Australian Government

BIOREGIONAL ASSESSMENTS

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

Developing a coal resource development pathway

A submethodology from the Technical Programme, part of the Bioregional Assessment Programme

22 October 2014

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

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>.

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ISBN-PDF 978-1-4863-0448-6

Citation

Lewis S (2014) Developing a coal resource development pathway. A submethodology from the Technical Programme, part of the Bioregional Assessment Programme. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

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Cover photograph

Outcropping coal of the Newcastle Coal Measures exposed in seaside cliffs at Catherine Hill Bay near Newcastle

Credit: Hashim Carey, Geoscience Australia

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Contents

Contributors to the Technical Programme vi

Acknowledgements viii

Executive summary 1

Introduction 2

The Bioregional Assessment Programme 2

Methodologies 4

About this submethodology 4

Technical products 5

1 Submethodology overview 8

1.1 Introduction 8

1.2 Focus of this submethodology 9

1.3 Submethodology objectives 10

1.4 Structure and format of this submethodology 10

2 The coal resource development pathway in bioregional assessments 12

2.1 Stage one: Coal and coal seam gas resource assessment 13

2.2 Stage two: Coal resource development pathway 13

2.3 Description of the coal resource development pathway 14

2.4 Using the coal resource development pathway 15

3 Stage one of the coal resource development pathway – data and information inputs 17

3.1 Geological and spatial context 17

3.2 Known coal and coal seam gas resources 18

3.3 Resource exploration history and development 20

3.4 Distribution of coal and petroleum exploration tenements 21

3.5 Current status of coal and coal seam gas development 22

3.6 Proposed coal and coal seam gas resource developments 24

3.7 Bringing the data together for the coal resource development pathway 28

4 Stage two of the coal resource development pathway – assessment 31

4.1 Introduction 31

4.2 Scope of the coal resource development pathway 31

4.3 Specifying the development baseline 33

4.4 Development time frames 34

4.5 Regional focus 34

4.6 Out of scope 35
4.7 Assessment of the coal resource development pathway 36
4.8 Engagement with experts 41
4.9 Bringing the concepts together and writing the coal resource development pathway in companion product 2.3 42
4.10 Information requirements for numerical modelling 44
4.11 Information sharing with the wider bioregional assessment team 45

Appendix A Overview of Australia's coal and coal seam gas resources 50

A.1 Classifying coal and coal seam gas resources 51

Appendix B Coal and coal seam gas resource definitions for bioregional assessments 54

B.1 Coal 54
B.2 Coal seam gas 56

Appendix C Supply chain of coal and coal seam gas resource development 58

C.1 Exploration 59
C.2 Identification of resources 60
C.3 Feasibility studies and construction 60
C.4 Full-scale operational production 61
C.5 Post-production operations 61

Appendix D Useful data sources on coal and coal seam gas resources 63

D.1 OZMIN 63
D.2 Register of Australian Mining 63
D.3 Australian Atlas of Mineral Resources, Mines and Processing Centres 63
D.4 State government online geological mapping and database systems 64

Shortened forms 65

Figures

Figure 1 Schematic diagram of the bioregional assessment methodology 3

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment 6

Figure 3 Black and brown coal resources in Australia 50

Figure 4 Coal seam gas resources (2012) in Australian sedimentary basins 51

Figure 5 Australia's national classification system for resources, including coal and coal seam gas (petroleum) 52

Figure 6 Transformation of peat into brown and black coal 54

Figure 7 Classification of coals by rank 56

Figure 8 Australia's coal supply chain 58

Tables

Table 1 Methodologies and associated technical products listed in Table 2. The red rectangle indicates this submethodology 4

Table 2 Technical products being delivered as part of the Bioregional Assessment Programme 7

Table 3 Process to determine coal resource development pathway for each bioregion or subregion 12

Table 4 Sources of data and information on coal and coal seam gas resources for bioregional assessments 19

Table 5 Development categories for coal mines 24

Table 6 Recommended content for companion product 1.2 29

Table 7 Example of catalogue of potential coal resource developments 37

Table 8 Example of catalogue of potential coal seam gas resource developments 37

Table 9 Summary of coal resource development pathway minimum data requirements for modelling and expected data availability for EIS and non-EIS stage coal and CSG resource projects 46

Table 10 Coal rank classification terminology used in Australia and Europe 55

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Acknowledgements

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Executive summary

This submethodology describes the process for developing the coal resource development pathway in bioregional assessments (BA). It provides detail of the information required in the coal resource development pathway, including definition of the baseline against which future development is measured and how to determine what the most likely pathway is. The importance of successfully engaging with relevant groups in industry (e.g. coal and coal seam gas (CSG) development companies), government and regional communities is emphasised, so that the coal resource development pathway can be suitably tested and validated. This coal resource development pathway submethodology is a standalone document, but it is recommended that it be read in consultation with the BA methodology (Barrett et al., 2013). It should be used by individual Assessment teams involved in researching, compiling and writing companion products 1.2 (about coal and CSG resource assessment) and 2.3 (about conceptual modelling) for each bioregion or subregion in the BA Programme.

Developing the coal resource development pathway is a two-stage process that occurs across the contextual information and model-data analysis stages of a bioregional assessment. The initial stage of work for each bioregion or subregion involves compiling relevant data and information about the geology, coal resources, current mines and CSG production facilities, and the potential coal resource developments (including both new operations and expansions to existing sites). This provides the requisite contextual information to later assess and determine the coal resource development pathway and these details are reported in each coal and CSG resource assessment (companion product 1.2).

Following the coal and CSG resource assessment, critical data analysis and evaluation of the potential developments are needed to determine the combination of individual projects that will define the coal resource development pathway in each bioregion or subregion. All coal and CSG resource projects that are within the environmental impact statement (EIS) assessment process, or are expected to submit EIS documentation within two years, will be included in the coal resource development pathway. Likewise, most projects with a defined economically demonstrated resource (EDR) will also be part of the coal resource development pathway. Other less-advanced resource development proposals, such as those with only current subeconomic or inferred resources, may also be incorporated in the coal resource development pathway if a strong case (based on currently available data and information) can be mounted by respective Assessment teams.

The coal resource development pathway is an important part of each BA and largely determines the resource developments that will be incorporated as part of later numerical modelling simulations to assess the impacts of future development on water-dependent assets. However, this is also dependent on the availability of suitable fit-for-purpose data on the likely development characteristics and processes. Other important components of the coal resource development pathway process outlined in this submethodology include specifying the development baseline, consideration of development time frames, and clarification of the type of resource operations that do not form part of BAs.

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.

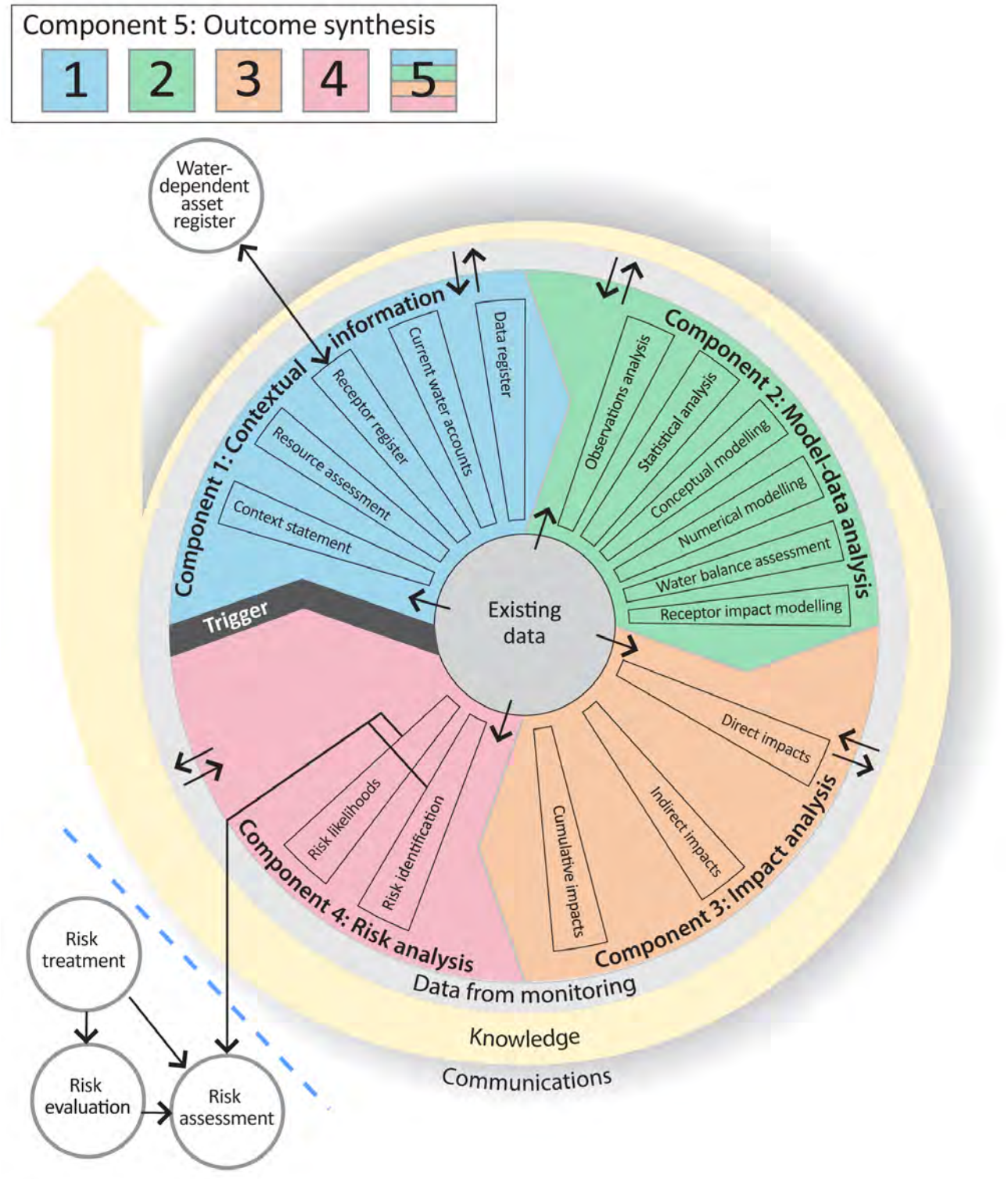

Figure 1 Schematic diagram of the bioregional assessment methodology

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 to 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 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.

About this submethodology

The following notes are relevant only for this submethodology.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of the BAs for inclusion in this document used the Albers equal area with a central meridian of 140.0° East for the Lake Eyre Basin bioregion and its subregions, and 151.0° East for all other bioregions and subregions. The two standard parallels for all bioregions and subregions are –18.0° and –36.0°.

Table 1 Methodologies and associated technical products listed in Table 2. The red rectangle indicates this submethodology

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

Code	Proposed title	Summary of content	Associated technical product
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
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
M12	*Fracture propagation and chemical concentrations*	Describes the likely extent of both vertical and horizontal fractures due to hydraulic stimulation and the likely concentration of chemicals after production of coal seam gas	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 subregion or 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.

Technical products are delivered as reports (PDFs). 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.

Technical products, and the additional material, are available online at <http://ww.bioregionalassessments.gov.au>.

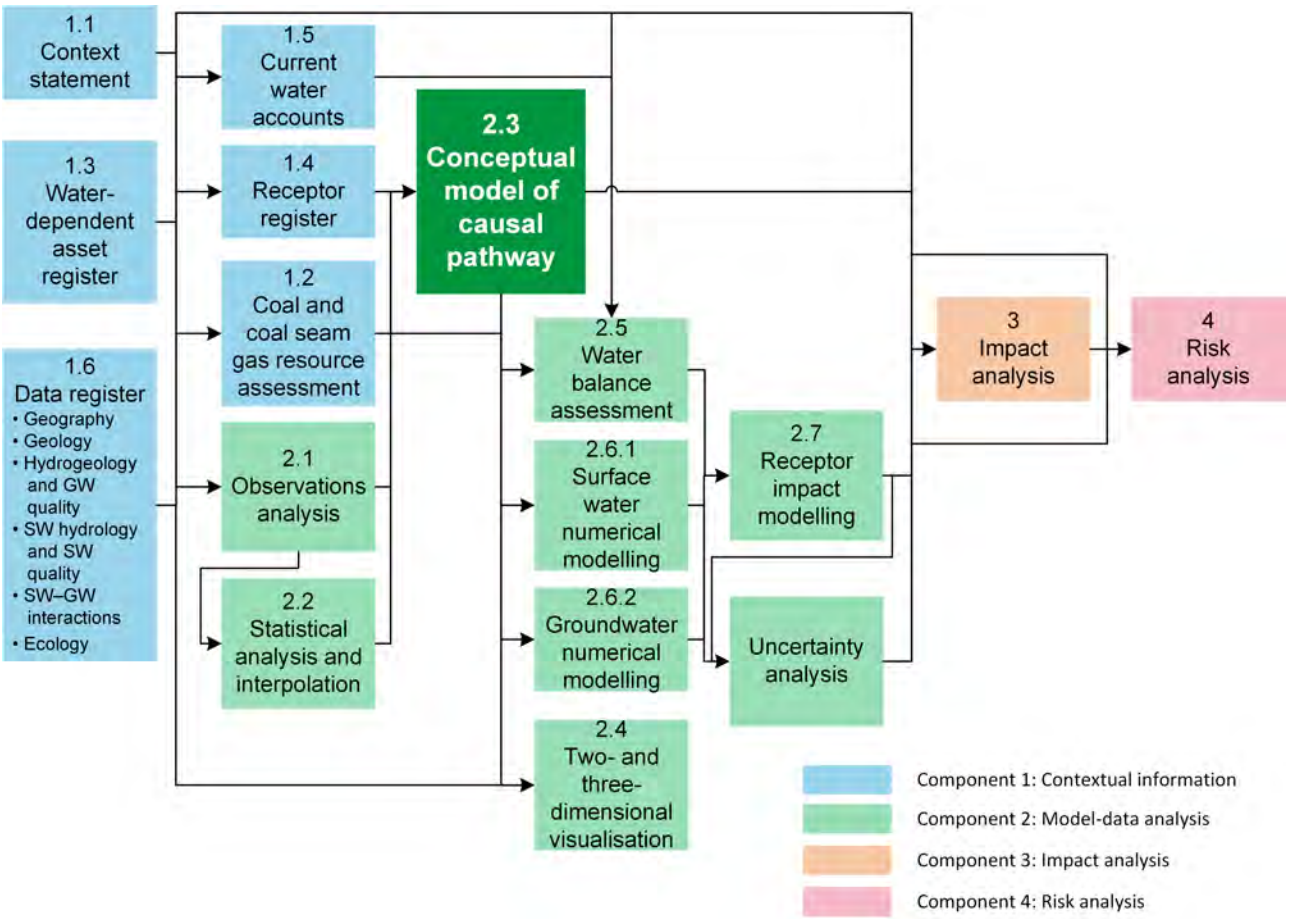

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

Table 2 Technical products being delivered as part of the Bioregional Assessment Programme

For each subregion in a bioregional assessment, technical products will be delivered as data, summaries and reports (PDFs) as indicated by ■ in the last column of Table 2. A suite of other technical and communication products – such as maps, registers and factsheets – will also be developed through the bioregional assessments.

Component	Product code	Information	Section in the BA methodology[a]	Report
Component 1: Contextual information for the bioregion or subregion	1.1	Context statement	2.5.1.1, 3.2	■
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	■
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	■
	1.4	Description of the receptor register	2.5.1.4, 3.5	■
	1.5	Current water accounts and water quality	2.5.1.5	■
	1.6	Data register	2.5.1.6	
Component 2: Model-data analysis for the bioregion or subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	■
	2.3	Conceptual modelling	2.5.2.3, 4.3	■
	2.4	Two- and three-dimensional representations	4.2	[b]
	2.5	Water balance assessment	2.5.2.4	■
	2.6.1	Surface water numerical modelling	4.4	■
	2.6.2	Groundwater numerical modelling	4.4	■
	2.7	Receptor impact modelling	2.5.2.6, 4.5	■
Component 3: Impact analysis for the bioregion or subregion	3	Impact analysis	5.2.1	■
Component 4: Risk analysis for the bioregion or subregion	4	Risk analysis	2.5.4, 5.3	■
Component 5: Outcome synthesis for the bioregion	5	Outcome synthesis	2.5.5	■

[a]Barrett et al. (2013)
[b]The two- and three-dimensional representations will be delivered in products such as 2.3, 2.6.1 and 2.6.2.

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 23 October 2014, <http://www.environment.gov.au/coal-seam-gas-mining/pubs/methodology-bioregional-assessments.pdf>.

1 Submethodology overview

1.1 Introduction

The extraction of coal and coal seam gas (CSG) from Australia's onshore sedimentary basins may have a direct, indirect and cumulative impact on water resources and water-dependent assets. This can include impacts to surface water bodies such as rivers, lakes and wetlands, as well as local to regional scale groundwater flow systems in aquifers. For example, in areas where coal mining occurs below the watertable, ongoing dewatering of aquifers is required to develop open-cut and underground mining operations. Similarly, the successful production of CSG relies on hydrostatic depressurisation of the coal-bearing strata, so that gas can desorb from the coals and then be pumped to the surface for extraction. At the scale of individual bioregions or subregions in the Bioregional Assessment Programme, the cumulative impacts of these activities may be of particular importance as they potentially affect both surface water and groundwater systems over large areas. Such impacts may extend far into the future and, in some cases, decades beyond the lifespan of resource extraction operations.

The BA methodology (Barrett et al., 2013) provides the overarching framework that sets out the scientific steps involved in undertaking bioregional assessments. The central purpose of this work is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of CSG and large coal mining developments (Barrett et al., 2013). Such impacts may affect water-dependent assets of an ecological (e.g. wetlands and rivers), economic (e.g. quantity or quality of groundwater in an aquifer tapped for agricultural irrigation), or sociocultural (e.g. Indigenous) nature. Consequently, BAs will review, analyse and evaluate both present and expected future operations for coal and CSG extraction. This information is vital to the success of each bioregional assessment and forms a significant part of the BA workflow, both contextually and for model-data analysis (Table 2).

