Australian Government

BIOREGIONAL ASSESSMENTS

PROVIDING SCIENTIFIC WATER RESOURCE INFORMATION ASSOCIATED WITH COAL SEAM GAS AND LARGE COAL MINES

Coal and coal seam gas resource assessment for the Gippsland Basin bioregion

Product 1.2 from the Gippsland Basin Bioregional Assessment

22 June 2016

A scientific collaboration between the Department of the Environment, Bureau of Meteorology, CSIRO, Geoscience Australia and the Government of Victoria

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Programme is funded by the Australian Government Department of the Environment. The Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment

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Lake Victoria, Victoria, 2013

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Contents

Figures

Tables

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- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments.

Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments.

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made available to the public, providing the opportunity for all other interested parties, including government regulators, industry, community and the general public, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of CSG and coal mining development on water resources.

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA will be different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions:

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion
- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in a later section) will progressively be delivered throughout the Programme.

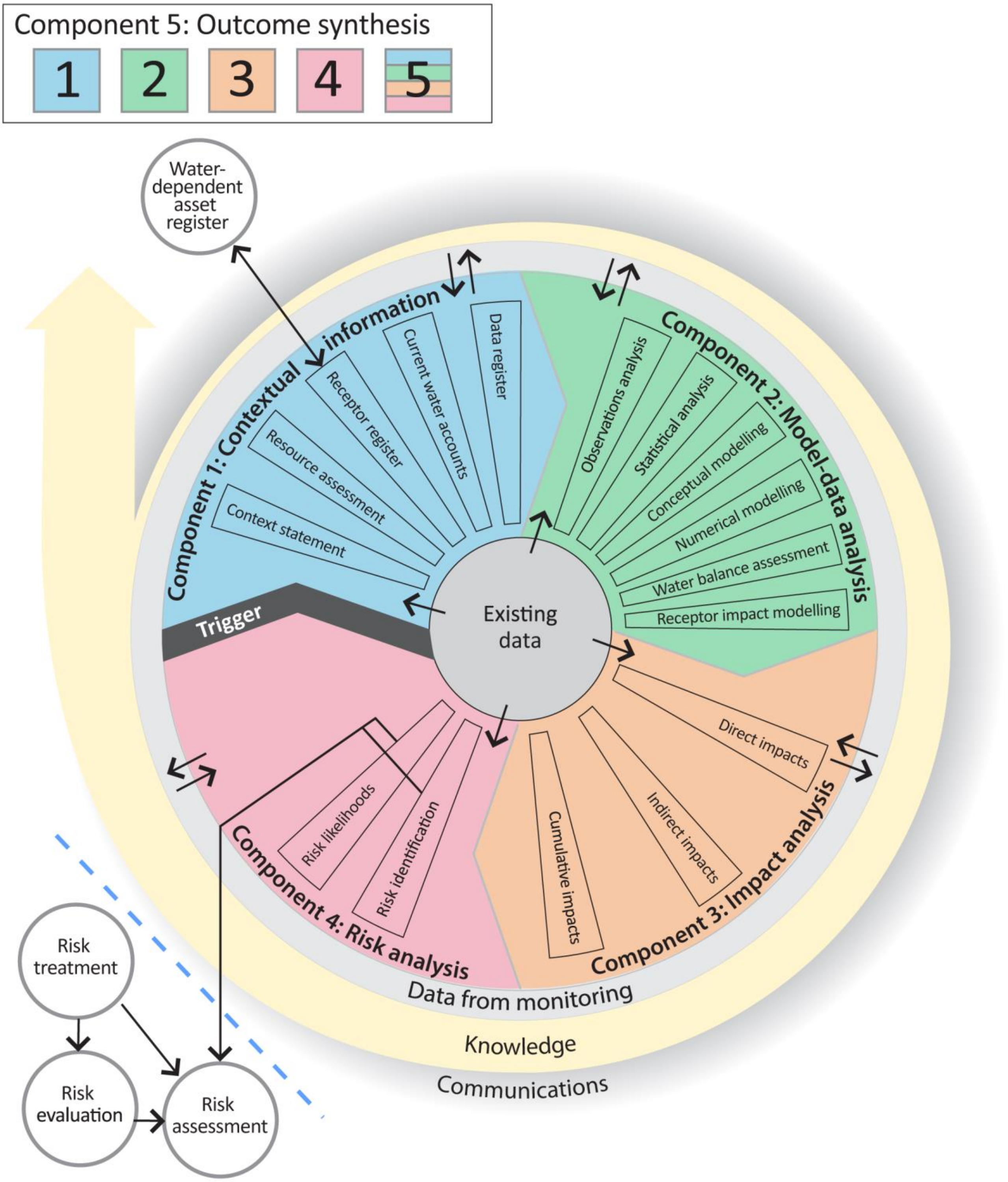

Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

For transparency and to ensure consistency across all BAs, submethodologies have been developed to supplement the key approaches outlined in the *Methodology for bioregional assessments of the impact of coal seam gas and coal mining development on water resources* (Barrett et al., 2013). This series of submethodologies aligns with technical products as presented in Table 1. The submethodologies are not intended to be 'recipe books' nor to provide step-by-step instructions; rather they provide an overview of the approach to be taken. In some instances, methods applied for a particular BA may need to differ from what is proposed in the submethodologies – in this case an explanation will be supplied. Overall, the submethodologies are intended to provide a rigorously defined foundation describing how BAs are undertaken.

Table 1 Methodologies and associated technical products listed in Table 2

Code	Proposed title	Summary of content	Associated technical product
M01	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments	All
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	*Assigning receptors and impact variables to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported in product 1.2 (i.e. known coal and coal seam gas resources as well as current and potential resource developments). Describes the process for determining the coal resource development pathway (reported in product 2.3)	1.2 Coal and coal seam gas resource assessment 2.3 Conceptual modelling
M05	*Developing the conceptual model for causal pathways*	Describes the development of the conceptual model for causal pathways, which summarises how the 'system' operates and articulates the links between coal resource developments and impacts on receptors	2.3 Conceptual modelling
M06	*Surface water modelling*	Describes the approach taken for surface water modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative.	2.6.1 Surface water numerical modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative. It also considers surface water – groundwater interactions, as well as how the groundwater modelling is constrained by geology.	2.6.2 Groundwater numerical modelling

Code	Proposed title	Summary of content	Associated technical product
M08	*Receptor impact modelling*	Describes how to develop the receptor impact models that are required to assess the potential impacts from coal seam gas and large coal mining on receptors. Conceptual, semi-quantitative and quantitative numerical models are described.	2.7 Receptor impact modelling
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantifying uncertainty in the modelled hydrological response to coal and coal seam gas development	2.3 Conceptual modelling 2.6.1 Surface water numerical modelling 2.6.2 Groundwater numerical modelling 2.7 Receptor impact modelling
M10	*Risk and cumulative impacts on receptors*	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	*Hazard identification*	Describes the process to identify potential water-related hazards from coal and coal seam gas development	2 Model-data analysis 3 Impact analysis 4 Risk analysis

Each submethodology is available online at http://www.bioregionalassessments.gov.au. Submethodologies might be added in the future.

Technical products

The outputs of the BAs include a suite of technical products variously presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential direct, indirect and cumulative impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are available to the public, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The information included in the technical products is specified in the BA methodology. Figure 2 shows the information flow within a BA. Table 2 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it. The red rectangles in both Figure 2 and Table 2 indicate the information included in this technical product.

This technical product is delivered as a report (PDF). Additional material is also provided, as specified by the BA methodology:

- all unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- the workflow, comprising a record of all decision points along the pathway towards completion of the BA, gaps in data and modelling capability, and provenance of data.

The PDF of this technical product, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

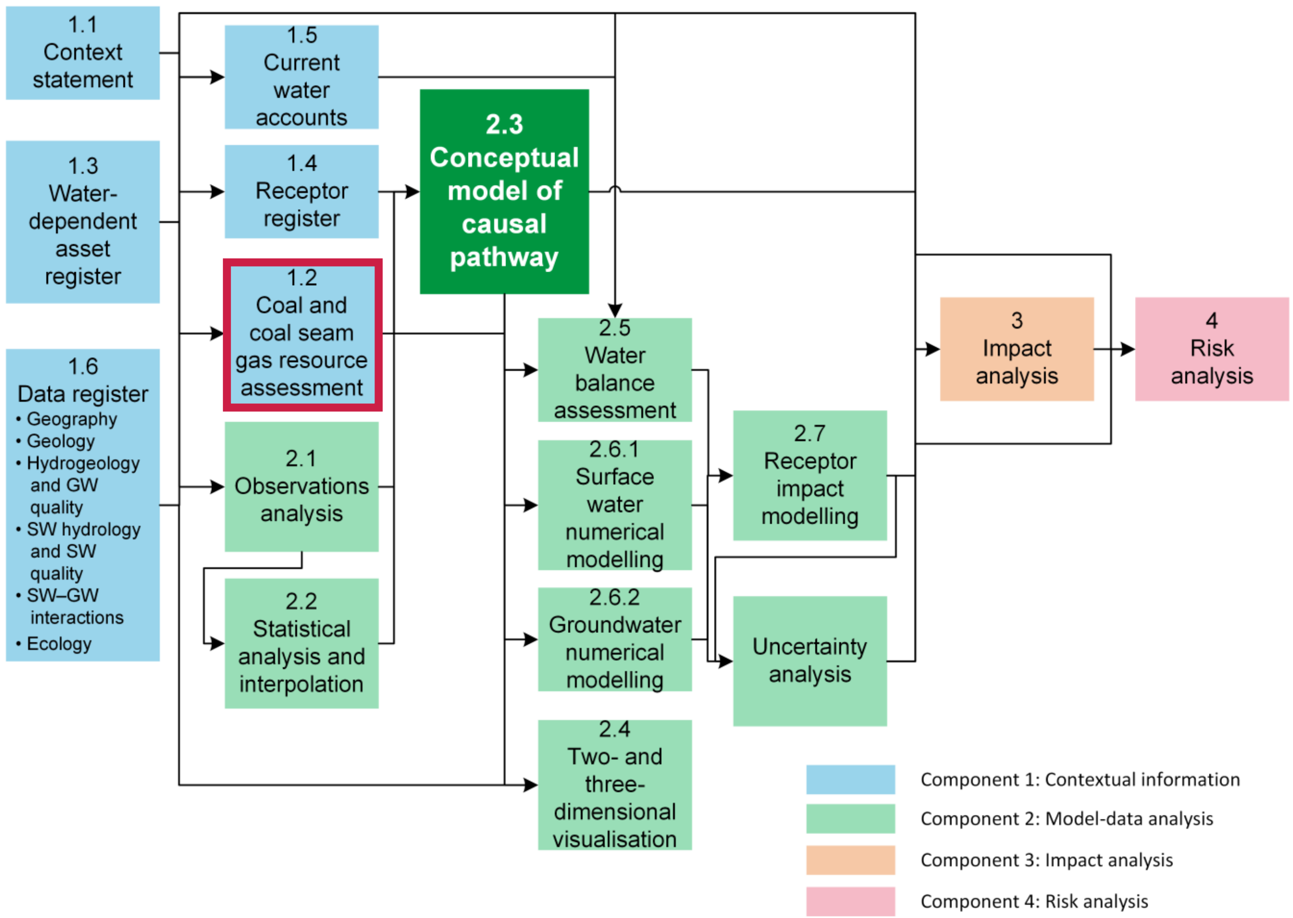

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

The red rectangle indicates the information included in this technical product.

Table 2 Technical products delivered by the Gippsland Basin Bioregional Assessment

For each subregion in the Gippsland Basin Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' column[a]. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online. There is no product 2.4; originally this product was going to include two- and three-dimensional representations as per Section 4.2 of the BA methodology, but these are instead included in products such as product 2.3 (conceptual modelling), product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling).

Component	Product code	Title	Section in the BA methodology[b]	Type[a]
Component 1: Contextual information for the Gippsland Basin bioregion	1.1	Context statement	2.5.1.1, 3.2	PDF, HTML
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	PDF, HTML
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.4	Description of the receptor register	2.5.1.4, 3.5	PDF, HTML, register
	1.5	Current water accounts and water quality	2.5.1.5	PDF, HTML
	1.6	Data register	2.5.1.6	HTML
Component 2: Model-data analysis for the Gippsland Basin bioregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	PDF, HTML
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	PDF, HTML
	2.6.1	Surface water numerical modelling	4.4	PDF, HTML
	2.6.2	Groundwater numerical modelling	4.4	PDF, HTML
	2.7	Receptor impact modelling	2.5.2.6, 4.5	PDF, HTML
Component 3 and Component 4: Impact and risk analysis for the Gippsland Basin bioregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	PDF, HTML
Component 5: Outcome synthesis for the Gippsland Basin bioregion	5	Outcome synthesis	2.5.5	PDF, HTML

[a]The types of products are as follows:

- 'PDF' indicates a PDF document that is developed by the Gippsland Basin Bioregional Assessment using the structure, standards and format specified by the Programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.

[b]*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (Barrett et al., 2013)

About this technical product

The following notes are relevant only for this technical product.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 151.0° East for the Gippsland Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Contact bioregionalassessments@bom.gov.au to access metadata (including copyright, attribution and licensing information) for all datasets cited or used to make figures in this product. At a later date, this information, as well as all unencumbered datasets, will be published online.
- The citation details of datasets are correct to the best of the knowledge of the Bioregional Assessment Programme at the publication date of this product. Readers should use the hyperlinks provided to access the most up-to-date information about these data; where there are discrepancies, the information provided online should be considered correct. The dates used to identify Bioregional Assessment Source Datasets are the dataset's published date. Where the published date is not available, the last updated date or created date is used. For Bioregional Assessment Derived Datasets, the created date is used.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 22 August 2016, http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology

1.2 Coal and coal seam gas resource assessment for the Gippsland Basin bioregion

The coal and coal seam gas resource assessment summarises the known coal and coal seam gas resources, and developments both now and potentially in the future. The following data and information are presented:

- the geology and spatial distribution of known coal resources
- the baseline of current coal and coal seam gas extraction
- exploration and mining tenements
- proposed future developments (both new developments and expansion or closure of existing developments), including details of location, timing, methods and extraction volumes as determined from proposed development plans.

This information will be used to develop the coal resource development pathway (as reported in product 2.3 (conceptual modelling)), which articulates the most likely combination of developments at the bioregion scale, including all individual coal and coal seam gas resource projects that are expected.

1.2.1 Available coal and coal seam gas resources

Summary

The geological Gippsland Basin (Gippsland Basin) is one of the world's major coal- and petroleum-bearing basins. The stratigraphy and structure of the onshore area and the manner of coal development have been reviewed by Smith (1982) and Gloe (1984).

Within the onshore margins of the Gippsland Basin occurs the largest Australian accumulation of Cenozoic brown coal, where the total in situ reserves of over 100 billion tonnes have been defined by extensive drilling (Gloe, 1975).

The Gippsland Basin also contains a significant black coal resource of which approximately 22 million tonnes (Mt) has been mined, with 17 Mt from the State Coal Mine at Wonthaggi. An estimated 9.5 Mt remains spread across eight black coalfields.

There is no history of coal seam gas (CSG) production in the Gippsland Basin bioregion but there is a relatively short history of CSG exploration. With only limited historical CSG exploration and associated data it is not possible to make an informed statement about the CSG potential of the Gippsland Basin.

There is currently a moratorium on CSG exploration in Victoria, in place since August 2012.

1.2.1.1 Coal

The Gippsland Basin in south-eastern Australia is one of the world's major coal- and petroleum-bearing basins, containing the largest brown coal resources in Australia. The basin covers an area around 46,000 km^2, 70% of which is located offshore beneath the waters of Bass Strait (Holdgate and Gallagher, 2003). Figure 3 shows the Gippsland Basin bioregion along with its main structural elements and the distribution of coal, petroleum and gas resources. The locations of wells drilled for conventional petroleum resources are also displayed. Companion product 1.1 for the Gippsland Basin bioregion (Yates et al., 2015) provides a detailed overview of the geology of the Gippsland Basin including stratigraphy and geological structure.

The Gippsland Basin has a long history of exploration and mining of black and brown coal. The first mining of black coal occurred at Wonthaggi in 1909 (Vines, 2008), ending with the closure of the State Coal Mine in 1968 (Holdgate, 2003). Brown coal mining began at a significant scale in 1924 when the State Electricity Commission of Victoria (SECV) took over operations of the Old Brown Coal Mine to supply coal to the Yallourn Power Station (Harvey, 1993). Brown coal mine development has continued since and now focuses on the three existing coal mines: Yallourn, Hazelwood and Loy Yang.

