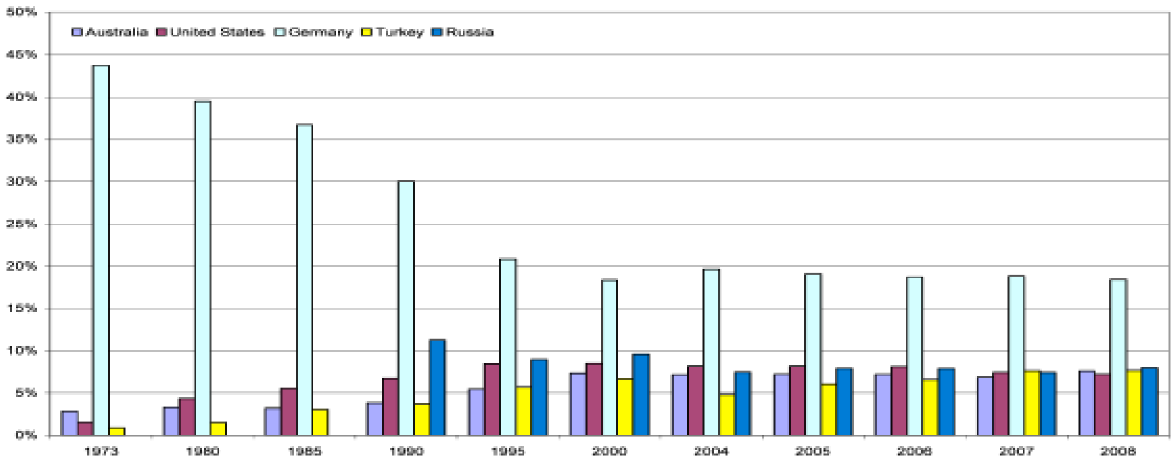

Figure A2-2: Historical trend of world brown coal production in the main producer countries from 1973 – 2008. (IEA 2009)

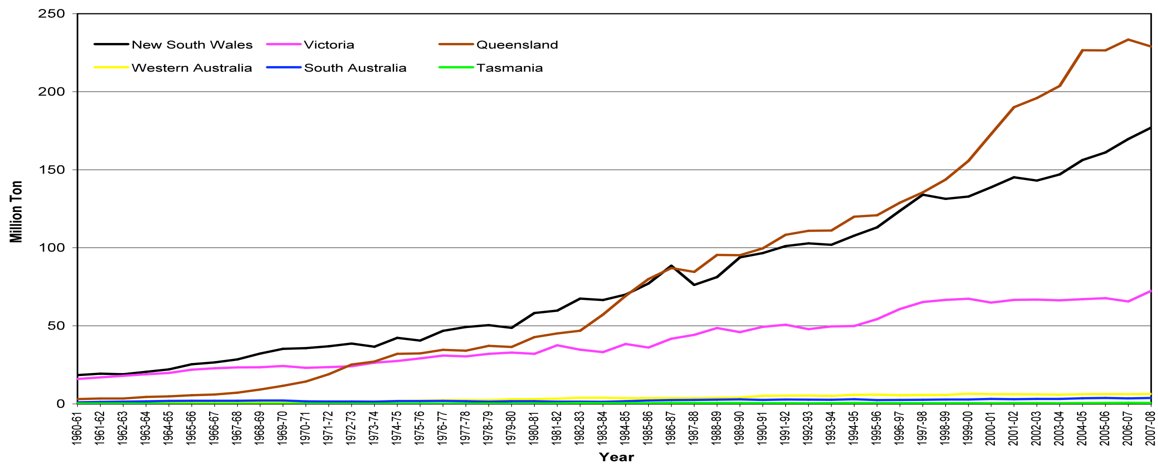

Figure A2-3: Historical Australian black and brown coal production by state from 1960 – 2008. (ABARE 2008)

COAL CONSUMPTION

Table A2-3: Historical world hard coal* consumption (thousand tonnes) from 1973 to 2008

