SECURING AUSTRALIA'S FUTURE

# Engineering Energy: Unconventional Gas Production

6

PROJECT

A study of shale gas in Australia.

EXTRACT

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SECURING AUSTRALIA'S FUTURE

A three-year research program funded by the Australian Research Council and conducted by the four Learned Academies through the Australian Council of Learned Academies for PMSEIC, through the Office of the Chief Scientist. Securing Australia's Future delivers research-based evidence and findings to support policy development in areas of importance to Australia's future.

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A study of shale gas in Australia.

Australian Academy of the Humanities

Australian Academy of Science

Academy of the Social Sciences in Australia

ATSE

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Established in 1971, replacing its parent body the Social Science Research Council of Australia, itself founded in 1942, the academy is an independent, interdisciplinary body of elected Fellows. The Fellows are elected by their peers for their distinguished achievements and exceptional contributions made to the social sciences across 18 disciplines.

It is an autonomous, non-governmental organisation, devoted to the advancement of knowledge and research in the various social sciences.

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ACOLA receives Australian Government funding from the Australian Research Council and the Department of Industry, Innovation, Science, Research and Tertiary Education. www.acola.org.au

# Summary

Many Australian sedimentary basins are prospective for unconventional gas and the undiscovered resource base is very large. The technology (such as horizontal wells, multi-well pads and hydraulic fracturing) is available to produce shale gas (and shale oil and tight gas) in Australia, but production costs are likely to be significantly higher than those in North America and the lack of infrastructure will further add to costs. Shale gas will not be cheap gas in Australia, but it is likely to be plentiful and it has the potential to be an economically very important additional energy source. Increased use of shale gas (and other gas) for electricity generation could significantly decrease Australia's greenhouse gas emissions based on gas replacing coal. Because of the manner in which shale gas is produced it has the potential to impact on the landscape, on ecosystems, on surface and groundwater, on the atmosphere, on communities, and rarely may result in minor induced seismicity. It will be vital for industry and government to recognise the complexity of the challenges posed by these possible impacts. However, most can be minimised where an effective regulatory system and best monitoring practice are in place and can be remediated where they do occur. If the shale gas industry is to earn and retain the social licence to operate, it is a matter of some urgency to have such a transparent, adaptive and effective regulatory system in place and implemented, backed by best practice monitoring in addition to credible and high quality baseline surveys. Research into Australia's deep sedimentary basins and related landscapes, water resources and ecosystems, and how they can be monitored, will be essential to ensure that any shale gas production is effectively managed and the impacts minimised.