Under the Australian classification system, it is estimated that Australia holds approximately 22.6% of the world's recoverable Economic Demonstrated Resource (EDR) of brown coal. Approximately 99% of Australia's brown coal EDR and 97% of its total Identified Resource of brown coal are located in Victoria – predominantly in the Latrobe Valley. Victoria is the only state in which brown coal is mined. Open-cut mines at Loy Yang, Yallourn and Hazelwood supply coal to nearby power stations. Small quantities of brown coal are also mined outside the Gippsland Basin at Maddingley near Bacchus Marsh to produce soil conditioners and fertilisers. Briquettes for industrial and domestic use, and low ash and low sulfur char products, are also produced from Victoria's brown coal.

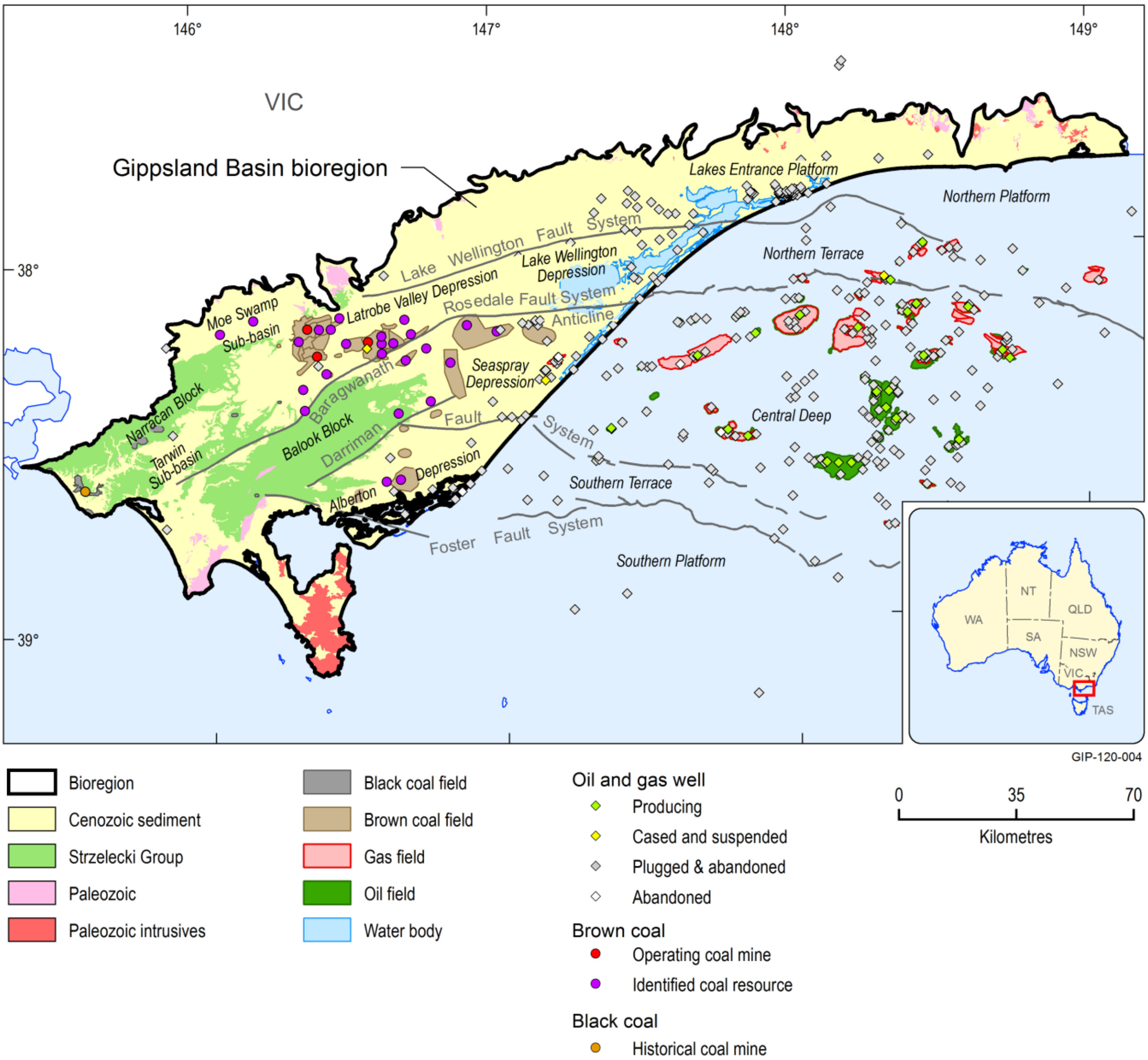

Figure 3 Distribution of coalfields and resources, oil and gas fields of the Gippsland Basin bioregion

Data: Victorian Department of State Development, Business and Innovation (Dataset 1, Dataset 3), Geoscience Australia (Dataset 2), Victorian Department of Environment and Primary Industries (Dataset 4)

1.2.1.1.1 Black coal

Strzelecki Group

The Strzelecki Group hosts the black coal deposits of the Gippsland Basin (Figure 3). The Strzelecki Group outcrops over two main elevated areas which trend north-east and form the South Gippsland Highlands (Jenkin, 1971). These two elevated areas are defined by the Narracan and Balook blocks in the south-west of the Gippsland Basin bioregion (Figure 3).

The distribution and surface expression of black coal in South Gippsland is controlled by the north-east striking Early Cretaceous basin forming faults (Holdgate, 2003). Most of the known black coal seams of South Gippsland are found at shallow depths (i.e. less than 400 m) on or adjacent to subsurface Paleozoic highs – the Wonthaggi and Tyers basement ridges. Productive black coal measures are confined to Lower Cretaceous Strzelecki Group units in west Gippsland.

The principal areas mined were Wonthaggi (Kirrak and Dudley basins), Korumburra, Jumbunna, Outtrim, Kilcunda, Woolamai, and Coalville with smaller producing areas at Berrys Creek, Boolarra and Cape Paterson (Table 3).

The black coal measures in the Wonthaggi region are strongly faulted, and there appear to have been two periods of faulting during the Cenozoic. East–west faults predominate at Wonthaggi. They dip to the north at about 65°, in contrast to the prevailing southerly dip of the coal seam and the major Kongwak Fault. The sediments between the top and bottom seams in the Dudley Basin thicken to the north, towards the Kongwak Fault, which may therefore have been active during sedimentation.

Dudley (1959) estimated that there is more than 6 km of Mesozoic sedimentary rock in the Balook Block, although it has not been tested by drilling to that depth. Onshore, the thickest sequence drilled of the Strzelecki Group exceeds 2500 m in Wellington Park-1 (Ingram, 1962) and Holdgate-1 wells without reaching basement. Only two wells have drilled through the sequence near the northern basin margins to reach basement: Megascolides-1 (Grosser, 2005) south of Warragul and Duck Bay-1 (Ingram, 1964) near Bairnsdale.

Coalfield areas

Figure 4 shows the locations of the black coalfields in the Gippsland Basin bioregion.

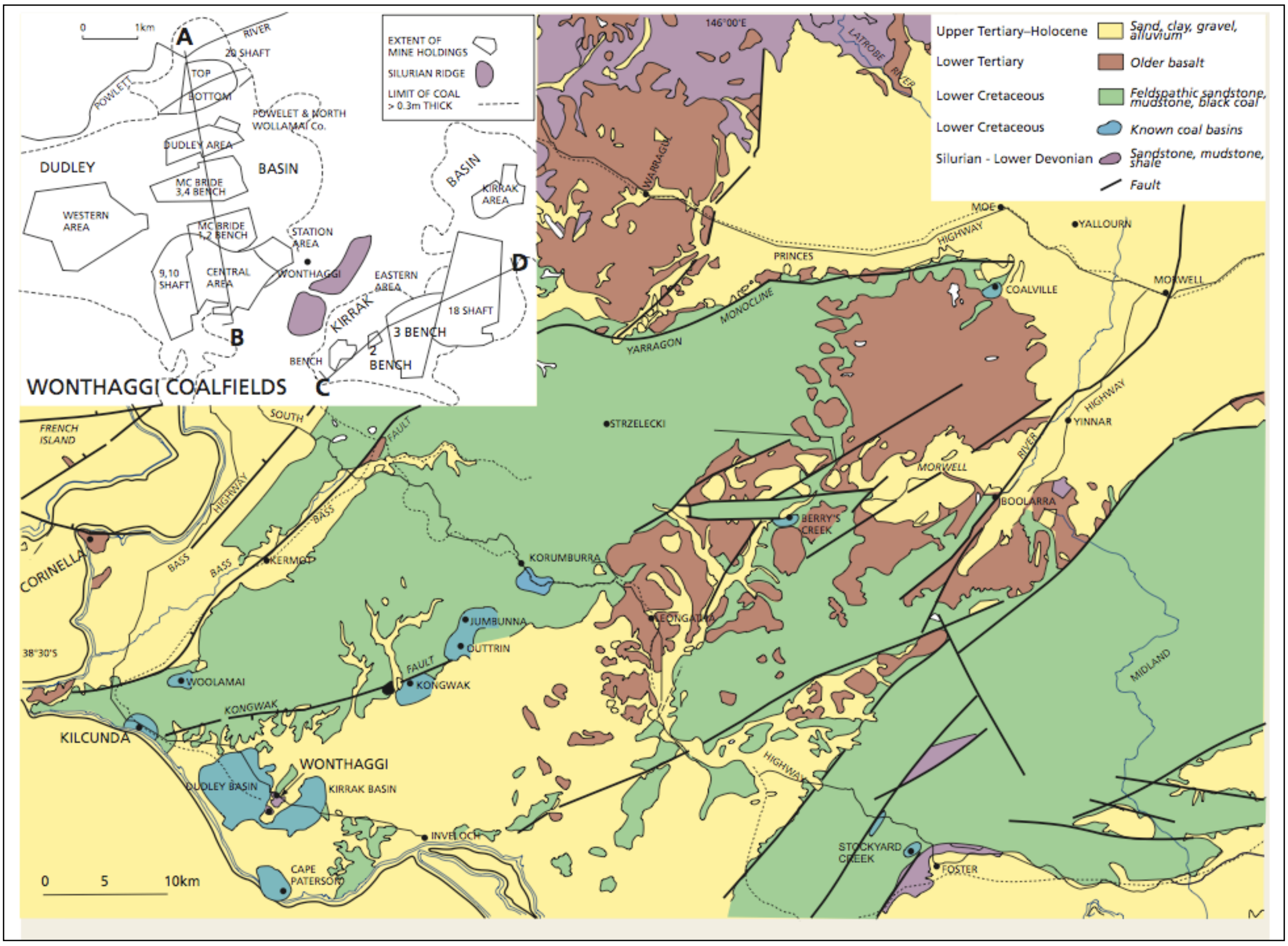

Figure 4 Geological map of South Gippsland Highlands showing locations of the main black coalfields in the Gippsland Basin bioregion. Inset shows layout of the State Coal Mine workings at Wonthaggi.

Source: Holdgate (2003)

Wonthaggi Coalfield

Most of the coal recovered was from the State Coal Mine at Wonthaggi, which was worked from 1909 to 1968. Here, the Kirrak Basin is separated from the Dudley Basin by a north-easterly ridge of Silurian basement rock overlain by alluvium (Figure 4). The coal measures generally strike east–west and dip southerly. There are two persistent seams separated by 150 m of feldspathic sandstone in the Kirrak Basin (Edwards et al., 1944). The upper seam is thin, but the lower seam is up to 2.2 m thick and has been mined over an area of 400 ha.

Three areas were mined in the Kirrak Basin, commencing with the Eastern Area tunnel driven in 1915 to 1918. The deepest workings in the Eastern Area were in the south section of No. 18 shaft, where a steeply dipping seam was worked to a depth of 440 m.

In the Dudley Basin eight seams were recorded in bores in a vertical section of 300 m, but only two were subsequently worked. The lower seam splits locally into ‘top’ and ‘bottom’ seams which were extensively worked in the Western Area pit. The ‘top seam’ may be correlated with the lower seams of the Kirrak Basin and attains a maximum thickness of 3 m near the Dudley Area shafts. It was mined over 650 ha in eight separate areas, each defined by major bounding faults with throws exceeding 30 m.

The 'bottom seam', commonly with shaly bands, is 75 to 105 m below the upper seam, and rarely thicker than 1 m; near the western limit of the coalfield the seam splits. The upper seam varies from massive coal 0.45 m thick to a banded seam up to 1.25 m thick, half of which comprises mudstone bands. The lower seam contains up to 1.1 m of coal with a persistent mudstone parting varying from 0.15 to 1.25 m in thickness (Edwards et al., 1944). It was mined over 530 ha in six areas.

Korumburra Coalfield

The Korumburra Coalfield produced just over 2 Mt of coal from 1893 to 1962 (Holdgate, 2003). Five distinct seams were recorded by test bores which reached the underlying Silurian rocks. The top (No. 1) and main seams (No. 2), stratigraphically 25 m apart and about 1 m and 1.4 m thick respectively, were extensively worked. There was production from the middle seam (No. 3), 82 m below the main seam, and minor production from the deep seam (No. 4), about 55 m below the middle seam. This seam was located by the Coal Creek shaft in 1891 and was reported to be 1.8 m thick with clean coal. Later diamond drilling revealed at least 1 m of carbonaceous mudstone bands in this seam. The deepest seam (No. 5) is about 15 m below the so-called deep seam and is about 60 cm thick.

The coal dips mainly to the north-west, and was worked over 200 ha by three main companies: Coal Creek Mining Company, Sunbeam Collieries, and the Austral Coal Company (see Vines, 2008).

Jumbunna – Outtrim Coalfield

The south-westerly extension of the Korumburra Coalfield has a main seam varying from 1.0 to 1.5 m in thickness and was worked at intervals between 1894 and 1962. It produced nearly 3 Mt of black coal from 300 ha (Jumbunna Colliery and Outtrim Howitt produced 93% of this). The seam dipped to the north-west and thinned out rapidly towards the margins of the basin (Holdgate, 2003).

Kilcunda – Woolamai Coalfield

Coal seams crop out on the cliffs and along the wave-cut platforms between San Remo and Cape Patterson. The seams were exploited between 1910 and 1966, in the Victorian and Kilcunda mines. A single seam up to 0.7 m in thickness was exploited, producing 522,275 tonnes from an area of 60 ha (Knight, 1988).

Coalville

From 1884 to 1897, the Coalville, North Coalville, and Moe companies worked a seam about 0.7 m thick in the valley of Narracan Creek by tunnels and a 30 m shaft. The seam dips to the north-west and the coals were similar in quality to the Korumburra coals. A total production of 62,745 tonnes is recorded (Knight, 1988).

Minor black coalfields

At Boolarra a northward-dipping seam 0.7 m thick produced 500 tonnes in 1887 to 1890. From 1928 to 1929, 3260 tonnes were won from a steep north-west-dipping seam near Berrys Creek

(Figure 4) at Mirboo North. Richard Daintree discovered coal 1.0 m thick, 2 km north-east of Kernot, but there was no production. Seams thinner than 1.0 m are known at Billys Creek near Hazelwood, Stockyard Creek near Foster, and the upper Powlett River near Kongwak (Knight, 1988).

Coal quality

Black coal in the Gippsland Basin is a banded bituminous type with medium moisture and volatile hydrocarbon content and medium to high ash content.

The Wonthaggi coals were described as alternating bands of bright and dull coal, of varying thickness (Edwards et al., 1944). Some bands and components (macerals) in the bright coals were described as having brilliant lustre and conchoidal fracture.

The air-dried moisture content of Strzelecki black coals is low: 5 to 10% moisture (Holdgate, 2003) and 2.9% moisture (from Megascolides-1, Grosser, 2005). Volatile matter is recorded from 30 to 35% (Holgate, 2003) and 23.7% (Grosser, 2005). The ash content of the Strzelecki black coals is variable. Traditionally low ash contents have been recorded (6 to 12%; Holdgate, 2003).

Although less efficient than black coal from many mines in NSW, it is of good steaming quality and was used for power stations and in locomotive boilers, but was unsuitable for gas and coke production.

Estimated resources

Altogether, 22.68 Mt of coal was mined from 12 pits, and reserves remaining in situ are estimated at 9.47 Mt (gross) (Table 3). Frequency of faulting and difficulties in mechanisation made mining uneconomic once the thicker seams were worked out.

Several areas with coal production potential adjoin former mines, and within some existing mines pillars were not removed or workings did not reach areas with proven reserves. Records of 1600 bores drilled on the Wonthaggi coalfield between 1908 and 1957 are available in the Geological Survey of Victoria archives.

