LOCK THE GATE **ALLIANCE**
AUSTRALIANS WORKING TOGETHER TO PROTECT OUR LAND, WATER, AND FUTURE

Reply to: Georgina Woods
PO Box 290
Newcastle, 2300
by email: georgewoods79@gmail.com

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Submission: Narrabri Gas Project

Thank you for the opportunity to respond to the Environmental Impact Statement for this project.

Lock the Gate Alliance objects to this project and finds the EIS to be riddled with holes and out-dated information. It is not acceptable that a project of this scale and impact should be the subject of an EIS that contains information that is three years old, and in many cases, fails to provide adequate information at all.

This proposal for an 850 well CSG production field near Narrabri is the largest development project that we are aware of ever being assessed under the *Environmental Planning and Assessment Act 1979*. The scale of what is proposed and the impacts that it will inflict are greater than anything previously considered under this legislation.

The area of the project on the surface covers 950km^2. This is three times the size of Penrith council area. It's more than four times the size of the only other two CSG production fields approved in NSW, the Camden gasfield, with 114 wells over 213km^2 and Stage 1 of the Gloucester gas project, approved for 110 wells over 50km^2, which AGL has since announced will not proceed.

We are deeply concerned that the current regulatory settings are not capable of properly weighing up the severity, extent and duration of this project across time and space.

There are serious questions of inter-generational equity that are scarcely touched upon in the EIS for this project that require the serious attention of the NSW Government. The substantial risk of drawdown or contamination of productive aquifers that supply whole communities and industries, the risk of mobilising large volumes of a potent greenhouse gas that once released will not be able to be controlled, the considerable risk of burying in unknown locations large volumes of salt with unknown chemical composition – all of these are burdens this industrial gasfield development proposes to leave for future generations, with profound and irreversible consequences.

The case that such risks and consequences must be taken is not made in the EIS presented by Santos. On the evidence available, even with the extensive inadequacies of the EIS, this project must be refused consent by the NSW Government and measures put in place to protect the recharge areas of the Great Artesian Basin permanently.

Summary of recommendations and objections

Incomplete and inadequate Environmental Impact Statement

- It is not acceptable or possible for adequate assessment of this gasfield to be undertaken without a spatial layout of the infrastructure being provided. This is crucial for understanding and describing the air quality, noise, water and biodiversity impacts the gasfield will have.
- The field protocol is not provided, nor described in detail. Those aspects of the field protocol that are described are patently inadequate.
- There are deficiencies in the data collection and analysis in a range of areas, notably groundwater, surface water quality, cultural heritage, migratory methane and fauna surveys.
- The EIS effaces mounting evidence that migratory and fugitive emissions of methane from unconventional gas development in particular have been dramatically under-estimated. We provide for the Department's consideration a recent report on the risk of migratory and fugitive methane emissions from unconventional gas as Appendix B.

Justification and economics

- There is no economic or strategic justification for this project. The economic information provided in Appendix was prepared three years ago. The market and forecast for domestic and international gas has fundamentally changed since that time.
- Santos provides no evidence to support the claim that this project will reduce gas prices on the east coast.
- On the contrary, there is evidence that the high price being demanded for gas in New South Wales now is not going to be alleviated by introducing a high cost low-yield unconventional gasfield that requires a new pipeline to be constructed and is being proposed by the very company at the centre of the current crisis.
- With production costs for this area previously estimated to be comparatively very high, the flow-on economic effects of this development must be rigorously scrutinised.
- The damaging impact that coal seam gas production has had on regional economies in Queensland indicates that this project poses considerable risk to the agricultural enterprises that are currently the economic lifeblood of the Narrabri Shire and surrounding areas. The extent of this risk, from high labour costs and competition to lost or contaminated water is not adequately addressed in the EIS.

Water and waste

- The large volume of water consumption drawdown risk created by this gasfield make it clearly unacceptable in a region that is depended on groundwater for town supplies and agriculture.
- Water loss from the Pilliga Sandstone amounts to nearly three-quarters of the total groundwater moved as a result of this project. The delayed onset of this impact and its excessive duration over many generations presents a significant challenge for NSW public agencies in properly understanding and assessing implications of this gasfield for intergenerational equity. There is no serious attempt to do this in the EIS and that is not acceptable.
- Bringing hundreds of thousands of tonnes of salt to the surface is irresponsible and unacceptable. There is no information provided in the EIS about the final destination of this dangerous waste product.
- There is a basic lack of data on the hydraulic head measurements prior to the development proceeding. This will make any landholder's attempt to secure "make good" actions from Santos next to impossible and is unacceptable.
- The EIS should provide detailed chemical characterisation of produced waters sampled during gas exploration, discussion of potential pathways for contamination and discussion and

assessment of risk and mitigation strategies. The information provided in the EIS lacks detail and critical supporting data commensurate with the significance of the risk.

- In light of the expert water reviews provided by the North West Alliance, we recommend substantial additional work be undertaken by the proponent, given the significance and severity of the risks involved:
    - At least two years of baseline monitoring of the Gunnedah-Oxley Basin hydrostratigraphic units must be conducted, using the Water Monitoring Plan monitoring bores.
    - At least two years of baseline data must be collected for the Great Artesian Basin hydrostratigraphic units, and any spatial gaps must be addressed.
    - A comprehensive baseline water quality testing regime must be conducted for at least two years, across all relevant units, that measures a systematic suite of key parameters and potential contaminants, including methane, hydrogen sulphide and uranium and other radionuclides.
    - The hydraulic conductivity of all apparent aquitards must be thoroughly determined.
    - Field-based techniques must be used to study and authoritatively assess the recharge processes and rates of the Pilliga Sandstone GAB recharge area.
    - An improved numerical model must be used, incorporating all of the above data, and then run to produce a 'worst case scenario' of potential groundwater drawdown.
    - There must be a thorough baseline microbiological characterisation of all relevant water sources.
    - Detailed life-cycle risk assessment and monitoring plans must be provided to detect and isolate contamination from structures storing and transmitting produced water.
    - Chemical assays, analyses and hazard assessments must be provided of waste brine materials
    - Baseline information on the chemical composition of produced water from the target coal seams must be collected.
    - Full disclosure must be provided on exactly where CSG wells will be drilled, and where pipelines for gas and produced water will be constructed.
    - Time-series data must be provided showing any trends in groundwater chemistry/quality through time at individual sites, or any maps showing spatial trends in groundwater quality through the region.
    - The monitoring network recommended by Dr Matthew Currell should be implemented in order to rapidly detect shallow groundwater contamination incidents resulting from produced water spills and leaks in the project area.

Social, air pollution and health

- The air quality impact of this project have not been assessed in accordance with NSW regulation. The $PM_{2.5}$ assessment is missing, and there is no adequate assessment of ozone, methane and other air pollutants known to be released by this industry.
- The social impact assessment is three years old. The gasfield must be assessed against the new social impact assessment guidelines prepared by the Department.
- The EIS claims to include a Health Impact Assessment but does nothing of the sort. There is barely even a literature review of the mounting evidence that unconventional gas has a range of deleterious health impacts associated with it.
- The Environmental Impact Statement is glib about the greenhouse and climate change contribution of gas, particularly unconventional gas and puts New South Wales at significant

risk of opening up large and uncontrolled fugitive emissions of methane directly to the atmosphere. We attach a recent report highlighting this risk for your consideration.

- The unknown quantum of methane migration and fugitive emissions into wells, bores, fractures, soils and the atmosphere presents a profound inter-generational challenge. For handful of short-term jobs, huge volumes of greenhouse gases will be mobilised that will continue affecting Australians for generations to come. There is no serious attempt to address and analyse this impact in the EIS.

Risk & insurance

- The Chief Scientist's Report recommended in 2014 that the Government consider a robust and comprehensive policy of appropriate insurance and environmental risk coverage of the CSG industry to ensure financial protection short and long term, including security deposits, enhancd insurance arrangements and an environmental rehabilitation fund.
- These recommendations have not been implemented and any decision now to approve a production CSG gasfield puts landholders and the public in the invidious position of carrying uncertain and potentially very high risk environmentally and financially.
- In the immediate term, comprehensive environmental insurance can be mandated by current legislative frameworks as conditions of consent and approval under the EP&A Act, the PO Act and the POEO Act and that must be done for this project.
- Beyond the risks to landholders and the statutory framework for rehabilitation securities, the proposal for an environmental rehabilitation fund made by the chief Scientist is similar to the long-term environmental harm mechanism identified as necessary recently by the NSW Audit Office in its review of the adequacy of mining rehabilitation security deposits and to the "future fund" proposed by Narrabri Shire Council to provide funds to deal with major future groundwater harm caused by this gasfield.
- EIS should be revised to address the Secretary's Environmental Assessment Requirement that it assess whether contingency plans are necessary to manage residual risk.
- All relevant Material Safety Datasheets and Operational Plans should be required to be made available by Santos and their agents and sub-contractors to the Department of Planning for publication prior to any project determination.
- MLA Guidelines should be consulted to determine banned chemicals compounds that cannot be used on livestock producing land and/or native habitat that could enter the food chain. Banned chemical compounds that could enter the food chain must be excluded from use in the CSG industry.

Biodiversity

- An industrial gasfield is not an appropriate land use in the nationally significant Pilliga forest.
- Attachment C to this submission is a report prepared for the Northern Inland Council for the Environment on the national significance of the Pilliga. It provide substantial additional information about the biodiversity significance and vulnerability of the area not included in the EIS and raises the concern that the future expanded development of coal seam gas extraction has the capacity to further impact on matters of national environmental significance under the EPBC Act, "and result in extinctions of local populations."
- The ecological impact assessment has failed to accurately or adequately quantify the cumulative impacts many of these species have suffered due to recent clearing for other resource projects in the region.

- The very marginal status of the Koala population in the Pilliga, once one of the largest in New South Wales, is cause for profound concern and hardly rates a mention in the EIS, except as an excuse to fragment, clear and degrade remaining koala habitat in this part of the Pilliga given that they are now, so rare.
- The results of the proponent's surveys indicate that the Koala population in the Pilliga "has declined substantially." This is an issue of profound concern, given the species' vulnerable status. Any koala habitat in the Pilliga being cleared and industrialised given the tenuous status of the entire population, could be hastening its local extinction.

Cultural heritage

- The Pilliga is a hugely significant place for Gomeroi people culturally and spiritually.
- We believe that decisions about the protection and management of Aboriginal cultural heritage should be in the control of Gomeroi people and urge the Department of Planning to ensure that there is free and informed consent by Gomeroi people in decisions about the management of the Pilliga.

Justification and context

Given the very severe and wide-ranging risks associated with introducing coal seam gas production to Narrabri, the purported justification and strategic context for this project will be crucial to the Department's evaluation of it. The decision in February 2014 to declare Narrabri CSG a "strategic energy project" was based on an evaluation of the gas market and its future at that time which has since been superceded. In general, the information presented about justification, gas market context and economics in this Environmental Impact Statement is outdated and meagre, and we urge the Department of Planning to review independent analysis of the gas market and options for demand management into the future that present a wiser and more efficient approach that the high cost-high risk and low-yield coal seam gasfield proposal being put forward with this EIS.

New analysis released in May 2017 shows that the 2018 shortfall predicted in gas supply by the Australian Energy Market Operator in March 2017 effectively vanished just eleven days later in an updated forecast. We append this report *Short-lived Shortfall* as Appendix A. The report found that:

- Increased gas prices are not a result of a shortage but due to gas companies exporting much of their gas.
- Wind and solar PV are cheaper forms of bulk energy than combined cycle gas turbines, and in some cases, the cost even of new-build renewable energy and storage is cheaper than generating electricity at existing gas power stations.
- Storage technologies are now competitive with open cycle gas turbines in providing flexible capacity.

There is severe economic stress being inflicted on New South Wales manufacturing and energy as a result of the gas price hikes that Santos and other companies set out to achieve when they initiated coal seam gas to LNG exports in Queensland. The high price being demanded for gas in New South Wales now is not going to be alleviated by introducing a high cost low-yield unconventional gasfield that requires a new pipeline to be constructed and is being proposed by the very company at the centre of the current crisis. Any assertion that this project will bring down the cost of gas must be rigourously and independently tested by the Government as it is contrary to the evidence now available to us.

The repeated statement in the EIS that "The Narrabri Gas Project can produce sufficient gas to meet up to half of NSW's natural gas demand" is key to the Environmental Impact Statement's case that the risks this project poses to water, health and communities are justified. And yet, this statement is several years old and there is no attempt in the EIS to situate the project in the current context of the east coast gas market and its price and transparency challenges. Domestic demand for gas is falling, as is electricity demand.

The proponent describes how export demand "is effectively 'locked in' by long-term contracts between liquefied natural gas suppliers and their customers," and notes that the volume tied up in these export arrangements exceeds total domestic consumption in eastern Australia. It more than exceeds it. The 1.4 million terajoules cited by the proponent as being exported from Gladstone is more than twice the 581,000 TJ cited as the *total* size of the east coast gas market. According to Geosciences Australia, the amount of gas expected to be produced at Narrabri is 73,000TJ per annum for 25 years.[1]

Santos quotes estimates by Manufacturing Australia in 2013 that the nation-wide manufacturing industry "will be exposed to $29 billion in lost value in the event of significant increases in the price of gas" (3-3). This price rise has already begun and is the direct result of Santos' own CSG to LNG experiment in southern Queensland and was in fact the strategic objective of opening up LNG exports – to raise the price of gas domestically. Similarly, Santos cite NSW Council of Social Services submission highlighting that escalations in utility prices have caused some families to forego other essentials in order to pay utility bills.

There is no debate about this. The cause of rising gas prices has been the onset of LNG exports from Queensland, coupled with the high cost of production and low yield from coal seam gas, such as Santos is now proposing in Narrabri. The chart provided by Santos bears this out. The price of gas in Queensland last year, where CSG has been rolled out, was over $10/GJ, compared to $8/GJ average on the east coast and under $6/GJ in Victoria, where conventional gas is produced.

The demand projections used by Santos in its EIS show gas demand falling in NSW out to 2020 and then increasing again. These forecasts are volatile and unreliable. The graph shows that 24 percent of NSW demand comes from gas fired power stations, forecast to reduce significantly and then start growing again. Santos admit that industrial demand for gas in NSW has declined by 13% since 2010. Again, this is directly attributable to the activities of the proponent and other gas companies in Queensland, over-committing LNG contracts on CSG supply that has been disappointing.

Santos states, "Gas prices in the eastern Australian has market have been increasing in recent years and may rise further due to uncertainty over the development of future gas projects." This is not accurate. Indeed, Santos later contradicts this statement, admitting that gas price rises "occurred when it was announced that the east coast gas market would be opened up, thereby exposing it to international as prices. This linkage, plus the ever increasing cost of exploring and developing more challenging gas deposits has resulted in a significant increase in price and a subsequent reduction in available, uncontracted supply over the last five years" (3-5). As the graph provided demonstrates,

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[1] see Geosciences Australia November 2014 "Upstream Petroleum and Resources Working Group Report to COAG Energy Council on Unconventional Reserves, Resources, Production, Forecasts and Drilling Rates" http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/Unconventional%20Reserves%20Resources%20Production%20Forecasts%20and%20Drilling%20Rates%202014_0.pdf

the gas price was stable and low until the onset of CSG and LNG exports in Queensland. Coal seam gas has raised the price of gas in three ways. Firstly, Santos and other gas companies initiated LNG exports from Gladstone, thereby linking the east coast gas market to the world market and sharply driving up the price. Second, CSG is expensive to produce, the costs are significantly higher than for conventional sources. Estimates by independent consultants put Narrabri CSG as almost the highest cost gas to produce in eastern Australia.[2] Thirdly, CSG is far lower yielding than conventional gas. There are significant losses and uncertainty over flows.

The EIS claims that "Only an increase in supply, especially for projects that are located near domestic demand centres, can assist putting downward pressure on prices." But there is no modelling or data presented to support this assertion and plenty of evidence that it is not the case.

It is fair to say that the Environmental Impact Statements presented by the proponents of the Queensland LNG projects, including Santos, did not accurately predict or describe the economic turmoil now being experienced in the wake of the CSG to LNG experiment. There has been considerable unforeseen economic upheaval. The CSIRO has estimated there has been a loss of 1.3 agriculture jobs for every gas job created. In the aftermath of CSG in Queensland, towns like Chinchilla are struggling just a few short years in, make good agreements are not finalised, companies are going back to regulatory authorities for approval for expansion projects, salt disposal is still not dealt with, offsets not yet finalised.

Field protocol approach

Rather than providing specific information about where Santos intends to place it 850 production wells, the company outlines a "field protocol" for siting wells post-approval, which it says will be amended to reflect conditions of consent.

It is fair to say that the proposed exclusion zones for this protocol barely if at all stem beyond the barest statutory minimum that would be required of Santos anyway. The first eight steps of the process outlined in the Field Development Protocol in Figure 5-1 should all have been undertaken as part of this EIS and subject to the scrutiny and feedback of the public and the agencies with statutory responsibility for the values being degraded by this gasfield.

Specifically, we see no impediment to the following elements being prepared and exhibited to the public and the agencies as part of the EIS process:

- desktop review,
- mapping constraints,
- developing initial conceptual design by overlying the constraints with the gas resource and then setting out optimal placement of infrastructure,
- reviewing the proposed infrastructure locations relative to the ecological sensitivity maps,
- reconciliation of potential disturbance of each development stage against the predicted cumulative disturbance calculations,

[2] see Core Energy's analysis Gas Production and Transmission Costs, prepared for AEMO, February 2015 https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2015/Core--Gas-Production-and-Transmission-Costs.pdf

All of these processes are described as being work that will be done in the future, but all of it is work that can and should have been done and presented in the EIS for the agencies and the public to review and comment on. The EIS presents and outline of a process for environmental assessment and project design, but this is precisely what an EIS is required, by law, in NSW to present.

So, we have the proponent's expectation that this process "will result in the majority of the well pads being located outside of high and moderate high ecological sensitivity classes" but no specific information that allows us to interrogate and review this. This is not acceptable.

The process they outline places "significant" endangered fauna habitat at the bottom of the priority list. The only habitat feature specifically listed and prioritised is hollow bearing trees, prioritised by size class, but other features, like rocky outcrops, soaks, stags are not included.

The last step in Santos' proposed protocol is to prepare and submit a "Plan of Operations" to the Department of Planning and the Federal Department of Environment and Energy. It is unacceptable that the majority of the work to be done to understand the actual impact of this project, its mitigation measures and design in the landscape is set for a future time once a consent is granted.

This Environmental Impact Statement is the public's opportunity to input into the design of the project, understand its impacts and make our views known about the balance of considerations that inform the decision to grant or refuse consent. Santos is locking the public out of this process, seeking to obscure public understanding of the nature of the impact of the gasfield by deferring accurate and detailed designing, assessment and planning of it to a later date, post-approval.

Santos provide a figure (7-1) mapping the ecological sensitivity classes. Though the scale is coarse, it is clear from this map that there are large portions of the proposed project area with areas of high and moderate-high sensitivity in the eastern and southern parts of the proposed project area. Thee high sensitivity areas are not scattered evenly throughout the forest, which would pose a challenge for planning and design, but are concentrated, presenting Santos with the opportunity to avoid putting wells, processes and associated infrastructure in these areas. They have not taken this opportunity.

Water resources

The EIS does deal with the significant risk that this project poses to groundwater and the thriving agricultural industries that rely on it. This risk primarily comes in the form of draw down and loss of water and pressure in productive aquifers, particularly the GAB, and in the risk of groundwater contamination either as a result of surface spills or well failure. Data is available about the rate of well failures leaks and spills and yet this very serious risk is hardly canvassed at all in the EIS.

A number of independent experts have reviewed the ground water and surface water components of the EIS for the North West Alliance. In light of those reviews, we conclude that:

1. The potential impacts on water resources (quality and volume) are very significant and unacceptable, both in terms of aquifer drawdown and contamination
2. The baseline datasets on which the EIS is based are demonstrably inadequate
3. The assessment of risks by Santos is flawed and fails the precautionary principle
4. The proposed project poses a major threat to intergenerational equity and rights to water

We contend that the Narrabri Gas Project represents a serious intergenerational threat to north-west New South Wales, given the short life of coal seam gas operations and the crucial importance of clean and abundant groundwater to agriculture and regional communities.

The major findings by the reviewers are that:

1. The Santos EIS fails to meet the NSW Secretary's Environment Assessment Requirements for the Narrabri Gas Project, because it has not established a groundwater baseline dataset incorporating 'typical temporal and spatial variations'.
2. The numerical groundwater model is not fit for purpose and cannot make reliable predictions of the long-term drawdown to beneficial aquifers due to CSG dewatering.
3. Santos has provided an inadequate and misleading groundwater baseline water quality dataset for formations which are considered very important in protecting GAB high value aquifers.
4. Santos cannot effectively predict the effects of CSG dewatering in the key portion of the GAB recharge area, because they do not have monitoring data representing drought periods.
5. The model is based on inadequate hydraulic properties and very limited data representing the deeper groundwater system (Jurassic, Triassic and upper Permian).
6. The groundwater model fails to provide a 'worst case scenario' showing what may happen to beneficial aquifers if modelling variables, and particularly hydraulic conductivity, are changed.
7. There is no baseline water table dataset against which to measure the Water Monitoring Plan for the Bohena alluvium.
8. The risks associated with waste water contamination are highly significant due to the unusually poor quality of the produced water and the unusually high quality of the shallow groundwater and surface water.
9. The EIS fails to properly acknowledge the outstanding national significance of the Pilliga Sandstone GAB aquifer, or to conduct any field study of recharge processes or rates of recharge
10. Using spill rates recorded in the US, up to 130 spills of wastewater could be expected to occur as a result of the project if 850 wells are drilled.
11. If spillage and leakage of wastewater occurs at rates that are standard for unconventional gas globally, it could threaten the viability of the aquifer as a potable water source as well as the long-term quality of the GAB recharge.
12. The baseline water quality data is demonstrably inadequate, and excludes key contaminant risks such as methane and uranium and other radionuclides, as well as lacking microbiological characterisation.
13. Groundwater quality baseline data does not constitute a rigorous baseline due to low number of bores in each aquifer, inadequate geographical spread
14. The risks of methane contamination are barely canvassed and the risks of spills and leakages on water resources are barely considered in the EIS.

In light of these glaring failures, we recommend that the following further work must be conducted before the Department of Planning and Environment allows Santos to proceed any further in the planning process:

1. At least two years of baseline monitoring of the Gunnedah-Oxley Basin hydrostratigraphic units must be conducted, using the Water Monitoring Plan monitoring bores.
2. At least two years of baseline data must be collected for the Great Artesian Basin hydrostratigraphic units, and any spatial gaps must be addressed.

3. A comprehensive baseline water quality testing regime must be conducted for at least two years, across all relevant units, that measures a systematic suite of key parameters and potential contaminants, including methane, hydrogen sulphide and uranium and other radionuclides.
4. The hydraulic conductivity of all apparent aquitards must be thoroughly determined.
5. Field-based techniques must be used to study and authoritatively assess the recharge processes and rates of the Pilliga Sandstone GAB recharge area.
6. An improved numerical model must be used, incorporating all of the above data, and then run to produce a 'worst case scenario' of potential groundwater drawdown.
7. There must be a thorough baseline microbiological characterisation of all relevant water sources.
8. Detailed life-cycle risk assessment and monitoring plans must be provided to detect and isolate contamination from structures storing and transmitting produced water.
9. Chemical assays, analyses and hazard assessments must be provided of waste brine materials
10. Baseline information on the chemical composition of produced water from the target coal seams must be collected.
11. Full disclosure must be provided on exactly where CSG wells will be drilled, and where pipelines for gas and produced water will be constructed.
12. Time-series data must be provided showing any trends in groundwater chemistry/quality through time at individual sites, or any maps showing spatial trends in groundwater quality through the region.
13. The monitoring network recommended by Dr Matthew Currell should be implemented in order to rapidly detect shallow groundwater contamination incidents resulting from produced water spills and leaks in the project area

Despite the demonstrable weaknesses of the Santos modelling, it still acknowledges that CSG extraction will induce flow from the Pilliga Sandstone GAB recharge and the Namoi alluvial aquifer to the coal seams below. It states that "ultimately, 37.5 gigalitres of water extracted for the project must be replenished by downward flows from overlying water sources." (11-48)

In all, the EIS shows that nearly three quarters of the 38.5 billion litres of groundwater that will be removed as a result of this project will be coming from the Great Artesian Basin. Under the high case scenario of water usage "induced storage release" from the GAB southern recharge is 120ML in the peak years 180-200 (see Table 6-25 Appendix F Part 1). In total, the high case scenario would see 65GL removed from the GAB.

Even the flawed Santos' EIS demonstrates that loss of water from the Pilliga Sandstone will occur long into the future after the gasfield has ceased operation.

The chapter on groundwater says "the project would require the extraction of approximately 37.5 gigalitres of groundwater from the Gunnedah-Oxley Basin Groundwater Source over 25 years, which is an average extraction rate of 1.5 gigalitres per year from deep groundwater sources that are hydrologically disconnected from the Namoi Alluvium." This is not accurate and is contradicted by the groundwater impact assessment provided as an appendix which clearly shows that the water removed from the Gunnedah Oxley Basin coal seams will be replenish with water from the overlying aquifers, including the Pilliga Sandstone and the Namoi alluvium.

Santos' core contention is that the loss of water from the overlying strata takes place over such a long time that it will not affect other users or groundwater dependent ecosystems. But this contention is based on the input of modelling parameters that do not present the "worst case" scenario. If hydraulic conductivity between the coal seams and the overlying strata is greater than Santos estimate (without having data to inform their estimate) then the impact on the GAB and the alluvium could be faster and greater than predicted in the modelling. The risk that this might be the case is real and should have been addressed by Santos with additional model runs with varying parameters. The importance of these water sources cannot be overstated and a highly precautionary approach with the best data that can be obtained is called for. Santos

We note the impacts that are predicted on the highly productive aquifers are not expected to occur for more than 100 years. This means that all the risk is shifted away from Santos and on to future water users and the public. The time to reach the maximum drawdown of the Pilliga Sandstone is 200 years in the high case and 325 years in the base case (Groundwater Chapter 11-47). The impact assessment states that "Extraction of water from deep coal seams in the Gunnedah-Oxley Basin is likely to result in depressurisation and drawdown of hydraulic head that will span hundreds to several thousands of years" (Appendix F). The impact of this gasfield in spatial and temporal scale is such that the current legislative framework will struggle to deal with it. Proper and sober consideration of the risks it poses are a matter of intergenerational equity and we do not believe that Santos has been sufficiently precautionary in its assessment.

Nearly three quarters of the 38.5 billion litres of groundwater that will be removed as a result of this project will be coming from the Great Artesian Basin. That seems tiny compared to the overall size of the Basin, but the impacts will be occurring for centuries after Santos has finished removing the gas, so who will be around to rectifying the loss of pressure and water availability that might ensue?

The potential cumulative impacts have not been considered. Santos modelled only the "base case" in conjunction with the adjacent Narrabri coal mine and in that model, draw down of the Pilliga Sandstone was 1.8m and occurs in 50 years. This raises the possibility that the "high case" impact cumulatively with the Narrabri coal mine could exceed 2m draw down in the medium term. If the hydraulic connectivity parameter is underestimated and the high case of water removal eventuates, what will be the draw down effect on the Pilliga Sandstone?

No assessment of the impact of the project on bores and Santos' language is non-committal throughout. Section 7.6 of Appendix F Part 1 refers to make good provisions "that *may* be followed" (our emphasis) and these appear to only be on the table for "unanticipated consequences" The anticipated consequences for existing users bores do not appear to be outlined in the report. In the event of these unanticipated consequences, the groundwater assessment says, "Santos *may* undertaken an assessment of the bore to determine the extent to which the bore is impaired and the likelihood that the impairment has been caused by the activities of the project. If impairment of the bore is shown to be an impact of the project, Santos may enter into a make good agreement with the bore owner…" (Appendix F Part 1 7-18)

Without baseline data being collected now to establish the water and pressure levels in the bores that use the aquifers that may be affected, the commitment to make good is meaningless. Landholders will have to spend considerable time and money demonstrating that the gasfield is responsible for the water they have lost and Santos will contest their assertions and hire experts to refute them.

The EIS proposes that Santos be allowed to undertake "Managed release of treated water to Bohena Creek when the flow in the creek equals or exceeds 100ML per day." This raises the question that capacity to hold water at the site and transport it might not be sufficient. If stream flow does not reach 100ML per day, but the site has excess water to deal with, what will Santos do?

Santos proposes that the Leewood water treatment plant will have a maximum design capacity of 14ML per day at the peak of the produced water volumes, which is 50% more than expected by the modelling, presumably the base case. But it is expected produced water volumes to peak at 10ML per day 2-4 years in. If the 10ML per day is the peak of the base case, then Santos need to ensure that there is sufficient capacity to handle the high case scenario daily water peak as well. They are bringing low-quality water to the surface in an area known to provide recharge for high quality Great Artesian Basin aquifers. The risk of contamination of highly productive groundwater by way of surface spills and leaks, accident or intended discharge to waterways or well failure is not given serious consideration.

The salinity of this water 14,000 micro siemens per centimetre on *average*. Very little other information is provided about the chemical make-up of the produced water that will be brought to the surface. Given that Santos has been exploring for gas in the area, they should be able to provide the agencies and the public with a chemical analysis of the coal seam water.

There are huge volumes of salt expected to be produced by the water treatment plant. It is unclear what volume of this is intended to be stored on site at any one time. It is also unclear what the final destination of this salt will be. Santos says it will be "disposed off-site to a licenced landfill" but provides no evidence there is a landfill facility with the capacity and willingness to take these volumes of salt.

One of the greatest risks of the proposed Narrabri Gas Project is that it may lead to contamination of groundwater resources.

An expert review by Dr Matthew Currell, who is a Senior Lecturer in hydrogeology, geochemistry and groundwater modelling at RMIT, has identified glaring weaknesses in the Santos EIS assessment of water impacts.

Groundwater contamination risk identified by Matthew Currell

As Dr Matthew Currell points out in his review of the EIS, which is provided by the North West Alliance as part of its submission, Santos falsely states in the Executive Summary of the EIS that the project is "not located in a major recharge area for the Great Artesian Basin." However, Currell notes on the contrary that there is strong evidence included elsewhere in the EIS that is, "consistent with parts of the project area being a significant recharge area" for the Pilliga Sandstone which is a recognised Great Artesian Basin aquifer.

He notes that, "the project areas is one of the few major areas where the Pilliga Sandstone (a GAB aquifer) is exposed at the surface, and that previous studies of the Great Artesian Basin (E.g. Habermahl et al, 1997; Brownbill, 2000; Herczeg et al, 2008; Ransley and Smerdon, 2012), map the area as a region of recharge and subsequent north-westerly groundwater flow to the wider Great Artesian Basin." He also cites further evidence provided by the unusual freshness of the water, particularly in relation to the low chloride concentration, and the presence of "rejected recharge springs" occurring nearby which are both recognised indicators of high recharge rates.

Currell also notes that elsewhere in the EIS, (Figure 11-3 of Chapter 11 and Table 2-2 of Appendix G3) it is noted that the Pilliga Sandstone "represents a GAB recharge bed."

Not only has Santos incorrectly claimed that the site is not a major recharge area for the Great Artesian Basin, but it has dramatically under-estimated the likely recharge rate for the Pilliga Sandstone aquifer in the project area and its significance. Currell derives an estimate of recharge volume to the Pilliga Sandstone using available data and concludes that, “This is a significant recharge volume, and higher than most of the Australian continent (see Herczeg, 2011 p.52) and most of the Great Artesian Basin (e.g., Ransley and Smerdon, 2012).”

He also notes that: “The restricted geographic areas where aquifer units are exposed at the surface and where direct groundwater recharge occurs are the hydrogeological equivalent to the ‘headwaters’ of a river catchment. In a recharge area, any impact to groundwater quality (e.g. due to CSG wastewater spills or leaks) will in the long term affect groundwater further down-gradient in the aquifer– in the case of the Narrabri Gas Project area, this means the GAB aquifers to the northwest of the project.”

Currell goes on to conclude that, “groundwater is of an unusually high quality in the Pilliga Sandstone” and that “most shallow aquifers on the Australian continent do not contain water so fresh and suitable for potable use.” We agree with Dr Currell’s conclusion that the importance of the Pilliga Sandstone as a recharge area means that it warrants additional protection, and urge the NSW government to make the area an exclusion zone for coal seam gas.

In contrast to Santos who have attempted to dismiss water risks, after reviewing the available information, Currell has concluded that: “Using … spill rates, which are based on tens of thousands of wells across the U.S., something on the order of 15 to 130 spills of wastewater could be expected to occur in association with the Narrabri Gas Project, if the planned 850 wells are drilled.” Currell notes that the quality of the waste water that is produced from extracting gas from the deep coal seams is particularly low in the project area. He concludes that: “If spillage/leakage of wastewater occurs at rates that are standard for unconventional gas around the world (e.g. Patterson et al, 2017, see section 1.2) this could have a significant material impact on the quality of groundwater in the area, and threaten the viability of the aquifer as a potable water source, as wells as the long-term quality of the groundwater recharge entering the Pilliga sandstone.”

Currell notes that contamination of shallow aquifers with stray gas has occurred in a number of areas in the US and that “most instances of fugitive gas contamination impacting shallow groundwater due to unconventional gas have to date taken place due to problems with the casing and cementing of gas and/or water wells…..”

He notes that “abandoned (legacy) wells are another possible conduit for cross-contamination of aquifers with fugitive methane.” He also identifies substantial risks from faults in gas wells, citing data ‘showing that between 3 and 6% of wells in the Marcellus Shale in Pennsylvania (a highly developed shale gas resource in the United States) experienced failures within the first 3 years of operation” and recognising that “well failures and faults will be likely to occur at some stage.”

Currell identifies numerous flaws in the baseline data and monitoring program provided by Santos, which has resulted in inadequate characterisation and poor knowledge of current water quality and thus a very limited ability to detect contamination. The most notable weaknesses are:

- The lack of any further study of recharge processes and rates of the Pilliga Sandstone using field-based techniques
- The failure to provide detailed chemical assays, analyses and hazard assessment of the brine material
- The failure to include detailed life-cycle risk assessment and monitoring plans to detect and isolate contamination from structures storing and transmitting produced water
- Monitoring network unlikely to be adequate in order to rapidly detect shallow groundwater contamination incidents resulting from produced water spills and leaks in the project area

- Groundwater quality baseline data does not constitute a rigorous baseline due to low number of bores in each aquifer, inadequate geographical spread
- Groundwater quality baseline data analysis provides inadequate number of parameters and constituents (ie missing redox potential, and some of the most likely contaminants including dissolved methane, hydrogen sulfide and uranium and other radionuclides)
- A lack of time-series data showing any trends in groundwater chemistry/quality through time at individual sites, or any maps showing spatial trends in groundwater quality through the region
- A lack of any reported baseline information on the chemical composition of produced water from the target coal seams
- A lack of microbiological characterisation of the groundwater and produced water.
- Lack of an indication of where exactly the CSG wells will be drilled, and where pipelines for gas and produced water will be constructed.

Groundwater impact assessment inadequacies identified by Andrea Broughton

In addition to the points outlined above, we would draw the Department's attention to the inadequacies of the groundwater impact assessment identified by Andrea Broughton, whose review is provided by the North West Alliance with its submission. Broughton identifies very serious inadequacies in the baseline groundwater data and conceptual model. She states that the "numerical model is not fit for purpose" and that "long-term predictions of drawdown effects due to CSG dewatering cannot be made reliably." She concludes that the Santos EIS fails to meet the NSW Secretary's Environment Assessment Requirements for the Narrabri Gas Project, because it has not established a groundwater baseline dataset incorporating "typical temporal and spatial variations."

She also raises questions as to whether the EIS meets the Commonwealth Governments *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources,* due to the absence of statistically significant baseline data which characterises the hydraulic nature and quality of groundwater over time and space for each hydrostratigraphic unit.

Santos have failed to properly measure the transmissivity of key geological formations which they are claiming are aquitards that will act to limit the drawdown on beneficial aquifers of the Great Artesian Basin, the Namoi Alluvium and the Bohena Alluvium. According to Broughton, critical information is missing with regard to the ability or inability of key hydrostratigraphic units to transmit, store and yield groundwater. Specifically, baseline data for the following key aquitards is considered to be inadequate:

- Gunnedah-Oxley Basin (GOB) Permian aged Upper Maules Creek, Porcupine and Watermark Formations,
- Gunnedah-Oxley Basin Triassic aged Digby and Basal Napperby Shale Formations, and
- Great Artesian Basin (GAB) Jurassic Purlawaugh Formation.

Broughton notes that, "the baseline dataset is not statistically viable (which would require at least 6 samples per bore). Given the importance of understanding the baseline water level and water quality of these aquitards, they are not sufficiently represented in the Narrabri Gas Field dataset."

Broughton provides the following points about the weaknesses of the baseline datasets:

- Gunnedah-Oxley Basin baseline datasets are lacking temporal and spatial data for key HSUs.

- The Black Jack and Napperby Formations include aquifers and aquitards. However, the strata in which the baseline monitoring bore is screened has not been identified, and therefore this does not allow for a meaningful baseline hydraulic head dataset.
- Variation in hydraulic head conditions in the five Santos bores located in the Gunnedah-Oxley Basin HSUs are temporally limited (one year) and therefore do not give representative baseline conditions in these deep hydrostratigraphic units especially since these units experience lag effects measured in years.

Broughton considers that the water monitoring network proposed for the Gunnedah-Oxley Basin should have been in place for the Water Baseline Report. She notes there are only two baseline water quality monitoring datasets provided for the GOB, and groundwater pressure has only been monitored for one year. She concludes that "Santos has provided an inadequate and misleading groundwater baseline water quality dataset for formations which are considered to be very important in protecting the GAB high value aquifers. In my opinion, at least two years of baseline monitoring, aiming for a temporally representative dataset, should occur using the WMP monitoring bores before the Santos EIS can be considered adequate and the NGP approved."

Broughton also contends that there is inadequate data for the GAB units: "Great Artesian Basin hydrostratigraphic units are well represented spatially, but not temporally, for the Pilliga Sandstone, Orallo and Mooga Formations which are part of the Keelindi Beds." She explains that, "The Santos bores in the Jurassic hydrostratigraphic units lack temporal coverage within the NGP. Only two bores have at least two years of data with the remaining having 1 to 1.5 years of data. This is not sufficient to form a temporally representative baseline dataset as these formations have lag periods measured in years." Since the effect of drought could take more than a year to manifest, she concludes that the effects of CSG dewatering this portion of the GAB recharge cannot be effectively predicted.

Aquitard groundwater chemistry can provide important datasets showing how leaky the aquitard can be perceived, however the data provided in the baseline dataset is inadequate for the key 'aquitards' which Santos rely on to control the extent of drawdown on beneficial aquifers. Broughton notes that, "The Great Artesian Basin Purlawaugh Formation leaky aquitard chemical characteristics are not statistically viable and have become hidden as a result of the incorrect incorporation of its dataset into the Permo-Triassic HSU dataset, which is also not representative."

She also notes that "Although the Purlawaugh Formation aquitard dataset is not statistically viable there is evidence that it has relatively low EC (at least an order of magnitude than the underlying Triassic aquitards) which indicates it may be able to transmit water more easily than is reflected in the conceptual model."

Lastly, she notes that ANZECC guidelines (200) require that there should have been an assessment of organic compounds, such as methane, and failure to capture methane concentration measurements means that it will not be possible to track whether methane migration/contamination of aquifers is occurring.

Broughton identifies very serious inadequacies in the conceptual model, concluding that the 'numerical model is not fit for purpose' and that 'long-term predictions of drawdown effects due to CSG dewatering cannot be made reliably'. This is the result of using the lowest model confidence level classification (Level 1) and the limited spatial and temporal data on which it relies.

She states that: "In my opinion, hydrogeological properties, and in particular vertical hydraulic conductivity (Kv), of the Triassic Digby and basal Napperby Shale and early Jurassic Purlawaugh Formation aquitards are not adequately represented in the conceptual model." She contends that

Santos should have measured the Kv of the critical units (Purlawaugh Formation, Basal Napperby Shales, Digby Formation, Watermark-Porcupine-Upper Maules Ck Formations), which are relied upon to protect the Pilliga Sandstone and alluvial aquifers, rather than using generic values.

She also notes that:

1. The model is calibrated only for steady state flow in the Namoi alluvial aquifer and not for transient state flow.
2. The predictive model time frame far exceeds that of calibration time based on the transient data period.
3. The model is based on inadequate hydraulic properties and very limited data representing the deeper groundwater system (Jurassic, Triassic and upper Permian).
4. CDM Smith did not undertake a Monte Carlo assessment to see what potential outcomes could occur with a range of hydraulic conditions and scenarios.
5. Given that CDM Smith state the aquitards are critically important, serving to physically dampen drawdown effects and temporally retard the pumping production water from the Permian coal seam measures, in my opinion, the predictive modelling is not entirely appropriate.

Broughton also finds that, “The Bohena alluvium has no baseline water table dataset to measure the Water Monitoring Plan against.” She also notes that there is a discrepancy in the baseline water quality data for the Bohena alluvium as to whether it was collected over three months or two years. The Bohena alluvium is an important beneficial aquifer in areas where the Namoi alluvium is absent. Broughton concludes that the shallow Bohena Alluvium is not adequately represented by baseline data “in the eastern portion of the NGP where leakages and spillages can occur from the Leewood Water Treatment Plant, brine ponds, irrigation fields, and pipeline infrastructure.”

She also considers that the Water Monitoring Plan bores for the Bohena alluvium are inadequate, and recommends that an additional four bores are established – two to the northwest of the Leewood Water Treatment Facility and two to the north-east.

Other specific issues raised by Broughton that need to be addressed by the Department include: The EIS does not specify which subsystem of the Namoi alluvium the bores are screened in.

1. Only two bores represent the crucial basal Jurassic Purlawaugh Formation ‘aquitard’, with one collecting data for just one year.
2. There is no baseline data given for the Orallo Formation in the Bibblewindi Field area. This is significant because it is expected to protect the Upper Pilliga Sandstone from lower quality water which may be present in the Bohena Alluvial aquifer due to past contamination events.
3. Santos has not used a bore to provide baseline data for the Napperby Formation (Napperby Shale beds).
4. The water quality dataset for Bohena Creek should have been be split into continuous flow and ceased flow datasets.
5. Failure to measure two nested bore sites concurrently has resulted in failure to get baseline groundwater head dataset for the Permo-Triassic-Jurassic HSUs.
6. CDM Smith state that water level impacts of gas extraction would be ‘Not Measurable’, which does not reflect predictions in the drawdown identified by the GIA.
7. CDM Smith also state that ‘changes to groundwater-surface water interactions’ would be ‘Not Measurable’, which is contested.
8. CDM Smith fail to consider the impacts of un-managed leaks from ponds and pipelines.

9. There is a discrepancy as to whether Santos' nested bore BWD28 is a Level 1 or Level 2 monitoring bore (it is a Level 1 bore in Figure 3-5 but a Level 2 bore in Table 3-5). In my view, it should be a Level 1 bore.

Climate change and energy

The Environmental Impact Statement is glib about the greenhouse and climate change contribution of gas, particularly unconventional gas and puts New South Wales at significant risk of opening up large and uncontrolled fugitive emissions of methane directly to the atmosphere.

The statement that, "Gas has an important role to play, not only in the future economic success of NSW, but also in enabling NSW and Australia to meet its international climate change commitments" (3-4) effaces mounting evidence that the fugitive emissions of unconventional gas in particular have been dramatically under-estimated. We provide for the Department's consideration a recent report on the risk of migratory and fugitive methane emissions from unconventional gas as Appendix B.

This report, from Melbourne Energy Institute, explores the risks of methane gases from a coal seam migrating to the surface as a result of coal seam dewatering and depressurisation for coal seam gas production. It identifies that such migratory emissions are a potentially significant source of greenhouse gases from coal seam gas extraction, but concludes that there is very limited data available to assess the full scale of the risk. It hypothesises that in the Surat Basin, dewatering and depressurisation of the Walloon coal measure for CSG extraction, together with continued agricultural water extraction from the Condamine alluvium, could enhance methane gas flow. It finds that migration of methane along existing natural faults and fractures is possible and may increase with continued depressurisation by coal seam gas mining. It notes that presence of free methane in water bores can be the direct consequence of depressurisation of the coal seams. It finds that due to a lack available data the likelihood of migratory emissions occurring as a result of gas extraction is difficult to assess, and highlights that to date the presence or scale of such emissions has been completely un-measured.

All of these risks are substantial and very difficult to mitigate, once unconventional gas drilling has been allowed to proceed. The EIS's comparison between the cost and scale of storage technologies and gas as an energy option is glib and out of date.

We urge the Department to review these claims in context, with an eye to the rapidly falling costs of renewable energy and storage and the significant uncertainties about the greenhouse gas profile of unconventional gas.

Social impacts and health

The social impact assessment provided in the Environmental Impact Statement is not adequate. Insufficient time has been spent directly consulting with people in the affected area and surrounding districts, including local Indigenous people. Table 6 of Appendix T1 indicates that it has been three years since Santos' consultants engaged with stakeholders for the preparation of the SIA. This considerable amount of time could have been spent conducting genuine data collection, consultation and analysis of the social impacts of this project, which are already occurring, but Santos have chosen instead to present meagre and out of date information.

The social impact assessment is out of date and should be revised to reflect the new social impact assessment guidelines prepared by the Department of Planning. Specifically, the role of the Pilliga and Yarrie Lake in the lives of people from Narrabri and Coonabarabran and the effect that degradation of the forest by an industrial gasfield will have is not addressed. The EIS anticipates that the “diffuse nature of the gasfield” would mean less impact on recreational enjoyment of the Pilliga, but it our view, precisely the opposite is true – a full 950 square kilometres of the forest will be radically changed in character, with lighting, noise and air quality changes that fundamentally change the community’s relationship with the area. There is no evidence that Santos approached bird-watching, bushwalking or camping groups or businesses that support these activities to gather evidence to support its sweeping generalisations.

The EIS makes repeated reference to establishment of a Gas Community Benefit Fund which would receive an estimated $120 million through the life of the project.” This estimate is based on outdated royalty estimates which have been updated in the EIS without also updating the Community Benefits Fund portion of overall royalty contribution.

The creation of this Fund could bring benefits to the local area, but this is by no means assured. Depending on the governance and consultation surrounding the Fund, it could, in fact, have a negative impact socially in Narrabri, intensifying already mounting divisions over mining and its impacts and splintering a hitherto cohesive community.

The EIS claims to include a Health Impact Assessment but does nothing of the sort. There is barely even a literature review of the mounting evidence that unconventional gas has a range of deleterious health impacts associated with it. Santos cite the Queensland health study at Tara, but not the regularly updated compendium of health studies produced by the Concerned Health Professionals of New York. The community Tara reported experiencing headaches, eye irritations, nosebleeds and rashes, and these symptoms are similar to symptoms reported by communities living near other unconventional gasfields, including Camden in western Sydney.

For mental stress, Santos briefly and broadly cite another Queensland study, but there is no evidence that it has conducted any serious assessment of the Narrabri area.

This is not a serious attempt at addressing an issue that is of profound concern for the communities that will have to live with this gasfield.

Over the last 4-5 years, community-based, neighbour to neighbour, surveys have been diligently conducted by local communities across the North West region. Survey teams visited every house in their district, inviting residents to respond to the question, “Do you want your land/road gasfield free?” Across the North West, 101 communities in the North West have overwhelmingly rejected gasfield expansion on their lands and rural communities and declared themselves gasfield free by this process.

Community survey teams were diligent in visiting every house in their locality and the results are overwhelming: on average, 96% of respondents want their homes, farms and communities to be gasfield free across an area covering 3.28 million hectares surrounding the Pilliga.

Air quality

The air quality assessment has not addressed the range of air pollutants and toxics that are associated with the drilling and processing of unconventional gas. In the absence of Santos providing detailed information about the likely layout of the gasfield, a proper assessment of the dispersement of pollutants from across the 950 square kilometres of the project area is hardly possible, nor is an adequate assessment of possible exposure pathways for communities living nearby. This is not acceptable.

As the air quality assessment makes clear, only a very limited number of pollutants were dealt with in any details: “The key air pollutant assessed for the project operations phase was nitrogen dioxide from gas and diesel fuel combustion sources associated with power generation, boilers, gas flaring and well head pumps. Other minor contaminants include fine particles and volatile organic compounds. The key air pollutants assessed for the project construction phase was dust as PM_{10}.” (Appendix L)

In a glaring omission, Santos has incorrectly applied the old air quality assessment methodology, which means they have not properly assessed emissions of $PM_{2.5}$. The “AUSPLUME” assessment was not applied to $PM_{2.5}$ for either construction or operation. Neither was it assessed for the power generation plant. Dispersal modelling for all health-harming air pollutants and methane must be undertaken. This includes toxics from the flares and $PM_{2.5}$ particulates for all stages of the operation.

Economic

Cotton is the major industry in the Narrabri shire, which hosts two of the five largest exporters of cotton in Australia. In Queensland, according to GISERA, 1.3 agricultural jobs were lost for every gasfield job created. This has implications for the future of agriculture in Narrabri shire and the critical cluster of cotton-related businesses and research institutions that operate there.

The macro-economic study in Appendix U2 makes clear that agriculture and its associated processing and transport are the primary drivers of economic activity in the region. This productivity is dependent on the natural resources that this project and potential wider coal seam gas development puts at risk. It is also intimately tied to the functional social bonds that an invasive gasfield puts at risk. If people are driven away and leave the area, as has occurred in southern Queensland areas adjacent to and amid gasfields, the social fabric that supports the agricultural productivity of the region will be put in jeopardy. The concentration of cotton farming, processing, transport, servicing and research activities in the Narrabi and Wee Waa area warrants protection under the State Environmental Planning Policy as a critical industry cluster.

The discussion of the “opportunity” from coal and gas development for Boggabri and Narrabri is simplistic and superficial and utterly at odds with the recent experience of Boggabri with the Maules Creek mine and with the experiences of towns in Queensland that have hosted the gas industry.

In the town, cost-of-living, labour market competition, increased housing demand will all have distorting effects. This latter is cited in Appendix T1 as a benefit of the project but it will not benefit low-income renters. Table 16 of Appendix T1 shows that 30% of the population of Narrabri shire rent, and 61% of Narrabri’s Indigenous population rent. Rental vacancies are already low. Table 15 shows that 37% of the Shore population and 53% of its Indigenous population are on less than $400 per week income. The effect of the project on cost-of-living in the Shire needs to be modelled, assessed and considered, as do the labour dynamics of the project.

The macro-economic analysis claims “tourism will remain important” but unlike for mining and agriculture, does not explore the number and distribution of tourism businesses, jobs and services in the Narrabri Shire and surrounding region. Evidence is emerging from Queensland that coal seam gasfields, because of the extensive surface infrastructure they require, has a negative impact on tourism in the surrounding area.

The very features that attract tourists to the region: the dark night, the peace and quiet, the extensive intact bushland, will be lost or jeopardised as a result of this project. Nowhere is this impact described and explored in the assessment material.

The macro economic study cites MDBA research that shows the extent of economic shocks the region would experience were there to be less water available for agriculture. The assessment fails to mention the prospect that the arriving of coal seam gas production might contribute to this loss of water. Indeed, it mentions that CSG production might *bring* water to the region, if produced water were of irrigation or town water quality.

Biodiversity

The Pilliga is the largest intact temperate woodland in Australia. It is part of the Brigalow Belt, one of 15 national biodiversity hotspots and a stronghold for many declining woodland bird species. Its national and state significance is not adequately described in the EIS, nor is the severe environmental stress that it is already experiencing. This context, the importance of the extensive habitat in the Pilliga and the stress and threat it is already facing due to bushfire and climate change is crucial to understanding the significance of the impact of this gasfield.

With that in mind, we attach to this submission a report prepared for the Northern Inland Council for the Environment on the national significance of the Pilliga. This report is Attachment C and it provides substantial additional information about the biodiversity significance and vulnerability of the Pilliga and raises the concern that the future expanded development of coal seam gas extraction has the capacity to further impact on matters of national environmental significance under the EPBC Act, "and result in extinctions of local populations."

The area to be cleared for the gasfield is 988.8ha with an additional indirect impact on another 181ha, so 1,000ha of vegetation in the Pilliga would be affected, but this clearing will take place over a huge area and the edge effects and indirect impacts associated with industrialising this part of the forest is not adequately addressed by the EIS. The assessment attempts to downplay the significance of this large area of clearing by noting that it is 1.29% of the vegetation across the huge area affected by the gasifeld. This does not ameliorate the impact. It arguably makes it worse. Fragmentation, clearing, traffic, disturbance and pollution will be introduced across a huge area of the largest temperate woodland in New South Wales. It will fundamentally change and degrade that woodland and this is hardly acknowledged in the EIS at all.

Of the vegetation being cleared, 796ha is habitat for Regent honeyeater, 449ha is habitat for koala and 135ha is breeding habitat for Pilliga Mouse. There is also breeding habitat for Yellow-bellied sheathtail bat and huge losses of large hollow bearing trees.

The ecological impact assessment has failed to accurately or adequately quantify the cumulative impacts many of these species have suffered due to recent clearing for other resource projects in the region. Notably, the Maules Creek and Boggabri mines have both cleared extensive areas of habitat for the Regent honeyeater and Yellow-bellied sheathtail bat and the Watermark coal mine is approved to clear significant areas of Koala habitat. More than 200 koalas are expected to be displaced by the Watermark coal mine only a 100 or so kilometres to the south.

Furthermore, the very marginal status of the Koala population in the Pilliga, once one of the largest in New South Wales, is cause for profound concern and hardly rates a mention in the EIS, except as an excuse to fragment, clear and degrade remaining koala habitat in this part of the Pilliga given that they are now, so rare. The results of the proponent's surveys indicate that the Koala population in the Pilliga "has declined substantially." This is an issue of profound concern, given the species' vulnerable status. Any koala habitat in the Pilliga being cleared and industrialised given the tenuous status of the entire population, could be hastening its local extinction. This prospect does not seem to be seriously addressed by the EIS.

Detailed assessments are provided for the Pilliga Mouse and the Koala, but not for the threatened bats and birds or the Black-stiped Wallaby. This is a serious omission and must be rectified with assessments considering the landscape context of the Pilliga for all threatened and migratory bird and bat species, the cumulative loss of habitat for these species over the last ten years and a frank assessment of the importance of the Pilliga habitat to be cleared and fragmented by this proposal to their survival.

The tables provided by Santos listing the disturbance limits for vegetation communities and habitat do not indicate which communities are listed under the State and Federal threatened species legislation or their status. This is important information to help the public understand the impact Santos is proposing to inflict. Nor do they provide, with these tables, any indication of community equivalences to listed communities with other names.

The numbers of records collected during surveys for this project are remarkably low compared to other recent surveys and not sufficient to assess the population patterns and high use areas that might be able to inform a "field protocol." There is little to no information about habitat values collected, mapped and presented in the EIS. The "Field Protocol" as presented in the EIS is woefully inadequate for the task of avoiding high conservation value areas and protecting key habitat features. This is no doubt caused by the EIS's failure to actually map such features in any detail. Hollow-bearing trees, for example, must be retained and all streams should have substantial exclusion zones for all surface infrastructure. The only areas where they are excluding surface development are State Conservation Areas. The "high constraint area" and "moderate constraint area" have the same prohibited and permitted activities.

Insurance

The Chief Scientist's Report recommended in 2014, "That Government consider a robust and comprehensive policy of appropriate insurance and environmental risk coverage of the CSG industry to ensure financial protection short and long term. Government should examine the potential adoption of a three-layered policy of security deposits, enhanced insurance coverage, and an environmental rehabilitation fund."

This has still not been implemented and the prospect of Santos securing consent to develop a full-scale production project in the absence of these arrangements is alarming landholders in the area.

As the first production project seeking approval since the report was completed, the Government's dealing with this project is a test of its commitment to implementing the Chief Scientist's report.

We note that the proposal for an environmental rehabilitation fund made by the chief Scientist is similar to the long-term environmental harm mechanism proposed recently by the NSW Audit Office in its review of the adequacy of mining rehabilitation security deposits and to the "future fund" proposed by Narrabri Shire Council to provide funds to deal with major future groundwater harm caused by this gasfield.

In the immediate term, we are of the view, and have obtained legal advice that supports this view, that comprehensive environmental insurance can be mandated by current legislative frameworks as conditions of consent and approval under the EP&A Act, the PO Act and the POEO Act. This must be done for this project.

Advice from landholders is that their farm insurance does not cover liabilities from unconventional gas activities that is of a creeping long term nature, that occurs over a wide area, and that is carried out under a Land Access Agreement or Conduct and Compensation Agreement. Standard farm insurance policy terms and conditions have provisions that:

1. Pollution is *generally excluded* in many common Farm Insurance policies[3] unless the pollution event arises from a sudden happening which is unintended and takes place entirely at one specific location.
2. "General Exclusions" may also exist where the damage or liability was *intentionally caused* or incurred by a person acting with the landholders express or implied consent[4]. This exclusion could include resource depletion and pollution arising from unconventional gas activities such as drilling, fracking, depressurising coal seams, etc
3. Landholders have a duty under s21(1) of the *Insurance Contracts Act 1984* to disclose every matter that the insured knows, or could be reasonably be expected to know, that is relevant to the insurers decision to insure the insured.

This duty of disclosure may mean that when gasfield operations begin, nearby landholders may need to disclose that event. This could lead to modifications to their existing farm insurance policies such as increased premiums, and doubts that existing insurance policies may not cover damages or liabilities that arise from gasfield operations.

The SEARs for the project included a requirement that Santos address "whether contingency plans would be necessary to manage any residual risks." This is not addressed in the EIS. Without insurance gas companies are managing the residual risk via risk transferring risk to landholders and the public. This is achieved through a combination of:

1. refusing to provide detailed, site specific baselines, including hydraulic head of water bores, water quality data and other environmental data.
2. Refusing to provide material safety data sheets and operational data, and the chemical makeup of proprietary chemical mixtures used in the drilling and treatment processes.
3. Insisting on legal indemnities in land access agreements that must be enforced in court. Enforcement success is remote due to a lack of baselines, monitoring and operational data identified in 1 and 2 above

The EIS does not include any commitments to carry comprehensive environmental insurance. This is consistent with the Santos Chairperson's avoidance of the issue and failure to commit to comprehensive environmental insurance in a waffling response to a direct question at the 2017 Santos AGM. His long winded answer caused serious concern among landholders in the project area. The Chairperson's assertion that Santos has never contaminated an aquifer and that its record

[3] Elders Farm Insurance, Product Disclosure Statement May 2016
https://www.eldersinsurance.com.au/uploads/PDS/QM3234-0516%20Elders%20Farm%20Pack_web_0516.pdf
[4] ibid

speaks for itself gives no comfort, since Santos's record includes a finding by the EPA in 2013 that an aquifer was contaminated by Santos near the Bibblewindi Water Treatment Facility.

By not taking out environmental insurance cover, Santos is effectively divesting its residual risk by transferring that risk to landholders, the environment and the public. This is clearly inequitable. Landholders, the environment and the public purse are subsidising the Narrabri Gas Project by unwillingly shouldering this risk - a risk that grows with heavy concern about Santos' finances and track record. Santos' track record in the Pilliga should be sufficient for the state government to insist that Santos be fully insured for any activities that they undertake. Recent statistical analysis of well failure and spills and leaks from all forms of unconventional gas wells in the United States, the limited data input and uncertainty analysis in Santos' modelling is further reason to fear there is considerable residual risk that for which there is no contingency plan either by Santos or the New South Wales government.

Farmers and landholders, in many cases have a multi-generational, low risk profile, seeking to minimise risk and pass on the property to the next generation in as good or better condition than they found it. Oil and gas companies, who seek to maximise shareholders returns, tend to have a high risk appetite, precisely because they don't own the land and have no monetary or long term interest in the land or the environmental services that it provides.

In general gas companies carry Public Liability Insurance only and their production operations represent a significant change to the risk profile of the farm and farming family. Insurance disclosure rules mean that farmers that host CSG activities on their land need to disclose this fact. Depending on the insurer and the farmer's bank, the disclosure could mean a significant increase in insurance costs, some exemptions to claimable events, the inability to get a new loan and/or an increase in the cost of finance. In fact Rabobank in its submission to NSW Inquiry into CSG in 2011 said there was a risk to Asset Values:

> When coal seam gas (CSG) mining activities are undertaken concurrently with agricultural activities on agricultural land, the size and scale of farming operations can be impacted, the production and efficiency base of the agricultural enterprise can be constrained and a new spectrum of operational risks could emerge.[5]

Rabobank went further in 2013 by banning loans to unconventional gas fuel projects including farmers who host unconventional gas operations.[6]

Livestock Producers hosting CSG are advised in the Livestock Protection Assurance (LPA) Guidebook, "A risk assessment must be carried out when any changes to the enterprise's current activities occur, such as a change in land use on the property. It will be examined in detail should your property be subjected to a random audit." [7] To manage risk, landholders need to identify the risks and mitigate where necessary and/or where mandated by industry or accreditation schemes.

For example the LPA scheme requires landholders to develop a Risk Assessment Plan (RAP) and manage risk. The LPA scheme specifically asks, "Do livestock have access to leaking electrical transformers, capacitors, hydraulic equipment or coal mine wastes?"[8]

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[5] Rabobank Australia and New Zealand, 2011, Submission 455 NSW Inquiry into Coal Seam Gas

[6] *The Australian*, 10 July 2013 "Rabobank bans loans to shale gas and tar sands" Retrieved 21.4.2017

[7] LPA Guidebook for Assessment http://www.mla.com.au/globalassets/mla-corporate/meat-safety-and-traceability/documents/lpa_guidebook_v7.pdf

[8] ibid

Landholders and land managers should be given access to the Material Safety Datasheets for all chemicals proposed to be used by Santos for these operations, including drilling and treatment fluids and documentation of gasfield operational practices. The landholders RAP may also require baselines of water and soil quality along with regular water testing. All this can become very expensive when taken over multiple sites and water sources. Such information should be provided by Santos as part of the EIS process to ensure that landholders that experience loss or damage can seek redress.

A Short-Lived Gas Shortfall

A review of AEMO's warning of gas-supply 'shortfalls', May 2017

Tim Forcey, Dylan McConnell

The University of Melbourne

Australian-German Climate & Energy College

About the Australian-German Climate & Energy College

The College is an international cohort of early career researchers. The College conducts climate and energy systems research in an interdisciplinary environment, advancing knowledge and informing responses to the complex challenges of climate change. We are a world-class research hub located at the University of Melbourne collaborating with leading Australian and German research institutions. The Climate & Energy College has been initiated and is supported by the Melbourne Sustainable Society Institute and the Melbourne Energy Institute.

The scope of College research includes science, engineering, governance, policy, and law, cutting across climate change and energy transitions research. This includes examining global and regional emission pathways and mitigation strategies, equity, carbon budgets, trade, finance, mitigation costs and opportunities of different climate change response options.

About the authors

Tim Forcey is a Chemical Engineer and independent energy advisor with over 35 years of experience in petrochemicals, oil, gas, electricity and energy efficiency with organisations including ExxonMobil, BHP Billiton, Jemena, and the Australian Energy Market Operator (AEMO). As Energy Advisor at the University of Melbourne Energy Institute (MEI), Tim has published leading research reports and articles covering topics such as methane emissions from unconventional gas production, eastern-Australian electricity and gas demand trends, and the economic advantages of alternatives to gas (such as heat pumps) and energy efficiency measures.

Dylan McConnell is a PhD candidate at the College. Dylan is a Chemical Engineer, with experience as an energy analyst. He has a detailed understanding of the cost structure of energy technologies and the electricity market. He was an author of the Melbourne Energy Institutes Renewable Energy Technology Cost Review, commissioned by the Garnaut Review, an investigation of renewable technology costs and projections. He has also developed detailed energy market models for analysing the National Electricity Market electricity dispatch and price-setting system, in the context of understanding the effect of distributed solar photovoltaic systems and other technologies affecting wholesale electricity demand.

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This report was prepared by Tim Forcey* and Dylan McConnell†

† Climate & Energy College, University of Melbourne.
* Corresponding author: forcey5@optusnet.com.au

Executive Summary

With the publication of the 9th March 2017 Gas Statement of Opportunities (GSOO), the Australian Energy Market Operator (AEMO) cautioned that within 18 months, "shortfalls" of gas supply could lead to shortfalls in the supply of electricity generated by burning gas. AEMO suggested solutions to potential shortfalls that included the construction of new pipelines or Coal Seam Gas (CSG) fields.

AEMO's warning was heard by the Australian Prime Minister who, by late April 2017, had announced plans to implement the "Australian Domestic Gas Security Mechanism". This will allow the government to impose gas-export controls on companies when there is a gas-supply shortfall in the domestic market. The Prime Minister also recognised that eastern-Australian wholesale gas prices are at historically high levels and are now linked to international prices.

Our report investigates AEMO's gas-and-electricity-system modelling results as well as the communications that followed. We explore reasonable alternate conclusions that can be drawn by analysing AEMO's published modelling inputs, assumptions, and results, and by contemplating future real-world events.

We recommend actions that would improve AEMO's scenario modelling, result interpretation, formulation of recommendations, and communication to stakeholders. We also list recommendations for governments, gas consumers, and other stakeholders. These recommendations aim to provide more information to the gas and electricity markets, ease the strain of rising gas and electricity costs, and avoid unnecessary expenditure on gas production and transportation infrastructure.

We find a shortage of 'cheap' gas ...

Our research finds that although a "gas-price crisis" exists in eastern-Australia, a gas-supply shortfall is very unlikely to occur.

We find that the former gas "buyer's market" that prevailed in eastern-Australia has shifted to become a "seller's market". Where before the wholesale gas price had been nearly the cheapest in the developed world at $3–4 per gigajoule (GJ), today it is now nearly the most expensive, with prices up to $20/GJ now on offer. These high prices are a result of the eastern-Australian gas market being linked to overseas benchmarks, over-building of gas export capacity with contractual export over-commitments, opaque gas market and gas-producer behaviour, and the high costs of producing unconventional CSG (now estimated to be around $7/GJ, excluding pipeline transportation costs).

Given the above, a return to delivered wholesale gas priced below $8/GJ is unlikely.

... but no gas-supply 'shortfall'

Our review finds that the size of AEMO's forecast shortfall is very small, amounting to no more than around 0.2% of annual supply (of either gas or electricity).

AEMO's modelled gas-supply gap is a simple annual imbalance between the volume of gas supplied to the eastern-Australian gas system versus forecast gas demand. Importantly, this means that AEMO is ***not*** indicating any short-term or acute gas-supply concern relating to, as an example, gas availability being constrained by pipeline capacity during peak winter-demand times. Because the modelled supply gap is an annual imbalance, over the course of a modelled year, any extra gas supply or demand reduction acts to narrow or even completely close the gap.

AEMO closes the supply gap eleven days after announcing it

The rapid rise in wholesale gas and electricity prices in eastern-Australia is reducing industrial activity. Industrial decline will reduce gas demand by an amount far larger than AEMO's forecast supply gap. Therefore, because of this "demand destruction", we find it very unlikely that gas-supply shortfalls will occur. Indeed, only eleven days after announcing its supply-gap concerns, AEMO essentially closed the gap when it published, on its website, updated (lower) electricity-demand forecasts that therefore lead to less demand for electricity generated by burning gas.

No need to expand gas-supply infrastructure

Given the above, we find it necessary to challenge AEMO's urgent warning of nearly-imminent gas shortfalls and AEMO's limited array of "potential solutions".

We find that AEMO focussed attention on a very small, very unlikely, and ultimately short-lived gas-supply shortfall concern. Furthermore, AEMO's suggested new pipelines and new (expensive) gas fields appear to be false "solutions". These massive fossil-energy infrastructure investments are not needed to address a supply shortfall that is very unlikely to occur.

Furthermore, these investments will not reduce the wholesale price of domestic gas. New gas sources are expensive to produce, and in any case, in the "seller's market" that now prevails, domestic-wholesale gas prices are linked to international benchmarks.

Expanding gas fired generation in the electricity sector is also inconsistent with Australia's long term climate change objectives. This, combined with the falling costs of renewable energy and storage technologies, raises questions about the role of gas in the electricity system. While gas has often been considered a 'transition fuel', this pathway is not necessary, and is in fact a detour.

Ways that consumers and suppliers can respond to high energy prices

The more useful message for energy consumers is that the wholesale price of gas has increased significantly and is unlikely to return to the low prices previously known. Therefore, AEMO and governments should focus on informing Australian energy consumers - ranging from home occupants, to commercial building managers, to large industries - of the cost-effective actions they can take to respond to rising energy costs, including:

- reducing gas and electricity consumption though energy-efficiency measures
- fuel-switching to lower-cost renewable energy options, e.g. electricity via on-site solar PV, heat pumps (often referred to as reverse-cycle air conditioners), or bioenergy
- utilising energy storage
- engaging with demand-side response in the electricity market
- accelerating renewable-energy deployment.

Addressing the opacity of the gas industry is warranted

Recent actions by Australian governments that seek to reduce gas-industry opacity are greatly warranted, particularly around gas reserves, facility production capacity, future development plans, and Liquefied Natural Gas (LNG) export contracts and commitments. Greater industry transparency would help to improve the usefulness of AEMO's planning activities.

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1 Introduction

With the publication of the 9 March 2017 Gas Statement of Opportunities (GSOO)[1], the Australian Energy Market Operator (AEMO) warned that by December 2018 (around 18 months from now) there could be "shortfalls" either of gas, or of electricity generated by burning gas[2]. AEMO suggested that new pipelines or gas fields were needed to avoid these shortfalls.

This reports critiques the robustness of both AEMO's communicated results and AEMO's recommendations for addressing gas and electricity supply security. Our report investigates gas and electricity system modelling results published in AEMO's Gas Statement of Opportunities[3] and other reports.

This report is structured as follows: we begin by providing an overview of the genesis and response of the widely reported 'gas crisis'. This is followed by a description of the dynamics of and recent disruptions to the gas market in eastern-Australia. From there, we examine AEMO's energy-system modelling methods and results. Following this, we explore reasonable alternate conclusions that can be drawn from AEMO's published modelling inputs, assumptions, and results. We consider alternate results that modelling would produce based on reasonable alternate assumptions and/or future real-world events. Finally, we list recommendations for governments and other stakeholders. These recommendations aim to provide more information to the gas and electricity markets, ease the strain of rising gas and electricity costs, and avoid infrastructure-expansion expenditures.

2 The gas 'shortfall crisis'

In this section of the report we examine the key messages and recommendations conveyed by AEMO, and the response from media and policy makers.

2.1 AEMO warns of "shortfalls"

On 9 March 2017, AEMO's Chief Operating Officer Mike Cleary was reported as saying[4]:

> *"If we do nothing, we're going to see shortfalls in gas, we're going to see shortfalls in electricity. We can either:*
>
> - *redirect some of the LNG from the international markets into the domestic market, assuming that the price allows that to happen*
> - *we can increase production from the existing fields*
> - *we can explore and develop new fields or we can have investment in the pipelines."*

In its GSOO, AEMO described three "potential solutions" to avoid shortfalls[5]:

1. Jemena Northern Gas Pipeline - a new gas pipeline that would link the Northern Territory with the eastern-Australian gas market via a connection at Mt Isa in Queensland[6]
2. Santos Narrabri Gas Project, in conjunction with the Queensland Hunter Gas Pipeline (New South Wales)
3. redirection of LNG export gas to the domestic market.

[1] AEMO, *Gas Statement of Opportunities*.
[2] Ibid.
[3] Ibid.
[4] Harmsen, "Homes could lose power as gas shortage looms, operator warns".
[5] AEMO, *Gas Statement of Opportunities*.
[6] Marks, *Second gas pipeline in the Northern Territory 'not viable without fracking'*, reports "Construction could get underway in mid-2017".

AEMO did not describe in depth other "potential solutions" such as:

- electricity supply-side options (e.g. faster expansion of renewable energy and storage)
- electricity demand-side options (e.g. accelerated energy efficiency measures, and demand response)
- gas demand-side options (e.g. accelerated energy efficiency and fuel-switching measures)
- non-fossil gas options (e.g. supply of biogas, biomethane, hydrogen)
- maintaining or expanding production from existing fossil-gas fields (e.g. gas producer response to attainable high sales-gas prices)
- other new gas-field developments (e.g. Western Surat, Ruby Project, Shell-Arrow, etc.)

In later sections of our report we explore these other options. We also explore why AEMO does not detail these options in its Gas Statement of Opportunities.

2.2 Media and political response

Given the public concern about energy supplies and cost, the Australian media widely reported AEMO's "shortfall" warning with headlines such as:

- "AEMO warns of blackouts as gas runs out" (The Australian[7])
- "Gas supply shortage will threaten nation's power supplies"(ABC[8].)

Australia's Federal Energy Minister Josh Frydenberg responded immediately to AEMO's report by calling for "more gas supply and gas suppliers"[9].

Australia's Prime Minister Malcolm Turnbull responded by arranging to hold "urgent crisis talks" with gas suppliers on 15 March. In a parallel activity, on 20 March, AEMO published on its website updated (reduced) electricity-demand forecasts[10]. These new forecasts reflected news of industrial "demand destruction" caused by high energy prices. These new forecasts meant that AEMO had closed its supply gap only eleven days after announcing it.