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# Project aims

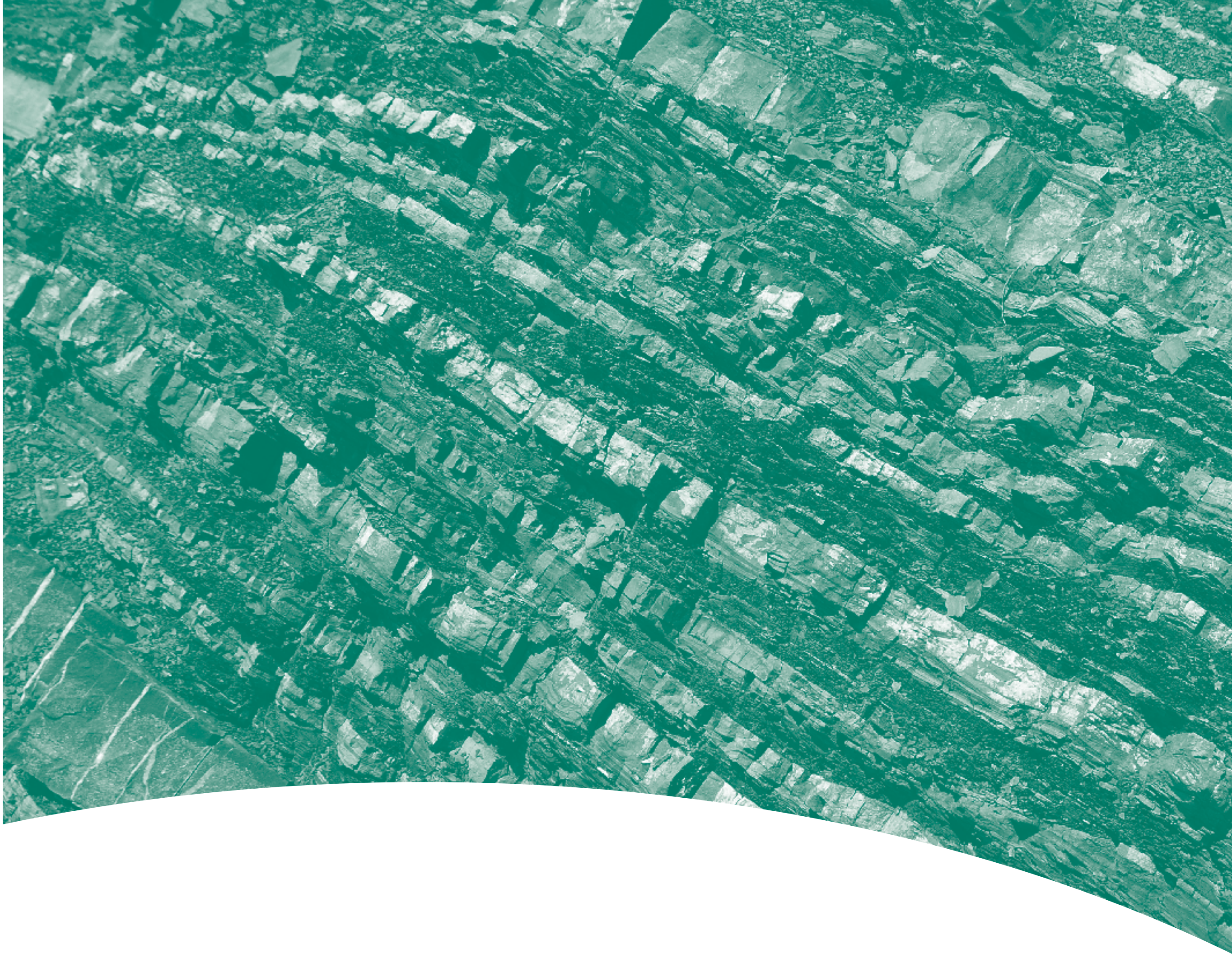
Energy needs will require us to keep turning to opportunities for alternative sources such as shale oil gas and coal seam gas. As technology and geological knowledge continue to advance, and the consequent economics of extracting unconventional natural gas become more feasible, Australia could be in a position to produce unconventional gas. This demands a comprehensive look at the scientific, social, cultural, technological, environmental and economic issues surrounding the reality of alternative energy sources such as unconventional gas.

*Securing Australia's Future*, Project Six, Engineering energy: unconventional gas production, aimed to undertake a study of shale gas in Australia which looks at: resources, technology, monitoring, infrastructure, human and environmental impacts, issues communication, regulatory systems, economic impacts, lessons learned from the coal seam gas industry, and impacts on greenhouse gas reduction targets.

# Executive summary

The development of the shale gas industry in the United States over the past decade has had a major impact on the energy market in that country and on its economy, but has also raised a number of environmental questions. The Australian shale gas industry is very small by North American standards but has had some early success, and together with work on tight gas, it expects to spend more than $500 million on exploration over the next 1-2 years. Given that the momentum of the industry in Australia is increasing, it is a matter of some urgency to more fully assess the nation's shale gas resources and reserves (as well as the more limited tight gas resources) because of their potential impact on the Australian gas market and gas prices, on jobs and on the economy more broadly. But equally importantly, the urgency arises because of the need to understand (whilst the industry is at an early stage) what the potential environmental, social and related impacts might be and the need to regulate the industry in an effective and transparent manner that will help to minimise or prevent any adverse impacts in order to establish and retain a "social licence" to operate.

A driver for an Australian shale gas industry is that most of the announced coal seam gas (CSG) reserves are committed to the LNG industry from 2015-2016, with the potential for domestic gas shortages in eastern Australia and the prospect of large increases in gas prices. It is very likely



that abundant shale gas will be found in Australia and this will help to ensure that there is no gas shortage. But shale gas will not be cheap gas in most circumstances. It will require a relatively high price to make it profitable to produce. The current low price of shale gas in North America is not sustainable but production there is being maintained, despite the low price, either for contractual reasons and/or because some of the gas is produced as a by-product of higher value oil derived from the shales. In Australia, shale gas will require a price of the order of $6-9 a gigajoule to make its production and transport profitable compared with the current East Coast wholesale gas price of about $6 a gigajoule. The suggestion has been made that a proportion of future shale gas should be reserved for domestic use, as a mechanism to hold down domestic gas prices. The Expert Working Group saw this as a challenge to implement in a market economy, but an alternative suggestion that Government could work with industry to create vital infrastructure, particularly in remote parts of Australia, to encourage the development of a more cost effective and more widespread shale gas industry, warrants consideration.