Country	1973	1980	1985	1990	1995	2000	2004	2005	2006	2007	2008
Australia	27,292	34,422	39,980	49,299	51,739	60,830	64,909	72,858	73,591	72,750	73,217
Germany	105,801	96,385	93,466	86,965	74,224	68,963	67,922	63,952	65,538	70,097	65,530
Japan	81,690	87,699	109,391	114,960	133,564	153,190	180,802	176,974	179,098	186,983	185,568
Korea	16,329	27,790	42,505	44,776	44,634	66,548	79,954	82,272	84,709	92,044	104,830
Poland	122,097	163,778	156,570	120,231	107,823	83,371	83,915	80,438	86,130	85,336	82,995
United Kingdom	133,527	123,610	105,980	106,722	75,916	59,868	60,568	61,779	67,341	62,865	57,001
United States	492,567	608,038	682,608	736,926	782,788	892,126	934,614	953,585	941,276	955,157	957,101
OECD Total	1,143,242	1,333,280	1,434,672	1,452,910	1,451,097	1,574,617	1,673,240	1,690,949	1,701,418	1,734,908	1,704,066
South Africa	60,408	86,961	125,870	124,900	147,205	157,135	178,995	175,403	177,880	183,591	175,928
India	73,410	108,622	154,347	211,533	278,553	338,729	411,237	430,693	459,760	500,092	547,849
Indonesia	129	237	771	1,943	4,746	5,600	13,287	15,445	23,717	33,902	43,580
Chinese Taipei	3,572	5,956	11,085	17,230	26,167	42,055	53,186	54,711	56,783	59,358	66,133
PR of China	414,180	626,010	803,907	1,050,951	1,316,890	1,214,956	1,886,367	2,098,830	2,305,093	2,454,333	2,759,637
Kazakhstan				85,806	61,195	47,000	58,465	58,561	65,401	65,302	77,421
Russia				240,033	163,266	142,222	144,978	141,438	145,771	142,034	171,571
Ukraine				139,440	86,898	65,887	64,464	63,614	68,237	68,196	65,351
Non-OECD Total	1,103,331	1,443,087	1,758,798	2,008,412	2,194,406	2,130,480	2,962,102	3,194,899	3,466,584	3,680,264	4,110,021
World	2,246,573	2,776,367	3,193,470	3,461,322	3,645,503	3,705,097	4,635,342	4,885,848	5,168,002	5,415,172	5,814,087

Data sources: (IEA 2009)
*Hard coal includes coking coal, anthracite and bituminous coal. In Australia, Mexico and United States sub-bituminous is included in hard coal.

Table A2-4: Historical world brown coal* consumption (thousand tonnes) from 1973 to 2008

Country	1973	1980	1985	1990	1995	2000	2004	2005	2006	2007	2008
Australia	24,121	32,894	38,380	45,990	50,752	67,293	66,343	67,152	67,737	65,613	72,400
Canada	8,058	15,911	26,653	30,260	36,734	40,465	40,493	39,760	36,701	37,777	42,951
Czech Republic	75,965	79,822	83,854	81,891	59,832	56,117	52,714	52,473	53,476	54,196	50,337
Germany	372,497	391,753	432,521	364,050	194,811	169,942	181,948	177,892	176,378	180,491	175,194
Greece	13,000	22,692	36,214	52,053	56,962	64,564	70,855	70,096	64,598	66,373	65,791
Hungary	26,896	25,849	24,593	19,005	15,529	13,893	12,173	10,247	10,181	10,088	9,940
Poland	34,282	35,308	57,565	67,391	63,196	59,488	61,175	61,589	60,800	57,529	59,552
Turkey	7,642	15,801	35,301	46,178	52,471	64,406	45,545	57,315	60,786	72,827	73,124
United States	12,948	42,129	62,063	79,023	80,764	74,264	76,119	76,136	75,785	71,851	69,352
OECD Total	598,920	700,632	845,129	825,388	637,310	629,833	625,056	629,474	621,225	630,264	625,234
India	3,762	5,059	7,913	14,985	22,298	24,825	30,033	30,239	30,808	34,654	35,325
Indonesia			163	4,422	5,598	13,755	22,900	25,697	27,794	30,238	26,218
Thailand	361	1,525	5,132	12,457	18,496	17,586	20,548	21,046	18,852	18,121	20,783
Bulgaria	26,311	29,704	30,657	31,778	30,873	25,844	26,292	24,870	25,775	28,687	28,748
Romania	17,690	27,364	38,404	36,872	40,635	29,313	32,574	32,961	37,627	36,613	34,938
Serbia				45,800	40,550	37,106	41,239	35,323	37,367	37,359	37,351
Estonia				25,954	14,561	13,232	15,503	14,804	14,028	16,810	16,193
Russia				134,047	82,065	88,257	72,060	73,156	73,929	70,147	75,683
Non-OECD Total	247,976	285,674	334,411	383,502	296,499	300,521	313,285	311,527	321,706	329,370	327,300
World	846,896	986,306	1,179,540	1,208,890	933,809	930,354	938,341	941,001	942,931	959,634	952,534

Data sources: (IEA 2009)

*Brown coal includes lignite. In Canada, Czech Republic, Hungary and Turkey sub-bituminous is included in brown coal.