Table 3 Reserves of black coal in the Gippsland Basin bioregion

Coalfield area	Seam thickness (m)	Number of bores	Reserves (t)	Quantity mined (t)	Years mined
Wonthaggi	0.40–1.72	444	6,800,000[a]	17,070,780[c]	1909–1968[c]
Korumburra	0.50–1.40	160	1,630,000[a]	2,000,000[c]	1893–1962[c]
Jumbunna	0.60–1.00	50	150,000[a]	3,000,000[c] (from Jumbunna and Outtrim)	1894–1929[c]
Outtrim	0.50–1.00	70	100,000[a]	See above	1894–1946[c]
Kilcunda – Woolamai	0.45–0.66	152	150,000[a]	550,000[c]	1910–1966[c]
Cape Patterson	0.40–0.80	15	40,000[a]	2,000[b]	~1847[b]
Mirboo North – Berrys Creek	0.96–1.20	39	500,000[a]	2,000[b]	~1930[b]
Coalville	0.60–0.80	8	100,000[a]	62,700[c]	1884–1897[c]
Total			9,470,000		

Source: [a]GHD (2007), [b]Vines (2008), [c]Holdgate (2003)

1.2.1.1.2 Brown coal

Brown coal within the geological Gippsland Basin lies within three structural depressions: the Latrobe Valley, Seaspray and Gelliondale-Alberton depressions (Figure 3 and Figure 5). There are 28 defined coalfields within the Gippsland Basin bioregion (Table 4).

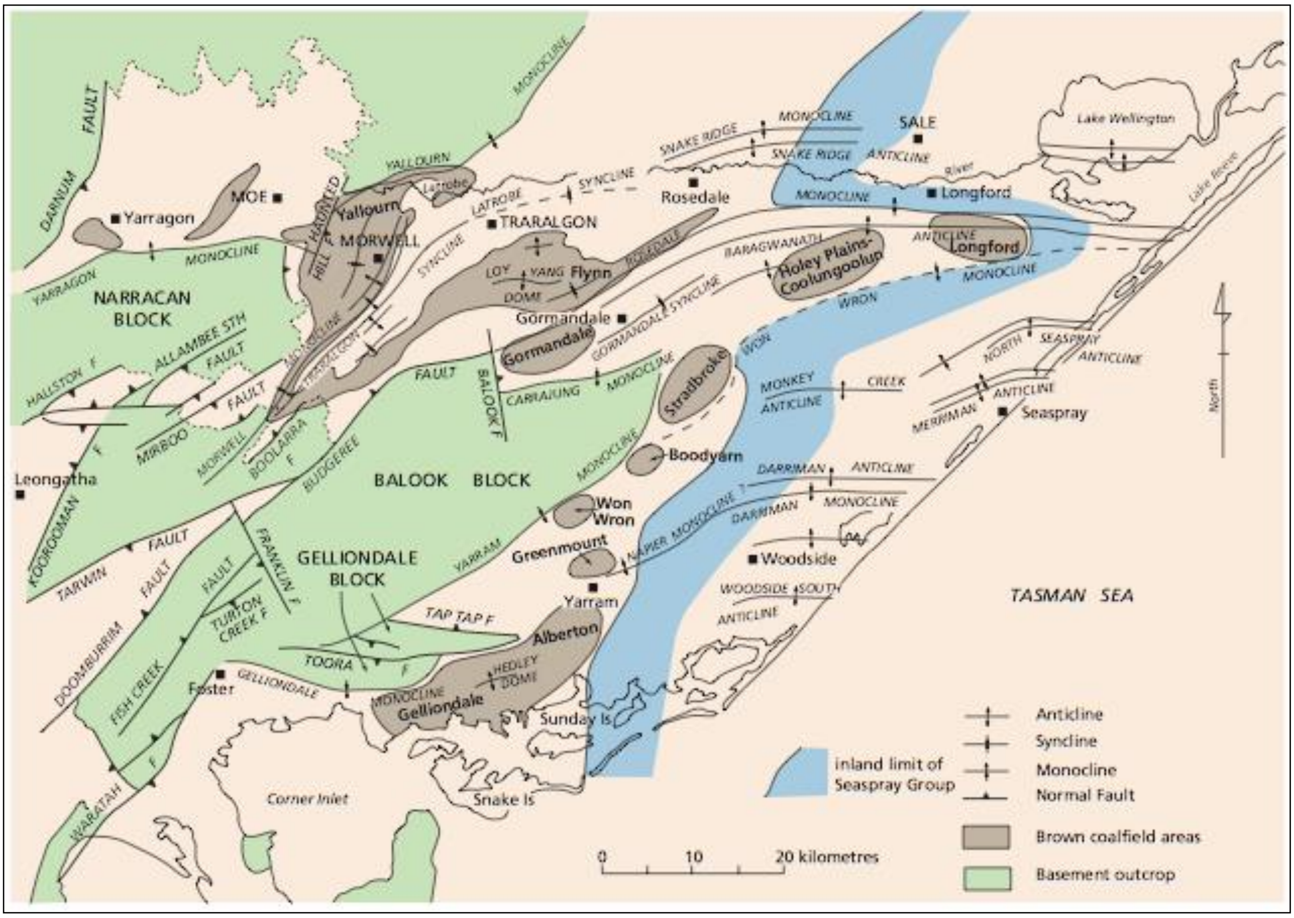

Figure 5 Structural elements and brown coal subcrop map for the onshore Gippsland Basin

Source: Holdgate (2003)

The thickness and uniformity of major coal seams over large areas are indicative of sustained periods of steady and slow rates of subsidence in the coal swamps. This is corroborated by the very low ash yield through the full thickness of seams. Each of the four main coal seams (Yallourn, Morwell 1A, Morwell 1B and Morwell 2) had roughly the same area of deposition (500 to 700 km^2) in which more than 80 m thickness of brown coal developed, each made up of four to five cycles (Holdgate, 2003).

Figure 5 shows the main tectonic subdivisions and brown coalfield areas of the onshore Gippsland Basin as defined by Hocking (1976). Figure 6 shows the stratigraphic nomenclature currently applied to the onshore deposits of brown coal in the Gippsland Basin.

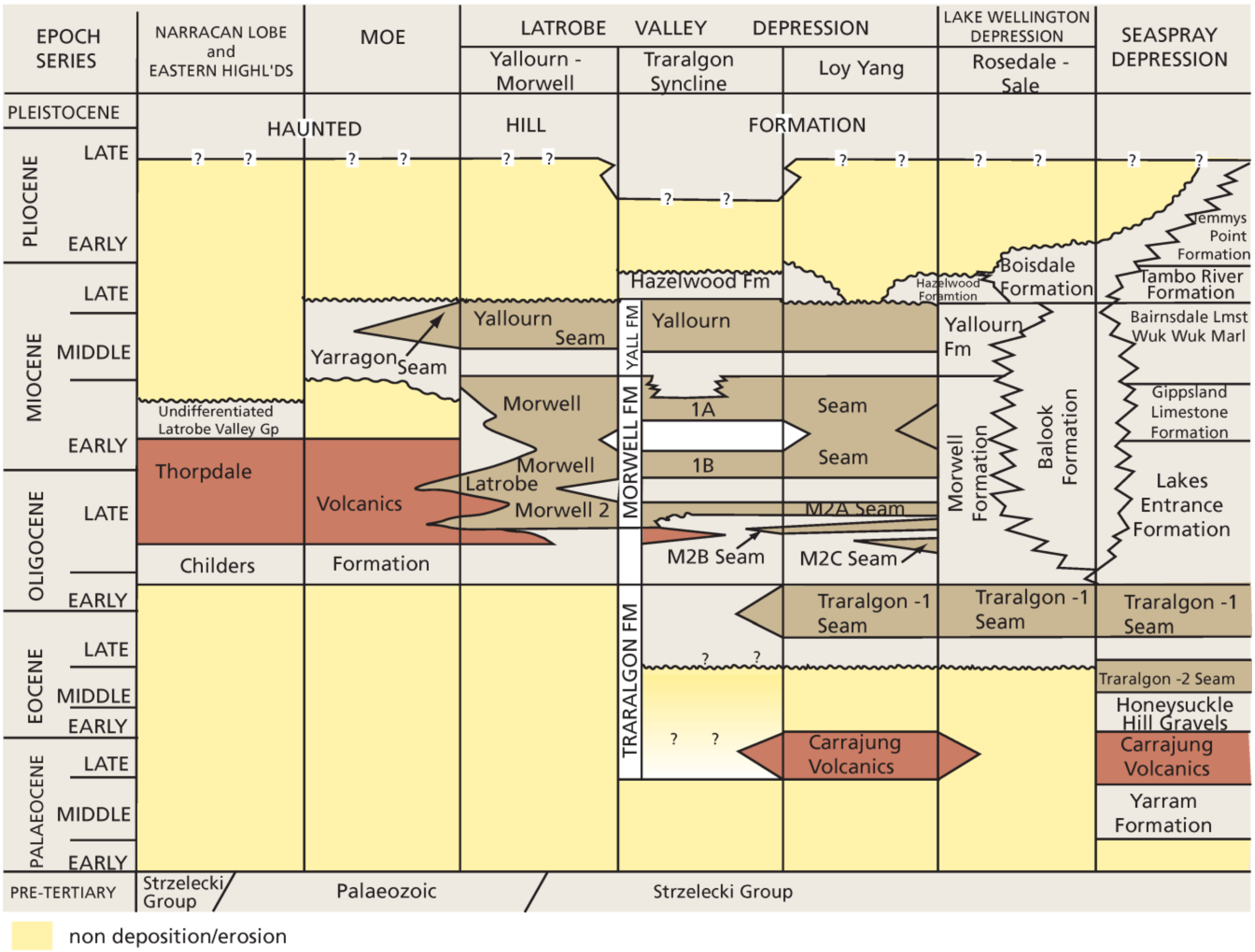

Figure 6 Main stratigraphic subdivisions of the onshore Gippsland Basin. Defined by structure-based areas

Source: Holdgate (2003)

Most of the main economic coal-bearing sequences formed from the late Eocene to the middle Miocene (Figure 6). As a consequence of erosion on anticlines, separate systems of stratigraphic nomenclature have arisen where coal-bearing sequences are not now directly connected, or where infill drilling in the deeper synclines was not available at the time of discovery.

Commencing with the work of Hocking (1969) and Partridge (1971), many workers (e.g. Gloe, 1975, 1976, 1984; Holdgate, 1982, 1985b; Smith, 1982; Thompson, 1980) recognised the essential two-fold subdivision of the coal measure sequences. These comprise the upper non-marine Yarragon, Yallourn, Morwell and Alberton formations, which are facies equivalents to the similar aged marine Seaspray Group; and the lower non-marine Traralgon and Yarram formations that underlie all the above formations and are consequently more widespread. Stratigraphic correlation of the coal seams is shown on the detailed cross-sections in the onshore Gippsland Basin (Figure 7).

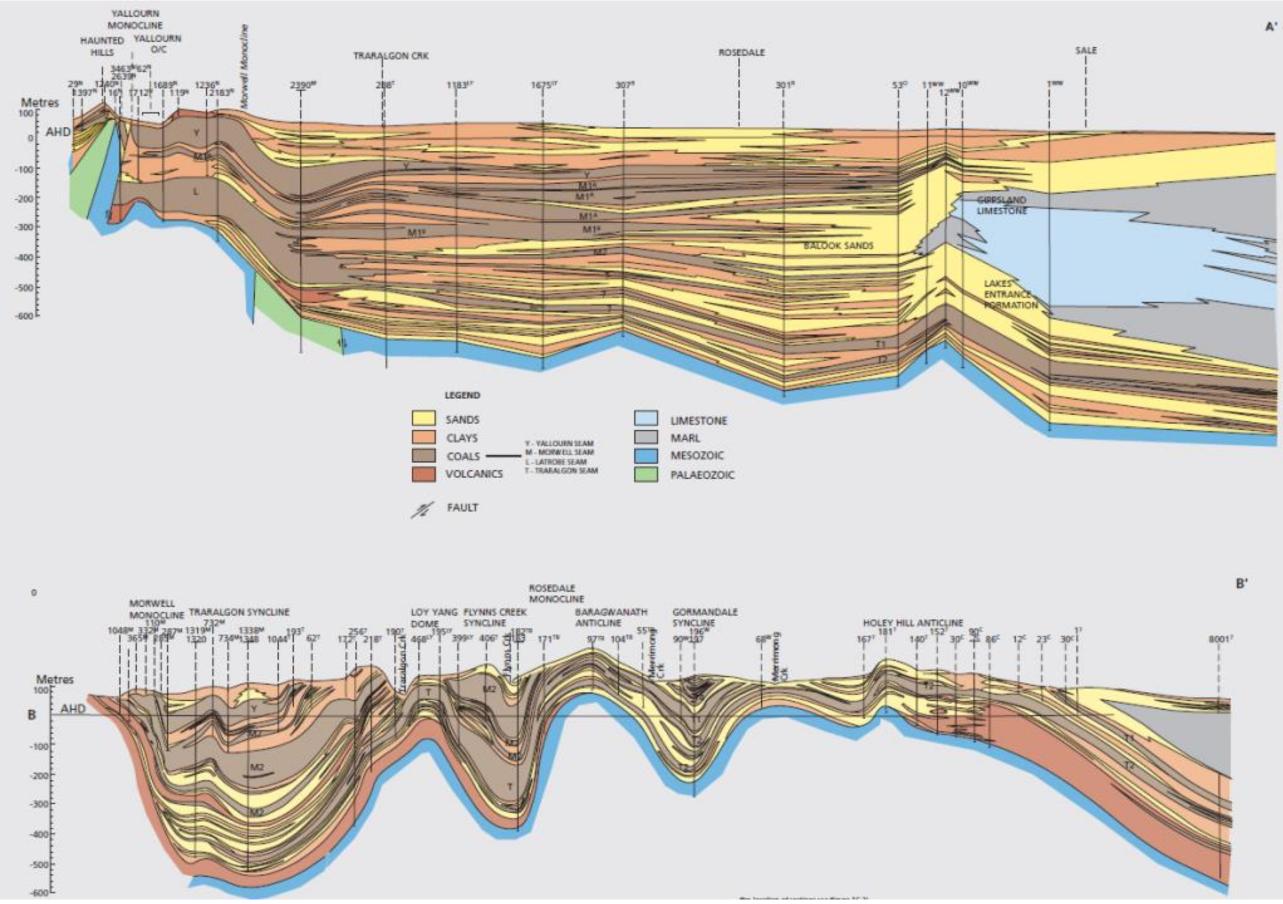

Figure 7 Cross-sections through the Latrobe Valley coal measures (see Figure 8 for locations of A-A' and B-B')

Source: Holdgate (2003)

Traralgon Formation

The Traralgon Formation is the oldest Paleogene unit (Figure 6) which includes useful economic accumulations of brown coal, and is dated by spore-pollen ages to the middle Eocene to early Oligocene (Holdgate et al., 2000). It is widespread throughout the onshore Gippsland Basin with the exception of the Lakes Entrance Platform, and is known to extend offshore.

The Traralgon Formation comprises interbedded gravels, sands, clays and major coal seams. Coarser grained sands and gravels predominate towards the base, with coals and clays in the middle, and sands, clays and minor coals near the top.

Where the Traralgon Formation subcrops or outcrops along the basin margins, or where it is not overlain by Morwell and Yallourn formations, economically recoverable coal seams occur. Such areas include all the major coalfields along the Baragwanath Anticline (Gormandale, Willung, Holey Plains, Coolungoolun, Longford Dome, Stradbroke, Boodyarn and Won Wron) and also on the Loy Yang and Gelliondale domes (Figure 5).

Across the Baragwanath Anticline the main coal seams recognised are the Traralgon 1 and Traralgon 2 seams. In the Latrobe Valley Depression only the Traralgon 1 Seam, and an overlying Traralgon 0 Seam, occurs west of the Rosedale Monocline where they extend as far as the Traralgon Syncline. The Traralgon 1 Seam at Gormandale and Flynns Creek Syncline can be over 100 m thick, and at Stradbroke the Traralgon 2 Seam is over 100 m thick. Further east at Holey

Plains, Coolungoolun and Longford Dome, thinning, splitting and interseam erosion has reduced each of the Traralgon seams to about 40 m (Holdgate et al., 2000).

A large proportion of the total Traralgon Formation coal resource lies beneath the marine carbonates of the Seaspray Group in the Seaspray Depression, and extends offshore for up to 27 km to the Barracouta structure (Holdgate, 1984). Here a number of seams aggregate up to 150 m of coal in places, but little is known of their quality as the limestone cover is 300 to 700 m thick. The Traralgon Formation seams contain, with some exceptions, the lowest moisture content (average 55%) for Gippsland Basin brown coals. The few samples analysed from deeper oil wells indicate similar coal qualities are higher in rank (i.e. bed moisture content is around 30%) (Holdgate et al., 2000). This resource is estimated to be in excess of the combined resources of brown coal without limestone cover, but the significant overburden precludes future development.