Australia has large undiscovered shale gas (and probably some shale oil) resources in many basins, mostly though not exclusively in remote parts of the country. Shale gas has many similarities with tight gas, but the resource is thought to be much smaller than that of shale gas. The available undiscovered resource figures for shale gas have a high degree of uncertainty attached to them. The commonly cited resource estimate of 396 trillion cubic feet (tcf) of gas is based on only four basins; if all prospective basins are considered, the undiscovered resource could be in excess of 1000 tcf, though the value has a high degree of uncertainty. Far more exploration is needed to turn those resource estimates into economic reserves. In the Cooper Basin, existing markets and available infrastructure can be rapidly deployed to accelerate shale gas (and tight gas) production. Elsewhere, the lack of infrastructure could hold back shale gas developments, but at the same time, major new finds could also provide the stimulus for new infrastructure. The technology to explore for and produce shale gas that has been developed largely in North America, is in general applicable to Australian geological conditions. There are no insurmountable technology barriers relating to shale gas production but there will be a need to adapt to particular geological features, such as high heat flow in parts of central Australia, which limit the applicability of some monitoring techniques. Also, variations in the stress field may require modified hydraulic fracturing (fracking) techniques in some basins. There are skill shortages in some areas of shale gas production which will need to be addressed if the industry is to progress and there may be an initial shortage of suitable drilling rigs, but overall it will be the lack of more basic infrastructure (roads, pipelines) and markets, that will slow shale gas growth in Australia compared to the rapid growth of the industry in North America.

A number of environmental issues related to the shale gas industry have arisen in the United States and similar questions have been raised about potential impacts in Australia. A large number of impacts are possible, but the likelihood of many of them occurring is low and where they do occur, other than in the case of some biodiversity impacts, there are generally remedial steps that can be taken. Nonetheless it is important that the shale gas industry takes full account of possible adverse impacts on the landscape, soils, flora and fauna, groundwater and surface water, the atmosphere and on human health in order to address people's concerns. This will require improved baseline studies against which to measure future change and to compare natural change and change resulting from industry activities. The footprint and regional scale over which shale gas operations may occur can be minimised by measures such as drilling multiple wells from one drill pad, but nonetheless there will be some cumulative regional, ecological and hydrological impacts, including fragmentation of habitats and overall landscape function. These will need to be carefully assessed and managed using best practice.

Impact on groundwater is likely to be a particular issue in many areas. Large amounts of water are used in hydraulic fracturing operations. In general, brackish or salty water can be used; small quantities of chemicals and sand are then added to the water to give it the right properties for the development of induced permeability, which in turn allows the gas to then flow from the shale. The water that flows back from the wellcan then be re-used or it may be disposed of at an approved site. Contamination of aquifers and surface water can result from chemical spillage. The industry already has rigorous systems for dealing with spillage, or from the incorrect disposal of the hydraulic fracturing fluid (already controlled by regulators under most jurisdictions), or from produced water. Contamination can also potentially occur via leakage from a borehole into a freshwater aquifer, due to borehole failure, particularly from abandoned bores, or (though less likely) from an incorrect hydraulic fracturing operation. These are unlikely to occur if best practice is followed, but regulations need to be in place and enforced, to help to ensure this.

Induced seismicity associated with shale gas operations has given rise to concern overseas, but the number of damaging seismic events that can be related to shale gas is very small indeed. The injection of large volumes of fluid (for example during geothermal projects) has been shown overseas to be more likely to cause a magnitude 3-4 seismic event than a hydraulic fracturing operation. This also is likely to be the case in Australia, with the risk arising from induced seismicity regarded as low. However an uncertainty for Australian operations is that the current seismological record has relatively coarse resolution and would not be adequate to detect 'natural' small magnitude earthquakes in areas where shale gas operations might be underway. There is seen to be a need to improve and prioritise the current seismic network. Best practice involving specific seismic 'triggers' for cessation of hydraulic fracturing may be usefully applied to minimise the prospect of damaging seismicity.