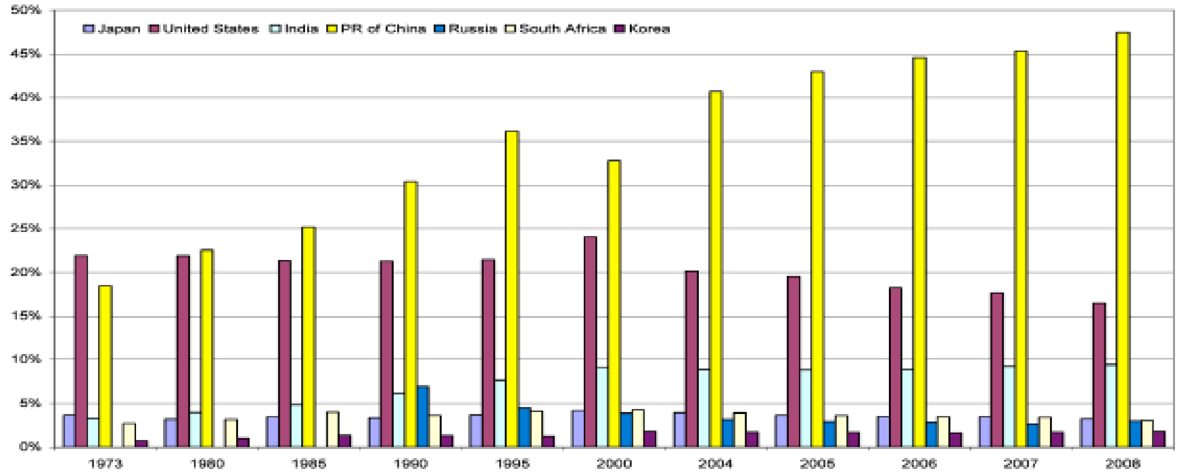

Figure A2-4: Historical trend of world hard coal consumption in the main consumer countries from 1973 – 2008. (IEA 2009)

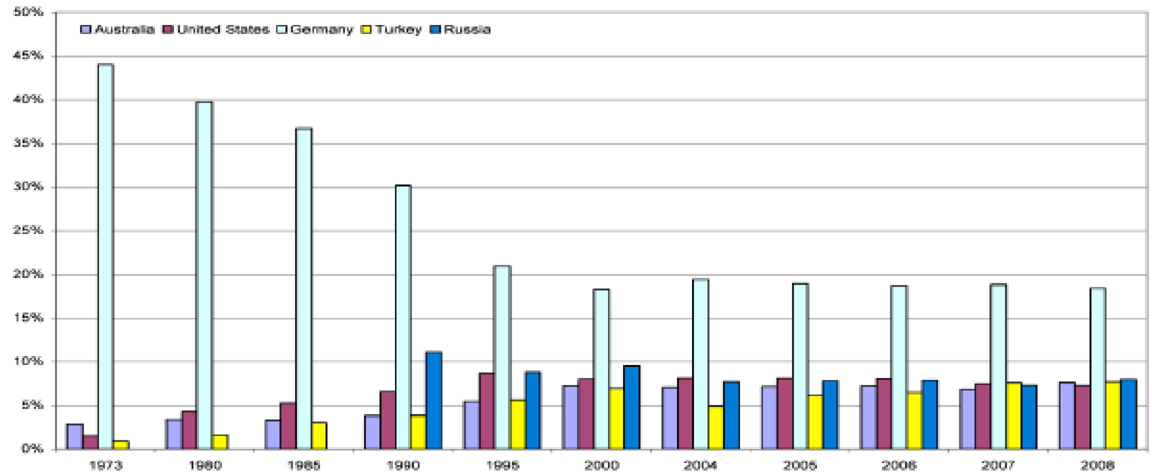

Figure A2-5: Historical trend of world brown coal consumption in the main consumer countries from 1973 – 2008. (IEA 2009)

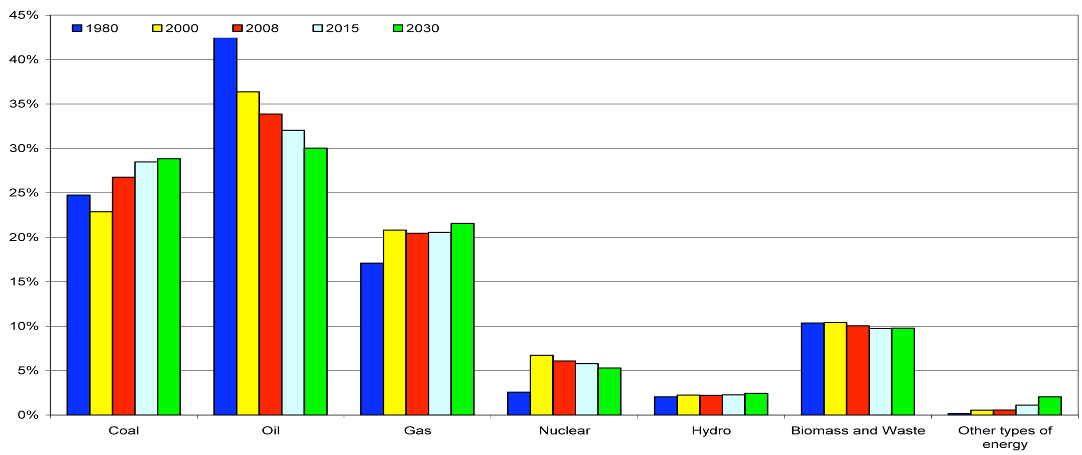

Figure A2-6: Current and projected distribution of worldwide energy consumption from 1980 – 2030. (EIA 2008a).