In addition to contextual information about coal resources within each bioregion or subregion, an understanding of the most likely coal resource development pathway[1] is a prerequisite for subsequent stages of the BA. These later phases include formulation of conceptual models that describe the causal pathways linking coal and CSG developments to impacts on water-dependent assets and receptors. Numerical modelling simulations of surface water and groundwater systems, which are intrinsically linked to the conceptual models, are then used (where data are available) to generate semi-quantitative to quantitative hydrological results (if possible) for the specified coal resource development pathway in each bioregion (Barrett et al., 2013).

[1] In the context of this submethodology and the broader Bioregional Assessment Programme the term 'coal resource development pathway' is used to refer to the possible combination of individual coal mining operations (either by open-cut or underground methods) as well as coal seam gas production.

This submethodology has been developed to guide individual Assessment teams by providing a practical approach to determine the most likely combination of individual coal resource projects that together will form the coal resource development pathway for their bioregion or subregion. Importantly, the coal resource development pathway description provides relevant information on the location, type and timing of each proposed development project, so that a regional perspective of multiple future developments (and any existing operations) is clearly articulated.

1.2 Focus of this submethodology

This submethodology is consistent with the stated premise of the broader BA methodology in that it does not outline a prescriptive process to produce the coal resource development pathway (Barrett et al., 2013). This approach reflects the practical considerations of assessing geological characteristics, and the variable coal and CSG resource development proposals, of the 12 coal-bearing sedimentary basins investigated in the Programme (Appendix A). Some resource developments may have unique characteristics that will require variation from the generic framework. In such cases, each Assessment team will be best-placed to evaluate the need for and the implications of these variations using scientific judgment based on their knowledge of region-specific geology, coal resources and proposed development pathways. Where such variations from the broader framework are needed, these will be clearly noted and explained to provide both transparency and a record of the decision-making process.

The most likely coal resource development pathway that can be described by each Assessment team is an important requirement for future components of BAs (Figure 2 and Table 2). The coal resource development pathway needs to take account of available information relating to the exploration, appraisal and proposed development of the known coal and CSG resources in the bioregion or subregion (Barrett et al., 2013). This assessment will focus on a range of parameters that may be available for each coal or CSG project including the quantity and quality of resources, the estimated time frames for the major development stages, the types of extraction processes, and any specific regulatory conditions.

Independent regional-scale assessments of coal resources and unconventional hydrocarbons (including CSG) in Australia's onshore basins have not yet been undertaken using a consistent and internationally recognised methodology. While it is not the purpose of the Programme to generate updated regional-scale estimates of coal and CSG resources, the Assessment teams will focus on compiling existing resource information from various sources such as exploration and development companies, relevant state government mining and resource departments, and academic research groups (see Section 3 for specific details). This information is reported within the companion product 1.2 for each bioregion or subregion (see Section 2), and this contextually focused work forms the first stage in developing the coal resource development pathway. Importantly, product 1.2 provides a catalogue of all potential coal and CSG resource developments that form the basis of further evaluation in BA Component 2: model-data analysis.

To determine the coal resource development pathway for their specific bioregion or subregion, Assessment teams must critically evaluate the relevant data available for each potential resource development listed in the catalogue (Section 1.2.4 in product 1.2). By working systematically through this evaluation process (which is the second stage of the overall coal resource

development pathway framework and described in Section 4), Assessment teams will be able to evaluate and describe a valid coal resource development pathway for their bioregion or subregion. A further and important part of the overall process involves consultation of the proposed coal resource development pathway with coal mining and CSG resource development companies, as well as others who are able to provide valuable input into the coal resource development pathway assessment such as the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC), relevant government agencies (State and Commonwealth) and local level experts.

1.3 Submethodology objectives

The objectives of this BA submethodology are to:

- provide a framework for evaluating and describing the coal resource development pathway that can be applied consistently across all bioregions
- guide Assessment teams that are working on individual bioregions or subregions to maintain a practical and structured approach to determine the coal resource development pathway for their Assessment area
- present the preferred terminology to be used in BAs for various characteristics or parameters associated with coal and CSG resources
- outline the data and information required to compile a thorough coal and CSG resource stocktake (reported in companion product 1.2 for each bioregion or subregion)
- prepare the information needed to select the combination of individual resource projects and deposits most likely to form the coal resource development pathway within each bioregion or subregion
- outline the analytical considerations, criteria and concepts needed for Assessment teams to construct and validate their coal resource development pathway.

1.4 Structure and format of this submethodology

This submethodology is divided into four sections:

- Section 1: submethodology overview (this section)
- Section 2: defines the concepts and uses of the coal resource development pathway in the BA context
- Section 3: (stage one) data and information inputs, presents the type of information required in companion product 1.2 for each bioregion or subregion, to understand the geology, coal and CSG resources, as well as current and proposed coal resource developments
- Section 4: (stage two) data analysis and evaluation to determine and justify the coal resource development pathway, reported in companion product 2.3 (about conceptual modelling).

In addition, there are four appendixes in this submethodology that provide relevant contextual information (for a wider public audience). This includes an overview of Australia's coal and CSG resources (Appendix A), coal resource definitions used in BAs (Appendix B), explanation of the coal resource development supply chain (Appendix C) and useful sources of data for assessing the coal resource development pathway (Appendix D).

2 The coal resource development pathway in bioregional assessments

An important output of the contextual phase (see Figure 1) of work for bioregional assessments (BAs) is an assessment of the coal and coal seam gas (CSG) resources of each bioregion or subregion (Barrett et al., 2013). It provides the necessary background information to be used in determining and describing each coal resource development pathway (Table 2).

This submethodology provides guidance to Assessment teams on the type of information to be compiled, reported and assessed when developing a coal resource development pathway. It is a two-stage process (Table 3). Firstly, a comprehensive coal and CSG resource stocktake is undertaken for each bioregion or subregion. Secondly, an analysis of available data from this stocktake is used to develop the coal resource development pathway specific to each region.

Table 3 Process to determine coal resource development pathway for each bioregion or subregion

Coal resource development pathway stage	Title	Purpose	Reported in BA product	BA component
One	Coal and coal seam gas resource assessment	• ensure thorough understanding of the geology and coal and coal seam gas resources • compile list of potential resource developments • engage with coal and CSG development industry experts to review information and access available datasets	Product 1.2	Component 1: contextual information
Two	Analysis and description of the coal resource development pathway	• critically evaluate available data to understand which resource developments are likely to proceed in future • describe the coal resource development pathway and main features of these developments • test and verify coal resource development pathway with relevant groups in government, industry and community	Product 2.3	Component 2: model-data analysis

2.1 Stage one: Coal and coal seam gas resource assessment

The starting point for the coal resource development pathway analysis is the catalogue of potential resource developments compiled and reported in Section 1.2.4 of companion product 1.2. This captures all projects with an *identified resource*[2] for each bioregion or subregion, as these are considered potentially viable for development within a 20 to 25 year future time frame (Geoscience Australia and BREE, 2013). For coal, an identified resource includes those which have reported either measured, indicated or inferred resources in accordance with the guidelines in the Joint Ore Reserves Committee (JORC) Code. The JORC Code is used commonly in the coal resources industry (as well as for many other resource commodities) to report coal reserves and resources (JORC, 2012). For CSG, an identified resource for BAs generally corresponds to a published estimate for at least one of the proved (1P), proved and probable (2P), or proved, probable and possible (3P) reserves classes in the Petroleum Resources Management System (SPE et al., 2011). Further information on the national resource classification scheme is in Appendix A.

The coal and CSG resource assessment is presented as a contextual report (companion product 1.2) for each bioregion or subregion, and consists of four main sections:

- **Section 1.2.1 available coal and coal seam gas resources**: presents the coal-bearing geological units in each bioregion or subregion and identifies their location and main characteristics relevant to BAs
- **Section 1.2.2 current mining activity and tenements**: provides an overview of mining operations or CSG production sites that are currently operating in the bioregion or subregion and presents the areal distribution of the various types of coal and hydrocarbon tenements
- **Section 1.2.3 proposals and exploration**: focuses on the extent and nature of exploration work in the bioregion or subregion and documents the nature of existing resource development proposals at various stages of assessment. This may include proposed extensions to existing operations, or development of entirely new extractive sites
- **Section 1.2.4 catalogue of potential resource developments**: presents two tables (one for coal and one for CSG) that list the various coal resource projects in each bioregion or subregion which may potentially form part of the coal resource development pathway. These tables form the starting point for the further analysis that each Assessment team must undertake to determine their region-specific development pathway.

2.2 Stage two: Coal resource development pathway

Assessment teams develop and describe the coal resource development pathway for each bioregion or subregion by evaluating available data and information on individual coal and CSG development proposals. This analytical work forms the second stage of the coal resource

[2] *Identified resource* is a specific term used in Australia's national resource classification scheme – see Appendix A for further details.

development pathway process, which is mostly undertaken during Component 2 of the BA methodology (Table 3). The results of this work are reported as part of companion product 2.3 (about conceptual modelling) (Table 2 and Figure 2). The analysis required to determine the coal resource development pathway follows-on closely from the initial stocktake of the coal and CSG resource assessment (part of the workflow in Component 1). Further discussion on the input data and assessment criteria required to analyse and understand the coal resource development pathway is outlined in Sections 3 and 4.

For resource projects that are relatively well advanced, much of the specific development information will initially be compiled from publicly available material lodged as part of environmental impact statements (EIS). These documents are produced by development companies as part of their statutory obligation under various government planning and environmental regulations. For projects that are at less-advanced stages of evaluation (such as an initial scoping or feasibility study) there is unlikely to be as much detailed information available to Assessment teams to assess and evaluate. In these cases, there will be a greater level of uncertainty around the decision to either include or exclude such coal or CSG projects from the coal resource development pathway. Ultimately, the decision on which projects are either included or excluded must be made by each Assessment team following their detailed analysis of the available data. The process for undertaking this evaluation is described further in Section 4.

As part of the reporting on the coal resource development pathway in companion product 2.3, the main areas of uncertainty relating to the progression of each development are fully described, particularly if the Assessment team recommends including the project in the coal resource development pathway. Likewise, for projects that are captured in the catalogue of potential resources (Section 1.2.4 in companion product 1.2) but subsequently determined not to be in the coal resource development pathway, sufficient justification will be reported by the Assessment team to validate their decision. This process will provide transparent and defensible decision making to underpin each coal resource development pathway.

2.3 Description of the coal resource development pathway

For BAs, the coal resource development pathway should consider all stages of proposed resource extraction operations, including exploration, appraisal, production, closure and any expected mine legacy issues (Barrett et al., 2013) that the Assessment team deems relevant. As an initial guide, the main information that should be included in the coal resource development pathway description reported in companion product 2.3 includes:

- a concise statement of the coal resource development baseline, which includes all commercially producing coal mines and CSG production sites (if they were operational as of the fourth quarter 2012, the baseline cut-off date for resource developments in BAs (Section 3.5))
- a summary of the names, locations, companies and main resource characteristics for each project in the coal resource development pathway
- the expected timelines for each development project, including proposed stages (phasing) and any known dependencies that may impact on the progression of development stages, such as the need to gain a certain type of government approval (e.g. approval as part of an EIS process)

- the nature of the proposed development operations, including the type of extraction methods (details of large coal mining and CSG extraction methods), associated infrastructure needs such as resource processing facilities or transportation networks, areal and depth extent of operations and any known risks that may impact on development plans.

Further details on the suggested type of information and level of detail to include in the description of the coal resource development pathway are outlined in Section 4.9. As part of the coal resource development pathway it is also recommended to include a map of the bioregion or subregion highlighting names and locations of all proposed resource projects, as well as a timeline diagram (Gantt Chart) outlining the timing (and stages) of individual operations.

Importantly, all detailed quantitative information relating to the management and use of surface water and groundwater during resource extraction (including mine dewatering for coal and aquifer depressurisation for CSG) is compiled and reported elsewhere in the suite of bioregional assessment products, that is, not in companion products 1.2 or 2.3. This water-related information is initially compiled as part of companion product 1.5 for each bioregion or subregion (about current water accounts and water quality) and then reported in the water balance assessment (companion product 2.5) (Table 2 and Figure 2). The reasons for this approach are further discussed in Section 3.6.1.

2.4 Using the coal resource development pathway

Most of Australia's coal-bearing geological basins (including those in the Bioregional Assessment Programme) are at various stages of regional-scale coal and CSG development. Some of the more geographically remote basins (e.g. the Arckaringa and Pedirka basins in the Lake Eyre Basin bioregion) are the focus of relatively greenfield exploration efforts that are working towards improved geological understanding and resource characterisation. There are no existing mining operations in these basins. In contrast, other BA regions have a very mature exploration history with many commercial coal mining operations that have been active for decades. The Hunter subregion in the Northern Sydney Basin bioregion, for example, has more than 30 currently operating coal mines. In some areas, more recent production sites may also operate within a basin that contains historical (i.e. now closed) mines.

For BAs, it is important to understand the current stage of coal and CSG resource development within each bioregion, as well as how this is likely to be transformed in the future as newly proposed developments emerge online. This is because this information is required for developing conceptual models (and associated numerical modelling simulations, if applicable) that seek to explicitly define the causal pathways that link coal or CSG developments with impacts on water-dependent assets and their receptors. The development time frames and opportunities for coal resources within a bioregion or subregion will likely differ from those for CSG. For example, in some basins coal mining may have a long and established history over many decades, but CSG development may remain in early exploration stages without existing commercial operations. The contrast between the current and future level of coal and CSG development thus needs to be explicitly stated in the coal resource development pathway. Given the considerable regional-scale development variation that exists in the BAs, the scale and maturity of both coal and CSG operations is expected to differ between all bioregions.

The description of the coal resource development pathway is written as a concise synthesis of all expected developments at the scale of the bioregion or subregion and not simply at the level of individual mines or resource projects (Section 4.9). As a result, the regional scale cumulative effects of development can be better understood and considered in later numerical modelling stages, with individual development components integrated into a whole-of-basin resource pathway. The information requirements needed from the coal resource development pathway to support subsequent numerical modelling are outlined in Section 4.10, and these provide guidance as to the type of information that Assessment teams need to compile during the research and evaluation stages. However, as noted in the BA methodology (Barrett et al., 2013), there may be developments in some bioregional coal resource development pathways for which there is currently insufficient data or knowledge available for them to be incorporated in numerical modelling simulations. Where such situations occur, these developments are clearly noted in companion product 2.3, as well as the reasons for not undertaking surface water and groundwater numerical modelling (although it is recognised that it may be possible for Assessment teams to qualitatively assess and comment on the potential impacts of some developments which cannot be numerically modelled, and this will be done as part of BA analysis if possible). Ideally in these circumstances, it is useful to also include a summary of the type of fit-for-purpose data that is further required to satisfy the modelling requirements for these resource projects. In this way, future data collection work can be appropriately targeted, and interactions with resource development companies may assist in gaining access to datasets that can then be incorporated in modelling simulations.

3 Stage one of the coal resource development pathway – data and information inputs

Stage one is focused on collating and understanding the data and information required to develop the coal resource development pathway. Important to the success of each BA is a comprehensive understanding of the geological and spatial (three-dimensional) extents, resource characteristics (tonnage, rank and grade) and potential viable development options for the known coal and coal seam gas (CSG) resources. At the bioregional or subregional scale in BAs, this requires the compilation and synthesis of multiple geoscience and resource-focused datasets. These are discussed under various thematic subheadings within this section. They provide direct inputs into relevant sections of the coal and coal seam gas resource assessment (companion product 1.2).

By systematically working through and understanding these data inputs, each Assessment team will have a consistent framework for completing coal and CSG resource assessments. This process represents stage one of the overall workflow needed to determine the coal resource development pathway, as shown in Table 3. These initial efforts are an important step in the BAs as they provide Assessment teams with the requisite background knowledge to understand and develop the most likely coal resource development pathway (for their respective bioregion or subregion) during the later analysis stage of Component 2.

Information is provided below on each of the main data themes (subheadings), including explanation of why they are important and examples of where information may be obtained. These subheadings should be used by Assessment teams as a guide when writing their coal and CSG resource assessments so that a consistent set of information is provided across all bioregional assessments.

3.1 Geological and spatial context

The first step in describing the coal resource development pathway for each bioregion or subregion is to understand its geological characteristics, particularly relating to the distribution of coal-bearing strata in the sedimentary basin (or basins) of interest. Some of this information will already be documented in the geology section of the contextual statement (Section 1.1.3 in companion product 1.1) and will not need to be explicitly included in the coal and CSG resource assessment (companion product 1.2). However, the following geological and spatial (three-dimensional) information for each bioregion or subregion forms the foundation for understanding the basin-scale coal resources:

- the geological structure and stratigraphic framework of the coal-bearing basin, especially as they relate to coal resources. This should include identifying the main coal-bearing strata (include groups, formations, down to level of individual coal members if such data are

available). All stratigraphic units identified in this phase must be validated as the most current, formal unit names as per the Australian Stratigraphic Units Database (Geoscience Australia and ASC, 2014). This information feeds directly into Section 1.2.1 of companion product 1.2

- the tectonic framework of the basin, including both the syntectonic (i.e. tectonic setting during deposition of the coal-bearing strata) and post-tectonic regimes that have influenced basin development. An understanding of basin tectonics is important as it plays a major role in determining the distribution and availability of coal resources, as well as their interactions with aquifer systems. Neotectonic (geologically recent) processes may also be important in considering the evolution of the current landscape, and the interaction of groundwater flow patterns in different aquifer systems
- the main geological characteristics of the coal-bearing units in the bioregion or subregion, such as:
  - spatial extent and depth below surface. If possible, existing maps of the spatial distribution of coal-bearing formations in the subsurface may be evaluated, such as those that show depth to tops of coal formations or isopachs (stratigraphic thickness) across each region. However, such maps, or the raw datasets used to create them, may not be readily available for all basins of interest. Assessment teams will evaluate the reliability and usefulness of any coal distribution maps that may be available and decide if they are worthwhile inputs for Section 1.2.1 of companion product 1.2
  - nature of overlying and underlying strata, as a guide to understanding potential hydraulic connectivity issues that may be important for modelling impacts of CSG extraction, as well as mining or petroleum reservoir engineering considerations
  - age of coals and their main parameters (e.g. rank, type and grade for coal, gas contents and gas saturation levels for CSG), particularly information on any spatial variability of these important features
  - extent and type of faulting and structural disruption of coal-bearing strata
  - interpreted depositional environments and sedimentary facies.