Morwell Formation

The Morwell Formation consists of a complex unit of thick coal seams and lesser clay-sand sequences, which disconformably overlies the Traralgon Formation in the Latrobe Valley Depression. The Morwell Formation, and similar aged Alberton Formation in the Yarram area, are confined to that part of the onshore Gippsland Basin west of the sand barriers (Balook Formation), which mark the predominant maximum point of marine transgression for the Seaspray Group (Figure 5). The Morwell Formation extends across the Latrobe Valley Depression and grades into the Thorpdale Volcanics in the Moe Swamp Basin and on the Narracan Block (Holdgate, 2003).

Both the Morwell and Alberton formations are dated late Oligocene to early Miocene by spore-pollen. The oldest Morwell 2 Seam attains a maximum thickness of 140 m in the area between Yallourn and Glengarry but here it is usually overlain by younger coal-poor Morwell Formation units and the Yallourn Formation. However, it does occur in a narrow subcrop where it has been uplifted along the Yallourn Monocline (Figure 5). The now defunct open-cut mines of Yallourn North and Yallourn North Extension are located along this monocline. The seam in this area is known as the Latrobe Seam because it includes a limited component of the Morwell 1B Seam. Elsewhere there is interseam separation between Morwell 1B and Morwell 2 seams so that the term Latrobe Seam has only local significance (Holdgate, 2003).

The Morwell 2 Seam thins to the south and west where it is replaced by sediments and volcanic rocks. At Morwell it is only about 40 m thick. On the Loy Yang Dome (Figure 5), a second area of thickening of the total coal seam interval occurs and three splits of the Morwell 2 Seam are known as the Morwell 2A, 2B and 2C seams. Here they aggregate over 80 m of coal. In 1982, open-cut development commenced at Loy Yang at the subcrop of the Morwell 2A and Morwell 2B seams. The Morwell 2 seams extend as far as Gormandale and Rosedale; east of which they grade into the sand-rich Balook Formation of the Seaspray Group (Holdgate, 2003).

The Morwell 1B Seam conformably overlies the Morwell 2 Seam usually with an interseam separation of clay and minor sand varying between 2 and 30 m. The Morwell 1B has wider extent and overall greater thickness than any other seam in the Latrobe Valley Depression, covering some 650 km^2 mostly south of the Latrobe River. In the Loy Yang Dome area between Traralgon Creek and the Rosedale Monocline the Morwell 1B reaches a maximum thickness between 100 and

120 m. Other major depocentres for this seam occur between Yinnar and Morwell Township and at the Flynn area (Figure 8).

East of Rosedale, the Morwell 1B Seam grades into barrier sands of the Balook Formation, north of the Latrobe River into clays and minor sands, and west of the Yallourn Monocline into interbedded sediments, lavas and tuffs of the Thorpdale Volcanics. The Morwell 1B and overlying Morwell 1A seams combine in the Morwell-Driffield area as the Morwell 1 Seam, which is up to 165 m thick. On the western flank of the Loy Yang Dome the Morwell 1A, 1B and 2 seams all combine producing up to 230 m of continuous low ash coal (Holdgate, 2003).

The upper coal seam of the Morwell Formation, the Morwell 1A Seam, is up to 80 m thick in places where it is currently mined (e.g. at Loy Yang and Hazelwood). Elsewhere, both the areal extent and thickness of coal are reduced compared to the Morwell 1B Seam, and mostly replaced by 80 m thick sequences of interbedded clays, ligneous clays and minor coal bands, as occurs in the Traralgon Syncline and the area from Yallourn to Glengarry. East of Rosedale the Morwell 1A Seam grades laterally into Seaspray Group barrier sands of the Balook Formation (Holdgate, 2003).

Alberton Coal Measures

The Alberton Coal Measures at Alberton and Gelliondale (Figure 5) is not directly connected with the Morwell Formation due to uplift and erosion on the intervening Baragwanath Anticline (Holdgate, 2003). However, it is of the same spore-pollen age. The unit also grades eastwards into an equivalent barrier sand sequence (the Balook Formation), which strikes northwards across the centre of the Seaspray and Alberton depressions (Figure 5).

Yallourn Formation

The Yallourn Formation is the youngest and uppermost coal-bearing formation in the Latrobe Valley and is dated by spore-pollen as middle Miocene age. In a similar manner to the Morwell Formation, which it conformably overlies, the Yallourn Formation grades laterally eastwards into barrier sands (the Balook Formation) of the Seaspray Group. The formation consists mainly of the Yallourn Seam, although in the deeper synclines it may include up to 200 m of clay above the coal seam. Where the underlying Morwell 1A Seam is fully developed, the two seams are separated by interseam burden known locally as the Yallourn clay that can be up to 5 m thick (Holdgate, 2003).

In the Moe Swamp Basin, west of Moe (Figure 5), an unconnected coal-bearing sequence of equivalent age is known as the Yarragon Formation (Holdgate, 1985a). Coal seams equivalent to the Yallourn Formation have not been recorded at Alberton and Gelliondale but ligneous clays overlying the Alberton Coal Measures contain the same spore-pollen assemblages.

The extent of the Yallourn Seam in the Latrobe Valley Depression has been subsequently modified by late Miocene erosion to a greater extent than for the deeper coal seams. Isopachs suggest that most developments of the seam occurred in the Maryvale East and Yallourn areas (Figure 8) where a continuous seam up to 100 m in thickness occurs (Figure 5). Elsewhere, seams greater than 40 m are restricted to south of the Latrobe River up to the edge of the Loy Yang Dome, and down the Traralgon Syncline as far south as Churchill and Yinnar. The seam grades laterally into clays north-east of Tyers and south-east of Yinnar. In most other areas, the seam edges are determined by the subcrop. In the Moe Swamp Basin, the Yarragon Formation includes coal seams including an upper A seam 15 m thick and a lower B seam 36 m thick. Westwards at Yarragon, similar coal seams overlie Thorpdale Volcanics (Fraser, 1983; Holdgate, 1985a).

Because of its younger age and shallow depth of burial, the Yallourn Seam averages 65 to 67% moisture content where it is mined at Yallourn open-cut. In the Traralgon and Latrobe synclines the seam can be buried by up to 200 m of younger Yallourn and Haunted Hill formation clays, and as a consequence its moisture may reduce to 60%. About 550 km^2 of the Latrobe Valley Depression is occupied by the Yallourn Seam.

Coalfield areas

There are 28 defined brown coalfields in the Latrobe Valley, Seaspray and Gelliondale-Alberton depressions (Table 4, Figure 8). This section focuses on the five main coalfield areas where current mining activity and the two most advanced coal resource development proposals are located.

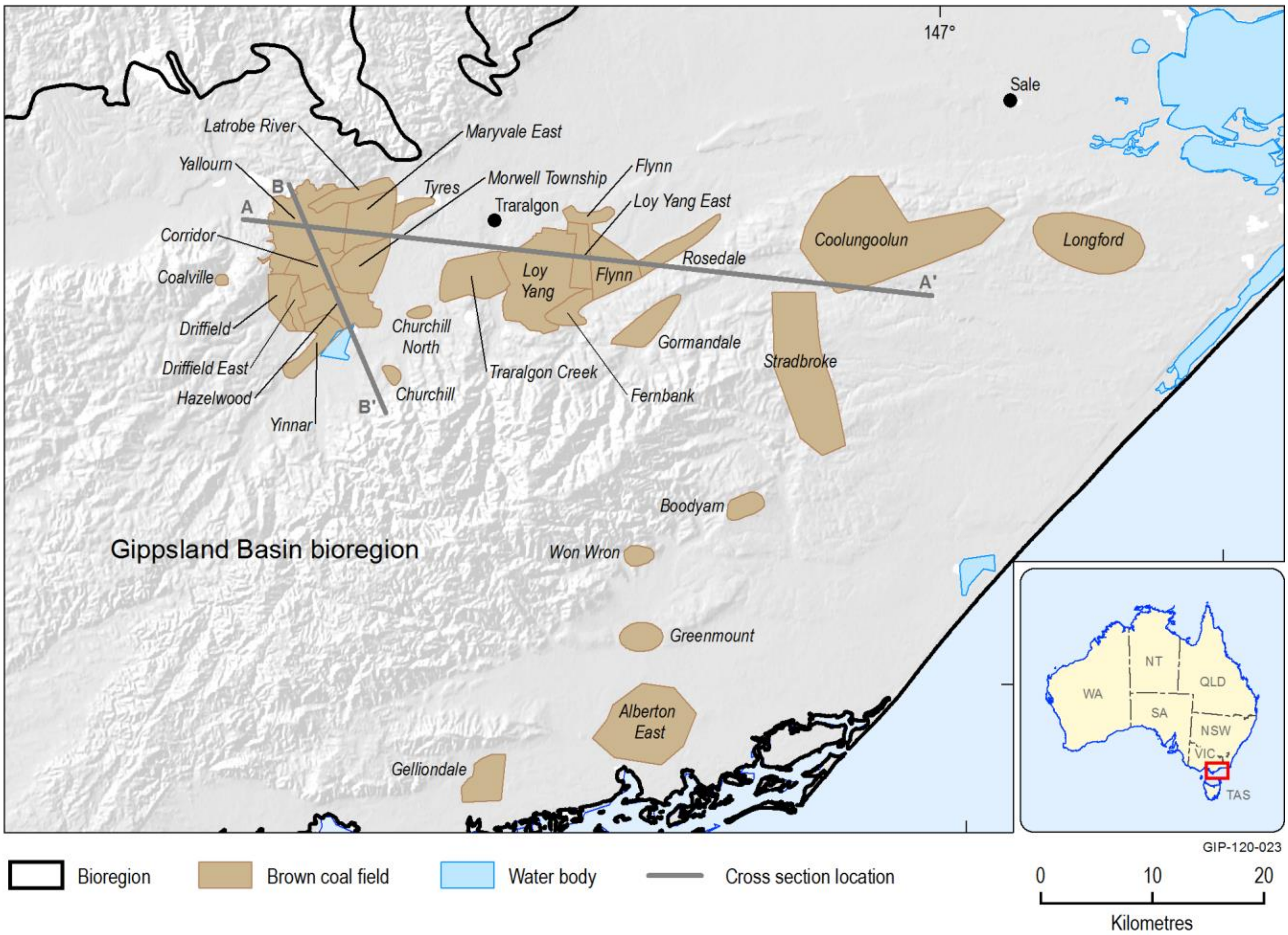

Figure 8 The 28 brown coalfields in the Gippsland Basin bioregion

Data: Victoria Department of State Development, Business and Innovation (DSDBI) (Dataset 5)

The active Yallourn and Hazelwood open-cut mines lie within the Yallourn - Morwell coalfield. Loy Yang Mine is within the Loy Yang - Flynn coalfield. Ignite Energy Resources Limited's (IER) Gelliondale project (IER, 2015) involves the development of the Gelliondale coalfield and IER's biogenic CSG project is within the Seaspray Depression so includes the Stradbroke, Holey Plains, Coolungoolun and Longford coalfields. The location of these coalfields is shown in Figure 5 and

Figure 8. The three mining operations and the two development proposals are further discussed in Section 1.2.2 and Section 1.2.3.

Table 4 Brown coalfields within the Gippsland Basin bioregion

Name	Coal age	Stratigraphic unit(s)
Alberton East	early Oligocene to early Miocene	Alberton Formation
Boodyarn	middle to late Eocene	Traralgon Formation
Churchill	early to middle Miocene	Yallourn and Morwell formations
Churchill North	early to middle Miocene	Yallourn and Morwell formations
Coalville	Early Cretaceous	Strzelecki Group
Coolungoolun	middle to late Eocene	Traralgon Formation
Corridor	early to middle Miocene	Yallourn and Morwell formations
Driffield	early Oligocene to late Miocene	Morwell and Yallourn formations
Driffield East	early Oligocene to late Miocene	Morwell and Yallourn formations
Fernbank	middle Eocene to late Miocene	Latrobe Valley Group
Flynn	middle Eocene to late Miocene	Latrobe Valley Group
Gelliondale	early Oligocene to early Miocene	Alberton Formation
Gormandale	middle Eocene to late Oligocene	Traralgon and Morwell formations
Greenmount	middle to late Eocene	Traralgon Formation
Hazelwood Mine	early Oligocene to late Miocene	Morwell and Yallourn formations
Latrobe River	early Oligocene to late Miocene	Morwell and Yallourn formations
Longford	middle to late Eocene	Traralgon Formation
Loy Yang East	middle Eocene to late Miocene	Latrobe Valley Group
Loy Yang Mine	middle Eocene to late Miocene	Latrobe Valley Group
Maryvale East	early Oligocene to late Miocene	Morwell and Yallourn formations
Morwell Township	early Oligocene to late Miocene	Morwell and Yallourn formations
Rosedale	early Miocene to middle Miocene	Morwell and Yallourn formations
Stradbroke	middle to late Eocene	Traralgon Formation
Traralgon Creek	middle Eocene to late Miocene	Latrobe Valley Group
Tyers	middle Miocene	Yallourn Formation
Won Wron	middle to late Eocene	Traralgon Formation
Yallourn Mine	early Oligocene to late Miocene	Morwell and Yallourn formations
Yinnar	early Miocene to middle Miocene	Morwell and Yallourn formations

Data: GHD (2007)

Yallourn – Morwell

Apart from Loy Yang all of the open-cut mines so far developed in the Latrobe Valley are located in the Yallourn – Morwell area. All the coal being excavated is from seams of the Yallourn and Morwell formations.

The Latrobe Seam (mainly Morwell 2) subcrops on the upthrown side of the Yallourn Monocline north of the Latrobe River. Development by open-cut occurs at three separate locations. Yallourn North, discovered in 1879, became the location for the first major development of brown coal in the Latrobe Valley, some 18 Mt of coal had been excavated up until 1963 when it closed. Similar quality coal was then won from the somewhat larger Yallourn North Extension open-cut, some 5 km further east. These small deposits contain lower moisture content (48 to 54%) and hence relatively higher net wet specific energy (10.5 to 12.4 MJ/kg) (Gloe, 1984).

The Yallourn open-cut located south of the Latrobe River is based on Yallourn Seam coal. The mean thickness of coal is 60 m with an operational coal-to-overburden ratio of around 3.5:1. Up to June 1986, 530.7 Mt of coal had been won from this, the first major open-cut operated by the State Electricity Commission of Victoria (SECV). All the coal mined has been used for electric power generation purposes or for the manufacture of briquettes. Currently Yallourn open-cut has moved east and south-east of the old Morwell River site and is mining the Yallourn East Field.

From the Yallourn open-cut area, the Yallourn Seam extends eastwards across the Morwell River as far as Glengarry and southwards into the Maryvale field area where future development is planned (see Section 1.2.3 for further details about development at the Yallourn Mine). The Yallourn Seam underlies the whole Morwell township area as far as the northern boundary of Morwell open-cut.

The Morwell open-cut is based on the thick Morwell 1 (Morwell 1A plus Morwell 1B) Seam, which reaches a maximum thickness of 165 m beneath Morwell township. Within the area of the planned development of Morwell open-cut, coal thicknesses range from 135 m in the north to 50 m in the south – reflecting the northerly dip of the base of the seam and the flat erosion surface of the top of coal beneath a thin layer of overburden. The overall average coal-to-overburden ratio is 4.1:1 and up until June 1986, a total of 293.7 Mt of coal had been won.

The coal from Morwell open-cut was found to be unsuitable for briquetting and has been used almost entirely for power generation purposes. Some 12,500 Mt of coal has been proved in the Yallourn – Morwell area, but the presence of towns, transport corridors, national parks and other constraints, reduces the quantity presently available for mining.

Loy Yang – Flynn

The Loy Yang Dome includes the Loy Yang open-cut development area and a further easterly extension into the Flynn field. Several other fringe areas could also be developed including the Traralgon Creek area south to Churchill, and south of Flynn field into the Flynns Creek Syncline and flanks of the Rosedale Monocline (Figure 5).

On the Loy Yang Dome the Yallourn and Morwell formations are underlain by the Traralgon Formation that includes the thick Traralgon 0 (T0) and Traralgon 1 (T1) seams. The Loy Yang Dome is the dominant structure in the area and the coal seams dip at a low angle towards the north.

Both the Yallourn and Morwell formations contain uniformly thick seams over much of the fields where interseam sediments are either thin or absent. Up to 230 m of continuous low ash yield coal has been proven. All seams, in general, consist of low ash coals of excellent quality with a mean moisture content of 63%. This is intermediate between those for Yallourn (66%) and Morwell (60%) seam coals as currently mined.

The Traralgon 0 and Traralgon 1 seams are intersected some 60 m below the base of the Morwell 2 Seam. The seam thickness is up to 60 m and the coal is also of good quality with a moisture content of 58%.

