Mineral Commodity Report 18 - Coal

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Discovery and Origin of Names

Coal has been known from ancient times, even though before the 'industrial revolution' it did not play a part of much importance. It is probable that the Chinese knew and exploited coal many centuries before Christ (Chengi mines). Much later, Marco Polo (1280) mentions coal as one of the curiosities he came across in China. Perhaps the earliest reference relating to the use of coal as a fuel is found in the book on 'Stones', by Greek philosopher Theophrastus, from about 315 B.C. He mentions an earthy substance called *anthrax*, which would kindle and could be used by smiths. When the Romans invaded Gaul in about 50 B.C., they were struck by the fact that in the vicinity of St. Etienne "flammable earth" was being excavated from the mountains.

In Britain coal had entered household use by the ninth century, and trade in it was active by the thirteenth century. The Newcastle Coalfield is thought to have been the earliest coal mining area, receiving its first charter or license from Henry III in 1239. With the depletion of British forests, coal became the principal fuel for industrial development from the seventeenth century, replacing charcoal in the smelting of iron after Dud Dudley originated the process in 1621. Development of the steam engine during the eighteenth century provided another huge stimulus to coal mining, and ushered in the industrial age in Britain, fuelled by coal.

It is probable that the first coal used in New Zealand was extracted in the early 1830s from outcrops at Shag Point, on the Otago coast north of Dunedin, by whalers as a fuel for their try-pots. In 1844 coal was discovered at Coal Point, north of the Clutha River mouth, while on the West Coast, Brunner discovered coal near Charleston in 1846 and on the Grey River in 1848. By 1880, coal had been discovered in many other parts of the North and South islands. The first recorded coal mine opened in 1849 on Saddle Hill near Dunedin.

The origin of the name coal is uncertain (Sanskrit *jval*, to glow, *kal*, black; Latin *calor*, heat; Greek *kelainos*, black; Arabic *kala*, black; German *Kohle*, coal; Russian *ugol'*, coal; Old English *col*, *cole*, *kole*, *cool*, *coyll*, *coale*, etc.). The Old English word *cole* originally implied any substance which could be used as a fuel, usually being added to another word as a suffix. The oldest form is probably *charcole*, and the word *cole* for a long time meant simply charcoal. Coal, in the sense in which we now use the term, was originally spoken of as *pit cole* or *earth cole*. As wood became scarce and charcoal fell into disuse, pit coal became increasingly important, and the word coal emerged as the name for pit coal, no longer confused with charcoal.

The names of coal rank classes are of more certain origin. Lignite is from the Latin *lignum* meaning wood. Bituminous is an old name derived from the Latin *pix*, pitch, *tumeo* to swell, *pixtumens*, swelling pitch, and applied to coking coal, either because it was believed to represent a compact form of bitumen, or because this type of coal gave abundant coal tar on heating. Anthracite is from the Greek *anthrax*, an old word for coal or charcoal.

Formation and Properties

Coal is a readily combustible sedimentary rock formed by the compaction or induration of plant debris. Schopf (1956) defined coal as a rock containing more than 50% by weight and more than 70% by volume of carbonaceous material. The physical and chemical properties of coal are determined by two major factors: the nature of the original plant debris and the degree of chemical alteration, or diagenesis of the debris. The original plant material and its biochemical alteration before burial determines coal type, whereas the degree of geochemical alteration, or coalification, resulting from burial determines coal rank. The properties of coals vary widely because of the many possible combinations of these two factors. Chemical differences are most marked in low rank coals but during the coalification process (rank increase) there is a convergence in their chemical character.

The two basic coal types are: humic coals derived mainly from macroscopic plant debris such as wood, bark and leaves, and sapropelic coals derived from microscopic plant parts such as spores, resins, waxes and algal materials. The vast majority of coals are humic, with their main organic component a lustrous dark brown to black material, originating from woody tissues preserved in peat mires. Humic coals commonly are stratified. Sapropelic coals, sometimes known as cannel or boghead coals, were deposited under anaerobic conditions as subaquatic organic muds, rich in pollen, spores, resin, and algal and fungal remains. They are dull and typically not stratified, but may occur as lenses or thin layers within humic coals.

The complete decay of plant material in swamps is prevented by the oxygen-poor conditions sustained by a water-table at or above the sediment surface, and by the formation of organic acids that limit bacterial activity. Under these conditions, plant materials accumulate and peat is formed by a process called humification, during which limited amounts of methane, carbon dioxide and water are given off. Important factors influencing peat formation are the climate and tectonic conditions. Plant production is fastest in hot humid areas and slowest in dry or cold areas, however, organic decay is also more intense and faster in hot humid climates. Tectonic events, such as the formation of depressions, graben structures or otherwise subsiding areas, favour the formation of peat. The accumulation and preservation of thick peat deposits usually requires an equilibrium between the accumulation rate of organic matter and subsidence to be maintained over a long period of time.

Coalification of the organic material preserved by the peat formation process involves chemical and physical change brought about by biochemical activity (bacteria and fungi, active only during the earliest phase of coalification), temperature, pressure and time. The well known terms peat, lignite, subbituminous, bituminous and anthracite represent different stages of the coalification process, indicating the rank of the coal. The term "brown coal" is often used for lignite and subbituminous coals while "hard coal" is used for those of higher rank. Coal rank can be determined by general parameters such as moisture and volatile matter content, vitrinite reflectance, or by essentially chemical parameters, such as carbon or hydrogen content and calorific value, but no one rank indicator is ideal for all rank ranges.

The major physical changes brought about by burial and coalification, are a reduction in moisture content, an increase in density and a decrease in porosity. Chemical changes are an extension of the humification process and include a decrease in volatile matter. The net result of changes during coalification is a continuous but nonlinear enrichment of carbon with increasing rank (Fig. 1). Depth of burial and geothermal gradient are the major factors affecting coal rank, but rank may also be increased by local igneous or tectonic activity.

Uses

Coal has a wide range of uses, but is most significant in electricity generation, steel and cement manufacture, and industrial process heating. In the developing world, coal is still important for household heating and cooking. According to the World Coal Institute, coal provides about 27% of global primary energy needs and its major uses are summarised in Fig. 2. Coal provides about 7% of New Zealand's primary energy supply and its major end uses are summarised in Fig. 3 (Ministry of Commerce 1998a).

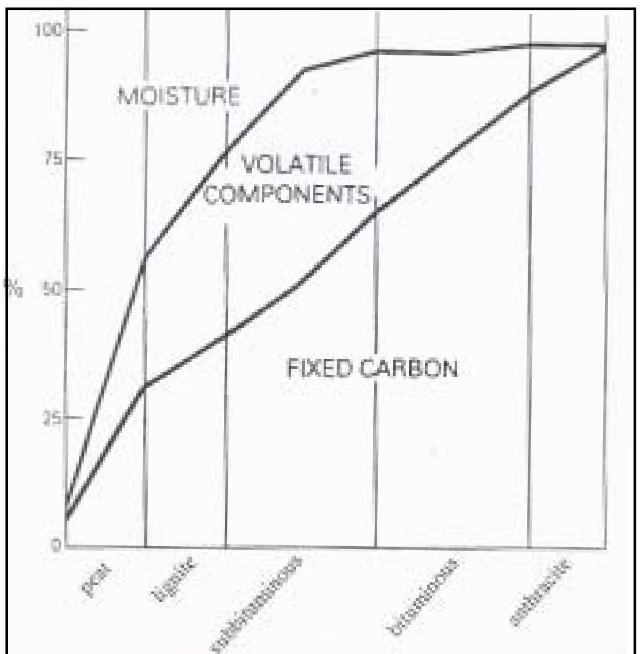

Figure 1: Generalised changes in coal composition during coalification (rank increase) (after Watson 1983).

Coal is the major fuel used for electric power generation, with more than half of total world production currently being used for this purpose (Fig. 2). In 1995, coal-fired power stations produced 37% of the world's electricity (Fig. 4). Many countries are heavily dependent on coal for electricity, including Poland (95%), South Africa (93%), Australia (83%), Denmark (77%), China (75%), Greece (69%), Germany (53%) and the USA (53%). New Zealand

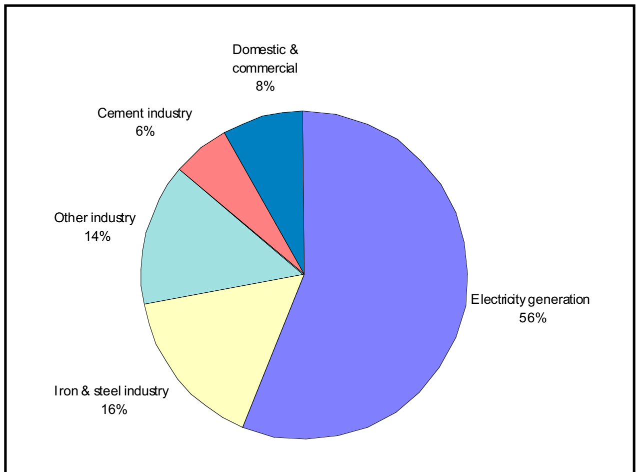

Figure 2: World coal use by sector for 1996 (source: World Coal Institute, London).