3.2 Known coal and coal seam gas resources

Having researched the geological structure and composition of the sedimentary basin, the next step is to identify the location and main features of the known coal and CSG resource projects or deposits. This can be compiled from published information available on the size, quality and areal and depth extents of coal resources, such as by state government agencies or from published national resource databases such as OZMIN (Ewers et al., 2002) or the Register of Australian Mining (RIU, 2014). The type and quality of available data for this inventory will likely vary among bioregions, and consequently it is up to each Assessment team to determine the extent to which such relevant information can be compiled and reported. A summary of useful data sources is in Table 4, with more detailed information in Appendix D.

Table 4 Sources of data and information on coal and coal seam gas resources for bioregional assessments

Data source	Compiler/s	Main reference	Comments
OZMIN	Geoscience Australia	Ewers et al. (2002)	OZMIN contains geological and resource information on Australia's mineral deposits, including black and brown coal, although petroleum resources (including CSG) are not included.
Register of Australian mining	Resource Information Unit	RIU (2014)	An online database with mining-related information such as mines, development projects, exploration and mining companies, and mineral-specific resource data.
Australian atlas of mineral resources, mines and processing centres	• Geoscience Australia • Department of Resources, Energy and Tourism • Mineral Council of Australia	Geoscience Australia, DRET and MCA (2012)	This is an interactive web mapping tool to locate Australia's mines and resources, and also compile datasets using various search criteria.
Minview	NSW Government	NSW Trade and Investment (2014a)	Minview provides online display and query of NSW tenement information and geoscience data.
Digital Imaging Geological Systems (DIGS)	NSW Government	NSW Trade and Investment (2014b)	DIGS is an online database containing open-file company exploration reports, NSW departmental publications, maps and titles information. It also has records of coal and petroleum exploration activities.
Interactive Resource and Tenure Maps (IRTM)	Queensland Government	Queensland DNRM (2014a)	The IRTM provides online access to Queensland geological and resources information and data.
Queensland Digital Exploration reports (QDEX)	Queensland Government	Queensland DNRM (2014b)	QDEX is the database of Queensland exploration company reports, including those for coal and CSG. It contains open-file reports submitted digitally since 2004 and older reports (scanned copies).
South Australian Resource Information Geoserver (SARIG)	SA Government	SA DMITRE (2014)	SARIG provides access to SA geological and geoscientific data including tenements for mineral, petroleum and geothermal companies, mines, advanced exploration projects and mineral deposits, geoscientific data, and publications, maps and reports.
Geovic	Victorian Government	Victorian DSDBI (2014)	Geovic contains Victorian geoscience datasets, including mineral and petroleum tenements, geophysical survey data, well data, mines, and geological maps and sections.

Although this is not an exhaustive listing of all possible information sources relating to coal and CSG, it is a useful initial compilation to assist Assessment teams.

An important component for the coal and CSG resource assessment (companion product 1.2 for each bioregion or subregion) is to ensure that all available and up-to-date resource statements are compiled and included in the assessment. In line with current resource reporting requirements (Appendix A) these statements are released by many exploration and development companies when new resource estimates are generated, for example, as company announcements to the

Australian Securities Exchange (ASX). A useful step when developing companion product 1.2 is to tabulate this type of published resources data, along with information on the project name, development companies, location, tonnage and any other relevant project details. These tables effectively form the basis for the catalogue of potential resource developments (Section 1.2.4 of companion product 1.2), the starting point for the coal resource development pathway. As part of this work it is also helpful to display all of the identified coal and CSG resource locations on a regional-scale map. This type of data compilation will assist in developing a thorough understanding of each coal or CSG resource which, in turn, helps populate the coal resource development pathway.

Although largely beyond scope for providing input for companion product 1.2 (except, possibly, for certain greenfield subregions), useful information on some coal and CSG resources and host rock sequences may be extracted from publicly available reports (open-file) on drilling results from prior exploration and well development testing. Information obtained from this type of primary data evaluation may also be useful and relevant to other components of BAs, such as compiling data registers (companion product 1.6) and undertaking observational and statistical data analysis and interpolation (companion products 2.1 and 2.2). However, this exercise may not be appropriate to all bioregions, and the potential benefits should be judged by each Assessment team, based on knowledge of their specific bioregion or subregion and their assessment of the merits and usefulness of accessing such information.

Other sources of information on regional-scale coal and CSG resources include various publications released by Australian and state government agencies and academic institutions. A particularly useful reference for many basins that contain black coal is the Bureau of Mineral Resources Bulletin on the Permian coals of eastern Australia (Harrington et al., 1989). A useful recent publication on most Australian CSG reserves and resources is the report, *Eastern and southern Australia: existing gas reserves and resources* (Core Energy Group, 2012).

3.3 Resource exploration history and development

In developing the coal resource development pathway for each bioregion or subregion, it is important to understand the basin-scale exploration and development history for coal and CSG. Consequently, a brief overview of the history of exploration is useful to include in Section 1.2.3 of companion product 1.2. This review may address questions such as:

- when exploration first started and which companies were involved
- what the outcomes of this work were
- when the initial discoveries for coal and CSG were made
- how resource development has proceeded since the initial discoveries
- have there been any peaks or troughs in the exploration and development cycle.

Briefly outlining this exploration history helps to assess the level of exploration and development maturity in the basin, thereby implicitly indicating potential for new resource discoveries or upgrades to existing deposits. This historical perspective should be written as a brief qualitative overview. The key reason for addressing this issue is to indicate the level of uncertainty around the

potential for new exploration discoveries to be made at some future stage. Assessing such uncertainty (even qualitatively) provides a simple proxy for the likely time frame that the proposed coal resource development pathway may remain valid (see Section 4.4). Significant 'new' exploration successes (i.e. of large and previously unknown deposits) are more likely to occur in relatively greenfield areas, indicating that the most likely coal resource development pathway proposed for such bioregions or subregions may not remain valid for as long as those with a more 'mature' exploration history. In brownfield areas, exploration successes are more likely to identify an additional resource base for current mining operations, thereby potentially leading to future expansion proposals rather than new mines.

For the purposes of BAs, this information can be adequately summarised from existing basin-wide review papers or publications (e.g. such as those released by state government mining or resource departments or as part of academic reviews). Such brief exploration summaries are likely to be available for most sedimentary basins in Australia. However, developing this type of exploration summary using a 'first principles' approach of researching exploration company tenement reports or well-completion reports is generally beyond the scope of the Programme.

3.4 Distribution of coal and petroleum exploration tenements

For BAs it is necessary to identify the coal and CSG exploration tenements and the companies that currently hold these exploration titles in each bioregion or subregion. Tenement information is held by state government agencies that administer the distribution and regulation of mining and mineral exploration (for coal resources), and petroleum exploration and development (for CSG). These datasets are freely available from state governments and are regularly updated (weekly to monthly) as tenement status changes over time. Tenement data has been sourced from all relevant jurisdictions as part of the BAs and will be consulted to develop the description of resource company exploration and development activity. Much of this information is publicly available from online web mapping systems (or in Google Earth format) that are operated by various state government departments responsible for resources, mining and energy (see Section 3.2 of this submethodology and Appendix D).

Publicly available information on listed resource companies will also be investigated as part of this stage, as it may provide further indication about the geology or resource characteristics of interest. Published information relating to resource companies is available from various state or national sources, such as:

- state government agencies and their websites (Table 4 and Appendix D)
- Register of Australian Mining (RIU, 2014)
- recent exploration successes, which are described by commodity and listed for relevant 2012 exploration results in the Australian Mineral Resource Assessment, including relevant sections on coal resources (Geoscience Australia and BREE, 2013)
- Australian Mineral Exploration – A Review of Exploration for the Year (a report compiled nationally and available annually since 2000). For example, Senior and Skirrow (2013) is the

current version, with publications for previous years also available from the Geoscience Australia website

- Australia's Identified Mineral Resources – an annually published series (since 1992) which is accessible via the Geoscience Australia website. For example, McKay et al. (2014) is the current version available for download, although the back catalogue of annual publications can also be obtained from the same website listed in the references section.
- Many publicly listed companies also provide access to corporate presentations or annual reports via their websites. Consequently, once all tenement holders in a bioregion or subregion are known, online searches of their exploration holdings and recent tenement activities may provide access to more up-to-date technical or development planning information for some resource projects.

Section 1.2.2 of companion product 1.2 for each bioregion or subregion provides a table and map showing all of the mining and exploration companies that currently hold ground in the area. The table may contain other relevant information about the tenements or companies involved, such as the company type (public or private-listed company), number of tenements held and the status of their holdings. A simple map showing the distribution and type of current coal and CSG exploration and production tenements (or applications for same) for each bioregion or subregion will be included in resource assessment reports.

3.5 Current status of coal and coal seam gas development

For each coal or CSG resource identified during the initial assessment, it is important to collate data relevant to the present development status. This requires an understanding of the current extent, distribution and capacity of coal mining activity and CSG production in the bioregion or subregion (if any). This will help determine the nature of the *baseline* of coal and CSG development. In the context of the BAs, the baseline development situation includes all coal mines and CSG operations that were engaged in commercial production (i.e. operating mines or wellfields) as of the last quarter (calendar year) of 2012. Thus, resource projects that have come into commercial operation after 31 December 2012 are not considered in the baseline situation, but instead are included in the coal resource development pathway. The end of 2012 was selected as the coal resource development pathway baseline cut-off date as it is the last complete year of resource-related activity prior to the official start of the Bioregional Assessment Programme in early 2013.

The suggested information inputs for the resource development baseline include (but are not limited to):

- location of active coal mines and CSG production facilities (it is useful to highlight the spatial distribution of these on a map in companion product 1.2)
- location of any coal or CSG resource feasibility or pilot production studies
- listing of companies currently involved in exploring, developing or mining coal, or producing CSG, from the bioregion or subregion. In particular, it is useful to identify if the company is privately owned or publicly listed on the ASX and if it is a subsidiary of a larger parent company, as well as other relevant company-specific information

- background information about the resource discovery and feasibility studies is also worthwhile and may include details such as the companies involved, the year of discovery and the exploration methods used. However, it is noted that access to this type of information may not always be readily available, so each Assessment team will need to determine if these details can be included
- characteristics of current mining operations, such as the size and grade of the mineable resource, the start-up date of mining, the amount mined per year (tonnage), the estimated mining life remaining, and the extraction methods used (i.e. open cut or underground)
- three-dimensional extents of existing mining operations, including total surface area covered and the depth of operations, as well as the planned extents of future mining or production activity under the currently approved operations. Other useful information is the number and type of open-cut pits in the current development and brief description of any underground workings
- understanding of infrastructure layout that exists in the bioregion or subregion, particularly relevant to transporting the extracted coal resources to market. Access to existing infrastructure such as rail networks (for transporting coal) or gas pipelines may be a limiting factor for future development to proceed. For example, major greenfield developments will generally be more costly and less attractive development options (at least initially) than areas that already have existing infrastructure that can be readily accessed to deliver resources to market. Knowledge of such information can help to inform Assessment teams about the likely timeframe of development within the bioregion or subregion.

The full-scale commercial development of coal or CSG (i.e. resource extraction) involves a number of progressive stages in the overall resource supply chain (Appendix C). Resource development usually starts with the initial exploration success that identifies the potential for a deposit of sufficient scale and quality to be commercially viable. The decision to progress from one stage to the next stage is usually based on a variety of factors, including geological, engineering, environmental and commercial.

The nomenclature to use in BAs for describing the development status of a mineral deposit is provided in Table 5, based on input from the Coal and Coal Seam Gas Advice Section at Geoscience Australia (S Cadman (Geoscience Australia), 2013, pers. comm.). Although other classification schemes exist (e.g. refer to nomenclature in Geoscience Australia and BREE, 2013), to ensure consistency across the Bioregional Assessment Programme it is recommended to use the terms in Table 5 for resource assessment and coal resource development pathway reporting for all bioregions and subregions.

Table 5 Development categories for coal mines

Category	Definition
Operating mine	Either open-cut or underground mining operation in commercial production
Mine under care and maintenance	A mine that has been in production until relatively recently but has been 'mothballed' due to the prevailing economic conditions (the implication is that the mine will be brought back into production if the economic environment improves)
Historical mine	A mine that has ceased production for an extended period of time and is unlikely to be brought back into production
Resource development project - feasibility stage	More detailed evaluation of project characteristics being undertaken and there is a significant possibility that a coal mining operation will proceed
Pre-feasibility stage (scoping)	An initial study is underway to determine the possibility that a coal mining operation will proceed
Deposit evaluation	A significant coal deposit is known to exist, although it is uncertain (due to lack of knowledge of resource characteristics) if a coal mining operation is viable
Coal deposit	A coal deposit is known to exist, although there is insufficient knowledge of the deposit to determine if it is economic or subeconomic
Advanced exploration	Coal is known to exist within the title, based on drilling of boreholes, sampling, analyses, geotechnical and hydrogeological studies, etc. Information in the final report to be used as a basis for succeeding feasibility studies
Grass roots exploration	Initial exploration in greenfield areas – unknown if coal exists within the title

This scheme can also be readily modified to describe the development stages of CSG resources, although aspects of process and terminology will vary. For example, coal seam gas developments may refer to gas fields or gas projects, rather than coal mines or coal projects

Information to assist Assessment teams in understanding the development history of a particular resource, or of the company or joint venture involved in the operation, may also be published in various mining and resource trade journals. These include publications such as Mining Australia or the Australian Journal of Mining. It is recommended that, as part of the research to evaluate current coal and CSG operations, these types of publications should be accessed for relevant articles. Most such journals provide searchable access to their back catalogue of publications and simple searches of these archives (based on resource deposit names or development companies) may provide further information as part of the wider resource assessment or coal resource development pathway analysis. As previously mentioned in this section (with full details in the references section of this submethodology), other useful sources of information at this stage of the assessment include:

- Australia's Mineral Resource Assessment 2013 (Geoscience Australia and BREE, 2013)
- Australian Gas Resource Assessment 2012 (Geoscience Australia and BREE, 2012)
- Australian Energy Resource Assessment 2010 (Geoscience Australia and ABARE, 2010).

3.6 Proposed coal and coal seam gas resource developments

By this stage of working through the coal resource development pathway submethodology, Assessment teams will have comprehensive information on coal and CSG deposit names, locations, sizes, known resource qualities and quantities, stratigraphic host sequences and other relevant geological and resource-specific features. This information, which effectively informs the

baseline situation for current coal resource activity in the bioregion, is important to compile and evaluate before proceeding to stage two of the submethodology.

Following characterisation of the baseline, the next step involves researching detailed plans proposed by resource development companies for future resource extraction in the bioregion or subregion. In most cases, the more advanced development proposals are covered by a mining lease (or mining lease application), signifying that development of future mining operations are considered likely for that resource. These resources can include 'virgin' deposits that are not currently mined, as well as proposed plans to expand or modify existing operations, for instance, in response to additional resources being added to the mine reserves through further brownfield exploration.

In the course of mining and ongoing exploration work near an existing mine site (brownfield exploration) resource development companies may discover extensions to the size, shape or quality of the deposit. As the extraction of these resources may not be factored into the original mine design, new plans to extract these additional resources are needed. These expansion plans must be submitted to the relevant state government regulatory body (and also to Australian Government agencies in the case of referrals under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*) to initiate the start of further assessment procedures such as an environmental impact statement (EIS).

Other important input for deciding which resources will be included in the coal resource development pathway includes data and information submitted as part of current (or recent) EIS submissions, which are commonly made available online as part of the EIS review process. Assessment teams will access all relevant EIS documentation to evaluate proposed resource developments during the course of their evaluation. The relevant state government departments[3] responsible for administering and providing access to EIS documentation are:

- **NSW** – project proposals in NSW with potential to adversely impact the environment due to their size, nature or location are termed 'designated developments'. These require submission of an EIS through NSW Planning and Environment (NSW Planning and Environment, 2014a). Many mining or petroleum extraction operations are also considered to be State Significant Developments (SSD). There are specific development assessment guidelines that apply to EIS for coal mines and associated infrastructure, as well as separate guidelines for CSG developments. In addition, the recent NSW Government Strategic Regional Land Use Policy stipulates that for any proposed mining or CSG developments on areas of strategic agricultural land, an initial 'Gateway assessment' (undertaken by a panel of independent scientific experts) is required before applications can be submitted for development (NSW Planning and Environment, 2014b). Documentation submitted for both current and recently completed EIS will be consulted by Assessment teams working in NSW bioregions.

[3] The information listed here is restricted to the jurisdictional governments that are signatories to the National Partnership Agreement on Coal Seam Gas and Large Coal Mines, these being NSW, Queensland, SA and Victoria.

- **Queensland** – the Queensland Office of the Coordinator-General oversees the evaluation of project proposals that have the potential to cause major environmental, social or economic impacts (in Queensland these are known as 'coordinated projects'). The development of new mining or CSG production facilities, or the expansion of existing operations, requires an EIS to be submitted. Information from the Queensland Coordinator-General's office will provide important inputs for all bioregions and subregions in Queensland (Queensland C-G, 2014). Additional information on coal and CSG developments may also be sourced from other Queensland Government agencies involved in their administration and/or regulation, such as the Department of Environment and Heritage Protection which administers many environmentally relevant resource activities that require an environmental authority to operate (Queensland Government, 2014).
- **SA** – proposed coal mines, expansions and CSG developments in SA are likely to be classed as major developments due to their potential economic, social and environmental impacts. The South Australian Development Assessment Commission (DAC) determines if the proposal requires submission of an EIS (SA DAC, 2014).
- **Victoria** – development projects that have potentially significant environmental impacts, such as new mines and expansions, are required to prepare an environmental effects statement (EES) under Victorian planning legislation. The Victorian Department of Transport, Planning and Local Infrastructure are responsible for managing the assessment and approvals process for EES (Victorian DTPLI, 2014). Similar to other jurisdictions the EES process involves scoping, preparation, public review and final assessment decisions. BAs in Victoria (such as for the Gippsland bioregion) will consult the list of current and completed EES to develop their coal resource development pathway.