Total measured economic reserves of coal on the low dipping northern flanks of the Loy Yang Dome are 7000 Mt with a further 4400 Mt within the adjacent fringe areas. The Loy Yang and Flynn open-cut areas could recover 3400 Mt with coal-to-overburden ratios of about 4:1.

Holey Plains, Coolungoolun and Longford Dome

In the central and eastern portion of the Baragwanath Anticline only seams of the Traralgon Formation occur. The main seam is the Traralgon 2 Seam that is up to 45 m, while the Traralgon 1 seam reaches up to 33 m in thickness. In the Holey Plains area 1000 Mt of economic coal are vertically overlain by 1400 million m^3 of sandy overburden and interburden (Gloe et al., 1988). In the Coolungoolun area, the values are 300 Mt and 400 million m^3 respectively, and at Longford, 164 Mt and 300 million m^3 respectively. These coals are the highest rank coals in the Latrobe Valley with moisture contents of 49% to 56% and specific energy values of 28 to 29 MJ/kg on a dry ash basis. Ash yields are low averaging 2.6% to 3.1% (dry basis) but sulfur contents are high averaging up to 5.8% (dry basis).

Currently there are no plans for open-cut development in these areas, some parts of which underlie the Holey Plains National Park and parts under Longford township.

Stradbroke

This coalfield (Figure 5) consists of high quality brown coal comprising the Traralgon 1 and Traralgon 2 seams. The seams dip gently east (Thompson, 1979) and are overlain to the east by the Cenozoic marine marls of the Seaspray Group and Haunted Hill Formation to the west.

The coal in the Traralgon Seam reaches a maximum thickness of 136 m. The quality is good with a generally low ash yield (3.9% dry basis), a relatively low moisture content (58.4%) and high net wet specific energy (9.6 MJ/kg). As with all Traralgon Seam coals in this general area, sulfur contents are higher (averaging 3.1% dry basis) than those of the Latrobe Valley coals. The Stradbroke Field was examined by the Victorian Brown Coal Council (VBCC) in 1981 to 1982 as a development option for a coal-to-liquids plant; and in 2005 by IER who carried out further drilling that defined a measured and indicated coal reserve of 2580 Mt (Thompson, 1979; VBCC, 1983).

Gelliondale

The Gelliondale Seam forms the main thick coal seam in the Gelliondale field, occurring either as one seam (50 m or more thick) or as two splits (Greer and Smith, 1982). A younger Alberton Seam occurs to the east of the field and is designated as an upper split of the Gelliondale Seam.

Structurally, the Cenozoic coal measures are considered to be drape folded over fault blocks of the Lower Cretaceous Strzelecki Group, forming a series of anticlinal ridges and synclinal troughs. A large anticlinal structure known as the Hedley Dome runs approximately east–west through the centre of the field. Some faulting is indicated from drill-hole data.

The mean moisture content of the coal (66%) and net wet specific energy value (6.8 MJ/kg) are similar to those of the Yallourn Seam at Yallourn. However, the ash yield (63% dry basis) and sulfur content (0.9% dry basis) are somewhat higher.

The indicated and inferred coal resource within the Gelliondale Coalfield is estimated as 5200 Mt (1700 Mt indicated and 3500 Mt inferred) (GHD, 2007). Of these, 1050 Mt are considered to be economically recoverable.

Ignite Energy Resources Limited (IER) has the exploration licence (EL 4416) which includes the Gelliondale coalfield. IER have preliminary development plans to potentially mine, upgrade and export the brown coal from Gelliondale, as discussed in Section 1.2.3.1.4 (IER, 2015). In June 2015 IER were granted a retention licence (RL 2013) over the Gelliondale brown coal resource.

Coal quality

Victoria's lignite is typically low in ash, sulfur, heavy metals and nitrogen, making it very low in impurities by world standards.

In the Latrobe Valley, the ash yield is usually 1 to 4% on a dry basis. Minerals such as quartz, kaolinite, and iron account for up to half the ash-forming constituents (Gloe, 1984). Inorganics such as organically-bound cations and dissolved salts of sodium and magnesium (as chlorides) tend to be higher in the main coal depocentres.

In all Gippsland coals, organic sulfur tends to increase towards the marine barrier system as documented at Stradbroke (Thompson, 1980), Holey Plains – Coolungoolun (Holdgate, 1980), Alberton (Holdgate, 1982) and the Latrobe Valley (Holdgate, 1985b; Kiss et al., 1985). Where marine sediments overlie coal seams of the Traralgon Formation, the sulfur content tends to be higher in the uppermost seam suggesting that stratigraphic proximity controls sulfur content (Holdgate, 1980). In the Latrobe Valley, marine incursions represented by a mud and silt interseam facies within the Morwell Formation have tended to increase sulfur levels in the coal seams immediately underlying these inter-seams (Holdgate and Sluiter, 1991).

The high moisture content of brown coal from Gippsland, which ranges from 48 to 70%, reduces its effective energy content (average 8.6 MJ/kg on a net wet basis or 26.6 MJ/kg on a gross dry basis). The high water content and reactivity of Gippsland lignite has to date precluded it from coal export. With the development of new drying, gasification and liquefaction technologies, direct export may become an option.

Estimated resources

Coal reserve and resource data has been compiled from a number of sources, and represents the present state of knowledge on economic brown coal resources in the onshore Gippsland Basin (Table 5 to Table 7). It should be noted that the definition of an economic reserve or resource varies according to mining practices. Most of the defined reserves and resources referred to here are based on the former SECV definition of brown coal reserves and their economically mineable properties. Further definitions are provided from Gloe's (1980) report number 28 – a major SECV review of reserves, coal quantities and coal quality in the Latrobe Valley area.

Subsequent to the Gloe (1980) report, additional brown coal resources were discovered by SECV and Geological Society of Victoria drilling that include the coalfields of Stradbroke, Longford, Boodyarn, Greenmount and Alberton, all of which occur within the south Gippsland area.

Of course, none of the following resource figures in Table 5 and Table 6 takes into account the geographic or cultural features that affect mine design because the influence of these factors may change and is impossible to predict. Features such as land use, national parks, river diversions, floodplains, towns, roads, open-cut operating practices, designs and operating strips all effect the ultimate reserve accessible and recoverable for mining.

A complete list of the published brown coal resource estimates for the Gippsland Basin is given in Table 8. There are some significant differences in the resource estimates from various different sources. Investigating the reasons for these differences is not within scope of this product but the estimates are included here for reference. The sources of the estimates are listed in Table 8.

The following data in Table 5 on resource figures and coal quantities is derived from the Gloe (1980) data for areas going from west to east across the Latrobe Valley. The remaining coalfield resources are compiled in Table 6 from other later published data as referenced. This includes the coalfield areas of Stradbroke, Longford, Boodyarn, Won Wron, Greenmount, Alberton and Gelliondale. Table 7 is an estimate of the Traralgon coal seam resource within the Gippsland Basin. These are included because they have recently been targeted as a source of CSG.

Table 5 Estimates of brown coal resources for Latrobe Valley in the Gippsland Basin (original quantities in place as at 1 July 1979)

Field	Seam	Measured (Mt)	Indicated (Mt)	Total (Mt)	Economic (Mt)	Recoverable (Mt)
Yallourn-Morwell	Yallourn	6,820	NA	6,820	6,416	2,800
	Morwell 1	3,583	2,658	16,511	7,351	5,330
	All	20,573[a]	2,658	23,331[a]	13,757[a]	6,130[a]
Loy Yang	Yallourn	1,859	2,318	4,172	1,515	NA
	Morwell	14,653	6,342	20,995	8,052	4,700[b]
	Traralgon	4,820	256	5,076	1,939	NA
	All	21,332	8,916	30,248	11,506	4,700
Gormandale	Morwell	306	NA	306	33	NA
	Traralgon	3,944	NA	3,944	2,084	600
	All	4,250	NA	4,250	2,117	600
Holey Plains	Traralgon	2,439	NA	2,439	1,297	200
Rosedale	Yallourn	305	NA	305	220	NA
	Morwell	1,076	NA	1,076	953	NA
	All	1,381	NA	1,381	1,173	NA
Traralgon Syncline	Yallourn	3,827	5,498	9,325	2,778	NA
	Morwell	5,314	14,320	19,634	2,177	NA
	Traralgon	NA	976	976	NA	NA
	All	9,141	20,794	29,935	4,965	NA
Other areas Latrobe Valley	Yallourn	194	3,067	3,261	307	NA
	Morwell	1,419	4,284	5,703	508	NA
	Traralgon	4,094	3,205	7,299	939	NA
	All	5,707	10,556	16,263	11,063	NA
All Latrobe Valley	Yallourn	13,005	16,883	23,888	11,063	2,800
	Morwell	36,521	27,604	64,225	18,863	8,030[b]
	Traralgon	15,297	4,437	15,734	828	800
	All	64,923[a]	42,924	107,847[a]	35,754[c]	116,300[a]

[a]Includes 625 Mt excavated to 1 July 1979
[b]Includes some Yallourn Seam coal
[c]Includes 625 Mt excavated to 1 July 1979 and about 5000 Mt under Latrobe Valley townships, storage dams, etc, and about 1000 Mt under APM Mill area
Data: Gloe (1980)

Table 6 Summary of the brown coal resources of the Gippsland Basin

Area	Quantity (Mt)
Latrobe Valley Depression	158,026
Moe-Yarragon	773
Stradbroke	3,700
Won Wron – Boodyarn	288
Alberton	4,887
Gelliondale	5,200
Total Gippsland Basin	172,874

Data: Holdgate (2003)

Table 7 Total inferred Traralgon Formation brown coal resources for the Gippsland Basin – mainly Exploration Licence 4416

Traralgon Seam	Limits	Coal (Mt)
T2 coal seams (5)	No overburden limits	98,002
T1+T0 coal seams (5)	No overburden limits	247,379
Total all T seams	Includes measured coal reserves	345,381

Data: Holdgate et al. (2000)

Table 8 Gippsland Basin brown coal resource estimates

Name	Total coal (Mt)	Resource classification	References for data	Date of estimates
Alberton East	4,890	Indicated	GHD (2007)	1986
Alberton East	3,455	Inferred	VBCC (1983)	1982
Alberton East	3,271.8	Inferred	Geoscience Australia (2015)	1982
Alberton East	4,890	In Situ	Waghorne (2005)	2005
APM Mill	3,347.8	Measured plus Indicated	Geoscience Australia (2015)	1982
Boodyarn	276	In Situ Quantity (Mt)	GHD (2007)	1986
Boodyarn	251	Inferred	VBCC (1983)	1982
Boodyarn	524.4	Inferred	Geoscience Australia (2015)	1982
Boodyarn	270	In Situ	Waghorne (2005)	2005
Boolarra	part 100,000	In Situ	Waghorne (2005)	2005
Budgeree	230	Inferred	VBCC (1983)	1982
Budgeree	437	Inferred	Geoscience Australia (2015)	1982
Churchill	100	Potential Economic Resource	GHD (2007)	2005
Churchill	7767.2	Measured plus Indicated	Geoscience Australia (2015)	2000
Churchill	100	Economic	Waghorne (2005)	2005

Name	Total coal (Mt)	Resource classification	References for data	Date of estimates
Churchill North	100	Potential Economic Resource	GHD (2007)	2005
Churchill North	100	Economic	Waghorne (2005)	2005
Coalville	part 100,000	In Situ	Waghorne (2005)	2005
Coolungoolun	4,370	Indicated	GHD (2007)	1986
Coolungoolun	1,072	Indicated	VBCC (1983)	1982
Coolungoolun	1,929.6	Probable	Geoscience Australia (2015)	1982
Coolungoolun	1,300	In Situ	Waghorne (2005)	2005
Corridor	2,200	Potential Economic Resource	GHD (2007)	2005
Corridor	2,200	Economic	Waghorne (2005)	2005
Driffield	520	Potential Economic Resource	GHD (2007)	2005
Driffield	520	Economic	Waghorne (2005)	2005
Driffield East	400	Potential Economic Resource	GHD (2007)	2005
Driffield East	400	Economic	Waghorne (2005)	2005
Driffield-Narracan	5,566	Measured	VBCC (1983)	1982
Driffield-Narracan	10,575.4	Measured	Geoscience Australia (2015)	1982
East Gippsland ^	221,000	In Situ Quantity (Mt)	GHD (2007)	2003
Fernbank	1,500	Potential Economic Resource	GHD (2007)	2005
Fernbank	1,075.4	Measured plus Indicated	Geoscience Australia (2015)	1982
Fernbank	1,500	Economic	Waghorne (2005)	2005
Flynn	4,500	Potential Economic Resource	GHD (2007)	2005
Flynn	4,500	Economic	Waghorne (2005)	2005
Flynn 1	2,718.9	Measured plus Indicated	Geoscience Australia (2015)	2003
Flynn 2	6,644.3	Measured plus Indicated	Geoscience Australia (2015)	2003
Flynn Railway Station	3,000	Indicated	VBCC (1983)	1982
Flynn Railway Station	5,700	Indicated	Geoscience Australia (2015)	1982
Flynns Creek	4,928.6	Measured plus Indicated	Geoscience Australia (2015)	2003
Gelliondale	3,500	Inferred	GHD (2007)	2003
Gelliondale	1,700	Indicated	GHD (2007)	2003
Gelliondale	2,976	Measured/Indicated	VBCC (1983)	1982
Gelliondale	5,662	Indicated (532 Mt measured)	Geoscience Australia (2015)	2010
Gelliondale	5,200	In Situ	Waghorne (2005)	2005
Gippsland (Fringe Areas)	147,500	Inferred	Geoscience Australia (2015)	1982
Gormandale	2,120	Potential Economic Resource	GHD (2007)	unknown
Gormandale	3,100	Measured/Indicated	VBCC (1983)	1982

Name	Total coal (Mt)	Resource classification	References for data	Date of estimates
Gormandale	4,600	Measured	Geoscience Australia (2015)	2010
Gormandale	1,100	Economic	Waghorne (2005)	2005
Greenmount	500	In Situ	Waghorne (2005)	2005
Hazelwood	8,882	Indicated	VBCC (1983)	1982
Hazelwood Mine	420	Proven & Probable Reserves	GHD (2007)	2006
Hazelwood Mine	3,429.7	Measured	Geoscience Australia (2015)	2001
Hazelwood Mine	500	In Situ	Waghorne (2005)	2005
Hazelwood-Yinnar	22,251	Indicated	Geoscience Australia (2015)	1982
Holey Plains	3,295	Indicated	VBCC (1983)	1982
Holey Plains	8,297.3	Indicated	Geoscience Australia (2015)	1982
Latrobe River	500	Potential Economic Resource	GHD (2007)	2005
Latrobe River	500	Economic	Waghorne (2005)	2005
Latrobe Valley	65,000	Measured	GHD (2007)	2003
Latrobe Valley	158,000	In Situ	GHD (2007)	2003
Latrobe Valley	43,000	Indicated	GHD (2007)	2003
Latrobe Valley	50,000	Inferred	GHD (2007)	2003
Latrobe Valley	549.1	Inferred	Geoscience Australia (2015)	2013
Loy Yang	17,660	Measured/Indicated	VBCC (1983)	1982
Loy Yang East	2,500	Potential Economic Resource	GHD (2007)	2005
Loy Yang East	2,500	Economic	Waghorne (2005)	2005
Loy Yang Extended	1,500	Inferred	Geoscience Australia (2015)	1982
Loy Yang Mine	1,740	Proven & Probable Reserves	GHD (2007)	2006
Loy Yang Mine	1,400	Economic	Waghorne (2005)	2005
Loy Yang Mine	2,000	In Situ	Waghorne (2005)	2005
Maryvale	10,053	Measured	VBBC (1983)	1982
Maryvale	18,922.3	Measured	Geoscience Australia (2015)	1982
Maryvale East	4,700	Potential Economic Resource	GHD (2007)	2005
Maryvale East	4,700	Economic	Waghorne (2005)	2005
Moe Swamp	460	Inferred	GHD (2007)	2005
Moe Swamp	110	Indicated	GHD (2007)	2005
Moe Swamp Basin	1,088.7	Inferred	Geoscience Australia (2015)	2012
Moe Swamp EL 4877	125	Inferred	Greenpower Energy (2012)	2012
Moe Swamp Gippsland EL4500	581.4	Inferred	Geoscience Australia (2015)	2012
Moe Swamp Gippsland EL4500	306	Inferred	Greenpower Energy (2012)	2012