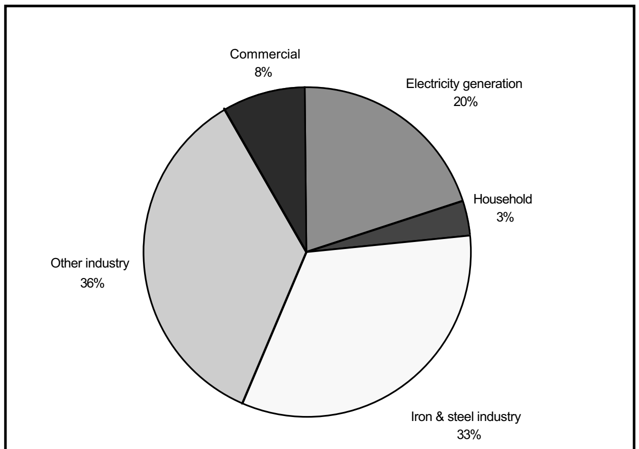

Figure 3: Average New Zealand domestic coal use by sector for the period 1994-98 (source: Ministry of Commerce 1998a).

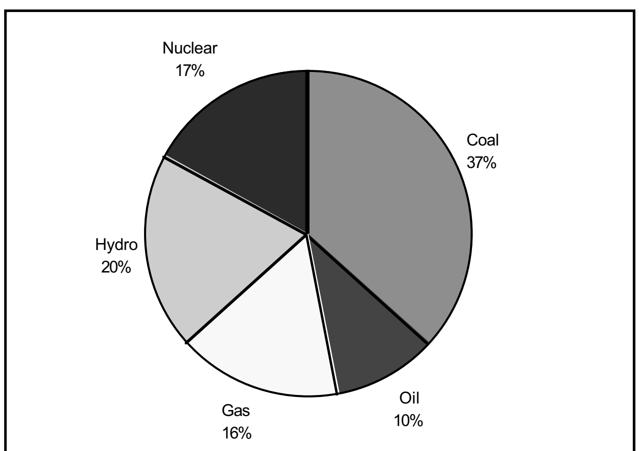

Figure 4: World electricity generation by fuel type (source: EIA International Energy Outlook, 1995 data).

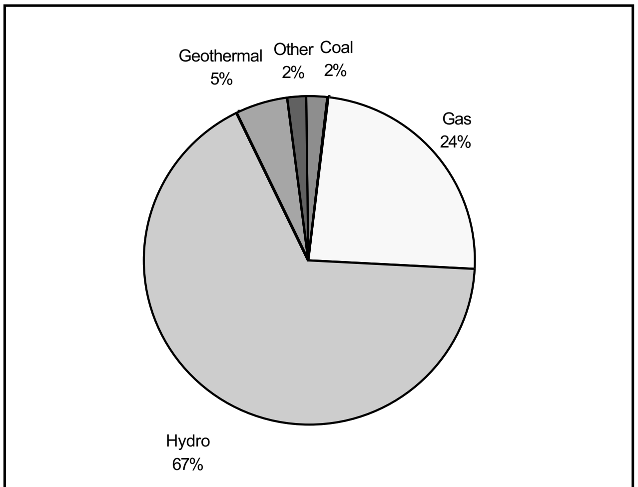

Figure 5: Average New Zealand electricity generation by fuel type for the period 1994-98 (source: Ministry of Commerce 1998a).

generates a comparatively small amount of its electricity using coal. About 2% of electricity generation was produced from coal during the five year period from 1994 to 1998 (Fig. 5), consuming about 12% of total coal production and 20% of domestic coal use (Fig 3) (Ministry of Commerce 1998a). There has been considerable fluctuation in the use of coal for electricity generation, with annual use ranging from 9% to almost 40% of New Zealand's domestic coal use over the last five years.

Coal is also essential for iron and steel production, with about 70% of world steel production coming from iron made in blast furnaces using coal and coke. In 1995, the steel industry consumed 16% (592 Mt) of the world's hard coal production. The steel industry in New Zealand consumed about 33% of domestic coal supply during the five year period from 1994 to 1998 (Fig. 3) (Ministry of Commerce 1998a).

The majority of cement works worldwide are coal-fired and use about 6% of world coal production. Coal is also used for industrial process heating within many other industries including lime and plaster, meat, dairy products, pulp and paper, and wool.

Price

The price of coal on the world market varies considerably, with factors such as coal quality, production costs and country of origin contributing to price differences. The marker price for steaming coals delivered to northwest European ports has ranged from US$31.8 to US$45.8 per tonne (cost, insurance, freight or CIF) since 1991 (McCloskey Coal Information Services 1998). The average marker price for the first quarter of 1998 was US$34.5 per tonne. The average price of coal delivered to United States steam-electric utility plants during 1997 was US$28.8 per tonne.

On the Japanese bench mark system, the price of coking coal was US$55.5 per tonne (CIF) in 1997, having ranged between US$51.8 and US$60.5 per tonne over the previous decade. The bench mark price for steaming coal in 1997 was US$45.5 per tonne (CIF), having ranged between US$41.3 and US$50.8 per tonne over the previous decade. However, the Japanese bench mark system is now breaking down, with Japanese utilities experimenting on the spot market and obtaining coal at a considerable discount to the bench mark price. Indonesia, Colombia and South Africa are the lowest cost steaming coal exporters, with average FOB (free on board) cash costs of about US$22 per tonne (AME Mineral Economics 1997).

World Production and Consumption

Coal is by far the most abundant fossil fuel, occurring in over 100 countries. The world's total proven reserves at the end of 1997 have been estimated at 1 040 000 million metric tonnes (Mt), economically accessible using current mining technology (BP 1998). About half of this is hard coal (anthracite and bituminous). The USA and former Soviet Union each contain 23% of the world's reserves, China has 11% and western Europe has 10%. Other countries with large reserves include Australia, India, Germany, South Africa and Poland.

At 1996 levels of consumption, world proven coal reserves are sufficient to last another 225 years. However, it is likely that additional reserves will be proved by on-going exploration and some coal that is currently inaccessible will become economically accessible as further improvements are made in mining technology and through the increased use of presently uneconomic lower grade coals.

Total world coal production in 1996 was 4 630 Mt, comprising 3 705 Mt of hard coal and 925 Mt of brown coal/lignite (IEA 1996). The major producing countries were China (1 375 Mt), USA (959 Mt), India (296 Mt), Russia (255 Mt), Australia (247 Mt), Germany (240 Mt), South Africa (208 Mt) and Poland (202 Mt). Of the coal produced in 1996, 480 Mt of coking and steaming coal were traded internationally. The major exporters were Australia (140 Mt), USA (83 Mt), South Africa (59 Mt), Indonesia (36 Mt), Canada (34 Mt), China (29 Mt), Poland (27 Mt), Colombia (25 Mt) and Russia (21 Mt). Major coal importers were Japan (126 Mt), South Korea (46 Mt), Taiwan (31 Mt), UK (17 Mt), the Netherlands (17 Mt), Italy (17 Mt) and Germany (16 Mt).

Coal is mined using either opencast methods where the coal seam is near the surface, or underground mining where the seam is too deep to be recovered economically by opencast mining. The majority of the world's coal reserves are recoverable by underground mining. Currently, about 65% of world hard coal production comes from underground mines, but for some major coal producers, such as the USA and Australia, the proportion is significantly lower.

World coal production is expected to match demand without difficulty until at least 2020, with the main growth in coal demand arising from increasing electricity generation. By 2010, annual world coal consumption is projected to reach 5 940 Mt, with increased consumption in China alone accounting for more than 75% of the projected increase (EIA 1995).

New Zealand Occurrence, Production and Resources

Coal is New Zealand's most abundant fossil fuel and has been an important energy source since the late nineteenth century. Workable seams are present in the Northland, Waikato and Taranaki regions of the North Island, and in the Nelson, West Coast, Canterbury, Otago and Southland regions of the South Island (Figs 6 and 7). The total in-ground resource is estimated to be 15 563 Mt, of which about 8 643 Mt (55%) is considered to be recoverable (Barry et al. 1994). Most of the resource is in the South Island, where over 13 000 Mt (84%) of the in-ground resource is present, mainly in the huge lignite deposits of Southland (Table 1). The North Island in-ground resource of about 2 461 Mt (16%) is almost entirely subbituminous coal. Of the recoverable resource, 7 756 Mt (90%) is in the South Island and 887 Mt is in the North Island (Barry et al. 1994).