Important information for BAs sought via state government regulatory channels may include:

- project development documents that provide the location plans for existing mines, or proposed developments
- companies involved in the development plans
- extent and type of proposed resource development, for example, a new development or a capacity expansion to an existing production facility
- type of mining or extractive methods to be used
- stages and timing of proposed development – including available details on expected construction and start-up time, date of expected full production, anticipated life-of-operations and whether there are likely to be multiple stages of activity
- plans for management of extractive by-products such as overburden waste
- infrastructure requirements, including layout of existing and proposed infrastructure such as roads, railways and pipelines, etc.
- for CSG operations, it is useful to evaluate how widespread hydraulic fracturing will need to be to ensure successful development. Thus, it is helpful to briefly describe the variables and parameters that determine if hydraulic fracturing of coal seams may be required in the bioregion

- rehabilitation plans – including recognition of land proposed to be off-set for ecological conservation to account for areas that will be subject to intensive mining development and loss of natural habitat.

Some of these details will be included by Assessment teams in Section 1.2.3 of companion product 1.2 and will also be necessary to support decisions on the mix of resource projects described in the coal resource development pathway (reported in companion product 2.3).

3.6.1 Note on environmental impact statement documentation for coal resource developments

Most EIS documentation contains a significant amount of information that may feed directly to other components of the bioregional assessment, including those not directly related to the nature of the coal and CSG resources. For example, EIS documents may identify assets (including, but not limited to, water-dependent assets) that the proponent believes may be affected by the proposed development activity. Although documentation and analysis of this and other additional information in EIS is beyond the scope of work specific to the coal and CSG resource assessment and the coal resource development pathway, Assessment teams are encouraged to flag items of potential interest where noted as part of their EIS review, especially where such information is likely to be useful for other discipline themes of the BA. Some of these data or information could then be used for subsequent analysis, modelling and interpretation in other BA components. These decisions will be made using the judgment of respective Assessment teams, and will likely form a standard part of EIS data review and assessment.

3.6.2 Discussion of water management in the coal resource assessment and development pathway

Detailed quantitative information on surface water and groundwater management, including details of mine dewatering and co-produced CSG water volumes and quality, is critical information for BAs. However, the cataloguing, description and analysis of this type of water-related data does not form part of either the coal and CSG resource assessment report (companion product 1.2), or the coal resource development pathway description (part of companion product 2.3). Instead, this type of information is assessed and reported in other BA products, such as companion product 1.5 (about current water accounts and water quality) and companion product 2.5 (about water balance assessment) (Table 2). However, there is scope in companion product 1.2 for Assessment teams to provide a brief qualitative description of significant water-related issues associated with resource development. For example, this may include brief discussion if mining activities are likely to result in diversion of a surface water body, or whether target coal seams for CSG production are stratigraphically or structurally adjacent to important aquifers.

3.7 Bringing the data together for the coal resource development pathway

By working consistently through the main themes presented in this section, each Assessment team will be able to compile the range of data and information needed as the starting point for their analysis (in BA Component 2) to determine the coal resource development pathway for specific bioregions or subregions. This process is discussed in the next section (Section 4).

The main data themes discussed here in Section 3 provide direct contextual inputs that cover the four parts of companion product 1.2 (Table 3). Thus, the information compiled by each Assessment team during this research stage will be used as the basis for writing these sections. For example, the information needed to write Section 1.2.1 of companion product 1.2 (about available coal and coal seam gas resources) can be sourced from understanding the geological and spatial context of the bioregion (see Section 3.1. of this submethodology), coupled with information on the known coal and CSG resources (see Section 3.2). An overview of the main information requirements to include in each section of companion product 1.2 is outlined in Table 6. As with most of BA Component 1 (contextual information), this list of suggested content depends on the availability of fit-for-purpose data, and it may not be possible to include all of this content for every bioregion or subregion.

Table 6 Recommended content for companion product 1.2

Section number	Title of section	Main content to include in section
1.2.1	Available coal and coal seam gas resources	• describe geology relevant to coal resources, clearly identifying the main coal-bearing stratigraphic groups and formations, including their age and any significant compositional or geological architectural features • characterise the spatial distribution of coal-bearing strata, including both areal and depth extents. It may be possible to present this distribution on maps and/or cross-sections • identify important geological features or parameters that significantly influence the distribution of coal resources, for example, structural elements or depositional facies • outline the parameters of the main coal units, such as type, rank and grade • it is useful to include a basin-scale stratigraphic chart that identifies the various coal members in each sedimentary basin of the bioregion or subregion
1.2.2	Current activity and tenements	• identify current coal mines or CSG production sites by name and describe location, resource target and any other significant site features • describe the main characteristics of each mine or CSG operation, such as start-up date, expected duration, extraction methods used, areal and depth extents, number of existing pits, shafts or wells, etc. • provide brief overview of the extraction process, mine-site facilities, operational infrastructure and supply chain to market • outline the current stage in the overall development and extraction of the resource, and summarise information about the expected future mining or CSG production operations that are planned to occur • tabulate information on the companies involved in owning and/or operating existing production sites, including names and status (public or private, national or international) • tabulate and map the existing coal and hydrocarbon exploration, mining and production tenements for the bioregion or subregion, including information on tenement numbers, owners/operators, size, purpose, etc. • identify and briefly describe any historical coal mining operations (no longer operating), such as their duration, quantity and quality of resources extracted, reason for closure, etc.
1.2.3	Proposals and exploration	• provide brief review of the exploration history in the bioregion or subregion to indicate exploration maturity (e.g. greenfield vs. brownfield) and the likely potential for new discoveries • briefly outline the main focus areas and identify the active companies and methods of current exploration for coal and CSG resources. It may be useful to explain any major changes of exploration focus or history, if relevant. The main exploration areas should be shown on a map of the bioregion or subregion • based on available information, for instance from EIS documentation or consultation with development companies, tabulate the current status of proposed new or expanded coal resource developments, identify proponents, projected start-up dates and operational duration, likely tonnage and grade, expected annual production rates, etc. • describe main resource, engineering, mining and production aspects of proposed developments, including total development area and depths, extraction techniques, overburden and waste rock management, processing facilities and methods • outline proposed market for resources to be sold and mention expected transport mechanism to reach markets, as well as if new infrastructure is required to be built

Section number	Title of section	Main content to include in section
		• brief outline of projected costings for development, such as capital expenditure and operations (if available) • describe the proposed rehabilitation and post-operational closure plans for the production site • note the past and expected future extent and magnitude of hydraulic fracturing for CSG operations
1.2.4	Catalogue of potential resource developments	• tabulate all identified coal resources known in the bioregion or subregion, using most current estimates available (e.g. by deposit or project name and mention if compiled in accordance with the JORC Code) and describe or map their distribution, size, grade and other important characteristics (an example of this information table is in Section 4) • similar to coal resources, tabulate and map (could be same map as for coal resources) all identified CSG resources in the bioregion or subregion

JORC = Joint Ore Reserves Committee. CSG = coal seam gas

4 Stage two of the coal resource development pathway – assessment

4.1 Introduction

The assessment of the coal resource development pathway for each bioregion or subregion is produced through the critical evaluation of data inputs collated and described previously (Section 3). Decisions about which of the projects are considered likely to be developed in the future are made through scientific analysis of the available data and information, combined with the technical knowledge and judgment of the Assessment teams. This detailed analysis is primarily needed to focus the subsequent surface water and groundwater numerical modelling to be done in the bioregional assessments (see Section 4.10). The coal resource development pathway thus represents the culmination of independent evaluation by each Assessment team, and is tested and verified through discussions with relevant coal and CSG companies and other experts in industry, government and local communities (see Section 4.8).

The coal resource development pathway is based on a thorough understanding of the current status of resource operations (i.e. the development baseline), coupled with a realistic projection of how future resource development is most likely to unfold across the bioregion or subregion. This may include both new resource extraction proposals, as well as expansion plans for existing operations. To the extent possible, the coal resource development pathway will cover all potential development stages including exploration, production, closure and mine legacy issues (Barrett et al., 2013).

Stage two of the submethodology presented here has been developed primarily as a practical guide for Assessment teams and provides the flexibility to research and determine the coal resource development pathway in areas with diverse coal resource characteristics and development situations. These potential developments range from areas in remote greenfield coal-bearing basins such as Arckaringa and Pedirka, through to areas with a long history of coal mining and significant investment in associated infrastructure, for example, the Hunter subregion in the Northern Sydney Basin bioregion. The results of the detailed analytical work to determine each coal resource development pathway are written as a concise statement, and reported in companion product 2.3 (about conceptual modelling) for each assessment. Specific guidance on the reporting requirements is in Section 4.9.

4.2 Scope of the coal resource development pathway

The coal resource development pathway must be specified for each bioregion or subregion to describe the most likely combination of known coal and CSG resources (deposits) that are expected to progress to become commercially operating mines or gas production sites (Barrett et al., 2013). This timeline of proposed developments extends the baseline of current commercial resource operations (as noted for each bioregion or subregion as of the last quarter of

2012) into the foreseeable future. The timespan that the coal resource development pathway covers will likely differ between bioregions and subregions due to variability in the nature, extent and timing of existing and proposed developments (and the amount of information available to base the assessment on). However, an indicative coal resource development pathway focused on those projects expected to start commercial production within approximately 15 years (from time of assessment) is here suggested as the likely development time frame that most Assessment teams will plausibly be able to evaluate. This reflects the long lead-in times required to progress from exploration success through various stages of appraisal, concept planning and approvals before commercial operations commence. This period is also in line with the time frame of expected development for identified resources described in the Australian resource classification scheme (Geoscience Australia and BREE, 2013).

The coal resource development pathway is focused at the bioregion or subregion scale and provides the regional understanding of where and when future development activities will be focused (including areally, stratigraphically and their depth extents), the total number and type of developments, and the variation in production rates for coal and CSG over the coal resource development pathway timespan. It is also useful to briefly outline the coal and CSG handling, processing and transportation infrastructure of each assessment region, particularly if significant new investment in such infrastructure is required as part of future development.

Further to the regional overview and synthesis of coal and CSG resources (companion product 1.2), the coal resource development pathway describes the:

- current baseline of coal resource development
- name and type of each resource development
- timing of main development stages and expected life-of-operations
- potential for subsequent modification of original development plans, for example, the possibility of further expansion of open-cut mines beyond the initial proposal, or cases where open-cut mines may proceed to underground operations
- names of relevant companies (or joint ventures) owning and/or operating resource developments
- size of the mineable resource and expected annual production rates at the bioregion or subregion scale.

It is useful to graphically display these development stages on a timeline diagram, and also their areal distribution on a map of the subregion.

By defining the suite of potential resource developments that are considered most likely to proceed into the future, subsequent numerical modelling work will be able to effectively focus on changes to surface water and groundwater systems caused by the combined (cumulative) effects of these developments. This numerical modelling will occur in BA Component 2 (model-data analysis) following definition of the coal resource development pathway and other required conceptual modelling inputs (companion product 2.3). An overview of the application of the coal resource development pathway in these subsequent modelling stages is presented in Section 4.10, which will help Assessment teams to recognise the minimum information requirements to

describe in their coal resource development pathways. Details of the modelling approaches are covered in pending companion submethodologies listed in Table 1 (e.g. M06 about the BA surface water modelling approach and M07 about the BA groundwater modelling approach).

A further important point here is that bioregional assessments will only specify one most likely coal resource development pathway for each bioregion or subregion. Thus, multiple coal resource development pathways (or potentially a set of different development pathways or scenarios) are not described in BAs. This decision provides the certainty and consistency of a standard BA-wide approach to determining the development pathway for each bioregion or subregion. The single coal resource development pathway also avoids future subjective debate and ambiguity over the relative likelihood of prospective, but different, development pathways occurring (from a potentially long list of possibilities). It also helps to ensure that the impacts and risks to water-dependent assets are conditional on a specific coal resource development pathway. Due to the BA requirement to propagate model uncertainties throughout all stages, a single coal resource development pathway also means that the relative uncertainty levels that would need to be associated with different development pathways do not have the effect of overwhelming the later numerical model uncertainty estimates that are subsequently developed in the BAs.

4.3 Specifying the development baseline

The baseline for each bioregion or subregion is defined by the collective suite of large coal mining and CSG extraction operations that were engaged in commercial production as of the last quarter of 2012 (as explained in Section 3.5). This means that any resource projects that were not extracting coal or CSG for sale to a buying market by 31 December 2012 will not be included as a baseline operation, but will instead be considered as a future development in the coal resource development pathway. Historical mining operations should also be mentioned here, although their potential water-related impacts will likely diminish with the overall length of time that the mine has been non-operational. Knowledge of these current and historical resources is based on the outcomes of the data and information synthesis outlined in Section 3, which is reported in companion product 1.2 for each bioregion or subregion. The baseline describes the situation prior to the future resource development of the coal resource development pathway, and as a minimum should include:

- name, location and type of large coal mining or CSG operations
- main companies involved in these operations
- for CSG production sites, specify the number of operational wells and their areal distribution
- the length of time that the operations have been engaged in commercial production, as well as information about the timing of any major development stages and expected life of future operations, extraction volumes and area of production
- total amount of resources extracted annually from the basin (aggregated from all mines and production sites) – this could usefully be displayed as a graph showing coal production tonnage or CSG volume extracted over the last 5 to 10 years.

It is also helpful to show the areal distribution of baseline operations on a map of the bioregion or subregion. Further information about the inputs to baseline reporting is in Section 3.5.

4.4 Development time frames

An important concept for Assessment teams to be aware of is the potential for future variability of their respective coal resource development pathways. This may alter some aspects of the stated coal resource development pathway that were based on analysis of data available at the time of the assessment. As decisions to progress resource developments are subject to a wide range of geological, engineering, technological, legislative and economic considerations, the nature and timing of development plans proposed by individual (or joint venture of) companies may change over time, for example, within the space of several years (and sooner in cases). Companies may reassess and reprioritise their development plans as new data or information on the tonnage and grade of the resource becomes available, or in response to key market variables that can directly influence the economic viability of a project.

Due to this potential for change over time, each Assessment team should be mindful that the most likely coal resource development pathway that they describe may be applicable only for some limited amount of time from the point that the pathway is initially defined. This is based on their considered understanding of the available information, including direct input and validation from relevant groups in industry (such as resource development companies) or government, if possible. Consequently, the coal resource development pathway stated for each bioregion or subregion should clearly be '*time-stamped*' when described in companion product 2.3. This pathway will then be valid for a certain time frame into the future, although it may prove difficult for individual Assessment teams to speculate about what this length of time will be for some bioregions or subregions. However, it is recommended to further assess and re-evaluate the originally stated time frame of the coal resource development pathway during the later stages of the BA, such as during Component 4 – Risk analysis. This process may help to identify the optimal time frames for repeating certain aspects of the BA, such as defining the coal resource development pathway.

As part of the time-stamp process it is also helpful for Assessment teams to be clear about which (if any) of the main assumptions underpinning their coal resource development pathway may alter within the foreseeable future, and what the expected impacts of such changes may be. If these impacts are deemed significant, then it may be possible to update the coal resource development pathway at a later stage of bioregional assessments (if needed) and then reassess predicted development impacts via further modelling based on the revised coal resource development pathway.

4.5 Regional focus

Potential development pathways for coal and CSG resources are determined by the interplay of a range of important factors. These include geological parameters such as coal characteristics (type, rank, grade), abundance, location and depth, environmental and land access considerations (e.g. areas where mining cannot take place due to existing legislation such as national parks or other types of legislated exclusion zones), technological constraints associated with mining and production, and various economic factors (primarily a viable long-term market contract for sale of the resource). Critically, the combination of these factors at the bioregion or subregion scale will present a unique narrative of the coal resource development pathway.

As a consequence of this, the description of the coal resource development pathway needs to present the regional scale development outlook and not be restricted or overly focused at the level of individual mines or resources projects. In this way, the wider cumulative effects of development can be considered in later modelling stages with individual components integrated into a whole-of-basin understanding (this is also important for understanding cumulative impacts, see pending submethodology M10 for identifying and analysing risk as listed in Table 1). Ideally, each Assessment team will include a regional scale map in companion product 2.3 showing the location of all components of the expected development pathway (i.e. individual mines and CSG production sites) that includes the:

- current development status (see Table 5)
- projected time frame for each proposed development to become operational
- type of extractive method to be used
- expected annual production rate.

However, as such spatial outputs depend on the availability of detailed information relating to delineated resources, this may not be possible for some regions. A note will be made where such information is not available for inclusion, as well as the nature of any assumptions made by Assessment teams in the absence of data.

4.6 Out of scope

There are several resource-related factors that are out of scope for the coal resource development pathway:

- Multiple coal resource development pathways will not be described or modelled for BAs. Instead, there will be a single indicative coal resource development pathway for each bioregion or subregion consisting of the combination of individual resource projects considered most likely to proceed through future stages of development into commercial mining and CSG operations.
- Any resource projects or development stages which cannot be independently confirmed by available information in the public domain (or information which may be placed in the public domain to support the coal resource development pathway analysis, within the time frame of the BAs) will not be included. Preferably multiple sources of corroborating evidence (e.g. company or government reports, ASX announcements, public presentations) will be used to validate each resource development. Unconfirmed hearsay or speculation about resources or potential development situations will not be considered, so as to maintain the transparency of the Programme and the credibility of the Assessment teams undertaking the work.
- The coal resource development pathway will not include or speculate on the location, tonnage or potential for extraction of undiscovered or unidentified resources within a bioregion. Independent estimates of total undiscovered coal and CSG resources are not consistently available for most onshore Australian sedimentary basins, and hence cannot be widely used for the purpose of BAs. Additionally, including potential undiscovered resources in future modelling stages will introduce significantly high levels of uncertainty into the

overall BA workflow, which could potentially overwhelm the uncertainty estimates of subsequent modelling predictions.

- Any coal or CSG occurrences that do not meet the national classification scheme definition of a 'resource' should not be included for consideration in the coal resource development pathway, such as those that are classed only as *occurrences* or *undiscovered* (prospective) resources (Appendix A).
- Resources based on extraction via underground coal gasification (UCG) technology, as well as all other unconventional and conventional petroleum gas resources (e.g. shale gas and tight gas resources), will not be considered in the coal resource development pathway, as they are out of scope for the BAs.