Name	Total coal (Mt)	Resource classification	References for data	Date of estimates
Moe Swamp EL5227	136	Inferred	Greenpower Energy (2012)	2012
Moe-Yarragon	773	Indicated	GHD (2007)	2003
Morwell M1	1,651	Measured	VBCC (1983)	1982
Morwell M2	584	Measured	VBCC (1983)	1982
Morwell Township	4,400	Potential Economic Resource	GHD (2007)	2005
Morwell Township	4,400	Economic	Waghorne (2005)	2005
Rosedale	1,800	Potential Economic Resource	GHD (2007)	2005
Rosedale	9,300	Measured/Indicated	VBCC (1983)	1982
Rosedale	3,393.4	Measured plus Indicated	Geoscience Australia (2015)	1982
Rosedale	1,800	Economic	Waghorne (2005)	2005
Stradbroke	2,400	Measured	GHD (2007)	2005
Stradbroke	1,300	Inferred	GHD (2007)	2005
Stradbroke	3,700	Indicated	VBCC (1983)	1982
Stradbroke	4,902	Indicated	Geoscience Australia (2015)	2010
Stradbroke	3,700	In Situ	Waghorne (2005)	2005
Traralgon	5,919	Measured/Indicated	VBCC (1983)	1982
Traralgon	11,246.1	Measured plus Indicated	Geoscience Australia (2015)	1982
Traralgon Creek	5,300	Potential Economic Resource	GHD (2007)	2005
Traralgon Creek	5,300	Economic	Waghorne (2005)	2005
Tyers	1,300	Potential Economic Resource	GHD (2007)	2005
Tyers	1,300	Economic	Waghorne (2005)	2005
Tyers South	3,473.2	Indicated	Geoscience Australia (2015)	1982
Tyers South	1,826	Indicated	VBCC (1983)	1982
Victorian Inferior Coals	3,543.5	Inferred	Geoscience Australia (2015)	1982
Willung	2,596	Indicated	VBCC (1983)	1982
Willung	4,932.4	Indicated	Geoscience Australia (2015)	1982
Won Wron	12	In Situ Quantity (Mt)	GHD (2007)	1986
Won Wron	12	Measured	VBCC (1983)	1982
Won Wron	22.8	Measured	Geoscience Australia (2015)	1982
Won Wron	120	In Situ	Waghorne (2005)	2005
Won Wron - Boodyarn	288	Indicated	GHD (2007)	2003
Yallourn Mine	463	Proven Probable Reserves	GHD (2007)	2006
Yallourn Mine	3,320	In Situ	Waghorne (2005)	2005
Yallourn Mine	460	Economic	Waghorne (2005)	2005
Yallourn open-cut	430	Measured	VBCC (1983)	1982

Name	Total coal (Mt)	Resource classification	References for data	Date of estimates
Yarragon	200	Inferred	GHD (2007)	1986
Yarragon	258.4	Inferred	Geoscience Australia (2015)	2012
Yarragon EL 5210	289	Inferred	Mantle Mining (2013)	2013
Yinnar	1,000	Potential Economic Resource	GHD (2007)	2005
Yinnar	2,860	Indicated	VBCC (1983)	1982
Yinnar	1,000	In Situ	Waghorne (2005)	2005

1.2.1.2 Coal seam gas

Two coal-bearing sedimentary sequences in the onshore Gippsland Basin and one in South Gippsland are prospective for natural gas. The Early Cretaceous Strzelecki Group across the Gippsland region is a potential CSG target, as is the overlying Latrobe Group in the onshore Gippsland Basin (Goldie Divko, 2015).

In 2004 Karoon Gas carried out the only gas test to date on the black coals of the Strzelecki Group in the Gippsland Basin bioregion. In the exploration well Megascolides-1, Karoon Gas intersected coal seams that were thin and sparse with a single gas content of 3.37 m^3/t recorded (Grosser, 2005). The subsurface geology of the area is largely unknown with very limited data collected to date (Goldie Divko, 2015).

Brown coals within the Traralgon Formation of the Latrobe Group are extensive and attain great thicknesses, with some individual seams aggregating up to 150 m (Holdgate, 2003). Although there has been some preliminary exploration targeting these seams (e.g. Gastar Exploration Ltd, 2005), and an estimate of 3.7 trillion cubic feet (TCF) of gas (IER, 2014), no gas content or permeability measurements have been collected from the lignite seams of the Traralgon Formation (Goldie Divko, 2015). Hence, there is significant geological uncertainty associated with the prospectivity of the region for CSG.

1.2.1.2.1 Coal seam gas from black coal

There is no history of CSG production from Strzelecki Group black coals in the Gippsland Basin bioregion, and there has been only limited exploration. Black coals to the north of the traditional mining areas of Wonthaggi and Korumburra have been targeted for CSG. The well Megascolides-1 drilled in the Narracan Trough by Karoon Gas intersected around 12 m of Strzelecki Group coals, present as thin (5 cm to 1 m) seams (Grosser, 2005). Most of the thin coal seams did not have butt cleats, although face cleats were commonly seen with spacing ranging in size from 7 to 25 mm (Grosser and Smith, 2008). A single desorption coal sample had air-dried moisture content of 2.9%, ash of 47.4%, volatile matter of 23.7% and fixed carbon of 26.0%. It also had a vitrinite reflectance (VR) range between 0.64 and 0.89 (within the optimum gas-producing range). The desorption gas content was 3.37 cubic metre/tonne dry ash free (DAF) and the gas composition approximately 100% methane, with very low carbon dioxide (Grosser, 2005). Grosser and Smith (2008) concluded at the time, that low total coal thickness and gas contents made this coal unsuitable for a commercial CSG development.

The role of gas in mine disasters that killed miners at the State Coal Mine at Wonthaggi is often cited as evidence for the presence of CSG. Official reports on the disaster indicate that open-flame lamps were routinely used, which suggests that gas influx was not a major concern. A 1936 report by the mine manager quoted in Harper (1987) stated that 'the mines are not gaseous, and naked light is used, but stone dusting is adopted'. Stone dusting is a form of coal-dust hazard reduction, indicating that coal dust was considered the greater fire and explosion hazard.

Data pertaining to the prospectivity of the Gippsland Basin black coals as a source of CSG are very limited. As a result, there are no identified CSG resources from black coals (i.e. there are no known reserves that are commercially viable at this time), and their prospectivity is considered poor (Goldie Divko, 2015). There remains a large degree of geological uncertainty associated with CSG potential from Strzelecki Group black coals.

1.2.1.2.2 Coal seam gas from brown coal

The Traralgon Formation coals have been considered a possible CSG resource. The coals are thick and widely distributed, underlying most of the onshore Gippsland Basin. However, there is scant data available on coal rank and moisture content of these deeper brown coal seams, and no gas content or permeability measurements (Goldie Divko, 2015). Considering the lack of key data, there is significant uncertainty associated with the prospectivity of the Traralgon Formation coal seams as a CSG resource.

Ignite Energy Resources (IER) holds the current exploration licence for the 3800 km^2 EL 4416 over a portion of the onshore Gippsland Basin. IER are targeting exploration of the deeper lignite seams of the Traralgon Formation, containing biogenic natural gas (~100% methane), which it considers has been created by microbial activity within the lower-rank coal (IER, 2014). The potential resource size reported by IER (2014) is 3.7 TCF contingent resource (2C – best estimate of contingent resources); independently estimated by MHA Petroleum Consultants.

Prior to IER's involvement, the previous tenement holder, CBM Resources Pty Ltd commenced a drilling program in 2002. The drilling program included participation in two conventional petroleum wells. In one of these wells, York-1, coals between 567 and 640 m were tested and showed indications of methane gas and permeability within the coals (Gastar Exploration Ltd, 2002).

Gastar Exploration Ltd (Joint Venture Partner with CBM Resources Pty Ltd – EL 4416 holder prior to IER), announced the drilling of the first pilot well specifically for CSG in EL 4416 in the Gippsland Basin in May 2005. The pilot well (Burong #2) was drilled to a depth of 692 m, intersecting a coal seam around 14 m thick (Gastar Exploration Ltd, 2005). A second pilot well (Burong #3) close to Burong #2 was planned, along with well completions using techniques commonly used in the Powder River Basin in the United States with open-hole completions to be stimulated with water enhancements to flush away coal fines. The same article reported the intention to put the wells on production to gauge water and gas rates. However, no further information regarding the planned wells, techniques used and water production is available.

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1.2.2 Current activity and tenements

Summary

Brown coal is synonymous with the onshore geological Gippsland Basin and in particular the Latrobe Valley, which generates more than 43,000 GW hours of electricity (BREE, 2014; NEM, 2014) for the State of Victoria. This accounts for more than 80% of the state's electricity output from the vast shallow coal deposits of the Oligocene to Miocene Yallourn and Morwell seams. The underlying Traralgon Formation seams are for the most part too deep to mine at the surface but are considered to have potential for coal seam gas (CSG) (Holdgate, 2003).

There are three coal mines currently operating in the geological Gippsland Basin (Gippsland Basin). These are Yallourn, Hazelwood and Loy Yang in the Latrobe Valley. The Loy Yang Mine is the largest mine in the Latrobe Valley and supplies approximately 29 million tonnes (Mt) of brown coal annually to two power stations, Loy Yang A and Loy Yang B. The Yallourn Mine is Australia's second largest open-cut mine. It is adjacent to the Yallourn Power Station and annually mines around 13 Mt of high moisture brown coal. The Hazelwood Mine supplies 17 Mt of coal annually to the Hazelwood Power Station.

1.2.2.1 Coal

1.2.2.1.1 Exploration licences

Twenty-eight mineral exploration licenses (as at 19 May 2015) in the Gippsland Basin bioregion have selected brown coal, black coal and/or coal seam gas (CSG) as their target mineral for exploration (Figure 9). Under the same exploration licence, a company may also nominate other minerals, such as mineral sands. CSG activities in Victoria are governed by Victoria's *Mineral Resources (Sustainable Development) Act 1990* (MRSDA), however shale and tight gas are regulated under Victoria's *Petroleum Act 1998* (Petroleum Act). Sixteen of the 28 licences have selected CSG as one of their target commodities. Table 9 lists the owners and status of the licences shown in Figure 9. The majority of CSG activity carried out to date is limited to desktop studies, although there has been some drilling (e.g. Gastar Exploration Ltd, 2005).

Ignite Energy Resources Limited (IER) currently holds the largest mining exploration licence (EL) in the Gippsland Basin bioregion (EL 4416), which covers an area of 3837 km^2 (Figure 9). This licence includes the recognised coalfields of Longford, Boodyarn, Stradbroke, Greenmount, Alberton East and Gelliondale. IER's operations are divided into three subsidiaries: Ignite Resources, Gippsland Gas and Licella. Licella has developed a modified Catalytic Hydrothermal Reactor (Cat-HTR) technology that rapidly converts wet biomass (plant material) into 'BioCrude' oil and high-value bio-chemicals. IER currently has plans to exploit the relatively shallow brown coal at Gelliondale using conventional brown coal mining and upgrade with its Cat-HTR process. The 6.2 billion tonne (Bt) Gelliondale deposit consists of thick, shallow seams (less than 200 m depth and 100 m overburden) of lignite with low impurities – 6.2% ash and 0.9% sulfur (IER, 2015b).

IER consider that the deeper lignite seams within EL 4416 contain biogenic natural gas and are planning to investigate this potential with further drilling and gas testing (IER, 2015a).

An independent report by MHA Petroleum Consultants, commissioned by Ignite Energy Resources, has estimated that EL 4416 hosts a 3.7 trillion cubic feet (TCF) natural gas contingent resource (2C – best estimate of a contingent resource) (IER, 2015a). However, it is currently unclear how this resource estimate was calculated as no gas content is known to have been measured.

The other advanced coal resource exploration/appraisal project in the Gippsland Basin bioregion is in EL 5173 (Figure 9), 8 km south-west of Longford. Verso Energy Pty Ltd plan to use microbial coal conversion (MCC), targeting the Traralgon seams as part of its Coolung pilot project (Verso Energy, 2015), which sits within the Coolungoolun coalfield.

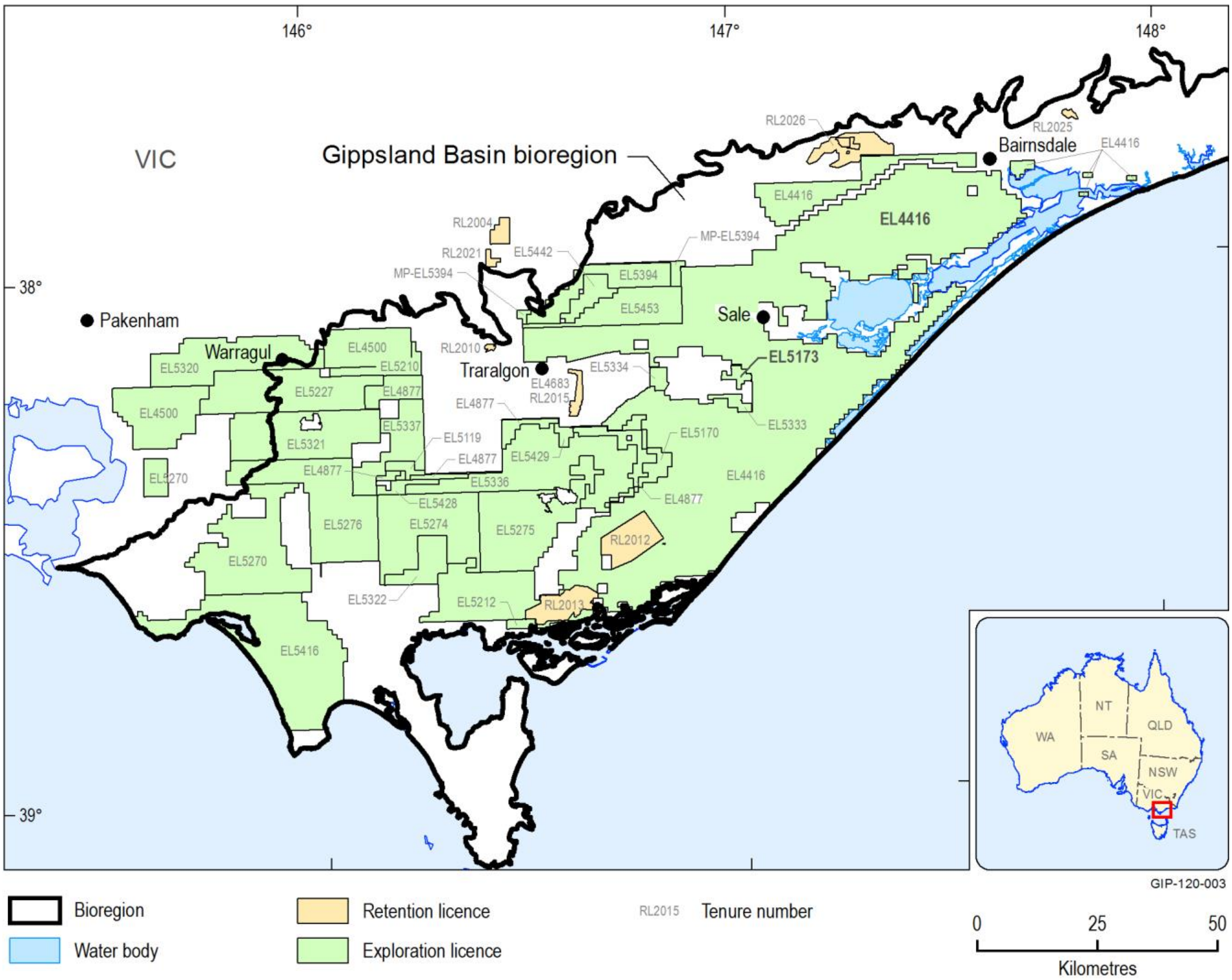

Figure 9 Coal exploration (exploration licences), retention and mining licences within the Gippsland Basin bioregion

EL = exploration licence
Data: Department of Economic Development, Jobs, Transport and Resources (Dataset 5)