COAL RESERVES

Table A2-5: Top twenty countries with proven black and brown coal reserves in 2008

Country Rank	Country	Reserve				Reserve/Production Ratio		
		Anthracite & Bituminous (Mt)	Sub-bituminous & Lignite (Mt)	Total (Mt)	Share of Total	Anthracite & Bituminous	Sub-bituminous & Lignite	Total
1	United States	112,261	130,461	242,722	26.8%	216	257	237
2	Russia	49,088	107,923	157,011	17.3%	242	1464	568
3	China	62200	52,300	114,500	12.6%	30		55
4	India	90,085	2,360	92,445	10.2%	227	78	216
5	Australia	38,600	39,900	78,500	8.7%	145	362	209
6	South Africa	48,750	0	48,750	5.4%	199		199
7	Ukraine	16,274	17,879	34,153	3.8%	271	44698	565
8	Kazakhstan	28,151	3,128	31,279	3.5%	340	823	361
9	Mongolia			22,300	2.5%			2965
10	Poland	14,000	0	14,000	1.5%	144	0	88
11	Brazil	0	10,133	10,133	1.1%	0	1778	1634
12	Germany	183	6,556	6,739	0.7%	7	37	33
13	Colombia	6,230	381	6,611	0.7%	105		112
14	Canada	3,471	3,107	6,578	0.7%	121	85	101
15	Czech Republic	2,094	3,458	5,552	0.6%	157	71	89
16	Indonesia	740	4,228	4,968	0.5%	5		33
17	Turkey	278	3,908	4,186	0.5%	126	70	72
18	Hungary	198	3,159	3,357	0.4%		329	350
19	Bulgaria	4	2,183	2,187	0.2%	444	88	89
20	Mexico	860	351	1,211	0.1%	478	39	112
	World	479,697	425,451	905,148	100.0%	118	313	167

Data sources: (BP 2009; Methane to Markets 2009)

COAL TRADE

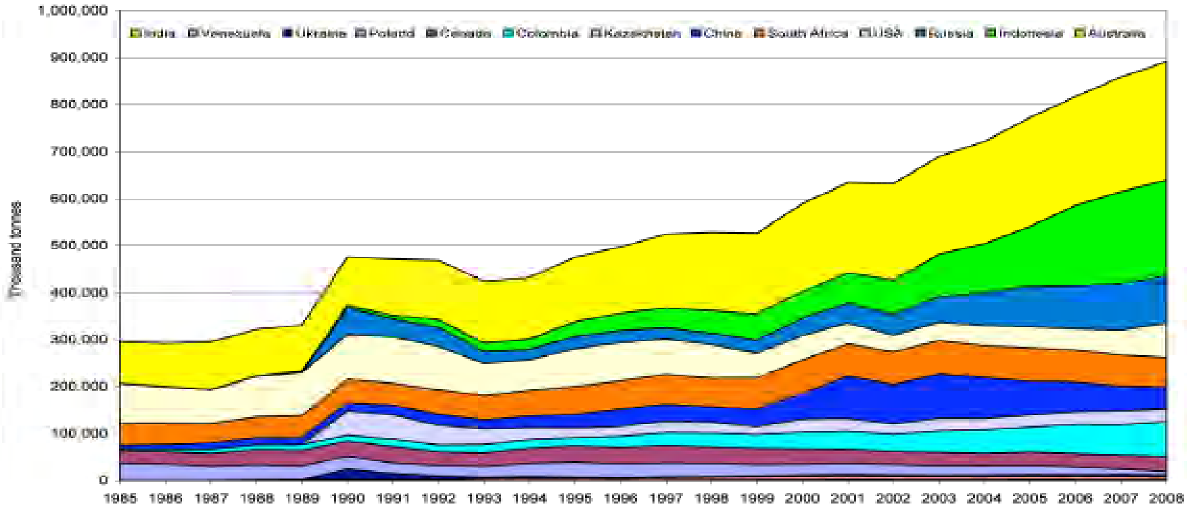

Figure A2-7: Historical trend of world hard coal exports from major exporting countries 1985 – 2008. Data sources: (IEA 2009)