4.7 Assessment of the coal resource development pathway

4.7.1 Stages

Determining the combination of potential coal resource projects that define the coal resource development pathway is a two-stage assessment process that takes place across components 1 and 2 of the BAs.

4.7.1.1 Contextual information

In Component 1, the catalogue of potential resource developments compiled for each bioregion or subregion is the starting point for the more detailed coal resource development pathway analysis undertaken by Assessment teams. This catalogue, which is reported in Section 1.2.4 of companion product 1.2, provides the list of all identified coal and CSG resources (Appendix A) which could *potentially* be developed into full-scale commercial production at some stage in the future.

An example of both the coal and CSG catalogues is shown in Tables 6 and 7[4]. Information for the notes column of these tables may include details of the mining lease and exploration tenements associated with each project, as well as the proposed operational footprint (areal extent) of each site.

As discussed in Section 3, the analysis completed during this stage is required to understand the geology and three-dimensional spatial distribution of coal and CSG, and to identify the main companies involved in exploring and producing these resources. However, it is not expected that all of the resources identified in the catalogue will necessarily be included in the coal resource development pathway. For example, some deposits for which only an inferred resource (as reported in accordance with the JORC Code) is currently available may not be sufficiently enough well understood (in terms of geology and economics) to be included in the coal resource development pathway.

[4] The information provided in these tables does not relate to any specific subregion or bioregion in the BAs, and is purely illustrative. Thus, the references shown in the notes column are used only as examples, and are not included in the chapter reference list.

Table 7 Example of catalogue of potential coal resource developments

Project name	Company	Longitude	Latitude	Record date[a]	Material[b]	Total coal resources[c] (Mt)	Status of EIS[d]	Notes
Project 1	Company 1	119°	–22°	2 Apr 2013	Thermal coal	17,880	EIS closed	Jones et al. (2011)
Project 2 (PRJ2)	Company 2	148°	–32°	1 Sep 2012	Unspecified	453	EIS approved	Stage 2 has been fast-tracked
Project 3	Company 3	150°	–34°	26 May 2014	PCI	10	Pre-EIS	Tonnage uncertain
Project 4	Company 3	139°	–28°	9 Dec 2013	Coking coal	708	EIS submitted	AGL (2014)
Project 5	Company 4	128°	–20°	24 Aug 2013	PCI	8,352	Supplementary EIS	Underground mine

[a]The record date is the most recent date for updated coal resource numbers.
[b]Materials fall into one of the following four classes: thermal coal, coking coal, pulverised coal injection (PCI) and unspecified.
[c]This is calculated by summing the resources with Joint Ore Reserves Committee (JORC) codes of measured, indicated and inferred.
[d]The status of the project within an environmental impact statement (EIS): pre-EIS, EIS in preparation, EIS submitted, EIS closed, supplementary EIS and EIS approved.

Table 8 Example of catalogue of potential coal seam gas resource developments

Project name	Company	Longitude	Latitude	Record date[a]	2P coal seam gas reserves[b] (PJ)	Status of EIS[c]	Notes
Project 1	Company 1	119°	–22°	2 Apr 2013	1880	EIS closed	Jones et al. (2011)
Project 2 (PRJ2)	Company 2	148°	–32°	1 Sep 2012	453	EIS approved	Stage 2 has been fast-tracked
Project 3	Company 3	150°	–34°	26 May 2014	10	Pre-EIS	Smith (2013)
Project 4	Company 3	139°	–28°	9 Dec 2013	708	EIS submitted	AGL (2014)
Project 5	Company 4	128°	–20°	24 Aug 2013	8352	Supplementary EIS	Underground mine

[a]The record date is the most recent date for updated coal seam gas resource numbers.
[b]The Petroleum Resource Management System of the Society of Petroleum Engineers (PRMS-SPE) code 2P refers to estimated quantities of proved reserves plus probable reserves.
[c]The status of the project within an environmental impact statement (EIS): pre-EIS, EIS in preparation, EIS submitted, EIS closed, supplementary EIS and EIS approved.

4.7.1.2 Model-data analysis

Analysis of relevant data and information by Assessment teams is undertaken for each listing in the catalogue of potential resource developments. The main assessment criteria used to evaluate each resource project and determine the coal resource development pathway for each bioregion or subregion are presented in Section 4.7.2. If possible, the factors likely to influence the final investment decision for a project to advance to mine development will also be considered by Assessment teams as part of this analysis.

4.7.2 Assessment criteria

There are many factors (e.g. geological, economic, infrastructure access, legislative) that can provide incentives or constraints to resource development, and together these may influence the final investment decision to proceed (eventually) to commercial production. Consequently, this coal resource development pathway submethodology has been developed to capture the potential influence of this range of factors via a discretionary (case-by-case) assessment approach. The decision to include projects in the coal resource development pathway is thus based on the accumulated knowledge and region-specific understanding developed by the individual Assessment teams. As with other reporting for BAs, the rationale for determining which projects are included (and excluded) from the coal resource development pathway needs to be clearly articulated (in the case of the coal resource development pathway, this is done in companion product 2.3).

For the purpose of BAs, there are two important criteria for initially determining if a resource development project will be part of the coal resource development pathway:

- Projects that have been referred, or have already submitted documentation, for assessment of an EIS. As previously explained (Section 3.6), the EIS process is administered by various government departments and involves a multi-stage process of assessing a range of potential environmental (and other) impacts due to the proposed development. Due to the complexity, costs and consequences of submitting an EIS for assessment, reaching this stage usually signals an appropriate level of confidence from the resource developer in the economic viability of the operation. Projects which are expected to submit an EIS within the next two years are also to be included in the coal resource development pathway.
- Projects with an *economically demonstrated resource* (EDR, as defined in the Australian resource classification scheme – see Appendix A for details) are those considered to be the best understood in terms of their geology and the economic feasibility of future development. Thus, the default position for BAs is to include all coal and CSG projects with an EDR in the coal resource development pathway for each bioregion or subregion (it would be expected that all resource development projects at EIS stage as noted above would also have an EDR associated with them).

In the context of BAs the above two criteria provide strong justification for inclusion in the coal resource development pathway. However, it is possible that Assessment teams may recognise some situations where such resource development projects (either at EIS stage or with an EDR)

are not expected to proceed to full-scale development. For example, this may arise if the set of economic assumptions that currently underpin the viability of the resource development are significantly altered, to the extent that commercial extraction is no longer profitable. Alternatively, changes in government legislation or regulatory conditions may also affect the commercial viability of an otherwise economic resource (note that if these types of situations affected resources owned by a publicly listed company then they would also be required to provide public notification of such changes, e.g. through an announcement to the ASX). In these cases, the coal resource development pathway submethodology is sufficiently flexible to allow exclusion of such projects, although these decisions must be fully explained and justified in writing the coal resource development pathway description. Furthermore, the case for exclusion must be effectively argued by the Assessment team and supported by the BA Science Leadership Group and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). In this way, there is clear accountability and documentation of these important decisions across the Programme.

For those resource projects listed in the catalogue of potential developments which are not at EIS stage, or which do not have an EDR, multi-criteria assessment of relevant and available information covering geological, economic, environmental, legislative and technical issues may be required for Assessment teams to judge the likelihood of development proceeding within the coming (approximately) 15 years (thus providing a basis to decide on its inclusion or exclusion from the coal resource development pathway). This case-by-case assessment may focus on various factors such as:

- the nature and level of current activity taking place at the identified resource (usually by the resource owners, their affiliates or joint venture partners), particularly if this activity is at an advanced mine planning feasibility stage or involves preparation of material for future EIS submission. For example, initial concept plans or preliminary designs may be available to indicate the nature, style and timing of the resource development as well as the associated critical infrastructure demands and access option
- the likelihood of the current resource base being reclassified with greater certainty at some stage in the near- to medium-term, that is, within the assessment time frame for the Programme. This may alter the distribution of the project resource base (e.g. the ratio of resource categorised in accordance with the JORC Code classes of measured, indicated and inferred), thereby enhancing the probability of future development proceeding
- recognition of potential major impediments to development, such as factors associated with legislative, economic, infrastructure, environmental, social, or technological issues, and how these may affect the future and timing of the proposed development
- basic understanding of economic factors and market conditions that may affect the viability of a resource development to proceed, e.g. current and future market price estimates for coal. Although it is beyond the scope of BAs to undertake a detailed analysis of resource economics for each potential development, Assessment teams may consider the influence of major economic factors affecting the viability of particular resource projects in the coal resource development pathway. If such information can be obtained, this may involve brief analysis of capital funding provisions, joint venture arrangements, or the existence of locked-in take-or-pay contracts

- understanding of the mine or petroleum reservoir engineering considerations that may affect the method of extracting the resource
- consideration of current understanding of the development company (or joint venture) intentions for the project – such as their current level of interest and at what stage are they in terms of capital raising or securing financial backing for the project. It is also useful to recognise the expected level of appetite that the company has to work towards upgrading and developing the resource and if there are any existing timelines associated with such planning
- if the proposed development of the project has already been recognised as being of particular interest to relevant regulatory authorities, or has attracted significant opposition from local groups, such as community representatives
- any relevant technical and scientific factors (e.g. geological or environmental conditions), or legislative information that may assist the Assessment team in determining the likely status and timing for future development of the resource.

Simple flow chart analysis and the use of basic (e.g. yes/no) evaluation criteria are generally not appropriate techniques for many of the datasets (as outlined above) that need to be considered for this stage of the coal resource development pathway assessment. This is because of the expected complexity of inter-data relationships and the variability in weighting of different factors between subregions and bioregions. If required, alternative multi-criteria data assessment methods, possibly using tools such as concept-maps, may be investigated by Assessment teams as an aid to capture and assess the range of factors for evaluation.

By considering as many of these relevant factors as possible, each Assessment team will need to decide if they can build and effectively argue the case for the overall coal resource development pathway proposed for respective bioregions and subregions. This approach provides for sufficient scrutiny of the suite of projects considered for inclusion at the time of assessment.

4.7.3 Potential difficulties

One of the main difficulties facing Assessment teams in deciding which projects to include in the coal resource development pathway is the lack of specific threshold values for the information that may need to be assessed for some projects. Thus, while it is possible to identify here the factors to be evaluated for each resource project, it is not always possible to provide clear guidance to Assessment teams on the quantitative values that can be used to determine if a particular project is considered likely to proceed or not. This will particularly be the case for projects which are currently not well defined geologically or economically (i.e. inferred or subeconomic resources), or which are not yet at EIS or mine feasibility planning stages. Where such examples occur, respective Assessment teams must exercise independent judgment based upon their overall evaluation of the most relevant information available (case-by-case) and with due regard to wider resource and infrastructure development trends within each bioregion or subregion.

If, in the opinion of the Assessment team, most factors assessed for each resource project are considered to favour that project becoming an operational production site, then it is likely to be included in the coal resource development pathway. To ensure transparency of decisions, for those projects listed in the catalogue of potential resource developments that are deemed unlikely to be developed, the factors that have led to its exclusion should be adequately described and explained as part of the reporting of the coal resource development pathway (companion product 2.3).

4.8 Engagement with experts

Engagement with relevant industry groups, individual resource development companies and acknowledged experts in government agencies, academic institutions and local communities is crucial to independently evaluate the proposed coal resource development pathway. This provides the opportunity to present the results of the initial research based on the key data themes (companion product 1.2) and test the preferred pathway concept with a range of experts that are well-placed to provide direct feedback on its validity. Initial engagement should preferably occur during the development of companion product 1.2, so that Assessment teams can start to formulate initial ideas about the development potential for each resource. This also provides opportunity to identify and test various development assumptions, as well as providing a mechanism to potentially access a wider range of data and information about resource projects. Ongoing communication with relevant experts as data analysis proceeds (in Component 2) for the coal resource development pathway is also recommended, as it is likely to provide useful input and clarification of uncertainties.

There are many potential benefits for Assessment teams in establishing productive working relationships with a network of experts for each bioregion and subregion. For example, relevant industry representatives from coal resource companies may be able to address uncertainties about the status of particular projects or help to confirm the proposed development pathway as being feasible and in line with current corporate expectations. This type of engagement needs to involve both coal mining and CSG development companies, as each may have unique characteristics relevant to assessing the coal resource development pathway. Ongoing dialogue with relevant resource companies and state government agencies, combined with well-targeted workshops, are also important components of the coal resource development pathway process and provide important mechanisms for productive engagement. Furthermore, it is part of the overall BA process for each Assessment team to engage and seek feedback from relevant experts and other interested groups (e.g. local communities) about each coal resource development pathway, and respond appropriately to this feedback prior to publication of the coal resource development pathway for each bioregion or subregion.

4.9 Bringing the concepts together and writing the coal resource development pathway in companion product 2.3

The description of the coal resource development pathway for any bioregion or subregion is best written as a concise and focused synthesis, which is reported in companion product 2.3 (about conceptual modelling). This will initially be based on the projects and deposits listed in the catalogue of potential resource developments from the coal and CSG resource assessment (companion product 1.2). However, to decide which combination of individual projects should be included in the coal resource development pathway, new data analysis and evaluation of important criteria (as previously outlined in this section) needs to take place to build upon the contextual information and provide justification for decisions. This information is largely based on the Assessment teams' understanding of the intentions of each company engaged in resource development, and is independently validated (to the extent possible) with relevant experts.

The main focus of the coal resource development pathway description in companion product 2.3 should be to articulate the manner in which coal and CSG resource development is most likely to progress from its current situation (baseline) into the future. For many bioregions and subregions the coal resource development pathway may include multiple CSG production and/or large coal mining developments. Thus, it is suggested here that the coal resource development pathway be simply stated in an overarching introductory section of companion product 2.3. To provide an illustrative example of how such a coal resource development pathway overview could be written, the following statement has been prepared as a generic guide[5]:

> 'The coal resource development pathway for the X subregion includes three new open-cut coal mines (include the names of the proposed mines here), two new underground longwall coal mines (include names here) and one coal seam gas development (include name here). The distribution and characteristics of these developments are shown in Figure A. Figure B shows the most likely timeline that each of these development stages becomes operational, and this timeline will be used when doing the surface water and groundwater modelling. Future development operations are expected to involve *this*, *that*, and the *other* (to be qualified to the extent possible based on available information). While there are a few other resource projects with economically demonstrated resources which could potentially be extracted at some stage in the future, these were deemed unlikely to proceed due to the following reasons…. Consequently, these projects were not included in the coal resource development pathway.'

As shown above, it is useful to include a new map as part of the coal resource development pathway description. This map can be used to display the location and type of proposed

[5] The X subregion name in the example here does not relate to any specific subregion, and is provided only as an illustrative example of how to write the description of the coal resource development pathway. The names of individual coal mines and coal seam gas sites will of course vary for each bioregion or subregion, so actual names have not been used in this example. Likewise, the references to Figure A and Figure B in this statement are purely illustrative and do not relate to any actual figures within this document.

development, as well as projected start dates for various phases and other characteristics of the development such as annual tonnage to be extracted and proposed mining methods. It may be useful to show this in the context of existing infrastructure, towns and major environmental features such as rivers or lakes. To complement the map, it is also important to include an indicative *timeline diagram* (similar to a Gantt Chart) that effectively illustrates the temporal progression of each resource project (over the life of the expected development) within the bioregion or subregion, including recognition of the baseline projects as well as major development stages for each operation in the coal resource development pathway.

Building on the suggested high-level overview above, further information articulating the coal resource development pathway in any bioregion or subregion may also include (to the extent possible):

- explicit recognition that the stated coal resource development pathway represents the most likely development pathway at the time of writing (ensure that the coal resource development pathway is 'time-stamped') and that the actual roll-out of development may differ due to unforeseen factors as circumstances change in the future. In particular, resource development proposals may change over time in response to the main variables that influence development decisions. These may include revised updates on resource tonnage and grade based on new geoscientific data, changes to proposed mining techniques, or variations in market conditions and/or legislative arrangements. If known, such information should be clearly articulated as part of the description and assumptions used as basis for the coal resource development pathway
- a brief re-iteration of the development starting point of the BA, that is, the resource development 'baseline' as of the last quarter of 2012. This should include a high-level summary of the number of currently operating coal mines and CSG production operations, as well as key information such as location, project name, areal extent, mining and extraction methods, size of resource remaining and estimated mining life at current rates. There is no need to provide additional detailed information here, as this is a simple statement of current operations that is consistent with information already outlined in companion product 1.2
- the basis for which the proposed coal resource development pathway has been determined. For example, is it mainly based on plans outlined in submitted EIS documentation, or are there other elements that the respective project team has included, and on what basis were these inclusions made
- a description of any expectation for multiple development stages to occur for each resource project. For example, initial development of an open-cut mine, followed (at some time in the future) by a larger expansion of the open-cut operation and eventually proceeding to a late-stage underground mining situation. If there is little information available on the possibility of later-stage expansions for individual projects, it may be possible for Assessment teams to base the potential for this to occur on the typical historical development trends of other deposits within or near to the bioregion or subregion. Of course, this approach will not be possible in some areas, such as greenfield coal development basins like the Galilee and Arckaringa

- an overarching explanation of how many individual developments comprise the most likely pathway, as well as a brief review of their main features such as name, type and status. This should also identify if these are new operations or expansions and modifications of existing mines
- additional information (e.g. supplied by resource development companies) that may help understand the circumstances for which the coal resource development pathway is considered valid. This may not always be possible due to information constraints (such as confidentiality), or independent variables that are difficult to anticipate or are outside of the control of the developers. It is useful to mention which companies have provided input to help verify or dispute a particular development for inclusion in the pathway
- explicit recognition of the identified coal or CSG resources (as listed in Section 1.2.4 of companion product 1.2) that have not been included in the coal resource development pathway and brief explanation of the reasons. This would not necessarily have to be done on a deposit-by-deposit basis, but could be grouped into larger themes relating to why certain resources are excluded, such as excluded due to economic factors, or lack of resource understanding, or technological and extraction difficulties, etc. To provide transparency of decisions in the BAs, it is important that the reasons for including or excluding each entry in the resource catalogue are adequately explained in the coal resource development pathway description. As for other components of BAs, justification of key decisions made in the course of the Programme need to be clearly stated
- a final part of the coal resource development pathway should also briefly describe the expected level, extent, style and focus of future exploration activities in the bioregion or subregion. This is important as it provides the context for the likelihood of future exploration programmes to contribute to further expansion of the identified coal and CSG resource inventory. Although it is not feasible for Assessment teams to speculate about the potential future for extraction of unknown resources, a brief review of current exploration activity will provide useful context for interested parties.