Very large quantities of coal are also known from petroleum exploration wells at depths down to 5 km in the Taranaki, Canterbury, Westland and Great South basins (Sherwood 1985). Isaac et al. (1994) suggest that extensive coal measures are also present in the Northland basin, west of the Northland peninsula. These deep coals are never likely to be mineable, but are of considerable economic importance as petroleum source rocks. They will not be considered further in this report.

With the exception of a few thin seams in Permian to early Cretaceous basement rocks (Suggate 1990), all New Zealand coals occur within overlying late Cretaceous-Cenozoic sedimentary rocks. Coal measures commonly rest directly on basement rocks and are commonly overlain by marine sediments. Less commonly they occur above mid-Tertiary marine beds, at the base of overlying non-marine sediments, or are rarely interbedded within a marine sequence.

Differential subsidence during and after coal formation has led to wide variation in rank. New Zealand coals range from high moisture lignite to low volatile bituminous rank, with minor anthracite occurrences resulting from local contact metamorphism (Fig. 8) (Suggate 1959). Lignite and subbituminous coals are most abundant, comprising over 90% of in-ground and recoverable resources.

The following summary of the geology and resources of New Zealand's coal regions and significant coalfields draws extensively on detailed reviews by Suggate (1959), Willett (1965), Taylor and Kunz (1983), Sherwood (1986), Ankorn et al. (1988) and Barry et al. (1994). The methods used to calculate resource quantities and terms used to describe them are defined by Sherwood (1987).

Northland Coal Region

Late Eocene Kamo Coal Measures up to 20 m thick overlie basement in eastern Northland and are overlain by either marine Ruatangata Sandstone or Northland Allochthon. The coal measures outcrop intermittently between Kerikeri and Waipu, but are thickest between Kawakawa and Whangarei. Their distribution is strongly influenced by basement relief, indicating that they may have been deposited mainly in WSW-ENE oriented half-grabens (Isaac 1985). A single lenticular coal seam up to 8 m thick is usually present close to basement. A near-vertical seam is present within the Northland Allochthon at Avoca, 15 km north of Dargaville. The coal is older than that of the coalfields to the east, and lower in rank, but is thought to have little or no economic potential (Isaac et al. 1994).

Coal was formerly mined at Kawakawa, Hikurangi, Kamo and Kiripaka (Fig. 6), the last major mine (at Kamo) closing in 1955 due to flooding following the removal of pillars. Predominantly underground workings produced about 7.3 Mt of subbituminous A to high-volatile C bituminous coal, with a medium to very high sulphur content of 1-5% (Isaac

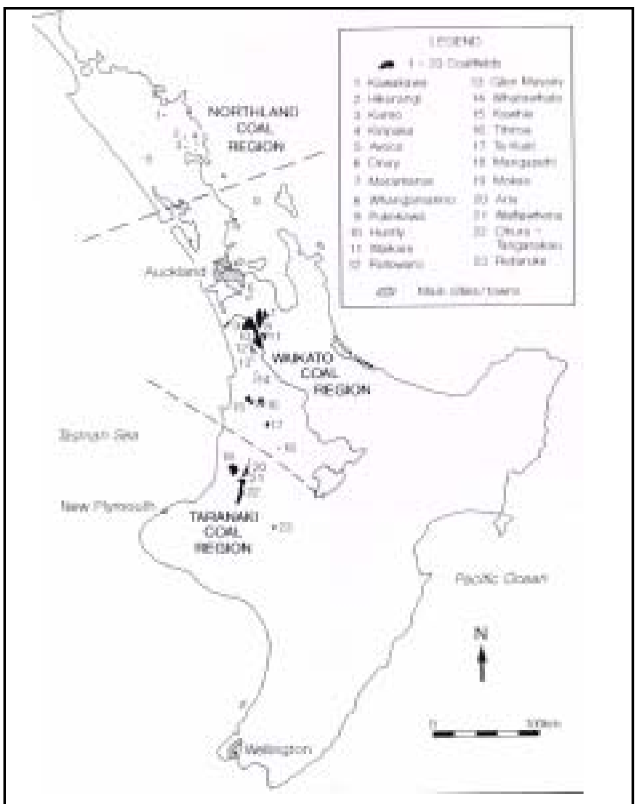

Figure 6: Coal regions and coalfields of the North Island, New Zealand

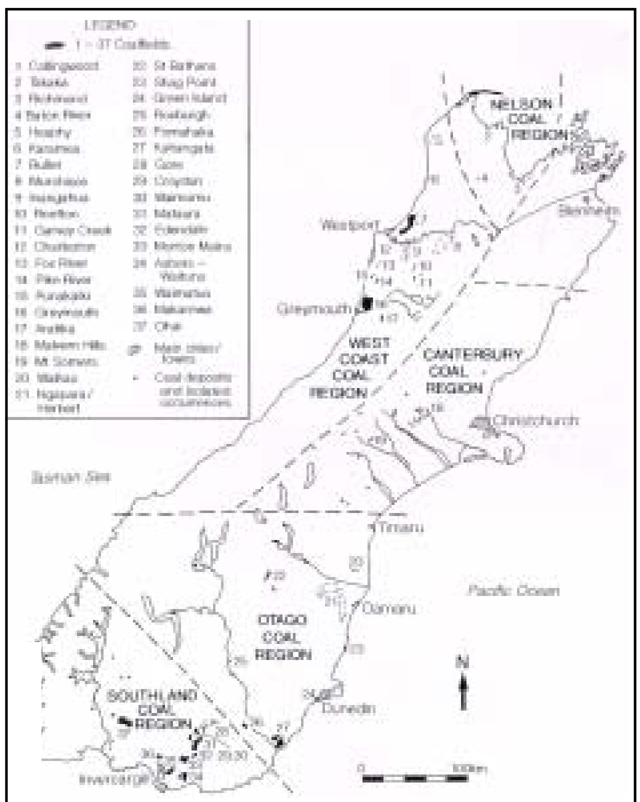

Figure 7: Coal regions, coalfields and small coal deposits of the South Island, New Zealand (after Barry et al. 1994).

Region/Coalfield	Coal-in-ground resource (Mt)	Recoverable coal resource (Mt)
Northland Region	2.5	-
Waikato Region	2078.7	714.1
Pukekawa	40.7	12.2
Whangamarino	28.9	8.7
Maramarua	233.2	101.9
Waikare	219.8	96.8
Huntly	1048.2	313.6
Rotowaro	70.9	48.7
Glen Massey	2.1	1.1
Whatawhata	3.7	2.9
Kawhia	181.9	59.2
Tihiroa	181.1	49.2
Te Kuiti	38.4	11.6
Mangapehi	29.8	8.2
Taranaki Region	379.9	173.5
Mokau	164.9	108.1
Aria	1.9	-
Waitewhena	89.8	32.1
Ohura-Tangarakau	110.9	33.3
Retaruke	12.4	-
Total North Island	**2461.1**	**887.6**
Nelson Region	1.5	-
West Coast Region	983.5	343.3
Buller	193.4	118.4
Inangahua	11.5	5.9
Reefton-Garvey Creek	25.2	11.6
Charleston	16.5	12.9
Pike River	94.3	28.3
Greymouth	543.9	163.5
Aratika	90.1	-
Minor coalfields	8.6	2.7
Canterbury Region	3.6	2.2
Otago Region	2721.8	1154.2
St Bathans	1027.1	569.1
Roxburgh	248.3	156.1
Minor Central Otago coalfields	123.6	6.2
Ngapara-Herbert	4.5	3.6
Waihao	14.8	11.9
Shag Point	1.1	-
Green Island	18.1	4.3
Kaitangata	1249.2	386.2
Pomahaka	35.1	16.8
Southland Region	9392.2	6256.4
Gore	304.4	244.1
Croydon	483.5	333.1
Waimumu	285.5	233.1
Mataura	2940.1	1944.9
Edendale	618.7	494.9
Morton Mains	1225.7	547.1
Waimatua	961.9	833.9
Ashers-Waituna	1356.6	746.1
Makarewa	1026.8	820.9
Ohai	179.1	50.4
Orepuki	9.9	7.9
Total South Island	**13102.6**	**7756.1**
Total New Zealand	**15563.7**	**8643.7**

Table 1: Summary of New Zealand coal resource estimates (source: Barry et al. 1994).