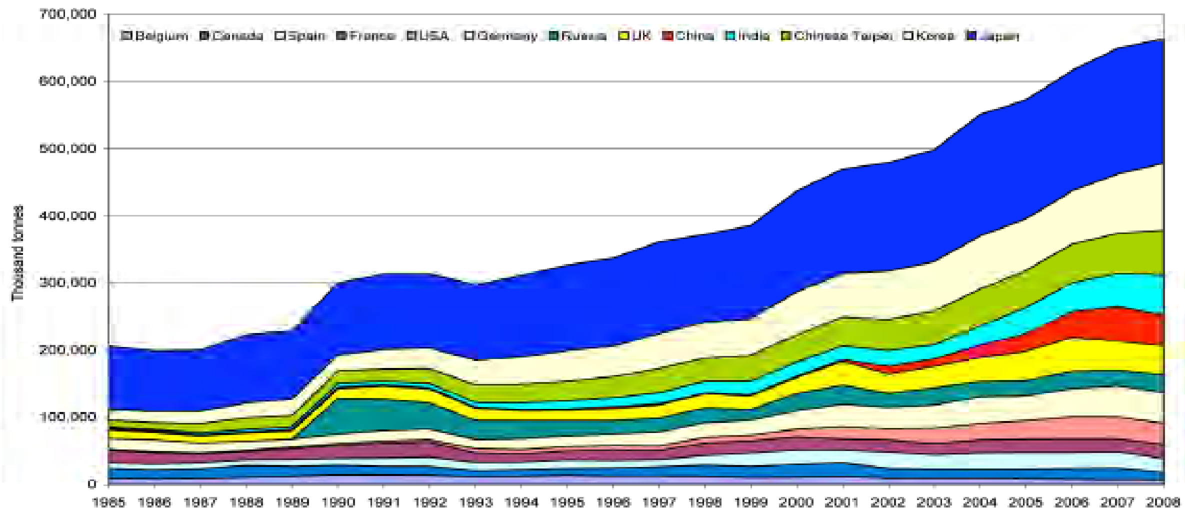

Figure A2-8: Historical trend of world hard coal imports from major importing countries 1985 – 2008. Data sources: (IEA 2009)

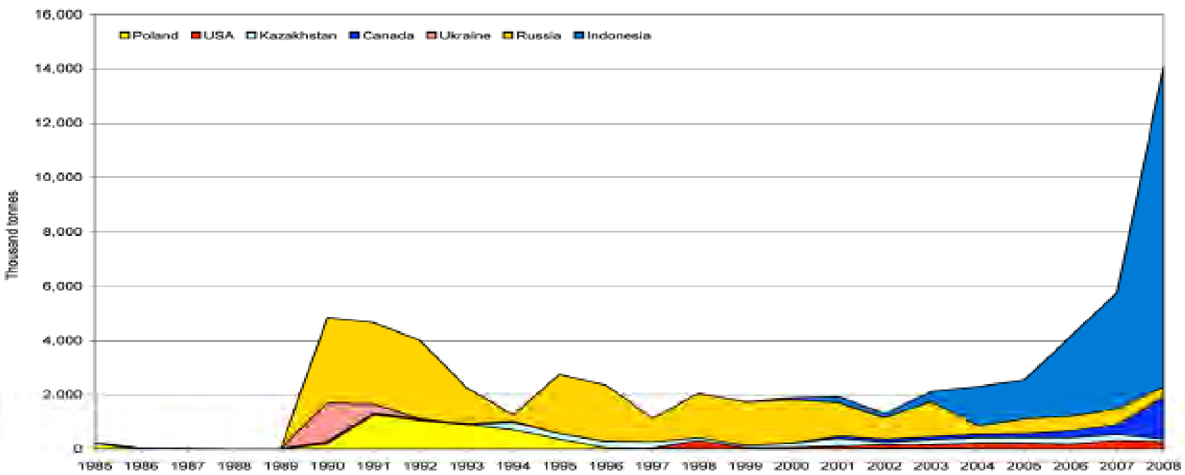

Figure A2-9: Historical trend of world brown coal exports from major export countries, 1985 – 2008. Data sources: (IEA 2009)