On 21 March, the gas-producing company Shell announced it would proceed with Project Ruby[11]. Because this project was not included in AEMO's energy-system modelling, Project Ruby also has the effect of closing AEMO's supply gap.

By 30 March 2017, AEMO downplayed the risk of gas shortages by saying "authorities and companies had begun to address the issue"[12].

Nevertheless, given the acute and ongoing concerns about high gas prices, following another meeting with the gas industry (19 April), the Prime Minister tasked the Australian Competition and Consumer Commission (ACCC) to carry out a new three-year investigation into the gas industry. (This follows just one year after a previous investigation[13]). In this latest investigation and with a first report due October 2017, the ACCC[14]:

> *" . . . will use its inquiry powers, including its ability to compulsorily acquire information, to increase transparency and address opaqueness in the gas market. The inquiry will examine how gas suppliers will make more gas available to Australian industry and other domestic gas users, and the effect this has on overall market dynamics. Improved transparency will provide a clear overview of the entire market and help ensure it is operating efficiently and that competition is benefiting all gas users."*

[7] Chambers, *Blackouts warned as gas runs out*.
[8] Harmsen, "Homes could lose power as gas shortage looms, operator warns".
[9] Josh Frydenberg, *'We need more gas and gas suppliers'*.
[10] AEMO, *Update: National Electricity Forecasting Report*.
[11] Shell Australia, *Media release: Shell invests in east coast gas supply*.
[12] Morton, "What we'll do to keep the lights on post Hazelwood".
[13] ACCC, *Inquiry into the east coast gas market*.
[14] ACCC, *ACCC to investigate and report on Australian gas markets and market transparency*.

Other responses reported in the media were suggestions that gas pipelines could be installed from the Northern Territory[15] or Western Australia[16,17] connecting in to South Australia or Queensland.

As the operator of the National Electricity Market (NEM) in Australia, AEMO has been widely criticised over its role in recent electricity-supply disruptions[18]. In addition to its market-operations role, AEMO has certain long-term planning responsibilities for Australian gas and electricity networks and is legislatively required to publish the annual GSOO. Given the responses by the Australian media and government to AEMO's messages about gas "shortfalls", it is clear AEMO's messages had the effect of attracting attention to gas-supply concerns.

In a significant move, on April 27 the Prime Minister declared that there was a shortage of gas supplies for eastern-Australia and that certain restrictions may be placed on gas exports[19]. The gas industry responded by saying that "restricting exports is almost unprecedented for Australia" and that it would need to "carefully consider the details" of the announcement[20].

In more detail, the Prime Minister's announcement said:

> *" . . . the Australian Domestic Gas Security Mechanism will give the government the power to impose export controls on companies when there is a shortfall of gas supply in the domestic market.*
>
> *The Minister for Resources, in consultation with relevant ministers, will impose export controls based on advice from the market operator [Australian Energy Market Operator] and regulator [Australian Energy Regulator]"*

Key to the application of this new Australian Government initiative, therefore, is AEMO's declaration of whether gas-supply shortfalls do or don't exist and the circumstances under which shortfalls might occur. The practicalities of how this mechanism would work were questioned in a Renew Economy article entitled 'The Shortage may be Short-lived'[21]:

> *"Exactly how a physical shortage is defined is not disclosed and in our view it's almost impossible to operationalise it in a fully satisfactory manner. For instance, the 'need' or 'supply' of gas-fired electricity generation is both price and cost elastic. If the gas was cheap enough there would be more demand and vice versa."*

[15] Marks, *Second gas pipeline in the Northern Territory 'not viable without fracking'*.
[16] Flint, *Colin Barnett calls for 'nation-building' gas pipeline*.
[17] The Australian Pipeliner, *Barnett calls for trans-continental pipeline*, reported pipeline from Western Australia "to cost upwards of $5 billion."
[18] Evans, "SA Energy Minister fumes in phone call to AEMO on power cuts".
[19] Prime Minister, *Delivering Affordable Gas for all Australians*.
[20] APPEA, *Media Release: Gas export controls no substitute for genuine reform*.
[21] Leitch, "Gas shortfall may be short-lived, thanks to growing renewables".

3 Context: Disruption to the Australian gas market

This section describes how, over a two-year period, the export of Liquefied Natural Gas (LNG) from Queensland disrupted the gas and electricity markets. High energy costs are leading to domestic "demand destruction", particularly in the industrial sector. It is now uncertain what role gas will play as the eastern-Australian electricity grid evolves and decarbonises. Figure 1 illustrates eastern-Australian gas production and transmission infrastructure.

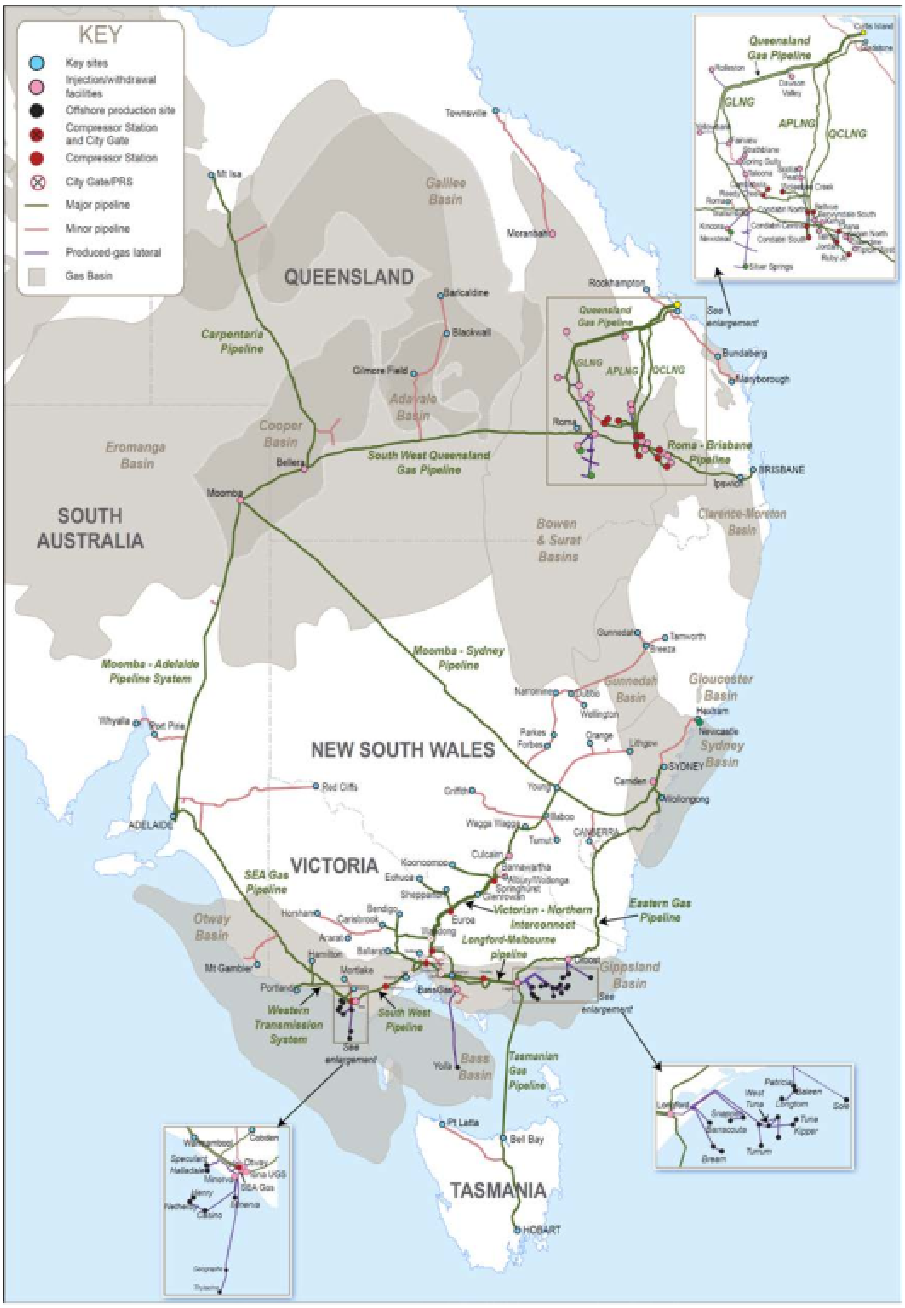

Figure 1: Eastern and south-eastern Australian gas basins and infrastructure [source: AEMO[22]]

[22] AEMO, *Gas Statement of Opportunities*, page 28, Figure 12.

3.1 The creation of the eastern-Australian LNG export industry

The export of LNG from eastern-Australia commenced from Gladstone, Queensland in January 2015. Prior to this event and since the 1970's, eastern-Australian gas had been characterised as a low-value by-product of conventional crude oil exploration and production[23]. In those earlier times, gas in eastern-Australia was some of the cheapest in the developed world.

Local and federal governments encouraged the use of gas in industry, in buildings, and for electricity generation. Encouragement continues even today with programs such as the Victorian Government "Regional Gas Infrastructure Program"[24].

Starting in the late 1990's, gas produced from vast coal seams in Queensland began to enter the eastern-Australian domestic market. As the assessed reserves of this "unconventional" coal seam gas (CSG) grew (see Section 9.3), CSG developers sought and attracted large overseas gas customers.

Figure 2 shows the rapid ramp-up of the CSG - LNG industry from late 2014 to the present. The gas required by this new industry will become nearly three times larger than the, now in-decline, domestic market.

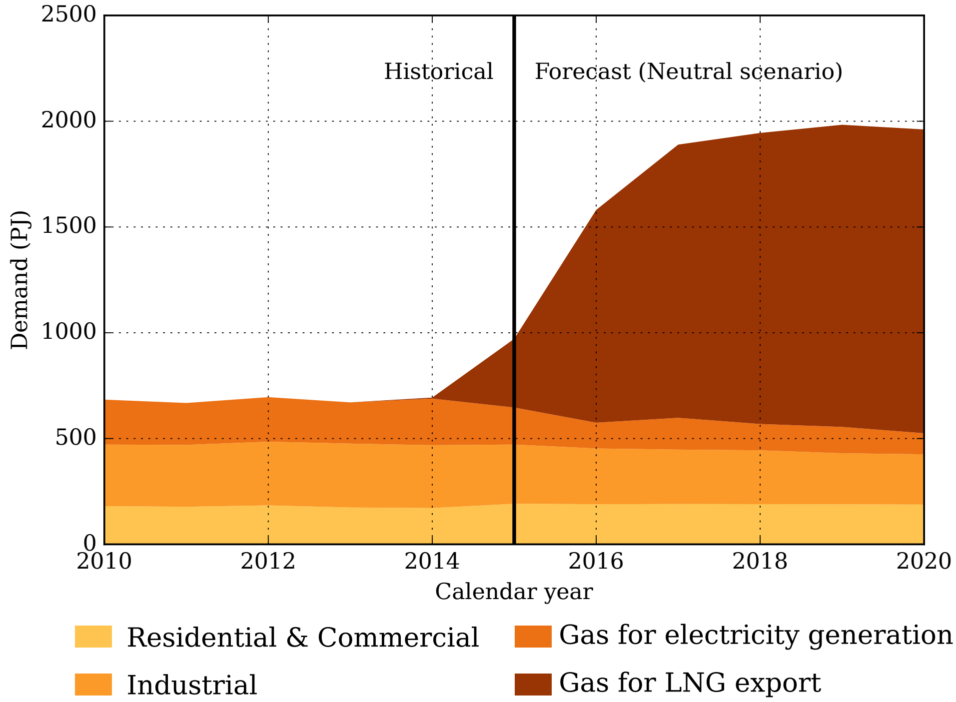

Figure 2: Historic and forecast gas demand for eastern-Australia, showing ramp-up of LNG exports. The 'neutral' scenario from AEMO's *2016 National Gas Forecast Report* is illustrated. Australian gas production has more than doubled from around 700PJ a year from before 2014 to an expected 1900PJ in 2017 [source: AEMO[25]].

[23] Forcey, "Victoria's days of gas dependence are fading".
[24] http://www.rdv.vic.gov.au/regional-projects/regional-gas-infrastructure .
[25] Data from AEMO, *National Gas Forecasting Report*, available at `http://forecasting.aemo.com.au/`.

Over 10,000 CSG wells have so far been drilled in Queensland[26] and New South Wales, with further potential to over 40,000 wells. Figure 3 shows before-and-after aerial photos of a small section of the Queensland CSG fields and the placement of 150 wellpads. The spacing between wellpads is 500 to 700 metres.

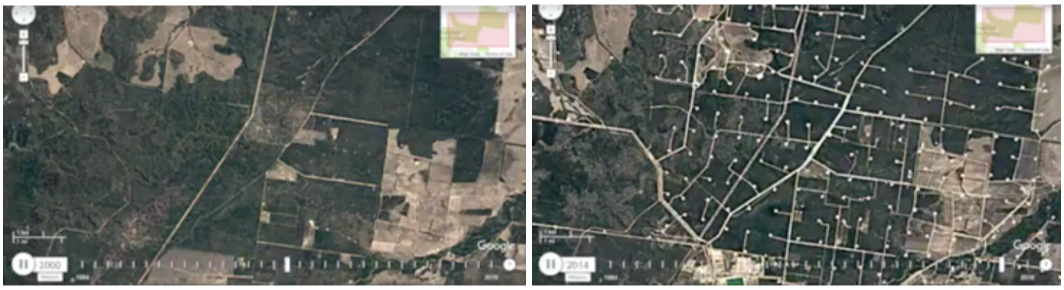

Figure 3: 'Before and after' aerial photographs showing the placement of more than 150 CSG wellpads in Queensland [source: **Google earth**].

Six LNG "trains" now operating at Gladstone, Queensland (Figure 4) are owned by three separate consortiums known as:

- APLNG - operated by Origin
- GLNG - operated by Santos
- QCLNG - operated by Shell.

Beyond the first six LNG trains, given the potential CSG volumes in Queensland and New South Wales, as many as eleven more LNG trains had at one time been envisioned[28]. The most advanced of these additional CSG-LNG projects is the Shell-controlled Arrow project,

Figure 4: The six Gladstone Queensland LNG trains are owned by the consortium's APLNG, GLNG, and QCLNG [source: **Stock et al.**[27]].

[26] Queensland Government, *Queensland Globe*.
[27] Stock et al., *Pollution and price: the cost of investing in gas*, page 27.
[28] Lewis Grey Advisory, *Projections of Gas and Electricity Used in LNG*.

which received Queensland government approval in September 2013 for an additional four LNG trains[29]. Despite having proven-up substantial gas reserves, Shell placed that project on hold in January 2015. These gas reserves could potentially be directed to the other Gladstone LNG projects or to the domestic market[30].

Although the reserves and resources of CSG throughout Queensland are large, not all of the three operating Gladstone CSG-LNG consortiums are equally endowed with reserves. In particular, Santos-GLNG is reported to have purchased 59% of its export gas from "third-parties", including from suppliers of conventional gas[31].

The Shell-controlled Arrow CSG reserves are one such source of additional gas. Farther afield, in January 2016 gas flow in the large Moomba-to-Sydney pipeline was reversed. For the first time, conventionally-produced gas from the offshore Bass Strait fields was transported over thousands of kilometres from Victoria to Queensland[32].

3.2 Wholesale gas price increases

With the 2015 commencement of LNG-exports, the eastern-Australian gas market was transformed from a captive domestic "buyer's" market to an internationally-linked "seller's" market. As was confirmed by the Australian Prime Minister on 27 April 2017, wholesale gas prices are now linked-to and are reported to even exceed international prices[33]. Figure 5, from the Australian Energy Regulator (AER), shows the rapid increase in the wholesale gas price from historical values of around $3 per GJ to present prices as high as $9/GJ. This price escalation occurred as several Gladstone LNG trains began operating.

Gas buyers continue to report difficulties agreeing long-term contracts with gas suppliers quoting wholesale prices of $20/GJ[34] or higher[35].

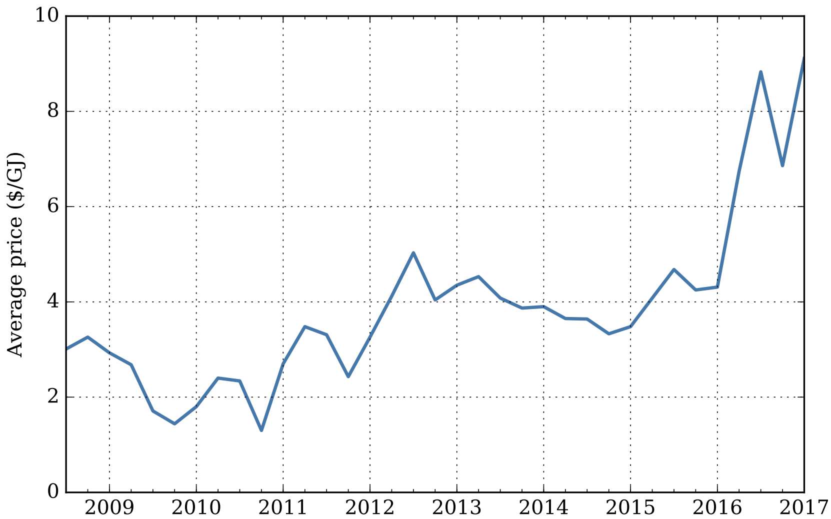

Figure 5: Victorian gas market average-daily-weighted imbalance prices by quarter [source: AER[36]].

[29] Jeff Seeney, *Media statements: $15b Arrow LNG project given approval - The Queensland Cabinet and Ministerial Directory*.

[30] Macdonald-Smith, "Shell shelves plans for Arrow LNG project in Queensland".

[31] Chambers, "Santos taps outsiders for gas".

[32] Forcey, "Heading north: how the export boom is shaking up Australia's gas market".

[33] Karp, "Gas producers attack export controls as industrial users cheer 'bold' changes".

[34] This is higher-cost energy that what can be provided with crude oil of diesel. Currently the energy value of crude oil is $14/GJ ($US 50 per barrel of oil and Australian/US foreign exchange rate of 0.75).

[35] Macdonald-Smith, "Gas producers defiant ahead of recall to Canberra".

[36] Data available from the AER: `https://www.aer.gov.au/wholesale-markets/wholesale-statistics/victorian-gas-market-average-daily-weighted-prices-by-quarter`.

In April 2016, the ACCC released the findings of an inquiry into the competitiveness of wholesale gas prices in eastern-Australia[37]. The ACCC characterised the gas outlook as "uncertain" and made a number of recommendations in relation to[38]:

- *"Enabling new gas supply to come to market, in particular in south eastern-Australia,*
- *Revisiting the regulatory coverage of pipelines, increasing the ability for pipelines with market power to be regulated; and*
- *The consistency and transparency of the provision of information to the market."*

Notably, the ACCC did not attempt to restrict or influence the behaviours of gas producers.

3.3 Impact of gas prices on electricity prices

Given the role of gas as a marginal energy source in the National Electricity Market, rising wholesale gas costs have contributed to wholesale electricity price increases.

Pressure on electricity prices also occurred as renewable-energy deployment slowed and coal-fired electricity generators retired. Retirements include most recently Victoria's 1,600 MW Hazelwood facility that closed at the end of March 2017.

Figure 6 illustrates the recent, sudden, and large increase in wholesale electricity prices in, for example, New South Wales, where the price tripled over the two-year period March 2015 to March 2017.

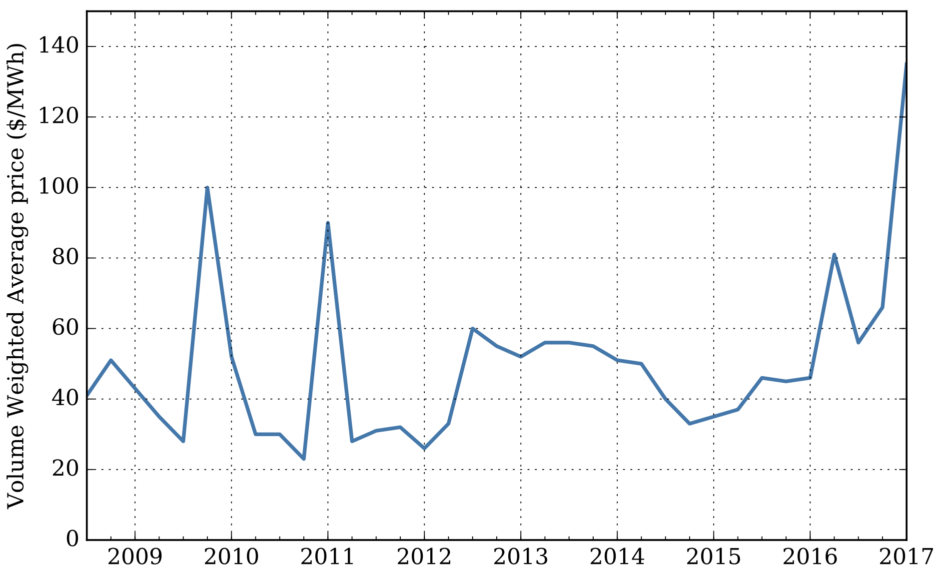

Figure 6: Quarterly volume weighted average electricity spot prices for New South Wales [source: AER[39]].

[37] ACCC, *Inquiry into the east coast gas market*.

[38] ACCC, *Media Releae: Release of East Coast Gas Inquiry report into the increasingly complex and uncertain gas market*.

[39] Data available from the AER: `https://www.aer.gov.au/wholesale-markets/wholesale-statistics/quarterly-volume-weighted-average-spot-prices`.

3.3.1 High energy costs & "demand destruction"

Rapidly escalating gas and electricity costs are significantly impacting the profitability of energy-intensive Australian industries and are already driving gas and electricity "demand destruction".

On 20 March 2017, AEMO published an "Update" to its National Electricity Forecasting Report[40]. In this update, AEMO reduced its forecast for grid-supplied electricity by approximately one per cent (1,580 GWh in Financial Year (FY) 2021-22).

AEMO updated its forecast because of "more recent information on electricity usage from Queensland's Boyne Island Smelter and the Liquefied National Gas (LNG) sector". In its "Update", AEMO referenced a news report that the aluminium output of the Boyne Island smelter would be reduced by 14% due to high electricity costs[41].

As MEI reported previously[42], the potential that this series of events - from the creation of gas-export capability, to higher gas and electricity prices, to energy demand destruction - would eventually lead to reduced economic activity was forewarned by the Australian Industry Group in 2013 in its report "Energy shock: the gas crunch is here"[43]. In 2014, a study conducted by Deloitte found a possible $120 billion loss in manufacturing output (net present value) with increased gas prices[44].

[40] AEMO, *Update: National Electricity Forecasting Report*.
[41] Annett, *What 'significant number' of job cuts mean for BSL*.
[42] Forcey and Sandiford, *The dash from gas: Could demand in New South Wales fall to half?*
[43] AIG, *Energy shock: the gas crunch is here*.
[44] Deloitte, *Gas market transformations- Economic consequences for the manufacturing sector*.

4 AEMO's Gas Statement of Opportunities

This section of work details the modelling approach and results of AEMO's 2017 Gas Statement of Opportunities. The sensitivities of AEMO's result to changes in various input assumptions are also highlighted. These sensitivities are explored in further detail in later sections of the report.

4.1 AEMO modelling approach

AEMO's recently-published Gas Statement of Opportunities and media statements are based on AEMO's annual electricity and gas-system modelling. AEMO's modelling results, methodologies, and inputs are described in annual reports such as:

- the Electricity Statement of Opportunities (ESOO)
- the National Electricity Forecasting Report (NEFR)
- the National Transmission Network Development Plan (NTNPD)
- the National Gas Forecasting Report (NGFR)
- the Gas Statement of Opportunities (GSOO).

AEMO's electricity-and-gas-system modelling techniques have evolved over several years and continue to grow in complexity. However, there is limited transparency as to how sensitive AEMO's modelling results are to variations in key assumptions and inputs.

AEMO's modelling depends on information provided by the gas industry. The accuracy and relevance of this information cannot be independently confirmed or cross-checked. There is a concerning level of opacity and uncertainty around Australian gas reserves, gas processing capacity and constraints, and gas supply contracts. A gas industry consultant commented[45]:

> *"Another impediment to investment is the general lack of transparency of the Australian upstream gas market. Any overseas investor is likely to have great difficulty getting the most basic information about reserves, production and drilling results.*
>
> *An executive in a US oil and gas company without interests in Australia recently made the comment: 'Australia is not a very data transparent country. It's not as bad as Malaysia but light-years away from Norway, which has excellent transparency. Thailand is much more transparent than Australia. I suspect that Australia does not view transparency as being in the national interest.'*
>
> *If better information helps attract additional investment it is indeed in the national interest. The worst offender in this regard is the Commonwealth Government, which has jurisdiction over offshore waters beyond the three-mile limit but information on activities in Commonwealth waters is deteriorating, not improving, immersed in a fog of confidentiality.*

At a major gas conference, another gas-industry commentator lamented that "this is no way to run a country" when major gas suppliers such as Esso and BHP Billiton are not required to publish their assessments of gas reserves in the strategic Bass Strait.

Given the opacity of the gas industry and the limited information on which AEMO must base its conclusions, our report illustrates how small changes to AEMO's modelling assumptions can lead to significantly different conclusions and planning messages.

As defined by the National Gas Law[46], the purpose of AEMO's "Gas Statement of Opportunities" report is to:

[45] Bethune, *Where is the east coast domgas development boom?*

[46] Government of South Australia, *National Gas (South Australia) Act*, Part 6, Division 4.

> *"Provide information to assist Registered participants and other persons in making informed decisions about investment in pipeline capacity and other aspects of the natural gas industry."*

In its electricity and gas forecasting and planning, AEMO has tended to over-estimate future demand[47,48]. AEMO has then tended to focus on supply-side solutions (i.e. new gas field and pipeline investments) rather than giving equal weight to demand-side solutions such as economic fuel-switching, energy- efficiency, and demand-response measures.

4.2 Results of the Gas Statement of Opportunities

This section describes the small gas-supply gap (no more than 0.20% of annual supply) that AEMO's modelling indicates could occur in three of the next thirteen years. This section also then describes how this small gap closes with slightly different modelling assumptions or the occurrence of real-word events.

AEMO's modelled gas-supply gap is a simple annual imbalance between the volume of gas input to the eastern-Australian gas system versus the forecast gas volume demanded by consumers. Importantly, this means that AEMO's modelling is not indicating any short-term or acute gas-supply concern relating, for example, to gas availability at peak winter-demand times. Since the modelled supply gap is an annual imbalance, any extra gas input or reduced demand that is considered over the year in question acts to narrow or perhaps completely close the gap.

Further, AEMO has modelled how this gas-supply gap could manifest as a small electricity supply-gap[49]. The largest gap modelled by AEMO (in financial year 2020-21, see Table 1) is equal to only 0.19% of the annual electricity supply, or 363 gigaawatt hour (GWh). In gas-supply terms, this is equivalent to only 0.20% of the annual gas supply, or 3.9 petajoule (PJ).

AEMO's forecast 0.20% gas-supply gap is illustrated by Figure 7.

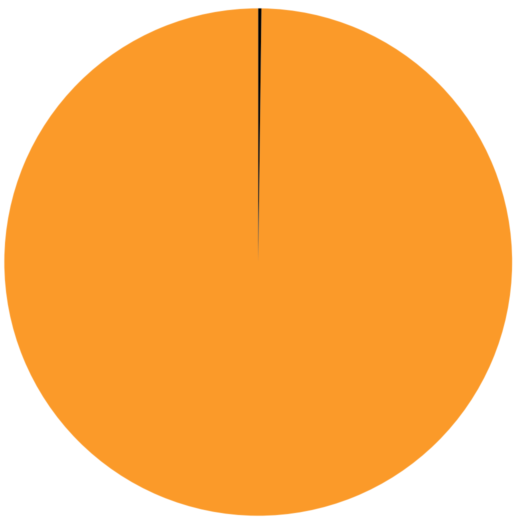

Figure 7: AEMO's modelled gas-supply gap is no more than 0.20% of annual gas supply (shown on the pie chart as a black sliver).

[47] Sandiford et al., "Five Years of Declining Annual Consumption of Grid-Supplied Electricity in Eastern Australia".

[48] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.

[49] See AEMO, *GSOO methodology*, Figure 6, page 15.

Table 1: AEMO's modelled gas-supply gap

Financial Year (1-July to 30 June)	AEMO electricity supply gap caused by gas supply gap (Figure 8)	Supply gap is what % of annual electricity supply?	Supply gap is how many hours electricity supply?	Equivalent gas supply gap*	Gas supply gap is what % of annual gas supply?	Gas supply gap is what how many hours gas supply?
2016-18	--	--	--	--	--	--
2018-19	80 GWh	0.039%	3.4 hrs/yr	0.086 PJ	0.044%	3.9 hrs/yr
2019-20	--	--	--	--	--	--
2020-21	363 GWh	0.19%	15 hrs/yr	3.9 PJ	0.20%	18 hrs/yr
2021-22	1 GWh	0.001%	0.1 hrs/yr	0.01 PJ	0.001%	0.1 hrs/yr
2022-26	--	--	--	--	--	--

**Conversion efficiency for gas fired elelctricity is assumed to be 33%. For example, 363 GWh * 3.6 TJ/ GWh *1 PJ / 1000 TJ / 0.33 = 3.9 PJ*

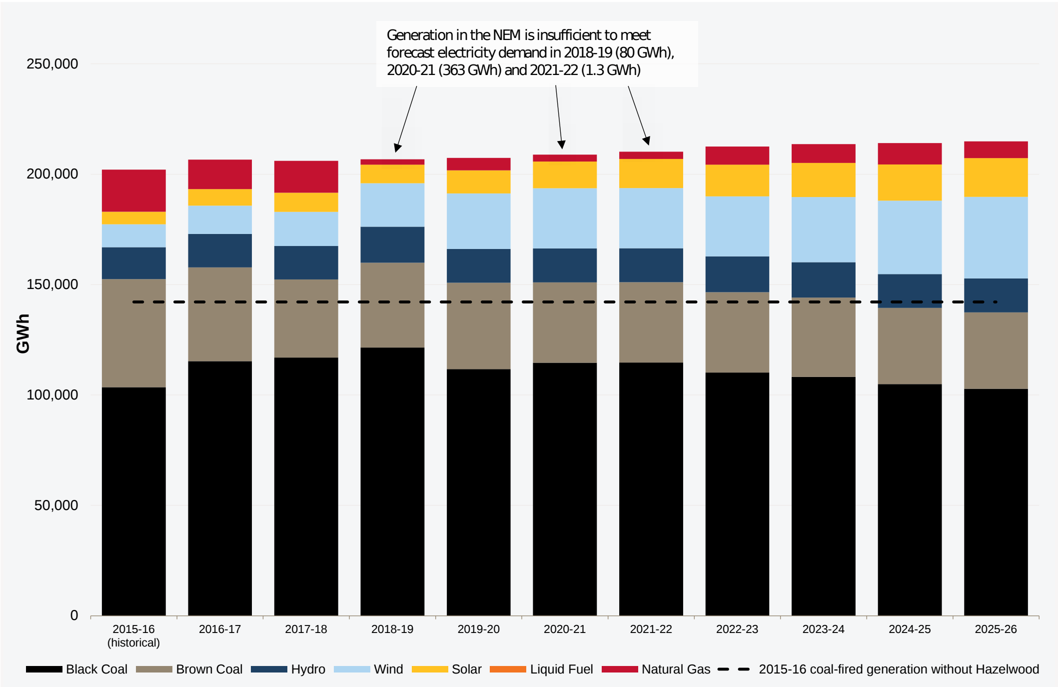

Figure 8: AEMO's forecast electricity generation mix [source: AEMO[50]].

[50] AEMO, *Gas Statement of Opportunities*, Figure 6, page 15.

4.3 Impact of modelling assumptions

Given that the gas-supply gap modelled by AEMO is so small (no more than 0.20% of annual supply in any year) the gap closes entirely with slightly-changed modelling assumptions. Table 2 illustrate some of the key sensitivities of AEMO's result to changes in various input assumptions. These are explored in further detail in the following sections of the report.

Table 2: Change required to close the AEMO supply gap

Electricity demand	In FY 2020-21, AEMO forecasts that the demand for grid-supplied electricity in eastern-Australia will be around 187,000 GWh. AEMO's FY 2020-21 electricity-supply gap (363 GWh shortfall caused by lack of gas supply) would be closed if electricity demand were 0.19% less than AEMO forecasts. See Section 5 for more discussion.
Electricity supply	As shown in AEMO's 2017 GSOO Figure 6, AEMO forecasts that in, for example FY 2020-21, electricity will be generated in eastern-Australia by a mixture of energy sources including coal, hydro, solar, wind, and gas. To close the 363 GWh electricity-supply gap listed in Table 1, electricity generated by wind and solar would have to be 0.9% greater than AEMO's forecasts for those sources. Alternatively, electricity generated from coal would have to be 0.2% greater than AEMO forecasts. See Section 6.
Diversion of gas from LNG	In its 9 March 2017 announcement, AEMO pointed out that diverting a small amount of gas from LNG export to the domestic market would close the gas-supply gap. As shown in Table 1, the largest gas-supply gap modelled is 3.9 PJ in the financial year (FY) 2020-21. For that year, AEMO's forecasts that the volume of gas used for LNG export is around 1,430 PJ. Therefore, a diversion of only 0.3% of the gas used for export LNG would be required. See Section 7.
Domestic gas demand	In FY 2020-21, AEMO forecasts that the demand for gas consumed within eastern-Australia (i.e. not exported) will be around 530 PJ. AEMO's FY 2020-21 gas-supply gap (3.9 PJ) would be closed if gas demand were 0.7% less than AEMO forecasts. See Section 8.
Gas supply capacity	AEMO bases its gas-system modelling on information provided by the gas industry. Prior to any Final Investment Decisions (FID) for a new gas project, the gas industry often does not provide AEMO with information such as start-up dates or facility capacities. As indicated in Table 1, the largest supply gap occurring in FY 2020-21 can be closed if the capacity of gas supply facilities available in FY 2020-21 is increased by 0.2%. See Section 9.

5 Declining electricity demand

This section describes how high energy costs are impacting eastern-Australian electricity users.

This section also shows that AEMO's forecast FY 2020-21 electricity-supply gap is only 0.19% of the total amount of electricity that is forecast to be required that year. This gap is readily closed by small changes in demand-forecast assumptions, (declining gas demand is discussed in Section 8).

AEMO's electricity-demand forecasts were published in its 2016 National Electricity Forecasting Report or NEFR[51]. That forecast indicates that the demand for grid-supplied electricity will remain relatively flat for the next 20 years ("2016 - Neutral" scenario shown in Figure 9, despite projected 30% population growth and growth of the Australian economy[52].

Two factors restraining demand for grid-supplied electricity are:

- the continuing deployment of "behind-the-meter" rooftop solar photovoltaic (PV).
- continually increasing electrical appliance efficiency.

AEMO's forecast electricity-supply gap of 363 GWh (FY 2020-21) is only 0.19% of forecast demand for that year (187,000 GWh).

Figure 9: AEMO electricity-demand forecasts (published in 2015 and in 2016). AEMO's small forecast supply gap (363 GWh in FY 2020-21) would not be visible on this chart [source: AEMO[53]].

[51] AEMO, *National Electricity Forecasting Report*.
[52] Ibid., page 3.
[53] Ibid., page 22, Figure 5

AEMO also published electricity-demand forecasts for "Strong" and "Weak" scenarios which were characterised by stronger or weaker Australian economic conditions.

In FY 2021-22 (as an example year), the difference between AEMO's "Neutral" scenario versus the "Strong" and "Weak" scenarios is about +/- 5%, or +/ 8,500 GWh. This range highlights the uncertainty of electricity forecasts and is far greater than the 363 GWh supply gap described by AEMO in its 9 March 2017 announcement. A 363 GWh electricity-supply gap is only 0.19% of the total electricity demand forecast for that year (187,000 GWh).

As also shown in Figure 9, AEMO's electricity-demand forecasts published in the previous year's 2015 NEFR featured an even broader range from the "High" to the "Low" scenario: +/-12% (+/ 23,000 GWh).

AEMO has a track-record of reducing electricity-demand forecasts from year to year[54]. From the 2015 NEFR to the 2016 NEFR, AEMO reduced its electricity demand forecast for FY 2020-21 (for example) by approximately 2%.

As described in the next section, it is becoming clear that eastern-Australian electricity demand will trend below AEMO's "Neutral" scenario given the outlook for continuing high gas and electricity prices and the impact of these higher energy costs on industrial consumers[55].

5.1 Update to the National Electricity Forecast Report

Just eleven days after the 9 March 2017 supply-gap warning, AEMO published updated electricity-demand forecasts in a "NEFR Update"[56].

In the NEFR Update, AEMO reduced its forecast NEM electricity demand by approximately 1% (1,580 GWh in FY 2021-22). This update was necessary because of "more recent information on electricity usage from Queensland's Boyne Island Smelter and the Liquefied National Gas (LNG) sector". In its NEFR Update, AEMO referenced a news report that the aluminium output from that smelter would be reduced by 14% due to high electricity costs[57]. The revised forecast published in the NEFR Update easily closes the 363 GWh electricity-supply gap.

As was highlighted by industrial gas buyers at an AEMO-led industry consultation forum held in Melbourne on 11 April, electricity and gas 'demand destruction' is likely to result from high energy costs. Industrial gas users characterised the impact of increasing energy costs with comments such as:

- "frightening from an end-user perspective"
- "no major gas users can afford this gas"
- "there will be a significant loss of industrial activity"
- "it is inevitable that high energy prices will reduce gas and electricity demand".

[54] Sandiford et al., "Five Years of Declining Annual Consumption of Grid-Supplied Electricity in Eastern Australia".
[55] AIG, *Energy Shock: No gas, no power, no future?*
[56] AEMO, *Update: National Electricity Forecasting Report*.
[57] Annett, *What 'significant number' of job cuts mean for BSL*.

6 Demand response & other electricity sources

This section describes how AEMO's forecast gas-supply related electricity-supply gap (363 GWh, or just 0.19% of electricity demand in FY 2020-21) can be closed by small increases in the use of renewable energy or coal. Energy storage and demand response will also have a role to play in ensuring reliable electricity supply.

As described in AEMO's 2017 GSOO (and as reproduced in Figure 10 below), AEMO forecasts that in the coming decade and beyond, grid-supplied electricity in eastern-Australia's NEM will be generated by a mixture of energy sources including coal, liquid fuel (e.g. diesel), hydro, solar, wind, and gas.

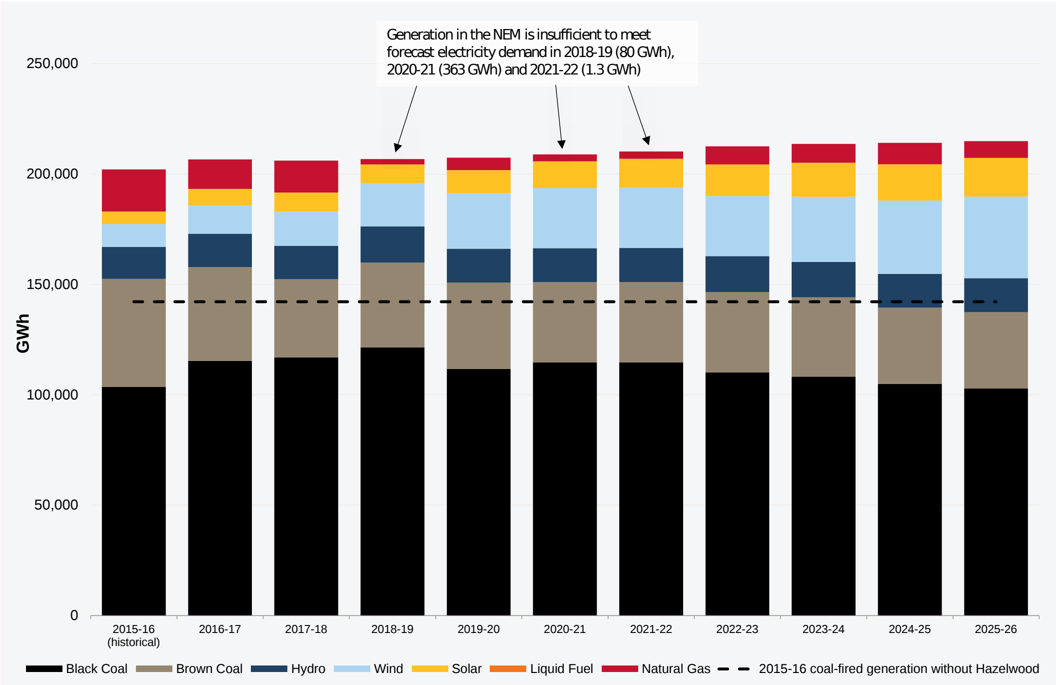

Figure 10: AEMO's forecast electricity generation mix [source: AEMO[58]].

[58] AEMO, *Gas Statement of Opportunities*, Figure 6, page 15.

In Figure 11, AEMO's small FY 2020-21 supply gap (363 GWh) is compared with the amount of electricity that AEMO forecasts will be generated in that year by a range of energy sources.

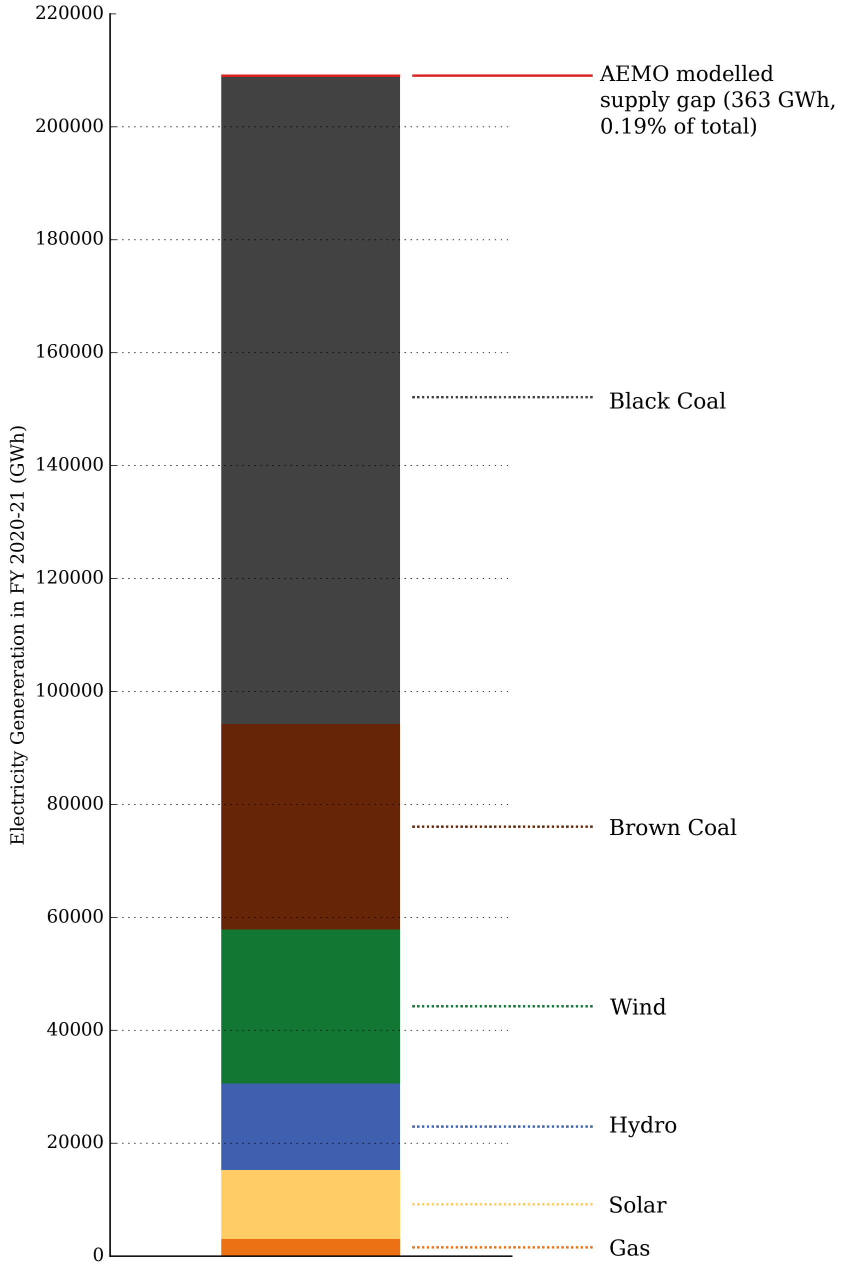

Figure 11: AEMO forecast electricity generated by fuel source in FY 2020-21, showing AEMO's small forecast supply gap as a thin red line at the top of the stack [source: AEMO[59]]

[59] AEMO, *Gas Statement of Opportunities*.

6.1 Renewable generation

As shown in Figure 10, AEMO forecasts that the use of wind and solar to supply grid electricity increases from an actual amount of 16,000 GWh in FY 2015-16 to a forecast amount of 54,000 GWh in 2025-26, an increase of 240%. This increase is driven by renewable energy deployment and greenhouse-gas emission-reduction requirements.

In Figure 11, AEMO's small forecast supply gap (shown as a thin red line) is compared with wind and solar electricity generation expected in FY 2020-21. To close the key 363 GWh electricity-supply gap that AEMO describe for FY 2020-21, the amount of electricity generated from wind and solar would have to be only 0.9% greater than AEMO's modelling forecasts for that year. (Table 1) Assuming a 25% capacity factor, a solar or wind generation facility of approximately 170 megawatt (MW) would produce 363 GWh of electricity in one year.

AEMO includes in its modelling the federally-mandated Large-scale Renewable Energy Target (LRET) and the Victorian Renewable Energy Target (VRET). AEMO does not intend to include in its modelling consideration of the following state-based targets, which AEMO refers to as "aspirational", until mechanisms to achieve these targets are confirmed[60]:

- South Australia – 50% renewable energy by 2025
- Queensland – 50% renewable energy by 2030
- New South Wales – net zero emissions by 2050.
- Victoria – net zero emissions by 2050[61].

Regarding the rate at which renewables-based electricity generation is being installed in eastern-Australia and the impact of this activity on AEMO's forecast supply shortfall, an article published by Renew Economy (28 April 2017) entitled "The shortage may be short-lived" claimed[62]:

> *"AEMO forecasts will likely be revised. There is much more renewable generation being built than is generally acknowledged, something like 5 megawatt (GW) of power and over 11.5 terawatt hour (TWh) of energy. We expect still more projects will be confirmed. In short, the [AEMO forecast gas-supply] shortfall may largely disappear."*

6.2 Thermal generation

For the years shown in Figure 10, AEMO forecasts that the use of coal for electricity generation reaches a maximum level in FY 2018-19. For the following year, AEMO forecasts that coal-use falls significantly by around 6% and then remains at approximately that level for the years after that. During an industry consultation meeting held on 11 April 2017, AEMO stated that this modelling outcome is driven by greenhouse-gas emissions reduction requirements and modelling parameters relating to coal plant flexibility, reliability and availability.

To close the 363 GWh electricity-supply gap that AEMO describe for FY 2020-21, the amount of electricity generated from coal would have to be only 0.2% greater than what AEMO forecasts. (Table 1)

6.3 Energy storage

Energy storage will play a key role in future electricity supply and in closing electricity-supply gaps that might occur for example in AEMO's critical FY 2020-21.

Storing energy with chemical batteries, pumped hydro, or molten salt has been a topic of great discussion in Australia over recent months.

[60] AEMO, *Gas Statement of Opportunities*.
[61] Government of Victoria, *Climate Change Act 2017*.
[62] Leitch, "Gas shortfall may be short-lived, thanks to growing renewables".

In February 2017, Australia's Prime Minister announced a study into the feasibility of incorporating a very large pumped hydro-energy storage scheme into the existing Snowy Mountains Hydro Scheme. This new scheme (known as "Snowy 2.0") might have the capacity to store the equivalent of nearly 400 GWh of electricity in a single weekly charge and discharge at a rate of 2 GW. However, this concept would be unlikely to be built before 2022[63]. Similar concepts have also recently been described where Tasmania becomes "the nation's battery"[64].

For more immediate installation, the state of Victoria has tendered for 100 MW of energy storage, likely to be in the form of chemical batteries. Similarly, South Australia has tendered for 100 MW / 100 megawatt hour (MWh) of battery storage[65]. These facilities could be in place by 2018. 200 MWh of energy storage, used throughout the year, would provide 73 GWh of energy.

Of course because of system losses, any form of stored energy requires a charge of energy that is greater than what the device will supply during subsequent hours or days.

Large-scale energy storage is yet to feature in AEMO's annual planning documents such as the Electricity Statement of Opportunities (ESOO[66]) or the National Transmission Network Development Plan (NTNDP[67]).

6.4 Demand response

The most critical time for the reliability of an electricity grid is during times of high demand. In eastern-Australia, high electricity demand occurs during the evenings following hot summer days when air conditioners are in widespread use. Electricity consumers (ranging from home occupants to very large industries) can be incentivised during critical times to reduce electricity demand. This activity is referred to as Demand Response (DR) or Demand-Side Participation (DSP).

According to the incoming Chief Executive Officer of AEMO Audrey Zibelman[68]::

> *"You don't have to invest in generation that you are only going to use a few hours a year, because you can use the load itself as a balancing resource. It is that signal that says [to peaking power plants]: "Hey there, we don't really need you" that is going to help moderate [wholesale electricity] prices. It's pure economics applying to them and making demand a much more active portion of the grid".*

According to the demand-response vendor Enernoc[69]:

> *"Relative to global peer market, the NEM has exceedingly low levels of demand response participation in its wholesale markets. However, this can be rectified with relatively simple improvements to the NEM's market design."*

In eastern-Australia, AEMO has described demand response activities such as:

- centralised control of appliances, for example air conditioners and hot water heaters
- interruptible commercial and industrial loads / load shedding
- behavioural (incentivised) residential-consumer response
- Distributed Energy Resource (DER) – small generators (including diesel-fuelled) that can be activated at critical times[70].

Such demand-side options may provide more economical ways to deal with critical periods for the electricity grid than using high-cost gas-fuelled electricity generation.

[63] Aston, "Snowy Hydro 2.0 could hasten death of fossil fuel-generated electricity".
[64] Burgess, "Turnbull outlines vision for Tasmania to become 'battery of Australia"'.
[65] Giles Parkinson, "Storage boom".
[66] AEMO, *Update: Electricity Statement Of Opportunities*.
[67] AEMO, *National Transmission Network Development Plan*.
[68] Parkinson, "South Australia should dump diesel plan and think smarter".
[69] Ibid.
[70] AEMO, *National Transmission Network Development Plan*.

7 Diverting LNG

In its 9 March 2017 announcement[71], AEMO pointed out that diverting a small amount of gas from LNG export to the domestic market would close the gas-supply gap.

As shown in Table 1 the largest gas-supply gap modelled is 3.9 PJ in FY 2020-21. For that year, AEMO's expected volume of gas used for export LNG is around 1,430 PJ. Therefore, in that year, a diversion to the domestic gas market of only 0.3% of the gas used for export LNG would be sufficient to close AEMO's forecast supply gap.

Likewise, a small change to AEMO's forecast of the volume of LNG exported closes the supply gap.

AEMO's most recent LNG-export forecasts were published in the 2016 National Gas Forecasting Report (NGFR)[72]. AEMO's forecast methodology is described in AEMO's NGFR methodology report[73] and in a report by Lewis-Grey Advisory[74]. In short[75]:

> *"LNG forecasts were developed undertaking modelling, using a range of public data and the outcomes of technical engagement with producers".*

Following AEMO's 9 March 2017 announcement and actions taken by Australia's Prime Minister (as described in Section 2), gas-industry spokespeople were reported to be critical of AEMO's LNG export forecasts, saying that AEMO over-estimated the volume of LNG sales and therefore the volume of gas that would be required by the LNG industry[76]. Judging from this, gas industry sources are implying there is no gas-supply gap.

In the 2016 NGFR, AEMO offers a range of LNG-export forecasts. As shown by Figure 12, in the year 2021 the "Strong" and "Weak" scenarios vary from the "Neutral" scenario by approximately +/- 15% (+/- 200 PJ). This range of uncertainty is much larger than the 3.9 PJ supply gap described above.

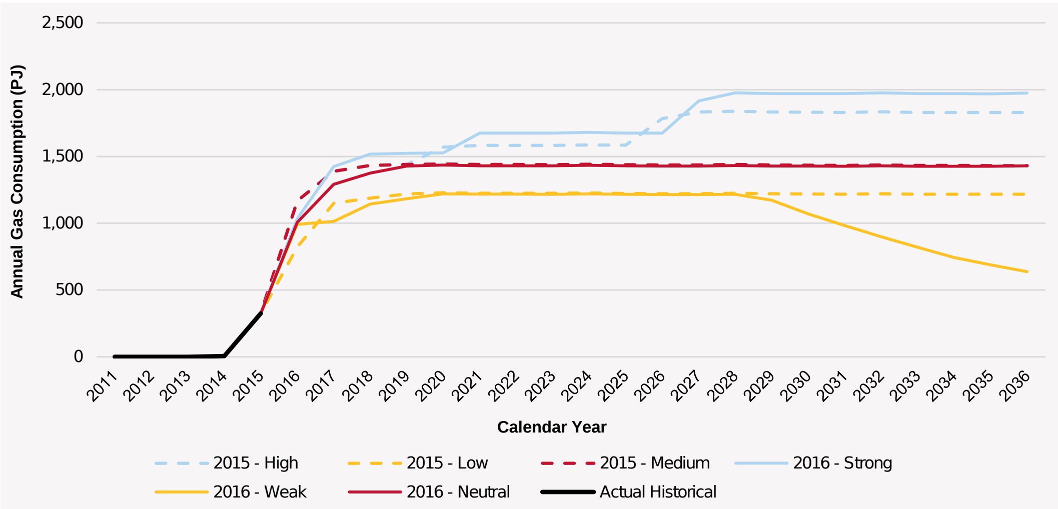

Figure 12: AEMO eastern-Australian gas demand forecast showing ramp-up of LNG exports [source: AEMO[77]].

[71] AEMO, *Media statement: Gas development required To meet future energy demand*.
[72] AEMO, *National Gas Forecasting Report*.
[73] AEMO, *Forecasting Methodology Information Paper*.
[74] Lewis Grey Advisory, *Projections of Gas and Electricity Used in LNG*.
[75] AEMO, *Forecasting Methodology Information Paper*.
[76] Macdonald-Smith, "Gas producers defiant ahead of recall to Canberra".
[77] AEMO, *National Gas Forecasting Report*, page 19, Figure 2.

8 Declining domestic gas demand

This section describes the impact of high energy costs on eastern-Australian energy users, and how gas users might respond. This section also describes how a small change to forecast domestic-gas demand closes AEMO's small forecast supply gap.

Figure 13 shows that domestic-gas demand (excludes gas used for LNG export) peaked in 2012 at 713 PJ[78], and by 2016 had fallen 16% to 589 PJ.

Domestic-gas demand has declined in all sectors: gas used by industry, gas used to generate electricity, and gas used in buildings.

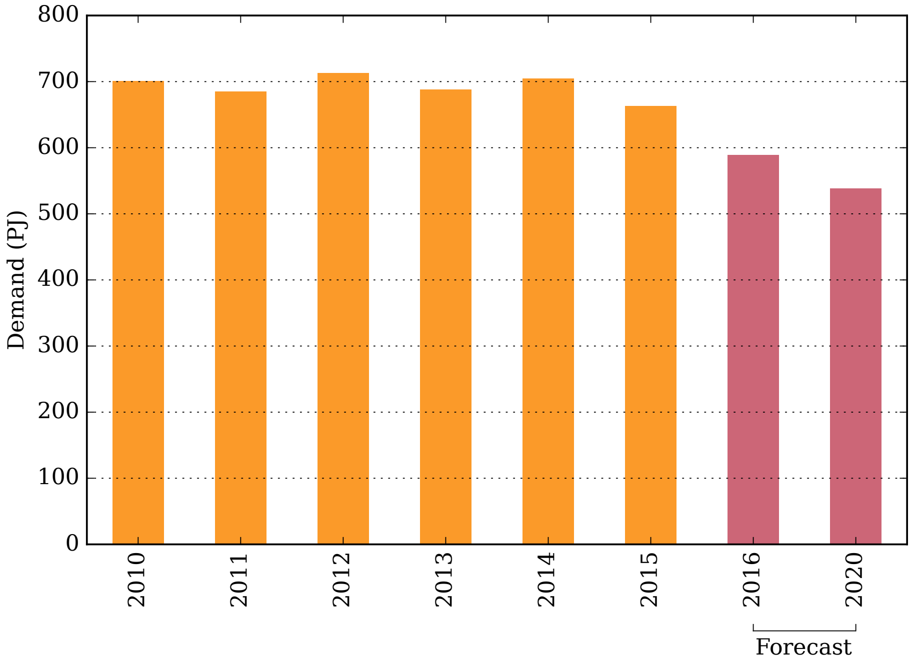

Figure 13: Actual and forecast eastern-Australian gas demand (petajoules). The forecast are taken from the 'neutral' scenario from AEMO's *2016 National Gas Forecasting Report* [source: AEMO[79]].

[78] As described in Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.

[79] Data from AEMO, *National Gas Forecasting Report*, available at `http://forecasting.aemo.com.au/`.

8.1 Gas demand continues to fall

AEMO published its most recent gas-demand forecasts in the December 2016 National Gas Forecasting Report[80]. AEMO forecasts that domestic-gas demand will decline by another 9% over the period 2016 to 2020 to reach a level just 74% of the 2012 peak at 525 PJ (Figure 14).

AEMO forecasts that gas demand will continue to decline in all sectors. The greatest per cent decline is in the gas-for-electricity generation sector (19% decline), followed by gas for industry (10% decline), and then residential and commercial (only a 1% decline).

AEMO forecast that the largest gas-supply gap (3.9 PJ, see Table 4) could occur in FY 2020-21. For that same year, AEMO forecast that eastern-Australian domestic-gas demand will be around 530 PJ. Therefore, AEMO's FY 2020-21 gas-supply gap would be closed if domestic gas demand were just 0.7% less than what AEMO has forecast.

As was described in Section 5.1, on 20 March 2017 AEMO revised down its electricity demand forecasts to reflect reduced industry activity. AEMO's most recent gas demand forecasts do not reflect the continuing escalation of wholesale gas prices seen so far in 2017 and the impact of this price escalation on gas-consuming industries. We judge that in the coming months AEMO will also further revise down its gas demand forecasts.

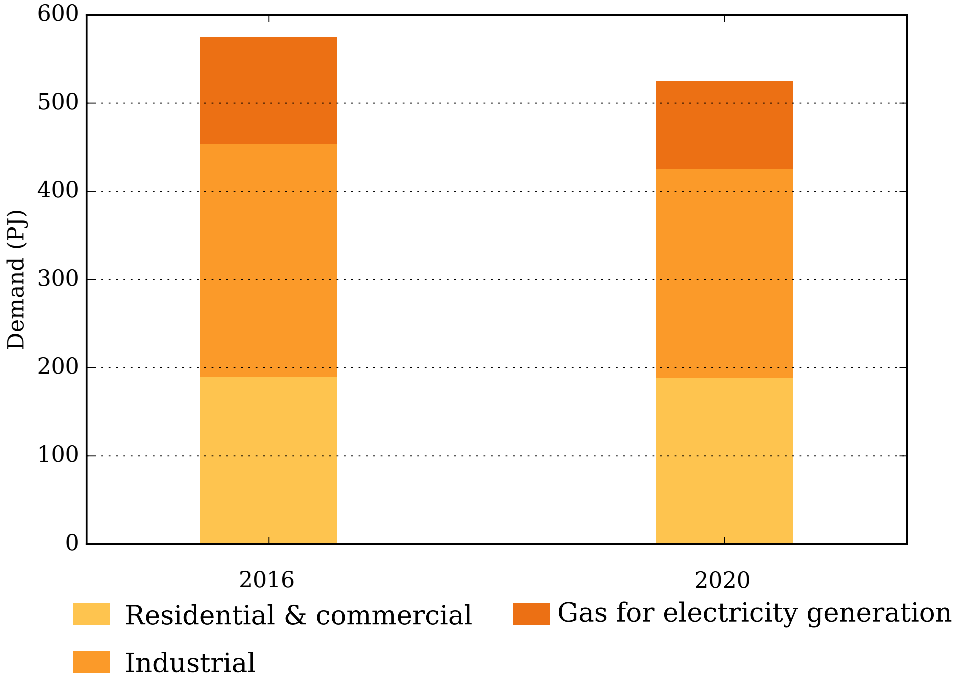

Figure 14: Domestic gas demand forecast for 2020 compared with 2016. The 'neutral' forecast scenario from AEMO's *2016 National Gas Forecasting Report* is illustrated [source: AEMO[81]].

[80] AEMO, *National Gas Forecasting Report*.
[81] Ibid., data available at `http://forecasting.aemo.com.au/`.

8.2 Industrial gas demand

This section describes in more detail how industrial gas demand is declining in eastern-Australia. It also describes options and opportunities for existing and new industries in this new expensive-gas world.

As described in Sections 3.3 and 5, high energy costs are already causing electricity and gas “demand destruction” in eastern-Australia, particularly in the industrial sector.

As shown in Figure 15, AEMO forecasts that eastern-Australian industrial gas demand will continue to decline. In the “Weak” scenario, industrial gas demand in the year 2026 falls to only two-thirds of the 2013 peak (204 PJ vs 302 PJ). In the ‘Neutral” scenario, demand falls to three-quarters of the 2013 peak.

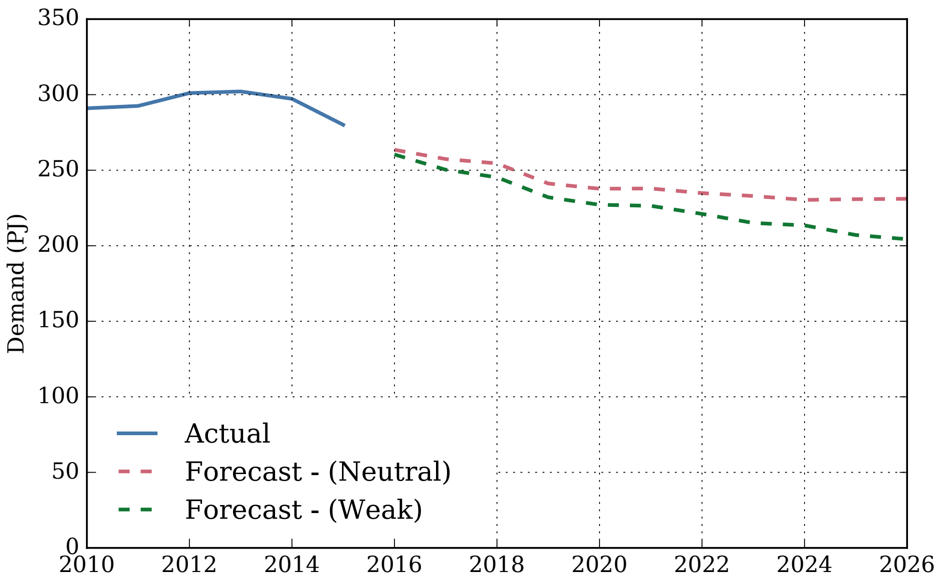

Figure 15: Actual and forecast industrial gas demand in eastern-Australia. The ‘neutral’ and ‘weak’ scenarios from AEMO’s *2016 National Gas Forecasting Report* are illustrated [source: AEMO[82]].

[82]Data from AEMO, *National Gas Forecasting Report*, available at `http://forecasting.aemo.com.au/`.

8.2.1 Fuel switching

In response to high energy costs, industry may employ the energy-efficiency and fuel-switching measures we described in 2015[83,84].

For example in a study for the Australian Renewable Energy Agency (ARENA), IT Power quantified the amount of gas-derived energy used at various temperature levels and potential renewable energy alternatives[85]. Table 3 shows that some of these technologies can achieve very high process temperatures.

Electricity-based technologies can be powered by renewable or non-renewable energy sources. These include:

- heat pumps
- electric-induction heating
- electric-resistive heating
- electric-arc heating.

Process heat level used in manufacturing	**Less than 250°C**	**250°C to 1300°C**	**Greater than 1300°C**
Share of total process heat requirement (33)	9%	45%	47%
Applicable renewable energy technologies for process heat generation			
Electric heat pump – air source	yes		
Electric heat pump – ground source (geothermal)	yes		
Geothermal - direct	yes		
Biomass combustion	yes	yes	
Biogas combustion	yes	yes	yes
Solar thermal - direct	yes	yes	yes

Table 3: Renewable energy alternatives for process heat [source: **MEI**[86]]

[83] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.
[84] Forcey and Sandiford, *The dash from gas: Could demand in New South Wales fall to half?*
[85] ITP, Pitt & Sherry, and ISF, *Renewable Energy Options for Australian Industrial Gas Users*.
[86] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*, page 18, table 2.

8.2.2 Biogas and biomethane

As the price of fossil gas rises and the preference for lower-carbon sources of energy and chemical feedstock increases, the distributed production of renewable biogas and biomethane will become increasingly economic in eastern-Australia. Renewable biogas / biomethane is gas derived from biomass sources and municipal waste[87].

Bioenergy and gas from waste[88] is proving to be a significant resource in countries such as Denmark and Germany[89].

In 2013, the City of Sydney identified that up to 50 PJ/yr of gas[90] could be produced from sources located around Sydney[91,92]. As an example, Sydney Water reports that up to 5 PJ/yr of gas could be created from their own waste sources[93].

In 2012, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) completed work for AEMO's "100% Renewable Energy Study" for eastern-Australia that identified recoverable biogas resource of more than 200 PJ/yr[94].

In 2015 in a report for the ARENA, IT Power described how biogas can displace fossil gas in industrial applications[95].

The above gas volumes can be compared with small gas-supply shortfall of 3.9 PJ/yr that AEMO forecast will occur in FY 2020-21.

8.2.3 Renewable hydrogen

Renewable hydrogen, manufactured via renewable-energy-powered electrolysis, may become the basis for new Australian domestic and export industries[96].

The South Australian government is developing a hydrogen "road map"[97], and in March 2017 commissioned an exploratory "Green Hydrogen Study". That study "is intended to assess the technical and commercial feasibility of producing green hydrogen in South Australia as a central piece of quantitative input to underpin the roadmap." South Australia's aim is to capitalise on their "abundance of renewable resources to become the green hydrogen capital of Australia"[98].

In the Australian Capital Territory (ACT) the feasibility of adding hydrogen to the gas distribution network is also being investigated[99].

[87] This section adapted from 'Switching off gas – An examination of declining gas demand in eastern-Australia' Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.

[88] IEA, *IEA Bioenergy Annual Report 2013*.

[89] IEA Bioenergy Task 37, *Country Reports Summary 2015*.

[90] Note that the City of Sydney study does not utilise timber plantations or native forest timber. The study included a small amount of bioenergy (0.4 PJ/yr) from pine wood processing residues.

[91] City of Sydney, *Decentralised energy masterplan*.

[92] Pigneri Attilio, *Renewable Gases Supply Infrastructure*.

[93] Anders, Peter, *New energy paradigm, better energy better business*.

[94] James and Hayward, *AEMO 100% Renewable Energy Study: Energy Storage*.

[95] ITP, Pitt & Sherry, and ISF, *Renewable Energy Options for Australian Industrial Gas Users*.

[96] Forcey, "Meeting the future needs of Australia's energy customers with renewable energy chemicals".

[97] Government of South Australia, *Our Energy Plan South Australian power for South Australians*.

[98] Dunis, "Could South Australia be the nation's hydrogen state, too?"

[99] ACT Government, *Media Release: ACT Government brings hydrogen energy storage to Canberra*.

8.3 Options for homeowners and building managers - fuel switching

In 2015, we described how home owners and building managers can reduce gas use as well as energy-use overall by implementing energy-efficiency measures and "fuel-switching" from gas-fired appliances to heat pumps[100,101,102].

In 2016, ClimateWorks Australia, in a report for the Australian Sustainable Built Environment Council (ASBEC), also described a scenario where[103] "emissions from gas combustion in buildings can be largely eliminated through a switch to electric alternatives."

For home space-heating, Figure 16 illustrates how a modern heat pump (known as "reverse-cycle air conditioner", RCAC, on mainland Australia) can use just 1/13th of the energy used by a gas-fired system to deliver the same amount of useful heat.

In the diagram on the left, a ducted gas-fired system consumes 33 megajoule (MJ) of gas energy (plus 0.6 MJ of electrical energy) to produce 10 MJ of useful space-heating.

In the diagram on the right, a reverse-cycle air conditioner (or air-source heat pump) uses only 2.5 MJ of electrical energy to produce the same amount of useful heat. This is possible because in space-heating applications, heat pumps recover free renewable-ambient heat from the air surrounding a building. Air-source heat pumps can be said to harvest solar energy because it is the sun that warms the Earth's atmosphere.

Heat pumps can also be used in a similar way to heat water. In Australia, the act of installing a hot-water heat pump can earn renewable energy certificates[104].

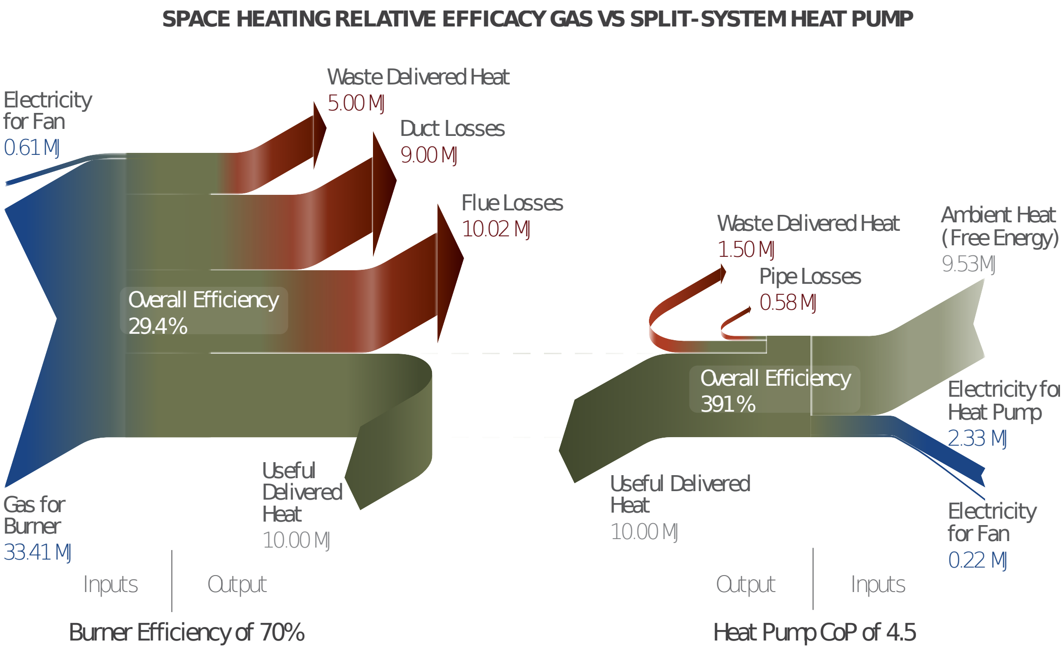

Figure 16: A heat pump space heater (aka reverse-cycle air conditioner) can use just 1/13th the energy of a gas-fired heating system while delivering the same amount of heat to living spaces [source: BZE[105]].

[100] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.
[101] Forcey and Sandiford, *The dash from gas: Could demand in New South Wales fall to half?*
[102] Arup, "Heat pump' tech could save Victorian homes up to $658 a year on gas".
[103] Climate Works, *How buildings can make a major contribution to Australia's emissions and productivity goals*.
[104] Hot water heat pumps are classified grouped with "solar" water heaters at this Clean Energy Regulator.
[105] BZE, *Buildings Plan*, page 85, Figure 3.20.

Table 4 highlights the operating-cost savings possible when using an air-source heat pump (aka reversecycle air conditioner or RCAC) for home space-heating. Savings of $1,733 per year are possible for a large home in Canberra[106].

Location	Home type	Gas space-heating costs (energy- only, excludes fixed supply charges)	RCAC space-heating costs (energy- only, excludes fixed supply charges)	Heating cost savings with RCAC	% savings with RCAC
		($/year)	($/year)	($/year)	(%)
Canberra, ACT	large	$2,255	$522	$1,733	77%
Melbourne, VIC	large	$1,049	$391	$658	63%
Orange, NSW	medium	$1,370	$949	$421	31%
South NSW	small	$599	$415	$184	31%
Adelaide, SA	small	$180	$124	$56	31%
This table lists only five of the 156 region/zone and dwelling-type combinations examined by the ATA.					

Table 4: Annual savings possible by heating with heat pump (reverse-cycle air conditioner or RCAC) [source: MEI[107]]

Figure 17 further emphasises that heat pumps harvest renewable energy. In Australia, where heat pumps are particularly well-suited in our relatively mild climate zones, RCACs recover more renewable energy than is recovered by roof-top solar panels[108]. The amount of energy recovered by RCACs will grow significantly as more Australians learn of their value.