1982). Kamo and Hikurangi coalfields still have small in-ground resources of about 1.5 Mt and 1 Mt respectively, but all other areas are considered to have been worked out. None of the coal at Kamo and Hikurangi is considered economically recoverable (Barry et al. 1994). Coal Resources Survey drilling in 1982-83 found no new areas of coal measures between those previously mined and the chances of finding further mineable deposits are assessed as poor (Isaac 1985).

Pleistocene dune complexes on the west coast of Northland contain lenticular lignite seams up to 7 m thick, but typically less than 3 m thick. They are best developed in the southern Aupouri Peninsula and North Kaipara Barrier (Sherwood and Schofield 1985), but high overburden:coal ratios are likely to make opencast mining uneconomic.

Waikato Coal Region

Waikato Coal Region comprises some 13 coalfields developed in late Eocene-middle Oligocene Waikato Coal Measures, extending from Drury, near Auckland, to Mangapehi, south of Te Kuiti (Fig. 6). It is subdivided into northern and southern subregions by basement rocks of the NE-trending Hakarimata and Taupiri ranges, located south of Huntly and between Glen Massey and Whatawhata coalfields (Edbrooke et al. 1994). At present, it is the only producing North Island coal region.

Coal has been mined from Waikato seams since the late 1840s, almost entirely by underground methods prior to the 1940s, but with greater use of large-scale opencast mining since then. By the 1950s annual production exceeded 1 Mt and recent production has been between 1.3 and 1.6 Mt, which is almost half New Zealand's total annual production. Over 80 Mt has been produced from the region, with more than 90% coming from Maramarua, Huntly and Rotowaro, the region's major coalfields. Waikato coal supplies the North Island market for power generation, industrial steam raising and the Glenbrook steel mill, and is the major source for the domestic market. The Glenbrook steel mill is currently the largest single consumer of Waikato coal, using about 0.8 Mt per year for direct reduction ironmaking.

Waikato Coal Measures are the basal formation of the predominantly transgressive Te Kuiti Group, resting on an undulating erosion surface cut into deeply-weathered Mesozoic basement rocks, and grading up into shallow marine formations. The coal measures were deposited within a N to NNW-trending valley system, about 35 km wide and 200 km long, flanked by low basement hills. They are typically less than 100 m thick but exceed 200 m locally, and contain 8 significant coal seams; four in the northern subregion and four in the southern subregion (Edbrooke et al. 1994).

Taupiri Seam is known only from near the base of locally thick coal measures in Callaghans Sector of Rotowaro Coalfield. Its numerous splits are typically 3-8 m thick and have been mined extensively. Kupakupa Seam occurs only in the northern subregion (north of Glen Massey), but is the most widespread seam within Waikato Coal Measures and is the usual target for mining. Except in the Callaghans Sector of Rotowaro Coalfield, it occurs at or near the base of the coal measures and is typically 3-12 m thick, but may reach

20 m in parts of Huntly and Waikare coalfields. Renown Seam overlies Kupakupa Seam in Glen Massey, Rotowaro, Huntly and Waikare coalfields; it is typically less than 8 m thick and has a greater degree of splitting than Kupakupa Seam. Ngaro Seam occurs within the upper part of the coal measures in Huntly and Waikare coalfields; it is usually less than 3 m thick and has never been mined. Kemps Seam is a thin (1-2 m) seam lying immediately above the coal measures in Glen Massey Coalfield; it has been worked by a small opencast mine in conjunction with the underlying Renown Seam.

In the southern subregion, Pirongia Seam lies near the base of locally thick coal measures in Tihiroa Coalfield. It is up to 14 m thick, but typically is less than 7 m and has never been mined. Waipa Seam overlies Pirongia Seam and is also restricted to Tihiroa Coalfield; it is a thin 'dirty' seam, typically less than 4 m thick. Okoko Seam is the most widespread seam in the south, occurring near the top of the coal measures in all south Waikato coalfields except Mangapehi. Okoko Seam is typically less than 4 m thick but may reach 10 m locally. It has been mined in Whatawhata, Kawhia and Te Kuiti coalfields. Mangapehi Seam is restricted to, and is the only seam in Mangapehi Coalfield. It is up to 14 m thick and lies within the lower half of the coal measures. The seam has been worked by Mangapehi and Benneydale mines.

Waikato coals span the range of ASTM subbituminous rank (Fig. 8), from subbituminous C in Tihiroa, Kawhia, Waikare and Maramarua coalfields, to high subbituminous A in Glen Massey, Rotowaro, Huntly and Pukekawa coalfields (Edbrooke et al. 1994). Northern seams are characterised by low to medium ash contents and low sulphur, whereas southern seams typically have medium to high ash and medium to high sulphur. Variation in sulphur content is primarily a consequence of the varying depth of seams below overlying marine formations.

The total coal in-ground resource for the Waikato region is estimated at 2 078 Mt, of which 714 Mt is considered to be recoverable currently (Barry et al. 1994). The majority of the recoverable resource is in Huntly Coalfield (44%), with significant resources also in Maramarua (14%), Waikare (13%), Kawhia (8%), Rotowaro (7%) and Tihiroa (7%) coalfields.

Coal is currently being, or has recently been mined from Maramarua, Huntly, Rotowaro, Kawhia and Mangapehi coalfields. Opencast mines in Maramarua Coalfield produced 148 000 t from Kupakupa Seam in 1997, mainly for industrial steam raising. Prior to the closure of Meremere power station, the Kopako Mine at Maramarua produced between 0.4 and 0.6 Mt annually, and was for many years New Zealand's largest producing mine. The coalfield has produced a total of about 15 Mt and a large resource suitable for both opencast and underground mining remains (Table 1).

Huntly Coalfield produced 314 000 t in 1997, mainly from Kupakupa Seam in Solid Energy's Huntly East Mine (286 000 t). Huntly West Mine has produced only small quantities since the explosion which virtually closed it in 1992. A small private opencast mine contributes nearly 10 000 t annually. Huntly coal is supplied to the Glenbrook steel mill and is also used for power generation, as well as supplying the domestic market. Total production from Huntly Coalfield has been about 18 Mt and a large resource suitable for underground mining remains in northern parts of the coalfield (Edbrooke 1987).

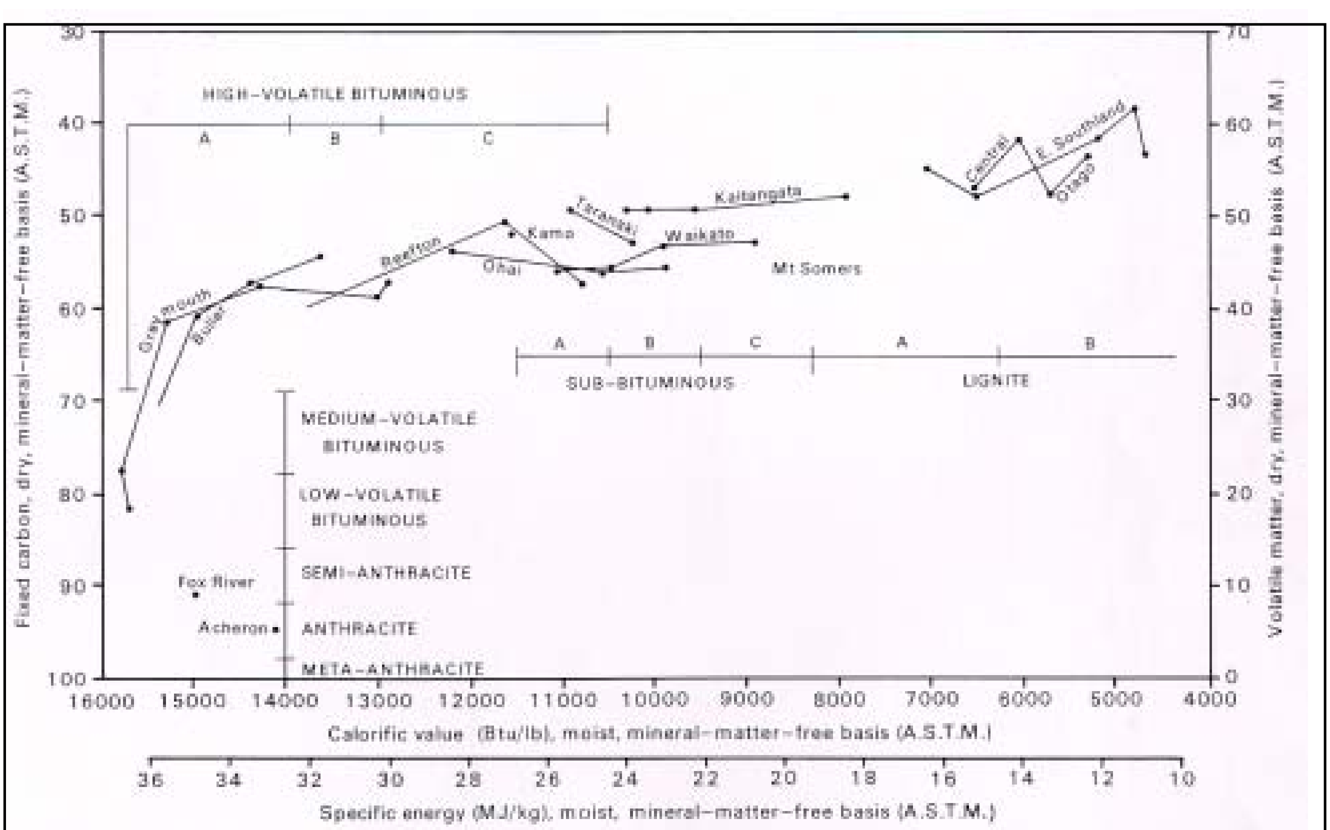

Figure 8: A generalised diagram illustrating the rank range of New Zealand coals from peat (right) to anthracite (left). The full range of variation within any particular coalfield is not necessarily indicated. In New Zealand, anthracite rank has been reached only as the result of contact metamorphism (after Sherwood 1986).