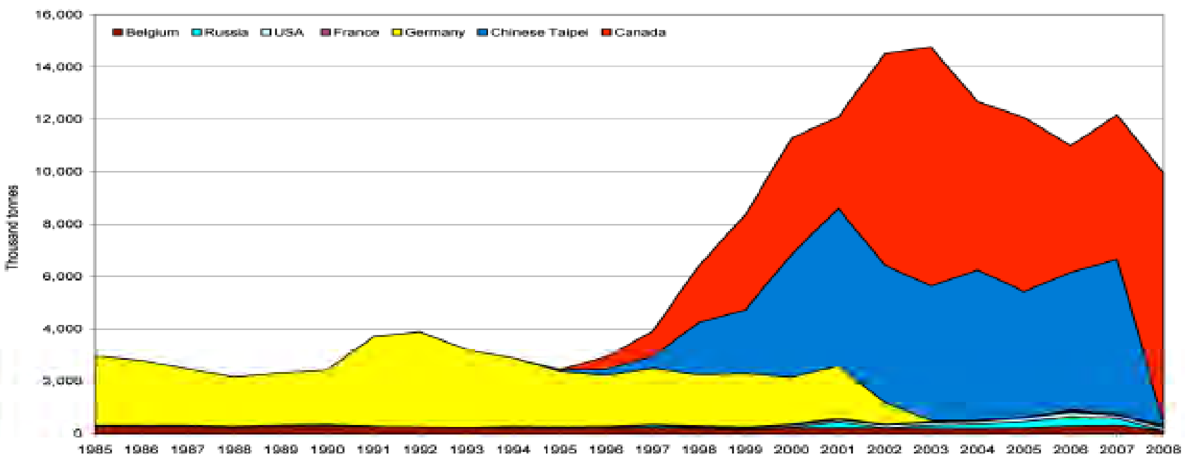

Figure A2-10: Historical trend of world brown coal imports from major import destinations, 1985 – 2008. Data sources: (IEA 2009)

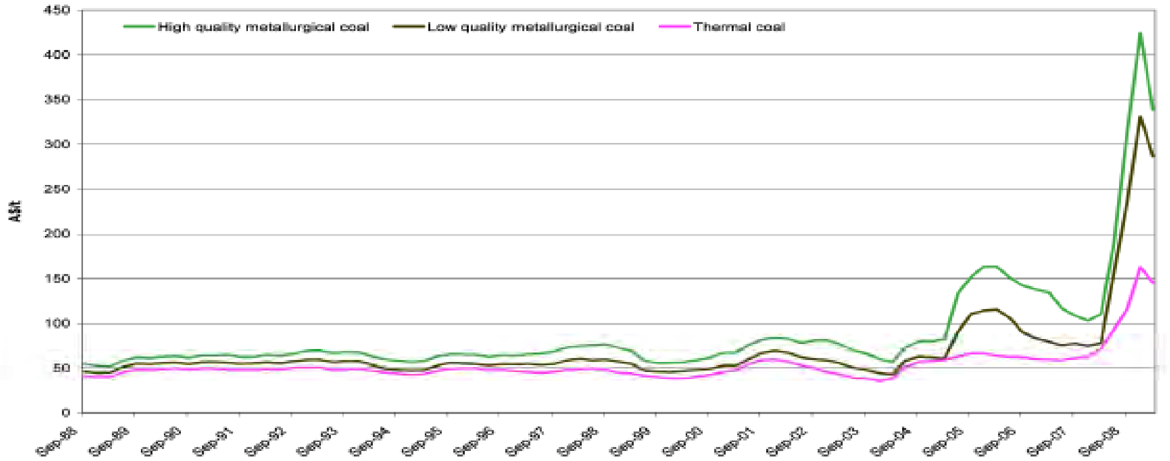

Figure A2-11: Australian Thermal and Metallurgical Coal Price (A$/t) from Sep 1988 to Mar 2009. Source of data: (ABARE 2009).

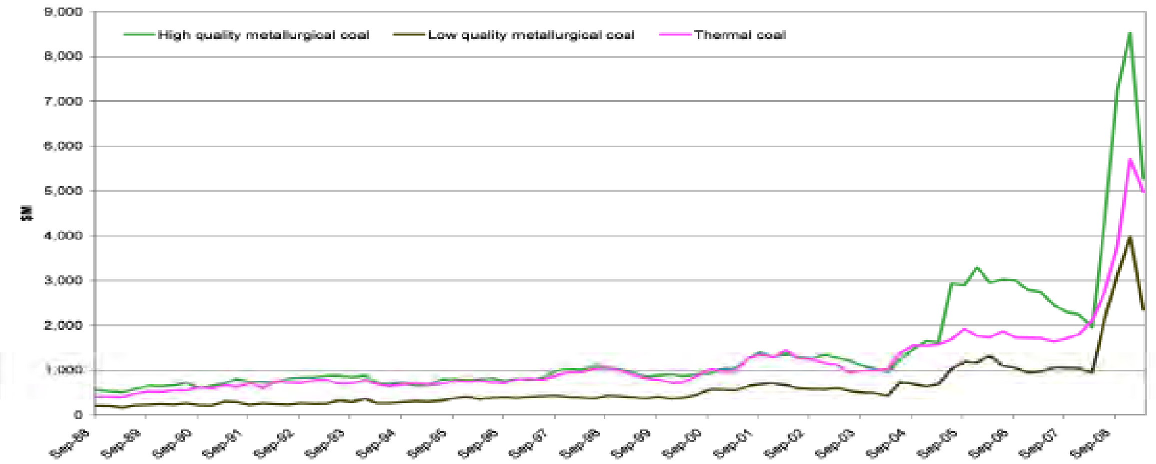

Figure A2-12: Australian Thermal and Metallurgical Coal Exports value ($M) from Sep 1988 to Mar 2009. (ABARE 2009).