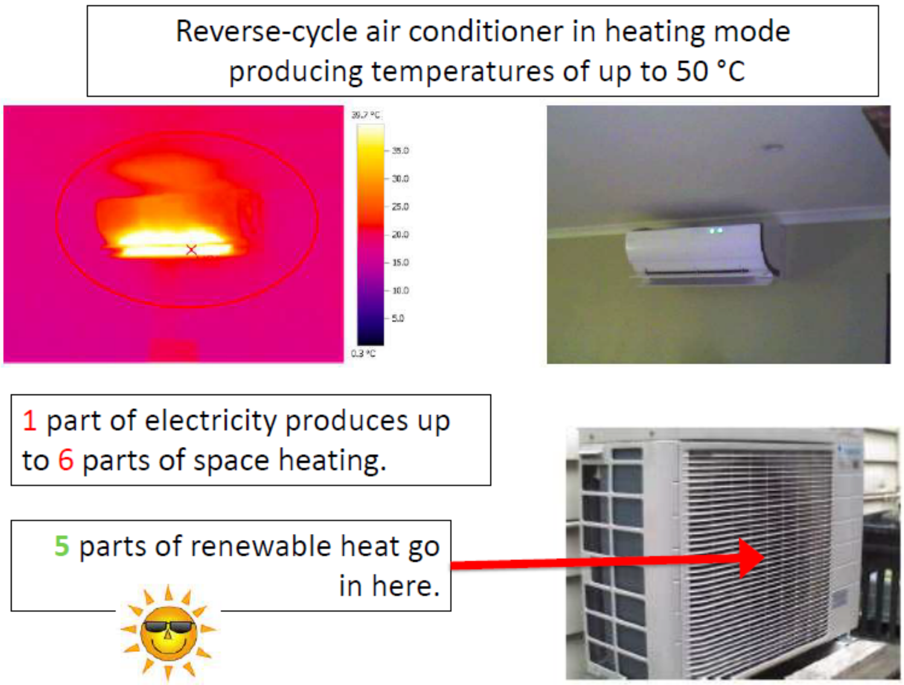

Figure 17: - A reverse-cycle air conditioner in heating mode harvests renewable-ambient heat [source: Tim Forcey[109]].

[106]Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.
[107]ibid., page 24, table 7.
[108]Forcey, "The cheapest way to heat your home with renewable energy - just flick a switch".
[109]Forcey, *Reverse-cycle Air Conditioners: Australian Renewable Energy Giants*.

Given the effectiveness of using air-source heat pumps in Australian buildings, the Alternative Technology Association (ATA) found that there is no economic reason for any new home or suburb to be connected to the gas-distribution system[110].

Previously we described how reducing the uneconomic use of gas in Australian buildings can "free-up" significant volumes of gas for other uses[111]. Figure 18 illustrates how the amount of gas that can be saved annually in eastern-Australian buildings (versus today's consumption) approaches a forecast level of industrial gas demand.

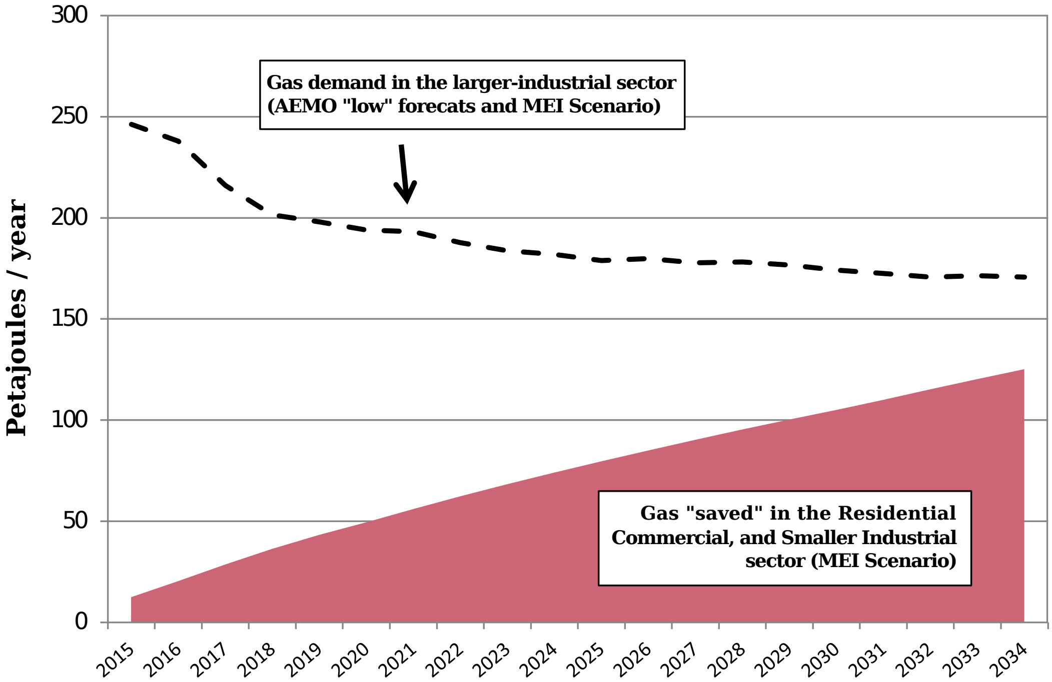

Figure 18: Industrial gas demand (forecast) vs potential for saving gas in building [source: MEI[112]].

[110] ATA, *Are we still Cooking with Gas?*
[111] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.
[112] Ibid., page 40, Figure 20.

9 Existing gas supply

This section describes how the volume of eastern-Australia's gas reserves and resources is significantly in excess to what is required for both domestic use and LNG export. Therefore, it is not a shortage of gas reserves that leads to AEMO's modelled gas-supply gap. Rather, as will be described in Section 9.3, it is AEMO's assumptions and modelling inputs around gas-production-facility capacity that leads to the forecast supply gap.

This section also discusses the high cost of producing certain eastern-Australian gas reserves.

9.1 Current reserves & resources

According to the AEMO report "GSOO Methodology"[113], AEMO obtains information about gas reserves and resources from the consultants Core Energy Group and gas-producing companies.

Shown in Figure 19 and Table 5 are AEMO's forecasts for cumulative gas production over the next 20 years (to 2036), and also an indication from which gas reserve or resource category the produced gas is derived (proved and probable, contingent resources, or prospective resources).

As shown in Table 19, AEMO forecasts that the total amount of gas to be produced over the next 20 years in eastern-Australia is 39,460 PJ (average production of approximately 2,000 PJ/yr). Subtracting that amount from the total reserves and resources of 257,613 PJ leaves a potential-remaining volume of recoverable gas of 218,153 PJ, a volume 5.5 times larger than what will be produced in eastern-Australia over the next 20 years.

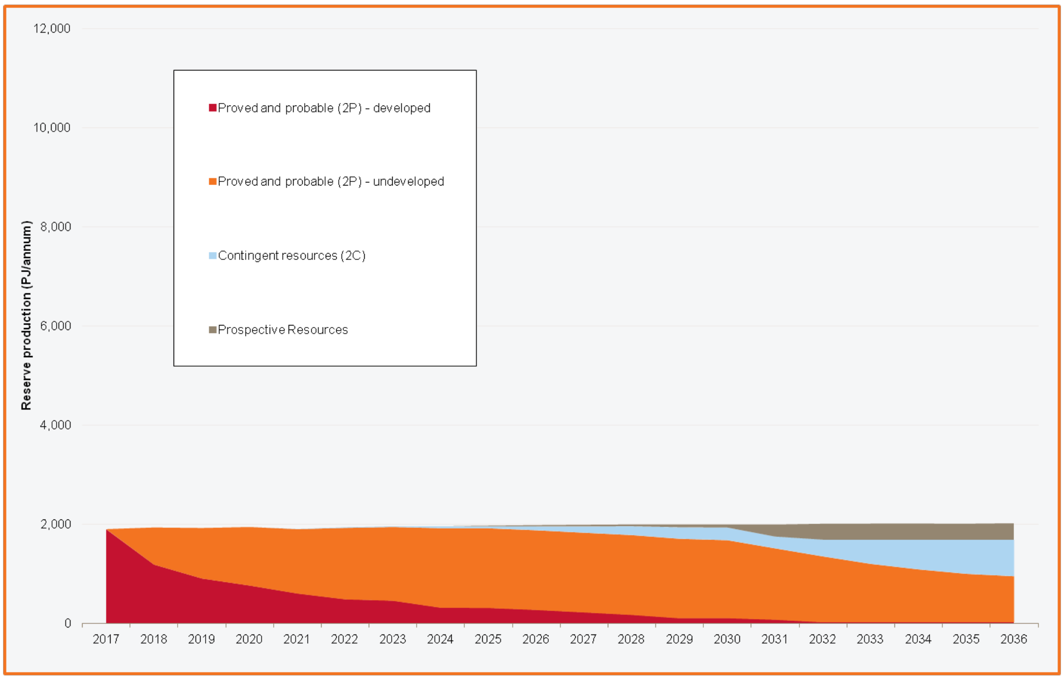

Figure 19: Eastern-Australian 20-year outlook for gas production and use of reserves and resources [source: derived from AEMO[114]].

[113] AEMO, *GSOO methodology*.
[114] AEMO, *Gas Statement of Opportunities*, derived from figure 3.

Table 5: Eastern-Australian gas reserves and resources

Reserve or resource category	Reserves & resources as at 31/12/16 (PJ)	Forecast gas production remaining 2017-2036 (PJ)	Reserves & resources remaining 2036 (PJ)	Reserves & resources remaining 2036 (%)
Proved and probable (2P) reserves	49,316	33,352	15,964	32%
Contingent resources (2C)	56,429	4,052	52,377	93%
Prospective resources	151,867	2.057	149,810	99%
Total	**257,613**	**39,460**	**218,153**	**85%**

Figure 20 reproduces the data shown in Figure 19, but then also shows, for comparison purposes, the remaining 218,153 PJ of gas reserves and resources as if that volume of gas were produced over the 20-year period beyond the year 2036. Figure 20 illustrates that the volume of gas remaining in the ground in eastern-Australia in the year 2036 will far exceed (by 5.5 times) what was produced over the preceding 20 years. This illustrates that the cause of the AEMO-modelled gas supply gap is not a lack of gas reserves and resources.

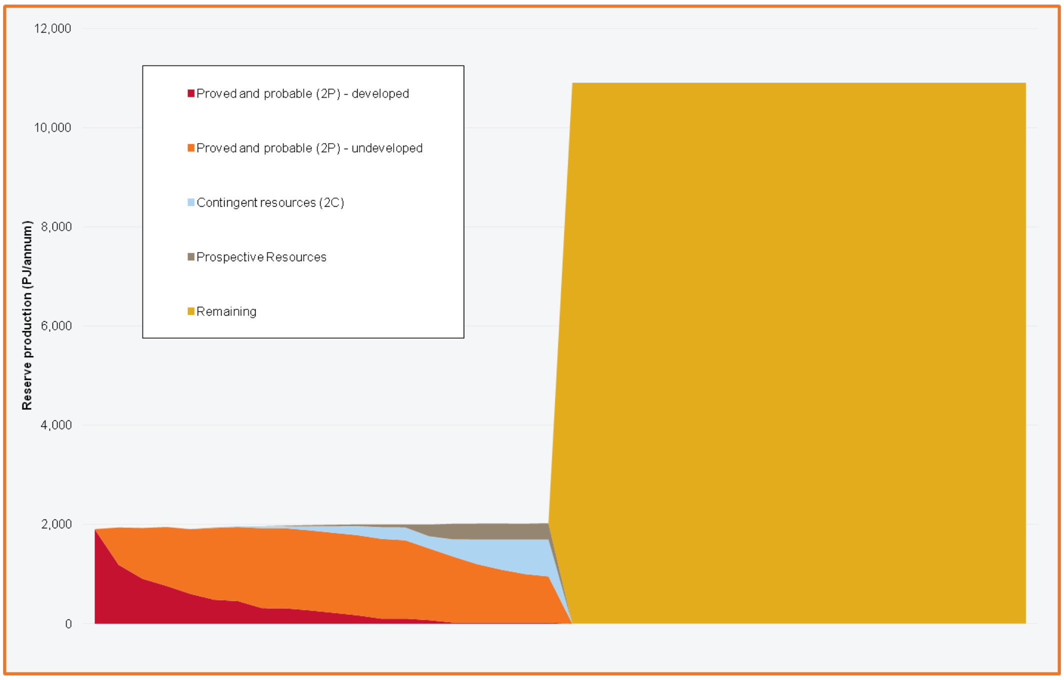

Figure 20: Eastern-Australian gas reserves and resources remaining after 2036 are 5.5 times larger than the volume of gas that will be produced over the 20-year period 2017-2036 [Source: data from AEMO[115]].

[115] AEMO, *Gas Statement of Opportunities*.

Figure 21 illustrates the assessed gas reserves and resources of eastern-Australia's larger gas fields. The reserves and resources directly associated with the three LNG-export projects are shown: Shell-operated QCLNG, the Origin-operated APLNG, and the Santos-operated GLNG.

Of the LNG projects, GLNG has the least amount of proved and probable reserves (shown in orange in Figure 21) and is reported to be purchasing "3rd party" gas to meet its contractual LNG-export commitments made to overseas buyers[116].

The reserves and resources shown below can be compared with the approximately 10,000 PJ forecast to be enough to supply all of eastern-Australian domestic gas needs for the next 20 years.

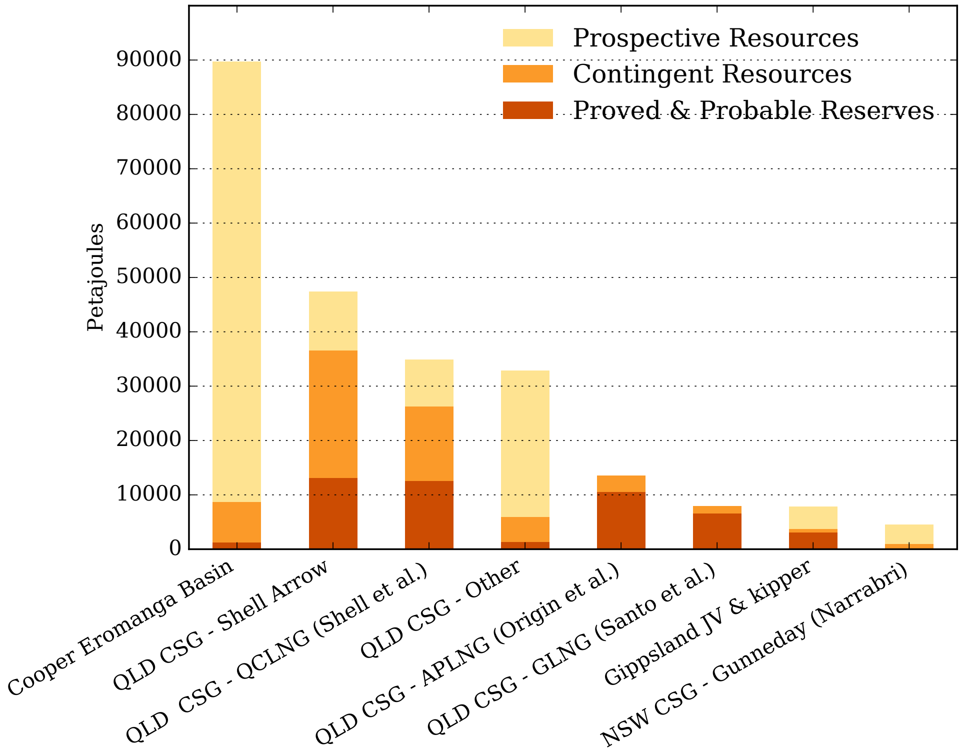

Figure 21: Certain significant eastern-Australian gas reserves and resources by field and project [source: AEMO[117]].

[116]Stevens, "GLNG partners clash over domestic gas plan".

[117]Data from AEMO, *Gas Statement of Opportunities* input data files, available at `https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2017/2017-Gas-Statement-of-Opportunities-input-data-files.zip`.

As was shown by (Table 5), AEMO's modelling indicates that 32% of the gas reserves currently classified as proved and probable will still remain in the ground after 2036. A large part of this "un-produced" 2P-classified gas is controlled by the gas company Shell. The Shell-Arrow Queensland CSG-LNG project has received all regulatory development approvals; however, in early 2015 Shell announced it would defer development[118]. In March 2017, the energy industry consultants Energy Quest commented on the large Shell-controlled eastern-Australian gas reserves[119]:

> *"Sitting quietly in the background on the east coast is a large undeveloped resource of 9,000 petajoules of coal seam gas in Surat and Bowen Basins in Queensland, owned equally by Shell and PetroChina following their takeover of Arrow Energy. These reserves would be enough to supply east coast demand for 15 years at current levels of demand. They were originally earmarked for a fourth LNG project in Queensland but the high costs of development put an end to that.*
>
> *Shell and PetroChina have been silent on development of these reserves, but would be closely monitoring the domestic gas prices and working out the best way to play their hand. It has not worked out well so far. They have spent billions of dollars and all they have to show is lots of feasibility studies but only modest levels of gas and electricity production. Should they throw more good money after bad or just get out"*

AEMO's modelling assumes this Shell-controlled gas is not produced over the next 20 years. However, on 21 March 2017, Shell announced that they would proceed with the 161-well Project Ruby (See also Section 9.3).

Figure 21 also shows the large reserves and resources of the Cooper Eromanga Basin, and those described as "QLD CSG - Other". The smaller gas volumes of the Gunnedah (Narrabri) CSG field, currently under environmental review[120], are also shown.

[118] The Observer, "Shell takes Arrow LNG project off the table —".
[119] Bethune, *Where is the east coast domgas development boom?*
[120] https://narrabrigasproject.com.au/about/environment/.

9.2 Gas production costs

This section describes how the costs of producing newer sources of eastern-Australian gas, in particular coal seam gas (CSG), are at a level where it is unlikely that "cheap" gas prices seen decades ago will return.

AEMO's forecast eastern-Australian gas-production costs are only marginally higher than AEMO and its supporting consultants had forecast a few years ago (for example in August 2012[121]). This as-forecast result is contrary to statements made by gas-industry commentators (including AEMO[122]) about sudden and unexpectedly-high gas production costs related to poorly-understood geology, poor weather conditions, community obstruction, or other reasons.

Figure 22 shows the eastern-Australian gas supply-cost curve. AEMO indicates that at the low-cost end, gas-production costs of around $2/GJ still apply for some proved and probable developed CSG and conventional gas reserves. Figure 22 also shows that 40,000 PJ of gas (i.e. the forecast volume required for 20 years of domestic and LNG-export supply) is available at production costs of less than $5.50/GJ with an average of approximately $4.25/GJ.

This forecast average production cost of $4.25/GJ is only $0.62/GJ higher (17%) than the forecast average of $3.63/GJ published in 2012 (2012 dollars). This result is nearly in-line

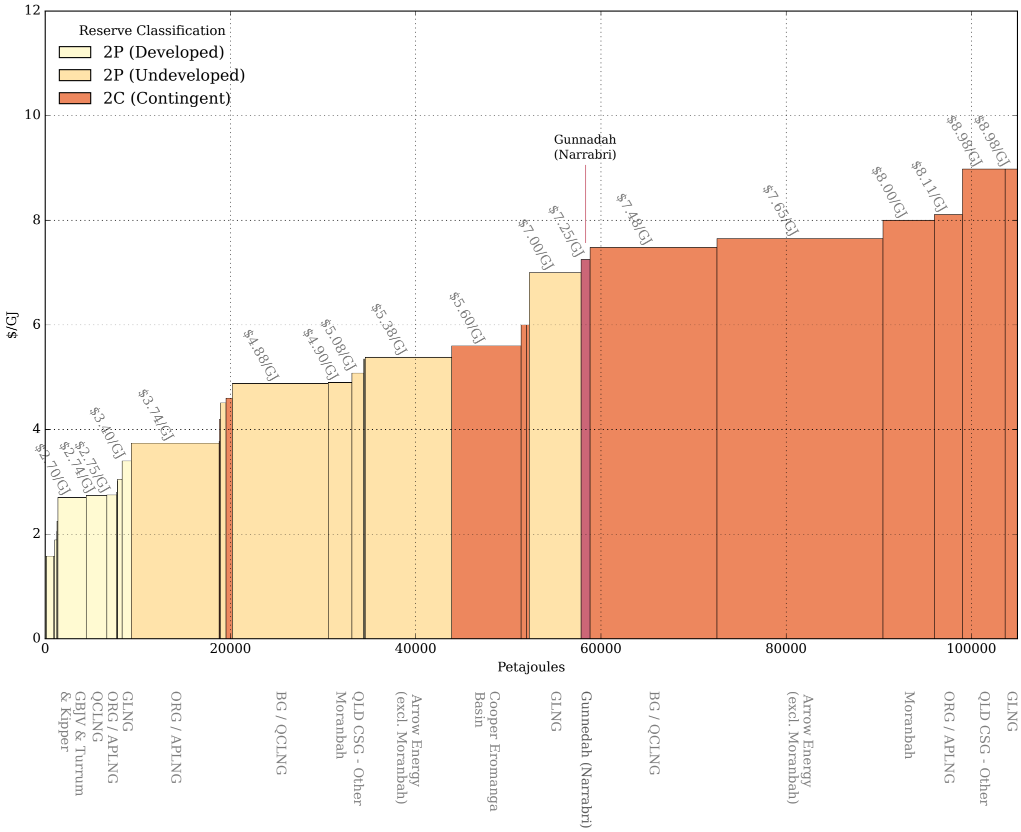

Figure 22: Supply cost curve for eastern-Australian proved and probable gas reserves and contingent resources. Prospective resources with production costs assumed to be greater than $10/GJ are not shown on this figure. Gunnedah (Narrabri) contingent resources are highlighted in red (971 PJ with $7.25 production costs) [source: AEMO[123]].

[121] Core Energy Group, *Gas Production Costs*.

[122] AEMO, *Gas Statement of Opportunities*, See Section 2.1, "Rising production costs and prices".

[123] Ibid. Input data files, data available at `https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2017/2017-Gas-Statement-of-Opportunities-input-data-files.zip`.

with inflation[124]. Nevertheless, considering production costs alone (ignoring international market-price linkages), it is unlikely that low-cost gas, which was available to wholesale gas buyers years ago at only $3 to $4/GJ, will ever return.

Figure 22 shows that production costs as high as $7/GJ apply for some proved-and-probable undeveloped CSG reserves. Some contingent resources may cost around $9/GJ to produce.

Not shown on Figure 22 are 150,000 PJ of prospective resources that are estimated to cost more than $10/GJ to produce. Some offshore gas and some unconventional gas (CSG, shale, tight sandstone) is included in this category of gas resources. Also not shown on this figure is Northern Territory gas. AEMO judges the production costs of that gas to be no less than $6.50/GJ[125].

As shown on Figure 22, the production costs of Gunnedah (Narrabri, NSW) CSG graded as contingent resources are estimated by AEMO and its consultants to cost no less than $7.25/GJ to produce. In other words, this gas is estimated to be more expensive to produce than 58,000 PJ of other eastern-Australian gas reserves and resources, a volume of gas equivalent to approximately 30 years of domestic and LNG-export supply at current extraction rates. Included amongst these cheaper-than-Gunnedah gas resources are the Shell-Arrow CSG and Cooper-Eromanga basin resources.

The costs of transporting gas by pipeline must be added to all sources of gas supply. Pipeline transmission costs vary between regions[126]. We estimate that transmission adds $2 to cost of delivering gas from the Gunnedah (Narrabri, NSW) development, bring total delivered costs to $9.25. The cost of Northern Territory gas when delivered to east coast market is expected to be above $12-$13[127].

[124] Core Energy Group, *Gas Production Costs*.

[125] AEMO, *Gas Statement of Opportunities*, Input data files, data available at `https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2017/2017-Gas-Statement-of-Opportunities-input-data-files.zip`.

[126] Core Energy Group, *Gas Price Consultancy*, see table 3.3, page 13.

[127] Anthony Barich, "NEGI Economics Based On Hope: Wood Mac".

9.3 Increased production

This section describes the gas-production-facility capacity assumptions used by AEMO in its modelling of the eastern-Australian gas-supply system. This section also describes how small changes to AEMO's modelling input assumptions readily close the small forecast gas-supply gap.

As described in its Gas Statement of Opportunities[128]:

> *"AEMO surveyed gas industry participants to obtain detailed gas information including:*
>
> - *processing facility capacities, and potential or committed future expansions.*
> - *pipeline capacities, and potential or committed future expansions.*
> - *LNG facility capacities, and potential or committed future expansions.*
> - *gas project developments (including reserves).*
> - *storage facility capacities and potential or committed future developments.*
>
> *This information is up to date as of 31 December 2016, although AEMO has endeavoured to incorporate more recent information where practical. Collated results from the survey of gas industry participants are available on AEMO's website."*

AEMO then uses the information received from the gas industry as input to its modelling processes. Unfortunately, AEMO has limited powers or capability to confirm, cross-check or assess the accuracy of information provided by the gas industry. For example, discussing the limited information available about gas controlled by Shell, AEMO stated that[129]:

> *"Information relating to the probably timing, production profile, and target market(s) of this gas is not publicly available."*

Therefore, in its modelling, AEMO assumes this Shell-controlled gas is never developed and no gas production capacity is ever built to produce this gas.

Due to the lack of information about gas industry plans, AEMO models certain other gas supplies in a similar way. AEMO highlighted the lack of transparency around other potential gas supplies[130]:

> *"Producers have advised that, under market conditions that incentivise increased production, there may be some scope for supply from existing fields to exceed current projections. The size of this potential increase is unknown."*

As described in Section 4, AEMO's forecast supply gap is only 0.20% of annual gas supply (3.9 PJ/yr). Therefore, if any gas supplier increases supply capacity, beyond what they reported to AEMO, by just 3.9 PJ/yr, the supply gap closes.

Indeed, on 21 March 2017, just days after AEMO announced its gas-supply concerns, Shell announced that it would proceed with the 161-well "Project Ruby"[131]. In its GSOO modelling input datafiles, AEMO shows no information about Project Ruby[132].

[128] AEMO, *GSOO methodology*.
[129] AEMO, *Gas Statement of Opportunities*.
[130] Ibid.
[131] Shell Australia, *Media release: Shell invests in east coast gas supply*.
[132] AEMO, *Gas Statement of Opportunities*.

10 The longer term: Alternatives to gas in the electricity sector

In this section of the report, we look alternatives to gas generation in the power sector in the longer term. We first look at the current role gas plays in the National Electricity Market (NEM), and then consider alternative options for providing this service. Finally, we discuss the long term role of gas in power sector in the context of the *'Paris Agreement'*[133], and limiting dangerous anthropogenic climate change.

10.1 Generation in the National Electricity Market

Electricity is a unique commodity that requires the real-time balance of supply and demand. As electricity demand fluctuates over seasonal, daily, hourly and second scales, the electricity supply system has to be sufficiently flexible to ensure the system remain in balance and demand is met, at all times.

No single technology is currently able to provide this capability at low cost. For example, some generators have the ability to quickly change output levels, but have high operating costs or other limitations. Other technologies have low operating costs, but are less flexible. By combining a range of technologies with differing characteristics and technical capabilities, flexible supply at low cost is provided. It is the responsibility of the AEMO to schedule the differing technologies to ensure demand is met, at lowest cost to consumers.

Brown and black coal have historically provided low cost bulk electricity in Australia. With many power stations built at the mine mouth, the fuel costs have been low. However, a coal generator requires two to three days to start up[134], and the start-up and shutdown cost can be high. As such, coal plants tend to run relatively continuously. This is reflected in Figure 23, with coal providing the majority of energy supplied in then NEM.

Hydro and gas have historically provided flexible supply. These generators have the ability to quickly change output levels and have much smaller shut down and start up times and cost. However, gas generation have higher operating costs, and hydro power is limited by other factors such as rainfall, reservoir size and competing use[135].

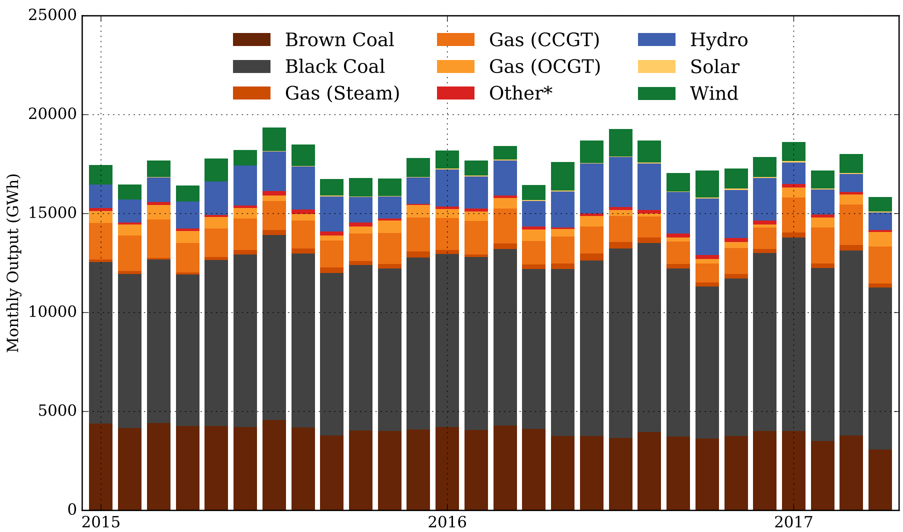

Figure 23: Monthly generation in the National Electricity Market by technology type. Other includes reciprocating engines (both distillate and gas power) as well as biomass. Data from AEMO; own analysis.

[133] United Nations, *Paris Agreement*.

[134] AER, *State of the energy market 2015*, page 27.

[135] For example irrigation, environmental or recreational use.

Role of gas

There are several generation technologies available for converting gas to electricity, each with its own characteristics. In the NEM, three[136] main technology types provide the majority of gas power generation, which are briefly described below.

Steam cycle turbines: These turbines are based on the Rankine Cycle. In this cycle, a source of energy is typical used to heat water and run a steam turbine. This is the cycle that is employed in coal fired power stations.

This generation technology is not particularly flexible. It cannot rapidly start-up and shut-down and tends to operate more continuously. Currently, only some older power stations use this technology[137]. These plants have relatively low thermodynamic efficiency (∼30%), which represents the amount of thermal energy that is converted to electricity.

Open Cycle Gas Turbine (OCGT)): these are based on the Brayton thermodynamic cycle. The turbines are similar to jet engines, with the gas mixing with air and burning to produce a high temperature and pressure gradient which drives a turbine.

OCGT's are very flexible and can both start-up and shut-down quickly, as well as ramp production up and down quickly. These are sometime described as *'peakers'*, able to rapidly respond during peaks in demand, and are typically not utilised much of year. The amount of time they are used varies from a couple of full load hours per year for some plants (capacity factor of <1%), to above 2,500 full load hours for others (capacity factor above 30%).

The thermal efficiency of an OCGT is also relatively low, at around 30%. This results in OCGT's having a relatively high emissions intensity, at 580 to 670 g-CO_2e per kWh of electricity produced[138].

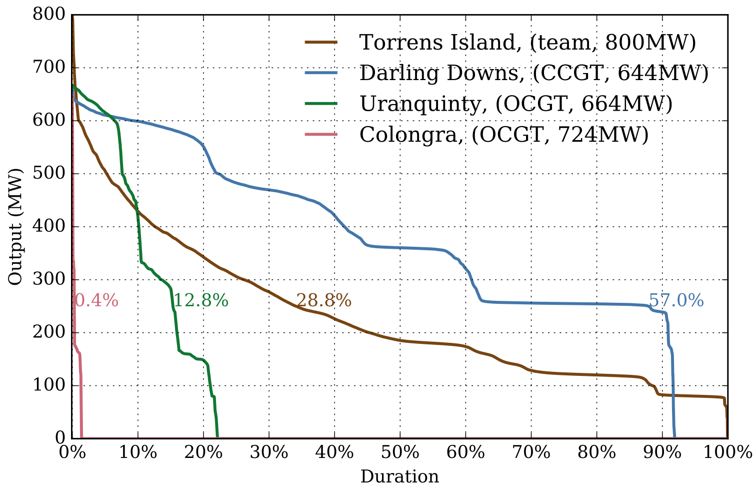

Figure 24: This figure illustrates the *output duration curves* for four different gas generators in the NEM in 2016. In this figure, the output of the generators is ranked in descending order, illustrating the proportion of time that output exceeds a certain level. The percentage figure refers to the capacity factor over the course of the year. While the three plants are roughly similar size, they are operated very differently. Data from AEMO; own analysis.

[136]There is a fourth type: reciprocating engines. This are similar to diesel generators, and have low thermodynamic efficiency.

[137]Torrens Island A & B in South Australia, and Newport Power Station in Victoria.

[138]Combustion emission only. Does not include upstream emissions or methane emissions.

Combined Cycle Gas Turbine (CCGT):

The other type of gas power generator is known as a Combined Cycle Gas Turbine (CCGT). These are based on both the Brayton cycle *and* the Rankine Cycle , hence the name combined cycle. With the CCGT's, heat from the output from a Brayton cycle (e.g. jet engine) is recovered through a steam cycle. As a result, CCGT's are more efficient and able to extract 50% of energy from the gas. As a result, their emissions intensity is lower, approximately 400 g/kWh.

This technology is not as flexible as an OCGT. It cannot start-up and shut-down as easily as an OCGT, and tends to operate more continuously to provide bulk energy, like coal generators. These stations are typically utilised much more than OCGT's. The superior thermal efficiency of these plants means they have super-seeded the gas generators with a steam cycle only.

Figure 24 provides one illustration of the different technologies are used over the course of the year. Four different generators are shown; one steam generator, one CCGT and two OCGT's (a high capacity factor OCGT and a low capacity factor OCGT). As can be seen, the OCGT spend most of their time idle, where as the steam generator is never off. The CCGT is also operating most of the time, and has a high capacity factor (57%).

Figure 25 provides another illustration of different gas generators operating in the NEM. As can be seen, the average output of OCGT's vary considerably more over the course of the day, reflecting the flexibility of the technology. The peaks in average output between 8am and 10am and 4pm and 8pm for OCGT's refelect their role in meeting peak demand. While, CCGT's and steam generators are flexible they have a more steady profile.

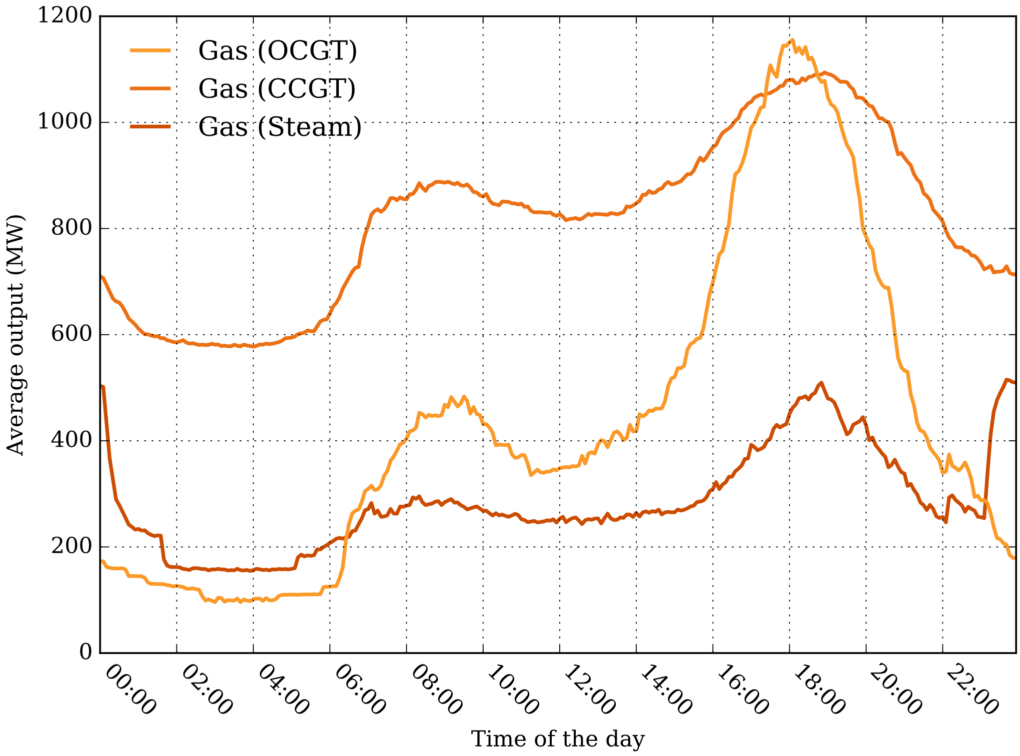

Figure 25: Average output of gas generators by time of day for the 2016 calendar year. The figure illustrates that Open Cycle Gas Turbines mainly operate between 7am and 10pm. Both the Combined Cycle Turbines and the Steam power generators have a more stable output over the day. Data from AEMO; own analysis.

Price formation in the NEM

AEMO schedules different generation technologies to ensure demand is met, at lowest cost to consumers. Conceptually, generators offer their capacity to the market and AEMO dispatches them in order of price (in merit order) to ensure demand is met, subject to a variety of constraints. The last generator dispatched to meet demand sets the clearing price for all generators in the system. This generator is known as the 'price setter', and this process occurs on a five minute basis[139].

The prices that generators offer their capacity to the market is often informed by their marginal cost of production. This the marginal cost of producing an additional unit of power in the short term, and is usually dominated by fuel costs. For renewable energy the fuel cost is $0, and as such the marginal cost of production is zero, or close to zero. Fuel costs for coal are in vicinity of $5–$20 per MWh, and gas is higher again. Some representative marginal fuel costs are presented in Table 6 below.

Gas is increasingly the price setter in the NEM (see Figure 26). Increases in gas prices thus flow through to electricity prices. This has two related implications when considering alternative options to gas generation. As gas is the marginal generator, new lower cost energy generation is likely to displace gas, thus reducing both gas consumption and prices in the NEM.

Table 6: Indicative marginal fuel costs

Technology	Thermal Efficiency (%)	Fuel Cost ($/GJ)	Marginal Fuel Cost ($/Mwh)
Wind	-	$0.0	$0
Brown coal	23%	$0.5	$8
Black coal	36%	$1.5	$15
Gas	45%	$9.0	$72
Gas (peak)	30%	$10.0	$120

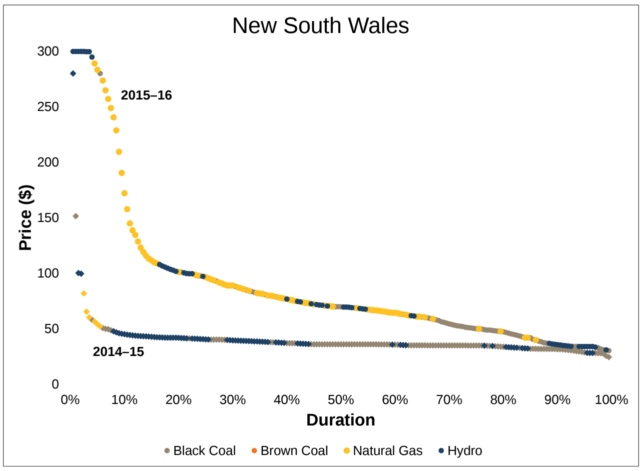

Figure 26: This figure shows the price duration curve for the mainland NEM jurisdictions across two separate years (FY15 and FY16). The fuel type responsible for setting the price indicated by color. As can be seen, prices across FY16 are higher than those in the previous year, and natural gas is setting the price most often [source: AEMO[140]].

[139] Imbalances in supply in demand at sub-5 minute time scales are corrected with the Frequency Control and Ancillary Services market.

[140] AEMO, *Update: Electricity Statement Of Opportunities*, page 23, Figure 8.

10.2 Providing bulk energy

As discussed in Section 10.1 coal fired generation and some gas generation technology has historically provided low cost bulk energy. Over the past seven years, the cost of wind has dropped over 50%, while solar PV costs have dropped over 80%. The fall in the cost of renewable energy continues to exceed expectations[141]. Reductions in the cost of solar and wind technologies in recent years mean that in the future, these technologies will be providing low cost bulk energy.

Solar PV and wind have very low operating costs, which is similar to some coal plants[142]. Where coal has limitations with flexibility, and high start-up and shut down cost, variable renewable generation such as wind and solar PV are limited to operation when weather conditions are favourable. However, and similar to coal, combining these technologies with other forms of generation allows demand to be reliably met at lowest cost to consumers.

In this section, we compare the cost of providing bulk energy from variable renewable sources with bulk energy from gas generation. Specifically, the cost of bulk energy from new build solar PV and wind is compared with sourcing the same energy from both new gas generation and existing gas generation. A *Levelised Cost Of Energy* (LCOE) analysis is performed for new build generation. The LCOE represents the average cost of producing electricity from a particular technology over its life, given assumptions about how the power station will operate. For existing generation, the cost is assumed to be the cost of fuel only (marginal fuel cost), and does not include capital or other costs. The assumptions used in both calculations can be found in Appendix A.

As can be seen in Figure 27 the cost of new build solar PV and wind generation compares favourably with both the cost of new build CCGT *and* existing gas generation. Wind and

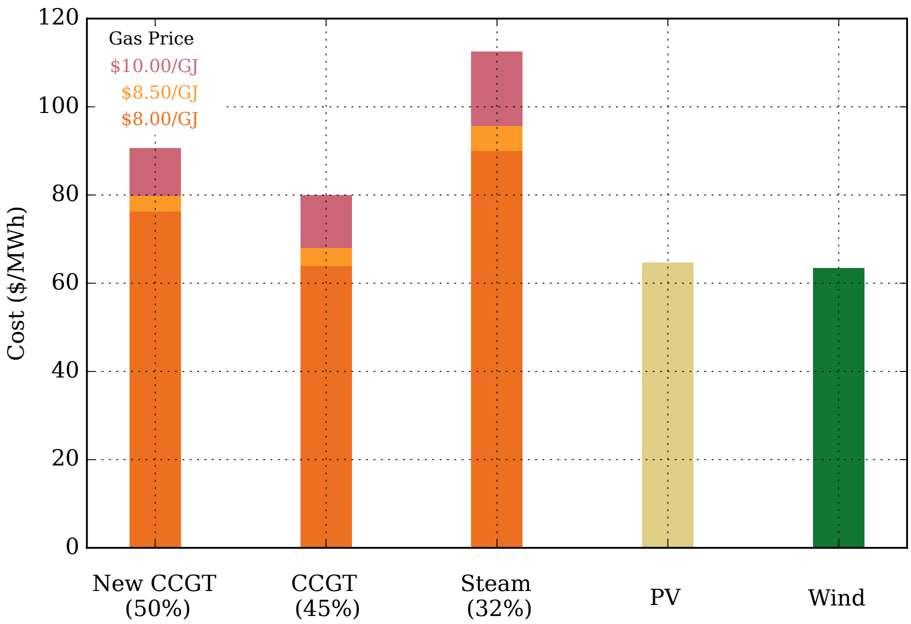

Figure 27: This figure compares the cost of providing bulk energy with gas and renewable technologies. The 'new CCGT', PV and wind cost represent the LCOE (see Appendix A for more details). The other two gas generation costs illustrated ('OCGT' and 'Steam') represent the marginal fuel costs at the respective thermal efficiencies. The steam thermal efficiency is similar to that of an OCGT. The range of gas costs reflects different gas price assumptions. The range of solar and wind costs reflect different capital cost assumptions.

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[141] Finkel, *Preliminary Report of the Independent Review into the Future Security of the National Electricity Market*, page 19.

[142] Brown coal plants have particularly low fuel and operating costs.

solar PV are actually cheaper than new build CCGT, and in same cases cheaper than gas generators that are already built. These are similar findings to analysis recently presented by AGL[143] (see Figure 28).

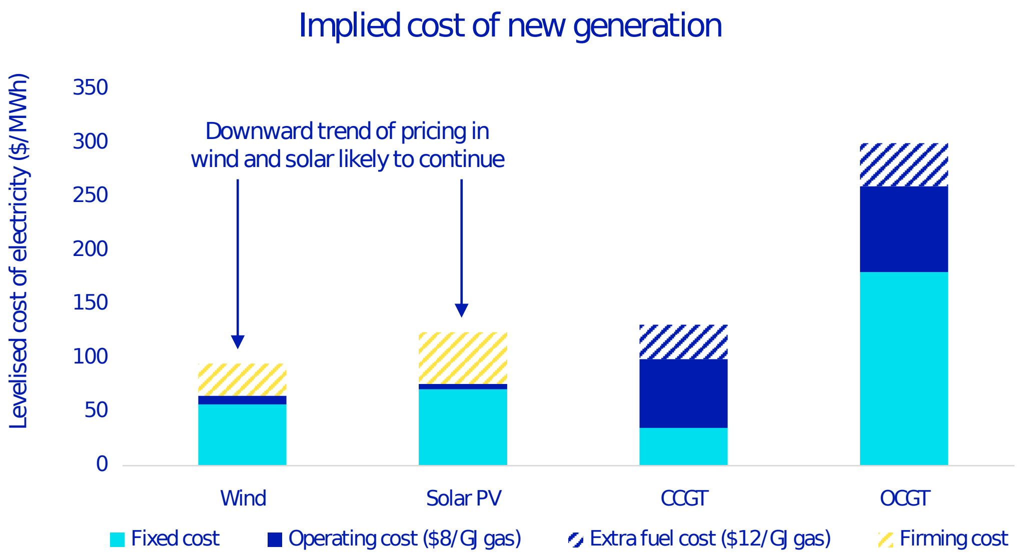

Figure 28: Adapted from AGL. Implied costs of new generation, based on AGL estimates [source: AGL[144]].

10.3 Capacity and flexibility

Historically, hydro power and OCGT's have been the primary provider of capacity and flexible supply in the NEM (as discussed Section 10.1).

The LCOE metric does not provide a good representation of the *value* of energy provided, or the value of flexible *capacity*. OCGT's provide a good example of the limitations of using the LCOE metric. According to the recent Australian Power Generation Technology Study, the LCOE of OCGT is reported to be in the range of $158-$269[145], with further exposure to rising gas prices. This is a high LCOE relative to other technologies (including wind, solar, gas and coal), and higher than historic wholesale prices. However, OCGT stations have been built in recent history[146], since their primary value is providing *capacity* and flexible supply, not bulk energy.

In this section, we compare the cost of capacity of a range of different technologies. We use a modified LCOE calculation to determine the Levelised Cost of Capacity (LCOC) based on the long-run marginal cost of supplying additional capacity (rather than energy). The LCOC represents the price of capacity required for a project to have a net present value of zero. There are many studies that analyse the LCOC[147].

For this analysis, we assume that storage technologies derive additional revenue from providing arbitrage as well as capacity[148]. This is an additional revenue stream that is not available to an OCGT gas *peaker*. Figure 29 compares the cost of providing flexible capacity between gas and storage technologies. Two storage technologies are analysis, battery storage and Pumped Hydro Energy Storage (PHES). As can be seen, storage technologies can provide flexible capacity at similar or lower costs to OCGT technology.

[143] Brett Redman, *A future of storable renewable energy*, page 6.
[144] Ibid., page 6.
[145] Bongers, *Australian Power Generation Technology Report*, page 131.
[146] For example, the 550MW Mortlake OCGT was completed in 2012.
[147] See McConnell, Forcey, and Sandiford, "Estimating the value of electricity storage in an energy-only wholesale market", for a study that specifically looked at the value of storage in the South Australian electricity market.
[148] We assumie storage technologies have sold cap contracts at $300/MWh. For prices at and above $300, the technology only receives $300/MWh in exchange for cap contract revenue.

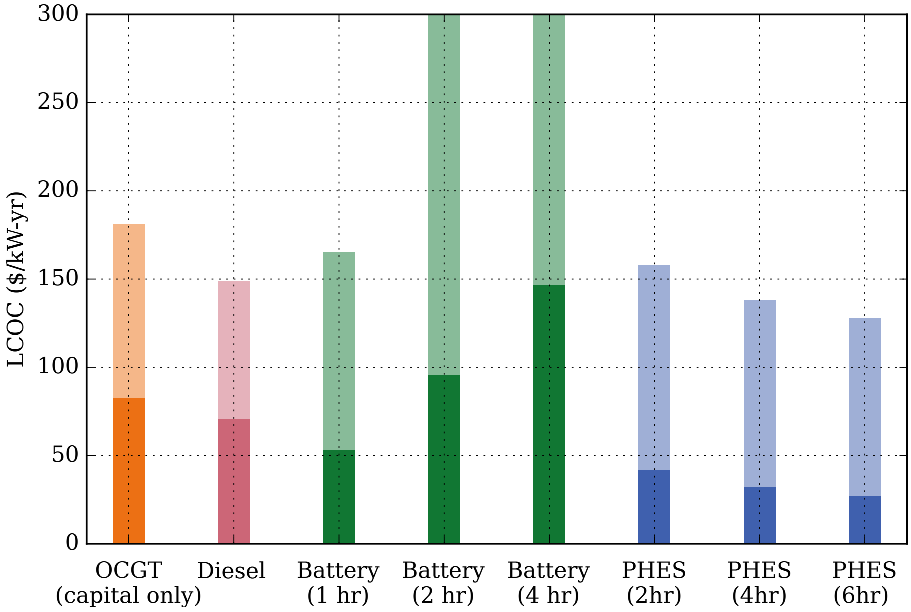

Figure 29: This figure compares the cost of providing flexible capacity between gas and storage technologies. The assumptions used in the *levelised cost of capacity* (LCOC) can be found in Appendix B. For OCGT, the low bound represents the cost of a frame OCGT and the upper bound represents the cost of an aero derivative OCGT. For the storage technologies and diesel, the upper and lower bound represent capital cost ranges. As can be seen, storage technologies can compete with OCGT in providing flexible capacity depending on technology and capital cost.

In this analysis, we consider an OCGT that predominantly provides capacity. This would be similar to the operation of the Colongra plant as illustrated in Figure 24. In this case, fuel costs are not a material factor in determining economic viability.

Whilst OCGT can't derive additional revenue from arbitrage, they can also provide energy. This might result in an operating profile more like Uranquinty, as illustrated in Figure 24. However, as previously discussed, OCGT's do not have a high thermal efficiency, and would incur high operating costs for fuel consumption. Providing bulk energy from an OCGT is even more expensive than CCGT and alternative options (as discussed in Section 10.2).

10.4 Gas powered generation and climate change

In December 2015, a historic global climate agreement was agreed under the United Nations Framework Convention on Climate Change at the 21st Conference of the Parties in Paris. This agreement included a global goal to hold average temperature increase to well below 2°C and pursue efforts to keep warming below 1.5°C above pre-industrial levels. This *'Paris Agreement'* entered into force on the 4th November 2016, after the required ratification conditions were met. On November the 10th, the Federal Government reaffirmed Australia's strong commitment to effective global action on climate change with the ratification of the Paris Agreement[149].

In order to meet the objectives of Paris Agreement, analysis from the International Panel on Climate Change (IPCC) illustrate *'large-scale global changes in the energy supply sector (robust evidence, high agreement)'*[150]. In scenarios where the 2°C objective is achieved, emissions from the energy supply sector are projected to decline by 90% or more below 2010 levels between 2040 and 2070 on global level. Emissions in many of these scenarios are projected to decline to below zero from them onwards.

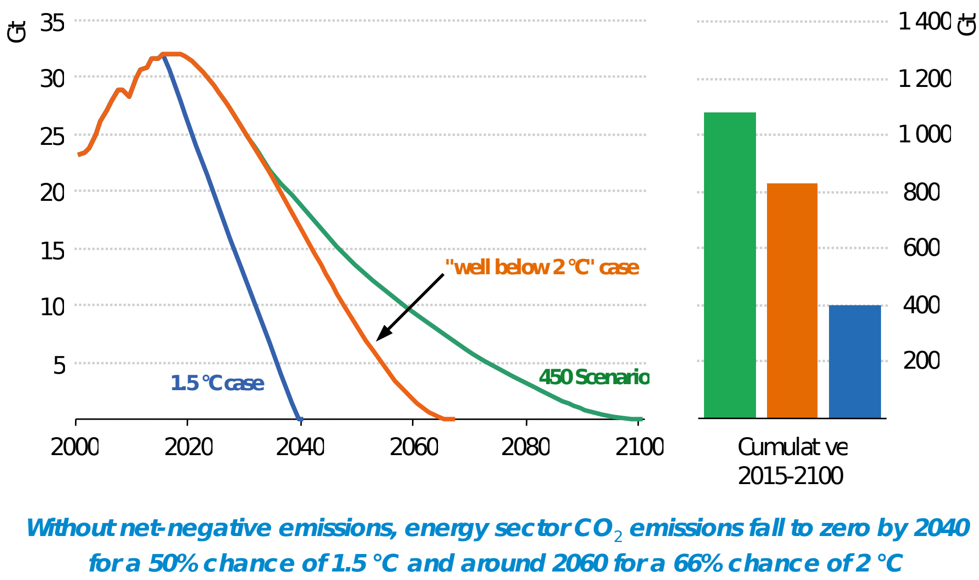

Figure 30: Indicative global energy sector emissions budgets and trajectories for different decarbonisation pathways [source: IEA[151]].

Figure 30 illustrates the direct emissions of CO_2 in the power sector in mitigation scenarios that maintain emissions consistent with a 2°C pathway without assuming "net negative" emissions. According to the International Energy Agency (IEA), for *"likely"*[152] case of being below two degrees, the global emissions intensity in the power section must fall to 0.065 t-CO_2e/MWh by 2040[153]. By 2050, the average CO_2 intensity of electricity in OECD countries needs to fall from 0.411 t-CO_2e/MWh in 2015 to 0.015 t-CO_2e/MWh to meet this the goal[154].

[149] Prime Minister, Minister for Foreign Affairs, and Minister for the Environment and Energy, *Ratification of the Paris Agreement on climate change and the DOHA amendment to the Kyoto Protocol — Prime Minister of Australia*.

[150] IPCC Climate Change, "Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change".

[151] International Energy Agency and Organisation for Economic Co-operation and Development, *World energy outlook 2016*, 75, Figure 2.9.

[152] 66% chance of staying below 2°C.

[153] International Energy Agency and Organisation for Economic Co-operation and Development, *World energy outlook 2016*, page 75.

[154] IEA, *Re-powering Markets*.

Based on current NEM generation, emissions intensity would currently be approximately three times greater than this 15 g-CO_2e/kWh value if all coal generation was to closed today. About 70% *less* gas must be burnt to stay within this emission intensity range at current demand levels.

Figure 31 shows the registered capacity, emissions intensity and age of gas power stations in the NEM[155]. As can be seen both existing and new build gas generation are well below the threshold IEA figure of 15 g-CO_2e/kWh.

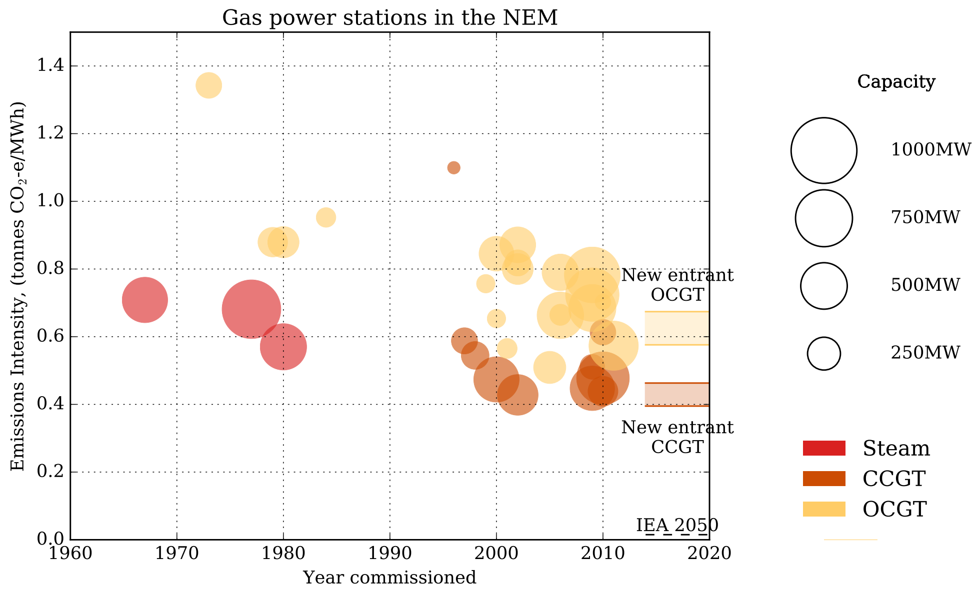

Figure 31: This figure illustrates the emissions intensity, capacity and age of gas power stations in the National Electricity Market (NEM). Generator capacity is illustrated by the size of bubbles, while age is represented on the horizontal axis and emissions intensity on the vertical axis. The different generation technologies include Open Cycle Gas Turbines (OCGT), Combined Cycle Gas Turbines (CCGT) and steam plants and are represented by different colours. The ranges of emissions intensity for both new entrant OCGT and new entrant CCGT are also shown to the right of the figure. The emissions intensity includes both scope 1 and scope 3 emissions[156]. Data from AEMO; own analysis.

[155] This figure only includes generators with publicly available emissions intensity data.

[156] Scope 1 greenhouse gas emissions are the emissions released to the atmosphere as a direct result of an activity, for example the combustion of gas. Scope 3 emissions relate to indirect emissions associated with the extraction, production and transport of fuel to the power station, including for example, methane emissions.

Summary points

- Gas technologies currently provide both bulk energy (CCGT & steam generators) and flexible capacity (OCGT)
- Wind and solar PV are cheaper forms of bulk energy than CCGT.
- In some cases, the cost of new-build renewable energy is cheaper than generating electricity at existing gas power stations.
- Alternative options such as renewable energy and storage can place a downward pressure on electricity prices.
- Storage technologies are competitive with OCGT's in providing flexible capacity.
- OCGT's with low capacity factors don't use much gas in any case.
- Increasing gas combustion in the power sector is inconsistent with Australia's commitment to the *Paris Agreement* objective.

Gas has often been characterised as a 'transition fuel', on the pathway to a zero-emissions power system. The falling costs of renewable energy and storage technologies, the increasing gas cost, and climate change objective suggest this transition is no longer necessary, and indeed a detour. This is a sentiment increasingly reflected by industry, most recently by AGL:

> *'...the National Electricity Market or NEM here in Australia could transition directly from being dominated by coal-fired baseload to being dominated by storable renewables.'*
>
> *"...the energy transition we have all been anticipating will skip big baseload gas as a major component of the NEM's base-load generation and instead largely be a case of moving from big coal to big renewable".*

11 Conclusion: AEMO shortfall was short-lived

Our review finds that the former gas “buyer’s market” that prevailed in eastern-Australia has shifted to become a “seller’s market”. Where formerly, the wholesale gas price had been nearly the cheapest in the developed world at 3 to 4 \$/GJ, today it is now nearly the most expensive - with prices up to \$20/GJ on offer. As was recently confirmed by Australia’s Prime Minister, like crude oil, the price of eastern-Australian gas is now linked to international benchmarks.

Given the high cost of marginal gas production in eastern-Australia (now estimated to be around \$7/GJ excluding pipeline transportation costs) as well as the international price-linkages, a return to delivered-wholesale gas priced below \$8/GJ is unlikely.

On 9 March 2017 with the publication of its Gas Statement of Opportunities, AEMO warned of a small gas-supply shortfall that might impact electricity supply 18 months from now (December 2018). As potential solutions to this shortfall, AEMO suggested new gas pipelines (i.e. from the Northern Territory) and/or new gas fields (i.e. Gunnedah / Narrabri in NSW).

Our review finds that AEMO’s forecast shortfall is very small, amounting to no more than around 0.2% of annual supply (of either gas or electricity). The rapid rise in wholesale gas and electricity prices is and will cause “demand destruction” that is far larger than AEMO’s forecast supply gap. Therefore, we find it unlikely that gas-supply shortfalls will occur as AEMO has described. Indeed, eleven days after announcing its supply-gap concerns, AEMO closed the supply gap when it published updated (lower) electricity-demand forecasts on its website.

We find that AEMO focussed attention on a very small forecast gas-supply shortfall, that is well within the range of uncertainties of the forecast. A more useful message for to gas consumers is that the price of eastern-Australian wholesale gas has increased significantly and is unlikely to return to the low prices previously known. AEMO should also inform energy consumers of the impact that high gas prices have on electricity prices.

Furthermore, our analysis suggests that new pipelines and new (expensive) gas fields might be false “solutions”. These massive fossil-energy infrastructure investments are not needed to address a supply shortfall that is unlikely to occur. Neither will such investments reduce the wholesale gas price.

Given this analysis, it seems pertinent that AEMO and governments inform Australian energy consumers (ranging from home occupants, to commercial building managers, to large industries) of the effective actions they can take to respond to rising energy costs, including:

- reducing gas and electricity consumption though energy-efficiency measures
- fuel-switching to lower-cost renewable energy options, including for example electricity via on-site solar PV, heat pumps (in space-heating applications often referred to as reverse-cycle air conditioners), or bioenergy
- utilising energy storage
- demand-side participation in the electricity market.

Recent actions by Australian governments that seek to reduce gas-industry opacity are greatly warranted, particularly information about gas reserves, facility production capacity, future development plans, and LNG-export contracts and commitments. Greater industry transparency would also improve the usefulness of AEMO’s planning activities.

12 Recommendations

This section describes recommendations that would increase the value of AEMO's planning activities for many stakeholders.

Absent, unclear, and changing government policies challenge AEMO

Over the last decade, the energy policies of Australian federal and state governments have often been short-lived, unclear, or absent. This policy landscape makes it difficult for AEMO to effectively fulfil its planning responsibilities and to anticipate, model, and communicate all reasonable future outcomes. More consistent and clear government energy policies would allow AEMO to more thoroughly investigate a range of relevant future scenarios.

AEMO's modelling is of little value if gas-industry input data is opaque

As described in this report, AEMO lacks information about gas reserves, gas production facility capabilities, and the short and long-term plans of gas producers. Were AEMO able to access better gas-industry information, AEMO's modelling activities would be more robust and have greater value. The Australian Government has directed the ACCC to again scrutinise the gas industry. AEMO should work with the ACCC to obtain the gas-industry information it needs to produce useful energy-system modelling results.

Developing an Integrated Resource Plan (IRP)

In 2015, MEI described that eastern-Australia needs an Integrated Resource Plan (IRP). This should consider not only gas-supply options but also gas demand-management options such as economic fuel-switching and energy-efficiency measures. As fuel-switching from gas to electricity occurs, the demand for electricity may increase. Therefore, consideration of electricity generation and distribution must also be part of the Integrated Resource Plan[157].

With its 2017 GSOO, AEMO now recognises the need to investigate and model gas and electricity in an integrated way, stating that "gas and electricity markets cannot be viewed in isolation"[158]. However, it is less clear that AEMO has recognised a responsibility to investigate demand-side opportunities with vigour equal to its investigation of supply-side opportunities.

As MEI wrote in 2015[159]:

> *AEMO publishes the Gas Statement of Opportunities (GSOO) in accordance with Section 91DA of the National Gas Law. A stated aim of the GSOO is to '...provide industry participants, investors, and policy-makers with transparent information to support decision-making to ensure gas – a key resource – is managed in Australia's long-term interests.'*
>
> *Regarding that stated aim, the often inefficient and wasteful use of gas, particularly in the buildings sector, is not in Australia's long-term interests. AEMO and other relevant authorities should develop an Integrated Resource Plan that, in addition to supply-side opportunities, also identifies and recommends economic opportunities for fuel-switching from gas to electricity and energy-efficiency measures. Such a plan is likely to identify that large and economic gas "discoveries" can be found in industry and in the buildings of eastern-Australia.*

[157] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.
[158] AEMO, *Gas Statement of Opportunities*.
[159] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.

AEMO should model all reasonable alternatives

Assuming, as per the above recommendations, that AEMO is able to access useful gas-industry data, and develops the capability to model and analyse gas and electricity demand-side and supply-side opportunities and interactions, then AEMO should model the full range of reasonable alternatives.

Often AEMO has restricted its modelling to describe established government policies. Alternative policies of great interest to stakeholders within Australian society should also be modelled and communicated. As one example, with the exception of the 2013 federal government-mandated '100 Per Cent Renewable Energy'[160], AEMO has not modelled scenarios that involve very strong climate policies aimed at minimising the impacts of climate change.

Communicating modelling results and potential consequences

Governments should work with AEMO to understand, test, and critique AEMO's modelling results. In the past, governments have interpreted AEMO's narrow messages as "gospel"[161]. When, in future, AEMO models and communicates all reasonable alternatives, there will be no single gospel. AEMO should then work with stakeholders to identify what possible future impacts are indicated by the range of modelled scenarios.

Helping large and small consumers to deal with high gas prices

As MEI suggested in 2015[162], in this era of sustained high gas and electricity prices, governments, AEMO, and consumer-assistance bodies can help small and large gas consumers to deal with high gas prices by:

- communicating what opportunities exist for energy efficiency and fuel-switching measures
- removing subsidies that encourage uneconomic use of gas
- removing subsidies that encourage uneconomic expansion of the gas grid
- strengthening the regulatory oversight of the marketing of gas and gas appliances - which are often claimed to be cheaper, more efficient, and more environmentally benign than all electrically-powered appliances
- facilitating the identification and financing of economic fuel-switching and energy efficiency projects
- reducing infrastructure costs by rationalising the gas grid where economic.

[160] AEMO, *100 Percent Renewables Study: Draft Full Report*.
[161] NSW Legislative Council., *Supply and cost of gas and liquid fuels in New South Wales*.
[162] Forcey, *Switching off gas: An examination of declining gas demand in Eastern Australia*.

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Appendix A Levelised Cost of Energy

Economic assumptions

The following assumptions were used across LCOE calculations for all technology. Real 2015 dollars are used, in order to directly use costs from the 2015 *Australian Power Generation Technology Report*[163]. Inflation is only used to de-escalate recent (2017) costs where necessary.

Table 7: Economic assumptions

WACC (real)	5%
Economic life	20 years
Inflation	2.5%

Capital costs

These costs are all from a range of sources. For CCGT and the 'high' range of renewable capital costs, data from the *Australian Power Generation Technology Report* from 2015[164] is used. Since cost reductions in renewable technology have continued to decline since this report was prepared, 'low' range estimates from media reports are also included[165,166].

Table 8: Capital Costs ($/kW installed)

Technology	Capital cost ($/kW)	Source
Wind (High)	$2,450	Bongers et al. (2015)
Wind (Low)	$2,100	Vorath (2017)
Solar PV (High)	$1,570	Macdonald-smith (2017)
Solar PV (Low)	$1,780	Macdonald-smith (2017
CCGT	$1,450	Bongers et al. (2015)

Operating & maintenance costs

These costs are all taken from the *Australian Power Generation Technology Report* from 2015[167].

Table 9: Operating & Maintenance Costs

Technology	Fixed O&M ($/kW-year)	Variable O&M ($/MWh)
Wind	$25	-
Solar	$55	-
CCGT	$20	$1.5

[163] Bongers, *Australian Power Generation Technology Report*.
[164] Ibid.
[165] Vorath, *ERM Power signs PPA for 212MW wind farm in Port Augusta*.
[166] Macdonald-Smith, "Solar closing cost gap with wind, conventional power".
[167] Bongers, *Australian Power Generation Technology Report*.

Fuel prices

Gas prices were drawn from Core Energy Group's most recent report to AEMO, the *NGFR gas price assessment: final report*[168]. Core Energy presents three different gas price scenarios (Neutral, Weak, and Strong), which form the basis of the three gas prices sensitivities explored in this analysis, which are shown in Table 10. The price projections for the neutral scenario are illustrated in Figure 32.

Table 10: Gas price assumptions

Sensitivity	Gas Price ($/GJ)
Low	$8.00
Mid	$8.50
High	$10.00

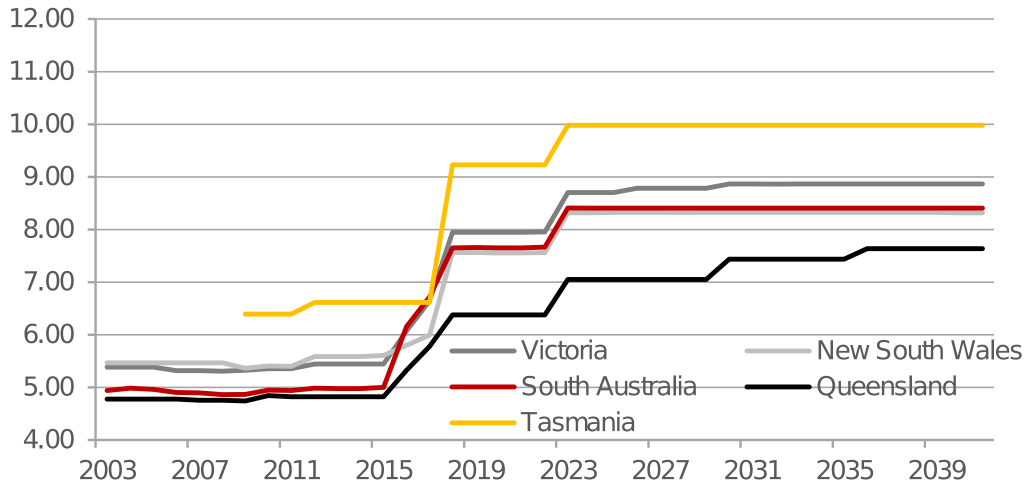

Figure 32: Projection of average gas powered generation gas prices for each NEM state, at transmission pipeline delivery point for the neutral scenario [source: Core Energy Group[169]].

Capacity factors

Capacity factor assumptions were also drawn from the *Australian Power Generation Technology Report*[170]. For wind, a mid point of the range reported was used.

Table 11: Capacity factor assumptions

Technology	Capacity Factor
Wind	38%
Solar	25%
CCGT	85%

[168] Core Energy Group, *NGFR gas price assessment*.
[169] Core Energy Group, *NGFR gas price assessment*.
[170] Bongers, *Australian Power Generation Technology Report*.

Appendix B Levelised Cost of Capacity

The Levelised Cost of Capacity analysis is based on the approach used in *Estimating the value of electricity storage in an energy-only wholesale market*[171]. See this paper for more details.

Economic assumptions

That same economic following assumptions were used across LCOC calculations for all technology as in the LCOE calculations (see Appendix A and Table 7).

Capital cost asssumptions

These costs are all from a range of sources. For CCGT and diesel, the high and low cost ranges were taken from the *Australian Power Generation Technology Report* from 2015[172]. Capital cost estimate for the range of battery storage options analysed where taken from *Lazard's Levelized Cost of Storage Analysis*[173]. The capital cost range for PHES was taken from *Estimating the value of electricity storage in an energy-only wholesale market*[174].

Table 12: Capital costs, ($/kW installed).

Technology	High	Low	Source
OCGT	$1,000	$1,200	Bongers et al (2015)
Diesel	$1,050	$950	Bongers et al (2015)
Battery (1h)	$758	$1,508	Lazards (2015)
Battery (2h)	$1,430	$3,276	Lazards (2015)
Battery (4h)	$2,052	$5,052	Lazards (2015)
PHES	$1,000	$2,000	McConnell (2015)

Annual fixed operation and maintenance costs where also considered for OCGT's ($8-$10 per kW-year[175]) and PHES ($7.5/kw-year[176]).

Replacement capital cost asssumptions

Replacement costs were also taken into account for battery storage (10 year replacement costs from *Lazard's Levelized Cost of Storage Analysis*[177]), summarised below.

Table 13: 10 year replacement costs for battery storage technologies ($/kW installed).

Battery Size	Low	High
Battery (1h)	$964	$1,344
Battery (2h)	$640	$884
Battery (4h)	$360	$455

[171] McConnell, Forcey, and Sandiford, "Estimating the value of electricity storage in an energy-only wholesale market".

[172] Bongers, *Australian Power Generation Technology Report*.

[173] Lazard, *Lazard's Levelized Cost of Storage Analysis*.

[174] McConnell, Forcey, and Sandiford, "Estimating the value of electricity storage in an energy-only wholesale market", see supplementary material.

[175] Bongers, *Australian Power Generation Technology Report*, see page 125.

[176] McConnell, Forcey, and Sandiford, "Estimating the value of electricity storage in an energy-only wholesale market", see supplementary material.

[177] Lazard, *Lazard's Levelized Cost of Storage Analysis*.

Arbitrage value

The arbitrage value of storage is taken into account in this calculation. To do this, the additional revenue from arbitrage when prices are less than ¡$300 are considered as an additional revenue stream. The additional arbitrage value for different amounts (hours) of storage is shown below in Table 14.

Table 14: Arbitrage value for energy storage technologies

Hours Storage	<$300 Arbitrage value ($/kW-year)
1	$40
2	$50
4	$60

Acronyms and abbreviations

ACCC Australian Competition and Consumer Commission.
ACT Australian Capital Territory.
AEMO Australian Energy Market Operator.
AER Australian Energy Regulator.
APLNG Australia Pacific LNG.
ARENA Australian Renewable Energy Agency.

CCGT Combined Cycle Gas Turbine.
CSG Coal Seam Gas.
CSIRO Commonwealth Scientific and Industrial Research Organisation.

DER Distributed Energy Resource.
DR Demand Response.
DSP Demand-Side Participation.

ESOO Electricity Statement of Opportunities.

FY Financial Year.

GJ gigajoule.
GLNG Gladstone LNG.
GSOO Gas Statement of Opportunities.
GW megawatt.
GWh gigaawatt hour.

IEA International Energy Agency.