Rotowaro Coalfield has the greatest production of all Waikato coalfields, producing just over 1 Mt in 1997. Current production comes mainly from Solid Energy's Waipuna (Fig. 9), Township and Awaroa opencast mines (0.9 Mt) and Glencoal Energy's Renown opencast mine (100 000 t). A small private underground mine also operates, winning coal from a Glencoal licence. Coal is worked mainly from Taupiri and Kupakupa seams, with smaller production from Renown Seam (Fig. 9). Rotowaro coal supplies the steel mill, Huntly power station, a range of industrial users, and the domestic market. Over 60 mines have operated in Rotowaro Coalfield since 1915, producing a total of about 50 Mt to date. A large resource remains, much of which is shallow and has been worked underground with a low extraction rate, but can now be worked opencast (Fig. 10) (Kirk et al. 1988).

Pirongia and Waitaheke opencast mines, operated by Glencoal Energy, produced 37 000 t from Kawhia Coalfield in 1997. Both mines work Okoko Seam, producing a poor quality coal with a medium to high ash content and high sulphur. Kawhia Coalfield has produced a total of about 1.5 Mt since 1930, with the majority of this coming from Pirongia Opencast mine (1.3 Mt). Only a small amount of opencast coal remains in southern Kawhia Coalfield, but a significant resource of deeper coal is present to the north and west (Kirk et al. 1988).

The underground Benneydale Mine has worked Mangapehi Seam in Mangapehi Coalfield since 1978, producing about 10 000 t annually, until it closed in 1998. Benneydale Mine and the earlier Mangapehi Mine have produced a total of just over 1 Mt since 1933. Mangapehi Coalfield is not well explored and the remaining resource is uncertain. However, recent drilling by Solid Energy north of Benneydale Mine has indicated a significant additional underground resource (N. Fowke pers. comm.).

Figure 9: Solid Energy's Waipuna opencast mine in Rotowaro Coalfield, with coal being extracted from Taupiri (bottom of pit), Kupakupa (middle) and Renown (top) seams (photo: Lloyd Homer).

Taranaki Coal Region

Taranaki Coal Region comprises the Miocene coal measures of northeastern Taranaki and southern King Country, and includes Aria, Waitewhena, Ohura-Tangarakau, Mokau and Retaruke coalfields (Fig. 6). South of the known coalfields,

Figure 10: Old underground mine workings exposed in Taupiri Seam, Maori Farm No. 3 mine, Rotowaro Coalfield. The low extraction percentages achieved by old underground mines makes many of these areas very attractive for modern opencast mines (photo: Wendy St George).

coal scout drillholes and oil prospecting wells have intersected Miocene coal measures at depths down to 1800 m (Sherwood 1984).

The geological setting of Taranaki coals is unusual as they lie within the predominantly marine Mokau Group. The economically important, early Miocene Maryville Coal Measures are underlain and overlain by shallow marine, Lower and Upper Mokau Sandstones. This setting, largely free from the effects of basement topography, has led to the development of typically thin seams of very uniform thickness, persisting over relatively large areas. Maryville Coal Measures are up to 100 m thick and occur over an area of more than 1000 km^2. They contain at least 11 coal seams up to 3 m thick, but no more than 5 seams occur at any one location (Manhire and Phelps 1988). The area of thickest coal formation migrated northward with time, producing a south to north pattern of lower seams pinching out and being replaced by new upper seams. Virtually all production from Mokau, Aria, Waitewhena and Ohura-Tangarakau coalfields has come from seams within the Maryville Coal Measures.

Thin coal measures of much more restricted distribution occur within the Upper Mokau Sandstone. These are the middle Miocene Mangapapa Coal Measures that are present in parts of Ohura-Tangarakau Coalfield. They reach a maximum thickness of 25 m and contain workable coal in a few places (Manhire and Phelps 1988). The correlation of late Miocene coal measures at Retaruke in the southeastern part of the region is unknown (Sherwood 1984).

Taranaki coalfields have a long history of predominantly small-scale underground and opencast mining, beginning as early as 1884 in Mokau Coalfield and continuing until 1990, when the last mine in Waitewhena Coalfield closed. Eleven mines operated in Mokau Coalfield between 1884 and 1987, producing a total of 240 000 t. Four small underground mines produced a total of 53 000 t from Aria Coalfield between 1917 and 1961. Mining in Waitewhena Coalfield began in 1935, and since then, 29 underground and opencast mines have produced a total of about 2 Mt. Production from Waitewhena Coalfield ended in 1990 with the closure of Squires Creek Opencast. Mining in Ohura-Tangarakau Coalfield began in 1927 with several small opencast and underground mines near Ohura, but the only mine with significant production was Tatu State underground mine, which produced just over 1 Mt between 1940 and 1971. Total production from Ohura-Tangarakau Coalfield is about 1.4 Mt. Small-scale opencast mines have produced a total of about 3 000 t from Retaruke Coalfield since 1938 (Sherwood 1984). Total production from the region is about 3.7 Mt.

All Taranaki coals are of subbituminous rank, ranging from subbituminous A to B in the ASTM classification. The majority have medium to high (1-4%) sulphur contents, but they range from 0.9% (low) to 5.7% (very high). The relatively high sulphur content is due to the significant marine influence on Taranaki coal measures. Most seams have low to medium ash contents, except those at Retaruke which have high to very high ash contents (10-20%) and numerous shaley partings (Sherwood 1984). When Taranaki coals were mined, they supplied local and provincial household and industrial markets.

The total in-ground resource is estimated at 380 Mt, of which 173 Mt is considered to be recoverable by opencast and underground mining (Barry et al. 1994) (Table 1). Mokau Coalfield contains the majority of the recoverable resource (62%); Waitewhena and Ohura-Tangarakau have the rest. Aria and Retaruke coalfields have small in-ground resources and no recoverable resources.

Nelson Coal Region

Nelson Coal Region includes Collingwood Coalfield and minor coal deposits at Takaka, Baton River and Richmond Hills (Fig. 7). A small area of coal measures near Picton (Morgan 1921) does not contain a coal resource of any significance and is no longer regarded as a coal deposit (Barry et al. 1994).

Collingwood Coalfield, in the northwestern part of Nelson Coal Region, contains mostly thin (<3 m), discontinuous seams within the late Cretaceous Pakawau Group. Seams are commonly highly split and of subbituminous A to high-volatile C bituminous rank, with low (<0.5%) sulphur and medium (5-10%) ash contents. The Richmond Hills, Baton River and Takaka deposits comprise small inliers and faulted blocks of Eocene Brunner Coal Measures, containing thin (<3 m), highly faulted and often sheared seams of limited lateral extent. Seams are of subbituminous B to high-volatile C bituminous rank, with low to high sulphur and highly variable ash content (Rattenbury et al. 1998).

The greatest production has come from Collingwood Coalfield, with five mines in the Puponga area producing about 0.9 Mt between 1899 and 1974. About 7 000 t were extracted from Takaka Coalfield between 1842 and 1965, mainly by small-scale opencast mines. Production from Richmond Hills and Baton River is estimated to have been about 5 000 t and 4 000 t respectively, before 1939. Most coal produced from the region was for local domestic use.

The region has a very small estimated in-ground resource of about 1.5 Mt, entirely within Collingwood Coalfield, but has no recoverable resource (Barry et al. 1994).