Table 9 Current coal exploration licences in the Gippsland Basin bioregion

Tenement number	Owner	First grant date	Expiry date	Current area (km^2)	First granted area (km^2)	Status description	Commodity
EL 4416	Ignite Energy Resources Ltd	12 Apr 2001	11 Apr 2017	3837	2100	Current	Antimony; Base metals (copper/lead/zinc); Black coal; Brown coal; CSG; Diamonds; Gold; Kaolin; Mineral sands; Platinum; Silver
EL 4500	Greenpower Natural Gas Pty Ltd	5 Oct 2000	5 Oct 2014	339	487	Renewal	CSG; Mineral sands
EL 4683	AGL Loy Yang Pty Ltd	14 Dec 2005	13 Dec 2013	34	34	Section 16A	Black coal; Brown coal; Gold; Platinum; Silver
EL 4877	Sawells Pty Ltd	10 Aug 2005	9 Aug 2014	170	269	Renewal	Black coal; Brown coal; CSG
EL 5119	Mecrus Resources Pty Ltd	18 Apr 2013	17 Apr 2018	33	33	Current	Base metals (copper/lead/zinc); Black coal; Brown coal; Kaolin
EL 5170	Latrobe Fuels Ltd			84	0	Application	Black coal; Brown coal; CSG; Gold; Mineral sands; Platinum; Silver
EL 5173	Verso Energy Pty Ltd	8 Apr 2009	7 Apr 2014	35	47	Renewal	Black coal; Brown coal
EL 5210	Mantle Mining Corporation Ltd	3 Jun 2009	2 Jun 2014	46	62	Renewal	Black coal; Brown coal; CSG
EL 5212	Resolve Geo Pty Ltd	3 Jun 2009	2 Jun 2014	22	30	Renewal	Black coal; Brown coal; CSG
EL 5227	Greenpower Natural Gas Pty Ltd	11 Nov 2009	10 Nov 2014	305	349	Renewal	Black coal; Brown coal; CSG
EL 5270	Basin Coal Pty Ltd	9 Jun 2010	8 Jun 2015	374	944	Current	Black coal; Brown coal; CSG
EL 5274	ECI International Pty Ltd			309	0	Application	CSG
EL 5275	ECI International Pty Ltd			313	0	Application	CSG
EL 5276	ECI International Pty Ltd	7 Jul 2010	6 Jul 2015	366	488	Current	CSG
EL 5320	ECI International Pty Ltd	7 Apr 2011	6 Apr 2016	258	344	Current	CSG

Tenement number	Owner	First grant date	Expiry date	Current area (km^2)	First granted area (km^2)	Status description	Commodity
EL 5321	ECI International Pty Ltd	7 Apr 2011	6 Apr 2016	299	399	Current	CSG
EL 5322	ECI International Pty Ltd			97	0	Application	CSG
EL 5333	Commonwealth Mining Pty Ltd	7 Apr 2011	6 Apr 2016	34	45	Current	Black coal; Brown coal
EL 5334	Commonwealth Mining Pty Ltd	26 Mar 2012	25 Mar 2017	25	25	Current	Black coal; Brown coal
EL 5336	Mantle Mining Corporation Ltd			368	0	Application	Black coal; Brown coal
EL 5337	Mantle Mining Corporation Ltd	20 Apr 2011	19 Apr 2016	148	201	Current	Black coal; Brown coal; CSG
EL 5338	Mantle Mining Corporation Ltd			3	0	Application	Black coal; Brown coal
EL 5394	Commonwealth Mining Pty Ltd	26 Mar 2012	25 Mar 2017	170	170	Current	Black coal; Brown coal; Mineral sands
EL 5416	Leichhardt Resources Pty Ltd			542	0	Application	Black coal; Brown coal; CSG
EL 5428	Mantle Mining Corporation Ltd			21	0	Application	Black coal; Brown coal
EL 5429	Mantle Mining Corporation Ltd			29	0	Application	Black coal; Brown coal
EL 5442	Commonwealth Mining Pty Ltd			49	0	Application	Black coal; Brown coal; Mineral sands
EL 5453	Verso Energy Pty Ltd	18 Apr 2013	17 Apr 2018	166	166	Current	Black coal; Brown coal

EL = exploration licence, CSG = coal seam gas
Data: Department of Economic Development, Jobs, Transport and Resources (Dataset 5)

1.2.2.1.2 Mining licences

The history of black coal mining at Wonthaggi is discussed in Section 1.2.1.1.1. The brown coal mining history is discussed here as it relates to current mining activity.

Brown coal mining history

Gloe (1984) documented the stages at which discovery, exploration and development of the Victorian brown coals took place. Brown coal was first discovered in the Latrobe Valley in the 1850s to the north-east of Moe. Numerous other discoveries had been made in previous decades but attempts at development were hampered by complex geological structure and variable coal quality (Gloe, 1984).

In the 1880s, activity initiated by a number of companies around Morwell led to the discovery of 30 m and 50 m thicknesses of brown coal. When six seams totalling 245 m thickness were encountered during drilling in 1890, the Mines Department proclaimed that the deposits were probably the greatest in thickness yet discovered in the world. In the early 1900s a programme of drilling established the presence of a large resource sufficient to establish the State Electricity Commission of Victoria in 1921. The State Electricity Commission of Victoria (SECV) oversaw the development of the brown coal resources of the State with an initial focus on establishing a power station and to manage electricity generation and supply (Vines, 2008). Exploration and resource delineation continued with further major phases of drilling from 1922 to 1941, 1941 to 1955, 1955 to 1980 and 1980 to 1990 (Gloe, 1984).

In the 1950s long-term planning to determine total coal resources and characteristics was undertaken. The variability in coal quality had become a processing issue and so repeat drilling took place in areas previously drilled but this time to greater depths and in order to test coal samples for key quality parameters (Gloe, 1984). Through the 1960s to 1980s, a combination of remote sensing using geophysical techniques and facies modelling followed by drilling helped to delineate additional fields outside the Latrobe Valley such as the Alberton coalfield (Holdgate, 2003).

Today in the Latrobe Valley, brown coal production is dominated by three mines – Hazelwood, Loy Yang and Yallourn. In 2012–13 total production in Victoria amounted to 58.9 Mt (DEDJTR, 2013).

Current mining licences

Mining activities in the Gippsland Basin bioregion are currently restricted to three mining licences (Figure 10 and Table 10). Three separate companies hold these licences to mine brown coal for electricity generation: Yallourn Energy Pty Ltd, Hazelwood Power Corporation Pty Ltd and AGL LYP 3 Pty Ltd. Three other mining or retention licences are located in the Gippsland Basin bioregion (mining licence (MIN) 5526, retention licence (RL) 2010 (MIN 5328), and RL 2013). A retention licence is an intermediate licence between an exploration licence and a mining licence. It allows activities such as intensive exploration, research and other development required to demonstrate the economic viability of mining.

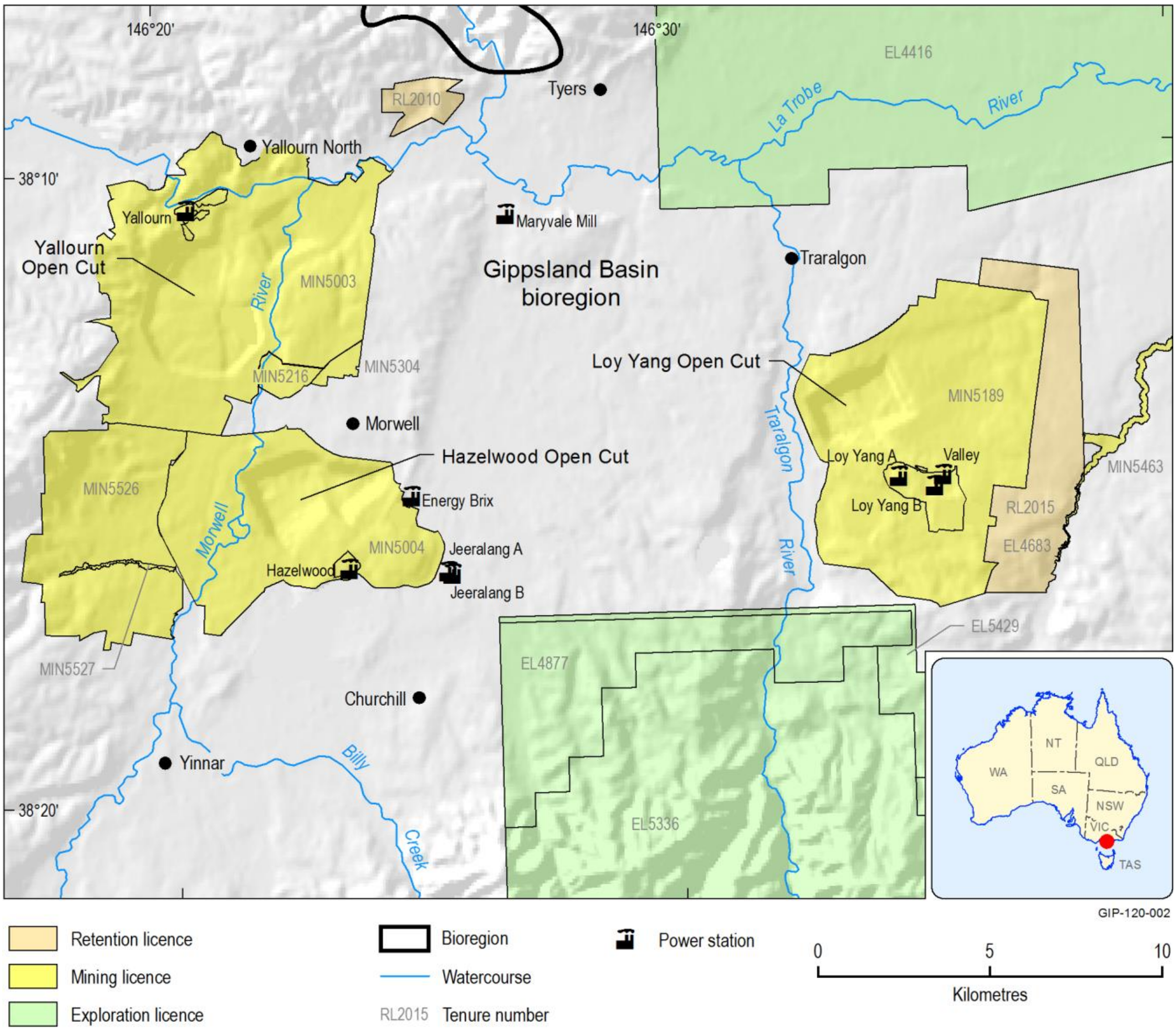

Figure 10 Current brown coal mining licences (MINs) and power stations in the Gippsland Basin bioregion

Grey background shading is from a digital elevation model (DEM). Within the yellow MIN areas, the open-cut mines are visible.
Data: Department of Economic Development, Jobs, Transport and Resources (Dataset 6)

Table 10 Coal mining licences in the Gippsland Basin bioregion which have current mining activity

Name and mining licence	Owner	Mining methods	Location	Year mining commenced	Expected final depth (mBGL)	Proven and probable reserves (Mt)	Expected mine life	Annual production (2012–13) (Kt)
Yallourn MIN 5003, MIN 5216, MIN 5304	Yallourn Energy Pty Ltd	Dozer/ truck	6 km north-west of Morwell township	1924	125	463	2032	12,885
Hazelwood MIN 5004	Hazelwood Power Corporation Pty Ltd	Bucket wheel Dredger	2.5 km south-west of Morwell township	1955	140	420	2036	17,118
Loy Yang MIN 5189	AGL LYP 3 Pty Ltd	Bucket wheel Dredger	6 km south-east of Traralgon township	1982	215	1740	2048	28,921
Total								58,924

mBGL = metres below ground level
Data: DEDJTR (2013); proven and probable reserves from GHD (2007)

1.2.2.1.3 Yallourn Mine and Power Station

In 1919 the State Government approved construction of a power station (50 MW) and a briquette factory at what was later called Yallourn. The State Electricity Commission of Victoria (SECV) was established on 1 January 1921. Among its immediate tasks associated with the management of electricity generation and supply throughout Victoria was the establishment of a power station, briquette works and open-cut mining at Yallourn.

Site works had commenced in October 1920 by the 'Electricity Commissioners' to plans previously approved by Parliament. Included in the defined role of the SECV was 'the development of the brown coal resources of the State.' From 1921 to 1924, as overburden was removed to expose a coal surface, a few hundred tonnes of coal in total was intermittently extracted for testing. Coal deliveries on an operational basis commenced on 21 August 1924 (Vines, 2008).

In 1936, proposals were advanced for a new open-cut mine in the vicinity of Yallourn (Yallourn North). This new open-cut mine was to have a coal transport interconnection with the current mine – Yallourn open-cut, to provide extra coal winning capacity and reliability for additional power and briquetting units. In 1955, Yallourn North Extension open-cut (YNX) was opened up by the SECV due to dwindling coal reserves at Yallourn North open-cut.

In 1964, operations at Yallourn North open-cut ceased. As a component of a long term rehabilitation plan, portions of the open-cut mined out area continue to be used as a below natural ground level storage for ash hydraulically pumped from the nearby Yallourn W Power Station (Figure 10). In 1989, Yallourn North Extension open-cut ceased coal mining operations due to APM Maryvale (the last remaining customer) converting fully to power generation from natural gas. Rehabilitation of the open-cut has occurred such that mining of an approximate 40 Mt of coal could be viable in the future (Vines, 2008).

The current power station commenced operations in 1974 with four generating units commissioned between 1974 and 1982 (Energy Australia, 2015).

Energy Australia owns the 1450 MW Yallourn Power Station in Victoria and the associated brown coal mine, which produces about 18 Mt of brown coal per year from the Maryvale Coal Field. Coal is mined using large satellite-guided bulldozers. These bulldozers are capable of pushing at least 2400 tonnes of coal per hour to a feeder breaker, which loads it onto a moving conveyor for delivery to the power station’s furnaces. More than 38 km of conveyors are located in the mine for carrying coal to the power station (Department of Primary Industries, 2010).

The mine has ample reserves to meet the projected needs of the power station (Figure 10) until 2032. The station supplies approximately 22% of Victoria’s electricity needs and approximately 8% of the National Electricity Market (NEM).

1.2.2.1.4 Hazelwood Mine/Morwell open-cut and Power Station

In 1964, the first unit of Hazelwood Power Station came into service supplied with coal from the Morwell open-cut mine. In 1970, the eighth 200 MW unit of Hazelwood Power Station came online, completing the generation plans based on Morwell open-cut. In 2004 the first deliveries of coal from the west field of Morwell open-cut occurred.

GDF SUEZ Australian Energy Hazelwood plant comprises a 1542 MW power station and an adjacent brown coal lignite mine that covers an area of 3554 ha. Hazelwood is jointly owned by GDF SUEZ Australian Energy and Mitsui and Co Ltd.

The brown coal fired power station produces around 10 TW hours annually and is supplied with up to 18 Mt of coal each year from the Hazelwood Mine (GDF SUEZ, 2015). The coal is covered by overburden, which is made up of clay, gravel and top soil. The mean depth of overburden is 18 m and the mean depth of the coal is around 100 m although in many places the coal depth can vary (Department of Primary Industries, 2010).

Hazelwood supplies between 20 and 25% of Victoria’s energy requirements and 5.4% of Australia’s energy demand. A pilot plant to capture carbon dioxide (CO_2) has been built at Hazelwood for the purpose of testing technologies for use in carbon capture and storage (CCS) for future commercial applications (GDF SUEZ, 2015).

1.2.2.1.5 Loy Yang Mine and Power Station

In 1976, the Victorian Parliament authorised the Loy Yang Project, which is located several kilometres south of Traralgon. A 4000 MW power station was to be fuelled from an adjacent open-cut coal mine. Site works commenced in February 1977. In 1982, the first dredger at the Loy Yang open-cut was commissioned and commercial operations commenced with the removal of overburden on 1 October 1982. The first coal deliveries occurred in July 1983, with commercial operation of the first 500 MW power unit officially on 30 June 1984 (Vines, 2008).

In 1996, the sixth 500 MW power unit was handed over for full time operation. Coal output averaged 30.7 Mt over the calendar years 1998 and 1999. Currently, AGL’s Loy Yang Mine has an average annual coal output of between 28 and 30 Mt. In 2003, the Hyland Highway was diverted over a length of about five kilometres to allow for expansion of the open-cut to the east and south (Vines, 2008).

The coal mine at Loy Lang is the largest mine in the Latrobe Valley, supplying coal to two adjacent power stations: Loy Yang A and Loy Yang B. Loy Yang A is owned by AGL Energy Limited and Loy Yang B is jointly owned by GDF SUEZ Australian Energy and Mitsui and Co Ltd. These two power stations have combined maximum electricity generation of about 3236 MW. AGL's Loy Yang A power station (over 2200 MW capacity) produces enough electricity to supply over 2 million Australian households (AGL, 2015). Loy Yang B supplies about 17% of Victoria's power needs (Department of Primary Industries, 2010).

The open-cut 650 ha coal mine at Loy Yang produces approximately 30 Mt of brown coal per year. The mine includes four coal dredgers and two transport conveyors (Department of Primary Industries, 2010).

1.2.2.2 Coal seam gas

A moratorium on CSG exploration and hydraulic fracturing (or "fracking") has been in place in Victoria since August 2012. A parliamentary inquiry into onshore unconventional gas was held in 2015, with a government decision on recommendations to follow in 2016.

There is no current commercial CSG production in the Gippsland Basin bioregion. For a development to be considered current in the Bioregional Assessment Programme, commercial production needs to have been commenced prior to December 2012.

In a concurrent activity to the Gippsland Basin Bioregional Assessment the Victorian Government has undertaken a series of Water Science Studies (Victoria State Government, 2015), including an assessment of potential impacts on water resources in the Gippsland region. The water science studies are to provide an initial screening analysis of the potential impacts of possible onshore gas development on water users and ecosystems. Although under the Bioregional Assessment Programme the potential for development of CSG within the Gippsland Basin bioregion is considered low, the Victorian water science studies have undertaken a conservative assessment of the potential impacts of aquifer depressurisation.