LCOC Levelised Cost of Capacity.
LCOE Levelised Cost of Energy.
LNG Liquefied Natural Gas.
LRET Large-scale Renewable Energy Target.

MEI Melbourne Energy Institute.
MJ megajoule.
MW megawatt.
MWh megawatt hour.

NEFR National Electricity Forecasting Report.
NEM National Electricity Market.
NGFR National Gas Forecasting Report.
NTNPD National Transmission Network Development Plan.

OCGT Open Cycle Gas Turbine.

PHES Pumped Hydro Energy Storage.
PJ petajoule.
PV photovoltaic.

QCLNG Queensland Curtis LNG.

RCAC Reverse-Cycle Air Conditioner.

TWh terawatt hour.

VRET Victorian Renewable Energy Target.

A review of current and future methane emissions from Australian unconventional oil and gas production

October 2016

Dimitri Lafleur - PhD student, Australian-German Climate and Energy College[1]
Tim Forcey - Energy Advisor, Melbourne Energy Institute[1]
Hugh Saddler - Hon. Assoc. Professor, Crawford School[2]
Mike Sandiford - Professor of Geology, School of Earth Sciences[1]

1. University of Melbourne
2. Australian National University

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Melbourne Energy Institute
McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

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Melbourne Energy Institute
McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

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Melbourne Energy Institute
McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

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The University of Melbourne Energy Institute is an access point for industry, government and community groups seeking to work with leading researchers on innovative solutions in the following areas: new energy resources; developing new ways to harness renewable energy; more efficient ways to use energy; securing energy waste; and framing optimal laws and regulation to achieve energy outcomes.

About the Authors

Dimitri Lafleur is a PhD student at the Australian German College of Climate and Energy Transitions at the University of Melbourne. Dimitri worked for the oil and gas company Shell for 11 years in the Netherlands and Australia after graduating from the University of Utrecht with an MSc geology/geophysics. Dimitri is researching the climate impact of fugitive emissions of the fossil fuel industry and unconventional gas in particular.

Tim Forcey is a Chemical Engineer with over 30 years of experience in industrial energy with ExxonMobil, BHP Billiton, and Jemena, including specific experience with assets such as the Bass Strait oil and gas joint venture and the Queensland Gas Pipeline. With the Melbourne Energy Institute, Tim has published reports and articles covering gas and electricity demand, gas-to-electricity fuel-switching, applications of heat pump technology, and pumped-hydro energy storage.

Dr Hugh Saddler is Principal Consultant in the Climate Change Business Unit of Pitt & Sherry and an Honorary Associate Professor at the Crawford School of Public Policy at the Australian National University. He has been fully engaged in the analysis of major national energy policy issues in the UK and Australia as an academic, government employee and consultant. He is the author of a book on Australian energy policy and of over 70 scientific papers, monographs and articles on energy, technology and environmental policy.

Prof Mike Sandiford is Chair of Geology at the University of Melbourne, and was Foundation Director of the Melbourne Energy Institute from 2009-2016. Mike has published over 170 peer-reviewed scientific papers. He was recipient of consecutive ARC professorial fellowships (2000-2009), the Mawson Medal from the Australian Academy of Sciences in 2004 for outstanding contributions to Australian Earth Science, the Hobbs Medal, the Carey Medal, and has thrice been awarded the Stilwell Medal from the Geological Society of Australia. He is a fellow of the Australian Academy of Science and the Geological Society of Australia.

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Executive summary

Background

Methane is a powerful greenhouse gas, 86 times more powerful than carbon dioxide when its atmospheric warming impacts are considered over a 20-year time period, and 34 times more powerful over a 100-year time period. Reducing methane emissions is therefore an important part of any strategy to avoid dangerous climate change, as agreed by world leaders at the December 2015 Paris conference. Given the vast growth potential of unconventional oil and gas in Australia, this review addresses the current understanding of methane emissions by that industry, referencing recent developments in overseas jurisdictions.

If natural gas is to provide maximum net climate benefit versus coal, the release of methane to the Earth's atmosphere (both intentional and unintentional) must be held to less than about one per cent of total gas production. In this context, the commitment of the Australian CSG-LNG industry[1] to limit methane emissions to no more than 0.1% of total gas production is commendable.

Findings

In its most-recent greenhouse-gas inventory submitted to the United Nations, the Australian Government reported that methane emissions from the oil and gas industry amounted to 0.5% of gas production. Despite rapid increases in produced-gas volumes, Australia's oil and gas sector-methane emissions have been reported as declining since 1990 and increasing only slightly since 2005. At face value, this result is in-line with industry commitments to keep methane emissions low.

However, this low level of reported methane emissions contrasts with unconventional gas developments in the United States where emissions ranging from 2 to 17% of production have been reported. These measurements have led the U.S. Environmental Protection Agency (EPA) to increase official estimates of methane emissions from the total 'upstream' oil and gas production sector by 134%, and to revise its estimates of emissions from gas production to 1.4% of total production. As a result, U.S. regulators are placing increasing scrutiny on unconventional methane emissions, with Canadian Prime Minister Justin Trudeau and U.S. President Barack Obama recently agreeing to new initiatives to reduce methane emissions.

[1] Coal seam gas (CSG) produced for the purpose of being exported as liquefied natural gas (LNG).

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

In the U.S., new technologies including satellite and aircraft-based systems have been used to detect methane emissions and quantify emission rates. Of particular relevance to Australia is the recent documentation of the San Juan Basin methane 'hot-spot' at the world's largest CSG-producing region. U.S. research has found that a few 'super-emitters' can dominate the methane-emissions profile of an oil and gas producing area. A key learning is that methane-emission surveys must comprehensively examine all potential emission points in order to ensure no 'super-emitters' are missed. Few of these technologies have yet been applied in Australian oil and gas fields, so the occurrence or otherwise of 'super-emitters' in Australia is unknown.

Detection and attribution of migratory emissions is a key concern. Migratory emissions may occur naturally, or as a result of the preliminary CSG-production phase of coal-seam dewatering, or as a result of cumulative activity by gas producers and other activities such as groundwater pumping. The pathway of migratory emissions can be impacted by the use of hydraulic fracturing and the presence of pre-existing water or minerals exploration bores. Gassy water bores and gas bubbles rising from streams and rivers provide clear evidence of migratory methane-emissions in Australian coal seam gas fields, although the scale of the issue is not able to be constrained and its relationship to coal seam gas development remains tenuous because of a lack of baseline information. In combination, such issues make it difficult to assess whether industry is meeting its methane-emissions commitment.

Currently, the National Greenhouse Gas Inventory reports methane emissions based on default emission factors, none of which relate specifically to the production of coal seam gas in Australia. The National Inventory Report (NIR) states that emissions from 'production' are estimated using a single emission factor of 0.058 tonnes of methane per kilotonne of methane produced, i.e. 0.0058%. The NIR states that this value is validated by measurements made by CSIR0. However, the CSIRO study was confined to methane leakage at well pads. CSIRO noted that large methane emissions emanating from neighbouring water-gathering lines, water-pump shaft seals, and gas compression plants were not measured because they were outside the prescribed scope of their study. Such observations suggest that the factor of 0.058 tonnes of methane per kilotonne of methane produced may substantially underestimate 'production' emissions for the associated network of gathering lines, compressors and pumps along with wellheads.

If Australia's methane emissions from unconventional gas production are higher than reported, this represents an opportunity cost in terms of last gas sales and a liability to future carbon pricing. Using the current global warming potentials of 34 (100-year) and 86 (20-year), and a carbon pricing regime of A$25 per tonne CO2-e, the potential economic costs of methane emissions from the Australian unconventional gas industry rise by A$230 - 580 million annually for each additional 1% of methane emitted. At double the current rate of production, and with methane emissions at 6% of gas production as appears to be the case in some U.S. gas fields, the forgone revenue from reduced sales volumes would amount to $2.2 billion per year at a gas sales price of $10/GJ, while carbon pricing liability would amount to A$2.8 - 7 billion per year.

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

In summary, our review finds that:

- no baseline methane-emission studies were completed prior to the commencement of the Australian CSG-LNG industry
- there is significant uncertainty about methane-emission estimates reported by oil and gas producers to the Australian government, and by the Australian government to the United Nations. The United Nations has requested that Australia improve its methodologies.
- Australian methane-emission reporting methodologies rely to a significant extent on assumed emissions factors rather than direct measurement
- the assumptions used to estimate methane emissions include some that are out-dated, and some that lack demonstrated relevance to the Australian unconventional oil and gas industry
- despite Australian Government greenhouse-gas reporting requirements having been established in 2009 and Australia's unconventional gas industry operating at significant scale since 2010 and rapidly expanding since, there has as yet been no comprehensive, rigorous, independently-verifiable audit of gas emissions. Indeed, to quote CSIRO, "reliable measurements on Australian oil and gas production facilities are yet to be made." (Day, Dell'Amico et al. (2014))
- if methane emissions from unconventional oil and gas production are being significantly under-reported, this could have a large impact on Australia's national greenhouse accounts.

Recommendations

Given the scale of Australia's prospective unconventional oil and gas reserves, the importance of the industry in economic terms, and the uncertainty surrounding current and future emissions, it is critical that greater certainty and transparency is established around the industry's methane emissions. To ensure that methane emissions from unconventional oil and gas production are minimised we recommend that

- in existing and prospective unconventional oil and gas production regions, baselines are established so that the methane-emissions character of a region is known prior to expansion of oil and gas production or deployment of wells and other equipment
- commitments made by CSG-LNG producing companies in Environmental Impact Statements (EISs) are mandated and confirmed with regular, rigorous, and verifiable audits. Factor-based assumptions should be replaced with direct measurement where emissions may be significant.
- the latest-globally-available technologies and techniques are used to detect, quantify, cross-check, and minimise methane emissions
- priority is given to the implementation of methane-emission-detection techniques that can ensure no 'super-emitters' go undetected.

1. Introduction

This report reviews current understanding of the methane emissions that may result from Australian unconventional oil and gas production. Informed by recent research from the United States and elsewhere, potential gaps in our knowledge about the Australian oil and gas industry's methane emissions are summarised, as are ways to fill those knowledge gaps. Actions are outlined for Australian industry, regulatory bodies, legislators, and researchers.

Oil and gas has 'conventionally' been produced from underground rock layers consisting of sandstone or carbonates. These rock layers must have adequate permeability and porosity in order for oil and/or gas to flow relatively-freely to a well bore.

'Unconventional' oil and gas is produced from underground rock layers that have lower permeability and porosity. Unconventional oil is produced from underground shale layers, while unconventional gas can be produced from shale, coal seams, and 'tight' sandstones.

In order for oil and/or gas to flow from rocks with low permeability and porosity, unconventional oil and gas is produced using technologies including:

- large numbers of densely-spaced wells
- horizontal directional drilling
- coal-seam dewatering
- fluid-flow stimulation methods such as hydraulic fracturing (i.e. fracking).

Unconventional gas production has rapidly expanded in Australia over the last decade. This is predominantly in the form of coal seam gas (CSG) produced in Queensland where more than $A 60 billion has been invested in gas production and liquefied natural gas (LNG) export facilities. With gas production set to triple, Australia is set to overtake Qatar as the world's largest LNG exporter. Australia is very prospective for ongoing expansion of coal seam gas production as well as unconventional oil and gas that may be produced from tight sandstones and shale.

Gas is comprised mainly of methane (CH_4). Direct emission of methane to the atmosphere during production and distribution need to be minimised because methane is a powerful greenhouse gas, with significant climate impact. Methane emissions can also have local health and safety impacts, and can contribute to regional air pollution and asthma via its contribution to the formation of low-level (tropospheric) ozone. Emitted methane also represents a loss of saleable product and revenue for gas producers and resource owners.

In the United States, official methane emissions from unconventional oil and gas production are based on estimates made by the U.S. Environmental Protection Agency (EPA). For the last few years, with funding of around $US 18 million, researchers have been challenging the validity of reported U.S. emissions data by conducting 'bottom-up' ground-level field measurements and analysing 'top-down' atmospheric data recorded via satellites, aircraft, and air-quality monitoring towers.

This recent research has led the several U.S. states and the U.S. EPA to regulate some methane emissions from oil and gas production activities. In February 2016, the U.S. EPA more than doubled estimates of methane emissions from 'upstream' oil and gas production facilities (Table 4).

On 10 March 2016 at a joint press conference with Canadian Prime Minister Justin Trudeau, U.S. President Barack Obama described new initiatives to reduce the amount methane emitted by the oil and gas industry.

In Australia, there are, at present, no regulations that directly limit methane emissions from oil and gas production. Currently, the oil and gas industry reports methane emissions to the Australian Government using the National Greenhouse and Energy Reporting Scheme (NGERS). However, the emissions reported by industry are generally estimates based on factors developed years ago by the United States oil and gas industry for estimating the amount of methane emitted using conventional production methods. Reviewers have questioned the relevance of these factors for use by the Australian coal seam gas industry. However, with the 2014 repeal of the Australian carbon-pricing mechanism, no financial transactions currently rely on these estimates.

Not reported in any jurisdiction globally are estimates of 'migratory' methane emissions that maybe impacted by unconventional oil and gas production. Migratory emissions occur when methane migrates upward and laterally out of its original reservoir, eventually reaches the Earth's surface, and enters the atmosphere possibly at a considerable distance away from the site of original oil and gas drilling or other disturbance.

2. Why it is important to focus on methane emissions from Australian unconventional oil and gas

This section describes why it is important to focus on methane emissions from Australian unconventional oil and gas production. The very large scale of Australia's current and possible-future unconventional oil and gas industry are briefly described, as is the potential for this industry to produce large volumes of methane emissions. This is followed by a discussion of the impacts of methane emissions on global climate change and on local and regional health, safety, and environment. As described in Section 7, gas-producing companies also have financial and reputational reasons to focus on methane emissions.

2.1. Australia's unconventional oil and gas industry and emission potential is large

The last decade has seen a rapid expansion of Australian unconventional gas production. Predominantly, this has been in the form of coal seam gas produced in Queensland.
In that state, more than $A 60 billion has been invested in facilities to produce, liquefy, and export gas. (See further discussion of coal seam gas in Section 5.1.) In 2017, gas production across eastern Australia will be three times what it was in 2013. When Queensland's gas exports are combined with those of Western Australia and the Northern Territory, Australia will overtake Qatar as the world's-largest gas exporting country.

In addition to coal seam gas, Australia is highly prospective for unconventional oil and gas that may be produced from tight sandstones and shale layers (Section 5.2). Taken together, sufficient gas resources exist in Australia that, if produced at current rates, would not deplete until well beyond one hundred years from today.

Given the massive size of these gas resources, Australia's oil and gas industry could also be among the world leaders in emitting methane to our Earth's atmosphere. As further described in Section 5, if Australian unconventional gas production expands to twice its present size (to 3,000 petajoules per year), and if a methane-emission rate of 6%-of-production prevails, the resulting emissions would be equivalent to approximately half of Australia's total nation-wide greenhouse-gas emissions currently reported across all sectors.

2.2. The Paris climate change agreement

In December 2015 with the adoption of the Paris Agreement, the global community agreed to limit dangerous climate change by:

> "holding the global average temperature to well below 2°C above pre-industrial levels and ... pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC (2015)).

In order to achieve this goal, the Paris Agreement also aims to achieve net-zero greenhouse-gas emissions in the second half of this century[2]. An important basis for the 2°C target in the Paris Agreement is the probability that planetary warming triggers 'positive' climate-feedbacks. A key objective of the Agreement is to reduce the probability of reaching tipping points that will trigger irreversible change to the Earth as we know it, including changes to human life, society, flora, fauna, and biodiversity.

Lenton, Held et al. (2008) postulated various elements that could trigger a different state of our Earth's climate. Examples of tipping elements include:

- the melting of Arctic summer sea-ice,
- the melting of the West Antarctic, Greenland and East Antarctic ice sheets,
- the overturning of the Atlantic Ocean thermohaline circulation
- dieback of the Amazon forest.

Joughin, Smith et al. (2014) and Rignot, Mouginot et al. (2014) found evidence for the current collapse of various West Antarctic ice sheets with no obstacles to further retreat, suggesting the West Antarctic tipping point has already been reached. Joughin, Smith et al. (2014) showed that current warming will result in a 1.2 metre sea-level rise from the West Antarctic Amundsen Sea sector. The full discharge of that ice from that sector would result in sea-level rise of three metres (Feldmann and Levermann (2015). It has been suggested that the Arctic summer-ice tipping point has also been reached (Lindsay and Zhang (2005)).

The main driver of climate change is human-induced (anthropogenic) greenhouse-gas emissions that result from burning fossil fuels and land use change. Given that the halfway mark to 2°C was surpassed in 2015 (1°C of warming since pre-industrial times, Met Office (2015)) and that only a limited carbon budget remains, large greenhouse-gas emission reductions in the next 20 to 30 years are critical in order to achieve the goals of the Paris Agreement. If emissions continue to rise as they have done in the recent past (the so-called RCP 8.5 Business-as-Usual scenario, Figure 1), a 2°C global temperature increase could be reached as early as between 2040 and 2050 (Figure 1, right-hand scale).

[2] Article 4.1 of the Paris Agreement (2015)

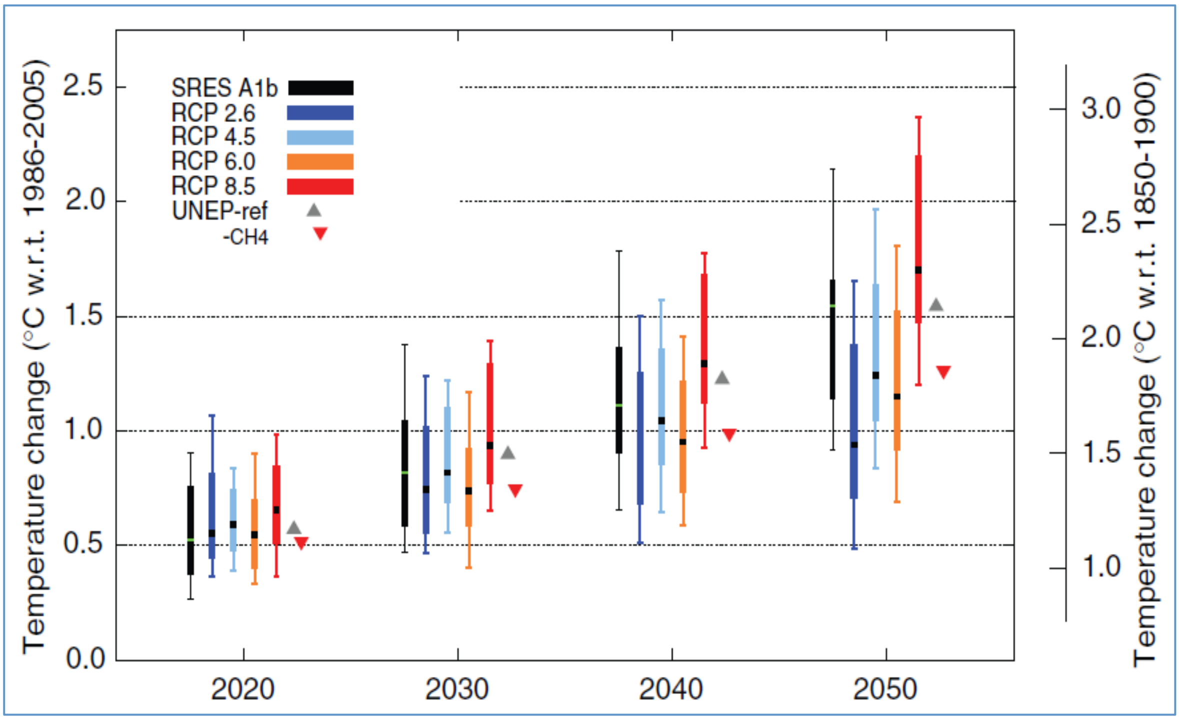

Figure 1: Global average 10-year mean surface temperature increase based on the current four IPCC model ensembles (dark blue: RCP 2.6, light blue: RCP 4.5, orange: RCP 6.0 and red: RCP 8.5), and the previous model ensembles (black: SRES A1b). Left vertical scale is temperature change with regards to 1986-2005 average; right vertical scale is temperature change with regards to 1850-1900 average. The bars represent 17-83% confidence intervals; the whiskers represent 5-95% confidence interval. The triangles represent UNEP model estimates (grey: the reference model and red: the model implementing CH4 emission reduction technologies). The 'business as usual' scenario (RCP 8.5) reaches a 2°C warming most likely between 2040 and 2050 (Figure 9.24a in IPCC (2013))

In the lead up to the Paris Agreement, most nations submitted intended nationally-determined contributions (INDCs) and pledged national greenhouse emission reductions for the period to 2030. If nations achieve emission reductions no greater than their INDCs, the total annual emissions (50 to 56 Gt CO2-e/yr) would be 1.6 times above the emission reductions required (37 Gt CO2-e/yr) to stay within 2°C (Meinshausen, Jeffery et al. (2015), Meinshausen (2015), Meinshausen (2016)). Current INDCs would cause a 2.6 to 3.1°C warming above pre-industrial times to occur by the year 2100 (Rogelj, Elzen et al. (2016, under review), CAT (2015)). Hence, greater emission reductions are necessary than the INDCs that have currently been submitted.

Australia's current pledge is to reduce 2030 emissions to a level 26 to 28% below the 2005 emissions level (UNFCCC (2015)). Based on a 'fair' contribution for a global 'least-cost' 2°C path, Australia's contribution should be higher than has so far been pledged. For example, an Australia showing global climate leadership would aim at a 66% reduction of 2030 emissions compared to 2010 emissions.

Based on equal cumulative per-capita since 1950 approach, Australia should adopt a 52% reduction (Meinshausen, Jeffery et al. (2015)), (Australia's INDC factsheet in Meinshausen (2016)).

The international community is committed to reducing carbon dioxide emissions in the next decennia. Given the commitment to the 2°C target, reducing methane emissions as soon as possible will provide the largest impact on global peak temperature, as well as the largest eco-system benefit. This role of methane emission reductions in a carbon-constrained world will be explained in the next section.

2.3. Methane emission reductions are most effective when done in the near term

This section discusses why near term methane emission reductions have the largest effect given the international commitment to the Paris Agreement.

The concentration of methane in our Earth's atmosphere has tripled since pre-industrial times and continues to rapidly rise (see Figure 2). Figure 2 also shows that following a decade of slow growth (1997-2006), the concentration of methane in the atmosphere has increased at an accelerating rate in the last decade (Turner, Jacob et al. (2016)).

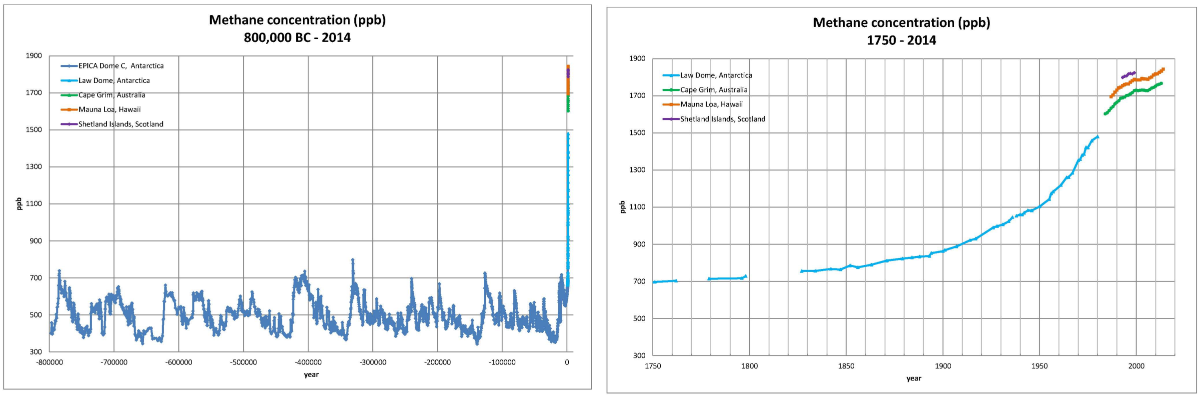

Figure 2: Atmospheric methane concentration shown in parts per billion (ppb), from hundreds of thousands of years ago, through to 2014. Left: Timeframe 800,000BC to 2014, showing concentrations have not been higher than 800ppb until very recent. Right: Timeframe 1750 to 2014, showing concentrations have almost tripled since 1750, and the rate of increase has accelerated again since 2006. Data source: EPA (2016). Data are from historical ice core studies (Loulergue, Schilt et al. (2008), Etheridge, Steele et al. (2002)) and recent air monitoring sites (NOAA (2014), NOAA (2015), Steele, Krummel et al. (2002)).

Given its chemical structure, methane is a more powerful greenhouse gas (has a higher 'global warming potential' or GWP) than carbon dioxide (on a per-kilogram basis). The global warming potential of methane equals the contribution to the climate forcing from one kilogram of methane when compared with the impact of one kilogram of carbon dioxide, integrated over a time period (e.g. Fuglestvedt, Berntsen et al. (2003)).

Carbon dioxide remains in the atmosphere for centuries, whereas methane decomposes to form carbon dioxide in approximately ten to twelve years (Myhre, G. and Shindell, D., 2013). Using standard comparison metrics (IPCC (2013)) methane is considered to be 86 times more powerful as a greenhouse gas than carbon dioxide when considered over a 20-year timeframe (GWP_{20} = 86), and 34 times more powerful when considered over a 100-year timeframe (GWP_{100} = 34)[3].

The use of GWP_{20} allows for an emphasis on the short-term impacts of a gas. The near term consequences of CH4 are certainly important: if one is concerned about tipping points in the next decades, about near term temperature thresholds, the use of GWP_{20} emphasises the near term effects of CH4 emissions. If CH4 emissions were to be reduced drastically in the near term, it would buy the planet some time with regards to the targets stipulated in the Paris agreement.

In this report we have decided to use a 20-year GWP for methane. The main reason is that there is a global agreement to stay within 2 degrees of warming. This warming may be reached as soon as 2040 if emissions are not curbed. This is a timeframe over which current and near-term methane emissions have the largest impact.

Bowerman, Frame et al. (2013) showed that under a RCP2.6 scenario (equivalent to a 1.5°C increase in global mean surface temperature at the end of the century), the climate will benefit most when methane emissions are reduced early, together with strong reductions in carbon dioxide.
The commitment to the Paris agreement implies strong reductions in carbon dioxide emissions in the near term. Reducing methane emissions and introducing strong methane emission reduction policies will therefore have the greatest effect on peak temperature when done in the near term (Figure 3, left graph).

[3] Note that there are inconsistencies between how methane emissions are reported to the IPCC and how they would be reported if the latest available science would be applied. The Australian Government reports methane emissions in units of tonnes CO2 equivalent (t CO2e), using the 100-year Global Warming Potential (GWP) of methane of 25. As agreed at the Doha 2012 conference, to convert methane emissions to CO2-e, they are multiplied by the 100-year GWP value of 25 as defined in the 4th IPCC Assessment report (2007). This conversion factor has been used by all parties reporting in the 2nd commitment Kyoto period (2013-2020). Australia is therefore currently following the international convention, although the National Inventory Report 2014 (August 2016) still uses a GWP of 21 for surface mines, presumably because it relies on reports that were prepared much earlier. In the 5th Assessment report (2013) methane's 100-year GWP has been revised to 28-34, depending on whether carbon cycle feedback are excluded or included. The change is due to the way GWP values are normalized against CO2, not because changes in our understanding of methane. Because the radiative absorption of CO2 decreases with increasing CO2 concentration, the GWP of methane relative to CO2 has increased with time from 25 in 2007 to 28 in 2013 (or 34 with feedbacks). It is important to note that the radiative forcing of CO2 dominates because of much higher abundance (400ppm, compared to 1.8 ppm methane).
If convention decided to increase the 100-year GWP for methane to 34, then all the historical reporting would likely also be adjusted to prevent a stepwise increase in emissions. Here we use a 20-year GWP of 86, and a 100-year GWP of 34 (including carbon cycle feedback), because those are the most recent best estimates.

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

In the situation where carbon dioxide emissions peak later than anticipated (e.g. RCP4.5), reducing methane emissions in the short term can delay global peak temperature and allow for a slightly larger carbon dioxide budget (Bowerman, Frame et al. (2013)). This delay will also be beneficial to global eco-systems as the short-term temperature increase will be slower (Figure 3, right graph).

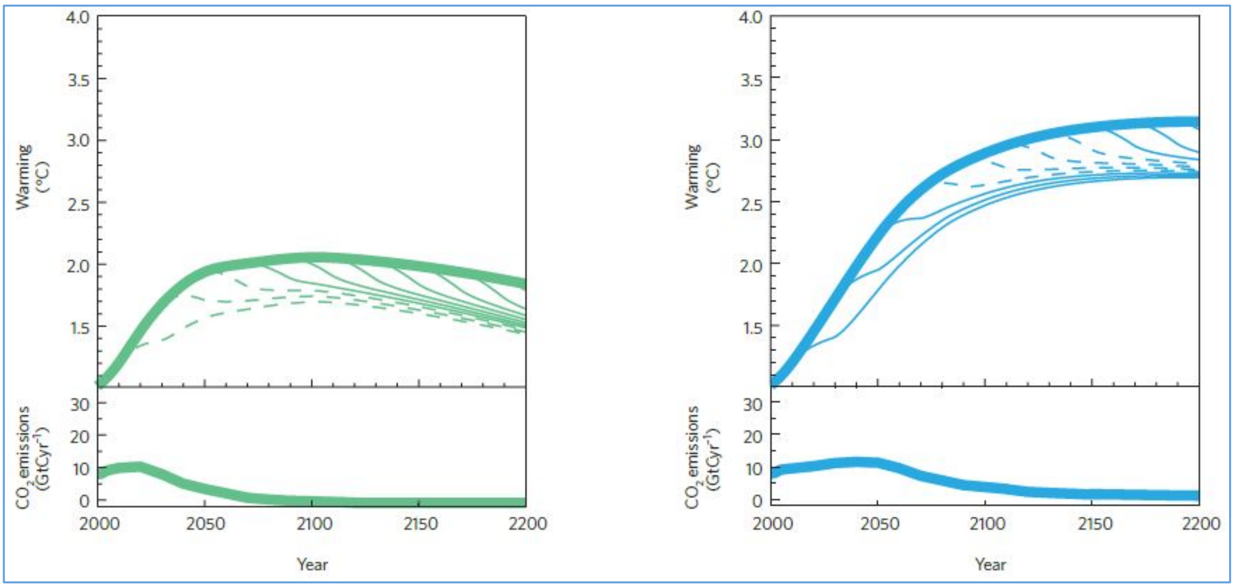

Figure 3: from Bowerman, Frame et al. (2013). Impact of short-lived climate pollutants (SLCP, incl. methane) in the RCP2.6 and RCP4.5 scenarios (1.5°C and 2.4°C warming at the end of the century respectively). The thick line represents the global warming (upper panel) and carbon dioxide emissions (lower panel). The thin lines represent the impact of cutting SLCPs at different times: a dashed line corresponds to SLCP cuts that have more than 0.06°C impact on peak warming relative to delaying the SLCP measures by two decades, whereas a solid line corresponds to SLCP cuts that less than 0.06°C impact.

Shindell, Kuylenstierna et al. (2012) calculated the financial valuation of the benefits of avoiding global warming, crop loss and loss of life by reducing short lived climate pollutants such as methane. These benefits outweigh the abatement cost[4]: two thirds of the benefits have a far greater valuation than the incurred abatement costs. The benefit however would not necessarily flow to those allocating investment for methane abatement. Emission reduction in the coal, oil and gas sector account for two-thirds of the benefits as the technologies to mitigate emissions are readily available. Methane emission reductions are therefore complementary to carbon dioxide reduction measures in order to limit global mean warming to less than 2°C.

In some future-energy scenarios, gas is considered to play a role in the transition to lower greenhouse-gas emitting energy sources (IEA (2012), IEA (2015), EIA (2015)). This is because burning gas results in 60% of the carbon dioxide emissions that occur when the same amount of energy is produced by burning coal. If Australia is to move away from coal and produce more gas (including LNG for export), in order to reduce carbon dioxide emissions and to meet its INDC,

[4] Since financial discounting emphasises near term impacts, a GWP20 or GTP20 for methane is used.

it would be prudent to mitigate methane emissions at the same time: if the climate benefit of reducing carbon dioxide emissions comes with an overhang of direct methane emissions, any benefit will be smaller than expected because methane is also a potent greenhouse gas (Sections 3, 4 and 5).

For these reasons, avoiding preventable methane emissions should be a standard practice and introduction of methane reduction policies in the near term would have the largest effect in light of the Paris Agreement.

2.4. Local and regional health, safety, and environmental impacts of methane emissions

As described in this section, in addition to the global climate impacts of methane, it is also important to minimise methane emissions in order that local and regional health, safety, and environmental impacts are also minimised.

2.4.1. Fire and explosion risks of methane emissions

Methane is colourless, odourless, yet flammable gas. If ignited, methane can pose a fire or explosion risk to people, infrastructure, or vegetation located nearby.

Methane is flammable in air when present at concentrations between 5 and 15% (by volume). At concentrations above 15%, the methane/air mixture is too 'rich' to burn; however, subsequent dilution with air can bring a release of concentrated methane into the flammable range.

Since methane is lighter than air, it will tend to quickly rise and disperse and eventually reach concentrations lower than what is required for the mixture to be flammable. However, methane emitted into confined spaces where it cannot disperse poses an explosion risk.

Once ignited, a methane fire can cause nearby vegetation or flammable infrastructure to also ignite. Ignition of methane present in a Queensland exploration well has been reported (Australian Government (2014)).

In gas-producing regions, methane present in water bores, in household water taps, and bubbling from the Condamine River in Queensland has been intentionally ignited.

Rather than simply venting (i.e. releasing or emitting) excess methane into the air, gas-facility operators may choose to burn methane by using a purpose-constructed 'flare'. Burning methane in this way (i.e. 'flaring') reduces the risk of fire occurring anywhere except at the flare. (Converting methane to carbon dioxide in the flare also reduces the climate impact of the original pollutant.) However, if not properly managed, flares themselves can constitute a fire risk to any people, infrastructure or vegetation nearby. Depending on their design, flares can also emit light, noise, and visible discharges such as smoke or soot that a local community may find objectionable. In certain situations, gas-facility operators may opt to not use an available flare and instead vent excess methane in order to reduce fire risk (for example on days of 'total fire ban') or the potential for community complaints.

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

2.4.2. Air quality and respiratory health impacts related to methane emissions

Methane (a colourless and odourless gas) is lighter than air. When released into the air, methane will tend to quickly rise and disperse.

Methane at high concentrations (where air is excluded) can asphyxiate humans and animals. For humans, exposure to oxygen-deficient atmospheres may produce dizziness, nausea, vomiting, loss of consciousness, and death. At very low oxygen concentrations, unconsciousness and death may occur without warning.

Breathing methane in air at low or dilute concentrations has not been identified as a health risk (Stalker (2013)). However, at a regional level, via its role in the formation of low-level (tropospheric) ozone, methane can contribute to smog and increase the frequency of asthma attacks (White House (2014)).

Gas released into the air, though predominantly consisting of methane, may also contain other contaminants that are hazardous to human health. These other contaminants may have come from the original coal, shale or sandstone reservoir, or have been added as part of processing the gas for transport or sale.

The act of burning methane (e.g. by using a flare, furnace, gas engine or other device), can produce pollutants such as formaldehyde which is a known respiratory health hazard, and other combustion by-products which contribute to the formation of smog.

2.4.3. Water-quality health impacts related to methane emissions

As a result of unconventional oil and gas extraction, methane has been known to enter drinking water supplied by water bores. When dissolved in and consumed with drinking water, methane has not been identified as a health risk (Osborn, Vengosh et al. (2011)). However, if methane enters aquifers used for drinking water, it can become a fire and/or explosion risk if the methane is released into confined spaces or ignited at the point of discharge from piping or water taps.

The presence of methane in water used for drinking or agriculture may indicate a risk of other contaminants. For example In 2015 in New South Wales, BTEX (benzene, toluene, ethyl benzene, xylenes) was found in water that had been extracted from coal seams by a CSG-producing company (NSW Government (2015)). BTEX in the community and environment is closely controlled because benzene is a known carcinogen.

2.4.4. Other flora, fauna, and biodiversity impacts of methane emissions

Methane emissions rising from the ground may impact the flora and fauna situated in close proximity to the release. This has been observed in the Queensland coal seam gas development area where vegetation stress has been observed at seep locations (Norwest (2014)). Loss of animal life is possible where methane displaces air, thereby creating a low-oxygen environment.

3. Methane emissions are critical when assessing the climate impact of gas

This section describes why the climate impact of using gas greatly depends on how much methane is emitted to the atmosphere when that gas is produced, transported, and used.

As described in Section 2.2, world leaders have agreed to act to limit dangerous climate change. Improving the efficiency of energy-use and shifting from fossil to renewable energy sources have been identified as a way to help achieve this goal.

However, often the climate change impact of gas is not compared with energy-efficiency and renewable energy alternatives, but rather with the impact of another fossil fuel: coal. Some proponents have claimed that gas can have lower climate impacts than coal (APGA (2016), APLNG (2016), APPEA (2016), CEFA (2016), ENA (2015)). Coal is composed predominantly of the element carbon. When carbon is burned, it is converted to carbon dioxide, a greenhouse-gas.

Gas, on the other hand, is composed largely of methane, which in turn is composed not only of the element carbon but also of hydrogen. This means that when gas is burned, some of the resulting useful energy is produced by oxidising hydrogen as well as carbon. The result is that combustion of gas produces significantly more energy per unit produced CO2 than coal.

Both gas and coal have a range of energy and chemical end-uses, however a major use of coal is for electricity generation. A commonly-cited comparison is whether it is better for our climate to use gas or coal for electricity generation. This comparison depends on many factors including:

- gas and coal composition
- how much methane is emitted when coal is mined (Kirchgessner, Piccot et al. (2000), Hayhoe, Kheshgi et al. (2002))
- how much energy is required to process and transport coal or gas to the site of electricity generation
- the efficiency of the electricity-generation equipment employed
- whether climate-impacting pollutants such as sulphate aerosols and black carbon are considered in the comparison (Wigley (2011))

and lastly, but importantly,

- how much methane is emitted during gas production, transport and end use.

3.1. Emitting methane can outweigh the climate impact of burning methane

When considering the climate-impact of using gas as a fuel, it is important to recognise that the impact of methane emissions can greatly exceed the climate-impact of final gas combustion (at which point the methane in the gas is converted to carbon dioxide and water).

Figure 4 illustrates that if more than about 3% of produced methane is emitted to the atmosphere, the climate impact on the 20-year timescale of the emitted methane is more important than the climate impact of the remaining combusted methane. For example, as shown by the column labelled "20%", if methane emissions are 20% of total gas production, the climate impact of those emissions is eight times greater than climate impact of burning the remaining gas on the 20-year time-scale (on 100-year time scales it would reduce to about three times.)

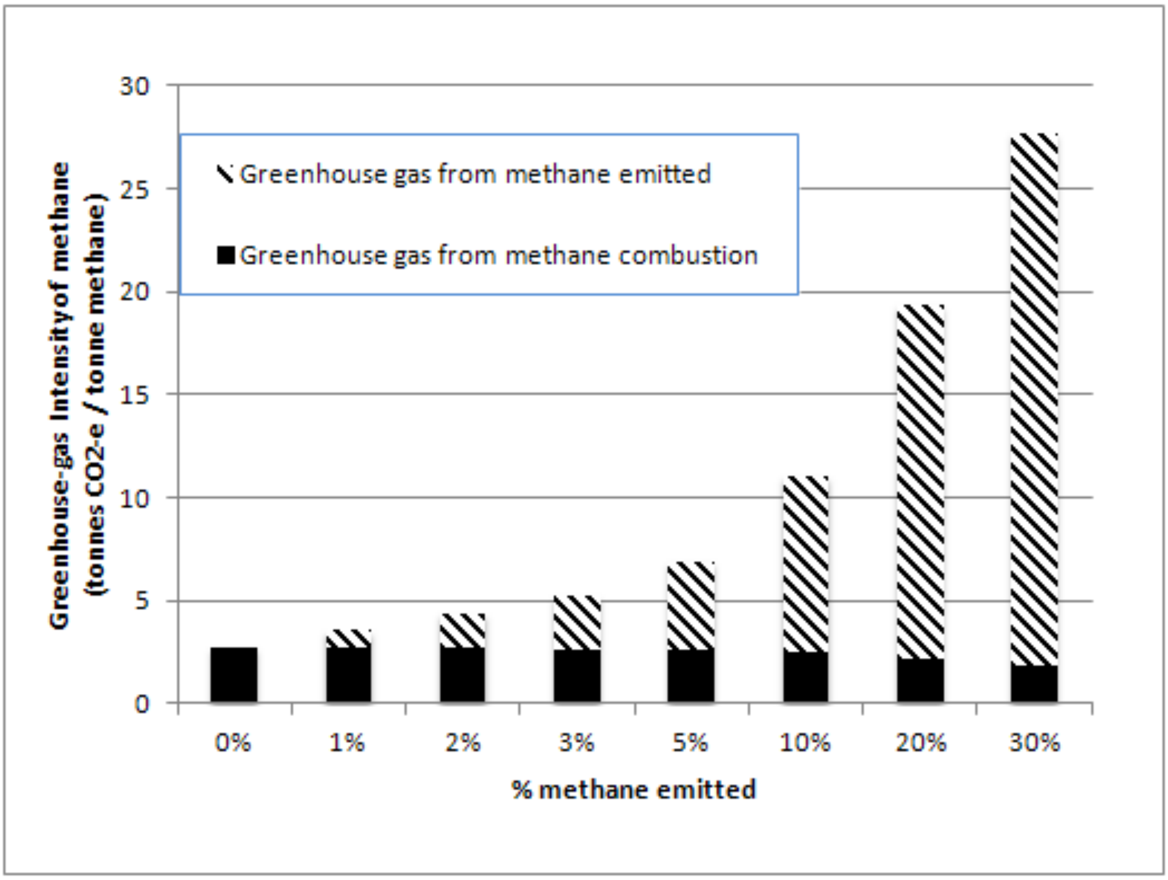

Figure 4: The climate impact of gas as an energy source greatly depends on what fraction is emitted to the atmosphere, versus what fraction is burned as fuel. Here we assume a global warming potential of 86 (appropriate to the 20-year timescale), with the y-xis showing the tonnes of CO_2-e emitted for each one tonne of methane gas produced.

3.2. Coal-versus-gas comparison studies and critiques

A number of studies have compared the climate impact of using coal versus gas as a fuel.

In 2011, a report commissioned by the Australian Petroleum Production and Exploration Association (APPEA), Clark, Hynes et al. (2011) found that using coal seam gas to generate electricity could produce less greenhouse-gas emissions than if coal were used. With respect to methane emissions that occur during coal seam gas production, processing, and transport, Clark et al. assumed that "best practice" would be applied "especially to the prevention of venting and leaks in upstream operations", and that for the category of emissions entitled "Flaring, venting, potential leaks", ... "an estimate of 0.1% gas lost is industry accepted practice."

CSIRO (Day, Connell et al. (2012)) found that the 0.1% figure used by Clark, Hynes et al. (2011) was:

> "much lower than estimates from other gas production sectors"

and that

> "it is not clear how this level was established."

The investment advisors Citigroup (Prior (2011)) reviewed the report by Clark and considered a sensitivity case in which "gas lost" was increased by eleven times, to 1.1% of production.

In 2011, Deutsche Bank Group (Fulton et al. (2011)) called for more research and analysis to be done regarding the coal-vs-gas comparison, stating:

> "Given the potential implications of life-cycle [greenhouse-gas] emissions comparisons... and the fact that many of the metrics and assumptions used today are from older studies, more research and analysis is needed on the life-cycle [greenhouse-gas] intensity of both fuels [gas and coal] so that clean energy policies are properly calibrated to incentivize investment decisions..."

Also in 2011, the investment advisers Merrill Lynch (Heard, Bullen (2011)) in their review entitled "Green gas debate: Who is hiding the fugitives", stated:

> "A thorough independent expert assessment of full life-cycle [greenhouse gas] emissions ... would be a worthwhile input in assessing the gas industry's claims."

Hardisty, Clark et al. (2012) found no climate benefit when gas is used for electricity generation instead of coal...

> "...if methane leakage approaches the elevated levels recently reported in some US gas fields (circa 4% of gas production)..."

The above studies generally and arbitrarily use the 100-year global warming potential for methane, although the sensitivity of study results to the 20-year global warming potential may also be presented in the above studies. To avoid the arbitrary nature of choosing a global warming timeframe, Alvarez, Pacala et al. (2012) developed the concept of Technology Warming Potential (TWP) that allows a limited climate-impact comparison of different technologies.

Alvarez et al. suggested the methane-emission threshold at which point using gas for electricity generation provides no benefits over using coal occurs at a methane-emissions level equal to 3.2% of total gas production. (As with all similar comparisons of gas-versus-coal, this analysis depends on the assumptions made by the researcher.)

In the case where gas is exported as LNG and used within the importing country to make electricity, the methane-emission threshold at which gas becomes more greenhouse-gas intensive than coal will be less than the 3.2% described by Alvarez. This is because of the additional greenhouse-gas emitted along the LNG export-and-import supply chain. The LNG-export case is quite relevant for Australia and is now also relevant for the United States given the recent start of LNG exports from that country.

As will be described in Sections 4 and 5, methane emissions from unconventional gas production may significantly exceed the 'Alvarez threshold' of 3.2%, which means there may be no climate benefit gained by using gas for electricity generation. The climate impact of methane emissions must also be taken into account when gas is considered for other energy applications.

4. U.S. to extend methane emission regulations

This section describes how recent research has lead to the United States Environmental Protection Agency significantly revising upwards its methane-emissions estimates for the oil-and-gas sector and to the Obama Administration intending to enact further methane emissions regulations.

4.1. The U.S. leads the world in unconventional oil and gas production

The U.S. leads the world in the development and deployment of 'unconventional' oil and gas production technologies including large numbers of densely-spaced wells, horizontal directional drilling, coal-seam dewatering, and hydraulic fracturing (i.e. fracking).

Gas is often a by-product of oil production and there are now more than one million wells producing gas in the United States (Figure 5).

Figure 5: Dense well spacing in the U.S. state of Wyoming
http://www.sacurrent.com/sanantonio/the-shale-booms-hard-sell-begins-pushing-up-against-reality/Content?oid=2341996

Over the last 25 years, gas produced in the United States by unconventional methods (from coal seams, shale layers, and tight sandstone reservoirs) has grown from around 15% of supply to now make-up about two-thirds of supply (Figure 6).

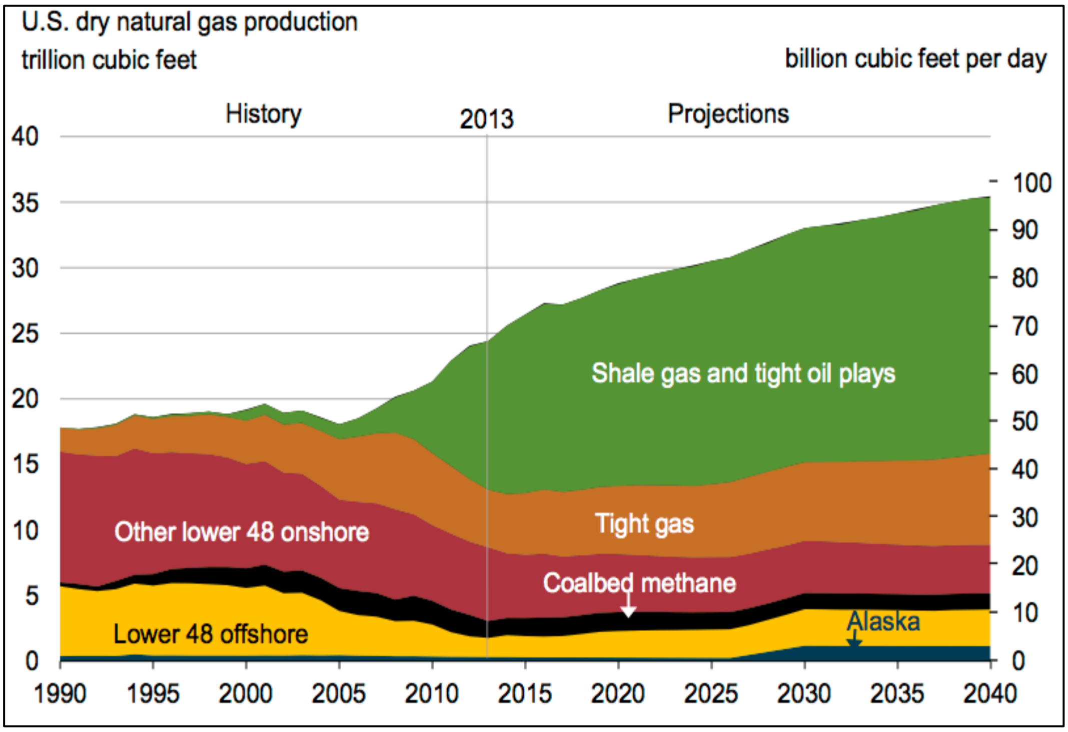

Figure 6: U.S. gas production 1990-2040 as per the EIA Annual Energy Outlook, 2015 Reference case scenario. Historical production until 2013, forecast from then onwards.
(EIA, Sieminski, A., 2015)
http://instituteforenergyresearch.org/analysis/eias-annual-energy-outlook-2015-fossil-fuels-remain-predominant-energy-providers/

4.2. Ways methane may be emitted as a result of unconventional oil and gas production

Gas is often a by-product of oil production. In turn, methane is often the largest chemical component of gas. Given the impacts listed in Section 2.4, for decades methane emissions have been a concern when oil or gas is produced via conventional methods. Methane emissions can be minimised with adequate oil and gas production facility design, construction, operation and maintenance. However in recent times, aspects of unconventional oil and gas production (i.e. large number of densely-spaced wells, horizontal directional drilling, producing from shallow, dewatered coal seams, hydraulic fracturing) mean there can be even greater potential for methane emissions when those techniques are used.

Table 1 broadly categorises seven ways in which methane may be emitted into our Earth's atmosphere when oil and gas is produced by unconventional methods, transported, and ultimately consumed by gas end-users. Some of these methane-emission pathways are further described in Sections 5 and 7.

Table 1

Ways in which methane can be emitted by unconventional oil and gas production and processing, gas transport and distribution, and use of gas by end-users			
	Emissions may occur...		
Methane emission source	**... during initial drilling and field development**	**... during commercial production phase**	**... potentially for many years after the production phase**
Emissions from **surface-production equipment:** leaks from pipes and equipment, venting/releases during the water and gas production phase, incomplete combustion in flares and gas-engine-driven pumps and compressors, etc.	✓	✓	
Acute well venting and releases: occurring during the drilling, well completion, coal-seam dewatering, and production phases.	✓	✓	
Sub-surface methane leaks from wellbores: occurring during drilling, production, and well-abandonment phases. Leaking methane may rise to the surface in the direct vicinity of the wellhead, or may join the category of migratory emissions if it rises to the surface at some distance from the wellhead.	✓	✓	✓
Migratory emissions: migration of methane from subsurface gas reservoirs to the surface (possibly at a considerable distance from the wellhead) during all phases of gas drilling and afterward (Section 5.6).	✓	✓	✓
Gas transportation pipelines and distribution piping: leakage and gas venting/releases.		✓	
LNG handling and shipping: gas venting/releases and leakage during transport of LNG from Australia to overseas locations.		✓	
Gas end-users: methane leaks and releases.		✓	

4.3. Quantifying methane emissions with 'top-down' and 'bottom-up' methods

In addition to being colourless and odourless, methane is lighter than air. When released into our Earth's atmosphere, methane will generally quickly rise and disperse. This behaviour means that detection and quantification of methane-emission volumes may require sophisticated techniques.

The dispersive nature of methane is illustrated by Figure 7, showing methane rising into the atmosphere from a gas storage facility at Aliso Canyon, California, in 2015. Although methane cannot be visually detected using the visible-light spectrum, it can be detected with infrared-spectrum sensing technology as shown in Figure 7.

Figure 7: 2015 methane leak made visible with infrared imaging, Aliso Canyon, California. (Earthworks/Reuters)

While Figure 7 illustrates the scale of the large Aliso Canyon gas leak, devising ways to quickly identify less-obvious methane releases and to quantify the volume of methane emitted across entire sections of the oil and gas industry has challenged experts around the world.

The next section describes new research that indicates the amount of methane being emitted into our Earth's atmosphere because of U.S. unconventional oil and gas production is large and significantly exceeds official-reported estimates.

Methane-emission measurement methods can be characterised as 'top-down' or 'bottom-up'.

'Top-down' methane-emission measurement refers to using satellites, aircraft, and/or ground-based towers in an attempt to measure the full extent of methane emissions across an extensive land area.

'Bottom-up' measurement refers to methods that endeavour to determine how much methane is emitted from specific individual emission points such as a single valve or vent. 'Bottom-up' methods use measurement apparatus that is sited in close proximity to the emission point.

Table 2 summarises certain characteristics of 'bottom-up' and 'top-down' methane-emission measurement methods.

Table 2

Comparison of methane-emission measurement methods		
	'Bottom-up' methods	**'Top-down' methods**
Can identify and quantify emissions from individual emissions points and sources	Yes	Generally not used for this purpose.
Can distinguish between different sources of methane emissions	Yes	Generally not used for this purpose. May be able to distinguish between oil & gas vs biogenic sources (e.g. isotope or other trace contaminant analysis).
Detects all emissions over a wide area	Can do this only if every individual emission source or point is known and assessed. May miss 'super-emitters'. (See below).	Aims to do so.
Shows trends with time	Can be expensive to do so if there are many individual emission sources or points.	Aims to cost-effectively do so.

Melbourne Energy Institute
McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

'Bottom-up' measurements are an important tool that the gas industry can use to minimise the amount of methane emitted from individual equipment pieces at gas-production, processing, and transport facilities. Industry can make use of various methane detection and flux-quantification techniques in order to enhance workplace health and safety, reduce loss of product, and reduce environmental impacts.

However, 'bottom-up' methane-emission measurement techniques have certain shortcomings when they are used to assess the total amount of methane emitted from widespread gas production and transmission infrastructure. For a broad assessment across a large land area where many emission points may exist, 'bottom-up' methods require knowledge about where all potential emission points might be and/or what gas field operations result in methane leaks. Unfortunately, if some emission points or methane-emitting operations are unknown or not assessed, total emissions from a large land area or region will be understated. Furthermore, often 'bottom-up' methods are not applied over continuous and long time periods and therefore can miss individual but significant emission events characterised as 'super-emitters' (see below). As described below, there have been cases where inappropriate use of 'bottom-up' methane-measurement equipment has been indicated.

Allen, Torres et al. (2013) conducted 'bottom-up' measurements of methane emissions at 190 onshore gas sites in the United States including "150 production sites with 489 hydraulically fractured wells, 27 well completion flowbacks, 9 well unloadings, and 4 workovers".
This work concluded that:

> "well completion emissions are lower than previously estimated; the data also show emissions from pneumatic controllers and equipment leaks are higher than Environmental Protection Agency (EPA) national emission projections."

However, later it was found by Howard (2015) and Howard et al. (2015) that these measurements systematically underestimated methane emissions because of detection instrument sensor failure. Important measurements by Allen et al. were reported to be "too low by factors of three to five".

Howard continued:

> "...it is important to note that the ... sensor failure in the ... study went undetected in spite of the clear artefact that it created in the emissions rate trend as a function of well gas CH4 content and even though the author's own secondary measurements made by the downwind tracer ratio technique confirmed the ... sensor failure. That such an obvious problem could escape notice in this high profile, landmark study highlights the need for increased vigilance in all aspects of quality assurance for all CH4 emission rate measurement programs" (Howard (2015)).

'Bottom-up' studies may also fail to assess every emission source. Sources may be unknown, unexpected, or outside of the scope assigned to assessors. CSIRO's experience (Day, Dell'Amico et al. (2014)) detailed in Section 5.4.7 is one example of the latter. Because emission-points can be vast in number, 'bottom-up' studies may of necessity measure only a limited number of points and then attempt to apply the limited results to an entire class of emission points.

According to Allen (2014):

> "The difficulty with 'bottom-up' approaches is obtaining a truly representative sample from a large, diverse population. ... For many types of emissions sources in the natural gas supply chain, however, extreme values can strongly influence average emissions."

Related to this, a third key concern with 'bottom-up' emission measurement and estimation is the existence of so-called 'super-emitters'. According to Zavala-Araiza, Lyon et al. (2015):

> "Emissions from natural gas production sites are characterized by skewed distributions, where a small percentage of sites - commonly labelled super-emitters - account for a majority of emissions."

Super-emitters may exist for reasons such as:

- intentional venting of methane from gas/water separation operations
- intentional well-venting events
- intentional venting of methane in preference to flaring
- other intentional methane venting
- incomplete combustion of methane in gas-engine driven pumps, compressors and electricity generators
- loss of well integrity during the drilling, operations, or 'well-abandonment' phases
- equipment malfunctions or other loss of equipment integrity.

4.4. 'Top-down' U.S. methane emissions measurements point to under-reporting

Several key methane-emission research publications are summarised in Table 3. Many of these publications point to significant under-reporting of methane emissions from unconventional oil and gas production in the United States and Canada. Some of these researchers conducted 'top-down' methane-emission measurements using satellites, aircraft, monitoring towers, and ground-based equipment.

Of particular note, satellite data suggests that U.S. methane emissions (all sources) have increased by more than 30% over the period 2002-2014:

> "The large increase in U.S. methane emissions could account for 30-60% of the global growth of atmospheric methane seen in the past decade" (Turner, Jacob et al. (2016)).

This increase in U.S. methane emissions has occurred during a time when the U.S. oil and gas industry drilled over 500,000 wells.[5]

In 1999, atmospheric composition measurements in urban areas showed higher levels of hydrocarbons in certain U.S. cities versus other cities (Katzenstein, Doezema et al. (2003)). Since then, various researchers have demonstrated that in U.S. states such as Colorado, New Mexico, North Dakota, Pennsylvania, Texas, and Utah, the oil and gas industry seems to be responsible for greater volumes of methane emissions than are reported.

Until recent years, methane emissions in the U.S. were reported to be 0.5 to 2% of total gas production (Harrison, Campbell et al. (1996), Allen, Torres et al. (2013), EPA (2013)). However, many of the research publications listed in Table 3 highlight the possibility of very large methane emission rates. One reference reported methane emissions as high as 30% of gas production (U.S. Dept. of Energy (2010)).

Figure 8 illustrates the ranges in methane emissions (from 2 to 17% of total gas production) reported in recent publications for key U.S. unconventional gas producing regions.

[5] EIA (2002-2010) http://www.eia.gov/dnav/pet/pet_crd_wellend_s1_m.htm , Oil and Gas Journal (2011-2012) http://www.ogj.com/articles/print/vol-110/issue-1a/general-interest/sp-forecast-review/strong-drilling.html, http://www.ogj.com/articles/print/volume-111/issue-1/special-report-forecast-review/slower-drilling-pace-likely-in-us.html , Baker-Hughes (2013-2014) http://phx.corporate-ir.net/phoenix.zhtml?c=79687&p=irol-wellcountus

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Table 3

Key, recent research publications describing North American methane emissions (reverse-chronological)			
Date	**Lead author**	**Publisher / publication**	**Summary of research**
March 2016	Turner, Jacob et al. (2016), Harvard Univ.	Geophysical Research Letters	Using satellite data and surface observations, **a 30% increase in U.S. methane emissions is indicated** over the past decade during a time **when emission inventories indicate no change.**
Dec 2015	Zavala-Araiza et al. 2015) Environ. Defense Fund	Proceedings of the National Academy of Science	Methane emissions at Barnett shale region of Texas were found to correspond to **1.5% of natural gas production, "1.9 times** the estimated emissions based on the U.S. EPA Greenhouse Gas inventory, **3.5 times** that using the EPA Greenhouse Gas Reporting Program, and **5.5 times** that using the Emissions Database for Global Atmospheric Research (EDGAR)."
Oct 2015	Howarth, R. (2015) Cornell Univ.	Energy and Emission Control Techn.	Considered global flux of C^{14} to conclude methane emission rate of **3.8% for conventional gas** and **12% for shale gas.**
Aug 2015	Marchese, A. et al. (2015) Colorado State Univ.	Environmental Science and Technology	Facility-level measurements obtained from 114 gas-gathering facilities and 16 processing plants in 13 U.S. states. Methane loss rate from this part of the gas production system was found to be 0.5%, which is up to **14 times higher** than tabulated by the U.S. EPA.
June 2015	Howard (2015), Indaco Air Quality Services	Energy Science and Engineering	The bottom-up methane-emission measurements reported in a landmark study (Allen, Torres et al. (2013)) were found to be **low by factors of three to five** due to **instrument sensor failure.**
1 April 2015	Peischl, Ryerson et al. (2015), Univ. of Colorado	American Geophysical Union	Using aircraft, **loss rates** for the Haynesville, Fayetteville, and north-eastern Marcellus shales found to **range from 0.2 to 2.8%.**
Oct 2014	Kort, Frankenberg et al. (2014), Univ. of Michigan	Geophysical Research Letters	Satellite observations indicate high methane-emissions **'hot-spot'** at the location of the **largest CSG-producing region** in the U.S. (New Mexico).

Oct 2014	Schneising, Burrows et al. (2014), Univ. of Bremen, Germany	American Geophysical Union	**Current inventories underestimate** methane emissions from Bakken (North Dakota, Canada) and Eagle Ford (Texas) shale gas production areas, found to be **10% and 9%** of production respectively, based on satellite data.
June 2014	Allen (2014), Univ. of Texas	Current Opinion in Chem. Engr.	**Current inventories underestimate** the amount of methane entering the atmosphere.
June 2014	Pétron, Karion et al. (2014), Univ. of Colorado	American Geophysical Union	Using measurements from aircraft, **losses of methane** estimated to be **2 to 8% of production** from oil and natural gas operations in the Denver-Julesburg Basin (Colorado)**.**
April 2014	Caulton, Shepson et al. (2014), Purdue Univ.	Proceedings of the National Academy of Science	An instrumented aircraft platform operated over southwestern Pennsylvania identified methane emissions from well pads in the drilling phase **100 to 800 times "greater than U.S. [EPA] estimates** for this operational phase", or **3 to 17%** of production in this region.
Feb 2014	Brandt, Heath et al. (2014), Stanford Univ.	Science	"...measurements at all scales show that **official inventories consistently underestimate actual [methane] emission**s with the [U.S. and Canadian natural gas] and oil sectors as important contributors." Possible methane emission rates range from **4 to 7%** of gas production. (Howarth (2014))
Aug 2013	Karion, Sweeney et al. (2013), Univ. of Colorado	Geophysical Research Letters	Airborne methane measurements point to **6 - 12% emission rate** in the Uintah Basin, Utah, **7 to 13 times higher** than U.S. EPA estimates of 0.88%.
Feb 2012	Pétron, Frost et al. (2012) Petron, G. (Univ. of Colorado)	Journal of Geophysical Research	Air samples collected from a tower in north-eastern Colorado from 2007 to 2010 indicated **"between 2.3% and 7.7% of the annual production being lost to venting."** "The methane source from natural gas systems in Colorado is most likely underestimated **by at least a factor of two**."
Sept 2010	U.S. Dept. of Energy (2010)		Measurements indicate that when producing gas from coal seams in the Powder River Basin, Wyoming, **up to 30%** of produced methane can be emitted to the atmosphere.
Aug 2003	Katzenstein, Doezema et al. (2003)	Univ. of California	Surface sampling in the southwestern U.S. "suggests that **total U.S. natural gas emissions may have been underestimated**' by a factor of around two".

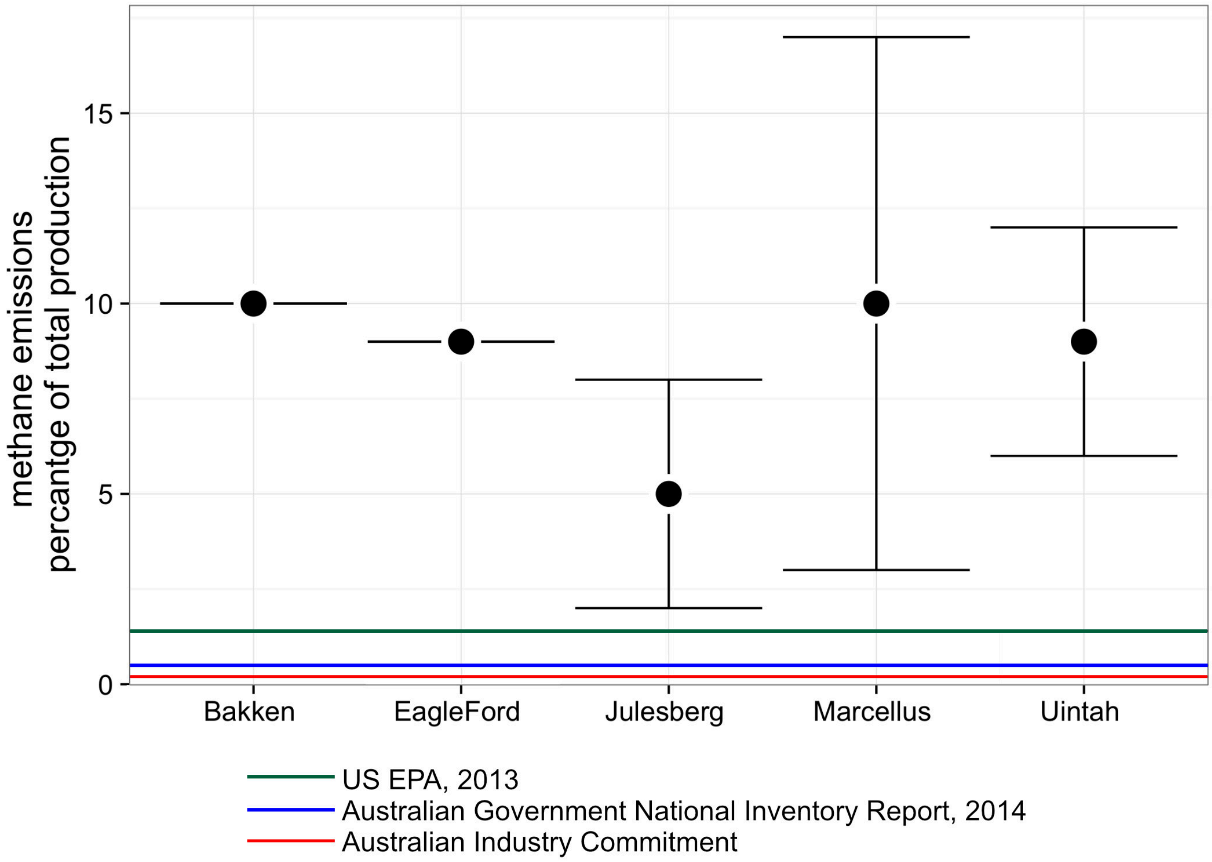

Figure 8: U.S. reported methane emissions (shown as black horizontal line), vs recent 'top-down' measurements for various unconventional gas basins (with reported ranges shown as error bars)

4.5. Methane-emission 'hot-spot' seen from space at largest U.S. CSG-producing region

Most U.S. methane-emissions research focuses on areas where oil and gas is produced from shale. Although Australia is said to have large shale potential, the greatest source of unconventional gas production today is Queensland coal seam gas. Although, as will be discussed in later sections, certain aspects of methane emissions resulting from shale oil and/or gas production are relevant to the coal seam gas operations in Queensland, it is even more relevant to review what is known about methane emissions from the United States' largest coal seam gas production area: the San Juan Basin. This basin, located in northwest New Mexico and southwest Colorado, is also a source of conventional oil and gas.

Satellite observations analysis was published in October 2014 that indicated a methane-emissions 'hot-spot' existed over the San Juan Basin during the 2003-2009 period of satellite data collection (Figure 9 and Kort, Frankenberg et al. (2014)).

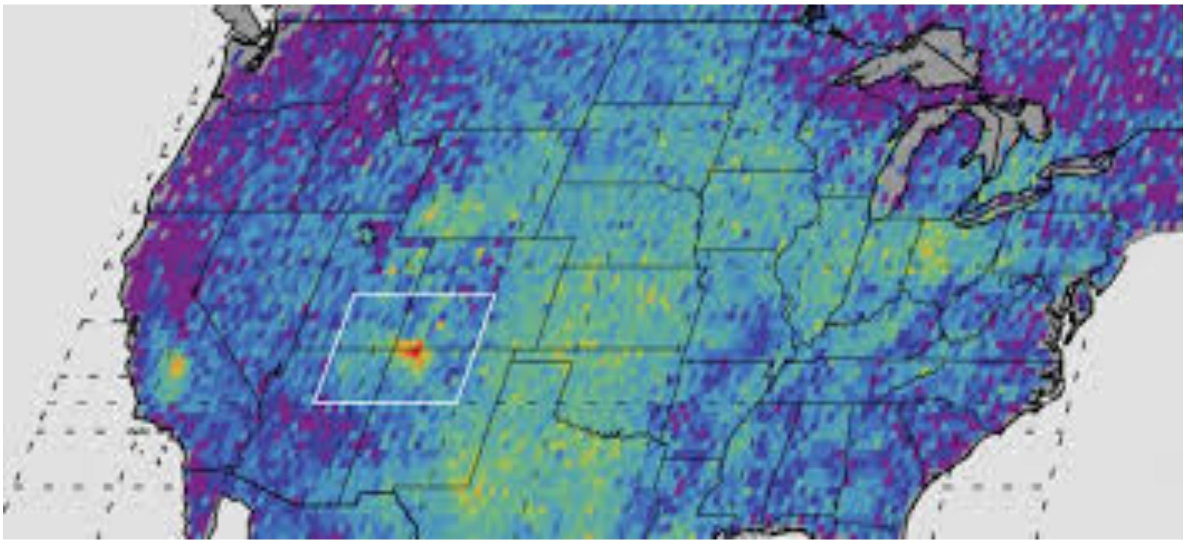

Figure 9: U.S. methane emissions 'hot-spot' revealed by satellite measurements. (Kort et al. 2014)

Based on the satellite data, methane emissions in the San Juan Basin are estimated to be 0.6 million tonnes per year. This quantity is 1.8 times greater than reported methane emissions for the region and equivalent to nearly 10% of the total amount of methane emitted as a result of U.S. gas production (as estimated by the U.S. EPA).

The San Juan Basin methane-emission 'hot-spot' continues to be under investigation by U.S. researchers. See the MEI companion report entitled *"The risk of migratory methane emissions resulting from the development of Queensland coal seam gas"* for further discussion of methane emissions from this region.

4.6. U.S. EPA increases estimated emissions from upstream oil and gas sector by 134%

On 23 February 2016, the U.S. EPA revised their estimates of methane emitted by the oil and gas sector during the year 2013. Table 4 shows that estimates for gas transmission, storage, and distribution were revised downward; however, estimates for the 'upstream' sectors denoted as "Petroleum Systems" and "Field Production (and gathering)" were increased by 134%.

The estimated methane emissions from the oil and gas sector as a percentage of total U.S. gas production in 2013 increased from 1.2 to 1.4%.

On 24 February 2016, speaking at an energy conference in Houston Texas, U.S. EPA Administrator Gina McCarthy said:

> "The new information shows that methane emissions from existing sources in the oil and gas sector are substantially higher than we previously understood.
>
> ...studies from groups like EF and its industry and research partners at Colorado State University, Carnegie Mellon, University of Texas, Washington State University, and others are contributing to our more-complete understanding of emissions from this sector.
>
> So the bottom line is - the data confirm that we can and must do more on methane." (EPA (2016))

Table 4

U.S. EPA estimates of methane emissions in the oil and gas sector occurring during the year 2013 (U.S. EPA GHG inventories)				
Sector	Previous estimate	Feb. 2016 revised estimate	Change	% Change
	(million tonnes of methane emitted / year)			
Petroleum Systems	1.009	2.535	1.526	+ 151%
Field Production (and gathering)	1.879	4.230	2.351	+ 125%
'Upstream' subtotal	**2.888**	**6.765**	**3.877**	**+ 134%**
Processing	0.906	0.906	-	-
Transmission and Storage	2.176	1.151	-1.025	- 47%
Distribution	1.333	0.458	-0.875	- 66%
Total	**7.303**	**9.280**	**1.977**	**+ 27%**
Methane emissions as a% of total U.S. gas production[6]	1.2%	1.4%		

[6] Based on 2013 U.S. gas production of 29.5 trillion cubic feet (31,400 petajoules).