West Coast Coal Region

The West Coast Coal Region comprises 13 coalfields located in north Westland between Aratika, southeast of Greymouth, and Karamea (Fig. 7). Virtually all New Zealand's bituminous coal occurs within the region, either within the late Cretaceous-earliest Tertiary (Haumurian-Teurian) Paparoa Coal Measures or the early Tertiary (Eocene) Brunner Coal Measures. Both sets of coal measures are present in Aratika, Greymouth and Pike River coalfields, and in the Fox River deposit, but elsewhere the Paparoa Coal Measures are absent and Brunner Coal Measures rest on middle Cretaceous or older rocks (Newman 1985). In addition to the Brunner Coal Measures, Miocene Rotokohu Coal Measures are present in Inangahua Coalfield, and Miocene coals occur in the Blue Duck Member of the Longford Formation in Murchison Coalfield.

Paparoa Coal Measures were deposited in a differentially subsiding elongate trough and consist of up to seven units of alternating fluviatile deposits (conglomerate, sandstone, mudstone, coal) and lacustrine siltstone.

Their maximum known thickness is 800 m in Greymouth Coalfield. Paparoa seams are typically up to 10 m thick and very lenticular, most having a maximum extent of about 1.5 km. They all have low sulphur contents and most mined seams have low ash contents and crucible swelling numbers up to 9+++. Brunner Coal Measures were deposited following an early Tertiary period of tectonic quiescence and peneplanation, when renewed widespread fluvial sedimentation occurred in the Eocene. Differential subsidence led to considerable variation in coal measures thickness, ranging from a few metres to more than 130 m in Greymouth Coalfield. Coal measure sedimentation ended with marine transgression and deposition of marine sandstone. Brunner seams have a sporadic distribution and are commonly of variable thickness and limited lateral extent. Seams are typically up to 10 m, but can be as thick as 20 m locally. Most mined seams have low to very low ash contents, particularly the thicker seams, but many have high to very high sulphur contents with substantial in-seam variation. Crucible swelling numbers range up to 9+++ (Sherwood 1986).

The region's complex tectonic history has led to considerable coal rank variation which is not related to age on a regional basis. Paparoa coals range from high volatile C bituminous to low volatile bituminous in Greymouth Coalfield, are high volatile B to A bituminous at Pike River Coalfield, and semi-anthracite in the small Fox River deposit. Brunner coals are within the range of high volatile C to A bituminous in Greymouth, Pike River, Reefton, Garvey Creek and Murchison coalfields, and increase from high volatile A to B bituminous to medium volatile bituminous, from east to west in Buller Coalfield. They are subbituminous C to A in other areas, including Karamea, Inangahua, Charleston and Punakaiki (Barry et al. 1994). Rotokohu coals at Inangahua are subbituminous C, and coals from the Blue Duck Member at Murchison are high-volatile B bituminous.

Mining began in the West Coast Region in 1864, with mines opening in Greymouth and Buller coalfields, and prospered up to the 1920s, despite often difficult mining conditions presented by the irregular, lenticular nature of seams and by unpredictable faulting and folding. Production from predominantly underground mines declined during the depression years and after the Second World War, as many industrial and domestic consumers converted to electricity and liquid fuels. Large-scale opencast mining began in the Buller Coalfield in 1944 and opencast production has gradually increased over the last 50 years, replacing more costly underground production. Buller Coalfield, with current annual production of over 1 Mt, is New Zealand's largest producing coalfield. Total production from the region to date has been over 50 Mt with most coal coming from Greymouth and Buller coalfields. Recent annual production has averaged about 1.7 Mt, which was almost half of New Zealand's annual production, and all of its bituminous coal production. Over 80% was produced from opencast mines, mainly in the Buller Coalfield. Most West Coast coal is exported via the port of Lyttelton, to meet an international demand for high-quality bituminous coals; it is also an important source of industrial and household fuel for the domestic market.

The total coal-in-ground resource for the West Coast Region is estimated to be 983 Mt, of which 343 Mt is considered to be recoverable currently (Table 1) (Barry et al. 1994). Greymouth and Buller coalfields contain the majority of the recoverable resource, having 47% and 34% respectively. Significant recoverable resources are also present in Pike River (8%), Reefton-Garvey Creek (4%) and Charleston (4%) coalfields. Current production comes from Buller, Greymouth, Reefton-Garvey Creek, and Inangahua coalfields, and a mining feasibility study is about to start on Pike River Coalfield.

Buller Coalfield is New Zealand's largest producer of bituminous coal, with current annual production of about 1.1 Mt. Most production comes from a single thick seam (Mangatini Seam) near the base of the Brunner Coal Measures, which is characterised by relatively high ash in the roof and floor, and extremely low ash and sulphur contents in the middle part of the seam (Nathan 1996). Five mines operate within the coalfield, but more than 99% of production is from Solid Energy's No. 2, Webb (Figs 11 & 12) and Mt Frederick opencast mines at Stockton in the western part of the coalfield. Most of the high quality bituminous coal produced is exported for use in the steel-making and chemical industries. Poorer quality coals from the eastern part of the coalfield are used locally, but are in less demand because of their lower specific energy and higher sulphur content. Buller Coalfield has an estimated in-ground resource of 193 Mt and a recoverable resource of 118 Mt, of which 103 Mt is opencastable.

More than 100 mines have operated in Greymouth Coalfield since 1864, producing more than 30 Mt to date from both Paparoa and Brunner seams. Most of the mining has been by underground methods and the generally unfavourable geological conditions offer only limited potential for future opencast mining. Seven underground mines are operating at present, producing about 350 000 t annually. Solid Energy's Strongman Mine is the largest producer, accounting for about 85% of Greymouth production. The new Mt Davy underground mine (under development) will soon significantly increase production. Greymouth Coalfield has an estimated in-ground resource of 544 Mt and a recoverable resource of 163 Mt, of which only 0.7 Mt is considered opencastable (Barry et al. 1994).

Reefton and Garvey Creek coalfields include Brunner Coal Measures located in the western foothills of the Victoria Range, and erosional remnants on hills south and southeast of Reefton. The coal measures are up to 300 m thick and contain up to six seams. They are moderately inclined to the northwest but generally undisturbed by faulting in Reefton Coalfield, but are often complexly folded and faulted in Garvey Creek Coalfield. Coal ash contents are generally low and sulphur contents range from less than 1% to greater than 7% (Sykes 1987). A number of small opencast and underground mines have operated for many years and about eight mines are working at present, most producing less than 20 000 t per year (t.p.y.). The largest producing mines are Solid Energy's Island Block Opencast (30 000 t.p.y) and Terrace Mine (25 000 t.p.y), and Francis Mining's Echo Opencast (45 000 t.p.y). Recent annual production from Reefton and Garvey Creek coalfields has been about 140 000 t. Five mines in the Inangahua Coalfield work Brunner and Rotokohu seams, producing about 70 000 t annually. Three mines produce high sulphur, subbituminous coal from the Brunner seams, and two produce low sulphur, high rank lignite to subbituminous C coal from the younger Rotokohu seams. Inangahua coal is used mainly as a thermal coal for domestic and industrial purposes, and is often blended with higher-rank bituminous coal from Buller or Reefton and Garvey Creek coalfields. The remaining in-ground resource for Reefton and Garvey Creek coalfields is estimated to be 25 Mt, of which 11 Mt is recoverable, mainly by underground methods. Inangahua Coalfield has an in-ground resource of 11.5 Mt and a recoverable resource of 6 Mt, most of which could be worked by opencast methods (Barry et al. 1994). A much larger resource may exist in Inangahua Coalfield, as it remains relatively unexplored.

Pike River Coalfield has never been mined because of its inaccessible location on the crest of the Paparoa Range, adjacent to Paparoa National Park. It contains an estimated in-ground resource of 94 Mt within the Paparoa and Brunner coal measures, and a recoverable resource of about 28 Mt (Barry et al. 1994). New Zealand Oil and Gas Ltd have been awarded a mining permit over the field and are about to begin a mining feasibility study. Coal production using underground hydro-mining methods, could begin in 2000 if international coal prices are favourable (New Zealand Oil & Gas Ltd 1998).

Canterbury Coal Region

Canterbury Coal Region comprises several small to very small coal deposits scattered along the eastern foothills of the Southern Alps. The main coal areas are the Malvern Hills and Mount Somers coalfields, and the Avoca-Broken River, Acheron River, Rakaia Gorge and Geraldine-Fairlie coal deposits (Fig. 7).