Table A2-6: Top ten export destinations for coking and thermal coal from Australia in 2008

Coking Coal			Thermal Coal			Total Coal		
Rank	Country	Export (tonnes)	Rank	Country	Export (tonnes)	Rank	Country	Export (tonnes)
1	Japan	37,918,366	1	Japan	18,811,614	1	Japan	56,729,980
2	India	20,857,269	2	Korea	10,748,417	2	Korea	23,384,809
3	Korea	12,636,392	3	Taiwan	7,651,771	3	India	21,473,906
4	Brazil	5,569,310	4	Thailand	1,158,090	4	Taiwan	13,177,099
5	Taiwan	5,525,328	5	Malaysia	934,385	5	Brazil	5,807,385
6	France	5,065,574	6	China	837,818	6	France	5,555,405
7	United Kingdom	3,973,720	7	India	616,637	7	Netherland	4,205,325
8	Netherland	3,636,706	8	Spain	582,098	8	United Kingdom	3,973,720
9	Belgium	2,782,239	9	Netherland	568,619	9	Belgium	2,856,236
10	Italy	2,561,877	10	France	489,831	10	Spain	2,816,090

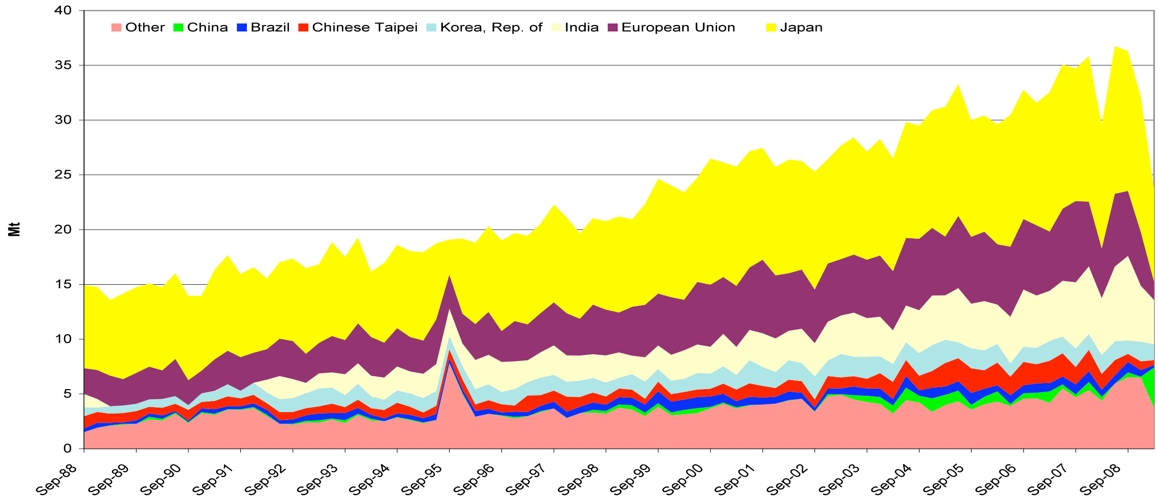

Figure A2-13: Australian metallurgical coal exports (Mt) from Sep 1988 to Mar 2009. (ABARE 2009).

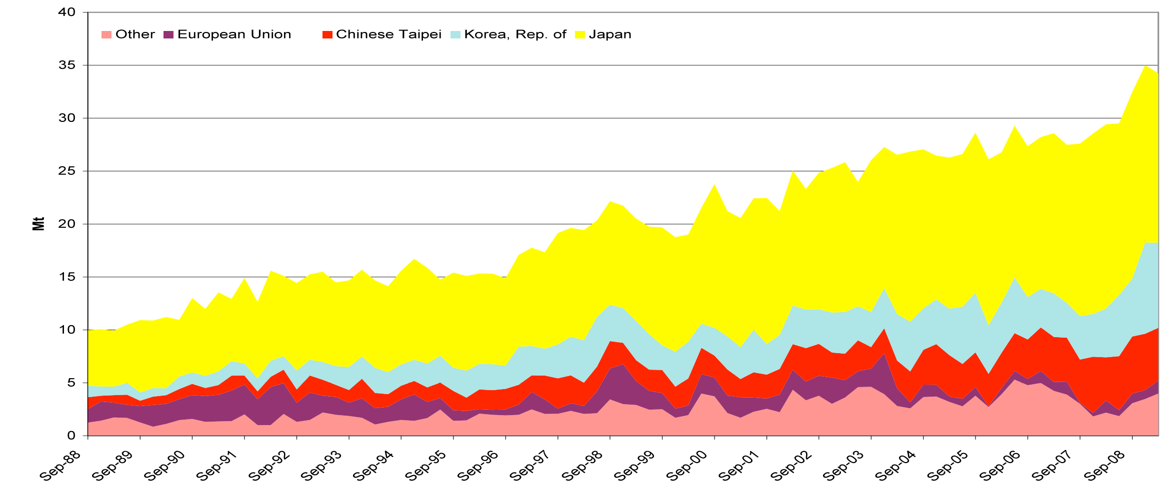

Figure A2-14: Australian thermal coal exports (Mt) from Sep 1988 to Mar 2009. Source of data: (ABARE 2009).