4.7. U.S. regulated emission sources in 2012; new rules to cover existing sources

Since at least 2012, the Obama Administration has been working toward tightening U.S. methane emission regulations. On 17 April 2012, the U.S. EPA set rules that included:

> "...the first federal air standards for [new] natural gas wells that are hydraulically fractured, along with requirements for several other sources of pollution in the oil and gas industry..." (EPA (2012))

Building on President Obama's June 2013 broad-based Climate Action Plan that aimed "to cut the pollution that causes climate change and damages public health", the March 2014 "Strategy to Reduce Methane Emissions" recognised that:

> "reducing methane emissions is a powerful way to take action on climate change"

and stated that with respect to methane emissions in the oil-and-gas sector:

> "...the Administration will take new actions to encourage additional cost-effective reductions..." (White House (2014))

On 14 January 2015, the Obama Administration announced:

> "...a new goal to cut methane emissions from the oil and gas sector by 40 to 45 per cent from 2012 levels by 2025, and a set of actions to put the U.S. on a path to achieve this ambitious goal." (White House (2015))

In August 2015 the U.S. EPA proposed new rules to reduce methane emissions from hydraulically-fractured oil wells and also to:

> "extend emission reduction requirements further "downstream" covering equipment in the natural gas transmission segment of the industry that was not regulated in the agency's 2012 rules." (EPA (2015))

And just recently on 10 March 2016 at a joint press conference with Canadian Prime Minister Justin Trudeau, President Obama said:

> "Canada is joining us in our aggressive goal to bring down methane emissions in the oil and gas sector in both our countries and, together, we're going to move swiftly to establish comprehensive standards to meet that goal."

while U.S. EPA Administrator Gina McCarthy blogged that:

> "EPA will begin developing regulations for methane emissions from existing oil and gas sources." (EPA (2016))

5. Australian methane emissions from unconventional gas production

This section describes Australia's rapidly-growing CSG-to-LNG industry and potentially-large 'tight' gas and shale oil-and-gas resources (Sections 5.1 and 5.2).

Section 5.3 then presents Australia's oil-and-gas-related methane-emission estimation methods that rely to a significant extent on assumed emissions factors.

Section 5.4 describes, chronologically, the results of limited Australian methane-emission field investigations and actual methane emission measurements, along with reviews of Australia's methane-emission estimation and reporting methods. These reviews point out that much of Australia's emissions reporting relies not on direct field-measurement of emissions but rather on assumed factors that may inadequately reflect, in particular, Australian coal seam gas operations.

Section 5.5 reports that methane emissions for 2014 were equivalent to 0.5% of total Australian gas production. This rather low-level of reported emissions are compared with recently-published estimates of U.S. oil and gas field emissions that range from 2 to 17% of production.

Furthermore, Section 5.6 refers to a companion 'migratory emissions' report that describes the potential for Australian coal seam gas production and other subsurface activities to cause methane to migrate away from its natural reservoir, reach the Earth's surface, and enter the atmosphere at some distance from CSG-production operations.

Based on the above, concluding Section 5.7 summaries key reasons why methane emissions related to Australian oil and gas industry operations may be under-reported.

Later sections of this report present scenarios describing how large methane emissions from this sector could be, full fuel-cycle greenhouse gas emissions of the CSG-LNG industry, and finally actions needed to reduce methane emissions and improve the quality of methane-emissions reporting.

5.1. The rapidly-growing eastern Australian CSG-to-LNG industry

The most significant form of unconventional oil or gas produced in Australia to date is coal seam gas. This industry operates mainly in Queensland and also in New South Wales. The large amount of coal seam gas present in those states led to the recent construction of six liquefied natural gas (LNG) 'trains' in Gladstone Queensland, at a cost of more than $A 60 billion. LNG was first exported from Gladstone in December 2014. Six trains are expected to be fully operational by the end of 2016 (Figure 10).

Figure 10: Liquefied natural gas (LNG) plants at Gladstone, Queensland (LNG World News)

As a result of this new CSG-to-LNG industry, the amount of gas produced in eastern Australia will soon triple (Figure 11). By 2017, the amount of coal seam gas produced in eastern Australia each year will rise to a level twelve times greater than what it was a decade prior.

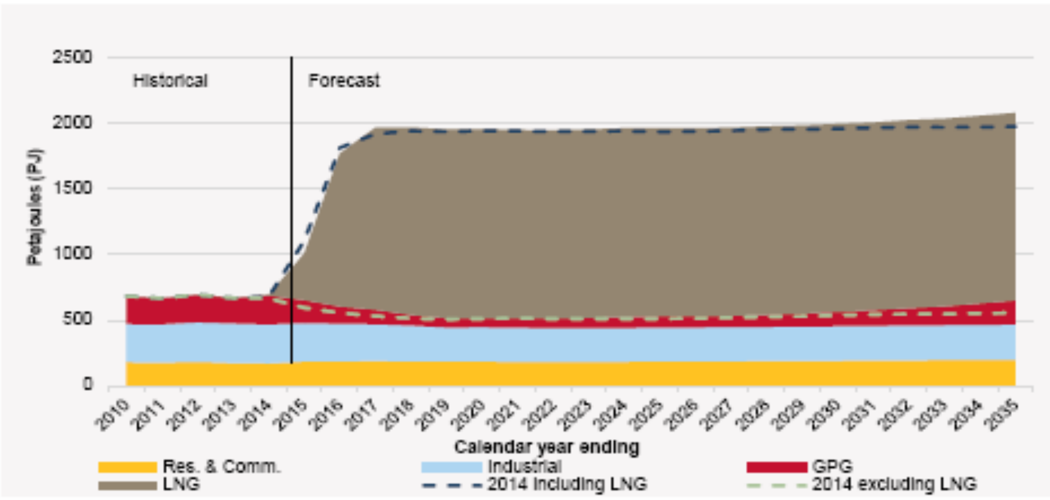

Figure 11: Eastern Australian gas production, recent past and projected future.
Australian Energy Market Operator National Gas Forecasting Report, Dec. 2015

Around 6,000 coal seam gas wells have so far been drilled in Queensland and New South Wales to support this industry (Figure 12).

Figure 12: Aerial photo of over 160 CSG wells near Tara, Queensland (Google Earth)

Because coal seam gas wells have a limited life and often deplete more rapidly than conventional gas wells, the Australian coal seam gas industry plans to drill a minimum of 1,000 wells each year over the next twenty years to maintain gas supply to the six LNG trains. Therefore it is planned that by 2035 this industry will have drilled a minimum of 30,000 coal seam gas wells in eastern Australia.

Table 5 shows certain results of AEMO's 2016 assessment of eastern Australian coal seam gas reserves and resources (AEMO (2016)). At a production rate of 1,500 petajoules per year[7] (PJ/yr), proved-and-probable (2P) coal seam gas reserves would deplete after 29 years. If the other classes of reserves and resources shown in Table 5 were found to be economical to recover, those reserves and resources would extend current rates of gas production out for another 96 years, or 125 years in total. Cook, Beck et al. (2013) reported similar resource numbers.

Given the large coal seam gas resources in Queensland and New South Wales, in 2011 the Australian Energy Market Operator (AEMO (2011)) described a scenario where 20 LNG trains were built at Gladstone. In other words, that scenario described LNG production and export capacity 3.3 times greater than what is in place today.

[7] 1,500 PJ/yr is approximately equal to the current or near-term Australian CSG production rate. See AEMO's National Gas Forecasting Report (December 2015) for context.

Table 5

CSG reserves and resources in Eastern Australia					
	'Proved plus probable' (2P) CSG reserves	CSG 'possible' reserves plus 'contingent resources'	CSG 'prospective resources'		Sum of all CSG reserves and resources
CSG reserves and resources (AEMO (2016))	44,000 PJ	70,000 PJ	75,000 PJ		189,000 PJ
Reserve life (CSG reserves and resources divided by a production rate of 1,500 PJ/yr)	29 years	46 years	50 years		125 years

5.2. Australia's 'tight' and shale oil-and-gas potential

In addition to coal seam gas resources, Australia also has very large 'tight' gas and shale oil and gas prospective resources, as listed in Table 6.

Shale oil and shale gas are oil and/or gas held in a shale reservoir.

'Tight' gas is defined as gas contained in low-permeability sandstone reservoirs. ‘Tight oil' may also refer to shale oil.

The EIA (2013) estimated that 18 billion barrels of technically-recoverable shale oil may be found in Australia’s sedimentary basins, in particular in the Canning Basin in Western Australia (9.7 billion barrels, Figure 13) and the McArthur Basin (Beetaloo sub-basin) in the Northern Territory (4.7 billion barrels).

Australia's largest shale gas resources are thought to be in the Canning Basin, assessed at a prospective resource level of 229 TCF (252,000 PJ) (Cook, Beck et al. (2013)).

Much of these shale and 'tight' resources are considered uneconomic under current market conditions given their remote location and other factors. Technological breakthroughs or improving market conditions may change the economics for tight and shale gas resources. The scale of tight and shale gas operations could be very significant, and of similar scale or even larger than the coal seam gas industry. Similar to coal seam gas development, large-scale shale and tight resource development would require thousands of wells.

Santos has drilled some tight gas wells in the Cooper Basin (Queensland and South Australia, Figure 13). These wells then connected to existing gas processing and pipeline infrastructure. Beach Petroleum, Drillsearch, and Senex continue to explore the Cooper Basin with a high rate of success.

Table 6

Australian shale oil, shale gas, and tight gas prospective resource estimates			
Type of resource		**Level of uncertainty**	**References**
Shale oil	18 billion barrels	Potentially in the ground, technical recoverable	EIA (2013)
Shale gas	6% of world's total shale gas resource	Undiscovered, prospective	EIA (2013)
	396 TCF (435,600 PJ)	Potentially in the ground, technically recoverable	Cook, Beck et al. (2013), GA and BREE (2012)
	2 TCF (2,200 PJ)	Sub-economic demonstrated (2C)	
Tight gas	20 TCF (22,000 PJ)	Sub-economic possible (3C)	

Further out on the development horizon is 'deep' coal seam gas: deep coal formations that require hydraulic fracturing to induce commercial flow. In May 2015, Santos connected its first 'deep' coal seam gas well to its Moomba infrastructure in the Cooper Basin (inferred from shareholder announcements to be at depths of around 2,000 metres).

5.3. Gas industry methane emissions in the National Greenhouse Gas Inventory (NGGI)

In the structure of national inventories, as specified in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, emissions arising from the use of energy are divided into two categories:

- 1A - fuel combustion activities
- 1B - fugitive emissions from fuels

Emissions for these two categories are considered in turn.

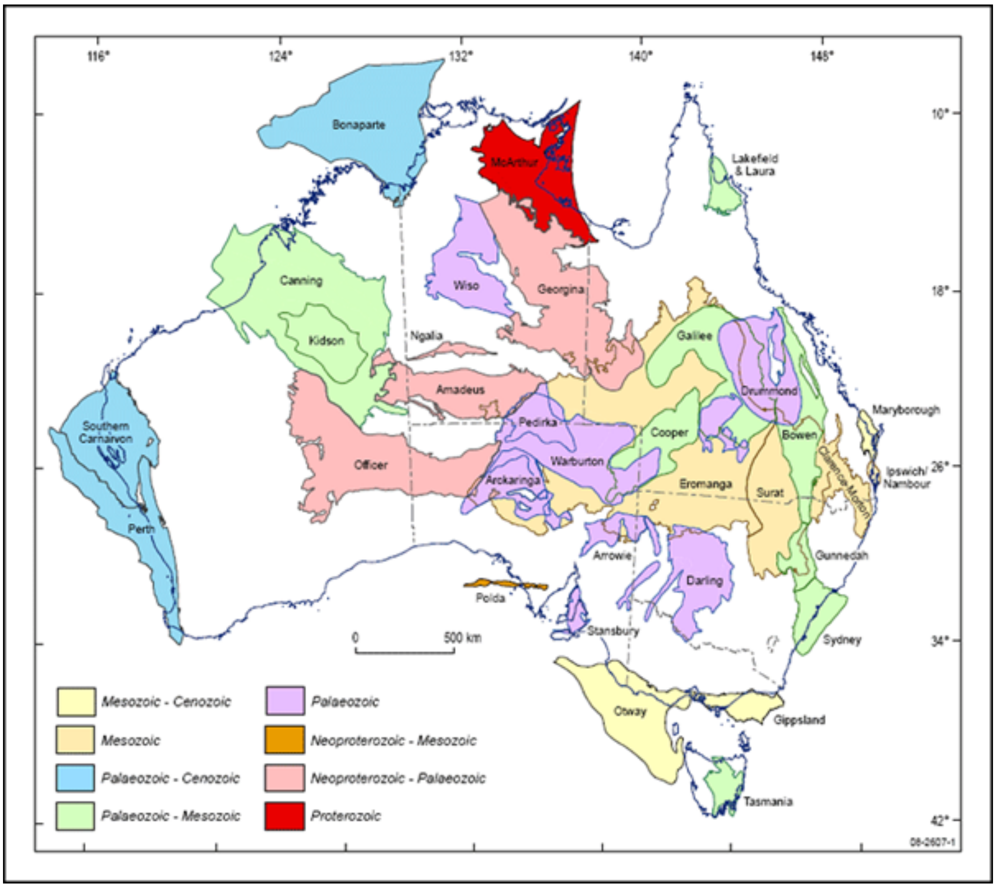

Figure 13: Australia's onshore sedimentary basins (Geoscience Australia, 2016.
http://www.ga.gov.au/about/what-we-do/projects/energy/onshore-petroleum

5.3.1. Fuel combustion emissions

Gas industry combustion emissions included in the national inventory mainly arise from the use of gas in gas engines, including both reciprocating and turbine engines, to power compressors, pumps and other equipment, which may be used:

- in the gas fields
- at gas processing plants
- on gas transmission pipelines
- at LNG plants
- in gas distribution systems.

In the case of coal seam gas, all three of the LNG plants at Gladstone, Queensland use a process based on the use of gas turbines to drive the compressors required to liquefy the gas, and also to drive generators that provide the electricity used for a multitude of purposes throughout the plants. A report prepared by Lewis Grey Advisory for the Australian Energy Market Operator (AEMO)[8] estimates that the liquefaction process uses 8% of the input gas. Negligible quantities of emissions from this source are included in the most recent NGGI, which covers the financial year 2013-14, because LNG production did not start until late in calendar year 2014. These emissions will be included in all future national inventories. They will also be included in NGERS public reports, but will probably not be separately identifiable because they will be included in the aggregated reports of the various joint venture partners.

Each of the three LNG-plant consortia owns and operates a separate transmission pipeline from its gas fields, located a considerable distance south west of Gladstone. Gas-transmission compressors may be powered either by gas engines or electric motors. Lewis Grey Advisory suggests that two of the lines may currently use electricity while the other uses gas. In either case, the associated emissions will be included in the national inventory, either directly as emissions from gas combustion, or indirectly as electricity generation emissions.

Production of coal seam gas differs from production of conventional natural gas in that very large numbers of individual wells are required, production usually requires water to be pumped out of the wells, and that gas emerges at low pressure and therefore requires compression to be transported through a network of gathering lines to a central point where it is compressed up to transmission pressure. Powering this equipment requires large amounts of energy. Initially, the CSG-producing companies all used gas-engine drive for this equipment but all are now progressively shifting across to electric motor drive for much, but by no means all of the equipment[9].

[8] Lewis Grey Advisory, 2015. *Projections of gas and electricity used in LNG*. Prepared for AEMO. http://www.aemo.com.au/Search?a=Lewis%20Grey%20Advisory
[9] Lewis Grey Advisory, *op. cit*.

Overall, the annual energy consumption for extracting, transporting and liquefying coal seam gas at the three plants (six liquefaction trains) is estimated by Lewis Grey Advisory to be about 123 PJ of gas and 9.3 terawatt-hours (TWh) of electricity. In its most recent electricity forecasting report[10], the Australian Energy market Operator (AEMO) has revised the latter figure down somewhat; AEMO now expects CSG-field electricity consumption to be about seven TWh per year (AEMO, 2016). The two figures for gas and electricity are equivalent to about 93 TJ of gas and 5.3 gigawatt-hours (GWh) of electricity per petajoule (PJ) of produced LNG. Emissions from all of this energy use will be included in the NGGI as and when they occur.

5.3.2. Fugitive emissions from fuels

The *IPCC Guidelines* subdivide fugitive emissions from the oil and gas industry into a number of sub- and sub-sub-categories relating to the gas industry. The various divisions were changed between the 1996 (as revised) and the 2006 editions of the *Guidelines*. Australia reports against what is essentially the 1996 structure, presumably so as to provider a clear and consistent time series from 1990 onward. When interpreting the reported emissions data, it is important to understand what is meant by and included under venting, as distinct from leakage. The 2014 National Inventory Report explains the distinction in the following terms:

> "The approach used for defining vents and leaks is provided below, and has been developed with a view to completeness and consistency with American Petroleum Institute's (API) 2009 *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry*:
>
> - vents are emissions that are the result of process or equipment design or operational practices;
>
> and
>
> - leaks are emissions from the unintentional equipment leaks from valves, flanges, pump seals, compressor seals, relief valves, sampling connections, process drains, open-ended lines, casing, tanks, and other leakage sources from pressurised equipment not defined as a vent." (p. 118)

[10] AEMO, 2016. National Electricity Forecasting Report. http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report

Table 7 shows the source category structure used for reporting 2013-14 emissions in the Australian Greenhouse Emissions Information System (AGEIS). The table includes brief descriptions of the categories relating to production, processing and transporting of gas, including coal seam gas.

Table 7

Emission-source category	Description / explanation
Fugitive emissions from fuels	
Solid fuels	NA
Various sub-categories	
Oil and natural gas	
Oil	NA
Various sub-categories	
Natural gas	
Exploration	
flared	Uncontrolled or partially controlled emissions from gas well drilling, drill stem testing and well completion
vented	
Production	Fugitive emissions occurring between the production well head and the inlet point of the gas processing plant (or the transmission pipeline if processing is not required)
Processing	Emissions other than venting and flaring at gas processing facilities
Transmission and storage	Emissions occurring between the inlet point of the transmission pipeline and its outlet to either a major consumer (including an LNG plant) or a distribution network
Distribution	Emissions resulting from leakage from gas distribution networks
Other	Includes emissions from well blowouts, pipeline ruptures etc.
Venting and flaring	
Venting	
oil	
gas	Managed venting at gas processing facilities
Flaring	
oil	
gas	Managed flaring at gas processing facilities
combined	

Table 8 shows the emissions under each of the above categories relevant to gas production and processing, as reported in the 2013-14 NGGI.

For comparison, the table also shows the corresponding values for 2004-05 when there was negligible coal seam gas production. This will help to identify where coal seam fugitive emissions are being reported. Each of the source categories is discussed in turn.

5.3.3. Exploration

Between 2005 and 2014 total emissions from flaring, total emissions for venting, total emissions of carbon dioxide and total emissions of methane are all reported as increasing by a factor of about 4.5. The 2014 National Inventory Report (NIR) shows the total number of oil and gas wells completed increasing by a factor of 5.3 over the same period and notes that:

> “The sharp recent expansion of the coal seam gas industry is evident in the sharp increase in the number of production wells since 2008.”

The NIR explains that the methane emission factor for well completions used the 2009 API emissions factor for onshore well completions, which is 25.9 tonnes methane per completion day. There is a different, higher factor for offshore wells. Factors for flaring and drilling mud degassing are also reported. It is our understanding that these latter two emission sources are mainly associated with conventional oil and natural gas wells, not coal seam gas wells.

The NIR does not provide enough data to allow the calculations of total emissions to be replicated. However, an approximate calculation, using total well numbers and well-completion emission factors gives a total estimate for 2014 which is slightly lower than the reported total for 2014, as shown in Table 8. This suggests that if the API emission factor of 25.9 tonnes of methane per completion-day is appropriate for Australian conditions, then the NGGI gives an acceptably-accurate estimate of methane emissions from drilling and completion of coal seam gas exploration and production wells. Unfortunately, we have been unable to find any published systematic data on methane emissions from Australian coal seam gas well completions. It is therefore not possible to determine whether the API emission factor is applicable to Australia.

Table 8

Fugitive emissions from gas production, processing and transportation, as reported in the NGGI (kilo-tonnes CO_2-e)					
	2004-05		2013-14		
Source category	**CO_2**	**methane**	**CO_2**	**methane**	**Total**
Fugitive emissions from fuels					
Natural gas					
Exploration					
Flared	25	8	113	34	148
Vented	0	258	0	1154	1154
Total	25	266	113	1187	1302
Production	0	69	0	85	
Processing					
Transmission and storage	0.44	230	0.56	290	291
Distribution			5	2377	2382
Other					
Venting and flaring					
Venting					
Gas	3104	1315	4119	1109	5230
Flaring					
Gas	989	332	2185	96	2305
Combined					

Note: For some source categories, the total includes small quantities of nitrous oxide

Interestingly, the NGERS *Technical Guidelines*[11] (Section 3.46A) provide two options for reporting fugitive emissions from well drilling and completion activities. The first is direct measurement of gas volumes released (Section 3.46B), either from all wells and well types in a basin, or from a sample of such wells. The section sets out in considerable detail the procedures to be followed in taking measurements and the calculation steps to be followed to convert the measured data to total emission estimates. The second option (Section 3.84) is use of the relevant API emission factor. It would appear that to date, all CSG-producing companies have used the second option.

[11] Department of the Environment, 2014. *Technical Guidelines for the Estimation of Greenhouse Gas Emissions by Facilities in Australia.* http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/nger/technical-guidelines

5.3.4. Production

The NIR defines this source category in the following terms:

> "This category represents emissions from natural gas production and processing, and includes emissions from the unintentional equipment leaks from valves, flanges, pup seals, compressor seals, relief valves, sampling connections, process drains, open-ended lines, casing, tanks and other leakage sources from pressurised equipment not defined as vent." (p. 125)

A different approach to defining, with exactly the same effect, is used in the NGERS *Technical Guidelines*:

> "This Division applies to fugitive emissions from natural gas production or processing activities, other than emissions that are vented or flared, including emissions from:
>
> (a) a gas wellhead through to the inlet of gas processing plants
> (b) a gas wellhead through to the tie-in points on gas transmission systems, if processing of natural gas is not required
> (c) gas processing facilities
> (d) well servicing
> (e) gas gathering
> (f) gas processing and associated waste water disposal and acid gas disposal activities." (p. 339)

Two of the main differences between coal seam gas fields and conventional onshore gas fields are that coal seam gas production requires a much larger number of individual wells and that gas typically emerges from wells at much lower pressures. Consequently, coal seam gas fields require a far more extensive network of gathering lines and far more use of pumps and compressors, as demonstrated by the very large expected consumption of electricity for electric motor compressor drive. All else being equal, these differences could mean that methane emissions per unit of gas produced are higher for coal seam gas than for conventional gas.

The NIR states that emissions are estimated using a single emission factor of 0.058 tonnes of methane per kilotonne of methane produced, i.e. 0.0058%. The NIR states that this value is validated by measurements made by a CSIRO study of coal seam gas fugitive emissions (Day *et al*., 2014):

> "The methane emission factor for general leakage of 0.058 t CH4/kt production was validated by a measurement study undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) during 2013/14 (Day et al., 2014). The study collected field data measurements from 43 coal seam gas wells and found the median and mean emission leakage rates corresponded to emission factors of about 0.005 and 0.102 t CH4/ kt production, respectively. CSIRO concluded that the range of leakage rates measured were consistent with the existing emission factor of 0.058 t CH4/kt production." (p. 125)

In fact, the CSIRO measurements were confined to methane leakage emissions detected on a sample of production well platforms. The work emphatically does not support the use of this single, very low emission factor for all fugitive emissions from the "gas wellhead through to the tie-in points on gas transmission systems".

This is particularly significant because in the course of the study the researchers noted large methane emissions emanating from neighbouring water-gathering lines, water-pump shaft seals, and gas compression plants. For example, they point out that they were not able to take measurements at some wells because 'high ambient CH_4 levels from major leaks or vents made locating minor leak points difficult'. They noted that in one case 'CH_4 released from a vent on a water gathering line was drifting over the pad components so it was not possible to determine if there were other leaks against the high background'.

However, because these emissions were outside the scope of the CSIRO study, which was confined to production well platforms, they were not measured. Nevertheless, the CSIRO researchers do comment on the potential scale and significance of emissions from these other sources, stating that:

> "We found a significant CH4 emission point from a water gathering line near Well B13. Methane was being released from two vents ... at a rate sufficient rate to be audible a considerable distance from the vents. ... Based on the prevailing wind speed, we estimate that the CH4 emission rate from the two vents was at least 130 [grams per minute].... This is a factor of three more than the highest emitting well examined during this study."

That admission alone is sufficient to confirm that the use of 0.058 tonnes of methane per kilotonne of methane produced is inappropriate, and is likely to be substantially underestimating production emissions.

The NIR prescribes one of two methods for estimating and reporting emissions from this source category. Method (1) (Section 3.72) is clearly designed to be applied to conventional natural gas production, as it uses equipment specific emission factors for various types of tanks. These are used in association with conventional gas production to store separated natural gas liquids, including condensate and LPG. They are not relevant to coal seam gas production.

Method (2) (Section 3.73) is designed to be applied to all types of gas production and uses equipment type specific emission factors, in this case sourced for the *API Compendium*[12]. The equipment types potentially relevant to coal seam gas production are listed in Table 6-4, p. 6.16 of the *Compendium*, and include wellheads, reciprocating gas compressors, meters/piping, dehydrators and gathering pipelines.

[12] American Petroleum Institute, 2009. *Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry*. http://www.api.org/~/media/Files/EHS/climate-change/2009_GHG_COMPENDIUM.pdf?la=en

As described above, the National Inventory currently includes an estimate of emissions from coal seam gas wellheads, which was derived from the emissions factor specified in the API *Compendium*, and has been found to be consistent with emissions measured at coal seam gas wellheads in Australia. However, emissions from all the other equipment types are, effectively, assumed to be zero. This means that the national emissions inventory currently understates emissions for coal seam gas production. The possible amount of the understatement is completely unknown.

As we read the NGERS *Technical Guidelines*, the coal seam gas producing companies should be reporting their emissions in accordance with Method 2 above. Detailed NGERS reports are of course strictly confidential, meaning that it is impossible to know whether the companies are complying with this reporting requirement. There is certainly no publicly available data, and it might be assumed that if the coal seam gas producing companies were reporting in this way, the resultant total emissions estimate would be included in the National Inventory.

It is understood the CSIRO is currently, or will shortly be, undertaking Phase 2 of its measurement of fugitive emissions from coal seam gas production. This Phase will seek to measure emissions from at least some of the potential leakage sources occurring between the numerous coal seam gas production wellheads and the tie-in points of the three gas transmission pipelines. It is unclear whether any of the CSG-producing companies have made any of their own measurements. If they have, none of the results have been made public.

5.3.5. Processing

Unlike conventional gas, coal seam gas does not require processing upstream of the transmission pipeline or the LNG plant. It is therefore appropriate that coal seam gas emissions from this source category are set at zero. Parenthetically however, it is strange that fugitive emissions associated with conventional gas processing are set at zero, without the citation of any supporting measurement data. Note that in 2008, supply of gas to much of WA was severely disrupted for several months by the rupture of a gas (methane) pipeline, and subsequent explosion and fire, the Varanus Island gas processing plant.

5.3.6. Transmission and storage

The NIR explains that losses from transmission lines are estimated as a uniform 0.005% of gas throughput, based on measurements made many years ago on the Moomba to Sydney gas pipeline. In the last year or two the estimates have also been scaled up by total pipeline length.

Until mid-2014 all coal seam gas production was flowing through established pipelines, mainly to markets in Gladstone and in the Brisbane region. Some was also flowing west to Moomba, thence to markets in the southern states. Each of the three Gladstone LNG consortia has built its own dedicated pipeline, each several hundred kilometres in length, from its coal seam gas fields to Gladstone. Gas started flowing through the first of these during the second half of 2014. This means that the national inventory figures in Table 8 include no significant additional emissions associated with coal seam gas, because up to mid 2014, coal seam gas was simply replacing conventional gas in the slowly growing domestic markets. However, from 2015 onward the national inventory should include the additional emissions arising from transmission of coal seam gas to the LNG plants, calculated in the same way as all other gas pipeline fugitive emissions. Because of both the volumes of gas and the length of the pipelines, this is likely to result in a significant increase in reported fugitive emissions from gas transmission.

The NIR does not mention emissions from gas storage. We understand that there are only a few gas storage facilities in Australia and we are not aware of any such facilities associated with coal seam gas production or use.

5.3.7. Distribution

These emissions relate to coal seam gas only to the extent that coal seam gas forms part of the total quantities of gas supplied through distribution networks to small consumers (termed mass market customers by the industry) in Queensland, NSW and SA. Note that these consumers account for a minority share of total gas consumption in these three states; most gas is consumed by electricity generators and large industrial customers.

5.3.8. Venting

In the words of the NIR, venting is defined as “emissions that are the result of process or equipment design or operational practices”. In practice, a large source of venting emissions is due to the separation and release of the carbon dioxide present in raw natural gas. Conversion of gas to LNG requires the almost complete removal of such carbon dioxide prior to refrigeration. On the other hand, coal seam gas contains negligible quantities of carbon dioxide, meaning that separation is not required. Hence zero venting emissions are associated with coal seam gas production and processing.

The large increase in venting between 2005 and 2014 has arisen because of increased production of conventional natural gas with high carbon dioxide content in Western Australia and the Northern Territory, most of which is converted to LNG.

5.3.9. Migratory emissions

There is also the possibility that depressurisation of the coal seams as a result of dewatering could result in gas migrating through existing geological faults, water bores, abandoned exploration wells or even the soil. This potentially significant source of methane leakage that is not covered at all under the NIR, but can be measured through atmospheric testing and modelling.

5.3.10. Summary

Emissions associated with the production of coal seam gas and its processing to LNG in Queensland arise from both use of fossil fuel derived energy for these activities and fugitive emissions of coal seam gas at various points along the supply chain.

The major uses of energy are electricity, and some gas, in production and pipeline transport, mainly to power compressors and pumps, and gas in processing to LNG at the three LNG plants, where gas turbines provide all the motive power needed to operate the plants. The quantities of electricity and gas consumed are well understood and the associated emissions are reported through NGERS and included in the NGGI.

By contrast, fugitive emissions are poorly understood. It appears that all data reported re based on the use of default emission factors, none of which relate specifically to the production of coal seam gas in Australia. The fugitive emission factors for drilling and well completion are the same as those used for conventional gas activities, but result in higher reported emissions because of the much large number of wells required for coal seam gas production. While there is no a priori reason to suppose that the emission factors are not applicable to coal seam gas activities, there are no publicly available measurement data to confirm, or otherwise, the assumed emission factor values. Emission factors for methane emissions on production well pads are small and are based on recent measurements by the CSIRO.

However, limited available observations suggest that by far the largest source of fugitive emissions is likely to be leakage from the extensive network of gathering lines, compressors and pumps which connect producing gas wells to the transmission pipeline tie-in points. On the basis of publicly available information, it appears that no systematic measurements have been made of emissions from these sources. In both individual company reports and in the national emissions inventory emissions from this source are set at zero. Consequently, it is probable that official data on total greenhouse gas emissions arising from the production of coal seam gas, and its conversion to LNG, significantly understate the true level of emissions.

Another potentially significant source of methane leakage that is not covered by the NIR is “migratory emissions” where methane leaks to the atmosphere through existing below-ground pathways as a result of depressurisation of the coal seams through dewatering. A separate report by the University of Melbourne Energy Institute examines migratory emissions.

5.4. Australian methane-emission field investigations and reviews of reporting methods

This section summarises, chronologically as listed in Table 9, the scope and results of certain limited field investigations and measurements of methane emissions, along with reviews of Australian oil-and-gas-related methane-emission reporting methods.

The reviews identified shortcomings that may cause Australia's methane emissions from this sector to be under-reported.

Table 9

Chronological listing of field investigations and reviews of emission estimation and reporting methods		
Date	**Field Investigation**	**Review**
2010 and 2011	Queensland regulatory authority wellhead investigation	
2012	Southern Cross University mobile surveys	CSIRO
"		Pitt & Sherry
2013		Pitt & Sherry
"		New South Wales Chief Scientist
"		Australian Government
2014	CSIRO well pad equipment investigation	
"	Gas industry mobile survey	
2016		United Nations Framework Convention on Climate Change (UNFCCC)
"		This report, University of Melbourne Energy Institute

Melbourne Energy Institute
McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

5.4.1. 2010 and 2011 investigation of Queensland CSG wellhead emissions

In 2010 in Queensland, people living near coal seam gas production equipment reported gas emissions. As a response, the Queensland government arranged to test 58 wellheads. Of these, 26 wellheads were found to be emitting methane. The most significant emissions were found at one wellhead emitting methane at a concentration of 6% methane-in-air, a potentially flammable mixture. Four other wellheads were found to be emitting methane at concentrations equal to or greater than 0.5% methane-in-air. The remaining 21 leaking wellheads were found to be emitting methane at concentrations less than 0.5% methane-in-air. The lowest reported methane concentration was 20 parts-per-million (Queensland DEEDI (2010)).

Following on from these investigations, the Queensland regulatory authority issued compliance directions to eleven gas companies to inspect and report on 2,719 coal seam gas wells in place in Queensland at that time. Five wellheads were reported to be emitting methane at concentrations greater than 5% methane-in-air. Another 29 wellheads were reported to be leaking methane at concentrations between 0.5% and 5% methane-in-air. Other leaking wellheads, where methane concentrations were less than 0.5%, were reported as being "numerous", but no further details were provided (Queensland DEEDI (2011)).

Subsequent to the above, the Queensland Government issued a Code of Practice covering coal seam gas wellhead-emissions detection and reporting (Queensland Government (2011)).

In the 2010-2011 actions described above, no attempts were made to quantify the rate at which methane was being emitted (i.e. no 'methane flux' was measured, for example, in kilograms per hour).

No emission sources other than wellheads were investigated at this time.

5.4.2. Southern Cross University mobile survey (2012)

Land-vehicle-mounted equipment has been widely used overseas to detect and map methane emissions, particularly in urban environments. For example, Figure 14 illustrates results of a vehicle survey in Boston in the U.S., which identified 3,356 methane leaks from the gas distribution system of the city of Boston (Phillips, Ackley et al. (2013)).

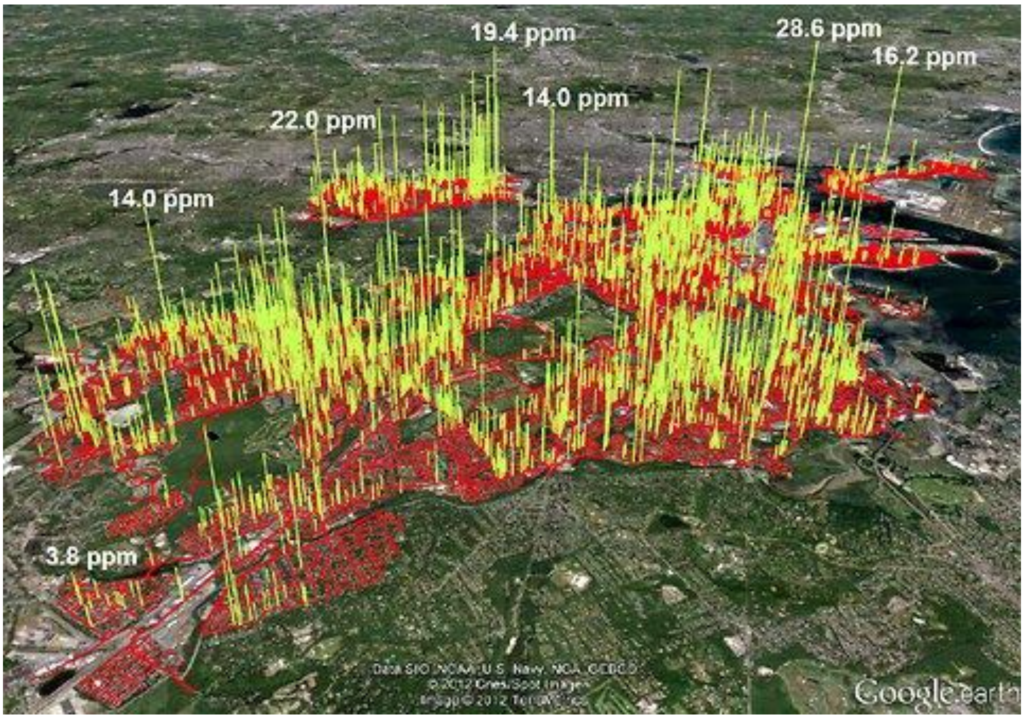

Figure 14: 3,356 methane leaks mapped in the city of Boston (Phillips, 2013)

In 2012, researchers from Southern Cross University used a vehicle-mounted mobile methane-emission detector to record "the first assessment of greenhouse gases in Australian CSG fields" (Maher, Santos et al. (2014)). Measurements recorded in the Tara, Queensland region indicated:

> "...a widespread enrichment of both methane (up to 6.89 parts-per-million (ppm)) and carbon dioxide (up to 541 ppm) within the production gas field, compared to outside. The methane and carbon dioxide carbon-13 isotope source-values showed distinct differences within and outside the production field, indicating a methane source within the production field that has a carbon-13 isotope signature comparable to the regional CSG."

The researchers concluded:

> "Data from this study indicates that unconventional gas may drive large-scale increases in atmospheric methane and carbon dioxide concentrations, which need to be accounted for when determining the net greenhouse gas impact of using unconventional gas sources.

> Considering the lack of previous similar studies in Australia, the identified hotspots of greenhouse gases and the distinct isotopic signature within the Tara gas field demonstrate the need to fully quantify greenhouse-gas emissions before, during and after CSG exploration commences in individual gas fields."

Though this study measured methane concentrations, it did not attempt to quantify a methane emission rate. Nor did this study attempt to identify specific methane emission points or causes.

5.4.3. 2012 CSIRO review of CSG-industry methane-emission reporting (2012)

In their October 2012 report entitled "Fugitive Greenhouse Gas Emissions from Coal Seam Gas Production in Australia", (Day, Connell et al. (2012)), the CSIRO reported that with regard to Australian methane-emissions reporting:

> "The fugitive emissions data reported to [the] National Greenhouse and Energy Reporting Scheme (NGERS) are subject to significant uncertainties and do not provide information specific to the CSG industry. The bulk of the reported fugitive emissions are due to venting and flaring which can be estimated to reasonable confidence - in some cases with Tier 3 [direct measurement] methods. However, for CSG production, most of the emissions from this sector are estimated using Tier 1 and Tier 2 [factor and estimate-based] methods described in the American Petroleum Institute's (API 2009) Compendium of Greenhouse Gas Emission Methodologies for the Oil and Natural Gas Industry, with emissions factors based on U.S. operations."

And in summary,

> "... it is clear that a comprehensive data set relating to the true scale of fugitive emissions from the CSG industry does not yet exist."

A key recommendation of this CSIRO study was that:

> "A programme of direct measurement and monitoring is required to more accurately account for fugitive emissions from CSG than is currently available."

As described in Section 5.4.7, the CSIRO were subsequently commissioned by the Australian Government to conduct limited methane emission measurements at coal seam gas well pads.

5.4.4. Pitt & Sherry reviews of CSG-industry methane-emission reporting (2012 and 2013)

Also in 2012, Pitt & Sherry (Saddler (2012)) conducted a "review of literature on international best practice for estimating greenhouse-gas emissions from coal seam gas production".

Pitt & Sherry reported:

> "There is effectively no public information about methane emissions associated with unconventional gas production in Australia. This is a matter of some public policy concern, given the projected large growth in production of CSG."

Regarding emission-estimation and reporting methods used in Australia, Pitt & Sherry reported:

> "The key point about all these methodologies is that they were specifically designed for use by the conventional natural gas industry, not for CSG production. This may well be appropriate for equipment used at gas processing facilities, since this is essentially the same for both gas sources. It may also be appropriate for gathering pipelines and compressors. However, it is less likely to be appropriate for well heads and it certainly does not address the possibility of uncontrolled emissions of methane escaping through the ground around wells, as has been claimed to occur in some CSG fields. It should also be noted that the emission factor values recommended in the API Compendium are mostly derived from measurements made in the USA in the 1990s, and so may not be appropriate for Australia today, and in the future."

In addition to the above shortcomings, in 2013 Pitt & Sherry (Saddler (2013)) reported that 'migratory' or 'diffuse' methane emissions are not included in methane-emission reporting required by NGERS. (The potential for methane migratory emissions occurring as a result of Australian coal seam gas extraction is discussed in Section 5.6).

5.4.5. NSW Chief Scientist commentary on emissions reporting (2013)

In July 2013, the New South Wales Chief Scientist and Engineer (2013) confirmed that with respect to estimates of methane emissions resulting from coal seam gas production:

> "...current estimates are made using methods for the conventional gas industry and do not take into account factors in the CSG industry such as increased well density and potential for hydraulic fracturing."

5.4.6. Australian Government technical discussion paper identifies concerns (2013)

In April 2013, the Australian Government (2013) released a technical discussion paper entitled:

> "Coal Seam Gas: Enhanced Estimation and Reporting of Fugitive greenhouse-gas emissions under the National Greenhouse and Energy Reporting (Measurement) Determination"[13]

This discussion paper presented proposals for enhancing...

> "... methods used by companies for the estimation of greenhouse-gas emissions during the exploration and production of coal seam gas."

The discussion paper recognised that:

> "... currently the NGER (Measurement) Determination does not differentiate between the methods used for the estimation of emissions from conventional gas and methods used for coal seam gas (CSG) production. Nonetheless, in practice, there are significant operational differences between conventional natural gas and CSG; most notably CSG production generally involves a higher density of well heads within a well field and CSG production may also involve the subterranean hydraulic fracturing process known as 'fracking'. This latter aspect is important as there is overseas evidence to suggest that use of fracking techniques may generate more emissions than when conventional CSG extraction techniques are used."

The Australian Government's technical discussion paper sought to:

> "... address the implications of the differences between conventional gas and CSG and to elaborate CSG-specific proposals for the estimation of fugitive emissions for the first time."

Following these reviews, in July 2013, Section 3.46B was added to the NGERS Technical Guidelines[14]. It describes more specific reporting requirements for well completions and well workovers. This new section applies to the reporting year ending 30 June 2014 and afterward.

5.4.7. CSIRO well pad methane emission measurements (2014)

In June 2014, Australia's CSIRO published what was referred to as "the first quantitative measurements of methane emissions from the Australian coal seam gas industry" (Day, Dell'Amico et al. (2014)).

However, as the CSIRO reported, their work scope was as prescribed by the Australian Government (Department of Climate Change and Energy Efficiency) and was limited to equipment located strictly on well pads. Equipment outside of well pads, which CSIRO researchers noticed was a significant source of methane emissions (e.g. entire gas processing plants, compressor stations, and water treatment plants) did not fall within the scope of CSIRO's investigations.

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[13] This technical discussion paper is no longer available on Australian Government websites.
[14] http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/nger/technical-guidelines

Five CSG-producing companies provided CSIRO access to 43 selected well pads in New South Wales and Queensland. Equipment at the well pads included a wellhead, a dewatering pump and gas-engine (if fitted), separator, pipework and associated valves, instruments, and fittings.

The largest well-pad emission source that CSIRO was able to measure was a vent from which methane was being released into the atmosphere at a rate of 44 grams per minute. This is equivalent to 23 tonnes of methane per year if these emissions were to continue for a full year. CSIRO's findings here contrast with CSG-LNG project Environmental Impact Statements commitments to "zero venting" of methane (Hardisty, Clark et al. (2012)).

At another gas operations site, the largest source of methane emissions was a buried gas-gathering line. CSIRO reported that:

> "We attempted to measure the emission rate ... however because of the diffuse nature of the emissions through the gravel, this was not successful."

CSIRO also highlighted significant methane releases from gas-engine exhausts (i.e. uncombusted methane fuel). One engine was emitting uncombusted methane at a rate of 11.8 grams per minute (or six tonnes per year if continuous), an emission rate 236 times greater than the factors that apply under NGERS reporting. (Note that in the electricity-generation comparison by Hardisty, Clark et al. (2012) of gas versus coal (see Section 3.2), no emissions from gas-engine exhausts were considered.)

In some instances CSIRO's attempts to measure leaks at well pads were overwhelmed by large methane emissions emanating from neighbouring water-gathering lines, water-pump shaft seals, and gas compression plants that CSIRO were not asked to investigate. The researchers described their experiences as follows:

> "On-pad measurements were made at most wells except in a few cases where high ambient CH_4 levels from major leaks or vents made locating minor leak points difficult. In one case at Well B2, CH_4 released from a vent on a water gathering line was drifting over the pad components so it was not possible to determine if there were other leaks against the high background. Similar conditions were encountered at Wells C3 and E4 where variable plumes from leaks around the water pump shaft seals precluded reliable leak detection. In one case we attempted to measure emissions from a well about 500 m downwind of a gas compression plant but the CH_4 emissions from the plant prevented any measurements being made on that site."

As an example of "significant" volumes of methane being released beyond well pads and therefore beyond CSIRO's assigned scope of investigation:

> "We found a significant CH4 emission point from a water gathering line near Well B13. Methane was being released from two vents ... at a rate sufficient rate to be audible a considerable distance from the vents. ... Based on the prevailing wind speed, we estimate that

> the CH4 emission rate from the two vents was at least 130 [grams per minute].... This is a factor of three more than the highest emitting well examined during this study."

In a reply to questions asked in the Australian Senate in 2014, CSIRO highlighted CSG/water separation activities as a particular operational source of methane emissions requiring further investigation (Australian Senate (2014)). CSG/water separation difficulties have been previously reported in the United States. Atmospheric venting of up to 30% of produced methane was found at gas-production sites where inadequate gas/water separation facilities were provided (U.S. Dept. of Energy (2010)).

In summary, the researchers qualified their limited fieldwork as follows:

> "...there are a number of areas that require further investigation. Firstly, the number of wells examined was only a very small proportion of the total number of wells in operation. Moreover, many more wells are likely to be drilled over the next few years. Consequently the small sample examined during this study may not be truly representative of the total well population. It is also apparent that emissions may vary over time, for instance due to repair and maintenance activities. To fully characterise emissions, a larger sample size would be required and measurements would need to be made over an extended period to determine temporal variation."

CSIRO's methane emission findings contrast with CSG-LNG projects Environmental Impact Statements that "best practice" would be employed by the industry, and that methane emissions would be limited to 0.1% of production (Clark, Hynes et al. (2011), Prior (2011), Hardisty, Clark et al. (2012)).

The CSIRO's limited well pad investigations are cited in the Australian Government's National Inventory Report (Australian Government (2016)) as validating the continued use of the 0.0058%-of-production emission factor for "general leakage". This factor was provided by the Australian Petroleum Production and Exploration Association (APPEA) and is based on 1994 analysis of emissions resulting from conventional gas production. Concerningly, continued use of the 0.0058% emission factor for "general leakage" in Australian emission inventories is questionable because:

- the CSIRO-reported mean (average) emissions value was 1.8 times higher than the Australian Government-accepted inventory emission factor (0.0102% vs 0.0058%)
- the CSIRO-reported mean emissions value excluded measurements from two well pads that, if included, would raise the CSIRO mean emissions value by four times to 0.04%. This highlights the skewed distribution of methane emission sources and the impact of 'super-emitters' (see Section 4.3).
- did not measure emissions from many other obvious emission sources near well pads

And furthermore, as noted by the CSIRO:

> "While wells represent a major segment of the CSG production infrastructure, it is important to note that there are many other components downstream of the wells which have the potential to release greenhouse gases. These include processing and compression plants, water treatment facilities, gas-gathering networks, high-pressure pipelines and several LNG production facilities currently under construction near Gladstone. In the study reported here, we have only examined emissions from a small sample of CSG wells; none of the other downstream infrastructure has been considered at this stage."

5.4.8. Gas industry mobile survey (2014)

Following on from the Southern Cross University research, in a report prepared for the Gas Industry Social and Environmental Research Alliance (GISERA), researchers used vehicle-mounted mobile equipment and measured methane concentrations in air as high as 18 parts-per-million (Day, Ong et al. (2015)). The researchers reported "numerous occasions where elevated methane concentrations were detected" but did not identify the emission sources.

A methane concentration of 5.8 parts-per-million was measured near an operating gas vent. This finding is contrary to commitments made in Queensland CSG-LNG project Environmental Impact Statements that there was to be "zero venting" of methane (Hardisty, Clark et al. (2012)).

Based on roadside measurements, a methane-emission rate of 850 kilograms/day was indicated near a gas plant, however the researchers stated:

> "Because of the uncertainties associated with these emission rate estimates it is stressed that the data presented ... are indicative only and cannot be interpreted as accurate emission rates from these facilities. Further work is required to better define the emissions from these sources.
>
> The atmospheric 'top-down' method using a network of fixed monitoring stations[15] proposed for Phase 3 of this project is likely to significantly reduce the uncertainty of flux estimates for [methane] sources, including major CSG infrastructure such as gas processing facilities."

[15] See Section 7.3.2.3 for a discussion of the capabilities of fixed (stationary) air quality monitoring stations.

5.4.9. UNFCCC review of Australian inventory submission (2016)

Following a review, in April 2016 (UNFCCC (2016)), the United Nations Framework Convention on Climate Change (UNFCCC) expert review team (ERT) reported on Australia's greenhouse gas inventory submission. With respect to emission from oil and gas production operations, the ERT described where action is needed for Australia to improve its submission. Some of these actions are described in Table 10.

Table 10

Partial list of oil-and-gas-related greenhouse gas inventory improvement described by UNFCCC	
UNFCCC issue no.	
E.12	"Improve the transparency of the discussion on the reasons underlying the following observed trends: large inter-annual changes in CH_4 emissions from natural gas production and processing; and the decline in CH_4 emissions from distribution while CO_2 emissions increased."
E.14	"Update the AD [activity data] for petroleum storage so that it truly reflects the actual AD the were applied to estimate emissions of petroleum storage since 2009."
E.17	"A new liquefied natural gas plant recently started operations in Australia. The ERT noted that the key emission data and country-specific CO_2 and CH_4 EFs used to report the emissions for this category, which considers several plants, were developed before the opening of the new plant, and may therefore not be representative of emissions from this plant type. The ERT recommends that Australia collect data on emissions from any new plant types, and update the country-specific CO2 and CH4 EFs, where appropriate."
E.18	During the review, Australia informed the ERT of the considerable projected growth in unconventional gas production (e.g. shale and coal bed methane) in Australia. The ERT notes that key EF [emissions factor] data used in the inventory calculations are based on data from the United States of America and may not be representative of the emissions from well completion activities associated with the commissioning of new production. The ERT recommends that Australia make efforts to improve the data for the emissions from this category, including the development of updated EFs that represent production activities in unconventional gas production." In its National Inventory Report, the Australian Government identified planned improvements to address UNFCCC-identified issue E.18.

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5.5. Australian methane-emission comparisons

In the National Inventory Report 2014 (Australian Government (2016)), the methane component of "fugitive emissions from oil and natural gas" was reported to be 5,453,000 tonnes CO_2-e. This quantity is approximately 0.5% of the total amount of methane produced for sale by the Australian oil and gas industry in 2014. As will be described below, this emissions rate is much lower than assessments reported recently by researchers investigating emissions from unconventional oil and gas operations in the United States.

Figure 15 illustrates that since 2005 Australian gas production has increased by 46%. Over this same time period, reported methane emissions have increased by only 9%. These discordant trends may indicate under-reporting of methane emissions.

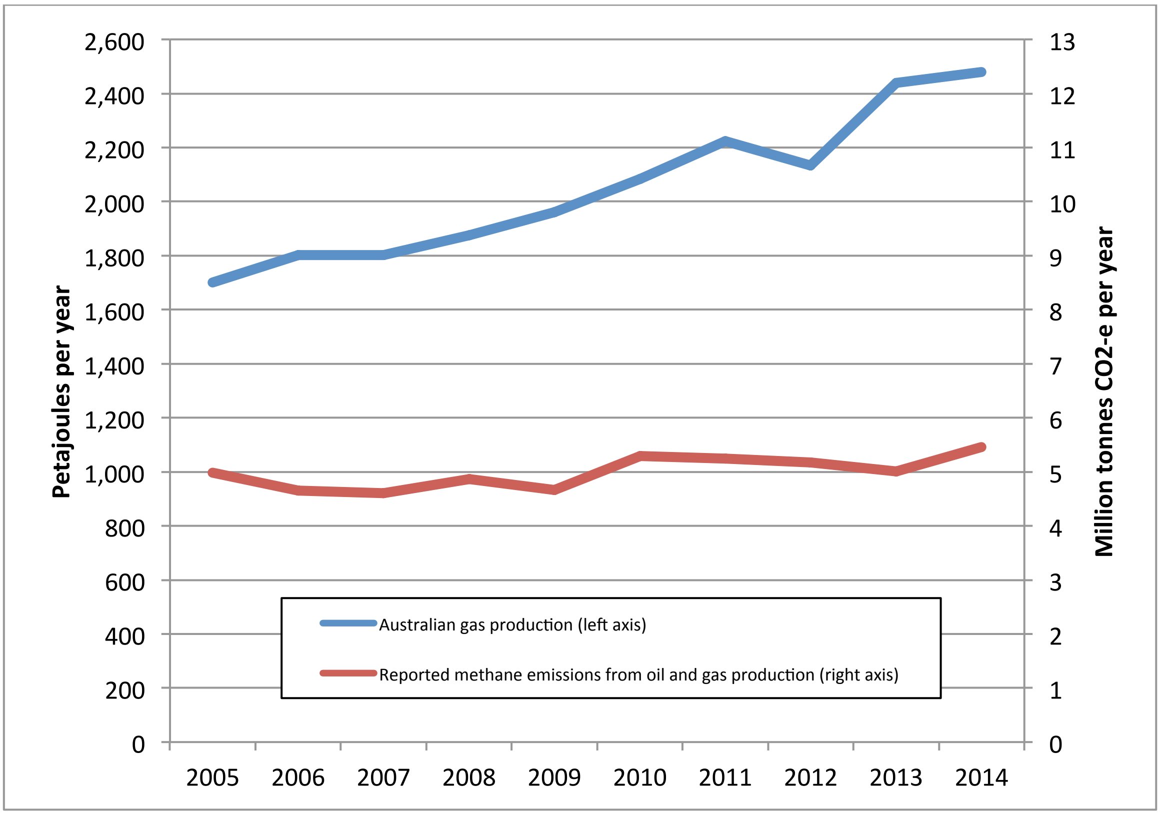

Figure 15: Australian annual gas production and reported methane emissions

As described above, Australia's reported methane emissions from the oil and gas sector are equivalent to at 0.5% of gas production. This relative level of methane emissions:

- exceeds by 25 times the level highlighted in a 2014 media release by the Australian Petroleum Production and Exploration Association (0.02%)[16]
- exceeds by five times the level of methane emissions (0.1%) expected according to the original Queensland CSG-LNG project Environmental Impact Statements (Clark, Hynes et al. (2011), Prior 2011), Hardisty, Clark et al. (2012))
- is only 36% of the U.S. EPA's recently revised estimates (1.4%, as described in Section 4.6)
- is far below levels reported for U.S. oil and gas-producing regions based on data recorded via aircraft or space satellites (2 to 17% of production).

Figure 8 compares certain estimated methane-emission levels reported for the U.S. and Australia with certain 'top-down' measurements conducted in the United States. (See also Table 11 for data and references.)

5.6. The risk of migratory emissions from Queensland coal seam gas

The MEI companion report on migratory emission entitled

> *"The risk of migratory methane emissions resulting from the development of Queensland coal seam gas"*

focuses on the single potential emission source known as 'migratory methane emissions'.

Current Australian methane-emission estimation methods ignore this potential source. The likelihood of migratory emissions occurring as a direct consequence of gas extraction, at present or in the future, is difficult to assess due to a lack of available data. The heterogeneity of the geology in the area where Queensland's Condamine Alluvium exists increases the risk of migratory emissions occurring.

[16] http://www.appea.com.au/media_release/csiro-report-points-to-environmental-benefits-of-csg/

Table 11

Reported oil and gas-related methane-emission estimates and top-down measurements				
		Basis	**% of production**	**Reference**
Australia	Oil and gas industry media release	limited well-pad measurements	0.02%	Footnote [17]
	Fugitive emissions reported in Queensland CSG-LNG environmental impact statements	factor-based estimates	0.1%	Clark, Hynes et al. (2011), Prior (2011), Hardisty, Clark et al. (2012)
	Australian Government reported (for the year 2014)	largely factor-based estimates	0.5%	See Section 5.5
U.S.	U.S. EPA (for the year 2013, latest revision)	largely factor-based estimates	1.4%	See Section 4.6
	U.S. Denver-Julesberg basin	aircraft measurements	2 to 8%	Petron, Karion et al. (2014), see Table 2
	U.S. Eagle Ford Basin (Texas)	satellite-based measurements	9%	Schneising, Burrows et al. (2014), see Table 2
	U.S. Bakken Basin (North Dakota)	satellite-based measurements	10%	Schneising, Burrows et al. (2014), see Table 2
	U.S Uintah Basin (Utah)	aircraft-based measurements	6 to 12%	Karion, Sweeney et al. (2013), see Table 2
	U.S. Marcellus Basin (southwestern Pennsylvania)	aircraft-based measurements	3 to 17%	Caulton, Shepson et al. (2014), see Table 2

[17] http://www.appea.com.au/media_release/csiro-report-points-to-environmental-benefits-of-csg/

Current Australian methane-emission estimation methods ignore this potential source. The likelihood of migratory emissions occurring as a direct consequence of gas extraction, at present or in the future, is difficult to assess due to a lack of available data. The heterogeneity of the geology in the area where Queensland's Condamine Alluvium exists increases the risk of migratory emissions occurring.

Migratory emissions could significantly increase with continued depressurisation of the coal seams while multiple users are extracting water from various aquifers. Migration of methane along existing natural faults and fractures is possible and may increase with continued depressurisation even when the leakage rates today may be minimal without disturbance. Water bores and coal exploration bores are known sources of methane emissions and the presence of free methane can be the direct consequence of the depressurisation of the coal seams. Well integrity of dedicated gas wells but also existing bores that were not designed to prevent migratory emissions is an area of concern.

The companion report on migratory emissions contains a more detailed discussion of migratory emissions.

5.7. Lost revenue and potential liabilities associated with future methane emission scenarios from unconventional gas production

This section outlines the value of lost gas production and potential carbon liabilities associated with methane emission scenarios resulting from Australian unconventional gas production, under various global warming potential assumptions, assuming some form of carbon pricing is reinstated at a future time.

In 2014, the Australian Government reported greenhouse gas emissions across all sectors totalling 525 million tonnes (CO_2-e) of which 5.4 million tonnes were attributed to oil and gas sector emissions. (Australian Government 2016) Consistent with current United Nations reporting guidelines, methane emissions are reported as having a 100-year global warming potential (GWP) of 25 tonnes of CO_2-e per tonne of methane emitted. The value of 25 for the 100-year GWP is based on the 4th Assessment Report of the IPCC (2007). In the 5th Assessment Report (2013) the IPCC updated the 100-year GWP for methane to 34 including carbon cycle feedbacks and 28 excluding carbon cycle feedbacks. The use of the updated GWP would increase the total methane emissions in CO_2-e e units by 26%, as methane emissions are multiplied with the GWP for a conversion to CO_2-e equivalent emissions. Reported fugitive methane emissions from oil and natural gas would increase by 2 million tonnes CO_2-e. Adjusting the reported greenhouse gas emissions for all Australian sectors for a 20-year methane GWP of 86 would increase the total by approximately 50% to 787 million tonnes CO_2-e.

Table 12 summarises predicted growth in total methane emissions from the Australian unconventional gas industry for several scenarios using different assumptions about the proportion of fugitive emissions and the growth in industry output. (For 2016, approximately 1,500 petajoules per year of unconventional gas will be produced in Australia, mostly in the form of Queensland coal seam gas.) We consider methane-emissions scenarios ranging from 0.5% of gas production (the current government-reported average of 0.5%) to 15% of gas production (a figure similar to some of the highest estimates of U.S. gas field emissions presented in Table 3).

Table 12

Liabilities for differing scenarios for methane emissions from Australian unconventional oil and gas production, in terms of lost value and potential carbon impost.

Column	A	B	C	D	E
Case	Unconven-tional gas production rate	Methane emissions rate	Methane greenhouse-gas emissions (100 yr – 20 yr GWP)	Sales value of lost gas (at $A 10 / gigajoule)	Carbon impost ($A 25/tonne CO_2-e; 100 yr – 20 yr GWP)
	PJ/yr	% of gas production	million tonnes CO_2-e/yr	million $A/yr	million $A/yr
1	**1,500 (*)**	0.5	5 - 12	75	115 - 290
2	"	2	18 - 46	300	459 - 1,162
3	"	6	55 - 139	900	1,367 - 3,485
4	"	10	92 - 232	1,500	2,296 - 5,808
5	"	15	136 - 348	2,250	3,443 - 8,712
6	**3,000**	0.5	9 - 23	150	230 - 581
7	"	2	37 - 93	600	918 - 2,323
8	"	6	110 - 279	1,800	2,755 - 6,969
9	"	10	184 - 465	3,000	4,590 - 11,615
10	"	15	275 - 697	4,500	6,887 - 17,423

* 1,500 PJ/yr is approximately equal to current or near-term (2016, 2017) CSG production capacity.

Table 12 (Column C) presents figures for ten 'cases' where methane-emissions range from 0.5 to 15% of total unconventional gas production. Table 12 also shows the financial impact of these emissions by applying a gas sales-value of $A 10 / gigajoule and a carbon impost of $A 25 / tonne of CO_2-e (Columns D and E).

As an example, Case 8 illustrates a 6%-of-production methane emission rate. This case shows that were the Australian unconventional gas industry to expand to twice its present size, and if the specified gas sales value and carbon impost applies, the value of lost gas sales would total $A 1.8 billion per year while the carbon impost would be between $2.7 - $7 billion per year depending on whether the CO2-e is calculated on at the 100-year, as is convention, or 20-year timescale, as might be considered relevant in setting near term targets such as 2030.

5.8. Conclusions

In summary, the information presented in Section **5** shows that Australia's unconventional gas industry is rapidly growing. There is also potential for unconventional oil production. Unfortunately, reviews of Australia's methane-emission estimation and reporting methods for this industry sector highlight shortcomings that may mean reported emissions, at only 0.5% of total-gas-production, are lower than what is actually occurring.

As summarised by CSIRO researchers in 2012:

> "... it is clear that a comprehensive data set relating to the true scale of fugitive emissions from the CSG industry does not yet exist."

This remains the situation today. No investigations have yet been published that quantify methane emissions across all potential emission points that exist throughout coal seam gas production, processing, and gas transport infrastructure.

In its National Inventory Report, the Australian Government cites CSIRO's investigations of just 43 well pads as validating the "general-leakage" emission factor assumption of just 0.0058%-of-production, while ignoring CSIRO's conclusion that:

> "In addition to wells, there are many other potential emission points throughout the gas production and distribution chain that were not examined."

In a reply to questions asked in the Australian Senate in 2014, CSIRO highlighted CSG/water separation activities as a particular operational source of methane emissions requiring further investigation.

In 2016, the UNFCCC "expert review team" (ERT) noted that regarding Australia's greenhouse gas inventory submission to the United Nations:

> "... key EF [emissions factor] data used in the inventory calculations are based on data from the United States of America and may not be representative of the emissions from well completion activities associated with the commissioning of new production."

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

The UNFCCC's review team went on to recommend that:

> "... Australia make efforts to improve the data for the emissions from this category, including the development of updated EFs that represent production activities in unconventional gas production."

Referring to the UNFCCC recommendations, the Australian Government identified improvement measures that it "hopes":

> "...can lead to the development of more representative EFs." (Australian Government (2016))

Finally, Section 5.6 highlighted the potential for migratory methane emissions to occur in Queensland's coal seam as basins. This is further described in the MEI companion report entitled:

> *"The risk of migratory methane emissions resulting from the development of Queensland coal seam gas".*

6. Full fuel-cycle greenhouse gas emissions from exported CSG

Full life-cycle emissions for the exported LNG include not only supply side emissions associated with production, but also emissions arising from processing shipping and use at the destination. Table 13 shows estimated greenhouse emissions arising from the various stages of production, processing and shipping coal seam gas in the form of LNG to Japan.

No estimate has been made of emissions associated with pipeline transport from port to point of consumption in the destination country, because there are a variety of LNG destinations. However, these emissions are likely to be very small. We assume that the imported gas will all be used for electricity generation and at other large industrial sites. For any gas supplied through distribution networks to small consumers, emissions could be considerably higher, because of the higher level of fugitive emissions from typical gas distribution systems, compared with those supplying large consumers such as power stations.

As discussed earlier, methane emissions from coal seam gas transport between wellhead and pipeline tie-in may be quite large. Hence the estimated total emissions shown here should be seen as a minimum value.

Table 13

Stage/activity	Emission source	Fuel (if applicable)	Emission factor (see text)	Emissions (tonnes CO_2-e/TJ gas delivered
Production and processing to LNG	Energy combustion (Scope 1)	gas	123 PJ/24 Mt LNG	5.05
	Energy combustion (Scope 2)	electricity	9.3 TWh/24 Mt LNG	5.80
Exploration	Reported fugitive methane under NIR		26 t/completion day	0.22
Production, well platform only	Reported fugitive methane under NIR		0.058 t/t produced	0.17
Production, other sources	Reported fugitive methane under NIR		Not estimated	
Shipping	Energy combustion	gas (boil off)	22.5 g CO_2/tonne nm	1.67
Regasification	Energy combustion	gas	1% of throughput	0.52
TOTAL supply system				13.6
Gas combustion				52.0
TOTAL fuel cycle				65.6

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

Total minimum fugitive and combustion emissions upstream of the point of combustion are estimated to be 13.6 tonnes of CO_2-e per terajoule (TJ) of gas delivered to the final user in the importing country. Using a direct-combustion emission factor of 52 tonnes of CO_2-e per TJ, this makes the full fuel-cycle greenhouse gas emissions 65.6 tonnes of CO_2-e per TJ of gas consumed.

6.1. Calculation assumptions and method

Production and processing to LNG	Energy consumption estimates from Lewis Grey Advisory, as discussed above.
Exploration	Estimate uses the per well emission factor from the National Inventory, as discussed above. It assumes an average production-life per well of 20 years and that the total number of wells drilled to support the three LNG trains will be 8,000. Note that wells drilled in Queensland up to June 2015 totalled a little over 7,000 and that annual numbers drilled reached a peak in 2013-14 and fell sharply in 2014-2015. (Queensland Department of Natural Resources and Mines, 2016)
Production (well platform only)	Estimate uses the per well emission factor from the National Inventory, as discussed above. The figure is 0.058 tonnes methane per tonne produced, as discussed above, converted to CO_2-e.
Production, other sources	No estimates available, as discussed above.
Shipping	It is assumed that all the fuel used in shipping comes from LNG boil-off, thereby reducing the volume of LNG delivered. The estimate is for a voyage from Gladstone to Yokohama, a distance of 4,045 nautical miles. The emission factor of 15 g CO_2 per tonne-nautical mile is towards the low end of the range reported by Wang, Rutherford and Desai, 2014, and is scaled up by a factor of 1.5 to allow for fuel use and resultant emissions on the empty return voyage.
Regasification	There are a number of different regasification technologies, using different energy sources and with different associated emissions. The technologies used at the regasification terminals to which the LNG will be exported are not known. It has been assumed that the technology will use gas boil-off as fuel and that the quantity used will equal 1% of the gas output. This is around the mid-point of the range quoted by Elsentrout, B., Wintercorn, S. and Weber, B. (2006).

7. Recommendation for industry and regulators; addressing methane-emission knowledge gaps

7.1. Australian oil and gas industry action needed to minimise current methane emissions

Within the rapidly-growing Australian CSG-LNG industry, reducing methane emissions may not have been top priority compared to constructing the $A 60 billion Queensland CSG-LNG facilities and subsequently initiating gas exports. Furthermore, the July 2014 removal of the carbon price reduced the economic incentives to minimise methane emissions.

Nevertheless, there remain reasons why the Australian oil and gas industry should act to reduce methane emissions including:

- moving toward the low-level of methane emissions expressed in CSG-LNG project Environmental Impact Statements (reported to be as low as 0.1% of production, see Section 5)
- reduced safety hazards and health impacts for industry workers and neighbouring community members
- global climate change mitigation
- reduced product loss
- reduced potential for future carbon liabilities
- improved reputation in the community and social 'licence-to-operate'
- improved public-perceptions regarding the role gas can play in the rapid movement to a net-zero-carbon future.

According to the Global Methane Initiative[18]:

> "In oil and gas systems, there are numerous opportunities to reduce methane emissions. Many emission reduction activities consist of relatively simple operational changes that can have a large impact for a relatively small cost. Opportunities to reduce methane emissions generally fall into the following categories:
>
> - change out existing equipment
> - Improve maintenance practices and operational procedures
> - study and undertake new capital projects."

The U.S. Government Accountability Office estimated[19] that around 40% of the gas that is vented and flared on onshore federally-leased land could be economically captured with currently available control technologies.

[18] The Global Methane Initiative is an international public-private initiative that advances cost effective, near-term methane abatement and recovery. http://globalmethane.org

According to the Environmental Defense Fund:

> "Cost-effective technologies exist to reduce routine and non-routine emissions of methane during oil and gas exploration and production. The U.S. Environmental Protection Agency (EPA), in conjunction with the natural gas and oil industry, has developed and tested more than 100 ways to reduce methane emissions while increasing revenues by keeping more product in the pipeline."[20]

Studies done for the U.S. (ICF International (2014)) and Canada (ICF International (2015)) found significant opportunities for cost-effective methane-emission reduction. For example:

> "Industry could cut methane emissions by 40% below projected 2018 levels at an average annual cost of less than one [U.S.] cent on average per thousand cubic feet of produced natural gas [$A 0.012 per gigajoule] by adopting available emissions-control technologies and operating practices. [When] the full economic value of recovered natural gas is taken into account, [a] 40% reduction is achievable."

Hardisty, Clark et al. (2012) put forward recommendations for the oil and gas industry regarding venting from pilot wells, well completions and workovers, compressor stations and pneumatic devices. Capturing gas and flaring wherever possible are obvious mitigation measures. Mitigating emissions should involve high quality equipment, adhering to high standards and implementation of leak detection programs.

Apte, McCabe et al. (2014) recommended procedures for well abandonment (coal exploration wells, coal seam gas wells, water bores and mineral exploration wells.

The oil and gas industry (and other stakeholders) can make use of emerging technologies to rapidly identify and quantify methane emissions. Examples include:

- drone technology to rapidly survey gas infrastructure (Section 7.3.2.3)
- the use of a 30 kilogram camera fitted with optimised infrared (IR) hyperspectral imaging to rapidly quantify methane fluxes as small as 25 grams per hour (Gålfalk, Olofsson et al. (2015)).

To rapidly reduce methane emissions, industry should focus on identifying methane 'super-emitters'.

Beyond the immediate industry actions described in this section, Section 7.2 describes recommended actions needed to regulate methane emissions in Australia. Section 7.3 describes actions that need to be taken by a broader range of Australian stakeholders to close knowledge-gaps and improve the access to information about methane emissions from unconventional oil and gas production.

[19] http://www.gao.gov/products/GAO-11-34
[20] https://www.edf.org/sites/default/files/methaneLeakageFactsheet0612.pdf

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

7.2. Regulating methane emitted by the Australian oil and gas industry

Currently in Australia, there are no specific federal or state regulations that limit, for climate or environmental protection reasons, the amount of methane that can be emitted by the oil and gas industry.

Formerly this was also the situation in the U.S and Canada. However, there has been significant change in those countries in recent years. In addition to the U.S. and Canadian federal government announcements described in Section 4, other recent initiatives at federal and state/province level include:

- 2013: The U.S. state of Wyoming is the first to require operators to find and fix methane leaks.
- 2014: The U.S. state of Colorado adopts the U.S. EPA's "Standards for Performance of Crude Oil and Natural Gas Production, Transmission and Distribution". Companies subsequently reported they had repaired more than 1,500 gas leaks in the last few months of 2014. Ohio also acts to regulate methane emissions.
- 2015: The Canadian province of Alberta announces plans to reduce oil and gas methane emissions by 45 per cent by 2025.
- January 2016: The U.S. state of Pennsylvania announces a "nation-leading strategy to reduce emissions of methane" during "development and gas production, processing, and transmission by requiring leak detection and repair (LDAR) measures, efficiency upgrades for equipment, improved processes, implementation of best practices, and more frequent use of leak-sensing technologies."
- February 2016: The U.S. state of Alaska announces a $US 50 million program to clean-up legacy oil and gas wells including attention to methane emissions. The U.S. state of New Jersey passes legislation to hasten repair and replacement of leaking gas pipelines. Following the Aliso Canyon gas storage facility release, the California state legislature proposes new nation-leading methane emission-prevention regulations.
- March 2016: The U.S. Methane Challenge Program is formally launched by the U.S. EPA[21].

In Australia (as described in Section 5.3) the oil and gas industry is required to report estimates of methane emissions via the National Greenhouse and Energy Reporting Scheme (NGERS). However there are no specific federal or state regulations that limit, for regional or global environment/climate-protection reasons, the amount of methane emitted by the oil and gas industry.

[21] https://www3.epa.gov/gasstar/methanechallenge/

McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

Regarding methane-emission regulation in Australia, a 2013 report by the New South Wales Chief Scientist and Engineer stated:

> "Fugitive and other air emissions can be mitigated through the application of best practice technology, operations and maintenance of wells and pipelines. Should mitigation measures fail, and emissions occur, then a well-planned and integrated monitoring and modelling system to detect, warn and potentially isolate the cause of the leak is required. Compliance with fugitive and air emissions standards should be enforced by regulators." (NSW Chief Scientist and Engineer (2013))

Given the significant potential for the growing Australian unconventional oil and gas industry to emit methane (as described in Section 5), there is a need for:

- reported methane-emission measurements to be independently verified by a regulatory body
  - This authority should have the power to conduct measurements when and where it deems necessary and to enforce industry best practices if and as required. This independent authority could be funded by levies placed on the industry.
- methane-emissions reported to NGERS to be based largely on direct measurements
- measured and reported methane emissions to include migratory emissions
- reporting, via a centralised geo-referenced database, of hydraulic fracture length and distance of fracture tip to edge of adjacent formation. This increases understanding of the potential risk for migratory methane emissions
- methane-emission volumes to be explicitly limited by regulation.