With the exception of a small area of Miocene coal measures in the Geraldine-Fairlie deposit, all other seams in the region are of late Cretaceous to Eocene age, occurring near the base of the transgressive Eyre Group (Field et al. 1989). Regional seam stratigraphy is complex, being characterised by thin, overlapping, lenticular seams of limited lateral extent. Seam thickness is highly variable, usually between 1 and 2 m, reaching a maximum of 9 m in Malvern Hills Coalfield. The Cretaceous-Eocene coals are of lignite A to subbituminous C rank, except in parts of the Malvern Hills Coalfield and Avoca-Broken River, Acheron River and Rakaia Gorge deposits, where Tertiary igneous intrusives have invaded the coal measures and locally raised coal rank as high as anthracite (Suggate 1959).

Figure 11: Solid Energy's Webb opencast mine at Stockton in the Buller Coalfield. The mine produces high-quality bituminous coal from a single thick seam near the base of the Brunner Coal Measures (photo: Lloyd Homer).

Miocene coals near Fairlie are of subbituminous B rank. Ash and sulphur contents are variable, but generally high for most coals. Malvern Hills coals have low to medium ash and sulphur.

Over 120 mines have operated in the region since 1866, producing a total of about 2 Mt, with most coming from underground mines in the Malvern Hills and Mount Somers coalfields. Currently only the Mount Somers opencast mine is operating, producing about 2 000 t.p.y. Although production from Canterbury has been small, it provided an important energy source for local industries such as brick and pipe manufacturing, foundries, glassworks and drying plants (Duff and Barry 1989).

The region's resources are difficult to assess because of the lack of subsurface coal thickness information, complex seam characteristics and the unknown extent of potential coal-bearing sediments. Discounting coal less than 1 m thick, the total in-ground resource is estimated to be about 3.6 Mt, with 90% in Malvern Hills Coalfield (Barry et al. 1994). The recoverable resource is about 2.2 Mt, with most being potentially opencast coal in Malvern Hills Coalfield (Barry et al. 1994).

Otago Coal Region

Otago Coal Region comprises the Central Otago lignite deposits at Roxburgh Coalfield, St Bathans Coalfield, and a number of other minor coalfields, the small North Otago coalfields between Ngapara and Herbert, and at Waihao and Shag Point, plus the Green Island, Kaitangata, and Pomahaka coalfields of Dunedin and South Otago (Fig.7).

At Shag Point, Ngapara-Herbert, Green Island and Kaitangata, the coal is of late Cretaceous age; the coal measures are typically found unconformably overlying basement rocks, and overlain by transgressive marine beds. At Shag Point the coal is of high volatile C bituminous rank, but the rank elsewhere ranges from subbituminous (e.g. Kaitangata lower seams) to lignite (Green Island, higher seams at Kaitangata). The Waihao and Pomahaka coalfields contain lignite and subbituminous coal of Paleocene and Eocene ages respectively.

Figure 12: Extraction of very low ash and sulphur coal from the middle of the thick Mangatini Seam in Webb opencast mine at Stockton in the Buller Coalfield (photo: Lloyd Homer).

Almost all the Central Otago coals are Miocene lignites, present within a fluviatile and lacustrine sequence now present in series of fault-bounded depressions (the Manuherikia Group; Douglas 1986). The lignites typically have in-ground moisture contents of 40-50%, with 3-15% ash and 0.2-0.5% sulphur. In the past the lignites were an important source of fuel, and they have been worked in many small opencast and underground mines. Only one mine is still working. At Roxburgh, the Harliwich opencast produces about 4 000 t a year from a thick seam present in a small area of Manuherikia Group west of the Clutha River. The same seam is present at shallow to moderate depths over a larger area east of the river, where drillholes have shown it to be up to 85 m thick. The coal-in-ground resource is approximately 248 Mt (Douglas 1986, Isaac 1981). In St Bathans Coalfield, the Manuherikia Group contains thick multiple seams of lignite at Home Hills and Hawkdun. Both areas were drilled in the late 1970s and early 1980s. The in-ground resources are approximately 680 Mt at Hawkdun, and 350 Mt at Home Hills (Douglas 1986, Isaac 1981).

The Ngapara-Herbert Coalfield was worked between 1869 and 1971 by 23 mines, with total production of about 0.5 Mt; no mines have operated since 1971. Waihao Coalfield produced a total of about 22 000 tonnes from 10 mines operating between 1893 and 1933, but has not been worked since. Shag Point Coalfield was worked from about 1848 to 1982, with total production of about 1.8 Mt from some 20 mines, making it the most productive coalfield in the now abandoned North Otago area. North Otago coals are generally of poor quality. Subbituminous coals of Ngapara-Herbert and Waihao coalfields typically occur in thin seams with medium to high ash (7-18%) and sulphur (2-4%) contents. Low swelling, high-volatile C bituminous coals at Shag Point occur in multiple, thin, impersistent seams with high ash and medium sulphur contents.

Green Island Coalfield has been worked mostly by underground methods since 1861, producing more than 4.2 Mt of lignite for local industrial and domestic use (Mutch 1982). No mines are currently operating and much of the remaining in-ground resource of about 18 Mt, lies beneath residential areas. Coal was first mined at Kaitangata in 1863, but most production was between 1904 and 1940. A number of underground and opencast mines have worked seams between 5 and 20 m thick, within the middle and lower members of the late Cretaceous to early Paleocene Taratu Formation, producing more than 10 Mt to date. Kaitangata Coalfield is the region's largest producer at present, its only operating mine, the Kai Point opencast (Fig. 13), producing about 50 000 tonnes annually for local and regional industrial and domestic use. The coalfield was drilled during the 1980s as part of the Coal Resources Survey and Liquid Fuels Trust Board investigations. The in-ground resource estimate of 1 249 Mt is based on this work. Green Island and Kaitangata coals range from lignite A to subbituminous C rank, and generally have a low to medium ash content (3-10%) and medium to high sulphur (1-5%). Pomahaka Coalfield contains a single, high-moisture, high-ash lignite seam, which has been worked by a number of small, short-lived mines (Liggett 1979).

Despite its current relatively small production, the Otago region has a substantial in-ground resource estimated at 2 721 Mt, of which 1 154 Mt is considered to be recoverable currently (Table 1) (Barry et al. 1994). This represents about 18% of New Zealand's in-ground resource and 13% of its recoverable resource. St Bathans, Kaitangata and Roxburgh coalfields contain most of the recoverable resource, having 49%, 33% and 13% respectively. The other coalfields have small recoverable resources, but all the accessible coal has probably been extracted from Shag Point Coalfield (Table 1). Almost 97% of the region's known resource is recoverable by opencast methods, with only Kaitangata and Green Island coalfields having significant coal recoverable only by underground methods.

Southland Coal Region

Southland Coal Region includes nine coalfields covering the extensive lignite deposits underlying the Eastern Southland Plains and Maitland Basin, the small Hedgehope Coalfield in Eastern Southland, and Ohai and Orepuki coalfields and a number of minor coal deposits in Western Southland (Fig. 7).

The lignites of Eastern Southland lie within the late Oligocene to early Miocene Gore Lignite Measures, which are at least 500 m thick over much of Eastern Southland, but are largely obscured by Pleistocene-Holocene gravels. The lignite measures were deposited in a fluvio-deltaic environment and typically comprise a lower sandstone-dominated unit with minor lignite, a middle lignite-bearing interval, and an upper unit of sandstone and conglomerate with thick intervening mudstones and little or no coal (Isaac and Lindqvist 1990). The main lignite-bearing unit is between 50 and 300 m thick and contains multiple, laterally persistent seams, usually up to 18 m thick. Seams often outcrop or subcrop beneath the younger gravels, as a result of faulting, folding and gentle tilting (Isaac and Lindqvist 1990). Eastern Southland lignite is mostly of lignite B rank, with some lignite A in the north (e.g. Croydon, Waimumu, Mataura lower seams), where most production has come from. In-ground moisture contents are in the range 40-65% and sulphur contents are very low to low, typically in the range 0.1-1% (Isaac and Lindqvist 1990).

The late Eocene to early Oligocene Mako Coal Measures of Hedgehope Coalfield contain thin, west-dipping subbituminous coal seams, within an interbedded sequence of mudstone and sandstone, resting unconformably on basement rocks.

Ohai Coalfield occupies a NW-SE oriented, fault-controlled depression with up to 2000 m of sedimentary rocks, including two distinct sequences of fluvial coal measures. The late Cretaceous Ohai Group unconformably overlies

Figure 13: Kai Point opencast mine in Kaitangata Coalfield is the largest producing mine in the Otago region. It works a seam within the late Cretaceous Taratu Formation (photo: Lloyd Homer).

basement rocks and contains the basal Wairio Coal Measures, separated from the economically important Morley Coal Measures by thick conglomerate. A low-angle unconformity separates Ohai Group from the Eocene Nightcaps Group, which contains the Beaumont Coal Measures and Orauea Mudstone, and is overlain by marine sediments (Sykes 1988). The Wairio Coal Measures contain only a few, thin, high-ash seams, but the Morley Coal Measures contain well developed seams up to 23 m thick. The Morley seams are of subbituminous A to high volatile C bituminous rank, with low to medium ash (1-8%) and low sulphur (0.2-0.6%) contents. The Beaumont Coal Measures contain thin, very lenticular seams of subbituminous C-B rank, with sulphur contents ranging from low to very high (<1-6%). Beaumont Coal Measures rest on basement in Orepuki Coalfield, and contain discontinuous coal seams up to 7 m thick.