In the Victorian Government Water Science Study, the hypothetical brown coal CSG and tight gas/shale gas Gippsland Basin development scenarios applied a causal pathway approach, describing where natural gas might be, where water resources are, the physical connection between the gas and water resources, and utilising modelling and analysis to infer impacts on water users and ecosystems. The modelling of CSG development (brown coal) in Gippsland suggests the potential impact of depressurisation on groundwater resources (particularly shallow resources) in the immediate vicinity of the gas development area was moderate to high for groundwater users (i.e. by more than 15 m) and inferred as moderate for groundwater quality. Potential impacts to surface water users and ecosystems are reported as being high in areas close to the hypothetical gas development and low elsewhere. For further information on the Gippsland Water Science Study refer to Victoria State Government (2015).

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1.2.3 Proposals and exploration

Summary

There are a limited number of coal development proposals in the Gippsland Basin bioregion. The proposed mine development plans for the three existing coal mines (Yallourn, Hazelwood and Loy Yang) are documented here. Ignite Energy Resources (IER) are exploring for coal seam gas (CSG) from the deeper coal seams within Exploration Licence (EL) 4416. IER also has preliminary plans to develop the relatively shallow brown coal deposit at Gelliondale using conventional brown coal mining and upgrade with its Catalytic Hydrothermal Reactor (Cat-HTR) technology.

1.2.3.1 Coal

As of February 2016, brown coal development proposals for the Gippsland Basin bioregion involve expansions of the three existing mines at Yallourn, Hazelwood and Loy Yang, as well as a new mining development proposal at Gelliondale.

1.2.3.1.1 Yallourn (Energy Australia)

The Maryvale Coal Field is currently being mined at Yallourn (Figure 11). The coal reserves are considered to meet the projected demands of the power station until 2032 (Energy Australia, 2015a).

The work plan to develop the Maryvale Coal Field (Yallourn Coal Field Development Project) was approved under the *Mineral Resources (Sustainable Development) Act 1990* in March 2002 (DPCD, 2010). As part of the development of the Maryvale Coal Field, the Morwell River was diverted in May 2005.

A realignment of the Maryvale Coal Field was considered necessary to reduce the overall volume of overburden to be removed within the mine boundary (DPCD, 2010). The variation area for realignment of the Maryvale Coal Field (Figure 11) was located along the eastern edge of the field, the south of the East Field extension. The diversion of the Morwell West Drain was also proposed.

In June 2012, the Morwell River diversion in the Yallourn Mine failed across an embankment engineered to carry the river across the coal mine (Department of Primary Industries, 2013). The failure damaged infrastructure and caused water to flow into the open-cut mine (Energy Australia, 2015b). Earthworks at the site, a liner system and extra drainage were completed to repair and remediate the site.

In 2013, Energy Australia applied to increase the volume of water discharged into the Morwell River (GHD, 2013). Variations to the Work Plan for the mine will increase the mine area and the catchment size, facilitating the need for discharge of waters above the Environmental Protection Authority (EPA) licence limits.

Figure 11 Yallourn general site plan and surrounds in the Gippsland Basin bioregion

Source: R Mether, Manager Mining (EnergyAustralia Yallourn), 2015, pers. comm

1.2.3.1.2 Hazelwood (GDF SUEZ and Mitsui)

The Hazelwood Power Station is fuelled by coal from the Hazelwood Mine. Development of the mine is in a westerly direction in two phases. Phase 1 began in 2001 under project approvals existing at the time. Phase 2 of the 'West Field' development of Hazelwood was proposed in 2004; expanding the mining area across the Morwell River to secure a coal supply until 2031 (DSDBI, 2014). The two main elements of the West Field development of the Hazelwood Mine were the westward advance of existing mining operations and the relocation of streams and roads to enable the advance to proceed.

The West Field will be developed in two phases, moving progressively from east to west (Figure 12). As each level of the South East Field is completed, the respective conveyor systems and bucket-wheel excavator plant will be relocated to the western batters of the mine. This transfer of operations and initial development of the West Field within the current mining licence boundary is Phase 1. Phase 2, for which an Environmental Effects Statement was prepared, involves relocation of streams and roads and the continuation of mining in the West Field up to and beyond the existing mining licence boundary. The progressive transfer of conveyors from Block 1B (Phase 1) to Block 1C (Phase 2) began with the overburden system in 2009.

The Morwell 1 Seam coal in the West Field is 100 m thick and between 8 and 15 m beneath shallow, mainly clay overburden. The Hazelwood Power Station was designed to burn Morwell 1 Seam coal and depends on this source. At January 2003, the mining reserves to meet the forecast demand of 557 Mt were as follows: 34 Mt in the South East Field, 495 Mt in the West Field (of which 90 Mt is located outside Hazelwood Power Corporation's current mining licence boundary), and 28 Mt in the Office Field (a potential development covered under the existing mining licence).

The West Field is currently being mined from east to west, with the coal mining and delivery sequence shown in Table 11. Mining is to the base of the M1 coal seam to a depth of 140 m. Overburden is currently being dumped within the existing mine.

Table 11 Sequence of mining and coal delivery for the Hazelwood Mine West Field mine extension, Gippsland Basin bioregion

Block	Block 1C	Block 2A	Block 2B	Block 3
Years	2011–2018	2015–2022	2019–2027	2025–2031
Total ('000 Tonnes)	90,260	65,700	105,160	93,640

Data: International Power Hazelwood (2004)

Figure 12 Hazelwood Mine plan in the Gippsland Basin bioregion

Source: DSDBI (2014)

1.2.3.1.3 Loy Yang (AGL – Loy Yang Power)

Loy Yang Power (1997) outlined a 40 year plan for Loy Yang A Power Station (until 2037) and a 30 year plan for Loy Yang B Power Station. The whole life potential mine development extent from 1996 is shown in Figure 13, described in the figure as future mining blocks. The potential mine development allowed for increased power station coal demands to extend power station life and coal supply to other industries (Loy Yang Power, 1997).

In 1996 it was proposed that the northern boundary of the mine would be optimised and that future planning activities would determine methods to maximise the recovery of coal from Block 2 (Loy Yang Power, 1997). Blocks 2 and 3 continue to be noted as ‘Future Mining Blocks’ (Figure 13).

Loy Yang Power also holds an exploration licence for an additional approximately 764 Mt of coal across approximately 1670 ha adjoining the mine site (Figure 13).

AGL Loy Yang has submitted an application to convert the existing Exploration Licence, which abuts to the east of Mining Licence MIN 5189 into a Retention Licence.

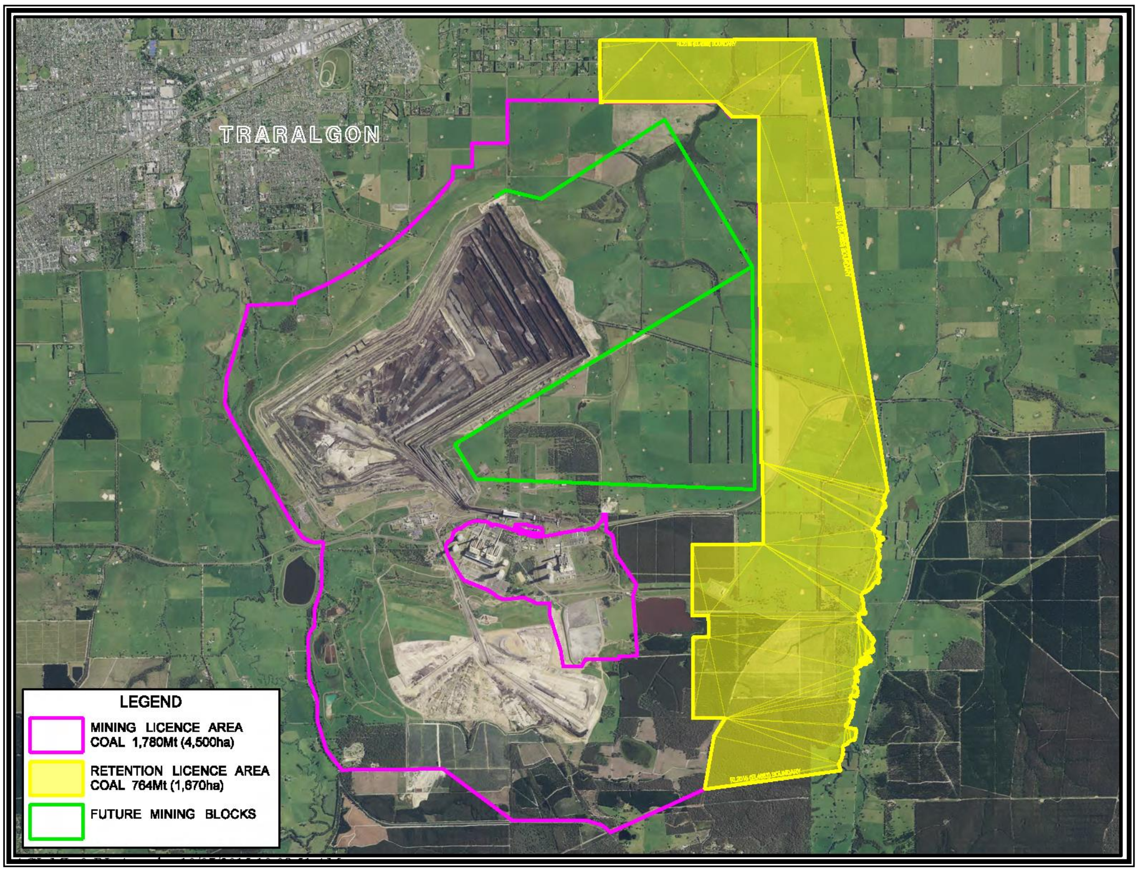

Figure 13 Loy Yang Power Mine Licence and exploration area in the Gippsland Basin bioregion

Source: Loy Yang Power (2012)

1.2.3.1.4 Gelliondale Energy Project (Ignite Energy Resources)

Ignite Energy Resources (IER) hold EL 4416, which includes the recognised coalfields of Longford, Boodyarn, Stradbroke, Greenmount, Alberton East and Gelliondale. IER plans to exploit the relatively shallow brown coal at Gelliondale using conventional brown coal mining and upgrade with its Catalytic Hydrothermal Reactor (Cat-HTR) technology. In June 2015, IER were granted a Retention Licence (RL 2013) for the Gelliondale brown coal deposit to enable feasibility studies and consultation activities (IER, 2016).

1.2.3.2 Coal seam gas

1.2.3.2.1 Gippsland Gas Project (Ignite Energy Resources)

The only CSG development project currently proposed in the Gippsland Basin bioregion is at a very early stage of exploration and assessment. Apart from the initial drilling of the first CSG pilot well in 2005 (Section 1.2.1.2.2), there have been no other major field-based exploration activities such as additional well drilling and formation testing. Consequently, there remains significant geological uncertainty about the commercial scale presence and viability of biogenic CSG resources in the brown coals of the Traralgon Formation.

Ignite Energy Resources (IER) hold the largest exploration tenement (EL 4416) targeting potential CSG resources in the Gippsland Basin bioregion. Following the drilling of the Burong #2 CSG pilot well in EL 4416 (Section 1.2.1.2.2), IER (in conjunction with then joint venture partner ExxonMobil) developed plans for drilling additional wells to better understand important coal seam parameters, such as the percentage of gas saturation within the coals, and coal seam permeability (IER and ExxonMobil, 2012). However, to date, this work has not been undertaken, and ExxonMobil withdrew from their Gippsland joint venture with IER in December 2014. Thus, there remains considerable uncertainty as to when any further exploration and appraisal for CSG resources will take place within EL 4416. This work is critically required to understand fundamental characteristics of the target coal formations, such as establishing if gas is trapped within the coal seams and, if present, whether it could be viably extracted or not (Goldie Divko, 2015). At the time of writing, there are no clear development plans available that document the nature, timing or extent of future work for the Gippsland Gas Project.

There is currently little exploration being undertaken for CSG resources in the black coals of the Strzelecki Group in southern Gippsland. There are no specific black coal CSG development proposals to include in this section. As previously noted (Section 1.2.1.2.1), the thin and discontinuous nature of the black coal seams, and their widespread structural disruption (i.e. fault displacement), suggests that the CSG prospectivity of black coals in the Gippsland Basin bioregion is poor (Goldie Divko, 2015).

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1.2.4 Catalogue of potential resource developments

Summary

There are currently four potential future coal developments in the Gippsland Basin bioregion. These include the expansion of the three existing coal mines and one new coal mine development at Gelliondale. Exploration for coal seam gas (CSG) near Seaspray is at an early stage. The three coal mine development plans extend the life of the existing mines out until the 2030s (Section 1.2.3 gives more detail of these plans).

1.2.4.1 Potential coal developments

Potential coal development projects in the Gippsland Basin bioregion are catalogued in Table 12. The Yallourn Mine has an Environment Effects Statement (EES) that allows for the development of the open-cut coal mine through the Maryvale Coal Field (DPCD, 2010). At the current levels of extraction (approximately 14 Mt/year) this will satisfy the mine to the end of its current life until 2032. Hazelwood Mine has an Environmental Effects Statement (International Power Hazelwood, 2004) that outlines the West Field Extension of the current mine that secures its mine life until 2031. AGL – Loy Yang Power does not have a current EES but the 1996 approved work plan outlines the eastward extension of the current open-cut to secure a 40 year mine life until 2036 (Loy Yang Power, 1997). There is very little available documentation on the plans for Ignite Energy Resources Gelliondale project in retention licence (RL) 2013. Ignite Energy Resources (IER, 2015a) highlights that the coal deposit at Gelliondale is shallow and close to an existing port at Barry Point. The project is at an early stage in the development phase, with a significant amount of further feasibility assessment and consultation required.

Table 12 Catalogue of potential coal resource developments in the Gippsland Basin bioregion

Project name	Company	Longitude	Latitude	Record date[a]	Material	Total coal resources[b]	Status of EES[c]	Notes
Yallourn Coal Field Development Project (supersedes Maryvale Extension Project)	Energy Australia – Yallourn	146.39°	–38.19°	2010	Brown coal/lignite	347.5 Mt[d] (as at 2001)	Approved	DPCD (2010)
West Field Project	Hazelwood Power Corporation Pty Ltd	146.35°	–38.26°	2005	Brown coal/lignite	470 Mt	Approved	See 2004 EES
Future mining blocks within current MIN	AGL - Loy Yang Power	146.62°	–38.22°	2012	Brown coal/lignite	1.78 Bt, a further 764 Mt of coal in EL 4683 (now RL 2015)	No current EES. Last one in 1975, SECV	Loy Yang Power (1997), Loy Yang Power (2012)
Gelliondale	Ignite Energy Resources Limited	146.51°	–38.65°	2014	Brown coal/lignite	6.2 Bt (IER, 2015a)	Not yet at EES stage	JORC classification level not stated on Ignite Resources website with resource estimate

[a]The record date is the most recent date for updated coal resource numbers.
[b]This is calculated by summing the resources with Joint Ore Reserves Committee (JORC) codes of measured, indicated and inferred.
[c]The status of the project within an environmental effects statement (EES)
[d]Total coal resources quoted directly from Yallourn Coal Field Development Project (2001), Table 5.2, Page 36

1.2.4.2 Potential coal seam gas projects

As previously outlined, coal seam gas exploration had begun in the Gippsland Basin bioregion prior to a moratorium on hydraulic fracturing and new coal seam gas licences in Victoria in August 2012. Drilling for gas is not allowed under the moratorium. Ignite Energy Resources planned to test the Traralgon Formation brown coals within the Seaspray Depression for biogenic natural gas (Table 13).

Table 13 Potential coal seam gas resource developments in the Gippsland Basin bioregion

Project name	Company	Longitude	Latitude	Record date[a]	2C coal seam gas reserves[b] (PJ)	Status of EES[c]	Notes
Gippsland Gas	Ignite Energy Resources	147.11°	–38.19°	2015	3.7 Tcf (Trillion cubic feet)*	Not yet at EES stage	An independent report by MHA Petroleum Consultants, commissioned by Ignite Energy Resources, has estimated that EL 4416 hosts a 3.7 Tcf natural gas contingent resource (2C) (IER, 2015b)

[a]The record date is the most recent date for updated coal seam gas resource numbers.
[b]The Petroleum Resource Management System (Society of Petroleum Engineers, 2007) a 2C resource is a contingent resource: a volume that may be commercially recoverable once certain contingencies are satisfied.
[c]The status of the project within an environmental impact statement (EES): pre-EES, EES in preparation, EES submitted, EES closed, supplementary EES and EES approved.

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