7.3. Filling methane-emission knowledge gaps

Our review has found that there is inadequate knowledge held by, and inadequate information available to stakeholders (e.g. the Australian and global community, land-holders, legislators, regulatory agencies, industry, academia) about:

- the ways in which methane may be emitted in Australia as a result of unconventional oil and gas production
- the potential amount of methane that may be emitted over the coming decades and centuries
- actions needed to minimise methane emissions.

Specifically with respect to methane emissions resulting from coal seam gas production, a report by the New South Wales Chief Scientist and Engineer stated:

> "There is currently an absence of fugitive emissions data for CSG activities in Australia. Therefore there is a requirement for further research, baseline and ongoing monitoring

to understand the level of fugitive emissions from the industry." (NSW Chief Scientist & Engineer (2013))

This section summarises some actions needed to close knowledge gaps and provide information in order for Australian and global stakeholders to be confident that methane emissions from Australian unconventional oil and gas production are kept below an understood and accepted level.

7.3.1. Establishing baselines: developing an understanding of pre-development conditions

A 'baseline' is defined as information that is used as a starting point by which to compare other information.

It is impossible to fully understand the impact of an industry if baseline data and knowledge of pre-development conditions is not available. Likewise, it is very difficult to assess whether any deteriorating conditions seen post-development, for example with regard to aquifers, atmospheric emissions, or vegetation are the consequence of industry activity. As described above, the NSW Chief Scientist and Engineer cited the need to collect baseline data so that any methane-emission impacts of coal seam gas development can be understood 'before' and 'after' development. In more detail, the NSW Chief Scientist's report described:

> "the importance of both obtaining baseline measurements of methane over a period of time (to account for seasonal variations) and using sophisticated techniques to monitor an area, to be able to distinguish between natural sources of methane, methane being emitted through other bores, and CSG fugitive emissions." (NSW Chief Scientist & Engineer (2013))

To establish a methane-emissions baseline for any area being considered for oil and gas development, data must be independently collected and analysed adequately in advance of the regulatory approval and/or the start of industry activity. Such data may include, but is not limited to the following:

- 'bottom-up' and 'top-down' methane-emission survey data collected at a sufficient number of locations, including randomised selection of locations
- mapping and monitoring of any natural methane seeps, including gas flux and composition
- establishment of water-monitoring wells in order to monitor aquifer water levels and water quality, including concentrations of oxygen, carbon dioxide, methane and other contaminants
- establishment of gas-monitoring wells in order to monitor gas flow and pressure gradients
- collection and analysis of drill-core data
  - Since there is often a lack of shallow-formation data, this should include permeability and thickness data of key aquitards and transition zones. Coring intervals should extend to shallow sections.
- permeability data of aquitards, in particular in areas where any aquitard may be thin or porous
- depth-migrated shallow-seismic-survey interpretations are needed in order to demonstrate a good understanding of any fault network in and above hydrocarbon reservoirs.

Techniques that may be used to collect some of the data listed above are further described in Section 7.3.2.

The data collection and analysis described above may form part of a Sedimentary Basin Management Plan as described in Section 7.3.3.

Even in areas where unconventional oil and gas production is already underway, there may be opportunities still to establish useful baseline information. For example, in 2013 the gas-producing company QGC had to temporarily shut-in most of its wells in the Argyle field in order to address problems with field compression and gathering systems (Norwest (2014)). Establishing baselines should be a priority before further industry development reduces the opportunity.

7.3.2. Methane-emissions monitoring: real-time, 'top-down'

Ideally, monitoring of methane emissions would take the form of a 'Google-Maps-like' website where the public could access comprehensive, continuous, high-resolution, quantitative emissions measurements taken real-time and identifying all significant methane-emission sources that exist in a given land area.

In future, the above goal could be achieved by using one or a combination of the following three air-quality monitoring methods:

- very-high-resolution satellite measurements
- a large and widespread network of ground-based monitoring stations
- regularly-scheduled unmanned aircraft fly-overs.

In addition to methane and other gas concentration data, weather data (e.g. wind direction and speed) would also need to be collected and processed so that quantitative methane-flux data could be published online and in near-real time.

One example of real-time air-quality monitoring is information published by the Victorian EPA "Airwatch" website[22].

Such a 'top-down' methane-emission monitoring system does not yet exist anywhere in the world. Until such a methane-monitoring system is deployed, there will be significant uncertainty about how much methane is emitted as a result of Australian unconventional oil and gas industry activity. However, given the rapid technology advances evident in fields such as satellite-based instruments, drone aircraft, and direct methane detection and flux quantification, with support from stakeholders, it may be possible to realise the above vision in less than a decade.

The three 'top-down' methane-emission monitoring methods listed above are discussed in the following sub-sections, as are the advantages of 'top-down' versus 'bottom-up' methods.

[22] http://www.epa.vic.gov.au/our-work/monitoring-the-environment/epa-airwatch

7.3.2.1. Space-satellite methane emission detection and quantification

Sections 4.4 and 4.5 described researchers' use of satellite-based observations to quantify methane emissions from U.S. oil and gas fields.

In an Australian report prepared for the Gas Industry Social and Environmental Research Alliance (GISERA) (Day, Ong et al. (2015)), researchers also used satellite measurements to illustrate levels of methane emissions in some CSG-producing regions of Queensland such as the Surat Basin (Figure 16).

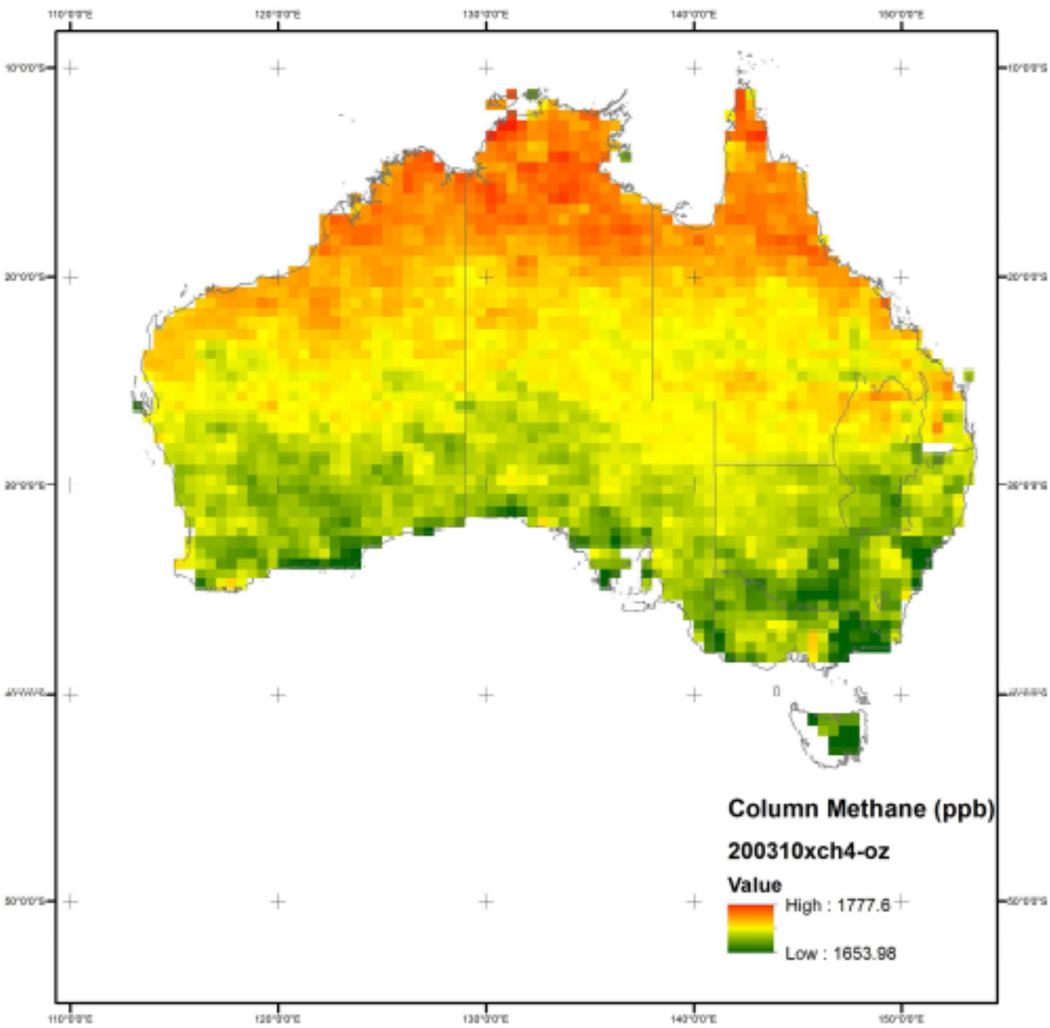

Figure 16: October 2003 satellite-data analysis of methane present in the air over Australia. (Day, Ong et al. (2015))

As in the U.S. studies, the satellite data analysed was collected using the SCIAMACHY instrument installed on the ENVISAT satellite. Data available from SCIAMACHY covered only the period 2003 to 2009, which pre-dates the 2013 start of very large-scale production of coal seam gas in Queensland.

Confirming the value of satellite data for use in monitoring methane emissions, the researchers stated:

> "If it is important to track the regional scale [methane emission] trends after the establishment of the CSG industry..., it may be useful to acquire longer term data of this nature."

The researchers identified other available satellite data as shown in the following list, but did not report on any analysis of data from these sources:

- Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE-FTS) (Canadian Space Agency (2016))
- Japan's Aerospace Exploration Agency (JAXA (2016)) Greenhouse gases Observing SATellite (GOSAT), launched in 2009
- Atmospheric Infrared Sounder (AIRS), launched aboard the NASA satellite Aqua in 2002 (NASA (2016))
- TROPOspheric Monitoring Instrument (TROPOMI)[23]
- Infrared Atmospheric Sounding Interferometer (IASI), launched in 2006 on-board the European Metop-A satellite (EUMETSAT (2016)).

Future satellite missions will observe greenhouse gases. For example, France and Germany are progressing mini-satellite MERLIN (Methane Remote Sensing Mission) toward launch in 2019.

The Sentinel satellites, part of Europe's Copernicus program, are the continuation of the work started with ENVISAT (the SCHIAMACHY platform described above). 'Sentinel 5' is a polar-orbiting atmosphere-monitoring mission that will monitor carbon dioxide, carbon monoxide, and methane at high resolution. Launch is scheduled no earlier than 2020[24].

At present, a shortcoming of satellite-based methane monitoring methods is the inability to operate at high resolution or to distinguish between individual emission sources. However, satellite data can provide useful baseline information and can be used to track emission changes over time.

Our review recommends that space-satellite data be used via an active and ongoing program to monitor methane emissions in current oil and gas-producing areas, and to establish baselines in areas of current and future interest to fossil-fuel developers.

[23] http://www.tropomi.eu/TROPOMI/Home.html
[24] http://www.eumetsat.int/website/home/Satellites/FutureSatellites/CopernicusSatellites/Sentinel5/index.html

7.3.2.2. *Using piloted and unpiloted aircraft for top-down emission investigations*

As described in Section 4.4, piloted fixed-wing aircraft were used in the United States to conduct top-down methane emission investigations over large land areas. No similar studies have yet been conducted in Australia.

An impediment to conducting piloted fixed-wing investigations are the costs involved. However, lower-cost investigations may be possible as a result of recent technology developments in the areas of:

- methane and related air-contaminant detection and flux-quantification instruments and data interpretation
- un-piloted aircraft (i.e. 'drones').

In 2014 in Australia, DRACO Analytics announced they had received funding from the Victorian Government to develop a drone-based methane-emissions detection system. A trial was planned with Melbourne Water to monitor methane emissions from water treatment systems (Draco Scientific (2014)).

In 2015, the United Kingdom Environment Agency reported the use of small fixed-wing and rotary (helicopter-type) unmanned aerial systems (UAS) to measure methane flux from landfill sites (Environment Agency (2015)).

On 23 March 2016, developers funded by the U.S. Department of Energy announced development of a low-cost methane-detection drone. The developers envision these devices could operate autonomously near any gas-production infrastructure to continuously monitor methane emissions[25].

On 28 March 2016, the U.S. National Aeronautics and Space Administration (NASA) announced progress applying drone-based methane-detection technology on Earth that is similar to technology used in experiments conducted on Mars[26].

Our review recommends the investigation of the cost and capabilities of using piloted and unpiloted aircraft to monitor methane emissions in current oil and gas-producing areas, and to establish baselines in areas of current and future interest to fossil-fuel developers.

7.3.2.3. *A widespread network of ground-based air-quality monitoring towers*

Stationary ground-based towers equipped with air-quality monitoring equipment are in use today to monitor a range of air pollutants.

[25] http://news.sys-con.com/node/3738950
[26] www.jpl.nasa.gov/news/news.php?feature=6192

Melbourne Energy Institute
McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

Given that methane is lighter than air, when released, methane will tend to quickly rise and disperse. This makes quantify methane emissions by using towers more challenging than may be the case with heavier air pollutants. Data describing atmospheric air movement (e.g. wind speed, direction) and local topography is also needed in order to model the trajectory and dispersion of a methane release and to quantify the rate at which methane is being emitted into the atmosphere.

Nevertheless, for example in the U.S. state of Colorado, Pétron, Frost et al. (2012) reported on the use of the National Oceanic and Atmospheric Administration (NOAA) Boulder Atmospheric Observatory (a single 300 metre-tall tower monitoring site) and other methods to characterise hydrocarbon atmospheric emissions. That study found inventories underestimated methane emissions by "at least a factor of two" and possibly by up to a factor of 4.6 times.

Berko et al. (2012) reported on the installation of the single-tower 'Arcturus' atmospheric monitoring station near Emerald, Queensland that was used to monitor greenhouse gases. Facilities included a ten-metre-high mast. In work commissioned by the Australian Gas Industry Social and Environmental Research Alliance (GISERA), Day, Ong et al. (2015) reported on progress to establish two fixed air-monitoring stations in the Surat Basin, Queensland. The first facility, 'Ironbark', which began operating on 17 November 2014, includes a ten-metre-high mast.

Our review recommends the continued investigation of the feasibility of a widespread long-term network of ground-based air-quality monitoring towers/stations in regions of active or prospective unconventional oil and gas production. We envision that in order to definitively quantify methane emissions, an extensive network of monitoring towers spaced 10 to 20 kilometres apart would be required. For example, a 200-kilometre by 200-kilometre gas production area would require 150 or more monitoring towers. This system would greatly improve modelling that aims to locate sources based on emission data (known as 'inverse' modelling).

Similarly, a long-term monitoring network in the Walloon coals outcropping area would be able to show if the depressurisation of the coals at depth increases methane emissions after heavy precipitation events. (The pressure gradient caused by natural rainwater recharge will mobilise gas. It is not known if methane emissions increase after heavy precipitation events because of ongoing depressurisation.)

Installing a secured gas analyser (e.g. Picarro or Los Gatos) at every monitoring station would cost around $50,000 per station. However, with technological development, gas analysers are becoming more mobile and less costly. The cost to build and maintain the network of monitoring facilities described above may mean that satellite or aircraft-based methane monitoring is more cost effective.

7.3.3. Sedimentary basin management plans needed

Sustainable and well-managed extraction of commodities (e.g. water and fossil fuels) from sedimentary basins requires a holistic sedimentary basin management plan (Rawling and Sandiford (2013))[27]. Without understanding the workings of a sedimentary basin that may provide multiple services, it is impossible to foresee the potential risks and consequences of human interventions.

Dafny and Silburn (2014) and Apte, McCabe et al. (2014) have pointed out that significant gaps remain in terms of subsurface understanding. Additional field data needs to be acquired to narrow down uncertainties around the spatial extend of the Condamine Alluvium and the transitional layer and the properties of the transitional layer. None of the hydrological models include all the hydrological processes that play a role (Dafny and Silburn (2014)).

In cases where there are competing demands on sedimentary basins, such as provision of water and fossil fuels, there is a need for an integrated geological-hydrological model. This model would assess the implications of formation heterogeneity, irregular formation thickness, coal-seam dewatering and depressurisation, and water extraction by all users. We acknowledge the computational challenges of such a complex model. This is further described in the Melbourne Energy Institute companion report entitled:

> *"The risk of migratory methane emissions resulting from the development of Queensland coal seam gas".*

[27] See also http://energy.unimelb.edu.au/research/eere/sedimentary-basin-management-initiative

8. Unit conversions

1 kJ (kilojoule) = 0.948 Btu (British thermal units)

1 PJ (petajoule) = 0.948 T Btu (trillion British thermal units)

1 TCF (trillion cubic feet) of gas = 1010 T Btu (trillion British thermal units)

1 TCF (trillion cubic feet) of gas = 1065 PJ (petajoules)

1 TCF (trillion cubic feet) of gas = 21 million tonnes of LNG

1 million tonnes of liquefied natural gas (LNG) = 48.6 T Btu (trillion British thermal units)

Source: BP Statistical Review (2015)

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NATIONAL SIGNIFICANCE

THE ECOLOGICAL VALUES OF PILLIGA EAST FOREST AND THE THREATS POSED BY COAL SEAM GAS MINING 2011-2012

NATIONAL SIGNIFICANCE

A report prepared for the Northern Inland Council for the Environment and the Coonabarabran and Upper Castlereagh Catchment and Landcare Group

This report was written by David Milledge, Landmark Ecological Services Pty Ltd, ABN 29 064 548 876, PO Box 100 Suffolk Park, NSW 2481 with the assistance of Caroline Blackmore, Origma Wildlife Research, ABN 93 648 603 795, PO Box 12, Bellingen NSW 2454, for the Northern Inland Council for the Environment, c/o 16 Roslyn Ave, Armidale NSW 2350, and the Coonabarabran and Upper Castlereagh Catchment and Landcare Group, ABN 24 154 221 076.

Flora and fauna data were collected by Darren Bailey, Georgia Beyer, Stephen Debus, Lorna Mee, David Milledge, Annette McKinley, Hugh and Nan Nicholson, David Paull, Harry Parnaby, Kate Smilie, Phil Spark, Kevin Taylor and Sally Townley.

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Northern Inland Council for the Environment

THE WILDERNESS SOCIETY

Black Cypress Pine and Scribbly Gum, small mammal trapping Site L, Falcon Trail. Photo Carmel Flint

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Pilliga Mouse woodland habitat in flower. Photo Hugh Nicholson

SUMMARY

The Pilliga Forest is the largest remaining unfragmented block of temperate dry forest and woodland in eastern Australia. It functions as a key flora and fauna refuge in a landscape largely cleared for agriculture and is recognised as part of a National Biodiversity Hotspot and as a globally significant Important Bird Area. It supports several endangered ecological communities and core populations of many threatened flora and fauna species. The latter include populations of a number of declining woodland bird species, virtually the entire population of the Pilliga Mouse *Pseudomys pilligaensis*, one of the largest NSW populations of the Koala *Phascolarctos cinereus* and one of only three significant populations of the South-eastern Long-eared Bat *Nyctophilus corbeni*. The Pilliga Forest also provides important seasonal habitat for a suite of nomadic and migratory bird species as a key part of the eastern Australian bird migration system.

An 85,000ha section of the eastern Pilliga Forest, termed the Project Area, was recently placed under threat from an application to develop it as a major coal seam gas field. Due to the likelihood of significant impacts from this proposal on the area's biodiversity, a survey targeting threatened plants, vertebrates and ecological communities was undertaken in October 2011 by a group of ecologists with relevant expertise. Shortly after this survey was completed the development application was withdrawn, but it is expected that another application for development of possibly an even larger area will be lodged in the near future.

The targeted survey employed systematic methods at sites stratified across the Project Area and resulted in records of four threatened species, one migratory species and one endangered ecological community listed under the Commonwealth's *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. These comprised one vulnerable plant species, *Rulingia procumbens*, the critically endangered ecological community White Box-Yellow Box-Blakely's Red Gum grassy woodland and derived native grassland, three vulnerable vertebrate species, the Koala, South-eastern Long-eared Bat and Pilliga Mouse, and the migratory Rainbow Bee-eater *Merops ornatus*. Seventeen additional threatened species that are listed under the NSW *Threatened Species Conservation (TSC) Act 1995* were also recorded during the survey. They included the endangered Black-striped Wallaby *Macropus dorsalis* and vulnerable Pale-headed Snake *Hoplocephalus bitorquatus*, Turquoise Parrot *Neophema pulchella*, Barking Owl *Ninox connivens*, Grey-crowned Babbler *Pomastomus temporalis*, Eastern Pygmy-possum *Cercartetus nanus* and Yellow-bellied Sheath-tailed Bat *Saccolaimus flaviventris*.

The survey results provided substantial new information on the distribution of some threatened species in the Project Area, with 21 individual South-eastern Long-eared Bats captured at eight sites and 25 individuals of the Pilliga Mouse trapped at seven sites, including three sites where breeding was indicated by lactating females. The Pilliga Mouse records showed that this species occurs and breeds in a wider range of floristic associations than previously reported, although established key structural habitat attributes of a dense low shrub layer, sparse ground cover vegetation and a well-developed litter layer were consistent throughout. A rapid habitat assessment indicated that approximately 20% of the Project Area area represented potential Pilliga Mouse habitat.

The single record of the Koala reflected the significant decline in this species reported across the Pilliga Forest since 2000, reputedly from drought and frequent wildfires.

Six of the seven sedentary declining woodland bird species listed under the *TSC Act*

were observed although relatively high numbers of only two of these species, the Grey-crowned Babbler and Speckled Warbler *Chthonicola sagittata*, were recorded. Other threatened bird species observed in numbers were the Glossy Black-cockatoo *Calyptorhynchus lathami* and Turquoise Parrot,

The survey resulted in an overall total of 176 vertebrate species consisting of 13 frog, 11 reptile, 119 bird and 33 mammal species, with groups such as diurnal raptors, parrots, honeyeaters and microchiropteran bats well represented. A number of species were recorded at or close to the limits of their ranges including Bibron's Toadlet *Pseudophryne bibroni*, the Eastern Pygmy-possum and Eastern Horseshoe Bat *Rhinolophus megaphyllus* at their western limits, and the Wood Mulch Slider *Lerista muelleri,* Spotted Nightjar *Eurostopodus argus* and Crested Bellbird *Oreoica gutturalis* at their eastern limits. Migratory and nomadic bird species including cuckoos, woodswallows, lorikeets and honeyeaters and one nomadic mammal species, the Little Red Flying-fox *Pteropus scapulatus*, were prominent in assemblages and a number of declining woodland birds not currently listed under the TSC Act such as the White-browed Babbler P*omatostomus superciliosus*, Crested Shrike-tit *Falcunculus frontatus* and Red-capped Robin *Petroica goodenovii* were also recorded.

Overall, the survey provided clear evidence that the Project Area, and by extrapolation the Pilliga Forest, are of national significance for biodiversity conservation and demonstrate the need for conservation planning across all tenures to sustain these values.

Despite the current values, the Pilliga Forest is likely to have experienced a number of vertebrate extinctions following European settlement of surrounding areas that highlight the vulnerability of these forests and woodlands to vegetation loss, fragmentation and degradation. Coal seam gas operations in the area to date have resulted in substantial clearing of vegetation resulting in habitat loss, fragmentation and degradation that have increased edge effects and facilitated invasions of introduced mammals, together with the pollution of streams, groundwater and soils. The likely future expanded development of coal seam gas extraction in the area has the capacity to further impact on Matters of National Significance (under the *EPBC Act*) and result in extinctions of local populations.

A moratorium is proposed on coal seam gas extraction and exploration in the Project Area, and the Pilliga Forest generally, until it can be scientifically demonstrated that this will have no adverse effects on the maintenance of biodiversity conservation values. A number of actions are recommended to inform production of a comprehensive management plan for the Project Area as part of this process.

Threatened *Rulingia procumbens*, Falcon Trail. Photo Hugh Nicholson.

INTRODUCTION

In April 2011, Eastern Star Gas Ltd referred the Narrabri Coal Seam Gas Field Development component (the "Pilliga Project") of their proposed Narrabri Coal Seam Gas Project to the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (DSEWPAC) for consideration under the *Environment Protection and Biodiversity Conservation Act* 1999 (*EPBC Act*). The referral was prepared by Eco Logical Australia (2011), who found that there was a likelihood of significant impacts from the proposal on a range of ecological communities and species listed as Threatened under the *EPBC Act* (DSEWPAC 2011).

The Pilliga Project was then the largest proposed coal seam gas project in NSW. It comprised the drilling of 1,100 gas wells, clearing of at least 2,410 ha of native vegetation and fragmentation of 85,000 ha of high conservation value forest. This area included known or potential habitat for up to 23 species and five endangered ecological communities (EECs) listed under the *EPBC Act* (Tables 1-3).

Table 1 Threatened flora species listed under the *EPBC* and *TSC Acts* known from the Project Area or predicted to occur on the basis of modelled habitat

common name	scientific name	*EPBC Act* status	*TSC Act* status	NPWS Atlas record location in the Project Area	likely to occur	recorded this study
Broad-leaved Bertya	*Bertya opponens*	vulnerable	vulnerable		X	
Granite Boronia	*Boronia granitica*	vulnerable	vulnerable		X	
Painted Diuris	*Diuris tricolor*	vulnerable	vulnerable		X	
Winged Pepper-cress	*Lepidium monoplocoides*	endangered	endangered		X	
Large-leafed Monotaxis	*Monotaxis macrophylla*	endangered	endangered	Pilliga East Aboriginal Area		
	Philotheca ericifolia	vulnerable	(previously vulnerable – delisted)		X	
Native Milkwort	*Polygala linariifolia*	endangered	endangered		X	
Cobar Greenhood Orchid	*Pterostylis cobarensis*	vulnerable	vulnerable		X	
a rulingia	*Rulingia procumbens*	vulnerable	vulnerable	Pilliga East State Conservation Area Pilliga East State Forest		X
Slender Darling-pea	*Swainsona murrayana*	vulnerable	vulnerable		X	
Narrow-leaved Tylophora	*Tylophora linearis*	endangered	endangered		X	
Total 11 species						

Table 2 Endangered Ecological Communities listed under the *EPBC* and *TSC Acts* known from the Project Area or predicted to occur on the basis of modelled habitat

community name *(EPBC Act/TSC Act)*	*EPBC Act* status	*TSC Act* status	likely to occur	recorded this study
Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains Bioregion (*TSC Act*)		endangered	X	
Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions (*EPBC Act*); Coolibah - Black Box Woodland of the northern riverine plains in the Darling Riverine Plains and Brigalow Belt South Bioregions *(TSC Act*)	endangered	endangered	X	
Grey Box (*Eucalyptus microcarpa*) Grassy Woodlands and Derived Native Grasslands of South-eastern Australia (*EPBC Act*); Inland Grey Box Woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South Bioregions (*TSC Act*)	endangered	endangered	X	
Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensl and (*EPBC Act*)	critically endangered		X	
Weeping Myall Woodlands (*EPBC Act*); Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes Bioregions (*TSC Act*)	endangered	endangered	X	
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland (*EPBC Act*);	critically endangered	endangered		X
Total 6 EECs				

Table 3 Threatened fauna species listed under the *EPBC Act* known from the Project Area or predicted to occur on the basis of modelled habitat

common name	scientific name	*EPBC Act* status	NPWS Atlas record	recorded this study	likely to occur	may occur
Malleefowl	*Leipoa ocellata*	vulnerable, migratory				X
Squatter Pigeon (southern)	*Geophaps scripta scripta*	vulnerable				X
Superb Parrot	*Polytelis swainsonii*	vulnerable			X	
Swift Parrot	*Lathamus discolor*	endangered			X	
Regent Honeyeater	*Anthochaera phrygia*	endangered, migratory			X	
Spotted-tailed Quoll (south-eastern mainland)	*Dasyurus maculatus maculatus*	endangered				X
Koala	*Phascolarctos cinereus*	vulnerable	X	X		
Brush-tailed Rock-wallaby	*Petrogale penicillata*	vulnerable				X
Grey-headed Flying-fox	*Pteropus poliocephalus*	vulnerable				X
Large-eared Pied Bat	*Chalinolobus dwyeri*	vulnerable			X	
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable	X	X		
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable	X	X		
Total 12 species						

Due to the probability of significant impacts on matters of national significance, together with other likely adverse effects on biodiversity values (The Wilderness Society 2011), the Northern Inland Council for the Environment (NICE) and the Coonabarabran and Upper Castlereagh Catchment and Landcare Group (CUCLG) organised an independent flora and fauna survey of the Gas Field Development Project Area (Fig. 1) in October 2011. This survey targeted threatened flora and vertebrate fauna species and endangered ecological communities (EECs) listed under the *EPBC Act*.

However, since the acquisition of Eastern Star Gas Ltd by Santos Ltd in November 2011, the Pilliga Project application under Part 3A of the NSW *Environmental Planning and Assessment Act 1979* (*EPA Act*) has been withdrawn and only exploration works are currently being proposed. Nevertheless, it is expected that Santos Ltd will lodge another application under the *EPA Act* for coal seam gas production in the Pilliga area in the near future, and a further referral will be made under the *EPBC Act*.

1.1 OBJECTIVES

The aims of this report are to:

i) provide accurate scientific information to relevant State and Federal Ministers and agencies on the significance of the Pilliga Project Area and adjoining habitats for biodiversity conservation, particularly with regard to threatened species and communities listed under the EPBC Act, and also under the NSW *Threatened Species Conservation Act 1995* (*TSC Act*); and

ii) to examine potential detrimental impacts on these threatened species and communities from activities expected from Santos Ltd's likely future coal seam gas production activities.

The report is informed by past records from the Project Area and adjoining areas of similar habitat, and by the results of the survey undertaken by ecologists in October 2011.

1.2 STUDY AREA

The Study Area covered by this report is defined by the boundaries of the former Eastern Star Gas proposal, termed the Pilliga Project Area (Fig. 1). This area lies mainly east of the Newell Highway to the south-west of Narrabri in the Pilliga Forest (Fig. 2). It falls within the Namoi Catchment Management Authority (CMA) region and encompasses Bibblewindi and parts of Jacks Creek and Pilliga East State Forests, Pilliga State Conservation and State Aboriginal Areas as well as some parcels of private and Crown land (Fig. 3). Its southern edge borders the Pilliga Nature Reserve.

At 500,000ha, the Pilliga Forest is the largest intact stand of temperate forest and woodland west of the Great Dividing Range in Eastern Australia. Key conservation attributes of the Pilliga Forest are its large size, un-fragmented condition and its function as a major flora and fauna refuge in a landscape largely cleared for agriculture and as a significant recharge area for the Great Artesian Basin. It is included within two biogeographical provinces (IBRA sub-regions; Department of Sustainability, Environment, Water, Populations and Communities website (Australia's bioregions) - accessed July 2012) characterised by different soil and vegetation types, the Pilliga Province and the Pilliga Outwash Province. The southern, central and eastern sections of the Pilliga Forest fall in the Pilliga Province, dominated by cypress pine (*Callitris glaucophylla, C. endlicheri*), ironbark (*Eucalyptus crebra, E. fibrosa*) and angophora (*Angophora floribunda, A. leiocarpa*) associations on relatively poor soils derived from coarse mesozoic sediments. However, the western and far northern sections, lying in the Pilliga Outwash Province, occur on higher nutrient sandy soils of alluvial origin and are dominated by cypress pine and ironbark associations interspersed by substantial stands of box eucalypts (*E. pilligaensis, E. albens, E. populnea*). Red gum (*E. blakelyi, E. chloroclada, E. dwyeri*) riparian associations occur throughout the Pilliga Forest along intermittent creeklines and old drainage channels.

The major unfragmented area of forest and woodland vegetation in the Project Area occurs in the southern section within the Pilliga Province, with smaller, partly fragmented stands falling mostly within the Pilliga Outwash Province occupying the northern section. Broad vegetation types, based on Lindsay types (Lindsay 1967) that occur in the Project Area and Province boundaries are shown in Fig. 4.

The biodiversity conservation values of the Pilliga Forest are well recognized. It forms a major component of the Brigalow Belt South Bioregion, recognized as a national Biodiversity Hotspot (Department of Sustainability, Environment, Water, Populations and Communities website (Biodiversity Hotspots) – accessed July 2012) and is a globally significant Important Bird Area (Birdlife Australia website (Important Bird Areas) – accessed July 2012). It supports over 240 species of birds, is a key refuge or stronghold for a relatively high number of threatened flora and fauna species and contains several EECs. The Pilliga Forest supports one of the largest populations of the Koala *Phascolarctos cinereus* in NSW, and the species was recently listed as vulnerable in NSW under the E*PBC Act.* Other Federally-listed vulnerable species with strongholds in the Pilliga Forest are the Large-eared Pied Bat *Chalinolobus dwyeri*, South-eastern Long-eared Bat *Nyctophilus corbeni* and Pilliga Mouse *Pseudomys pilligaensis* while the migratory Swift Parrot *Lathamus discolor* and nomadic Regent Honeyeater *Anthochaera phrygia* use the Pilliga Forest on an irregular basis depending on the availability of eucalypt nectar.

FIG 1

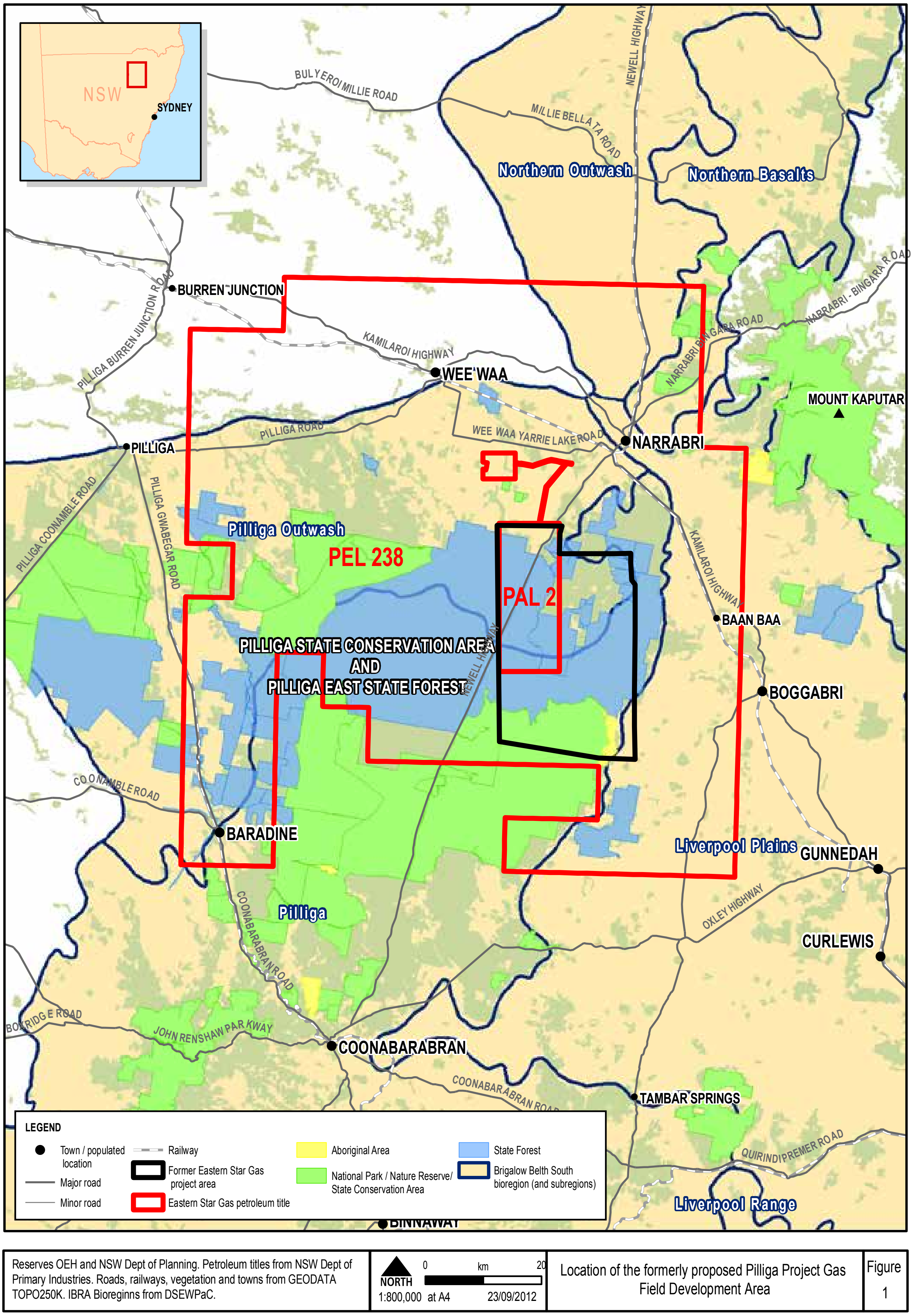
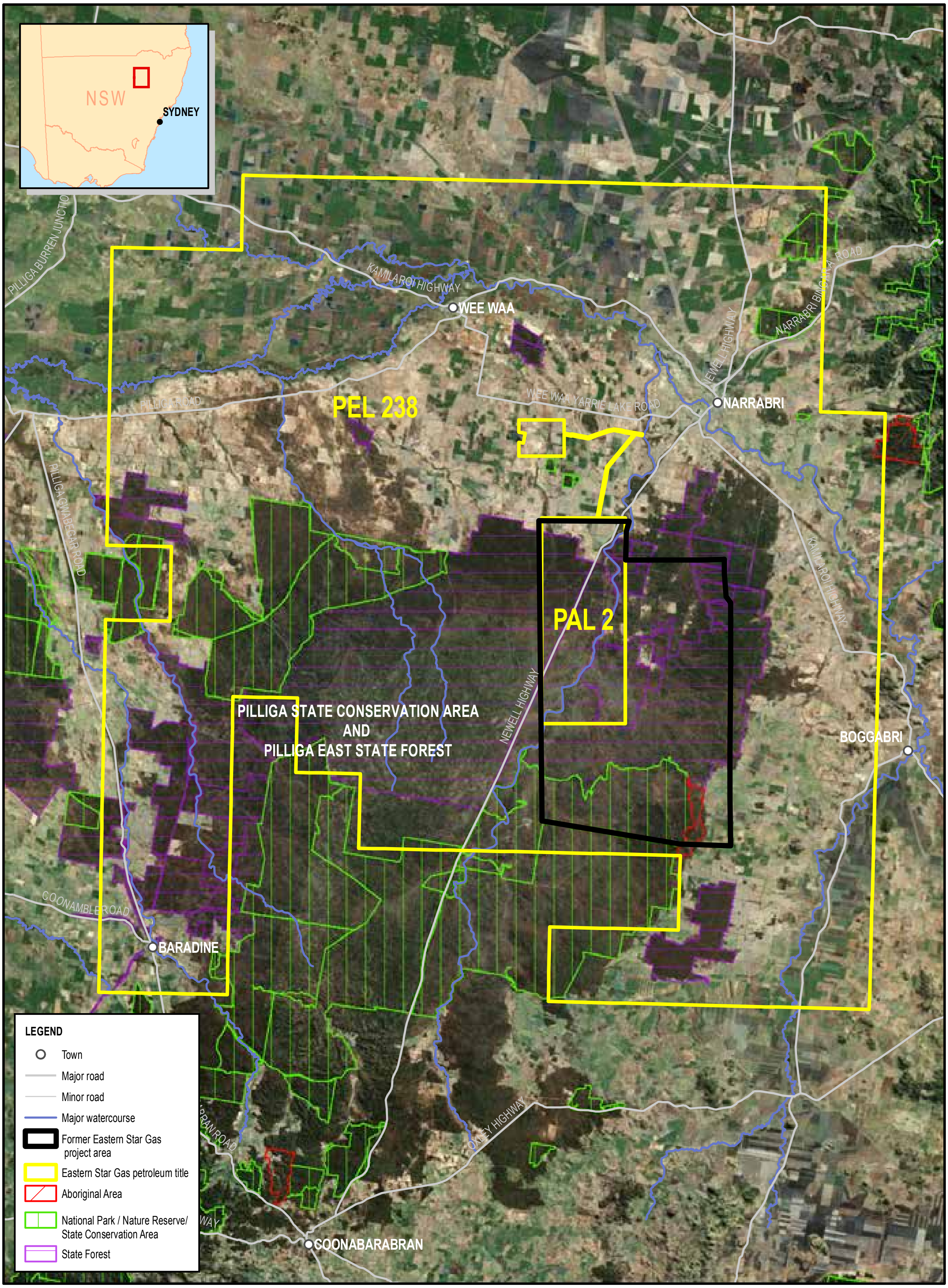


Fig. 1 Location of the formerly proposed Pilliga Project Gas Field Development Area. The Project Area is outlined in black.

FIG 2



Reserves OEH and NSW Dept of Planning. Petroleum titles from NSW Dept of Primary Industries. Watercourses, roads and towns from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 10 1:600,000 at A4 11/09/2012	Location of the formerly proposed Pilliga Project Gas Field Development Area superimposed on satellite imagery	Figure 2

FIG 3

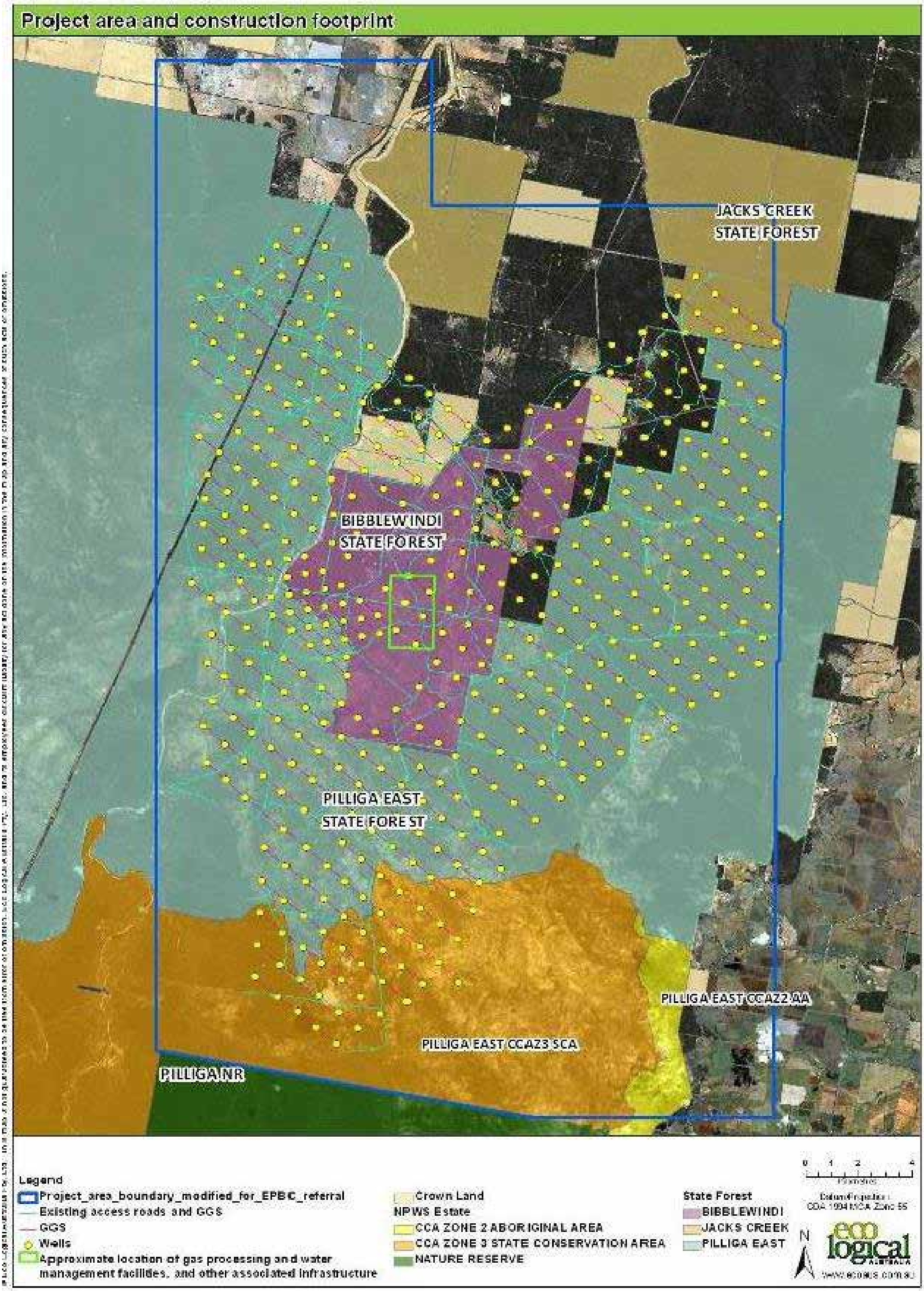
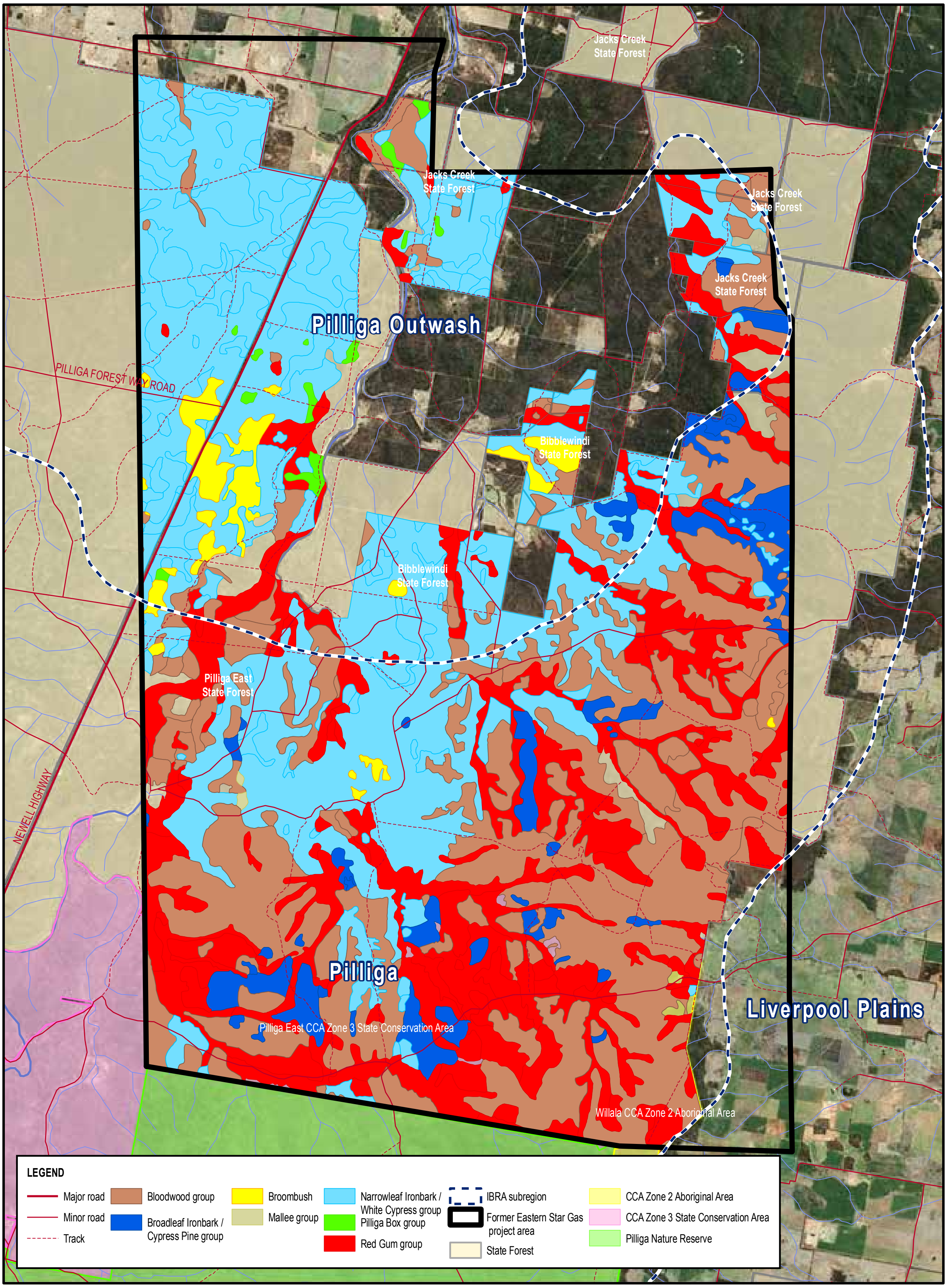


Fig. 3 The Pilliga Project Area showing the formerly proposed locations of gas wells, pipelines and processing infrastructure.

FIG 4



Reserves from NSW Dept of Planning and OEH.IBRA sub-regions from DSEWPaC. Vegetation groups from Lindsay, A.D. (1967) *Forest Types of the New South Wales Cypress Pine Zone Technical Paper No. 8. Forestry Commission of NSW.* Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Broad vegetation types in the Project Area (derived from Lindsay 1967 types) showing sub-regional boundaries of IBRA bio-regions	Figure 4

For the Project Area alone, up to 23 threatened species and five EECs listed under the *EPBC Act* and 38 threatened species and five EECs listed under the *TSC Act* are known or have been predicted to occur there on the basis of modelled habitat (Tables 1-3, 5). These include:

i) the Black-striped Wallaby *Macropus dorsalis,* listed as endangered under the *TSC Act,* which occurs there at the southern limit of its distribution (NSW Department of Environment and Heritage Threatened Species Information website – accessed July 2012);

ii) a number of declining woodland bird species listed as vulnerable under the *TSC Act* for which the Pilliga Forest is a known stronghold, including the eastern races of the Brown Treecreeper *Climacteris picumnus*, Black-chinned Honeyeater *Melithreptus gularis* and Grey-crowned Babbler P*omastomus temporalis*, the south-eastern races of the Varied Sittella *Daphnoesitta chrysoptera* and Hooded Robin *Melanodryas cucullata* and the Speckled Warbler *Chthonicola sagittata* and Diamond Firetail S*tagonopleura guttata*; and

iii) important populations of other vulnerable fauna species listed under the TSC Act including the Pale-headed Snake *Hoplocephalus bitorquatus*, Glossy Black-cockatoo *Calyptorhynchus lathami*, Turquoise Parrot *Neophima pulchella*, Barking Owl *Ninox connivens,* Eastern Pygmy-possum *Cercartetus nanus,* Little Pied Bat *Chalinolobus picatus* and Eastern Cave Bat *Vespadelus troughtoni*.

The Study Area is vital to maintaining connectivity in the north-east of the Pilliga Forest as it provides a continuous forested link between the Pilliga Nature Reserve and other important areas of habitat to the north-west, north and north-east. This crucial connectivity not only increases the biodiversity values of all sectors but is essential for maintaining the long-term evolutionary potential of resident populations by facilitating genetic exchange. The Pilliga Nature Reserve Plan of Management (NSW National Parks and Wildlife Service 2003) states that.

"Land adjoining the Reserve to the north and west is administered by State Forests for a variety of purposes including timber production and bee keeping. These areas provide continuous uninterrupted habitat. ….The large size of the Reserve and its connection to adjacent forest make the Reserve an important habitat for a wide range of threatened species including nomadic species such as the Regent Honeyeater".

The latter reference highlights another significant attribute of the Pilliga Forest, its role in providing seasonal habitat for a suite of migratory and nomadic birds as part of the eastern Australian bird migration system (Nix 1976, 1993, Griffioen and Clarke 2002).

1.3 THREATENING PROCESSES RELEVANT TO THE PILLIGA FOREST AND COAL SEAM GAS PRODUCTION

The following threatening processes are particularly relevant to likely impacts from the development of coal seam gas production in the Pilliga Forest.

i) <u>Loss of global climate change refugia</u> Positioned as a large intact vegetation remnant in a substantially cleared agricultural landscape with highly variable rainfall, the Pilliga Forest's resilience and role as a major climate change refuge against drought, rising temperatures and increasing fire frequency is threatened by the vegetation loss, fragmentation and degradation and resultant perturbations associated with coal seam gas production.

ii) Loss of spatially dependent evolutionary potential The size and un-fragmented condition of the Pilliga Forest allows species with healthy populations to achieve their full evolutionary potential. Recent speciation of the Pilliga Mouse, which has close relatives to the north and east illustrates this capacity, a capacity that is compromised by the habitat reduction and fragmentation resulting from coal seam gas production.

iii) Loss of habitat for long-distance migrants The Pilliga Forest as part of the Brigalow Belt South Bioregion provides transit, over-wintering and breeding habitat for many long-distance migratory and nomadic bird species of open forests and woodlands and is recognised as forming part of the east Australian bird migration system (as noted above). Vegetation loss (particularly of prolific nectar and pollen producing ironbark and box eucalypts that flower in autumn and winter), degradation and, to a lesser extent fragmentation, from coal seam gas production threaten the viability of these bird species at critical times of their life cycles. Such threats have already been implicated in population reductions of the Superb Parrot *Polytelis swainsonii,* Swift Parrot and Regent Honeyeater elsewhere in their ranges (NSW National Parks and Wildlife Service 2003, Garnett et al. 2011).

iv) Disturbance and habitat loss at regional and local scales On-going disturbance regimes operating in the Pilliga Forest include small scale clearing, forestry operations and associated roading, grazing, frequent wildfire and impacts from introduced mammals such as the Feral Goat *Capra hircus*, Feral Pig *Sus scofa* and Red Fox *Vulpes vulpes*. Although recent conservation gains have reduced some pressures, the additional clearing, roading, burning and associated impacts resulting from coal seam gas production will have a cumulative effect and are likely to result in further perturbations that could exceed survival thresholds for many species and communities.

v) Pollution of drainage systems and underground aquifers The potential for broad-scale pollution of drainage systems, underground aquifers and groundwater-dependent ecosystems from coal seam gas production is a new threat to the Pilliga Forest and surrounds, with large volumes of highly saline water containing other toxic chemicals likely to endanger ephemeral aquatic systems (including ecologically significant gilgais), adjoining wetlands and infiltrate into the Great Artesian Basin.

vi) Loss of productivity in low-nutrient systems Much of the central and eastern Pilliga Forest has been progressively degraded in recent decades by successive extensive hot fires (Kavanagh and Barrott 2001, Milledge 2004), resulting in reduced primary productivity in an already low nutrient system (based on coarse mesozoic sediments). Continuing frequent fires likely to be associated with coal seam gas production will increase vegetation recovery times, slowing the production of food and shelter resources for fauna including foliage, nectar and tree hollows and also slowing decomposition rates (e.g. Nix and Mackey 2000).

2 METHODS

2.1 IDENTIFICATION OF SPECIES LISTED AS THREATENED UNDER THE *EPBC* AND *TSC ACTS*

The EPBC Act Protected Matters Search Tool (SEWPaC) was used to identify listed threatened flora and fauna species and ecological communities recorded from, or having the potential to occur within the Project Area. Records of *EPBC Act*-listed threatened flora and fauna species together with *TSC Act* listed threatened species were also obtained from the Atlas of NSW Wildlife. Atlas search areas were defined as Pilliga East, Bibblewindi and Jacks Creek State Forests, Pilliga East Aboriginal Area, Pilliga East State Conservation Area and Pilliga Nature Reserve to provide records of threatened species known from or adjacent to the Project Area.

2.2 SURVEY DESIGN AND SITE SELECTION

The field survey was designed to fill gaps in current knowledge of the occurrence in the Project Area of the 25 *EPBC Act*-listed threatened flora and fauna species and five *EPBC Act*-listed EECs known from or predicted as likely to occur there (Tables 1-3). In particular, the South-eastern Long-eared Bat and Pilliga Mouse were targeted in areas and habitats in the Project Area not covered by past systematic surveys (RACAC 2000, 2002, NCC 2002, Date and Paull 2000, Eco Logical Australia 2011, Flint 2011). The occurrence of migratory species listed under the *EPBC Act* (Table 4) and additional threatened species and EECs listed under the *TSC Act* (Tables 4, 5) were also sought, but these were not specifically targeted apart from several largely nocturnal, cryptic species. The latter comprised the Pale-headed Snake, Barking Owl, Koala, Eastern Pygmy-possum, Black-striped Wallaby and Large-eared Pied Bat.

The surveys undertaken during this study were confined to the State Forest and a freehold property within the Project Area, apart from one bird survey site, four sites trapped for microchiropteran bats and some opportunistic searches carried out along the eastern boundary of Pilliga East State Forest adjacent to the Project Area's eastern boundary (Figs 5-7).

Threatened South-eastern Long-eared Bat. Photo David Milledge

Table 4 Migratory fauna species listed under the *EPBC Act* known from the Project Area or predicted to occur on the basis of modelled habitat

common name	scientific name	EPBC Act status	NPWS Atlas record	recorded this study	likely to occur	may occur
Malleefowl	*Leipoa ocellata*	vulnerable, migratory				X
White-throated Needletail	*Hirundapus caudacutus*	migratory	x			
Fork-tailed Swift	*Apus pacificus*	migratory			X	
Eastern Great Egret	*Ardea modesta*	migratory			X	
Cattle Egret	*Ardea ibis*	migratory			X	
White-bellied Sea-eagle	*Haliaeetus leucogaster*	migratory	X			
Latham's Snipe	*Gallinago hardwickii*	migratory				X
Rainbow Bee-eater	*Merops ornatus*	migratory	x	x		
Regent Honeyeater	*Anthochaera phrygia*	endangered, migratory			X	
Total 9 species						

Threatened Pilliga Mouse. Photo Justin McDowell

Table 5 Threatened fauna species listed under the *TSC Act* known from the Project Area or predicted to occur on the basis of modelled habitat

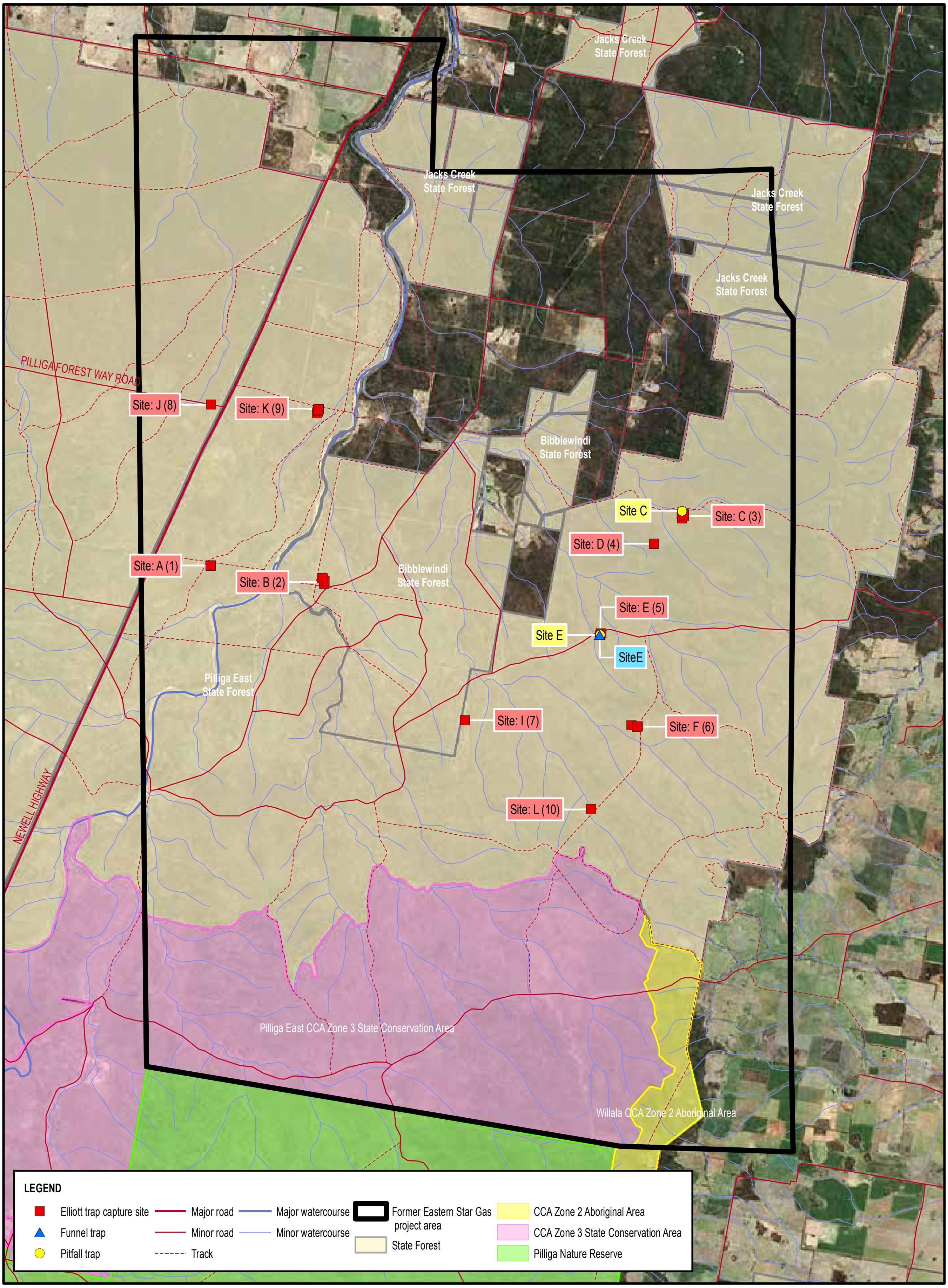
common name	scientific name	*TSC Act* status	NPWS Atlas record	recorded this study	likely to occur	may occur
Pale-headed Snake	*Hoplocephalus bitorquatus*	vulnerable	X	X		
Malleefowl*	*Leipoa ocellata*	endangered				X
Squatter Pigeon (southern)*	*Geophaps scripta scripta*	endangered				X
Square-tailed Kite	*Lophoictinia isura*	vulnerable			X	
Black-breasted Buzzard	*Hamirostra melanosternon*	vulnerable			X	
Spotted Harrier	*Circus assimilis*	vulnerable	X			
Little Eagle	*Hieraaetus morphnoides*	vulnerable	X	X		
Bush Stone-curlew	*Burhinus grallarius*	endangered	X			
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable	X	X		
Little Lorikeet	*Glossopsitta pusilla*	vulnerable	X	X		
Superb Parrot*	*Polytelis swainsonii*	vulnerable			X	
Swift Parrot*	*Lathamus discolor*	endangered			X	
Turquoise Parrot	*Neophema pulchella*	vulnerable	X	X		
Barking Owl	*Ninox connivens*	vulnerable	X	X		
Masked Owl	*Tyto novaehollandiae*	vulnerable	X			
Brown Treecreeper (eastern)	*Climacteris picumnus victoriae*	vulnerable	X	X		
Speckled Warbler	*Chthonicola sagittata*	vulnerable	X	X		
Regent Honeyeater*	*Anthochaera phrygia*	endangered, migratory			X	
Black-chinned Honeyeater (eastern)	*Melithreptus gularis gularis*	vulnerable	X			
Painted Honeyeater	*Grantiella picta*	vulnerable	X			
Grey-crowned Babbler (eastern)	*Pomastomus temporalis temporalis*	vulnerable	X	X		
Varied Sittella (south-eastern)	*Daphoenositta chrysoptera chrysoptera*	vulnerable	X	X		
Hooded Robin (south-eastern)	*Melanodryas cucullata cucullata*	vulnerable	X	X		
Diamond Firetail	*Stagonopleura guttata*	vulnerable	X	X		
Spotted-tailed Quoll (south-eastern mainland)*	*Dasyurus maculatus maculatus*	endangered				X
Koala*	*Phascolarctos cinereus*	vulnerable	X	X		
Eastern Pygmy-possum	*Cercartetus nanus*	vulnerable	X	X		
Squirrel Glider	*Petaurus norfolcensis*	vulnerable	X	X		
Black-striped Wallaby	*Macropus dorsalis*	endangered		X		

Brush-tailed Rock-wallaby*	*Petrogale penicillata*	endangered				X
Grey-headed Flying-fox*	*Pteropus poliocephalus*	vulnerable				X
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable	X	X		
Eastern Bent-winged Bat	*Miniopterus schreibersii*	vulnerable	X			
Large-eared Pied Bat*	*Chalinolobus dwyeri*	vulnerable			X	
Little Pied Bat	*Chalinolobus picatus*	vulnerable	X	X		
Eastern Cave Bat	*Vespadelus troughtoni*	vulnerable	X			
South-eastern Long-eared Bat*	*Nyctophilus corbeni*	vulnerable	X	X		
Pilliga Mouse*	*Pseudomys pilligaensis*	vulnerable	X	X		
Total 38 species						

* also listed under the *EPBC Act*

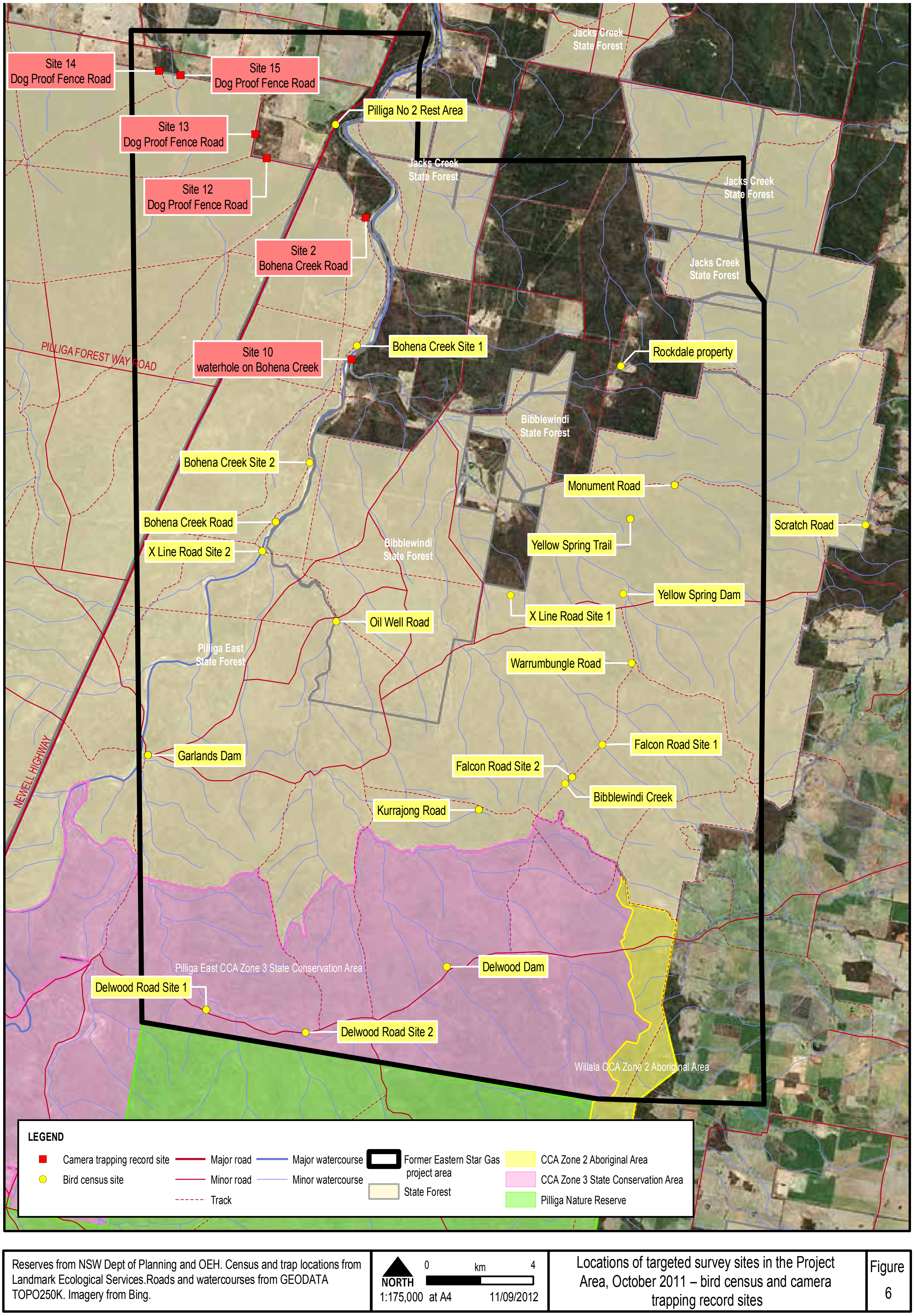
Threatened Pale-headed Snake, funnel trapping Site E, Warrumbungle Trail. Photo Phil Spark

FIG 5



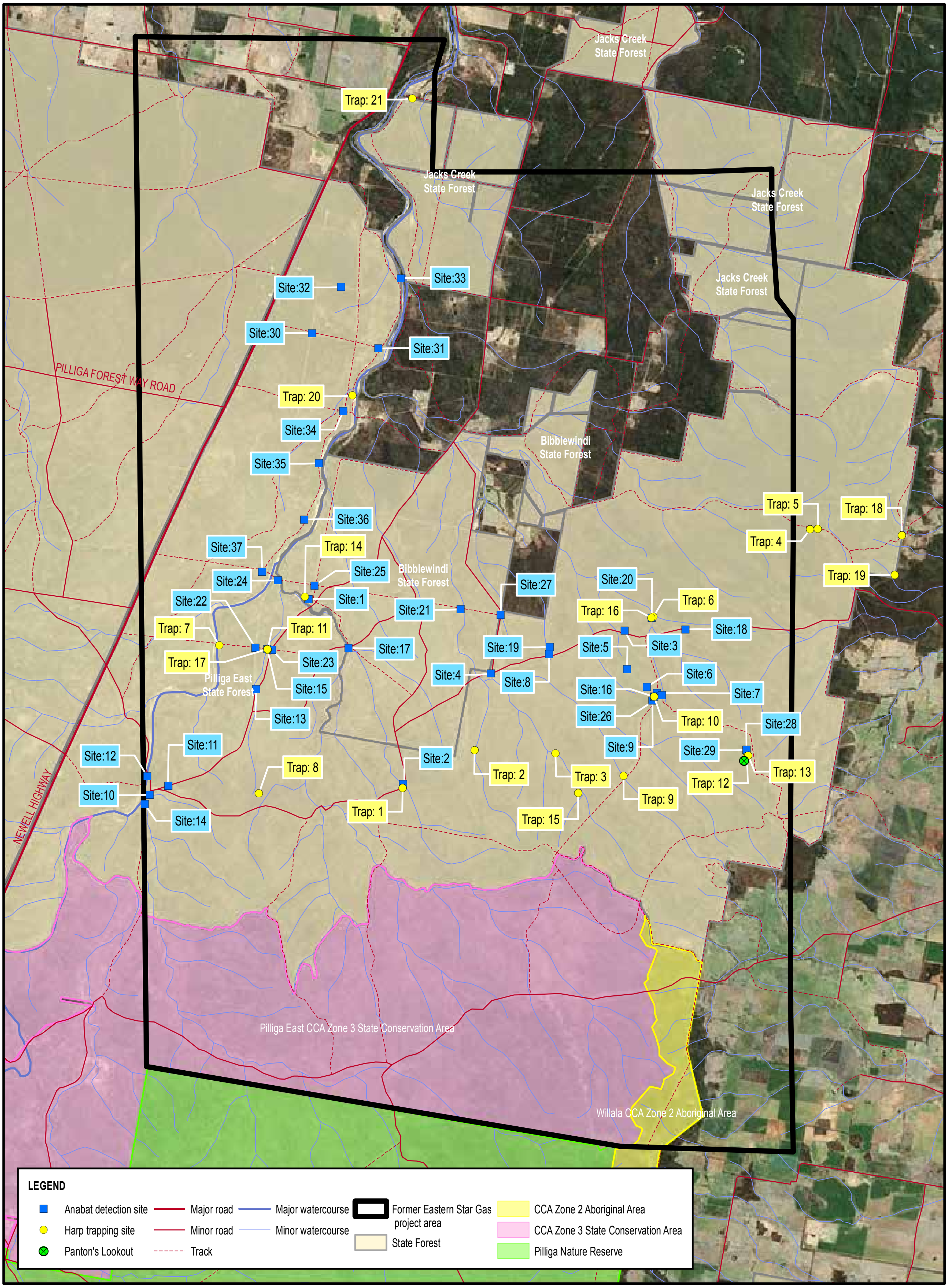
Reserves from NSW Dept of Planning and OEH. Trap locations from Landmark Ecological Services.Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Locations of targeted survey sites in the Project Area, October 2011 – pitfall trapping, funnel trapping and Elliott trapping sites	Figure 5

FIG 6



Site 14
Dog Proof Fence Road
Site 15
Dog Proof Fence Road
Pilliga No 2 Rest Area
Site 13
Dog Proof Fence Road
Site 12
Dog Proof Fence Road
Jacks Creek
State Forest
Site 2
Bohena Creek Road
Bohena Creek Site 1
Rockdale property
Site 10
waterhole on Bohena Creek
PILLIGA FOREST WAY ROAD
Bibblewindi
State Forest
Bohena Creek Site 2
Monument Road
Bohena Creek Road
Scratch Road
X Line Road Site 2
Yellow Spring Trail
Yellow Spring Dam
X Line Road Site 1
Oil Well Road
Pilliga East
State Forest
Warrumbungle Road
Falcon Road Site 1
Garlands Dam
Falcon Road Site 2
Bibblewindi Creek
Kurrajong Road
NEWELL HIGHWAY
Pilliga East CCA Zone 3 State Conservation Area
Delwood Dam
Delwood Road Site 1
Delwood Road Site 2
Willala CCA Zone 2 Aboriginal Area
LEGEND
Camera trapping record site
Bird census site
Major road
Minor road
Track
Major watercourse
Minor watercourse
Former Eastern Star Gas project area
State Forest
CCA Zone 2 Aboriginal Area
CCA Zone 3 State Conservation Area
Pilliga Nature Reserve
Reserves from NSW Dept of Planning and OEH. Census and trap locations from Landmark Ecological Services.Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.
NORTH
0 km 4
1:175,000 at A4
11/09/2012
Locations of targeted survey sites in the Project Area, October 2011 – bird census and camera trapping record sites
Figure
6

FIG 7



Reserves from NSW Dept of Planning and OEH. Trap locations and Anabat locations from Landmark Ecological Services.Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 12/09/2012	Locations of targeted survey sites in and adjoining the Project Area, October 2011 – harp trapping and Anabat detection sites	Figure 7

2.3 SURVEY METHODS

All surveys and opportunistic searches for species and communities were undertaken in the Project Area from 8-15 October 2011, with some opportunistic records made later in the month.