Coal occurrences are also known from a number of locations in the Waiau and Te Anau basins of Western Southland, and from Preservation Inlet in Southern Fiordland (Turnbull et al. 1993). Very little is known about the commercial potential of these deposits and there is little interest in them because of their general remoteness, inaccessibility and assumed small size.

Eastern Southland lignites have been mined on a small scale since the mid-nineteenth century, providing a cheap fuel for local domestic and industrial needs. About 166 opencast and underground mines have operated, most being small and short-lived, with only 21 producing over 50 000 tonnes. Four opencast mines are operating at present. The Goodwin and New Vale mines in Waimumu Coalfield produce about 40 000 tonnes and 140 000 tonnes per year respectively, supplying sized product to freezing works, dairy factories, hospitals, schools and the local domestic market. Solid Energy's Mataura Mine in Mataura Coalfield produces about 25 000 tonnes of lignite per year, and the small Waituna mine in Ashers-Waituna Coalfield produces about 1 000 tonnes per year.

Mining in Ohai Coalfield began in 1879 and reached peak annual production of around 0.3 Mt, from opencast and underground mines, in the early 1960s. Since then production has declined steadily. Present production comes mostly from Solid Energy's Wairaki underground mine with an annual output of about 150 000 tonnes. Small mines near Nightcaps and Mossbank produce about 6 000 tonnes annually. Ohai Coalfield has produced a total of about 19 Mt of coal for domestic, and a wide range of industrial uses in Otago and Southland. It is often blended with lower-rank lignite from Eastern Southland for industrial use. Mining in Orepuki Coalfield between 1883 and its cessation in 1962 produced a total of 85 000 tonnes.

Southland Coal Region has New Zealand's largest coal resource, mostly in the extensive lignite deposits of Eastern Southland. The region has an in-ground resource of 9 392 Mt, representing 60% of New Zealand's total resource; the recoverable resource of 6 256 Mt is 73% of the New Zealand total. Ohai and Orepuki coalfields are relatively minor contributors with in-ground resources of 179 Mt and 10 Mt, and recoverable resources of 50.4 Mt and 8 Mt respectively. The coalfields of Eastern Southland contain the vast majority of the resource, with Mataura, Ashers-Waituna, Morton Mains, Makarewa and Waimatua having the largest in-ground and recoverable resources (Table 1). Most of the resource in Ohai Coalfield is recoverable only by underground methods, but all of the lignite is recoverable by opencast methods.

Summary of New Zealand Production

Coal production increased rapidly in the late nineteenth century and into the early 1900s, with annual production first exceeding 1 Mt in 1900 and reaching 2 Mt by 1910. Production increased at a slower rate between 1910 and 1960, when annual production reached 3 Mt. Since 1960, annual production has fluctuated between 2 Mt and 3.5 Mt, but has exceeded 3 Mt since 1993. Total cumulative production from all New Zealand coalfields to the end of 1998 has been about 253 Mt. Over the last 20 years, the West Coast and Waikato regions have been the largest producers. In 1996, the West Coast produced 49% of New Zealand's coal while 41% was mined in the Waikato; Southland produced 9%, Otago 1% and a very small quantity was mined in Canterbury (Ministry of Commerce 1998b). Before 1940, less than 10% of production was from opencast mines, but since then opencast production has increased steadily to 80% of present production. A significant proportion (36%) of Southland production is obtained from underground mines at present.

Of the 3.5 Mt of coal produced in 1996, 47% was bituminous, 46% subbituminous and 7% lignite. All bituminous production was from the West Coast region, and most subbituminous production was from the Waikato region, with much smaller amounts from Southland and the West Coast. Lignite production was from the Southland and Otago regions, with very small amounts from Canterbury and the West Coast (Ministry of Commerce 1998b).

Coal Exports

In the mid 1970s, the international coal market and especially Japan, became aware of the special qualities of New Zealand's premium grade bituminous coals. These properties included a consistently low ash and sulphur content, a fixed carbon content of around 60%, and a crucible swelling number of 9 or more, making them suitable for use in the chemical and steel industries and valuable for blending. Coal exports, mainly to Japan, increased steadily to about 0.5 Mt annually by 1990. Expansion of export markets during the 1990s led to a rapid increase in exports between 1992 and 1997, peaking at 1.6 Mt (44% of total production) for the year ending March 1997. For the year ending March 1998, however, exports decreased by 50% to 0.8 Mt (26% of total production), due to substantial falls in exports to China, Japan, Australia and Chile. New Zealand's largest coal export markets for the 1998 year were Japan (29%), India (28%), Chile (15%), China (8%), Australia (7%) and Belgium (7%). Smaller export markets were Fiji, the Netherlands and Saudi Arabia (Ministry of Commerce 1998a). Most export coal comes from Solid Energy's Stockton No. 2, Mt Frederick and Webb opencast mines in Buller Coalfield, which have been producing a combined total of over 1 Mt annually since 1995.

Future Trends

Worldwide demand for coal is likely to continue to increase slowly, mainly because of its importance for electricity generation. With annual global electricity demand growth running at about 3% in recent years and widely expected to continue to rise, coal will remain a major energy source for baseload electric power generation into the future. However, the combustion of coal produces pollutants that adversely affect air quality, and it is a major source of greenhouse gases. Environmental concerns about the use of coal are likely to lead to some decline in its share of total energy consumption in the future, although this will be mitigated by advances in clean coal technologies. Electricity generators will increasingly require cleaner coals with low sulphur contents. Strong competition from other fuels, particularly oil and natural gas, will continue because of low oil and gas prices and new technologies that favour the use of natural gas for electricity generation.

Demand for coking coals is likely to decline in the future as developments in steelmaking technology bring about a shift away from coke-consuming integrated mills to smaller, electric arc furnace-based mills. Pulverized coal injection (PCI) technology, in which steam coal displaces some of the coal coke in blast furnace charges, is also making inroads. Historically, coking coals have dominated international coal trading, and they still play a significant role, but since about 1990 the steaming coal trade, mainly for electricity generation, has dominated international markets.

New Zealand's coalfields have been well explored by government-funded surveys in the past, and its coal resources are quite well known. Currently, little exploration for new reserves is taking place, and the industry is concentrating on improving knowledge of resources within existing licence areas. This is likely to be the situation for some time.

Electricity generation consumes about 20% of New Zealand's domestic coal supply, but is subject to considerable fluctuation, and is unlikely to increase significantly in the near future. The best prospect for an increase in coal-fuelled generation is if the existing coal/gas-fired Huntly station were to increase the proportion of coal it uses. The trend for new thermal generation is toward smaller, gas-fuelled stations, located close to major electricity consuming areas. New Zealand industry uses about 70% of domestic coal consumption, with BHP New Zealand Steel being the largest customer. The lack of a natural gas supply in the South Island has led to more widespread industrial use of coal in the south. Industrial coal consumption is likely to increase only slowly due to competition from gas in the North Island and environmental factors/regulations. Uncertainty about the future of BHP's steel mill at Glenbrook is a concern for future production from Waikato coalfields. Residential coal consumption is relatively small and has been static at about 3% of domestic consumption for many years. Residential use is likely to decline slowly as air quality concerns and regulations in urban areas, particularly Christchurch, are acted upon.

Coal exporting has been the major growth area for the New Zealand coal industry since about 1990 and should continue to be a good prospect for the future. While there has been demand for premium grade bituminous coal, there is also a growing international market for steaming coal, such as New Zealand's lower grade bituminous and subbituminous coals. Threats to New Zealand coal exports include economic problems in the countries exported to, such as has occurred recently in many Asian economies, leading to dramatic reductions in coal imports. Competition from new, low-cost producers of clean coals, closer to major markets, is also a threat. Countries such as Indonesia, Venezuela and Colombia are rapidly increasing production and export of cheap, clean, steaming coals.

In summary, New Zealand has a large proven coal resource suitable for domestic electricity generation and industrial use, but there is unlikely to be a significant increase on current consumption, while there are environmental concerns about the combustion of coal and a plentiful supply of natural gas to the North Island. The future looks good for increased coal exports, but the trade is vulnerable to changes in the state of importer economies, and is very competitive.

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