4.10 Information requirements for numerical modelling

Some of the details provided in the coal resource development pathway description are required data inputs for the subsequent quantitative modelling stages to assess development impacts to groundwater and surface water systems. However, an important point here is that some resource projects in the coal resource development pathway may not be able to be included in subsequent numerical modelling studies. This is most likely to occur for those projects that lack sufficient quantitative data (publicly available) about the proposed nature, scale and timing of development operations for them to be realistically included in modelling simulations (Table 9). In such cases, a qualitative explanation of potential impacts may be the only possible assessment. However, the main data gaps and uncertainties that restrict these developments from inclusion in modelling studies should be explicitly stated as part of the final modelling report.

The minimum information requirements that need to be reported in the coal resource development pathway for each coal or CSG resource development to satisfy the modelling inputs are shown in Table 9. This table distinguishes the expected variation in the availability of the most

important data between coal or CSG development projects at the EIS stage, compared with those which are less-advanced and have greater overall uncertainty about the proposed development characteristics.

Table 9 presents the current understanding of the main information required from the coal resource development pathway for later modelling, although as modelling work proceeds, other necessary details may also emerge that are not currently accounted for. For example, surface water modelling may require information concerning on-site storage of mine-related water (aquifer dewatering storages), including details of how this capacity may change over time and what contingencies are in place if storages are exceeded. Information relating to salinity (and possibly other water quality indicators) of discharge water may also be needed as model inputs for some subregions or bioregions (N. Viney, (CSIRO), 2014, pers. comm.).

4.11 Information sharing with the wider bioregional assessment team

Although it is not intended specifically for this purpose, the research undertaken to describe the coal resource development pathway may also help other components of the bioregional assessment to focus on the water-dependent assets that are proximal to the most likely development zones, and thus potentially the most likely to be impacted by future operations. Thus, as a final comment in this submethodology, key components of information obtained during the research and writing of companion product 1.2 (see Table 6) and the subsequent coal resource development pathway analysis and description should be shared broadly with other disciplines working as part of the same Assessment team. This is especially for cases where information obtained during a particular component of the study is recognised as being of value to other aspects of the BA. A relevant example of this is any information related to groundwater and surface water management and monitoring plans, and data which are not reported specifically in companion products 1.2 or 2.3 (see Table 2), but which may be uncovered during the research work required for these stages.

Table 9 Summary of coal resource development pathway minimum data requirements for modelling and expected data availability for EIS and non-EIS stage coal and CSG resource projects

Type and number of modelling requirement	Type of data and information required from coal resource development pathway for numerical modelling	Expected availability of data for identified coal or CSG resources within the EIS assessment system	Availability of data for identified coal or CSG resources not at EIS assessment stage
Surface water modelling requirement 1	Time series of mine development area. That is, the total area of mine operations in which rainwater is actively intercepted and retained. An annual time step is sufficient.	Mine development plans and the expected progression of mining over time are commonly provided in most resource company EIS documentation. These may be further modified or updated based on input from discussions with relevant companies.	Preliminary mine design and development plans may be publicly available for some resource projects prior to release of EIS (e.g. from company-released reports or information provided on websites). However, there are no statutory requirements for such information to be released and it is at the discretion of each development company. Additionally, any preliminary plans are likely to be subject to more future variation than those provided as part of EIS submissions.
Surface water modelling requirement 2	Locations and volume time series of any water extracted from the surface water network for mine or CSG operations. An annual time step may be sufficient.	Expected annual volumes of surface water required for extraction are usually provided in operational water management and monitoring plans which would be expected to be included as part of EIS documentation.	Details of surface water extraction volumes and timing are unlikely to be available for potential resource developments prior to EIS submission. If so, data availability would be at the discretion of the operating company.
Surface water modelling requirement 3	Locations and volume time series of any water discharged to the streams. Except for produced CSG water, discharges are likely to be irregular and opportunistic and may need finer time steps.	Expected annual volumes of surface water to be discharged to streams would usually be provided in operational water management and monitoring plans which would be expected to be included as part of EIS documentation.	Details of surface water discharge volumes and timing are unlikely to be available for potential resource developments prior to EIS submission.
Surface water modelling requirement 4	Details of extraction and disposal of water via the groundwater system. Preferably these will already be accounted for in the groundwater modelling.	Information on plans for extraction and disposal of groundwater from mining and CSG operations should be provided as part of EIS documentation.	Details of proposed groundwater extraction rates, volumes and timing for coal and CSG operations are unlikely to be publicly available for coal and CSG resources prior to EIS stage assessment.
Groundwater modelling requirement 1	Nature and phasing of the resource extraction development i.e. is it likely to be an open-cut or underground mine, or are there plans for multiple stages to occur, such as progression from initial open-cut to underground operations.	Initial mine development plans should be available as part of EIS documentation. However, many initial plans may not include details of larger-scale expansions or future underground operations. Thus, some additional analysis and expert judgment of how other nearby operations have progressed over time will be needed to decide if multiple development stages are likely in the future.	Depending on the depth to the resource from surface, there are some basic rules-of-thumb that can be used to judge if a coal resource is likely to be mined by either open-cut or underground operations. Recognition of the type of development can also be judged with reference to nearby mining operations in the same area.
Groundwater modelling requirement 2	Location of the resource development – note that this location will be represented in most BA groundwater models at 1000 metre grid cell resolution, so more precise location data (than this scale) will generally not be required for most subregions.	EIS documentation should provide relevant information on the location of the development, including in some cases detailed layouts of proposed pit designs or underground mining areas.	Detailed mining design plans are unlikely to be publicly available for most proposed resource projects prior to EIS stage. However, the approximate location of the development within a 1000 metre grid cell can probably be determined in most cases from other sources of information, such as company announcements or publicly available reports.
Groundwater modelling requirement 3	Timing of resource development operations, such as dates for initial start-up, ramp-up time to full-scale operations and the expected mine-life duration. Also, as above, any multi-stage development potential should be assessed.	EIS documentation should provide relevant information on the expected timing and phasing of development stages for mining and CSG operations. However, as mentioned above, this may not extend to coverage of potential additional stages of future development that may occur.	This type of mine design and development detail is unlikely to be publicly available for most coal/CSG resources prior to EIS submission. However, there may be some cases where companies make such information available at a relatively early stage of planning, although there is no legislative requirement for this to be done. Essentially, the release of this type of planning detail is at the discretion of the development company.
Groundwater modelling requirement 4	Fundamental stratigraphic information on the nature of the mineable coal-bearing formations, such as depth below surface to the top of the formations and the formation thickness. This is required to specify a target water-level for modelling of the mine dewatering plan.	Geological investigations undertaken as part of resource characterisation are commonly summarised and presented as part of EIS documentation. Such information should provide sufficient detail required for proposed BA groundwater modelling.	Basic information on the stratigraphy of the coal-bearing formations should be available from various public sources for most deposits, although it may not be as detailed for those deposits which are at a more preliminary stage of assessment (pre-EIS).
Groundwater modelling requirement 5	Depth below surface to the watertable, as well as the water level depth in other relevant aquifers, e.g. the potentiometric surface of a relevant confined aquifer.	Note that groundwater levels for most areas are likely to be obtained from other reference sources or components of work (contextual), rather than specifically from companion product 1.2 or the coal resource development pathway. However, EIS evaluation may provide more detailed understanding of groundwater levels and aquifer characteristics as part of relevant hydrogeology sections.	Basic information on watertable depth should be available for most subregions, although the accuracy may vary. In most cases, this information should be sufficient, although it will generally not be as detailed as that provided from the more detailed resource-specific studies of hydrogeology.

The information requirements outlined above that relate to geology, coal and CSG resource characteristics or mine development and operational plans and timelines will be reported as part of the coal resource development pathway discussion in companion product 2.3 (conceptual modelling). In contrast, the water-related information above will be provided and discussed in companion product 2.5 (water balance). EIS is environmental impact statement, CSG is coal seam gas. This table has been optimised for printing on A3 paper (297 mm x 420 mm).

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 25 August 2014, <http://iesc.environment.gov.au/pubs/methodology-bioregional-assessments.pdf>.

Core Energy Group (2012) Eastern and southern Australia: existing gas reserves and resources. Report prepared for the Australian Energy Market Operator, April 2012.

Ewers GR, Evans N, Hazell M, (Kilgour B, compiler) (2002) OZMIN mineral deposits database. [Digital datasets]. Viewed 3 February 2014, <http://www.ga.gov.au/meta/ANZCW0703003393.html>.

Geoscience Australia and ABARE (2010) Australian Energy Resource Assessment. Geoscience Australia and Australian Bureau of Agricultural Resource Economics, Canberra. Viewed 17 June 2014, <http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_70142>.

Geoscience Australia and ASC (2014) Australian Stratigraphic Units Database. Geoscience Australia and Australian Stratigraphy Commission, Canberra. Viewed 12 June 2014, <http://www.ga.gov.au/products-services/data-applications/reference-databases/stratigraphic-units.html>.

Geoscience Australia and BREE (2012) Australian Gas Resources Assessment 2012. Geoscience Australia and Bureau of Resources and Energy Economics, Canberra. Viewed 17 June 2014, <http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_74032>.

Geoscience Australia and BREE (2013) Australia's Mineral Resource Assessment 2013. Geoscience Australia and Bureau of Resources and Energy Economics, Canberra. Viewed 17 June 2014, <http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_efd34a82-a55e-1206-e044-00144fdd4fa6/Australia%27s+Mineral+Resource+Assessment+2013>.

Geoscience Australia, DRET and MCA (2012) Australian atlas of minerals resources, mines and processing centres. Geoscience Australia, Department of Resources, Energy and Tourism and Minerals Council of Australia. Viewed 3 February 2014, <http://www.australianminesatlas.gov.au/index.html>.

Harrington HJ, Brakel AT, Hunt JW, Wells AT, Middleton MF, O'Brien PE, Hamilton DS, Beckett J, Weber CR, Radke S, Totterdell JM, Swaine DJ and Schmidt PW (1989) Permian coals of eastern Australia. Bureau of Mineral Resources Bulletin 231, Canberra.

JORC (2012) Australasian Code for reporting of exploration results, mineral resources and ore reserves (The JORC Code). Joint Ore Reserves Committee. Viewed 12 June 2014, <http://www.jorc.org/>.

McKay AD, Miezitis Y, Porritt K, Britt AF, Champion DC, Cadman S, Towner R, Summerfield D, Whitaker A, Huston D, Jaireth S, Sexton M, Schofield A, Hoatson D, Senior AB and Carson L

(2014) Australia's identified mineral resources 2013. Geoscience Australia, Canberra. Viewed 3 February 2014, <http://www.ga.gov.au/cedda/publications/155>.

Moore TA (2012) Coalbed methane: a review. International Journal of Coal Geology 101, 36–81.

NSW Planning and Environment (2014a) Website homepage of the NSW Department of Planning and Environment. Viewed 16 June 2014, <http://www.planning.nsw.gov.au/en-au/aboutus.aspx>.

NSW Planning and Environment (2014b) Gateway assessment and site verification. NSW Department of Planning and Environment website. Viewed 10 October 2014, <http://www.planning.nsw.gov.au/en-us/planningyourregion/strategicregionallanduse/gatewayassessmentandsiteverification.aspx>.

NSW Trade and Investment (2014a) Minview (map viewer). [Digital datasets]. Viewed 3 February, 2014, <http://www.resources.nsw.gov.au/geological/online-services/minview>.

NSW Trade and Investment (2014b) Digital Imaging Geological Systems (report viewer). [Digital datasets]. Viewed 3 February 2014, <http://www.resources.nsw.gov.au/geological/online-services/digs>.

O'Keefe JMK, Bechtel A, Christanis K, Dai S, DiMichele WA, Eble CF, Esterle JS, Mastalerz M, Raymond AL, Valentin BV, Wagner NJ, Ward CR and Hower JC (2013) On the fundamental difference between coal rank and coal type. International Journal of Coal Geology, DOI: 10.1016/j.coal.2013.08.007.

Queensland C-G (2014) Website homepage of the Queensland Coordinator-General. Viewed 5 February 2014, <http://www.dsdip.qld.gov.au/coordinator-general/>.

Queensland DNRM (2014a) Interactive resource and tenure maps. Queensland Department of Natural Resources and Mines. [Digital datasets]. Viewed 4 February 2014, <https://webgis.dme.qld.gov.au/webgis/webqmin/viewer.htm>.

Queensland DNRM (2014b) Queensland Digital Exploration Reports. Queensland Department of Natural Resources and Mines. [Digital datasets]. Viewed 4 February 2014, <http://mines.industry.qld.gov.au/geoscience/company-exploration-reports.htm>.

Queensland Government (2014) Applying for an environmental authority. Queensland business and industry portal. Viewed 10 October 2014, <http://www.business.qld.gov.au/business/running/environment/licences-permits/applying-environmental-authority

RIU (2014) Register of Australian Mining. Resource Information Unit, Perth. Viewed 3 February 2014, <http://australian.miningregister.com.au/>.

SA DAC (2014) Website homepage of the South Australian Development Assessment Commission. Viewed 16 June 2014, <http://www.dac.sa.gov.au/>

SA DMITRE (2014) South Australian Resources Information Geoserver. South Australian Department of Manufacturing, Innovation, Trade, Resources and Energy. [Digital datasets] Viewed 3 February 2014, <http://www.minerals.dmitre.sa.gov.au/sarighelp/home>.

Senior A and Skirrow R (2013) Australian mineral exploration review 2012. Geoscience Australia, Canberra. Viewed 10 September 2014, < http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_d2d39b81-7b5e-3761-e044-00144fdd4fa6/Australian+Mineral+Exploration+-+A+Review+of+Exploration+for+the+Year+2012>.

SPE, AAPG, WPC, SPEE and SEG (2011) Guidelines for application of the Petroleum Resources Management System. Society of Petroleum Engineers, American Association of Petroleum Geologists, World Petroleum Council, Society of Petroleum Evaluation Engineers, and Society of Exploration Geophysicists. Viewed 12 June 2014, <http://www.spe.org/industry/reserves.php>.

Victorian DSDBI (2014) Geovic. Victorian Department of State Development, Business and Innovation. [Digital datasets]. Viewed 3 February 2014, <http://www.energyandresources.vic.gov.au/earth-resources/exploration-and-mining/tools-and-resources/geovic>.

Victorian DTPLI (2014) Website homepage for Environmental Assessment Planning in Victoria. Victorian Department of Transport, Planning and Local Infrastructure. Viewed 5 February 2014, <http://www.dpcd.vic.gov.au/planning/environment-assessment>.

Wood GH, Kehn TM, Devereux Carter M, and Culbertson WC (1983) Coal resource classification system of the U.S. Geological Survey. Geological Survey Circular 891, Denver. Viewed 26 August 2014, <http://pubs.usgs.gov/circ/1983/0891/report.pdf>.

Appendix A Overview of Australia's coal and coal seam gas resources

Australia is well-endowed in resources of both black and brown coal (Figure 3). The main coal-bearing basins occur in the eastern states of Australia and include the Bowen, Surat and Sydney basins for black coal, and the Gippsland Basin for brown coal. Most of Australia's black coal resources are of Permian or Jurassic age, whereas brown coals are geologically younger and were commonly deposited in either the Paleogene or Neogene (i.e. within the past ~65 million years). The combined tonnage of known coal resources in Australia accounts for approximately 9% of the entire global coal inventory (Geoscience Australia and BREE, 2013). Australia is also a significant international producer and exporter of coal, with total raw coal mined in Australia in 2012 in excess of 500 Mt.

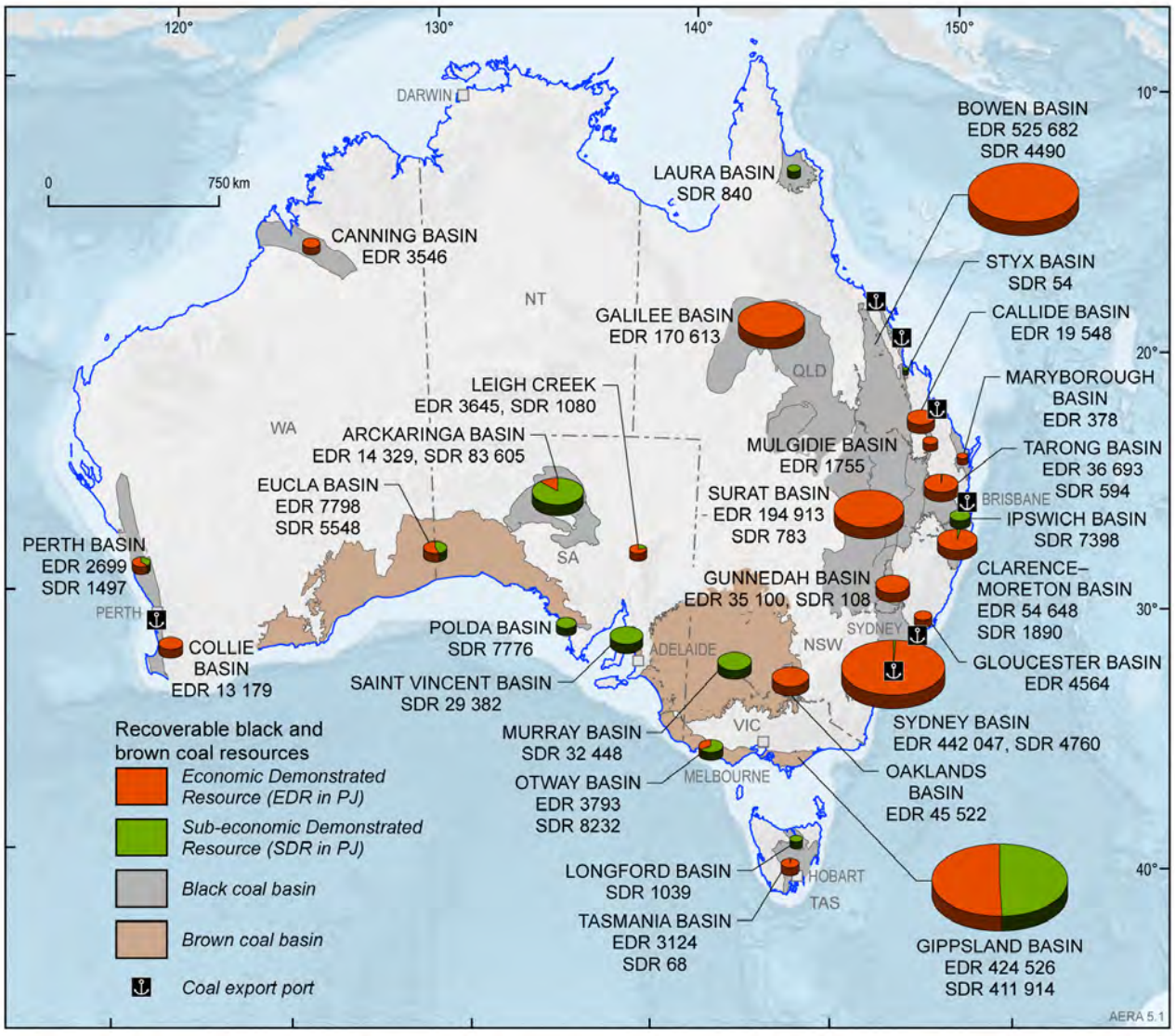

Figure 3 Black and brown coal resources in Australia

Source: Geoscience Australia and ABARE (2010), with updated coal resource figures used from 2013 OZMIN database

Australia's identified coal seam gas (CSG) resources have grown significantly in recent years due to extensive exploration, particularly in Queensland and NSW (Figure 4). In 2012, the economic demonstrated CSG resource amounted to over 35,000 petajoules (PJ).