2.3.1 Plant species: Opportunistic searches for plant species listed under the *EPBC Act* and predicted as likely to occur in the Project Area (Table 1) were undertaken by driving roads and trails throughout the area to detect potential habitat, with follow-up intensive ground searches.

2.3.2 Plant communities: EECs listed under the *EPBC Act* and predicted as likely to occur in the Project Area (Table 2) were also targeted by road-based searches. Once detected, a potential EEC was assessed for conformity with the formal description provided on the Department of Sustainability, Environment, Water, Population and Communities' (SEWPAC) website. In the field this involved obtaining information on the community's patch size and a detailed description of the species composition of the upper, mid and ground-cover vegetation strata. These data were then used to follow the flowchart of eligibility criteria provided on the SEWPAC website.

2.3.3 Amphibians: Nocturnal spotlight searches for amphibians were focused on dams and standing water in creek beds, and were undertaken at 4 sites on 5 nights. Pitfall traps with metal drift fences were used at small mammal trapping sites C and E (Appendix 3, Fig. 5), which targeted amphibians generally.

Opportunistic records of amphibians were made throughout the Project Area whenever species were observed or heard.

2.3.4 Reptiles: A targeted survey for the TSC Act-listed Pale-headed Snake and other small to medium-sized reptiles was undertaken at small mammal trapping site E (Appendix 3, Fig. 5), where reptile funnel traps were employed. As with amphibians, the pitfall traps with drift fences that were used at small mammal trapping sites C and E (Appendix 3, Fig. 5) generally targeted small to medium-sized reptiles.

Opportunistic visual searches for all reptile species were made when driving along roads and by turning over rocks, bark and other large debris when these were encountered throughout the Project Area.

2.3.5 Birds: Systematic surveys for diurnal birds were undertaken at 21 one ha sites stratified across the Project Area to obtain a representative sample of the habitats present (Fig. 6, Appendix 4). Records were made of all species observed or heard within a site from the central point during a 20 min period and numbers of all *EPBC/TSC Act*-listed species were also recorded.

Nocturnal call playback targeting the Barking Owl was used opportunistically at a number of locations in the northern section of the Project Area (within the Pilliga Outwash Province).

Opportunistic records of bird species were recorded whenever these were encountered while traversing the Project Area.

2.3.6 Mammals: Systematic trapping surveys for microchiropteran bats (targeting the South-eastern Long-eared Bat) and small mammals (targeting the Pilliga Mouse) were undertaken at 21 and 10 sites respectively throughout the Project Area (Figs 7 and 5; Appendices 5 and 8), with sites selected on the basis of known habitat preferences of the target species. Microchiropteran bats were also surveyed using the Anabat ultrasonic call detection system at 37 sites in the Project Area (Fig. 7; Appendix 7).

Microchiropteran bats were trapped at sites using a single 2 or 3-bank harp trap (apart from two sites where two traps were used, Sites 10, 15) with the trap placed across a road, track or dry creek bed, although traps at a few sites were placed about pools in creeks or against small cliff faces. Traps were set for one or two full nights per site apart from at two sites (Site 10 and one trap at Site 15), where the trap was closed after two hours.

Microchiropteran bat calls were recorded and identified throughout the Project Area using Anabat SD1 bat detectors with AnalookW version 3.8m software. Detectors were set and left unattended at 21 sites, while hand held detectors used in conjunction with a PDA display of calls in real time at 17 sites. Bat calls were analysed and identified by Harry Parnaby.

Small mammals were trapped at each site using two parallel lines of 25 A-size Elliott traps (total of 50 traps) placed 10m apart per line, with lines spaced 50m apart. Traps were set for three or four nights (Appendix 8) and baited with a mixture of peanut butter and oats flavoured with truffle oil.

A series of traverses along roads and trails through the Project Area were undertaken by an expert observer to identify potential Pilliga Mouse habitat (Fig. 8). Potential habitat was determined using a series of vegetation parameters including the presence of a dense low understorey with a high diversity of heathy shrub species regenerated after relatively recent fire, a well-developed litter layer and the absence of a continuous tall shrub layer. The identification of potential habitat was also informed by the trapping results from the current survey.

A targeted survey for the Black-striped Wallaby, incorporating a dusk visual search, was undertaken on three nights in the Brandon's Road area in the north of the Project Area. The Eastern Pygmy-possum was targeted at small mammal trapping sites C and E (Appendix 3, Fig. 5), where pitfall traps and metal drift fences were employed, and the Large-eared Pied Bat was targeted with harp traps 12 and 13 placed near and against a cliff face at Panton's Lookout (Fig. 7).

Diurnal Koala faecal scat and sign searches were undertaken in riparian vegetation along Cowallah and Bohena Creeks, with scat searches targeting the bases of Blakely's Red Gum *Eucalyptus blakelyi* and Baradine Red Gum *E. chloroclada* and scratch marks searched for on the trunks of smooth-barked eucalypts.

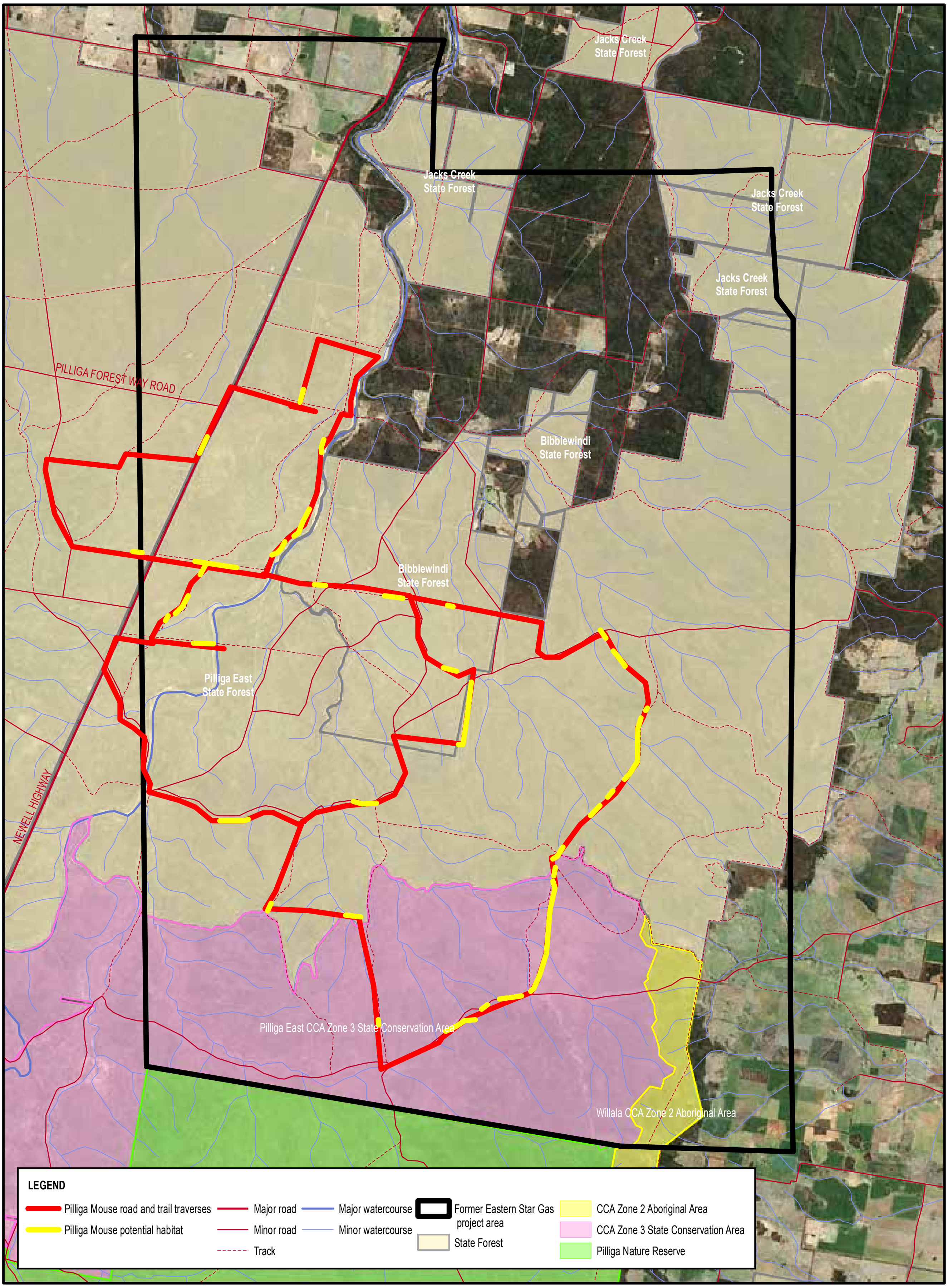
Seventeen camera traps were set on trails and at gaps along the dog-proof fence and near waterholes in the northern section, and at Panton's Lookout in the eastern section of the Project Area (Fig. 6), targeting medium and large-sized terrestrial mammals.

Opportunistic diurnal and nocturnal road-based searches for arboreal and medium to large-sized ground mammals were made throughout the Project Area. Nocturnal spotlight searches were concentrated in areas of box eucalypts *(Eucalyptus pilligaensis, E. albens)* and red gums *(Eucalyptus blakelyi, E. chloroclada)* along creeks, and in stands of flowering Baradine Red Gum to maximise records of arboreal species.

After the surveys were completed and the results compiled, an expert workshop was held to interpret the results and their significance. A workshop was held at the University of New England with seven experts from relevant fields and the outcomes have been included in this report where appropriate.

Broad-leaved Ironbark, Deldam Trai. Photo Hugh Nicholson

FIG 8



Reserves from NSW Dept of Planning and OEH. Pilliga Mouse transects from C.Flint. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Pilliga Mouse habitat assessment road and trail traverses	Figure 8

3 RESULTS

3.1 VEGETATION AND FLORA

3.1.1 Previous records of threatened species and communities listed under the *EPBC* and *TSC Acts*

A total of 11 threatened plant species (listed under the *EPBC* and *TSC Acts*) were previously recorded in the Project Area or were predicted as likely to occur there (Table 1). Species previously recorded were the endangered Large-leafed Monotaxis *Monotaxis macrophylla* and a vulnerable rulingia *Rulingia procumbens*.

Five EECs listed under the *EPBC Act* (including one not listed under the *TSC Act*) and five EECs listed under the *TSC Act* (including one not listed under the *EPBC Act*), resulted in a total of six EECs that were predicted as likely to occur in the Project Area (Table 2).

3.1.2 Threatened species and communities recorded by current survey

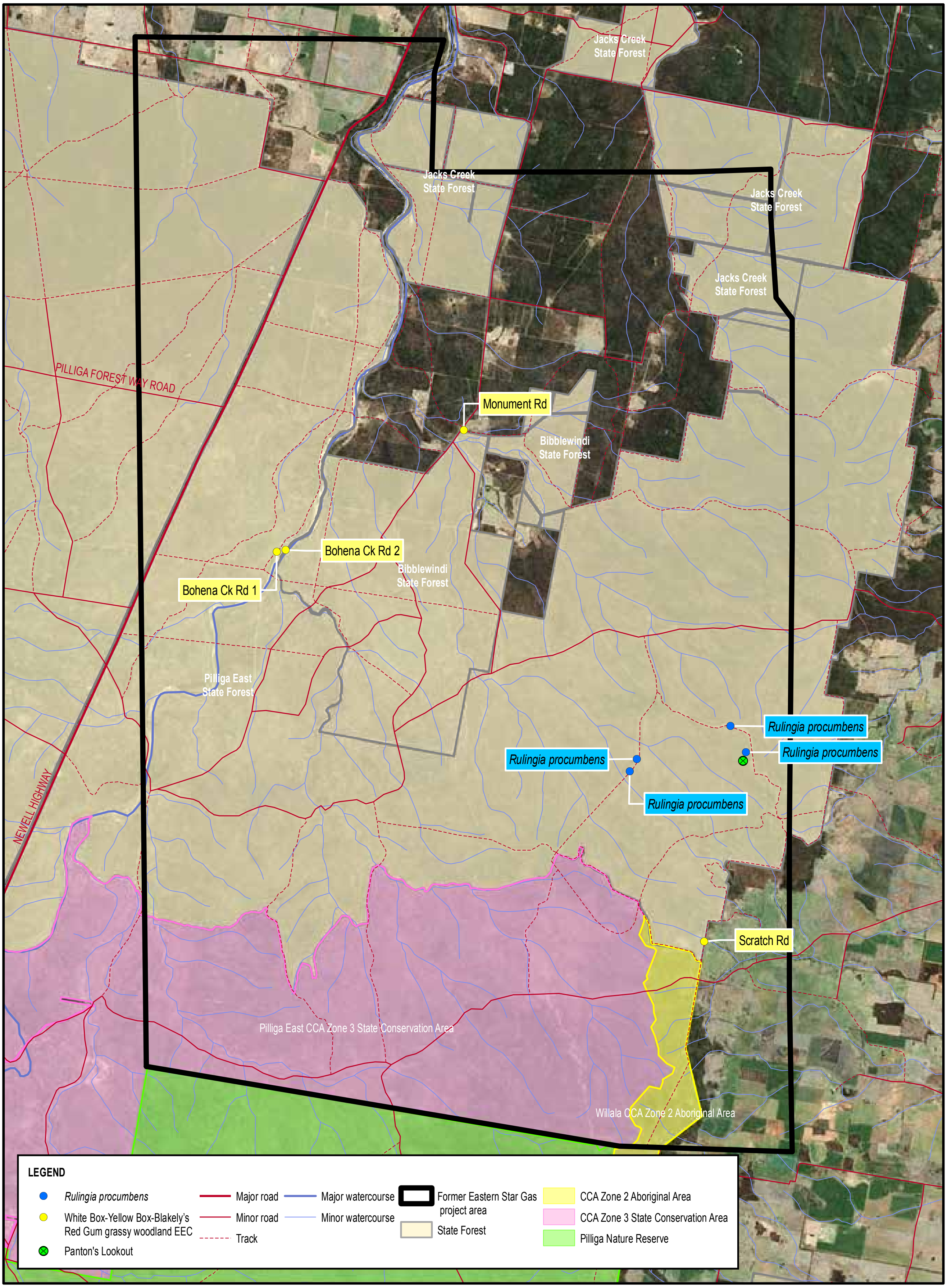
One threatened plant species, *Rulingia procumbens,* listed as vulnerable under both the *EPBC* and TSC *Acts*, was recorded during the current survey. Small populations of one to ten plants of this rare species (PlantNET-NSW FloraOnline website, accessed July 2012) were identified in the central eastern section of the Project Area to the west and north-west of Panton's Lookout (Fig. 9, Appendix 1), indicating that the Pilliga Forest represents a stronghold for this species.

One EEC, White Box-Yellow Box-Blakely's Red Gum grassy woodland and derived native grassland, listed as Critically endangered under the *EPBC Act* and endangered under the *TSC Act*, was recorded at four locations within the Project Area. These locations fell within the northern and south-eastern sections of the Project Area (Fig. 9, Appendix 2).

This EEC appears to be widespread along drainage lines throughout the Project Area and the four locations (above) were selected as representative samples to test that the community fitted the description given under the *EPBC Act* listing (Appendix 2). These findings demonstrate the importance of the Project Area for conservation of this community, which has been predominantly cleared within its range for agriculture (Department of Sustainability, Environment, Water, Population and Communities – Threatened species and communities website, accessed July 2012).

Seven Dwarfs Grevillea, small mammal trapping site A. Photo Hugh Nicholson

FIG 9



Reserves from NSW Dept of Planning and OEH. *Rulingia procumbens* and Box-Gum Woodland locations from Landmark Ecological Services. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Locations of *Rulingia procumbens* and White Box-Yellow Box-Blakely's Red Gum grassy woodland and derived native grassland Endangered Ecological Community	Figure 9

3.2 VERTEBRATES

3.2.1 Previous records of threatened and migratory species listed under the *EPBC* and *TSC Acts*

A total of 12 threatened vertebrate species and 9 migratory bird species listed under the *EPBC Act* were found to have been previously recorded from, or were considered likely to occur in the Project Area, based on a search of *EPBC Act* Protected Matters and Atlas of NSW Wildlife records (Tables 3, 4). Vulnerable species previously recorded were the Koala, South-eastern Long-eared Bat and Pilliga Mouse (Figs 11-13) and migratory species comprised the White-throated Needletail *Hirundapus caudacutus,* White-bellied Sea Eagle *Haliaeetus leucogaster* and Rainbow Bee-eater *Merops ornatus*.

An additional 26 vertebrate species listed under the TSC Act were also found to have been recorded from the Project Area or predicted to occur there on the basis of modelled habitat (Table 5). The former included the endangered Bush Stone-curlew B*urhinus grallarius* and vulnerable Barking Owl, Masked Owl *Tyto novaehollandiae,* Painted Honeyeater *Grantiella picta,* Squirrel Glider *Petaurus norfolcensis,* Eastern Bent-winged Bat *Miniopterus schreibersii* and Eastern Cave Bat.

3.2.2 Threatened and migratory species recorded by current survey

A total of 20 threatened species and one migratory species (*EPBC* and *TSC Acts*) were recorded from the Project Area during the current survey (Tables 6-11). These included the Koala, South-eastern Long-eared Bat and Pilliga Mouse, listed as vulnerable under the *EPBC* and *TSC Acts*, the Rainbow Bee-eater, listed as a migratory species under the *EPBC Act,* and another 16 species listed under the *TSC Act*. The latter included the endangered Black-striped Wallaby and vulnerable declining woodland bird species such as the Brown Treecreeper, Speckled Warbler, Grey-crowned Babbler, Varied Sittella, Hooded Robin and Diamond Firetail. Other vulnerable species recorded included the Pale-headed Snake, Glossy Black-cockatoo, Turquoise Parrot, Barking Owl, Eastern Pygmy-possum, Squirrel Glider, Yellow-bellied Sheath-tailed Bat *Saccolaimus flaviventris* and Little Pied Bat.

Previous records existed in the Project Area for all threatened species detected in the current survey apart from the Black-striped Wallaby (Table 5), which is at the southern limit of its range in the Pilliga Forest. However, the survey results provided new distributional and abundance data from within the Project Area for a number of these species including the Pale-headed Snake, Eastern Pygmy-possum, South-eastern Long-eared Bat and Pilliga Mouse (Figs 10, 12 and 13).

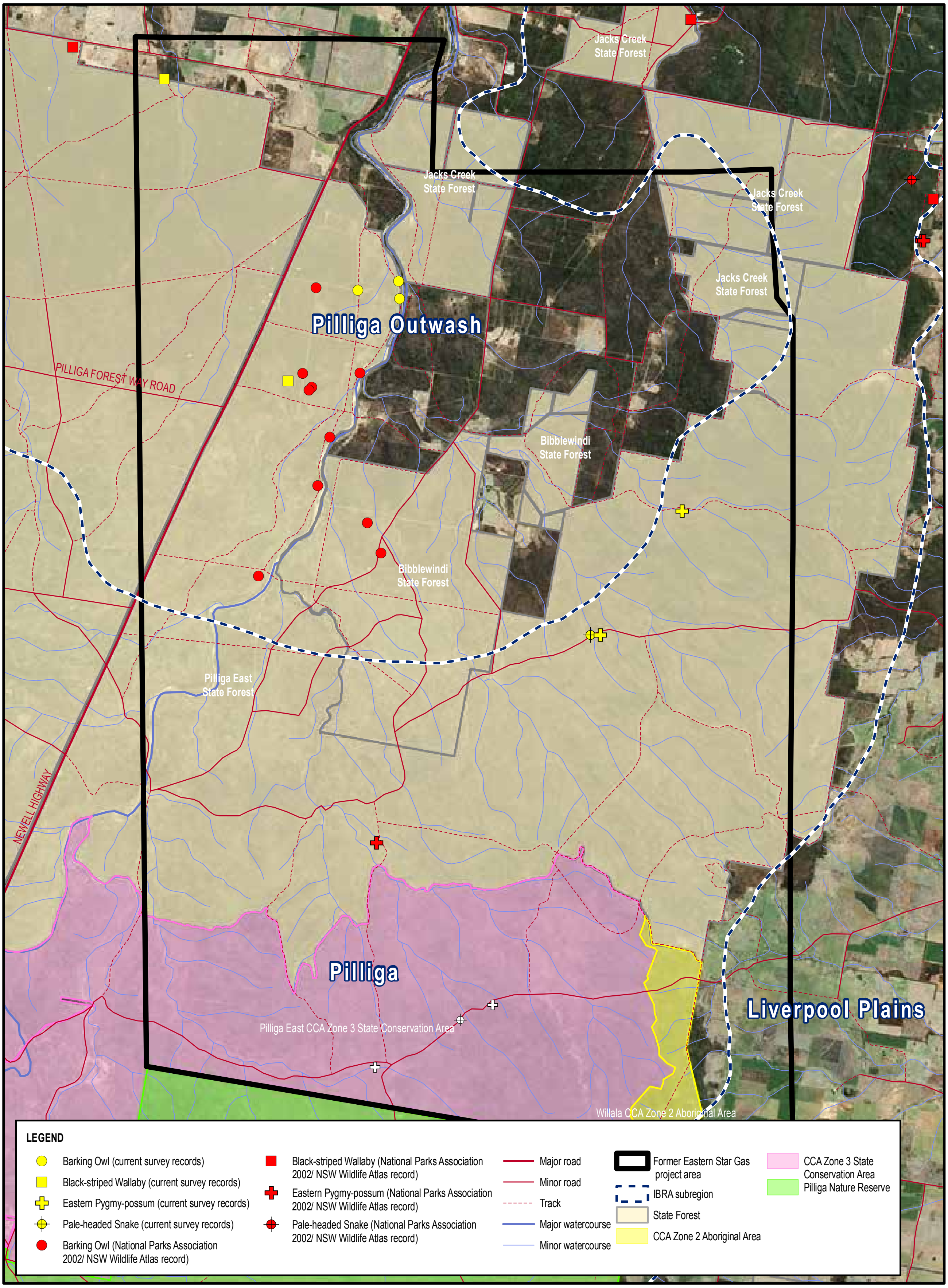
3.2.2.1 Koala Despite relatively extensive nocturnal spotlighting and diurnal faecal scat searches, only one record of the Koala was obtained during the current survey (Table 6, Fig. 11, Appendix 10). This contrasts with the 17 previous records of this species from the north and south of the Project Area (Fig. 11, Atlas of NSW Wildlife), although these were mostly obtained in the 1980s and 1990s (Atlas of NSW Wildlife records - accessed May 2012). The result parallels the overall substantial decline reported recently across the whole of the Pilliga Forest since the beginning of the 21st century (Paull in prep.). Reasons proposed for this decline include frequent extensive hot fires and prolonged drought over the past few decades (Kavanagh and Barrott 2001, Paull in prep.).

Past records of the Koala in the Project Area are concentrated in the north (within the Pilliga Outwash Province) and in the south-east on the edge of the Liverpool Plains (Fig. 11), where soil nutrient status is higher than that of the remainder, which falls within the Pilliga Province. This follows the pattern reported by Milledge (2004) of a distribution broadly similar to that of the Barking Owl, reflecting the occurrence of areas of higher productivity in the Pilliga Forests.

However, the Project Area contains extensive stands of riparian forest and woodland dominated by red gums (Fig. 4) and predominantly Blakely's Red Gum, an important Koala food tree in the Pilliga Forest (Paull in prep.). Baradine Red Gum, another important food

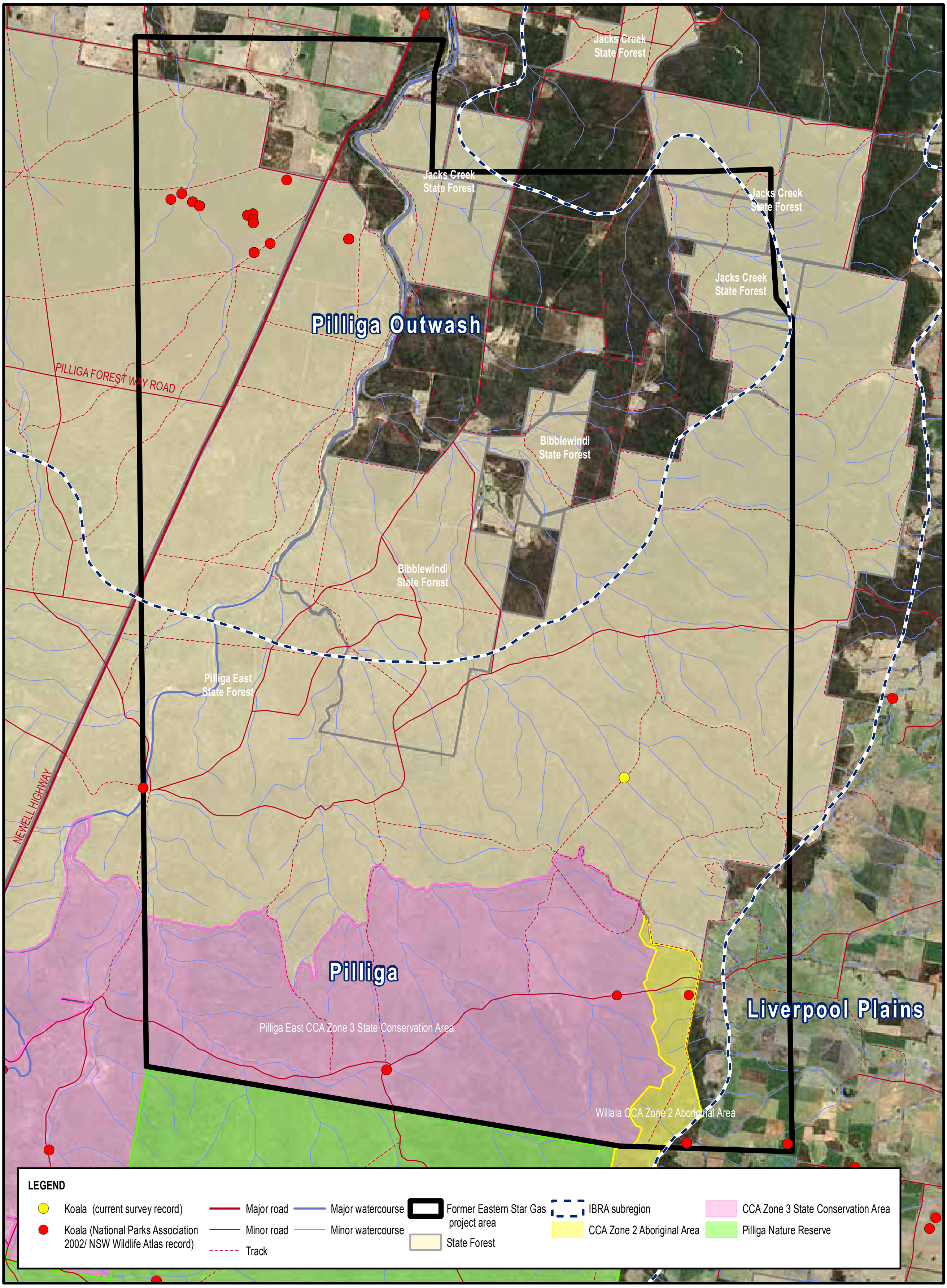
Threatened Hooded Robin. Photo David Milledge

FIG 10



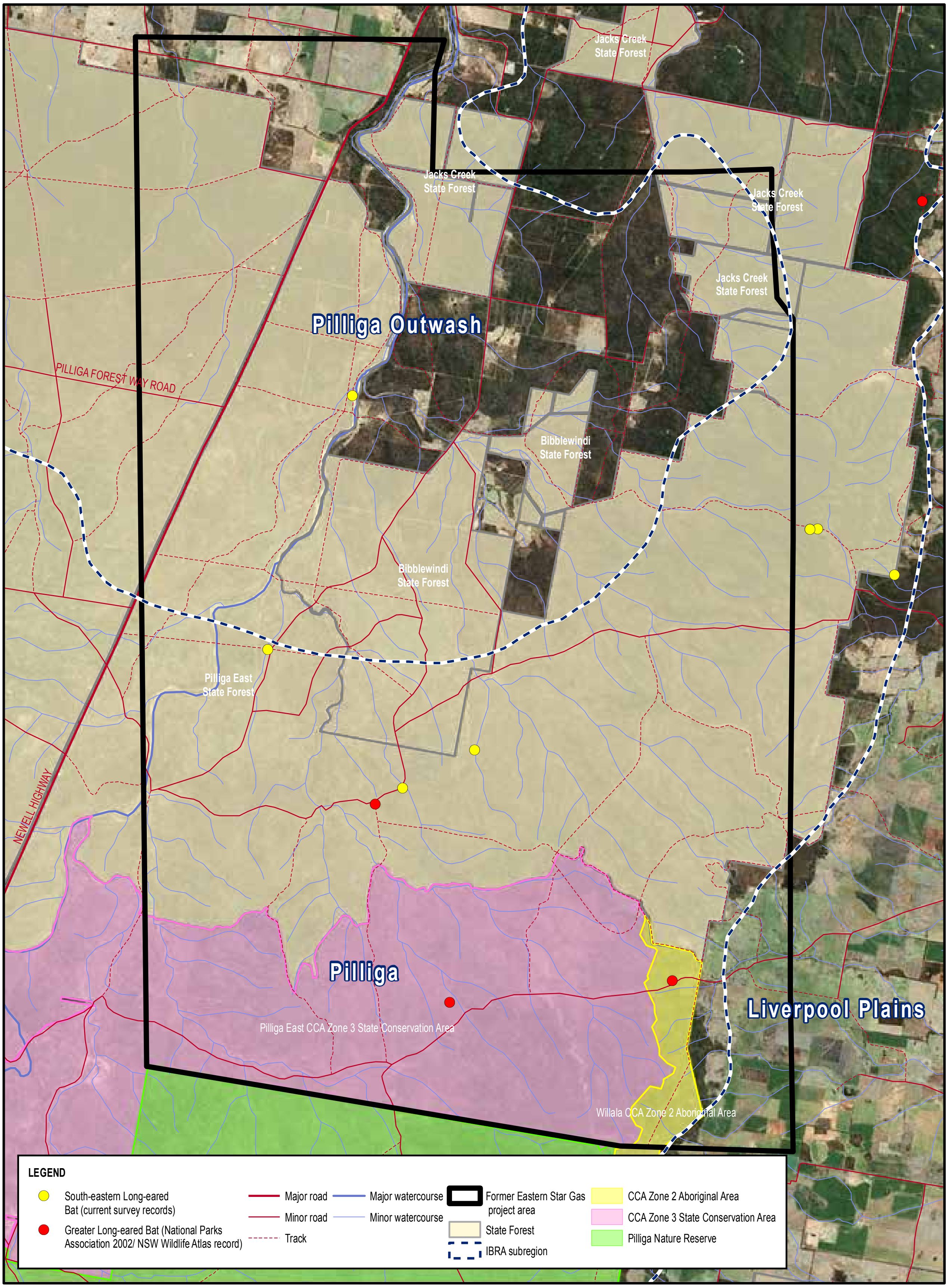
Reserves from NSW Dept of Planning. Threatened species records from Landmark Ecological Services. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Records of the Pale-headed Snake, Barking Owl, Eastern Pygmy-possum and Black-striped Wallaby in the Project Area	Figure 10

FIG 11



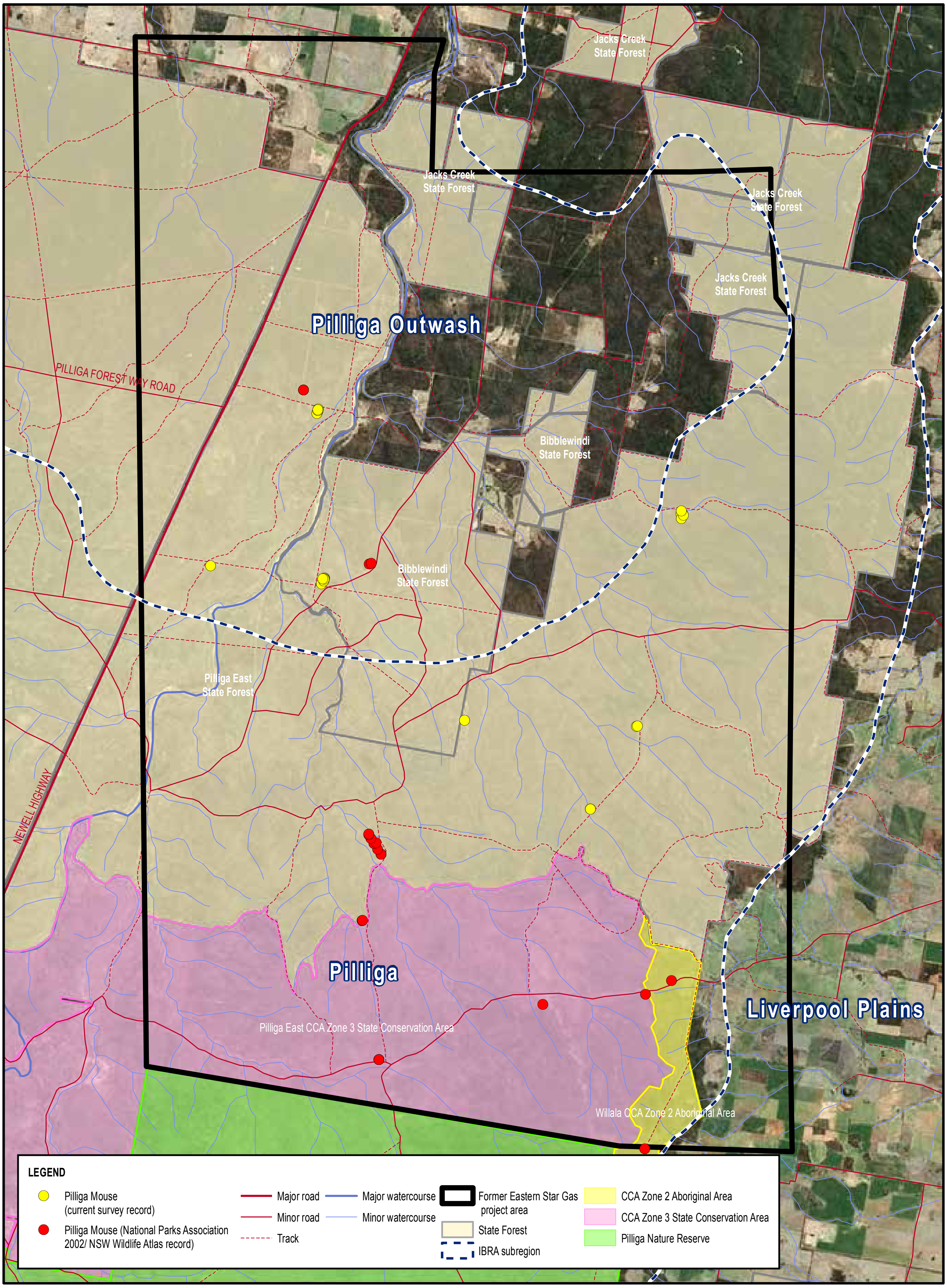
Reserves from NSW Dept of Planning and OEH. Koala records from Landmark Ecological Services. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Records of the Koala in the Project Area	Figure 11

FIG 12



Reserves from NSW Dept of Planning and OEH. South-eastern Long-eared Bat re from Landmark Ecological Services. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Records of the South-eastern Long-eared Bat in the Project Area	Figure 12

FIG 13



Reserves from NSW Dept of Planning and OEH. Pilliga Mouse records from Landmark Ecological Services. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Records of the Pilliga Mouse in the Project Area	Figure 13

tree (Paull in prep.), is a co-dominant with Narrow-leaved Ironbark *Eucalyptus crebra,* White Cypress Pine *Callitris glaucophylla* and Brown Bloodwood *Corymbia trachyphloia* in a number of other widespread associations (Fig. 4). As a consequence, the Project Area represents potentially suitable habitat for Koala recolonisation following a return to more favourable conditions.

3.2.2.2 South-eastern Long-eared Bat Prior to the current survey there were three records of the South-eastern Long-eared Bat in the Project Area (confined to the southern section), with a small number of records in adjacent areas (Fig. 12, Atlas of NSW Wildlife, Flint 2011). However, Pilliga East, a larger block enclosing the Project Area was identified by Turbill and Ellis (2006) as one of only three areas representing a "distinct stronghold" for the south-eastern form of the Greater Long-eared Bat *Nyctophilus timoriensis* (redescribed as the South-eastern Long-eared Bat *N. corbeni* by Parnaby 2009). This species appears to require large continuous (vegetation) remants to support high densities or core populations (Turbill and Ellis 2006). The results from the current survey support the finding of Pilliga East's importance for this species, with a total of 21 individuals captured at 8 sites throughout and adjoining the Project Area (Tables 6 and 8, Fig. 12). This included seven and eight individuals captured over two nights at two sites respectively (Appendix 6). The capture rate of 0.7 individuals per trap night (20 individuals for 30 trap nights, Table 8, Appendix 6), representing 8% of total bats captured (240 captures, Table 8) corresponds closely with the figures of 0.1-0.6 individuals per trap night and 7-9% of bat captures obtained by Turbill and Ellis (2006) for the species in

Table 6 Summary of records of threatened and migratory species obtained in the Project Area, 8-14 October 2011 – species and numbers of individuals

common name	scientific name	threatened status	no. sites	nos individuals
Pale-headed Snake	*Hoplocephalus bitorquatus*	vulnerable *(TSC Act)*	1	1
Little Eagle	*Hieraaetus morphnoides*	vulnerable *(TSC Act)*	2	2
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable *(TSC Act)*	8	67+
Little Lorikeet	*Glossopsitta pusilla*	vulnerable *(TSC Act)*	1	2
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	15	24
Barking Owl	*Ninox connivens*	vulnerable *(TSC Act)*	3	3
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	12	36+
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	12	16+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	15	28+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	37	112+
Varied Sittella	*Daphoenositta chrysoptera*	vulnerable *(TSC Act)*	3	9+
Hooded Robin	*Melanodryas cucullata*	vulnerable *(TSC Act)*	1	2
Diamond Firetail	*Stagonopleura guttata*	vulnerable *(TSC Act)*	3	6+
Koala	*Phascolarctos cinereus*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	1	1
Eastern Pygmy-possum	*Cercartetus nanus*	vulnerable *(TSC Act)*	2	3
Squirrel Glider	*Petaurus norfolcensis*	vulnerable *(TSC Act)*	1 +2*	1 +2*
Black-striped Wallaby	*Macropus dorsalis*	endangered *(TSC Act)*	2	8
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	15	17+/-
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	7 +1*	20 +1*
Little Pied Bat	*Chalinolobus picatus*	vulnerable *(TSC Act)*	1 +1*	1 +2*
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	7	25
Total 21 species				

* records outside Project Area

their three stronghold areas of Goonoo, Pilliga West and Pilliga East.

The South-eastern Long-eared Bat's ecological requirements and behaviour are poorly known (Schulz and Lumsden 2010, NSW Office of Environment and Heritage Threatened Species website – accessed July 2012) although Turbill and Ellis (2006) found that capture sites with highest densities were characterised by a "distinct" canopy and a dense "cluttered" understorey. The species' slow, highly manoeuvrable flight is likely to enable it to effectively exploit bark, branch and foliage substrates close to the ground in such habitat (Turbill and Ellis 2006), which predominates along drainage lines in the vegetation types of the Project Area and the East Pilliga block generally, and it is probable that these areas represent optimum foraging habitat for the species there.

3.2.2.3 Pilliga Mouse The Pilliga Mouse was known from a number of locations in the Project Area before the current survey, although the 19 records were concentrated in the southern section (Fig. 13), Atlas of NSW Wildlife, Flint 2011). A total of 25 Pilliga Mouse individuals were captured at 7 sites in the current survey, distributed throughout the Project Area (Fig. 13). These comprised 11 males, five females and seven subadults (plus two not sexed or aged, Tables 7 and 9; Paull *et al.* in prep.). Seven individuals were captured at two separate sites, and three females at three different sites were found to be lactating (Appendix 8), consistent with the previously reported October-April breeding season (Paull 2005, Tokushima *et al.* 2008). In addition, subadult individuals were captured at two of the latter sites plus another site (Appendix 8). An approximate density of 1.74 individuals per ha (n=24, range 1-7) was obtained from the Elliott trapping results (Paull *et al.* in prep.), which is also consistent with the previously reported breeding density of 1-2 individuals/ha (Paull 2005, Tokushima *et al.* 2008).

Threatened Black-striped Wallaby captured on camera trap during surveys

Table 7 Summary of results of pitfall and funnel trapping for small reptiles and mammals, targeting the Pale-headed Snake and Eastern Pygmy-possum in the Project Area, 10-14 October 2011 - species and numbers of captures

common name	scientific name	no. sites where captured	total nos captured	no. males captured	no. females captured
Ornate Burrowing Frog	*Limnodynastes ornatus*	1	1		
Wood Mulch-slider	*Lerista muelleri*	1	1		
Pale-headed Snake	***Hoplocephalus bitorquatus***	1	1		
Eastern Pygmy-possum	***Cercartetus nanus***	2	3	2	1
Pilliga Mouse	***Pseudomys pilligaensis***	1	1	1	
Total 5 species					

threatened species **bolded**

Table 8 Summary of results of harp trapping for microchiropteran bats in the Project Area, 10-14 October 2011 – species and numbers of captures

common name	scientific name	nos traps where captured	total nos captured#	no. males captured*	no. females captured*
Eastern Horseshoe Bat	*Rhinolophus mega-phyllus*	1	1	1	
Gould's Wattled Bat	*Chalinolobus gouldii*	5 +2*	12 +12*	3	9 +12*
Chocolate Wattled Bat	*Chalinolobus morio*	5 +1*	12 +1*	5 +1*	7
Little Pied Bat	***Chalinolobus picatus***	1*	2*	2*	
South-eastern Long-eared Bat	***Nyctophilus corbeni***	6 +1*	19 +1*	5	14 +1*
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	6 +2*	13 +3*	2 +1*	11 +2*
Gould's Long-eared Bat	*Nyctophilus gouldi*	6 +1*	15 +1*	8 +1*	7
Inland Broad-nosed Bat	*Scotorepens balstoni*	6 +2*	10 +15*	7 +3*	3 +12*
Little Broad-nosed Bat	*Scotorepens greyii*	3 +2*	4 +7*	1 +2*	3 +5*
Little Forest Bat	*Vespadelus vulturnus*	17 +2*	82 +30*	16 +13*	44 +17*
Total 10 species					

threatened species **bolded**
* nos captured outside the Project Area
# nos refer to captures (may include some retraps)

Table 9 Summary of results of Elliott trapping for small mammals, targeting the Pilliga Mouse in the Project Area, 10-14 October 2011 – species and numbers of captures

common name	scientific name	nos traps where captured	total nos captured	no. males captured	no. females captured	no. subads captured	no. prob. retraps
Nobbi	*Amphibolurus nobii*	2	2				
Striped Skink	*Ctenotus robustus*	1	1				
Pilliga Mouse	***Pseudomys pilligaensis***	7	24	10	5	7	7
House Mouse	*Mus musculus*	1	1				
Total 4 species							

threatened species **bolded**

Table 10 Summary of results of camera trapping for medium and large-sized terrestrial mammals in the Project Area, 9-14 October 2011 - species and numbers of individuals

common name	scientific name	no. sites where recorded	total nos recorded
Eastern Grey Kangaroo	*Macropus giganteus*	5	13
Black-striped Wallaby	***Macropus dorsalis***	1	1
Common Wallaroo	*Macropus robustus*	2	2
Red-necked Wallaby	*Macropus rufogriseus*	2	2
Swamp Wallaby	*Wallabia bicolor*	3	3
Feral Goat	*Capra hircus*	1	2
Red Fox	*Vulpes vulpes*	3	3
Feral Cat	*Felis catus*	1	1
European Brown Hare	*Lepus europaeus*	1	1
Total 9 species			

threatened species **bolded**

Table 11 Summary of threatened and migratory bird species recorded at 1ha/20min census sites in the Project Area, 8-14 October 2011

common name	scientific name	no. sites where recorded	total nos recorded
Little Eagle	*Hieraaetus morphnoides*	1	1
Little Lorikeet	*Glossopsitta pusilla*	1	2
Turquoise Parrot	*Neophema pulchella*	4	4
Rainbow Bee-eater	*Merops ornatus*	7	14+
Brown Treecreeper	*Climacteris picumnus*	2	2
Speckled Warbler	*Chthonicola sagittate*	9	18+
Grey-crowned Babbler	*Pomatostomus temporalis*	11	22+
Varied Sittella	*Daphoenositta chrysoptera*	2	6+
Hooded Robin	*Melanodryas cucullata*	1	2
Diamond Firetail	*Stagonopleura guttata*	1	1
Total 9 species			

All capture sites in the current survey were in heathy forest or woodland (15-40% canopy foliage cover), characterised by a dense, floristically diverse, low shrubby understorey, usually with a sparsely vegetated ground layer and well-developed leaf litter layer (Appendix 9, Paull *et al.* in prep.). Canopy or upper storey dominants or co-dominants at capture sites were mostly Brown Bloodwood, Baradine Red Gum and Broad-leaved Ironbark *E. fibrosa*, although Dwyer's Red Gum *E. dwyeri*, Scribbly Gum *E. rossii* and Rough-barked Angophora *Angophora floribunda* were co-dominant at one site each (Appendix 9). Commonly occurring plant species in the low understorey at capture sites were Common Fringe-myrtle *Calytrix tetragona* and Sandstone Boronia *Boronia glabra* (dominant at three sites) and Rhomb-leaved Bossiaea *Bossiaea rhombifolia* and Daphne Heath *Brachyloma daphnoides* (dominant at two sites) (Appendix 9). Common Fringe-myrtle has previously been recorded as characterising Pilliga Mouse capture sites (Paull 2009).

These records indicate that the Pilliga Mouse occurs and breeds in a wider range of floristic associations than previously reported (NCC 2002, Tokushima and Jarman 2008, Tokushima *et al.* 2008, Paull 2009, although anticipated by Paull 2009), particularly in associations co-dominated by Broad-leaved Ironbark and Baradine Red Gum. The species appeared to be absent from the sites with dense mid understories dominated by Spur-winged Wattle *Acacia triptera* and Broombush *Melaleuca uncinata* (Appendix 9).

The vehicular habitat traverses identified occurrences of potential Pilliga Mouse habitat across the Project Area, distributed both in forest and woodland on the lower nutrient soils of the Pilliga Province and the higher nutrient soils of the Pilliga Outwash Province (Fig. 8). Estimations based on these occurrences indicated that approximately 20% of the Project Area provides potentially suitable habitat for the species (Paull *et al.* in prep.).

The Pilliga Mouse has been shown to be irruptive during favourable conditions that result from relatively long-term climatic fluctuations such as la Nina events, contracting to refuges during unfavourable times (Paull 2005, Tokushima *et al.* 2008). However, breeding is not confined to periods of favourable conditions (Tokushima *et al.* 2008) and refuge habitat appears likely to be crucial for maintaining viable populations of the species.

3.2.2.4 Declining woodland bird species All but one of the seven species of sedentary woodland birds listed as threatened under the *TSC Act* were recorded during the current survey. These species have been identified in recent studies as key declining species under threat from habitat clearing, fragmentation, isolation and degradation (e.g. Barrett *et al.* 1994, Robinson and Traill 1996, Reid 1999, Ford *et al.* 2001). They comprised the Brown Treecreeper, Speckled Warbler, Grey-crowned Babbler, Varied Sittella, Hooded Robin and Diamond Firetail (Table 6). The Black-chinned Honeyeater, which was not detected, has previously been recorded from the Project Area (Atlas of NSW Wildlife, Flint 2011), although this species is considered rare in the Brigalow Belt South Bioregion (RACAC 2002).

The Project area was found to be a core area for the Speckled Warbler and Grey-crowned Babbler, with a substantial number of individuals recorded at numerous sites (Table 6, Fig. 14).

The declining woodland species listed above have been identified as requiring mature trees and grassy or patchy grassy and shrubby understoreys (Date *et al.* 2002), which are characteristic of much of the Pilliga Forest vegetation. However, despite the abundance of these elements and the large size of the Pilliga Forest block, which should militate against decline (e.g. Debus *et al.* 2006), these species are reported to be continuing to decline in the area due to disturbance regimes imposed by logging, frequent burning and grazing (Date *et al.* 2002). This trend may have been partly responsible for the relatively low numbers of the Varied Sittella, Hooded Robin and Diamond Firetail recorded in the current survey (Table 6).

3.2.2.5 Other significant threatened species The Pilliga Forest provides important habitat for a number of other species listed as threatened under the *TSC Act* and seven species were recorded during the current survey that are considered significant in this regard. These species comprise the vulnerable Pale-headed Snake, Glossy Black-cockatoo, Turquoise Parrot, Barking Owl, Eastern Pygmy-possum and Yellow-bellied Sheath-tailed Bat, and the endangered Black-striped Wallaby (Table 6).

One Pale-headed Snake was captured in a funnel trap in the central east of the Project Area in Broad-leaved Ironbark-Brown Bloodwood woodland with a dense low shrubby understorey (Table 7, Fig. 10). This record and a previous record in the south of the Project Area (Fig. 10) suggest that the Project Area may support a population of this rare and poorly known species.

Flocks of up to 30 or more Glossy Black-cockatoos were recorded at sites along Bohena Creek and also in the eastern section of the Project Area (Appendix 12, Fig. 14), on occasions feeding on seeds of Belah *Casuarina cristata* and Heath Oak *Allocasuarina diminuta*. These records indicate that the Project Area provides extensive foraging habitat for an important population of this species close to the western limits of its range.

The survey results demonstrated that the Project Area provides core habitat for the Turquoise Parrot, with widely distributed records in a variety of forest and woodland associations at numerous sites (Appendix 12, Fig. 14). As with the Glossy Black-cockatoo, the species is close to its western limits in the area.

The Barking Owl population in the Pilliga Forest, concentrated in the Pilliga Outwash Province, appears to be the largest in southern Australia (Milledge 2002, Soderquist 2009, Soderquist and Milledge in prep.) and is highly significant as a core population west of the Great Dividing Range. Three records, probably representing two territories of the Barking Owl were detected during the survey (Table 6, Fig. 10). Records consisted of individuals calling and one observation, but owls were not responsive to call playback, probably being engaged in incubation of eggs or young at the time. Territories were located along Bohena Creek in the vicinity of territories determined by playback surveys in 2001 (Milledge 2002) and within the Pilliga Outwash Province.

A total of three Eastern Pygmy-possums, including a pregnant female, was captured in pitfall traps at two sites in the central eastern section of the Project Area (Table 7, Appendix 3, Fig. 10). Both sites were in woodland with a dense low shrubby understorey, one dominated by Broad-leaved Ironbark, Brown Bloodwood and Baradine Red Gum with Heath Bog-rush *Schoenus ericetorum,* Hoary Guinea-flower *Hibbertia obtusifolia* and a grass *Cymbopogon sp.* dominating the low understorey. The other site was dominated by Broad-leaved Ironbark and Brown Bloodwood with Common Fringe-myrtle, Small-leaf Bush-pea *Pultenaea foliolosa* and a tea tree *Leptospermum sp.* dominant in the low understorey. The Eastern Pygmy-possum occurs in the Pilliga Forest at the western limit of its distribution and the population appears to be isolated from others on the western slopes and may be genetically distinct (D. Paull pers. comm.). In the Pilliga Forest this species favours riparian habitat and vegetation dominated by myrtaceous shrubs (Paull 1998).

Up to seven Black-striped Wallabies were observed crossing a wide gas pipeline corridor in the north of the Project Area during a dusk watch on two consecutive days and another was recorded by camera trap in the far north (Tables 6 and 10, Fig. 10). Both locations fell within the Pilliga Outwash Province and indicate a small but core population in the area. This occurence is considered highly significant as the species is at the south-western limits of its range in the Pilliga Forest (above) and is declining towards extinction in NSW.

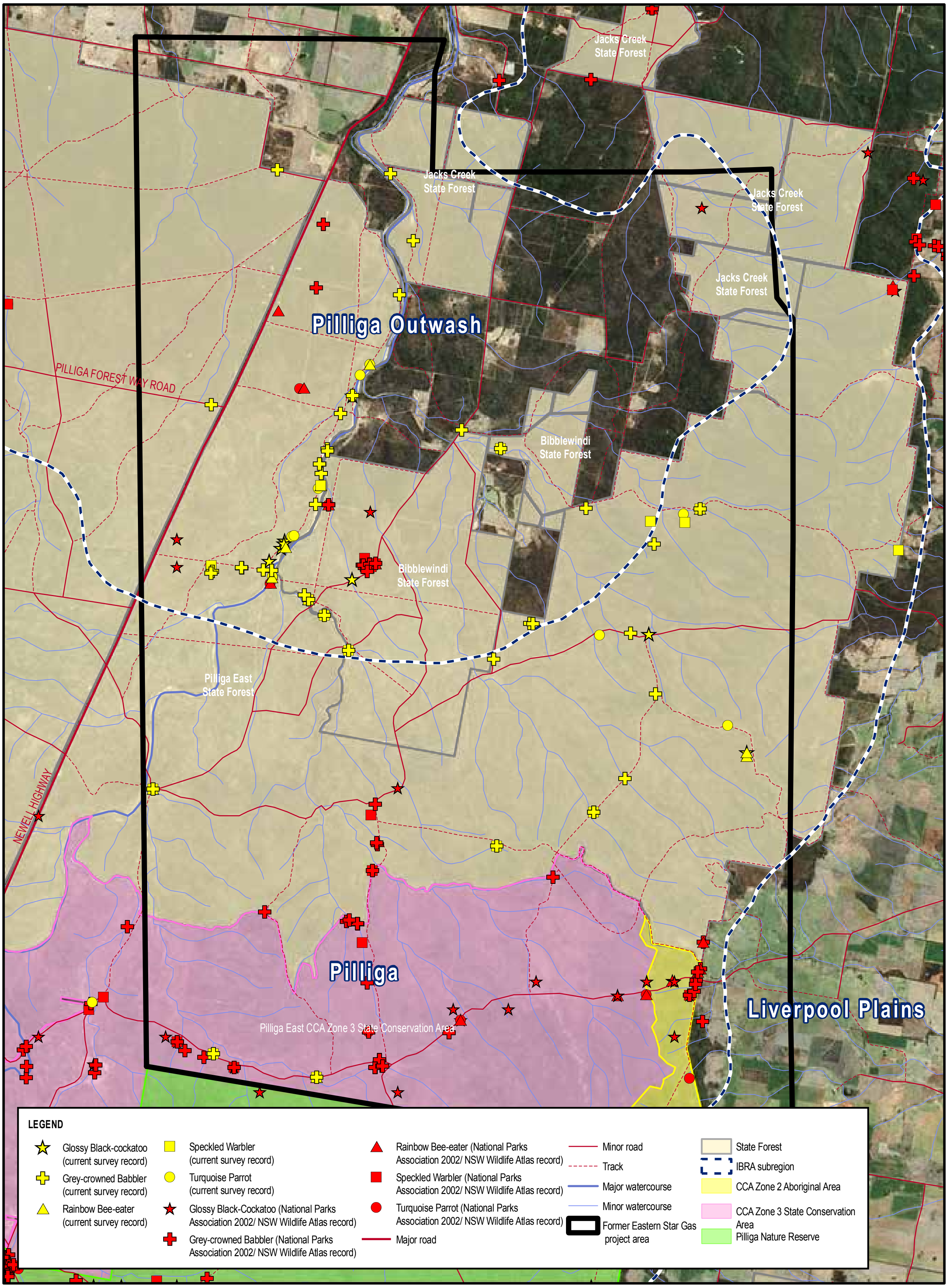
The Anabat detection results provided records of the Yellow-bellied Sheath-tailed Bat at 16 discrete sites (Appendix 7, Fig. 15) and while some of these may have involved records of the same individual at more than one site, it was evident that the species is widely distributed through the Project Area and it supports an important population. The Yellow-bellied Sheath-tailed Bat is likely to require large tree hollows for roost and maternity sites, which have been identified as a fast declining resource in the Pilliga Forest (Parnaby *et al.* 2011).

3.2.2.6 <u>Migratory species</u> Numerous records of the migratory (*EPBC Act* listed) Rainbow Bee-eater were obtained throughout the Project Area (Table 6, Fig. 14) and it clearly provides important habitat for this species, possibly for passage migrants moving north from breeding areas in southern Australia.

3.2.2.7 <u>Threatened species not detected during current survey</u> Seven threatened species (*TSC Act*) recorded from the Project Area (Atlas of NSW Wildlife, Flint 2011) but not detected during the current survey comprise the Spotted Harrier *Circus assimilis,* Bush Stone-curlew, Masked Owl, Black-chinned Honeyeater, Painted Honeyeater, Eastern Bent-winged Bat and Eastern Cave Bat (Table 5). These are primarily species lacking substantial suitable habitat in the Project Area or rare, patchily distributed, cryptic or nomadic species.

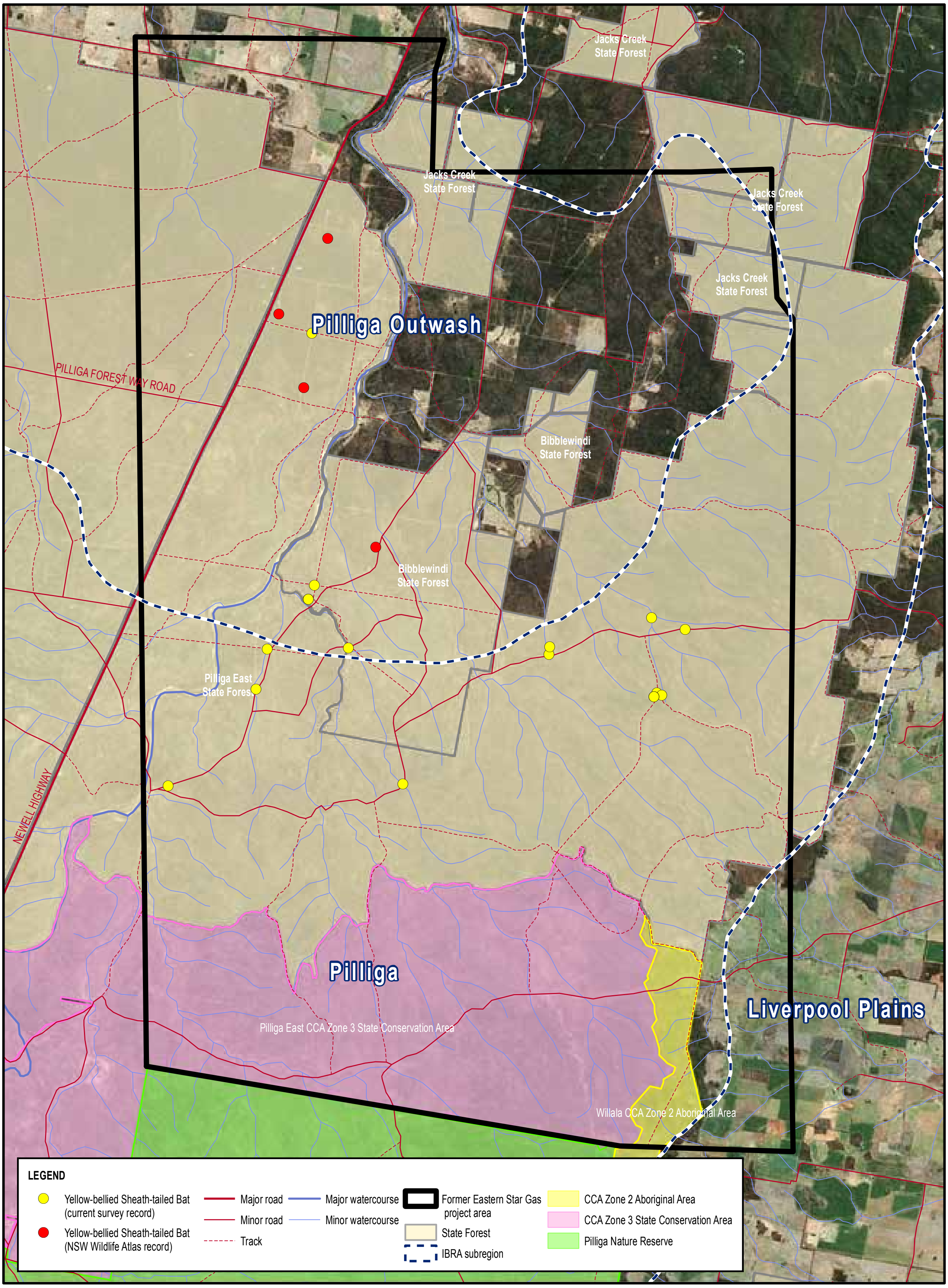
3.2.3 <u>Total vertebrate species recorded by current survey</u> An overall total of 176 vertebrate species was recorded from the Project Area during the current survey, comprising 13 frog, 11 reptile, 119 bird and 33 mammal species (Appendix 13). One additional mammal species, the Common Wombat *Vombatus ursinus,* was recorded (on the basis of faecal scats) at Willala Mountain, closely adjacent to the south-

FIG 14



Reserves from NSW Dept of Planning and OEH. Glossy Black-cockatoo, Turquoise Parrot, Rainbow Bee-eater, Speckled Warbler and Grey-crowned Babbler records from Landmark Ecological Services. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Records of the Glossy Black-cockatoo, Turquoise Parrot, Rainbow Bee-eater, Speckled Warbler and Grey-crowned Babbler in the Project Area	Figure 14

FIG 15



Reserves from NSW Dept of Planning and OEH. Yellow-bellied Sheath-tailed Bat records fromLandmark Ecological Services. Roads and watercourses from GEODATA TOPO250K. Imagery from Bing.	NORTH 0 km 4 1:175,000 at A4 11/09/2012	Records of the Yellow-bellied Sheath-tailed Bat in the Project Area	Figure 15

eastern boundary of the Project Area.

These results demonstrate that the Project Area supports rich assemblages of many bird and mammal groups including frogmouths and nightjars (four species recorded), hawks, eagles and falcons (eight species recorded), lorikeets and parrots (eight species recorded), cuckoos (five species recorded), Australian warblers or acanthizids (10 species recorded), honeyeaters (13 species recorded), macropods (five species recorded) and microchiropteran bats (14 species recorded).

3.2.3.1 Species recorded by targeted and systematic methods Five vertebrate species (one amphibian, two reptile and two small mammal species) were captured by pitfall and funnel trapping (Table 7), 10 microchiropteran bat species were captured in harp traps (Table 8), an additional four microchiropteran bat species were detected by Anabat (Appendix 7), four vertebrate species (two reptile and two small mammal species) were captured in Elliott traps (Table 9), and nine medium and large-sized mammal species were detected by camera traps (Table 10). Ten threatened and migratory bird species (EPBC and *TSC Acts)* were recorded during the 1ha/20min bird censuses (Table 11).

The species diversity and numbers of individuals of threatened (*TSC Act*) and migratory bird (*EPBC Act*) species (Table 11) and numbers of captures of microchiropteran bat species (Table 8) reinforce the importance of habitats in the Project Area for these groups.

3.2.3.2 Species with significant populations or at their distributional limits In addition to the threatened and migratory species (*EPBC* and *TSC Acts*) described above, other significant species recorded included species at or close to the limits of their ranges such as Bibron's Toadlet *Pseudophryne bibroni* (western limits), the Wood Mulch-slider *Lerista muelleri* (eastern limits), Spotted Nightjar *Eurostopodus argus* (eastern limits), Crested Bellbird *Oreoica gutturalis* (eastern limits), Eastern Horseshoe Bat *Rhinolophus megaphyllus* (western limits) and the Common Wombat (western limits) (Higgins 1999, Higgins and Peter 2002, Swan *et al.* 2004, Van Dyck and Strahan 2008, OEH 2012). Such records illustrate the Pilliga Forest's significance as a transition zone between Eyrean and Bassian faunas.

3.2.3.3 <u>Additional declining woodland bird species</u> A suite of woodland birds not formally listed as threatened but which have been identified as declining in a number of studies (e.g. Barrett *et al.* 1994, Reid 1999, Date *et al.* 2002, Watson *et al.* 2003, Debus *et al.* 2006) were also recorded in the Project Area and emphasise its importance for this group. These included the Emu *Dromaius novaehollandiae,* Peaceful Dove *Geopelia striata,* Painted Button-quail *Turnix varia,* Musk Lorikeet *Glossopsitta concinna,* White-browed Babbler *Pomatostomus superciliosus,* Spotted Quail-thrush *Cinclosoma punctatum,* Crested Shrike-tit *Falcunculus frontatus,* Crested Bellbird, White-browed Woodswallow *Artamus superciliosus,* Dusky Woodswallow *A. cyanopterus,* White-winged Chough *Corcorax melanorhamphos,* Red-capped Robin *Petroica goodenovii* and Double-barred Finch *Taeniopygia bichenovii.*

3.2.3.4 <u>Migratory and nomadic bird species</u> Nomadic and migratory bird species recorded during the current survey included Horsfield's Bronze-cuckoo *Chalcites basalis,* the Black-eared Cuckoo *C. osculans,* Pallid Cuckoo *Cuculus pallidus,* Fantailed Cuckoo *C. flabelliformis,* Dollarbird *Eurystomus orientalis,* Striated Pardalote *Pardalotus striatus*, White-bellied Cuckoo-shrike *Coracina papuensis,* Masked Woodswallow *Artamus personatus,* White-browed Woodswallow *A. superciliosus,* Dusky Woodswallow *A. cyanopterus,* Leaden Flycatcher *Myiagra rubecula,* Tree Martin *Petrochelidon nigricans*. These results illustrate the significance of the Project Area's location within the eastern Australian bird migration system (above) in providing passage habitats for a large and diverse group of open forest and woodland dependent bird species. In particular, these habitats cater for the group of species moving north from higher elevations and latitudes along the western side of the Great Dividing Range in autumn to overwintering habitats at lower elevations and latitudes, and returning south in spring (Nix and Mackey 2000).

3.2.3.5 <u>Nectarivorous species</u> Although only one eucalypt species, Baradine Red Gum, was flowering extensively during the survey period, a suite of nectarivorous species including the Musk Lorikeet *Glossopsitta concinna,* the vulnerable (*TSC Act*) Little Lorikeet, honeyeaters such as the Spiny-cheeked Honeyeater *Acanthagenys rufogularis,* Little Friarbird *Philemon citreogularis* and Striped Honeyeater *Plectorhyncha lanceolata* and the Sugar Glider *Petaurus breviceps,* vulnerable (*TSC Act*) Squirrel Glider and Little Red Flying-fox *Pteropus scapulatus* were recorded feeding at the flowers. These records underline the significance of the Pilliga Forest in providing a spring (and autumn-winter) nectar resource for nomadic and migratory birds and flying-foxes.

3.2.4 Introduced mammals The current survey provided a number of records of four introduced mammal species, the Feral Goat *Capra hircus,* Feral Pig *Sus scrofa,* Red Fox *Vulpes vulpes* and Feral Cat *Felis catus* (Table 10, Appendix 13) that are considered invasive and constitute key threatenening processes under the *TSC Act.* Three other introduced mammals, the European Brown Hare *Lepus europaeus*, European Rabbit *Oryctolagus cuniculus* and House Mouse *Mus musculus* were also recorded in the Project Area (Tables 9 and 10, Appendix 13). Extensive vegetation browsing and soil disturbance attributable to the Feral Goat and Feral Pig respectively were noted throughout the Project Area and disturbance from Feral Pigs was observed around Pilliga Mouse burrow systems at two capture sites.

Threatened Eastern Pygmy-possum. Photo Phil Spark

4 DISCUSSION

4.1 SIGNIFICANCE OF SURVEY RESULTS

The results of the current survey have shown that the Project Area contains a number of significant populations of plants and vertebrate species listed on the schedules of the *EPBC* and *TSC Acts*. The survey has demonstrated that the Project Area:

i) contains an important population of the vulnerable (*EPBC*, *TSC Acts*) plant *Rulingia procumbens* and represents a stronghold for the critically endangered EEC (*EPBC Act*, endangered under the *TSC Act*) White Box-Yellow Box-Blakely's Red Gum grassy woodland and derived native grassland;

ii) supports a core population of the vulnerable (*EPBC, TSC Acts*) South-eastern Long-eared Bat within one of its only three known strongholds, supports a core population of the vulnerable (*EPBC, TSC Acts*) Pilliga Mouse, a regional endemic, and appears to provide suitable habitat for the regionally-significant population of the vulnerable (*EPBC, TSC Acts*) Koala;

iii) supports important populations of six of seven sedentary, vulnerable (*TSC Act*) declining woodland bird species, including core populations of the Speckled Warbler and Grey-crowned Babbler, as well as populations of many other identified declining woodland bird species;

iv) supports significant populations of other threatened (*TSC Act*) species including the Pale-headed Snake, Glossy Black-cockatoo, Turquoise Parrot, Barking Owl, Eastern Pygmy-possum, Black-striped Wallaby and Yellow-bellied Sheath-tailed Bat;

v) contains at least 176 vertebrate species and supports rich and diverse assemblages of a number of major Australian bird groups (including a high proportion of declining woodland bird species) and macropod and microchiropteran bat species, emphasising the importance of the Pilliga Forest as the largest temperate forest and woodland refuge west of the Great Dividing Range;

vi) contains a number of vertebrate species at or close to the western and eastern limits of their distributions, underlining the zoogeographical significance of the Pilliga Forest as an overlap zone between Bassian and Eyrean faunas;

vii) provides important passage habitat for nomadic and migratory bird species from higher elevations and latitudes that overwinter to the north at lower elevations and latitudes and return south to breed;

viii) provides a spring nectar resource for nomadic and migratory bird and flying-fox species together with arboreal marsupial species; and

ix) contains established populations of four invasive mammal species that currently pose a threat to the viability of populations of significant conservation-priority native vertebrates.

These results have substantially added to the distribution and population density information for threatened species in the Project Area that remained following past surveys (NCC 2002, RACAC 2002, Eco Logical Australia 2011), particularly for key threatened species such as the South-eastern Long-eared Bat and Pilliga Mouse (Figs 12 and 13).

They also provide clear evidence of the national significance of the Pilliga Forest for biodiversity conservation and highlight the need for conservation planning across all tenures to sustain its values.

Threatened Glossy Black-cockatoo, Pilliga East State Forest. Photo Phil Spark

4.2 ON-GOING SPECIES EXTINCTIONS IN THE PILLIGA FOREST AND ADJOINING FLOODPLAINS

Despite the present conservation significance of the Pilliga Forest, a pattern of bird and mammal extinction following European settlement is evident in surrounding lands, which is likely to have also affected species assemblages in the remaining Pilliga forests and woodlands.

For example, species that occurred east of the Pilliga on the Liverpool Plains up until the mid 1800's and that are now presumed regionally or totally extinct include the Western Quoll *Dasyurus geoffroii,* Western Barred Bandicoot *Perameles bougainville,* Bilby *Macrotis lagotis,* Brush-tailed Bettong *Bettongia penicillata,* Eastern Hare-wallaby *Lagorchestes leporides,* White-footed Rabbit Rat *Conilurus albipes,* Plains Mouse *Pseudomys australis,* Gould's Mouse *P. gouldii* and Long-haired Rat *Rattus villosissimus* (Dickman 1994, Paull and Date 1999, Date and Paull 2000, Short and Calaby 2001; Australian Museum collection database, pers. comm Sandy Ingleby March 2004). Species known to have disappeared from the Macintyre, Gwydir and Namoi floodplains to the north, south and west of the Pilliga Forest at the same time include the Star Finch *Noechima ruficauda,* Bridled Nail-tail Wallaby *Onychogloa fraenata,* Plains Mouse and Gould's Mouse (Morris *et al.* 1981, Paull and Date 1999, Date and Paull 2000, Short and Calaby 2001, Australian Museum collection database, pers. comm Sandy Ingleby March 2004).