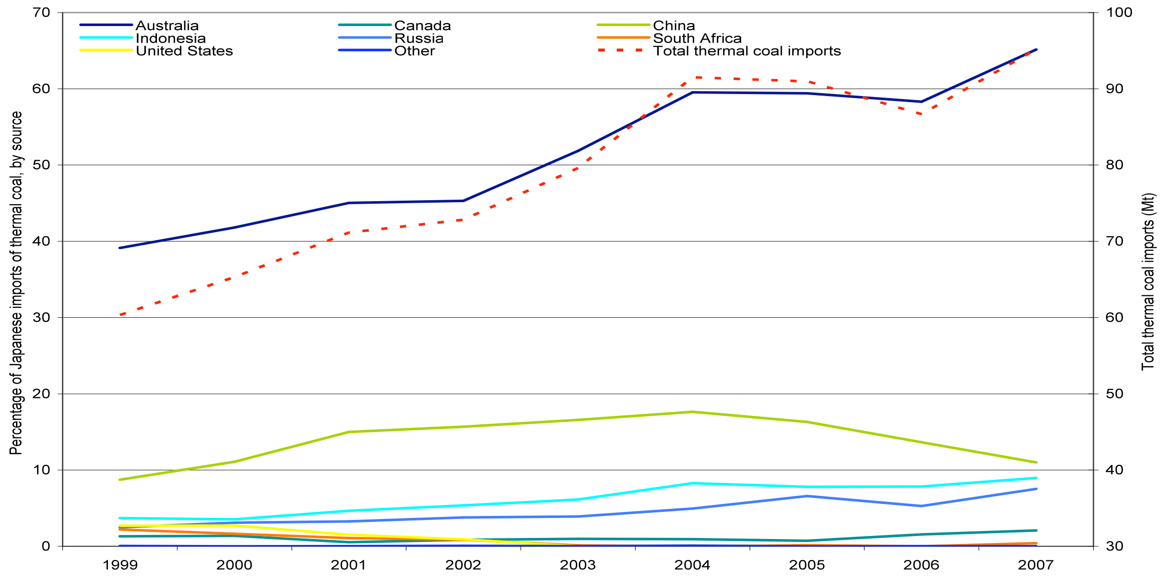

Figure A2-15: Japanese thermal coal imports from different export countries from 1999 to 2007. Source of data: (ABARE 2008)

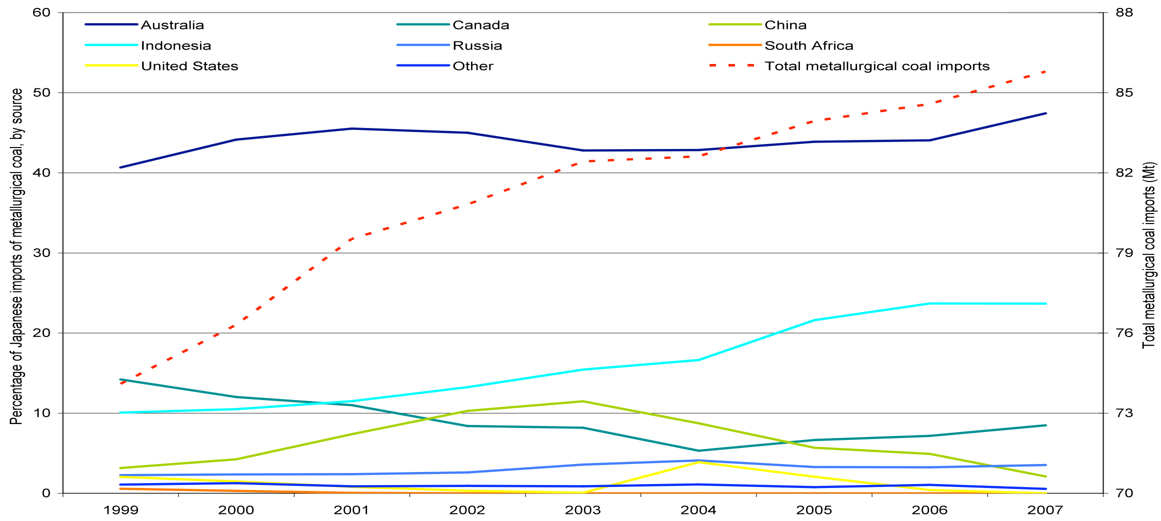

Figure A2-16: Japanese metallurgical coal imports from different export countries from 1999 to 2007. Source of data: (ABARE 2008)

Please refer to references at the end of Chapter 5.