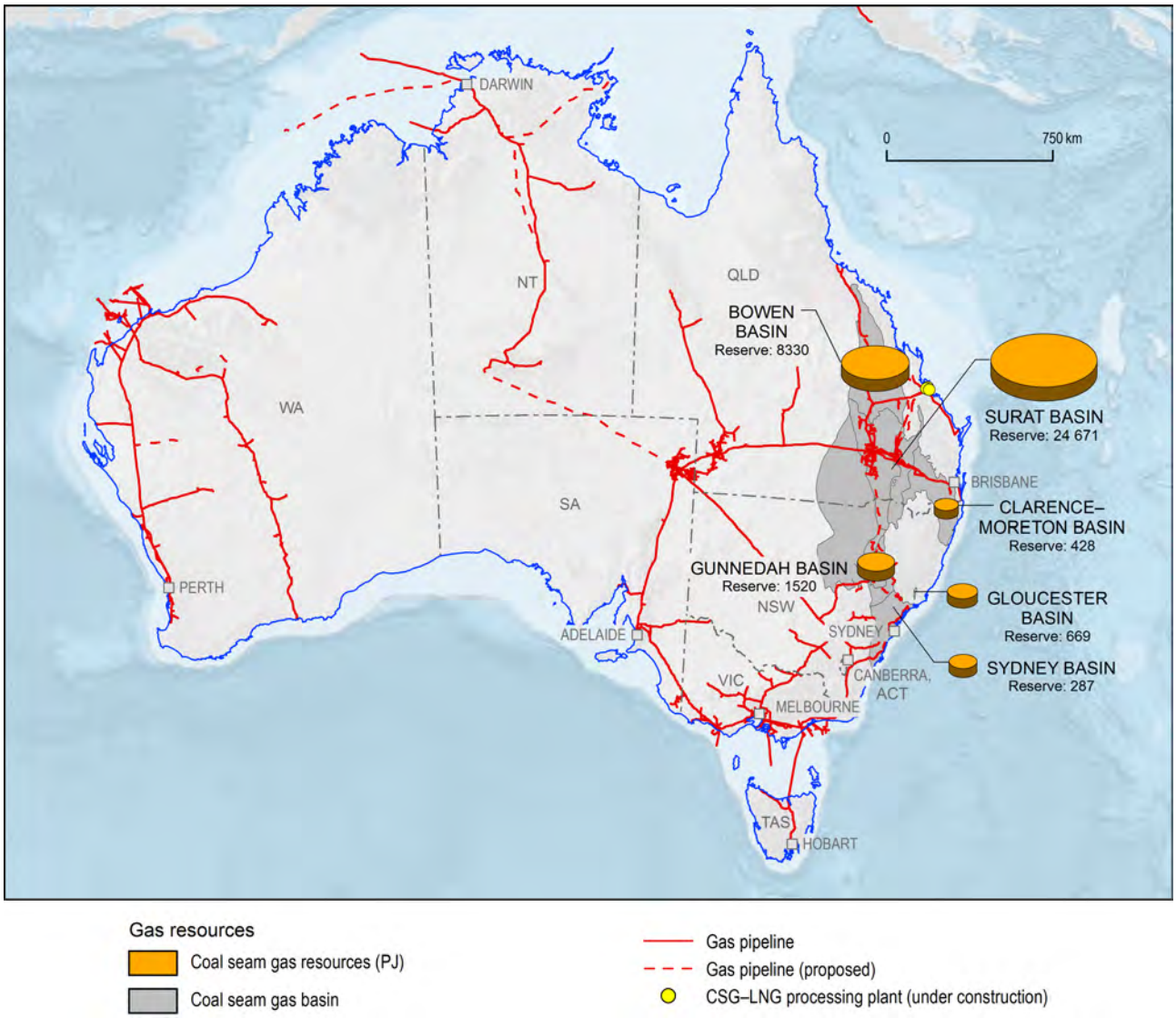

Figure 4 Coal seam gas resources (2012) in Australian sedimentary basins

Source: Geoscience Australia and BREE (2012)

A.1 Classifying coal and coal seam gas resources

The classification of Australia's coal resources is based on the national system for classifying identified mineral resources (Geoscience Australia and BREE, 2013). This classification scheme provides a suitable and readymade framework that is used as the initial basis for helping to determine the coal resource development pathway in each bioregion and subregion. Australia's national classification schemes for both mineral and petroleum resources are largely based on, and compiled from, information reported for individual mineral deposits and petroleum accumulations by resource development companies, although they take a long-term view (20 to 25 year time frame) of the feasibility of economic extraction (Geoscience Australia and BREE,

2012; Geoscience Australia and BREE, 2013). This information is reported by individual resource companies following a set of mandated standards (stipulated by the Australian Securities Exchange (ASX)) for the reporting of mineral and resources data. For mineral resources (which include coal), the reporting guidelines are provided by the Joint Ore Reserves Committee (JORC) Code. For petroleum resources, most companies follow the Society of Petroleum Engineers' Petroleum Resources Management System (SPE-PRMS) (SPE et al., 2011).

Both the JORC Code and the SPE-PRMS system are compatible with the Australian national classification system (both having evolved from the McKelvey resource classification system used in the USA), such that public resource announcements made by companies for individual deposits are compiled by Geoscience Australia and used as the basis for preparing the annual update on the national coal and CSG inventory (Geoscience Australia and BREE, 2013).

The publicly reported data and information are compiled, evaluated and aggregated into the various categories of the national classification scheme to provide a reliable estimate of the national resource base. The national resource classification scheme recognises resources based on the degree of geological assurance of the commodity, coupled with the economic feasibility of extracting the resource (either now or into the future). The former is based on the type, tonnage and grade of the resource, whereas the latter is based on economic considerations such as commodity prices, capital and operating costs, and any applicable discount rates. These concepts are illustrated in Figure 5.

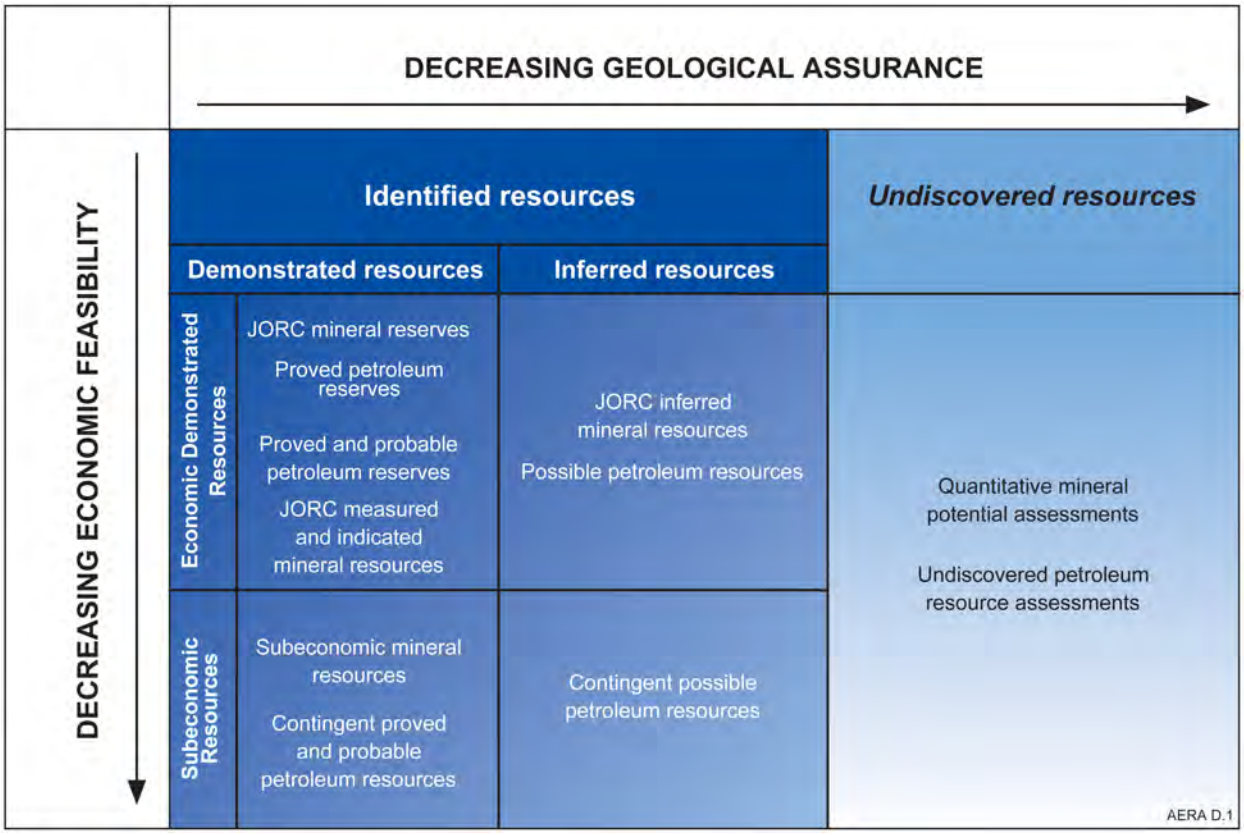

Figure 5 Australia's national classification system for resources, including coal and coal seam gas (petroleum)

Source: Geoscience Australia and BREE (2012)

The Australian resource classification scheme is used as the initial basis for defining the coal resource development pathway in BAs, specifically by determining which resource projects are included in the catalogue of potential coal and CSG resource developments (Section 1.2.4 of companion product 1.2). This provides an appropriate mechanism to align the coal resource development pathway with the existing national coal and CSG resource categories. This approach has the benefit of being based on an independent and widely used national system. Furthermore, it provides the opportunity to broaden the scope of individual deposits and projects assessed in the Programme (in line with recommendations from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development), as it is not contingent on regulatory procedures imposed as part of the EIS (or other regulatory assessment) pathway.

The national inventory category with the highest degree of both geological assurance and economic feasibility is referred to as *economically demonstrated resources* (EDR) (Figure 5). This national class combines the JORC categories of 'proved reserves' and 'probable reserves', as well as 'measured resources' and 'indicated resources'. Consequently, EDR is considered to provide a valid and objective estimate of the coal resources that will likely be mined in the long term (usually taken as the time frame within the next 20 to 25 years following publication) (Geoscience Australia and BREE, 2013). It is expected that, in most bioregions and subregions, resource projects with an EDR will be included in the coal resource development pathway. In comparison, it is likely that only a subset of the subeconomic and inferred resources within each bioregion or subregion will be considered sufficiently well understood (and likely to be developed in future) to be included in the coal resource development pathway.

Appendix B Coal and coal seam gas resource definitions for bioregional assessments

B.1 Coal

Coal is a combustible sedimentary rock of organic origin. It forms by the accumulation of ancient vegetation that is altered over geological timescales (millions of years) by microbial decay and the variable effects of temperature and pressure due to burial (Figure 6).

Layers of coal are consolidated and altered between other rock strata, such as sandstone and shale, in a process known as *coalification*. Individual layers of coal can range in thickness from millimetres to tens of metres. There is significant natural diversity in coal parameters such as type, rank and grade (discussed further below), which mainly reflects variations in the way in which coal is formed, such as different precursor vegetation types and variations in post-depositional heat and pressure.

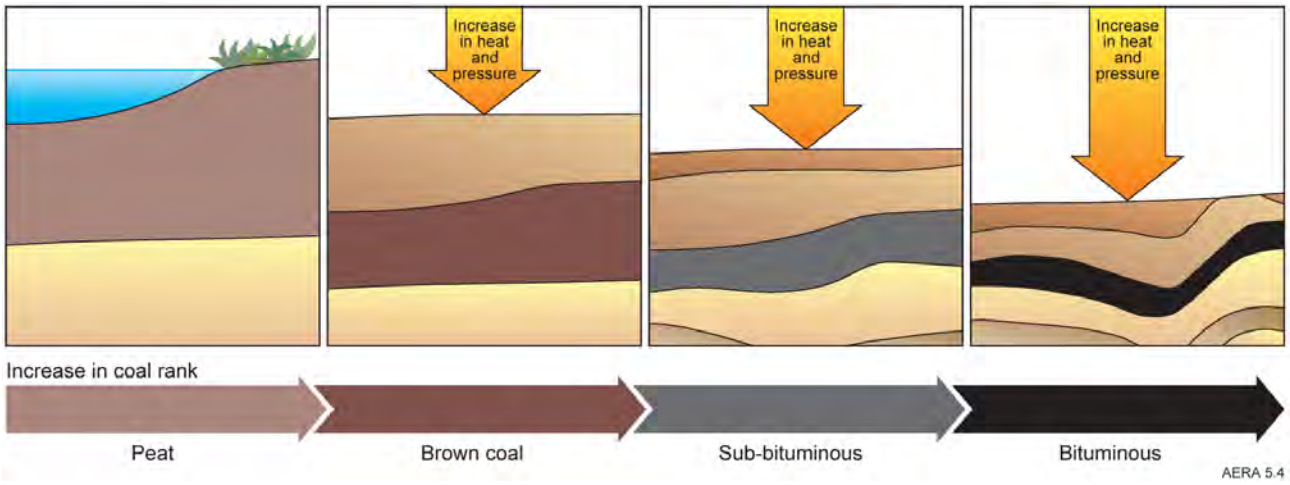

Figure 6 Transformation of peat into brown and black coal

Source: Geoscience Australia and ABARE (2010)

Coal consists mainly of carbon, hydrogen and oxygen, with minor amounts of nitrogen, sulfur and other elements. It also contains a variable percentage of water and inorganic minerals. In Australia, black coal (so-called because of its colour) refers to anthracite, bituminous and sub-bituminous coals (Table 10). This basic terminology has also been adopted for the BAs. Coal varies from a relatively bright and shiny rock, to a dull one and may be hard or soft (Geoscience Australia and BREE, 2013). Brown coal (or lignite) is lower in rank than black coal (Figure 3), contains more moisture and produces less energy during combustion.

Table 10 Coal rank classification terminology used in Australia and Europe

Coal rank	Australian term	European term
Lignite	Brown coal	Brown coal
Sub-bituminous coal	Black coal	Brown coal
Bituminous coal	Black coal	Black coal
Anthracite	Black coal	Black coal

Coal has long been used by people, initially to generate heat when burnt and, in more recent times, as feedstock for electricity generation and for various industrial applications. Coal currently provides the major energy source for Australia, accounting for about 60% of national electricity production (Geoscience Australia and BREE, 2013). Two common terms used to characterise black coal are thermal coal and coking coal. *Thermal coal* is black coal used to generate electricity in coal-fired power stations, where coal is pulverised and burnt to generate steam in large boilers. *Coking coal* is black coal used to make coke, a porous solid compound of carbon and ash used in blast furnaces to make various iron-based products. Due to their relative scarcity (as they must be relatively free of impurities such as sulfur), coking coals are sold at higher prices than thermal coals.

B.1.1 Coal type

Coal type relates to the depositional origin of coal at the time it initially began to accumulate and the resulting mix of organic components (macerals) and inorganic minerals (O'Keefe et al., 2013). Coal type is independent of rank and is expressed as the maceral composition of the coal. There are broadly two different types of coal: *humic coal* and *sapropelic coal*. Humic coals develop from woody or reedy vegetation that originally accumulates as peat and undergoes transformation to coal in relatively moist and aerobic conditions, for example, within a peat bog (O'Keefe et al., 2013). In contrast, sapropelic coals are formed from non-woody organic sources, such as algal and spore fragments, which decay within stagnant, anaerobic environments. These typically develop as organic-rich muds. Within these two main coal types, further subdivisions are possible based on maceral compositions and depositional environments (see O'Keefe et al. (2013) and references therein for further information).

B.1.2 Coal grade

Grade refers to the amount of inorganic mineral matter that is mixed with the organic components of the coal. Grade is independent of coal type or rank, such that a high-grade coal has a low percentage of inorganic minerals and thus, a high degree of organic matter.

B.1.3 Coal rank

Coal rank refers to the geochemical changes (and the allied changes in reflectance properties) that result from increased thermal maturity of coal. These provide a reflectance overprint on coal type and as the coalification process progresses this may vary the nature of both the organic and

inorganic components (O'Keefe et al., 2013). There are several parameters that can be used to determine or describe coal rank. These include, but are not limited to, percentage of volatile matter, percentage of carbon and calorific content (Figure 7). One of the most useful and widely used parameters is vitrinite reflectance.