More recently other species have apparently become regionally extinct in these areas, comprising the Black-throated Finch *Poephila cincta,* Australian Bustard *Ardeotis australis,* Narrow-nosed Planigale *Planigale tenuirostris,* Fat-tailed Dunnart *Sminthopsis crassicaudata,* Striped-faced Dunnart *S. macroura* and Long-nosed Bandicoot *Perameles nasuta* (Morris *et al.* 1981, Andren *et al.* in prep.).

The loss of so many bird and mammal species highlights the vulnerability of the vertebrate fauna of these dry temperate forest and woodland ecosystems to vegetation loss and associated pertubations. Although past impacts have predominantly involved vegetation clearing and fragmentation for agricultural development, edge effects, weed invasions and predation by introduced mammal species, most notably the Feral Cat and Red Fox (Dickman 1994, Short and Calaby 2001), have also been implicated.

Species known from the Pilliga Forest that presently appear to be approaching regional extinction include the Malleefowl *Leipoa ocellata,* Squatter Pigeon *Geophaps scripta,* Bush Stone-curlew *Burhinus grallarius,* Red-tailed Black-cockatoo *Calyptorhynchus banksii,* Rufous Bettong *Aepyprymnus rufescens* and Brush-tailed Rock-wallaby *Petrogale penicillata* (Date and Paull 2000, RACAC 2002, Ford and Aplin 2008, OEH 2012). Other as yet unidentified species detected in the Pillliga during recent surveys that may also fall into the above category comprise a quoll (probably the Spotted-tailed Quoll *Dasyurus maculatus*), a planigale Planigale sp., a dunnart *Sminthopsis sp.* and a hopping mouse *Notomys sp.* (Date and Paull 2000). Regional extinctions of some microchiropteran bat species have also been predicted by Parnaby *et al.* (2011) if current trends in hollow-bearing tree losses are not addressed.

All the above species have the potential to still be present in the Project Area, together with several additional threatened and cryptic species. The latter include microchiropteran bat species such as the Large-eared Pied Bat, known from Willala Mountain on the border of the Project Area, and Beccari's Free-tailed Bat *Mormopterus beccarii* and the Bristle-faced Free-tailed Bat *M. eleryi,* both predicted as likely to occur on the basis of the presence of suitable habitat.

Coal seam gas spill site

4.3 IMPACTS OF COAL SEAM GAS PRODUCTION IN THE PROJECT AREA

A wide range of known and potentially detrimental impacts from coal seam gas production are likely to occur in the Project Area. Observations of Eastern Star Gas' operations in extracting coal seam gas in the Project Area made during the current survey showed a series of direct and associated impacts that appeared to be having major detrimental impacts on the area's biodiversity conservation values. These included:

i) significant vegetation clearing throughout the Project Area for the construction of drill pads, wells and associated infrastructure, and widening of roads and construction of holding dams and pipeline corridors, all resulting in habitat loss, fragmentation and degradation, markedly increasing edge effects, increasing predation pressures and facilitating the establishment of invasive species;

ii) direct pollution of streams from waste water discharge probably causing habitat losses and food contamination resulting in deaths of aquatic vertebrates;

iii) increased salinity of ground water shown to have resulted in frog deaths at one site and possible vegetation death and dieback in other areas; and

iv) leakages from poorly maintained pipes that may have adversely affected vertebrates drinking pooled water, and contaminated soils and polluted drainage lines and ground water.

In particular, direct and indirect observations were made during the survey period of of widespread Feral Goat and Feral Pig activity in the Project Area, the former involving groups of animals seen traversing roads and foraging in native vegetation and the latter concerning heavily browsed shrubs and major soil disturbance in sensitive areas.

Other potential impacts from coal seam gas operations likely with future recommencement of production in the Project Area include:

i) additional vegetation clearing for protection of infrastructure from wildfires;

ii) the occurrence of unplanned fires;

iii) invasions of weed species, particularly introduced grasses resulting from vegetation disturbance and vehicle movements from outside the area;

iv) invasions of additional introduced vertebrate pest species such as the Common Myna *Acridotheres tristis* with increased habitat clearing and degradation;

Microchiropteran bats captured in a harp trap, Photo Hugh Nicholson

v) increased deaths of vertebrates from vehicle collisions as a result of increased human activity in the area.

4.3.1 Impacts on Matters of National Significance From the trapping results and survey of potential habitat (Figs 12 and 8), serious impacts on a Matter of National Significance (*EPBC Act*) are considered to have already occurred in the Project Area with respect to the Pilliga Mouse and Eastern Star Gas' past operations (Milledge 2011). These include:

i) the likely fragmentation of a population or metapopulation, based on the species' known contraction to a series of discrete refuges during unfavourable conditions (above), from road widening and pipeline corridor construction;

ii) the destruction of critical habitat from clearing for drill pad and well construction and associated infrastructure including pipeline corridors, based on habitat preferences and the occurrence of preferred habitat established during the current survey;

iii) disruption of the breeding cycle likely to have occurred from destruction, fragmentation and isolation of refuge habitat resulting from the clearing activities referred to above; and

iv) the increased establishment of invasive species such as the Feral Goat, Feral Pig, Red Fox and Feral Cat through substantial additional disturbance of refuge and favourable condition habitats.

Impacts on a Matter of National Significance from Eastern Star Gas' past operations are also likely to have occurred in the Project Area with respect to the South-eastern Long-eared Bat, through probable loss of foraging substrates (critical habitat) from the clearing referred to above and also the likely loss of hollow-bearing trees used as day-time and maternity roosts (disruption of the breeding cycle, Parnaby *et al.* 2011).

4.3.2 Impacts on other threatened species Another major impact on a threatened species observed during the survey period was the extensive clearing of endangered (*TSC Act*) Black-striped Wallaby resting and refuge habitat in the Brandons-Worombi Roads area in the north of the Project Area. This had involved clearing of several hectares of cypress-ironbark forest and woodland with a dense teatree *Leptospermum sp.* understorey for the construction of a large holding dam, road widening and a pipeline corridor.

Threatened Yellow-bellied Sheath-tailed Bat. Photo David Milledge

5 RECOMMENDATIONS

There should be a moratorium on coal seam gas extraction and exploration in the Project Area, and the Pilliga Forest generally, until it can be scientifically demonstrated that it will have no adverse effects on the maintenance of the area's biodiversity values, particularly as a refuge for its characteristic dry temperate forest and woodland ecosystems and their constituent communities and species. This must include the development of a comprehensive, all-tenure management plan to ensure the viability of all threatened species and ecological communities, and other conservation-priority species that are resident or use the area regularly or on an intermittent basis.

Specific actions to inform production of the management plan with respect to the Project Area must include:

i) further surveys across all seasons to comprehensively establish the Pilliga Mouse's use of habitats in the Project Area (informed by habitat modelling) and to determine the locations of refuges, particularly those where breeding takes place, and the establishment of sites for long-term monitoring of these areas;

ii) surveys to establish the occurrence of stands of hollow-bearing trees that are likely to be used as roost and maternity sites by the South-eastern Long-eared Bat, and the establishment of sites for long-term monitoring of the population;

iii) research data undertaken in the Pilliga Forest by ForestsNSW on the South-eastern Long-eared Bat be made available to determine whether this can be used to assist identification of the species' foraging and breeding requirements;

iv) additional Koala surveys of the Project Area, particularly within the Pilliga Outwash Province, involving detailed faecal scat and spotlight searches to establish Koala use of the area and the establishment of sites for long-term monitoring of the Koala population;

v) research to determine the distribution and size of the the Black-striped Wallaby population in the Project Area and the establishment of sites for its long-term monitoring;

vi) permanent survey plots established throughout the Project Area to monitor population numbers of declining woodland bird species;

vii) investigations during appropriate conditions of the use of the Project Area by nomadic and migratory *EPBC Act* - listed bird species such as the Superb Parrot, Swift Parrot and Regent Honeyeater;

viii) targeted surveys to investigate the occurrence of cryptic species and threatened species not yet recorded in the Project Area such as the undetermined species of quoll, planigale, dunnart and hopping mouse, the Rufous Bettong, Beccari's Free-tailed Bat and the Bristle-faced Free-tailed Bat;

ix) monitoring surveys to determine the distribution and densities of the Feral Goat, Feral Pig, Red Fox and Feral Cat in the Project Area;

x) genetic studies to clearly establish the taxonomic status of the Pilliga Mouse and investigate the status of the Eastern Pygmy-possum population; and

xi) consideration of nomination of the Pilliga Forest for World Heritage listing, or listing on the Register of the National Estate.

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Dwyer's Red Gum, Deldam Trail. Photo Hugh Nicholson

APPENDICES

Appendix 1 Results of searches for threatened plant species listed under the *EPBC* and *TSC Acts* in the Project Area, 10-30 October 2011

common name	scientific name	threatened status	date	Easting GDA94 MGA55	Northing GDA94 MGA55	nos and location description
a rulingia	*Rulingia procumbens*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	763669	6601047	several plants adjoining Falcon Trail, 2.5km south of junction with Warrumbungle Trail
a rulingia	*Rulingia procumbens*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	763420	6600609	one plant adjoining Falcon Trail, 2.9km south of junction with Warrumbungle Trail
a rulingia	*Rulingia procumbens*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	767060	6602240	eight plants adjoining Warrumbungle Trail west of Panton's Lookout
a rulingia	*Rulingia procumbens*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	30th Oct	767617	6601291	10 plants adjoing road to Panton's Lookout

Elliott trap targeting Pilliga Mouse in potential habitat. Photo Phil Spark

Appendix 2 Results of searches for EECs listed under the EPBC and TSC Acts in the Project Area, 11-14 October 2011

EEC	White Box-Yellow Box-Blakely's Red Gum grassy woodland and derived native grasslands			
threatened status	critically endangered (*EPBC Act*), Endangered (*TSC Act*)			
location		Monument Road		Bohena Creek Road 2
co-ordinates GDA94 MGA55	E766113, N6594450			
upper stratum dominants[1]	*Eucalyptus albens* *Eucalyptus blakelyi*	*Eucalyptus blakelyi*	*Eucalyptus blakelyi*	*Eucalyptus blakelyi*
upper stratum sub-dominants	*Callitris endlicheri* *Corymbia trachyphloia* *Eucalyptus chloroclada*	*Eucalyptus chloroclada* *Eucalyptus conica* *Eucalyptus pilligaensis* *Callitris endlicheri*	*Angophora floribunda*	*Angophora floribunda* *Eucalyptus chloroclada* *Eucalyptus conica*
mid stratum species2	*Acacia* sp. *Brachychiton populneus*3 *Callitris endlicheri*3 *Dodonaea viscosa*3 *Eucalyptus blakelyi* *Geijera paniculata* *Geijera parviflora*3 *Notelaea microcarpa*3	*Acacia* sp. *Callitris endlicheri*3	*Acacia deanii*3 *Callitris verricosa* *Acacia polybotria*	*Acacia deanii*3
ground cover species2	*Ajuga austalis*3 *Austrodanthonia bipartita* *Cassinia aculeata*3 *Chrysocephalum apiculatum*3 *Cymbopogon* sp. *Dianella revoluta*3 *Dichondra repens*3 *Melichrus urceolatus*3 *Notelaea microcarpa* *Pomax umbellata*3 *Stypandra glauca*3 *Themeda australis* *Vittadinia dissecta*3 *Wahlenbergia communis*3	*Acacia* sp. *Aristida* sp. *Austrostipa* sp. *Bracyscome* sp. *Cheilanthes* sp. *Chrysocephalum apiculatumv* *Cymbopogon* sp. *Dichondra repens*3 *Gahnia* sp. *Lomandra* sp. *Melichrus urceolatus*3 *Oxalis* sp. *Rumex brownii*3 *Themeda australis* *Wahlenbergia communis*3	*Aristida sp.* *Ajuga austalis*3 *Chrysocephalum apiculatum*3 *Dianella revoluta*3 *Glycine clandestina*3 *Imperata cylindrica* *Lomandra leucophela* *Lomandra longifolia* *Lomandra multiflora* *Melichrus urceolatus*3 *Wahlenbergia communis*3	*Ajuga austalis*3 *Austrostipa stipa* *Cheilanthes sieberi*3 *Chrysocephalum apiculatum*3 *Dichondra repens*3 *Gahnia sieberiana* *Glycine clandestina* *Imperata cylindrica*3 *Lomandra longifolia* *Lomandra multiflora* *Plantago debilis* *Pterostylis mutica* *Poa sieberiana* *Rumex brownii*3 *Swainsonii cadellii* *Vittadina falcata* *Wahlenbergia communisv*
important species2	*Ajuga austalis*3 *Chrysocephalum apiculatum*3 *Dianella revoluta*3 *Stypandra glauca*3 *Themeda australis*	*Chrysocephalum apiculatum*3 *Rumex brownii*3 *Themeda australis*	*Ajuga austalis*3 *Chrysocephalum apiculatum*3 *Dianella revoluta*3 *Glycine clandestina*3	*Ajuga austalis*3 *Chrysocephalum apiculatum*3 *Glycine clandestina*3 *Rumex brownii*3

1 qualifying criteria under *EPBC Act* listing of EEC include presence of one or more of *Eucalyptus albens, E. melliodora* or *E. blakelyi* among most common overstorey species

2 qualifying criteria under *EPBC Act* listing of EEC include presence of 12 or more native understorey species (excluding grasses) and at least one "important" species

3 included in *EPBC Act* listing of EEC as indicative species

Appendix 3 Results of pitfall and funnel trapping for small reptiles and mammals, targeting the Pale-headed Snake and Eastern Pygmy-possum in the Project Area, 10-14 October 2011

site	location	trap type	date	Easting GDA94 MGA55	Northing GDA94 MGA55	scientific name	nos/ sex	notes
C	Monument Road				6610025	***Cercartetus nanus***	1m	
C	Monument Road				6610025	*Limnodynastes ornatus*	l	
C	Monument Road				6610025	***Pseudomys pilligaensis***	lm	
E	Warrumbungle Road				6605535	***Cercartetus nanus***	1f	pregnant
E	Warrumbungle Road				6605535	*Lerista muelleris*	1	
E	Warrumbungle Road				6605535	***Hoplocephalus bitorquatus***	1	
E	Warrumbungle Road				6605535	***Cercartetus nanus***	1m	

* Threatened species bolded

Harp trap at Pantons Lookout. Photo Georgia Beyer

Appendix 4 Threatened and migratory bird species recorded at 1ha/20min census sites in the Project Area, 8-14 October

site	date	Easting GDA94 MGA55	Northing GDA94 MGA55	common name	scientific name	nos
Bibblewindi Creek	8 Oct	761823	6598878	nil		
Falcon Road Site 1	8 Oct	763212	6600346	Grey-crowned Bab-bler	*Pomatostomus temporalis*	2+
Kurrajong Road	8 Oct	758576	6597903	Turquoise Parrot Speckled Warbler Grey-crowned Babbler	*Neophema pulchella* *Chthonicola sagittata* *Pomatostomus temporalis*	1 2+ 2+
Warrumbungle Road	8 Oct	764316	6603400	Grey-crowned Babbler	*Pomatostomus temporalis*	2+
X Line Road Site 1	8 Oct	759778	6605951	Grey-crowned Babbler	*Pomatostomus temporalis*	2+
X Line Road Site 2	9 Oct	750439	6607616	Rainbow Bee-eater Hooded Robin	*Merops ornatus* *Melanodryas cucullata*	2+ 2
Bohena Creek Road	9 Oct	750944	6608714	Speckled Warbler Grey-crowned Babbler Varied Sittella	*Merops ornatus Climacteris picumnus* *Stagonopleura guttata*	2+ 1 1
Monument Road	10 Oct	765931	6610091	Turquoise Parrot Rainbow Bee-eater Speckled Warbler Grey-crowned Babbler Varied Sittella	*Neophema pulchella* *Merops ornatus* *Chthonicola sagittata* *Pomatostomus temporalis* *Daphoenositta chrysoptera*	1 2+ 2+ 2+ 3+
Scratch Road	10 Oct	773116	6608603	Speckled Warbler	*Chthonicola sagittata*	2+
Yellow Spring Trail	10 Oct	764265	6608825	Grey-crowned Babbler Varied Sittella	*Pomatostomus temporalis* *Daphoenositta chrysoptera*	2+ 3+
Rockdale property	10 Oct	763914	6614571	nil		
Bohena Creek Site 1	11 Oct	753997	6615333	Turquoise Parrot Rainbow Bee-eater	*Neophema pulchella* *Merops ornatus*	1 2+
Bohena Creek Site 2	11 Oct	752216	6610947	Rainbow Bee-eater Speckled Warbler	*Merops ornatus Chthonicola sagittata*	2+ 2+
Garlands Dam	11 Oct	746141	6599960	Little Lorikeet Turquoise Parrot Rainbow Bee-eater Speckled Warbler Grey-crowned Babbler	*Glossopsitta pusilla* *Neophema pulchella* *Merops ornatus* *Chthonicola sagittata* *Pomatostomus temporalis*	2 1 2+ 2+ 2+
Delwood Road Site 1	12 Oct	748322	6590385	Speckled Warbler Grey-crowned Babbler	*Chthonicola sagittata* *Pomatostomus temporalis*	2+ 2+
Delwood Road Site 2	12 Oct	752061	6589534	Rainbow Bee-eater Speckled Warbler Grey-crowned Babbler	*Merops ornatus* *Chthonicola sagittata* *Pomatostomus temporalis*	2+ 2+
Delwood Dam	12 Oct	757367	6591993	nil		
Falcon Road Site 2	12 Oct	762085	6599123	Speckled Warbler Grey-crowned Babbler	*Chthonicola sagittata* *Pomatostomus temporalis*	2+ 2+
Oil Well Road	12 Oct	753214	6604971	Speckled Warbler Grey-crowned Babbler	*Chthonicola sagittata* *Pomatostomus temporalis*	2+ 2+
Yellow Spring Dam	12 Oct	764000	6606000	nil		
Pilliga No 2 Rest Area	13 Oct	753187	6623634	Little Eagle Brown Treecreeper	*Hieraaetus morphnoides* *Climacteris picumnus*	1 1
Total 21 sites						

* Recorded outside Project Area

Appendix 5 Results of harp trapping for microchiropteran bats by location in the Project Area, 10-14 October 2011

trap no.	location	date	Eastin GDA94 MGA55	Northing GDA94 MGA55	scientific name	sex/ nos#
1	Beehive Road, on logging track off road	10 Oct	755177	6599999	*Chalinolobus morio*	
1	Beehive Road, on logging track off road	10 Oct	755177	6599999	***Nyctophilus corbeni***	1m
1	Beehive Road, on logging track off road	10 Oct	755177	6599999	*Vespadelus vulturnus*	1f
1	Beehive Road, on logging track off road	11 Oct	755177	6599999	*Vespadelus vulturnus*	1f
2	Falnoo Trail 1, on logging track next to creek	10 Oct	757775	6601364	***Nyctophilus corbeni***	1f
2	Falnoo Trail 1, on logging track next to creek	10 Oct	757775	6601364	*Vespadelus vulturnus*	3f
2	Falnoo Trail 1, on logging track next to creek	11 Oct	757775	6601364	*Vespadelus vulturnus*	1f
3	Nooboo Trail, in dry creek bed	10 Oct	760701	6601258	*Nyctophilus gouldi*	1f
3	Nooboo Trail, in dry creek bed	10 Oct	760701	6601258	*Vespadelus vulturnus*	4f
4	Monument Road 1, on track	10 Oct	769914	6609364	*Chalinolobus gouldii*	2f
4	Monument Road 1, on track	10 Oct	769914	6609364	*Chalinolobus morio*	3m,3f
4	Monument Road 1, on track	10 Oct	769914	6609364	***Nyctophilus corbeni***	2m,2f
4	Monument Road 1, on track	10 Oct	769914	6609364	*Vespadelus vulturnus*	1m,9f
4	Monument Road 1, on track	11 Oct	769914	6609364	*Chalinolobus morio*	3f
5	Monument Road 2, on track	10 Oct	770191	6609373	***Nyctophilus corbeni***	1f
5	Monument Road 2, on track	10 Oct	770191	6609373	*Nyctophilus gouldi*	1f
5	Monument Road 2, on track	10 Oct	770191	6609373	*Nyctophilus gouldi*	1f
5	Monument Road 2, on track	11 Oct	770191	6609373	*Nyctophilus geoffroyi*	1f
5	Monument Road 2, on track	11 Oct	770191	6609373	*Chalinolobus morio*	1f
5	Monument Road 2, on track	11 Oct	770191	6609373	*Chalinolobus morio*	1f
5	Monument Road 2, on track	11 Oct	770191	6609373	*Chalinolobus morio*	1f
6	Yellow Spring Creek Dam 1, in dry creek bed	10 Oct	764248	6609373	*Chalinolobus morio*	1f
7	Blue Nobby Road, on creek bank	11 Oct	748548	6609373	*Chalinolobus morio*	1f
8	Carbee Trail, on track	11 Oct	749984	6609373	*Chalinolobus morio*	1f
8	Carbee Trail, on track	13 Oct	749984	6609373	*Chalinolobus morio*	1f
9	Falcon Trail 1, on track	11 Oct	763169	6609373	*Chalinolobus morio*	1f
10	Falconl/Warrumbungle Trails junction, on track (trap 1)	11 Oct	764265	6609373	*Chalinolobus morio*	1f
10	Falconl/Warrumbungle Trails junction, on track (trap 1)	11 Oct	764265	6609373	*Chalinolobus morio*	1f
10	Falcon/Warrumbungle Trails junction, on track (trap 1)	11 Oct	764265	6609373	*Chalinolobus morio*	1f
10	Falcon/Warrumbungle Trails junction, on track (trap 2)	11 Oct	764265	6603300	*nil*	nil
11	Oil Well Road 1, on road	11 Oct	750294	6605003	*Vespadelus vulturnus*	1f
11	Oil Well Road 1, on road	13 Oct	750294	6605003	***Nyctophilus corbeni***	1m
11	Oil Well Road 1, on road	13 Oct	750294	6605003	*Scotorepens greyii*	1f
11	Oil Well Road 1, on road	13 Oct	750294	6605003	*Vespadelus vulturnus*	7f
12	Panton's Lookout 1, against cliff-face	11 Oct	767620	6601147	*Rhinolophus megaphyllus*	1m

threatened species bolded * records outside the Project Area # nos refer to captures (may include some retraps)

Continued: Appendix 5 Results of harp trapping for microchiropteran bats by location in the Project Area, 10-14 October 2011

12	Panton's Lookout 1, against cliff-face	11 Oct	767620	6601147	*Vespadelus vulturnus*	1m
12	Panton's Lookout 1, against cliff-face	12 Oct	767620	6601147	*Nyctophilus geoffroyi*	1f
12	Panton's Lookout 1, against cliff-face	12 Oct	767620	6601147	*Nyctophilus gouldi*	1m
13	Panton's Lookout 2, on track adja-cent to cliff	11 Oct	767669	6601184	*Chalinolobus gouldii*	1f
13	Panton's Lookout 2, on track adja-cent to cliff	11 Oct	767669	6601184	*Nyctophilus gouldi*	1m
13	Panton's Lookout 2, on track adja-cent to cliff	11 Oct	767669	6601184	*Vespadelus vulturnus*	2m,1f
13	Panton's Lookout 2, on track adja-cent to cliff	12 Oct	767669	6601184	*Vespadelus vulturnus*	2m,1f
14	Cowallah Creek Dam, between two dam pools	12 Oct	751639	6606922	*Nyctophilus geoffroyi*	1f
15	Falnoo Trail 2, on track (trap 1)	12 Oct	761530	6599824	*Chalinolobus gouldii*	1m
15	Falnoo Trail 2, on track (trap 1)	12 Oct	761530	6599824	*Scotorepens balstoni*	1m
15	Falnoo Trail 2, on track (trap 1)	12 Oct	761530	6599824	*Vespadelus vulturnus*	4f
15	Falnoo Trail 2, on track (trap 2)	13 Oct	761530	6599824	*Chalinolobus gouldii*	2f
15	Falnoo Trail 2, on track (trap 2)	13 Oct	761530	6599824	*Vespadelus vulturnus*	2m,4f
16	Yellow Spring Creek Dam 2, at dam	12 Oct	764171	6606164	*Vespadelus vulturnus*	1f
17	Oil Well Road 2, at pool in creek	13 Oct	750278	6605029	*Nyctophilus gouldi*	1m
17	Oil Well Road 2, at pool in creek	14 Oct	750278	6605029	*Nyctophilus gouldi*	1f
17	Oil Well Road 2, at pool in creek	14 Oct	750278	6605029	*Scotorepens balstoni*	1f
17	Oil Well Road 2, at pool in creek	14 Oct	750278	6605029	*Scotorepens greyii*	1f
18	Scratch Road 1, on road	13 Oct	773225	6609144	*Chalinolobus gouldii**	2f*
18	Scratch Road 1, on road	13 Oct	773225	6609144	*Chalinolobus morio**	1m*
18	Scratch Road 1, on road	13 Oct	773225	6609144	***Chalinolobus picatus****	2m*
18	Scratch Road 1, on road	13 Oct	773225	6609144	*Nyctophilus geoffroyi**	1f*
18	Scratch Road 1, on road	13 Oct	773225	6609144	*Nyctophilus gouldi**	1m*
18	Scratch Road 1, on road	13 Oct	773225	6609144	*Scotorepens balstoni**	1,2f*
18	Scratch Road 1, on road	13 Oct	773225	6609144	*Scotorepens greyii**	1m,2f*
19	Scratch Road 1, on road	13 Oct	773225	6609144	*Vespadelus vulturnus**	9m,13f*
19	Scratch Road 2, on road	13 Oct	772967	6607712	*Chalinolobus gouldii**	10f*
19	Scratch Road 2, on road	13 Oct	772967	6607712	***Nyctophilus corbeni****	1f*
19	Scratch Road 2, on road	13 Oct	772967	6607712	*Nyctophilus geoffroyi**	1m,1f*
19	Scratch Road 2, on road	13 Oct	772967	6607712	*Scotorepens balstoni**	2m,10f*
19	Scratch Road 2, on road	13 Oct	772967	6607712	*Scotorepens greyii**	1m,3f*
19	Scratch Road 2, on road	13 Oct	772967	6607712	*Vespadelus vulturnus**	4m,4f*
20	Bohena Creek Road, on road	14 Oct	753354	6614194	*Chalinolobus morio*	2m
20	Bohena Creek Road, on road	14 Oct	753354	6614194	***Nyctophilus corbeni***	1m
20	Bohena Creek Road, on road	14 Oct	753354	6614194	*Nyctophilus geoffroyi*	1m,3f
20	Bohena Creek Road, on road	14 Oct	753354	6614194	*Nyctophilus gouldi*	2m,4f
20	Bohena Creek Road, on road	14 Oct	753354	6614194	*Scotorepens balstoni*	4m
20	Bohena Creek Road, on road	14 Oct	753354	6614194	*Vespadelus vulturnus*	
21	McCann's Road, on road	14 Oct	755525	6624943	*Chalinolobus morio*	1f
21	McCann's Road, on road	14 Oct	755525	6624943	*Nyctophilus geoffroyi*	1m,4f
21	McCann's Road, on road	14 Oct	755525	6624943	*Nyctophilus gouldi*	2m,2f
21	McCann's Road, on road	14 Oct	755525	6624943	*Scotorepens balstoni*	1m
21	McCann's Road, on road	14 Oct	755525	6624943	*Scotorepens greyii*	1m,1f
21	McCann's Road, on road	14 Oct	755525	6624943	*Vespadelus vulturnus*	4m,10f

threatened species bolded * records outside the Project Area # nos refer to captures (may include some retraps)

Appendix 6 Results of harp trapping for microchiropteran bats by species records in the Project Area, 10-14 October 2011

common name	scientific name	trap no.	location	total nos#	nos males#	nos females#	no. nights
Eastern Horseshoe Bat	*Rhinolophus megaphyllus*	12	Panton's Lookout 1	1	1		2
Gould's Wattled Bat	*Chalinolobus gouldii*	4	Monument Road 1	2		2	2
Gould's Wattled Bat	*Chalinolobus gouldii*	13	Panton's Lookout 2	1		1	2
Gould's Wattled Bat	*Chalinolobus gouldii*	15	Falnoo Trail 2 (traps t1,t2)	3	1	2	2 (t2),
Gould's Wattled Bat	*Chalinolobus gouldii*	18	Scratch Road 1	2*		2*	(2hrs, t1)
Gould's Wattled Bat	*Chalinolobus gouldii*	19	Scratch Road 2	10*		10*	1
Gould's Wattled Bat	*Chalinolobus gouldii*	20	Bohena Creek Road	6	2	4	1
Chocolate Wattled Bat	*Chalinolobus morio*	1	Beehive Road	1		1	1
Chocolate Wattled Bat	*Chalinolobus morio*	4	Monument Road 1	6	3	3	2
Chocolate Wattled Bat	*Chalinolobus morio*	5	Monument Road 2	2		2	2
Chocolate Wattled Bat	*Chalinolobus morio*	18	Scratch Road 1	1*	1*		2
Chocolate Wattled Bat	*Chalinolobus morio*	20	Bohena Creek Road	2	2		1
Chocolate Wattled Bat	*Chalinolobus morio*	21	McCann's Road	1		1	1
Little Pied Bat	*Chalinolobus picatus*	18	Scratch Road 1	2	2		1
South-eastern Long-eared Bat	*Nyctophilus corbeni*	1	Beehive Road	1	1		1
South-eastern Long-eared Bat	*Nyctophilus corbeni*	2	Falnoo Trail 1	1		1	2
South-eastern Long-eared Bat	*Nyctophilus corbeni*	4	Monument Road 1	7	2	5	2
South-eastern Long-eared Bat	*Nyctophilus corbeni*	5	Monument Road 2	8		8	2
South-eastern Long-eared Bat	*Nyctophilus corbeni*	11	Oil Well Road 1	1	1		2
South-eastern Long-eared Bat	*Nyctophilus corbeni*	19	Scratch Road 2	1*		1*	2
South-eastern Long-eared Bat	*Nyctophilus corbeni*	20	Bohena Creek Road	1	1		1
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	5	Monument Road 2	1		1	1
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	10	Falcon/Warrum bungle Trails (trap 1)	1		1	2
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	12	Panton's Lookout 1	1		1	(2hrs)
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	14	Cowallah Dam	1		1	2
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	18	Scratch Road 1	1*		1*	1
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	19	Scratch Road 2	2*	1	1*	1
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	20	Bohena Creek Road	4	1	3	1
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	21	McCann's Road	5	1	4	1
Gould's Long-eared Bat	*Nyctophilus gouldi*	3	Nooboo Trail	1		1	1
Gould's Long-eared Bat	*Nyctophilus gouldi*	5	Monument Road 2	6	3	3	1
Gould's Long-eared Bat	*Nyctophilus gouldi*	12	Panton's Lookout 1	1	1		2
Gould's Long-eared Bat	*Nyctophilus gouldi*	13	Panton's Lookout 2	1	1		2
Gould's Long-eared Bat	*Nyctophilus gouldi*	17	Oil Well Road 2	2	1	1	2
Gould's Long-eared Bat	*Nyctophilus gouldi*	18	Scratch Road 1	1*	1*		2

Continued: Appendix 6 Results of harp trapping for microchiropteran bats by species records in the Project Area, 10-14 October 2011

Gould's Long-eared Bat	*Nyctophilus gouldi*	21	McCann's Road	4	2	2	1
Inland Broad-nosed Bat	*Scotorepens balstoni*	8	Carbee Trail	2	1	1	1
Inland Broad-nosed Bat	*Scotorepens balstoni*	10	Falcon/Warrum bungle Trails (trap 1)	1		1	2
Inland Broad-nosed Bat	*Scotorepens balstoni*		Falnoo Trail 2 (trap 1)	1	1		(2hrs)
Inland Broad-nosed Bat	*Scotorepens balstoni*	17	Oil Well Road 2	1		1	2
Inland Broad-nosed Bat	*Scotorepens balstoni*		Scratch Road 1	3*	1*	2*	1
Inland Broad-nosed Bat	*Scotorepens balstoni*		Scratch Road 2	12*	2*	10*	1
Inland Broad-nosed Bat	*Scotorepens balstoni*		Bohena Creek Road	4	4		1
Inland Broad-nosed Bat	*Scotorepens balstoni*	21	McCann's Road	1	1		1
Little Broad-nosed Bat	*Scotorepens greyii*	11	Oil Well Road 1	1		1	2
Little Broad-nosed Bat	*Scotorepens greyii*	17	Oil Well Road 2	1		1	2
Little Broad-nosed Bat	*Scotorepens greyii*		Scratch Road 1	3*	1*	2*	1
Little Broad-nosed Bat	*Scotorepens greyii*		Scratch Road 2	4*	1*	3*	1
Little Broad-nosed Bat	*Scotorepens greyii*	21	McCann's Road	2	1	1	1
Little Forest Bat	*Vespadelus vulturnus*	1	Beehive Road	2		2	2
Little Forest Bat	*Vespadelus vulturnus*	2	Falnoo Trail 1	3		3	2
Little Forest Bat	*Vespadelus vulturnus*	3	Nooboo Trail	4		4	1
Little Forest Bat	*Vespadelus vulturnus*	4	Monument Road 1	10	1	9	2
Little Forest Bat	*Vespadelus vulturnus*	5	Monument Road 2	5	1	4	2
Little Forest Bat	*Vespadelus vulturnus*	6	Yellow Spring Creek Dam 1	1		1	1
Little Forest Bat	*Vespadelus vulturnus*	7	Blue Nobby Road	1		1	1
Little Forest Bat	*Vespadelus vulturnus*	9	Falcon Trail 1	1		1	1
Little Forest Bat	*Vespadelus vulturnus*	10	Falcon/Warrum bungle Trails (trap 1)	1	1		(2hrs)
Little Forest Bat	*Vespadelus vulturnus*	11	Oil Well Road 1	8		8	2
Little Forest Bat	*Vespadelus vulturnus*	12	Panton's Lookout 1	1	1		2
Little Forest Bat	*Vespadelus vulturnus*	13	Panton's Lookout 2	6	4	2	2
Little Forest Bat	*Vespadelus vulturnus*	15	Falnoo Trail 2 (traps t1,t2)	10	2	8	2 (t2), (2hrs, t1)
Little Forest Bat	*Vespadelus vulturnus*	16	Yellow Spring Creek Dam 2	1		1	1
Little Forest Bat	*Vespadelus vulturnus*	18	Scratch Road 1	22*	9*	13*	1
Little Forest Bat	*Vespadelus vulturnus*	19	Scratch Road 2	8*	4*	4*	1
Little Forest Bat	*Vespadelus vulturnus*	20	Bohena Creek Road	14	2	12	1
Little Forest Bat	*Vespadelus vulturnus*	21	McCann's Road	14	4	10	1

threatened species bolded * records outside the Project Area # nos refer to captures (may include some retraps)

Appendix 7 Results of analysis of microchiropteran bat calls recorded by Anabat detector by location in the Project Area, 8-13 October 2011 – results for threatened species only

site no.	location	date	Easting GDA94 MGA55	Northing GDA94 MGA55	scientific name of threatened species detected	method#
1	Cowallah Creek Dam	8 Oct	751774	6606831	*Saccolaimus flaviventris*	passive
2	Beehive Road	9 Oct	755190	6600131	*Saccolaimus flaviventris*	passive
3	Beehive Road	9 Oct	762308	6605692		passive
4	Beehive Road	9 Oct	758361	6604144		passive
5	Warrumbungle Trail	9 Oct	763290	6604300		passive
6	Warrumbungle Trail	9 Oct	764003	6603654		passive
7	Warrumbungle Trail	9 Oct	764372	6603444	*Saccolaimus flaviventris*	passive
8	B and W Road	9 Oct	760469	6604834	*Saccolaimus flaviventris*	passive
9	Falcon Trail	9 Oct	764209	6603157		passive
10	Garlands Dam	10 Oct	746029	6599756		passive
11	Garlands Road	10 Oct	746703	6600074	*Saccolaimus flaviventris*	passive
12	Bohena Creek	10 Oct	745933	6600434		passive
13	Nickel Road	10 Oct	749872	6603574	*Saccolaimus flaviventris*	passive
14	Creaghs Road	10 Oct	745846	6599418		passive
15	Oil Well Road	10 Oct	750278	6605029	*Saccolaimus flaviventris*	passive
16	Warrumbungle Trail	11 Oct	764265	6603300	*Saccolaimus flaviventris*	passive
17	Self Camp Road	12 Oct	753222	6605060	*Saccolaimus flaviventris*	passive
18	Beehive Road	12 Oct	765394	6605739	*Saccolaimus flaviventris*	passive
19	B and W Road	12 Oct	760491	6605104	*Saccolaimus flaviventris*	passive
20	Yellow Spring Creek Dam	12 Oct	764174	6606160	*Saccolaimus flaviventris*	passive
21	X-Line Road	12 Oct	757271	6606461		passive
1	Cowallah Creek Dam	13 Oct	751774	6606831	*Saccolaimus flaviventris*	passive
1	Cowallah Creek Dam	13 Oct	751774	6606831	*Chalinolobus picatus*	passive
22	Nickel Road	8 Oct	749850	6605074		hand-held
23	Oil Well Road	8 Oct	750453	6605000		hand-held
24	X-Line Road	8 Oct	750660	6607516		hand-held
25	X-Line Road	8 Oct	751983	6607330	*Saccolaimus flaviventris*	hand-held
26	Warrumbungle Trail	9 Oct	764550	6603345	*Saccolaimus flaviventris*	hand-held
27	X-Line Road	9 Oct	758724	6606257		hand-held
16	Warrumbungle Trail	11 Oct	764265	6603300	*Saccolaimus flaviventris*	hand-held

Contiued: Appendix 7 Results of analysis of microchiropteran bat calls recorded by Anabat detector by location in the Project Area, 8-13 October 2011 – results for threatened species only

28	Panton's Lookout	12 Oct	767611	6601387	*Saccolaimus flaviventris*	hand-held
29	Yellow Spring Creek Dam	12 Oct	767611	6601387		hand-held
30	Apple Road	13 Oct	751897	6616448	*Saccolaimus flaviventris*	hand-held
31	Apple Road	13 Oct	754302	6615897		hand-held
32	Plumb Road	13 Oct	752946	6618124		hand-held
33	Maud's Road	13 Oct	755110	6618442		hand-held
34	Brandon's Road	13 Oct	753022	6613641		hand-held
35	Bohena Creek Road	13 Oct	752145	6611753		hand-held
36	Bohena Creek Road	13 Oct	751615	6609711		hand-held
37	Bohena Creek Road	13 Oct	750092	6607820		hand-held

passsive – detector set and unattended at a site, hand-held – detector used in conjunction with PDA in real time

Three additional non-threatened species detected at a number of sites but not trapped in harp traps (Table 8) comprised:

White-striped Free-tailed Bat *Tadarida australis*

Eastern Free-tailed Bat *Mormopterus ridei*

Southern Free-tailed Bat *Mormopterus sp.*4 (long penis)

Appendix 8 Results of Elliott trapping for small mammals, targeting the Pilliga Mouse, in the Project Area, 10-13 October 2011

site	location	date	Easting GDA94 MGA55	Northing GDA94 MGA55	scientific name	nos/ sex	notes
A (1)	X-Line Road	10 Oct	748237	6608034	***Pseudomys pil-ligaensis***	1f	trap A6, lactating
A (1)	X-Line Road	11 Oct	748238	6608050	***Pseudomys pil-ligaensis***	1f	trap A5, lactating, prob. retrap
A (1)	X-Line Road	12-13 Oct	748238	6608050	nil		
B (2)	X-Line Road	10 Oct	752363	6607588	***Pseudomys pil-ligaensis***	1subf	trap B49
B (2)	X-Line Road	11 Oct	752258	6607389	***Pseudomys pil-ligaensis***	1f	trap B6, lactating
B (2)	X-Line Road	11 Oct	752337	6607488	***Pseudomys pil-ligaensis***	1f	trap B38
B (2)	X-Line Road	11 Oct	752360	6607578	***Pseudomys pil-ligaensis***	1m	trap B48
B (2)	X-Line Road	12 Oct	752337	6607488	***Pseudomys pil-ligaensis***	1m	trap B38
B (2)	X-Line Road	12 Oct	752357	6607556	***Pseudomys pil-ligaensis***	1m	trap B45
B (2)	X-Line Road	13 Oct	752306	6607562	***Pseudomys pil-ligaensis***	1m	trap B15
C (3)	Monument Road	10 Oct	765339	6609912	nil		
C (3)	Monument Road	11 Oct	765339	6609912	***Pseudomys pil-ligaensis***	1subf	trap C5
C (3)	Monument Road	11 Oct	765271	6609916	***Pseudomys pil-ligaensis***	1	trap C31
C (3)	Monument Road	11 Oct	765284	6609753	***Pseudomys pil-ligaensis***	1subf	trap C42

Looking west from Panton's Lookout. Photo David Milledge

C (3)	Monument Road	12 Oct	765344	6609891	***Pseudomys pil-ligaensis***	1subf	trap C6, prob. retrap
C (3)	Monument Road	12 Oct	765356	6609865	***Pseudomys pil-ligaensis***	1f	trap C8, lactating
C (3)	Monument Road	13 Oct	765353	6609844	***Pseudomys pil-ligaensis***	1f	trap C9, lactating, prob. retrap
D (4)	Yellow Spring Road	11-13 Oct	764263	6608839	nil		
E (5)	Warrumbungle Road	11 Oct	762358	6605587	*Mus musculus*	1	trap E5
E (5)	Warrumbungle Road	12 Oct	762358	6605587	nil		
E (5)	Warrumbungle Road	13 Oct	762324	6605535	*Amphibolurus nobbii*	1	trap E28
F (6)	Falcon Road 1	11 Oct	763658	6602223	***Pseudomys pil-ligaensis***	1m	trap F36
F (6)	Falcon Road 1	12 Oct	763692	6602230	***Pseudomys pil-ligaensis***	1m	trap F32
F (6)	Falcon Road 1	12 Oct	763452	6602274	*Ctenotus robustus*	1	trap F24
F (6)	Falcon Road 1	13 Oct	763658	6602223	nil		
I (7)	Mt Pleasant Road	11 Oct	757437	6602451	nil		
I (7)	Mt Pleasant Road	12 Oct	757437	6602451	***Pseudomys pil-ligaensis***	1f	trap I36
I (7)	Mt Pleasant Road	13 Oct	757437	6602451	***Pseudomys pil-ligaensis***	1f	trap I36, prob. retrap
J (8)	Sparrow Road	10-13 Oct	748250	6613871	nil		
K (9)	Brandon's Road	10 Oct	752135	6613704	***Pseudomys pil-ligaensis***	1m	trap K9
K (9)	Brandon's Road	10 Oct	752127	6613643	***Pseudomys pil-ligaensis***	1subf	trap K15
K (9)	Brandon's Road	10 Oct	752105	6613586	***Pseudomys pil-ligaensis***	1 subf	trap K21, died (coll.)
K (9)	Brandon's Road	10 Oct	752084	6613550	***Pseudomys pil-ligaensis***	1m	trap K25
K (9)	Brandon's Road	11 Oct	752135	6613704	***Pseudomys pil-ligaensis***	1m	trap K9, prob. retrap
K (9)	Brandon's Road	11 Oct	752128	6613657	***Pseudomys pil-ligaensis***	1m	trap K14
K (9)	Brandon's Road	12 Oct	752127	6613643	***Pseudomys pil-ligaensis***	1m	trap K15, prob. retrap
K (9)	Brandon's Road	13 Oct	752134	6613703	*Amphibolurus nobbii*	1	trap K8
K (9)	Brandon's Road	13 Oct	752135	6613704	***Pseudomys pil-ligaensis***	1m	trap K9, prob. retrap
K (9)	Brandon's Road	13 Oct	752131	6613679	***Pseudomys pil-ligaensis***	2subm	trap K11
L (10)	Falcon Road 2	11 Oct	762000	6599237	nil		
L (10)	Falcon Road 2	12 Oct	762000	6599238	***Pseudomys pil-ligaensis***	1m	trap L41
L (10)	Falcon Road 2	13 Oct	762000	6599237	***Pseudomys pil-ligaensis***	1	trap L36

site	location*	upper storey	mid storey	lower storey	ground layer	nos other common species
A (1)	**X-Line Road (1)**	height 5-15m foliage cover 20% dominants *Corymbia trachyphloia Eucalyptus chloroclada*	height 1-3m foliage cover 20% dominants *Callitris endlicheri* *Cassinia arcuata* *Conospermum taxifolium*	height 0-1m foliage cover 50% dominants *Calytrix tetragona* *Grevillea floribunda* *Brachyloma daphnoides*	bare ground 40% leaf litter 30% foliage cover 30% dominants nil	18
B (2)	**X-Line Road (7)**	height 2-15m foliage cover 20% dominants *Angophora floribunda* *Eucalyptus chloroclada*	nil	height 0-1m foliage cover 50% dominants *Boronia glabra* *Dodonaea peduncularis* *Bossiaea rhombifolia*	bare ground 40% leaf litter 30% foliage cover 30% dominants nil	16
C (3)	**Monument Road (5)**	height 4-12m foliage cover 15% dominants *Eucalyptus fibrosa* *Corymbia trachyphloia* *Eucalyptus chloroclada*	height 0.2-2m foliage cover 50% dominants *Cassinia arcuata* *Brachyloma daphnoides* *Leptospermum parviflorum*	height 0-0.2m foliage cover 60% dominants *Schoenus ericetorum* *Hibbertia obtusifolia* *Cymbopogon* sp	bare ground 30% leaf litter 50% foliage cover 20% dominants nil	24
D (4)	Yellow Spring Road	height 2-10m foliage cover 10% *dominants* *Corymbia trachyphloia* *Eucalyptus fibrosa*	height 1-3m foliage cover 10% dominants *Eucalyptus fibrosa* *Corymbia trachyphloia*	height 0.2-1m foliage cover 60% dominants *Acacia triptera* *Calytrix tetragona* *Boronia bipinnate*	bare ground 50% leaf litter 35% foliage cover 15% dominants *Schoenus ericetorum* *Boronia bipinnate* *Aotus mollis*	1
E (5)	Warrumbungle Road	height 5-12m foliage cover 20% dominants *Eucalyptus fibrosa* *Corymbia trachyphloia*	height 1-4m foliage cover 20% dominants *Acacia triptera* *Allocasuarina dimunita* *Callitris glaucophylla*	height 0-1m foliage cover 50% dominants *Calytrix tetragona* *Pultenaea foliolosa* *Leotospermum* sp.	bare ground 5% leaf litter 65% foliage cover 30% dominants *Goodenia hederacea* *Pomax ubellata* *Dampiera adpressa*	21
F (6)	Falcon Road 1 (2)	height 3-10m foliage cover 20% dominants *Corymbia trachyphloia* *Eucalyptus fibrosa*	height 2-3m foliage cover 10% dominants *Leptospermum parviflorum* *Allocasuarina dimunita* *Brachyloma daphnoides*	height 0.2-2m foliage cover 40% dominants *Calytrix tetragona* *Platysace ericoides*	bare ground 10% leaf litter 65% foliage cover 25% dominants *Platysace ericoides* *Pomax ubellata* *Aristida* sp.	23
I (7)	Mt Pleasant Road (1)	height 7-15m foliage cover 5% dominants *Corymbia trachyphloia* *Eucalyptus dwyeri*	height 1-3m foliage cover 10% dominants *Allocasuarina dimunita* *Persoonia sericea* *Acacia gladiformis*	height 0-1m foliage cover 50% dominants *Calytrix tetragona* *Bossiaea rhombifolia* *Boronia glabra* *Dodonaea peduncularis*	bare ground 25% leaf litter 70% foliage cover 5% dominants *Pomax ubellata*	16
J (8)	Sparrow Road	height 4-12m foliage cover 10% dominants *Eucalyptus crebra*	height 0.5-2m foliage cover 60% dominants *Melaleuca uncinata* *Calytrix tetragona* *Westringia cheellii*	nil	bare ground 40% leaf litter 50% foliage cover 10% dominants nil	23

Appendix 9 Vegetation characteristics of sites trapped for small mammals in the Project Area, 10-13 October 2011

K (9)	**Brandon's Road (7)**	height 12m foliage cover 40% dominants *Eucalyptus chloroclada*	height 0.5-2m foliage cover 10% dominants *Philotheca salsolifolia* *Aotus mollis*	height 0-0.5m foliage cover 30% dominants nil	bare ground 10% leaf litter 60% foliage cover 30% dominants nil	11
L (10)	**Falcon Road 2 (2)**	height 5-15m foliage cover 40% dominants *Eucalyptus rossii* *Corymbia trachyphloia* *Eucalyptus fibrosa*	height 2-5m foliage cover 10% dominants *Acacia pilligaensis*	height 0-2m foliage cover 40% dominants *Bossiaea rhombifolia* *Cassinia arcuata* *Boronia glabra*	bare ground 10% leaf litter 60% foliage cover 30% dominants nil	20

sites where the Pilliga Mouse was trapped are bolded
* nos of Pilliga Mice individuals captured in brackets

Botanists assessing ecosystems against guidelines, Photo Hugh Nicholson

Appendix 10 Results of Koala faecal scat search in the Project Area, 9-14 October 2011

location	date	Easting GDA94 MGA55	Northing GDA94 MGA55	notes
Falcon Trail	9 Oct	763217	6600367	2 scats at base of senescent Red Gum (probably *Eucalyptus blakelyi*)

Appendix 11 Results of camera trapping for medium and large-sized terrestrial mammals at sites where species were recorded in the Project Area, 9-14 October 2011

site	location	date	Easting-GDA94 MGA55	Northing GDA94 MGA55	common name	scientific name	nos
2	Bohena Creek Road	12 Oct	754320	6620147	Eastern Grey Kangaroo	*Macropus giganteus*	3
2	Bohena Creek Road	12 Oct	754320	6620147	Swamp Wallaby	*Wallabia bicolor*	1
2	Bohena Creek Road	12 Oct	754320	6620147	Red Fox	*Vulpes vulpes*	1
10	waterhole on Bohena Creek	12 Oct	753791	6614827	Red-necked Wallaby	*Macropus rufogriseus*	1
10	waterhole on Bohena Creek	12 Oct	753791	6614827	Feral Goat	*Capra hircus*	2
12	Dog Proof Fence Road	12 Oct	750603	6622369	Eastern Grey Kangaroo	*Macropus giganteus*	3
12	Dog Proof Fence Road	12 Oct	750603	6622369	Red Fox	*Vulpes vulpes*	1
13	Dog Proof Fence Road	12 Oct	750165	6623286	Eastern Grey Kangaroo	*Macropus giganteus*	1
14	Dog Proof Fence Road	12 Oct	746566	6625653	Eastern Grey Kangaroo	*Macropus giganteus*	2
14	Dog Proof Fence Road	12 Oct	746566	6625653	**Black-striped Wallaby**	***Macropus dorsalis***	1
14	Dog Proof Fence Road	12 Oct	746566	6625653	Common Wallaroo	*Macropus robustus*	1
14	Dog Proof Fence Road	12 Oct	746566	6625653	Red-necked Wallaby	*Macropus rufogriseus*	1
14	Dog Proof Fence Road	12 Oct	746566	6625653	Swamp Wallaby	*Wallabia bicolor*	1
14	Dog Proof Fence Road	12 Oct	746566	6625653	Feral Cat	*Felis catus*	1
14	Dog Proof Fence Road	12 Oct	746566	6625653	European Brown Hare	*Lepus europaeus*	1
15	Dog Proof Fence Road	12 Oct	747367	6625496	Eastern Grey Kangaroo	*Macropus giganteus*	4
15	Dog Proof Fence Road	12 Oct	747367	6625496	Common Wallaroo	*Macropus robustus*	1
15	Dog Proof Fence Road	12 Oct	747367	6625496	Swamp Wallaby	*Wallabia bicolor*	1
15	Dog Proof Fence Road	12 Oct	747367	6625496	Red Fox	*Vulpes vulpes*	1

threatened species bolded

Appendix 12 Records of threatened and migratory species obtained in the Project Area, 8-14 October 2011 species and numbers of individuals

common name	scientific name	threatened status	date	Easting GDA94 MGA55	Northing GDA94 MGA55	nos indiv-iduals
Pale-headed Snake	*Hoplocephalus bitorquatus*	vulnerable *(TSC Act)*	14 Oct	762300	6605535	1
Little Eagle	*Hieraaetus morphnoides*	vulnerable *(TSC Act)*	11 Oct	761778	6623634	1
Little Eagle	*Hieraaetus morphnoides*	vulnerable *(TSC Act)*	13 Oct	753187	6623634	1
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable *(TSC Act)*	9 Oct	750343	6608218	2
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable *(TSC Act)*	11 Oct	764079	6605577	12
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable *(TSC Act)*	11 Oct	750910	6608949	2
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable *(TSC Act)*	12 Oct	767617	6601291	10
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable *(TSC Act)*	13 Oct	753343	6607558	2+
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable (TSC Act)	13 Oct	750782	6608683	30+
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable (TSC Act)	13 Oct	750875	6608857	5+
Glossy Black-cockatoo	*Calyptorhynchus lathami*	vulnerable *(TSC Act)*	14 Oct	753354	6614194	4
Little Lorikeet	*Glossopsitta pusilla*	vulnerable *(TSC Act)*	11 Oct	746141	6599960	2
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	8 Oct	751169	6609100	3
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	8 Oct	751770	6606818	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	8 Oct	758576	6597903	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	8 Oct	750476	6607617	2
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	8 Oct	750459	6607641	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	9 Oct	765339	6609912	2
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	10 Oct	751250	6609133	2
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	10 Oct	765931	6610091	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	11 Oct	753997	6615333	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	11 Oct	743943	6592243	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	11 Oct	746141	6599960	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	11 Oct	766932	6602264	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	12 Oct	752121	6610828	2
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	12 Oct	753638	6614940	2
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	14 Oct	762300	6605535	1
Turquoise Parrot	*Neophema pulchella*	vulnerable *(TSC Act)*	14 Oct	753354	6614194	2
Barking Owl	*Ninox connivens*	vulnerable *(TSC Act)*	12 Oct	755040	6618340	1
Barking Owl	*Ninox connivens*	vulnerable *(TSC Act)*	12 Oct	753555	6618004	1
Barking Owl	*Ninox connivens*	vulnerable *(TSC Act)*	12 Oct	755075	6617710	1
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	8 Oct	751770	6606818	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	8 Oct	751770	6606818	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	9 Oct	750944	6608714	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	9 Oct	750439	6607616	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	10 Oct	765931	6610091	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	11 Oct	750448	6607623	6+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	11 Oct	753997	6615333	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	11 Oct	752216	6610947	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	11 Oct	746141	6599960	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	11 Oct	767617	6601291	4+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	12 Oct	752061	6589534	2+
Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	12 Oct	767620	6601147	8+

Appendix 12 Records of threatened and migratory species obtained in the Project Area, 8-14 October 2011 species and numbers of individuals

Rainbow Bee-eater	*Merops ornatus*	migratory *(EPBC Act)*	12 Oct	767617	6601291	2+
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	8 Oct	751770	6606818	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	8 Oct	750476	6607617	4+
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	9 Oct	750944	6608714	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	10 Oct	750440	6607870	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	11 Oct	750448	6607623	2
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	12 Oct	754027	6615395	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	12 Oct	753638	6614940	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	12 Oct	754823	6624520	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	12 Oct	750640	6622370	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	13 Oct	753187	6623634	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	14 Oct	765800	6612341	1
Brown Treecreeper	*Climacteris picumnus*	vulnerable *(TSC Act)*	14 Oct	753354	6614194	1
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	8 Oct	751770	6606818	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	8 Oct	752339	6606242	2
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	8 Oct	751770	6606818	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	8 Oct	758576	6597903	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	10 Oct	773116*	6608603*	2+*
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	10 Oct	765381	6609619	2
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	10 Oct	765931	6610091	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	10 Oct	758712	6612276	1
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	10 Oct	764137	6609648	1
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	11 Oct	748237	6607977	2
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	11 Oct	746141	6599960	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	11 Oct	752216	6610947	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	12 Oct	762085	6599123	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	12 Oct	752061	6589534	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	12 Oct	748322	6590385	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	12 Oct	753214	6604971	2+
Speckled Warbler	*Chthonicola sagittata*	vulnerable *(TSC Act)*	13 Oct	748255	6608047	2
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	751770	6606818	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	752339	6606242	5
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	751770	6606818	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	763212	6600346	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	758576	6597903	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	764316	6603400	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	749352	6607966	3+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	749343	6607979	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	8 Oct	759778	6605951	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	751622	6606987	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	750440	6607870	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	761799	6610119	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	748250	6613871	5+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	759890	6605937	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	764265	6608825	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	752925	6613549	2+

Appendix 12 Records of threatened and migratory species obtained in the Project Area, 8-14 October 2011 species and numbers of individuals

Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	752441	6612269	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	757314	6612951	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	758712	6612276	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	763422	6605598	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	10 Oct	765931	6610091	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	11 Oct	752029	6610262	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	11 Oct	752227	6611382	6+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	11 Oct	746141	6599960	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	752061	6589534	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	752179	6611719	3+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	750127	6607885	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	752459	6612186	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	748322	6590385	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	762085	6599123	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	755555	6619801	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	753214	6604971	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	750640	6622370	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	752168	6611727	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	748291	6607837	2+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	12 Oct	758460	6604655	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	13 Oct	754728	6622225	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	13 Oct	748242	6607768	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	14 Oct	762085	6599123	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	14 Oct	753354	6614194	4+
Grey-crowned Babbler	*Pomatostomus temporalis*	vulnerable *(TSC Act)*	14 Oct	755059	6617847	4+
Varied Sittella	*Daphoenositta chrysoptera*	vulnerable *(TSC Act)*	8 Oct	751770	6606818	3+
Varied Sittella	*Daphoenositta chrysoptera*	vulnerable *(TSC Act)*	10 Oct	764265	6608825	3+
Varied Sittella	*Daphoenositta chrysoptera*	vulnerable *(TSC Act)*	10 Oct	765931	6610091	3+
Hooded Robin	*Melanodryas cucullata*	vulnerable *(TSC Act)*	8 Oct	750459	6607641	1
Hooded Robin	*Melanodryas cucullata*	vulnerable *(TSC Act)*	8 Oct	750476	6607617	1
Hooded Robin	*Melanodryas cucullata*	vulnerable *(TSC Act)*	9 Oct	750439	6607616	2
Hooded Robin	*Melanodryas cucullata*	vulnerable *(TSC Act)*	11 Oct	750448	6607623	1
Diamond Firetail	*Stagonopleura guttata*	vulnerable *(TSC Act)*	9 Oct	750944	6608714	1
Diamond Firetail	*Stagonopleura guttata*	vulnerable *(TSC Act)*	11 Oct	750448	6607632	4
Diamond Firetail	*Stagonopleura guttata*	vulnerable *(TSC Act)*	15 Oct	750585	6607900	1
Koala	*Phascolarctos cinereus*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	9 Oct	763217	6600367	1
Eastern Pygmy-possum	*Cercartetus nanus*	vulnerable *(TSC Act)*	10 Oct	765287	6610025	1
Eastern Pygmy-possum	*Cercartetus nanus*	vulnerable *(TSC Act)*	13 Oct	762324	6605535	1
Eastern Pygmy-possum	*Cercartetus nanus*	vulnerable *(TSC Act)*	14 Oct	762324	6605535	1
Squirrel Glider	*Petaurus norfolcensis*	vulnerable *(TSC Act)*	11 Oct	753013	6613592	1
Squirrel Glider	*Petaurus norfolcensis*	vulnerable *(TSC Act)*	11 Oct	766757*	6595315*	1*
Squirrel Glider	*Petaurus norfolcensis*	vulnerable *(TSC Act)*	13 Oct	773490*	6613087*	1*
Black-striped Wallaby	*Macropus dorsalis*	endangered *(TSC Act)*	11 Oct	751039	6614721	1
Black-striped Wallaby	*Macropus dorsalis*	endangered *(TSC Act)*	12 Oct	751039	6614721	6
Black-striped Wallaby	*Macropus dorsalis*	endangered *(TSC Act)*	12 Oct	746566	6625653	1

Appendix 12 Records of threatened and migratory species obtained in the Project Area, 8-14 October 2011 species and numbers of individuals

Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	8 Oct	751774	6606831	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	8 Oct	751983	6607330	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	9 Oct	755190	6600131	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	9 Oct	764372	6603444	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	9 Oct	760469	6604834	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	9 Oct	764550	6603345	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	10 Oct	746703	6600074	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	10 Oct	749872	6603574	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	10 Oct	750278	6605029	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	11 Oct	764265	6603300	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	11 Oct	764265	6603300	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	12 Oct	753222	6605060	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	12 Oct	765394	6605739	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	12 Oct	760491	6605104	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	12 Oct	764174	6606160	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	12 Oct	751897	6616448	1+
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	vulnerable *(TSC Act)*	13 Oct	751774	6606831	1+
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	755177	6599999	1
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	757775	6601364	1
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	769914	6609364	4
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	770191	6609373	8
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	769914	6609364	3
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	13 Oct	750294	6605003	1
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	13 Oct	772967*	6607712*	1*
South-eastern Long-eared Bat	*Nyctophilus corbeni*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	14 Oct	753354	6614194	1
Little Pied Bat	*Chalinolobus picatus*	vulnerable *(TSC Act)*	13 Oct	751774	6606831	1+
Little Pied Bat	*Chalinolobus picatus*	vulnerable *(TSC Act)*	13 Oct	773225	6609144	2*
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	748237	6608034	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	752363	6607588	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	752135	6613704	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	752127	6613643	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	752105	6613586	1
Pilliga Mouse	Pseudomys pilligaensis	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	10 Oct	752084	6613550	1

Appendix 12 Records of threatened and migratory species obtained in the Project Area, 8-14 October 2011 species and numbers of individuals

Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	752258	6607389	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	752337	6607488	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	752360	6607578	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	765339	6609912	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	765271	6609916	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	765284	6609753	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	763658	6602223	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	11 Oct	752128	6613657	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	752337	6607488	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	752357	6607556	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	765356	6609865	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	763692	6602230	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	757437	6602451	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	12 Oct	762000	6599238	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	13 Oct	765287	6610025	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable (EPBC Act) vulnerable *(TSC Act)*	13 Oct	752306	6607562	1
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	13 Oct	752131	6613679	2
Pilliga Mouse	*Pseudomys pilligaensis*	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*	13 Oct	762000	6599237	1

- records outside Project Area

Appendix 13 Vertebrate species recorded in the Project Area, 8-14 October 2011

common name	scientific name	status
Amphibians		
Plains Froglet	*Crinia parinsignifera*	
Common Eastern Froglet	*Crinia signifera*	
Barking Frog	*Limnodynastes fletcheri*	
Ornate Burrowing Frog	*Limnodynastes ornatus*	
Salmon-striped Frog	*Limnodynastes salmini*	
Spotted Grass Frog	*Limnodynastes tasmaniensis*	
Bibron's Toadlet	*Pseudophryne bibroni*	
Smooth Toadlet	*Uperoleia laevigata*	
Wrinkled Toadlet	*Uperoleia rugosa*	
Green Tree Frog	*Litoria caerulea*	
Broad-palmed Rocket Frog	*Litoria latopalmata*	
Peron's Tree Frog	*Litoria peronii*	
Desert Tree Frog	*Litoria rubella*	
Total 13 species		
Reptiles		
Prickly Gecko	*Heternotia binoei*	
Litter Skink	*Carlia foliorum*	
Striped Skink	*Ctenotus robustus*	
Tree Skink	*Egernia striolata*	
Wood Mulch-slider	*Lerista muelleri*	
Eastern Blue-tongued Skink	*Tiliqua scincoids*	
Nobbi	*Amphibolorus nobbi*	
Eastern Bearded Dragon	*Pogona barbata*	
Sand Goanna	*Varanus gouldii*	
Lace Monitor	*Varanus varius*	
Pale-headed Snake	***Hoplocephalus bitorquatus***	vulnerable *(TSC Act)*
Total 11 species		
Birds		
Emu	*Dromaius novaehollandiae*	
Brown Quail	*Coturnix ypsilophora*	
Australian Wood Duck	*Chenonetta jubata*	
Pacific Black Duck	*Anas superciliosa*	
Australasian Grebe	*Tachybaptus novaehollandiae*	
Common Bronzewing	*Phaps chalcoptera*	
Crested Pigeon	*Ocyphaps lophotes*	
Peaceful Dove	*Geopelia striata*	
Bar-shouldered Dove	*Geopelia humeralis*	
Tawny Frogmouth	*Podargus strigoides*	
White-throated Nightjar	*Eurostopodus mystacalis*	
Spotted Nightjar	*Eurostopodus argus*	
Australian Owlet-nightjar	*Aegotheles cristatus*	
White-necked Heron	*Ardea pacifica*	

Appendix 13 Vertebrate species recorded in the Project Area, 8-14 October 2011

Black-shouldered Kite	*Elanus axillaris*	
Brown Goshawk	*Accipiter fasciatus*	
Collared Sparrowhawk	*Accipiter cirrocephalus*	
Wedge-tailed Eagle	*Aquila audax*	
Little Eagle	***Hieraaetus morphnoides***	vulnerable *(TSC Act)*
Nankeen Kestrel	*Falco cenchroides*	
Brown Falcon	*Falco berigora*	
Peregrine Falcon	*Falco peregrinus*	
Masked Lapwing	*Vanellus miles*	
Painted Button-quail	*Turnix varius*	
Glossy Black-cockatoo	***Calyptorhynchus lathami***	vulnerable *(TSC Act)*
Galah	*Eolophus roseicapillus*	
Sulphur-crested Cockatoo	*Cacatua galerita*	
Musk Lorikeet	*Glossopsitta concinna*	
Little Lorikeet	***Glossopsitta pusilla***	vulnerable *(TSC Act)*

Australian King-parrot	*Alisterus scapularis*	
Red-winged Parrot	*Aprosmictus erythropterus*	
Eastern Rosella	*Platycercus eximius*	
Australian Ringneck	*Barnardius zonarius*	
Red-rumped Parrot	*Psephotus haematonotus*	
Turquoise Parrot	***Neophema pulchella***	vulnerable *(TSC Act)*
Horsfield's Bronze Cuckoo	*Chalcites basalis*	
Black-eared Cuckoo	*Chalcites osculans*	
Shining Bronze-cuckoo	*Chalcites lucidus*	
Pallid Cuckoo	*Cacomantis pallidus*	
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	
Barking Owl	***Ninox connivens***	vulnerable *(TSC Act)*
Southern Boobook	*Ninox novaeseelandiae*	
Laughing Kookaburra	*Dacelo novaeguineae*	
Sacred Kingfisher	*Todiramphus sanctus*	
Rainbow Bee-eater	***Merops ornatus***	migratory *(EPBC Act)*
Dollarbird	*Eurystomus orientalis*	
White-throated Treecreeper	*Cormobates leucophaea*	
Brown Treecreeper	***Climacteris picumnus***	vulnerable *(TSC Act)*
Superb Fairy-wren	*Malurus cyaneus*	
Variegated Fairy-wren	*Malurus lamberti*	
Chestnut-rumped Heathwren	*Hylacola pyrrhopygia*	
Speckled Warbler	***Chthonicola sagittata***	vulnerable *(TSC Act)*
Weebill	*Smicrornis brevirostris*	
Western Gerygone	*Gerygone fusca*	
White-throated Gerygone	*Gerygone albogularis*	
Striated Thornbill	*Acanthiza lineata*	
Yellow Thornbill	*Acanthiza nana*	
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	

Chestnut-rumped Thornbill	*Acanthiza uropygialis*	
Buff-rumped Thornbill	*Acanthiza reguloides*	
Inland Thornbill	*Acanthiza apicalis*	
Spotted Pardalote	*Pardalotus punctatus*	
Striated Pardalote	*Pardalotus striatus*	
Yellow-faced Honeyeater	*Lichenostomus chrysops*	
White-eared Honeyeater	*Lichenostomus leucotis*	
Fuscous Honeyeater	*Lichenostomus fuscus*	
White-plumed Honeyeater	*Lichenostomus penicillatus*	
Noisy Miner	*Manorina melanocephala*	
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	
Red Wattlebird	*Anthochaera carunculata*	
Brown Honeyeater	*Lichmera indistincta*	
Brown-headed Honeyeater	*Melithreptus brevirostris*	
Blue-faced Honeyeater	*Entomyzon cyanotis*	
Noisy Friarbird	*Philemon corniculatus*	
Little Friarbird	*Philemon citreogularis*	
Striped Honeyeater	*Plectorhyncha lanceolata*	
Grey-crowned Babbler	***Pomatostomus temporalis***	vulnerable *(TSC Act)*
White-browed Babbler	*Pomatostomus superciliosus*	
Spotted Quail-thrush	*Cinclosoma punctatum*	
Varied Sittella	***Daphoenositta chrysoptera***	vulnerable *(TSC Act)*
Black-faced Cuckoo-Shrike	*Coracina novaehollandiae*	
White-bellied Cuckoo-shrike	*Coracina papuensis*	
White-winged Triller	*Lalage sueurii*	
Crested Shrike-tit	*Falcunculus frontatus*	
Golden Whistler	*Pachycephala pectoralis*	
Rufous Whistler	*Pachycephala rufiventris*	
Grey Shrike-thrush	*Colluricincla harmonica*	
Crested Bellbird	*Oreoica gutturalis*	
Olive-backed Oriole	*Oriolus sagittatus*	
Masked Woodswallow	*Artamus personatus*	
White-browed Woodswallow	*Artamus superciliosus*	
Dusky Woodswallow	*Artamus cyanopterus*	
Grey Butcherbird	*Cracticus torquatus*	
Pied Butcherbird	*Cracticus nigrogularis*	
Australian Magpie	*Cracticus tibicen*	
Pied Currawong	*Strepera graculina*	
Grey Fantail	*Rhipidura albiscapa*	
Willie Wagtail	*Rhipidura leucophrys*	
Australian Raven	*Corvus coronoides*	
Leaden Flycatcher	*Myiagra rubecula*	
Restless Flycatcher	*Myiagra inquieta*	
Magpie-lark	*Grallina cyanoleuca*	

White-winged Chough	Corcorax melanorhamphos	
Apostlebird	Struthidea cinerea	
Jacky Winter	Microeca fascinans	
Red-capped Robin	Petroica goodenovii	
Hooded Robin	***Melanodryas cucullata***	vulnerable *(TSC Act)*
Eastern Yellow Robin	*Eopsaltria australis*	
Rufous Songlark	*Cincloramphus mathewsi*	
Brown Songlark	*Cincloramphus cruralis*	
Silvereye	*Zosterops lateralis*	
Welcome Swallow	*Hirundo neoxena*	
Tree Martin	*Petrochelidon nigricans*	
Common Myna	*Sturnus tristis*	introduced
Mistletoebird	*Dicaeum hirundinaceum*	
Double-barred Finch	*Taeniopygia bichenovii*	
Red-browed Finch	*Neochimia temporalis*	
Diamond Firetail	***Stagonopleura guttata***	vulnerable *(TSC Act)*
Australasian Pipit	*Anthus novaeseelandiae*	
Total 119 species		
Mammals		
Koala	***Phascolarctos cinereus***	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*
Common Wombat*	*Vombatus ursinus*	
Eastern Pygmy-possum	***Cercartetus nanus***	vulnerable *(TSC Act)*
Sugar Glider	*Petaurus breviceps*	
Squirrel Glider	***Petaurus norfolcensis***	vulnerable *(TSC Act)*
Common Brushtail Possum	*Trichosurus vulpecula*	
Eastern Grey Kangaroo	*Macropus giganteus*	
Black-striped Wallaby	***Macropus dorsalis***	endangered *(TSC Act)*
Common Wallaroo	*Macropus robustus*	
Red-necked Wallaby	*Macropus rufogriseus*	
Swamp Wallaby	*Wallabia bicolour*	
Little Red Flying-fox	*Pteropus scapulatus*	
Eastern Horseshoe Bat	*Rhinolophus megaphyllus*	
Yellow-bellied Sheath-tailed Bat	***Saccolaimus flaviventris***	vulnerable *(TSC Act)*
Eastern Free-tailed Bat	*Mormopterus ridei*	
Southern Free-tailed Bat	*Mormopterus sp. 4 (long penis form)*	
White-striped Free-tailed Bat	*Tadarida australis*	
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	
Gould's Long-eared Bat	*Nyctophilus gouldi*	

South--eastern Long-eared Bat	***Nyctophilus corbeni***	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*
Gould's Wattled Bat	*Chalinolobus gouldii*	
Chocolate Wattled Bat	*Chalinolobus morio*	
Little Pied Bat	***Chalinolobus picatus***	vulnerable *(TSC Act)*
Inland Broad-nosed Bat	*Scotorepens balstoni*	
Little Broad-nosed Bat	*Scotorepens greyii*	
Little Forest Bat	*Vespadelus vulturnus*	
Pilliga Mouse	***Pseudomys pilligaensis***	vulnerable *(EPBC Act)* vulnerable *(TSC Act)*
House Mouse	*Mus musculus*	introduced
Feral Goat	*Capra hircus*	introduced
Feral Pig	*Sus scrofa*	introduced
Red Fox	*Vulpes vulpes*	introduced
Feral Cat	*Felis catus*	introduced
European Rabbit	*Oryctolagus cuniculus*	introduced
European Brown Hare	*Lepus europaeus*	introduced
Total 33 (34) species		

* recorded outside Project Area

Threatened South-eastern Long-eared Bat being released. Photo Matthew Taylor