Class	Group	Fixed Carbon Limits (Dry, Mineral-Matter-Free Basis) (%)		Volatile Matter Limits (Dry, Mineral-Matter-Free Basis) (%)		Calorific Value Limits (Moist [A], Mineral-Matter-Free Basis) (MJ/kg)		Agglomerating Character
		Equal or greater than	Less than	Greater than	Equal or less than	Equal or greater than	Less than	
Anthracite	Meta-anthracite	98			2			Nonagglomerating
	Anthracite	92	98	2	8			
	Semianthracite [B]	86	92	8	14			
Bituminous	Low volatile bituminous coal	78	86	14	22			Commonly agglomerating [D]
	Medium volatile bituminous coal	69	78	22	31			
	High volatile A bituminous coal		69	31		32.6 [C]		
	High volatile B bituminous coal					30.2 [C]	32.6	
	High volatile C bituminous coal					26.7	30.2	
						24.4	26.7	Agglomerating
Subbituminous	Subbituminous A coal					24.4	26.7	Nonagglomerating
	Subbituminous B coal					22.1	24.4	
	Subbituminous C coal					19.3	22.1	
Lignite	Lignite A					14.7	19.3	
	Lignite B						14.7	

A. Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

B. If agglomerating, classify in low volatile group of the bituminous class.

C. Coals having 69% or more fixed carbon on a dry, mineral-matter-free basis are classified according to fixed carbon, regardless of calorific value.

D. There may be nonagglomerating varieties in these groups of the bituminous class, with notable exceptions in the high volatile C bituminous group.

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Figure 7 Classification of coals by rank

Source: modified after Wood et al. (1983)

B.2 Coal seam gas

Important characteristics of CSG resources that may be available from published accounts of exploration or development include whether the CSG is thermogenic or biogenic, as well as various gas compositional data, gas saturation levels and isotope parameters. The current understanding and knowledge of CSG reservoirs in the bioregion or subregion is useful information to provide as part of reporting in companion product 1.2 (if available). In particular, two key parameters for successful reservoir characterisation are permeability and gas saturation (as a percentage). Permeability determines the gas (and water) flow rates which largely governs the commercial success of a CSG development (Moore, 2012). Gas saturation percentage (which is measured from desorption and adsorption analyses of coals) also influences the flow rates and the overarching rate of recoverability of the gas in the coal reservoir.

Fundamental to the success of any CSG development is ensuring that the coal exists (thickness by area), determining its gas content (and hence sorption pressure via a sorption isotherm), and knowing what the permeability of the seam is now and how that permeability will change if depressurised. The latter point is extremely important as the permeability of coals is greatly

affected by the effective stress (S Cadman (Geoscience Australia), 2013, pers. comm.). Consequently, a summary of this type of CSG-related information is useful to provide in the BA. However, such data may not always exist or be readily available and the level of detail that individual Assessment teams may be able to derive from this type of research will consequently vary.

Appendix C Supply chain of coal and coal seam gas resource development

The commercial production of coal or coal seam gas (CSG) relies on the progression of a series of major stages that combine to form the overall development path for the targeted resource. An overview of the Australian coal supply chain, illustrating the progression from resource exploration and mine development through to stages of processing, transport and end-market use is schematically illustrated in Figure 8. The commercial decision to proceed to the major development stage (final investment decision) is based on a variety of geological, environmental, engineering and regulatory factors that interact to determine the economic viability of the resource development (Figure 8).

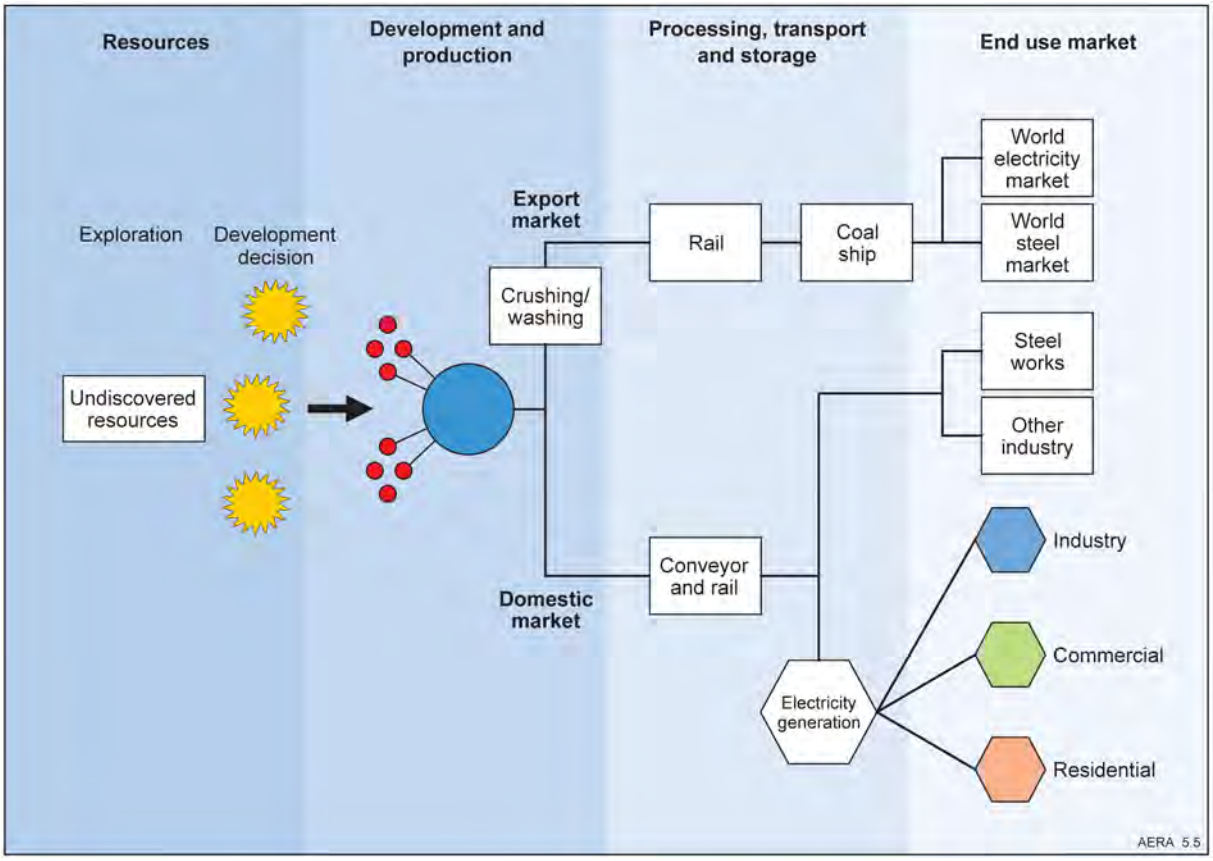

Figure 8 Australia's coal supply chain

Source: Geoscience Australia and ABARE (2010)

Following the guidelines outlined in the 2013 version of Australia's Mineral Resource Assessment (Geoscience Australia and BREE, 2013), these major pathway stages are:

- exploration
- identification of resources

- feasibility studies and construction
- full-scale operational production
- post-production operations (closure, rehabilitation and mine legacy issues).

In BAs, each bioregion or subregion will have a unique coal resource development pathway. This reflects the variability of location, geology, resource characteristics and economic drivers that play an integral part in shaping the manner in which coal and CSG are commercially developed and extracted. In most regions the time frame from initial exploration work to full-scale development is commonly 7 to 10 years (or even more), although this strongly depends on the status of existing critical infrastructure and transportation networks such as railways and pipelines. Within this time, there are likely to be changes made to the future development plans for the resource, for instance, as new information on the tonnage and grade becomes available. Additionally, resource development plans may also be adjusted in response to external factors that may relate to technological, economic, political or environmental forces. Some of these factors are very difficult to accurately predict based on available information.

C.1 Exploration

The exploration, development and mining of coal and CSG resources in Australia are undertaken by various private and publicly listed companies. These companies aim to generate profits through the commercially viable development and sale of the extracted resources. The Australian and state governments, although not actively engaged in the exploration and mining of such commodities, undertake various geoscience programmes to assist and support the development of national resources, such as the provision of pre-competitive geoscience datasets to encourage exploration in prospective greenfield areas (e.g. refer to information about pre-competitive data acquisition on the Geoscience Australia website). In onshore areas the ownership of coal and CSG resources is vested in state governments and companies pay a royalty fee to the government for the right to extract and sell the resource.

Resource exploration is broadly divided into two categories that are related to the proximity of other known deposits (including operating mines) of the same type of commodity. Exploration work undertaken in areas close to existing mines or known deposits is termed *brownfield* exploration. Brownfield exploration aims to grow or sustain existing operations, thereby enhancing the often significant level of investment that has already gone into capitalising production. Exploration costs are usually lower and land access issues are less of a problem. In BAs, an example of an area of brownfield exploration is the Hunter subregion in the Northern Sydney Basin bioregion.

In contrast, *greenfield* exploration occurs in areas remote from known deposits, but which are considered geologically favourable for similar resource types. Exploration risk is commonly much higher in these areas due to the lack of detailed data and knowledge. Greenfield regions are also unlikely to have supporting infrastructure and transportation networks readily available, making initial development investments significantly more expensive compared to regions that have existing resource developments. A relevant BA example of a greenfield exploration area is the Galilee subregion in the Lake Eyre Basin bioregion.

Greenfield resource exploration generally follows several major phases:

- initial data compilation and assessment of existing geoscientific information. This work usually involves desktop assessment of relevant geoscientific datasets to delineate prospective areas that may host the target resource type. Preliminary site visits may also be undertaken by the exploration team to familiarise themselves with field conditions (e.g. terrain, geology, infrastructure) and identify potential issues related to health, safety and environment
- acquisition of new exploration data to identify prospective areas or resource deposits. Exploration work commonly focuses on collecting various types of geological, geophysical and geochemical data. Modern coal and CSG exploration work typically involves considerable geophysical investigations, which may include two-dimensional or three-dimensional seismic reflection surveys to image the subsurface and provide important information on geological structures and strata. Drilling is required to identify and confirm the existence (i.e. discovery) of new resources
- if initial exploration work is successful new resource targets may be identified from drilling results and associated datasets. Further testing and evaluation studies (part of the next stage) are then required to more accurately define the spatial extents of the resource and understand the variability of quantity and quality.

C.2 Identification of resources

Following initial discovery, more detailed investigations are required to define the full extent of the resource and determine the spatial distribution and variability in grade (quality). This more advanced stage of investigation is required to evaluate the economic viability (and profitability) of developing a full-scale mining operation. Identifying the tonnage and grade of the resource and establishing its optimal extraction method involves a comprehensive analysis of the resource geology. Significant investment is needed in drilling during this stage to adequately define the extent of the resource (e.g. for coal, it must be reported in accordance with the guidelines in the Joint Ore Reserves Committee (JORC) Code, Appendix A).

Further information on researching and compiling coal and CSG resource data is discussed in Section 3.2.

C.3 Feasibility studies and construction

The decision to proceed with developing an advanced exploration project (‘greenlighting’ the project) with a defined resource will usually be determined during feasibility studies, which assess in detail a range of factors and are used as basis for deciding to proceed to development and mining phases (Geoscience Australia and BREE, 2013). Coal is mined either by open-cut or underground methods. The choice of mining method is an important decision which is assessed during the feasibility stage and is based on a detailed understanding of the local geology and various geotechnical and engineering considerations. Most coal mines in Australia (about 80%) are open-cut mines, reflecting that much of Australia’s identified coal resources occur at relatively

shallow subsurface depths (commonly less than 200 m below surface) (Geoscience Australia and ABARE, 2010).

Bulk sample trial open-cut developments may also be undertaken as part of the feasibility assessment, prior to the decision to commission a fully operational development. These activities aim to test the geological and mining characteristics of the coal resource in a small-scale extractive operation.

For CSG developments, pilot production wells are drilled following the initial exploration success. These aim to provide (among other things) further information on gas characteristics, groundwater flow rates and other water-related development issues.

This stage may also include development of associated infrastructure that is required to be built for the development to proceed. This may include ore processing facilities and new transportation systems, as well as roads, ancillary buildings and other infrastructure typical of mining operations.

C.4 Full-scale operational production

Modern coal mining techniques are significantly more productive and efficient than those used in the past. Large-scale open-cut mines are developed over many square kilometres and commonly use large draglines to remove overburden, with bucket-wheel excavators used to mine the coal (Geoscience Australia and BREE, 2013).

Many large coal mines can be operational for a significant period of time, with extraction commonly planned to occur over many decades. Thus, in describing the coal resource development pathway, it is important to indicate, where possible, the expected timespan over which operations are projected to occur, so that this information can be incorporated into subsequent modelling stages of BAs. Additional information relevant to describing full-scale operational production includes details of the expected number and extent of mining pits or CSG production wells and if any associated infrastructure or processing facilities are needed. Information on dealing with the by-products of resource extraction, such as mining overburden, must also be taken into account.

In cases where uncertainly is high, this clearly needs to be articulated and the implications for quantitative modelling of water-related impacts needs to be recognised (this is discussed in Section 4.10). Generic development rules, or comparison with similar types of deposits (preferable from the same bioregion or subregion), may need to be formulated in consultation with modelling staff from each Assessment team.

C.5 Post-production operations

Development plans for mining operations will usually also include plans for closing down the mining activities and rehabilitating the site. Contingency plans for any potential post-development legacy issues may also be addressed within these documents. As the potential impacts of coal and CSG resource developments on water-dependent assets may extend far into the future – often well beyond the time of closure of the actual extraction operations – it is important for any

available information on plans for post-mining operations to be documented as part of the information provided in the coal resource development pathway. Although such plans may be changed in the future by the development company (e.g. in response to the impact of unforeseen issues associated with mining, or recognition of new resources), outlining such information in the coal resource development pathway provides an indication of each developer's intentions after operations cease.

Appendix D Useful data sources on coal and coal seam gas resources

D.1 OZMIN

The OZMIN database contains geological and resource information on Australia's mineral deposits, including black and brown coal (Ewers et al., 2002). However, OZMIN does not cover petroleum resources and, consequently, does not contain information about Australia's CSG resources. OZMIN is compiled and updated on a regular basis to ensure that the most current information on national resources is available to the Australian Government. The information is derived from extensive analysis of available published literature and resource announcements (e.g. to the Australian Securities Exchange (ASX)) and is overseen by experienced economic geologists with relevant experience in the different commodities. The OZMIN database only contains information on deposits for reserves or resources that are reported in accordance with the JORC Code (see Appendix A). This means that if the resource estimate has not been JORC Code certified by a competent person (as defined in the JORC Code requirements), then it is not entered in the OZMIN database. The database is also updated on an approximately annual basis, so there may be a delay in incorporating recent resources which have gained JORC certification since the time of the most recent yearly update.

As part of their Bioregional Assessment Programme contribution, Geoscience Australia will assist individual Assessment teams by providing the most current OZMIN resource data and maps available for each bioregion or subregion.

D.2 Register of Australian Mining

The Australian Mining Register is an online database updated daily that provides searchable access to a range of mining-related information such as mines, development projects, exploration and mining companies, and mineral-specific data. The register is compiled and maintained by Resource Information Unit in Perth (RIU, 2014).

D.3 Australian Atlas of Mineral Resources, Mines and Processing Centres

This is an online interactive web mapping tool that allows users to quickly and easily locate mines within an area and also compile datasets using more advanced search criteria (Geoscience Australia, DRET and MCA, 2012). Data can also be downloaded as Excel spreadsheets or Google Earth files for use in other applications, such as geographic information systems (GIS).

D.4 State government online geological mapping and database systems

D.4.1 New South Wales

The NSW government has several online applications that can be used to search for exploration and geoscience data. These systems include Minview (NSW Trade and Investment, 2014a), which allows for online display and query of tenement information and geoscience data, as well as DIGS (NSW Trade and Investment, 2014b), the Digital Imaging Geological Systems, which is a large online database system that contains access to open-file company exploration reports, NSW departmental publications, maps and titles information. DIGS also contains specific records on coal and petroleum exploration, such as company reports, borehole and well-completion data, resource records and other types of relevant geoscientific data.

D.4.2 Queensland

Queensland provides online access to geological and resources information and data via the Interactive Resource and Tenure Maps system (Queensland DNRM, 2014a). In addition, the Queensland Digital Exploration reports (QDEX) system (Queensland DNRM, 2014b) provides online access to exploration company reports, including those for coal and CSG investigations. This system contains all open-file company reports submitted digitally to the Queensland Government since 2004, as well as older reports, which have been scanned and are now available for download.

D.4.3 South Australia

The South Australian Resources Information Geoserver (SA DMITRE, 2014) is an online web application developed by the South Australian Resources and Energy Group in the Department of Manufacturing, Innovation, Trade, Resources and Energy (DMITRE). SARIG provides online access to state-wide geological and geoscientific data including up-to-date tenement details for mineral, petroleum and geothermal companies, mines, advanced exploration projects and mineral deposits, geoscientific data, and various publications, maps and reports including open-file company exploration reports.

D.4.4 Victoria

Victoria's online earth resources web mapping application is called GeoVic (Victorian DSDBI, 2014). Geovic provides access to view and evaluate a variety of Victorian Government datasets, including mineral, petroleum and extractive industries tenements, geophysical survey boundaries and data, borehole and well data, mines and mineral occurrences, as well as geological and interpretive maps and sections at various scales.

Shortened forms

ASX	Australian Securities Exchange
BA	bioregional assessments
CSG	coal seam gas
DAC	Development Assessment Commission
DIGS	Digital Imaging Geological Systems
DMITRE	Department of Manufacturing, Innovation, Trade, Resources and Energy
EDR	economic demonstrated resources
EES	environmental effects statement
EIS	environmental impact statement
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining
IRTM	Interactive Resource and Tenure Maps
JORC	Joint Ore Reserves Committee
Mt	million tonnes
PJ	petajoule
PRMS	Petroleum Resource Management System
RIU	Resource Information Unit
SDR	subeconomic demonstrated resources
SLG	Science Leadership Group
SPE	Society of Petroleum Engineers
SSD	State Significant Developments

www.bioregionalassessments.gov.au

Australian Government
Department of the Environment
Bureau of Meteorology
Geoscience Australia

CSIRO