A vigorous scientific debate is underway about the level of greenhouse gas emissions associated with shale gas production and there are uncertainties in the estimates. At the early 'flowback' stage there can be methane emissions to the atmosphere unless so-called green completions, that minimise methane emissions, are used. It is desirable to put effective methane mitigation steps in place as soon as possible. The data available on natural and industrial methane and $CO_2$ emissions is quite limited and steps will need to be taken for methane monitoring of natural systems (for background) and shale gas operations. Using shale gas in gas turbines for electricity production will result, on average, in approximately 20% more emissions than using conventional gas, but 50-75% of the emissions than when using black coal, assuming green completions (based on life cycle emission considerations) for power generation. Increased use of shale gas (and other gas) for electricity generation could significantly decrease Australia's greenhouse gas emissions based on gas replacing coal-fired generation; the extent to which this actually occurs will depend on the price of shale gas compared to alternative energy sources.Some shale gas is likely to be high in carbon dioxide; depending on the cost, application of carbon capture and storage could be used to limit those $CO_2$ emissions.

Gaining and retaining a 'social licence to operate' will be important to all shale gas operations and will need to be approached not just as a local community issue, but also at regional, state and national levels. In order to develop effective relationships with communities potentially impacted by shale gas developments, it will be necessary to have open dialogue, respect and transparency. It will also be important there is confidence in the community that not only are shale gas operations and impacts being effectively monitored, but also that concerns will be identified and remediated, or operations stopped before a serious problem arises. Many of the most prospective areas for shale gas are subject to Native Title or are designated Aboriginal Lands and it will be important to ensure that traditional owners are aware of the nature and scale and the possible impact of shale gas developments from the start. The industry also has the potential to help address the aspirations of Aboriginal people to build greater economic self-sufficiency.

The possible impact of shale gas production on human health has received some attention overseas. There are limited overseas data suggesting some increased health risk. There are no Australian data to suggest that major health risks are likely to arise from shale gas operations (a recent Australian CSG study did not indicate any significant health risk), but the issue should not be ignored. The potential for health impacts will need considered attention in Australia, including the collection of baseline information for populated areas that are likely to have nearby shale gas operations.

Monitoring of shale gas production and impacts is likely to be undertaken by petroleum companies as part of their normal operations, but in order to win community confidence, truly independent monitoring will need to be undertaken by government or other agencies and/or credible research bodies. Induced seismicity, aquifer contamination, landscape and ecosystem fragmentation, greenhouse and other emissions to the atmosphere, together with potentially adverse social impacts, are all likely to be areas of community concern that will need to be monitored and for which baseline surveys will be required. It will not be feasible to monitor large areas for extended periods of time and therefore monitoring will need to be carefully and cost effectively targeted to answer specific questions and transparently address particular concerns. This will require a robust regulatory regime, which will build on existing regulations and which will also fully take account of the need for sensible and multiple land use, based around well-resourced regional planning and cumulative risk assessment. The regulation of abandoned wells, the abandonment process and the long-term prospect of 'orphan wells' are topics that require more careful consideration by regulators. A difficulty for governments if a shale gas industry rapidly expands, will be to find regulators with appropriate experience. It is in the interests of government and industry to ensure that this issue is addressed, particularly to ensure that companies less experienced in shale developments can be enabled to follow best practice.

Whilst there are no major technology gaps that relate to shale gas production, there are significant gaps in our knowledge of the way that sedimentary basins work and exploring for and producing shale gas will provide an unprecedented opportunity to undertake research and gather large amounts of new information on Australia's most important sedimentary basins. This will be of great value to the future assessment and management of landscape biodiversity and water resources particularly groundwater. Further research towards improved strategic accumulative risk assessment tools and methodologies that can assist in the minimisation of biodiversity loss, is an identified knowledge gap. Governments will need to take steps to adequately curate this new information, including perhaps placing requirements on industry to ensure that data is not lost and is made available. The same applies to the large amount of baseline and monitoring data that will be collected which will need to be over extended periods. New research will be important in addressing some of the particular issues facing the shale gas industry, such as understanding how shale gas systems work, developing innovative ways to minimise greenhouse gas emissions and ecological impact, improving ways to monitor hydraulic fracturing, particularly at high subsurface temperatures and establishing better ways to ensure resilient systems and minimise adverse impacts. A major coordinated program of research should be initiated at an early stage.

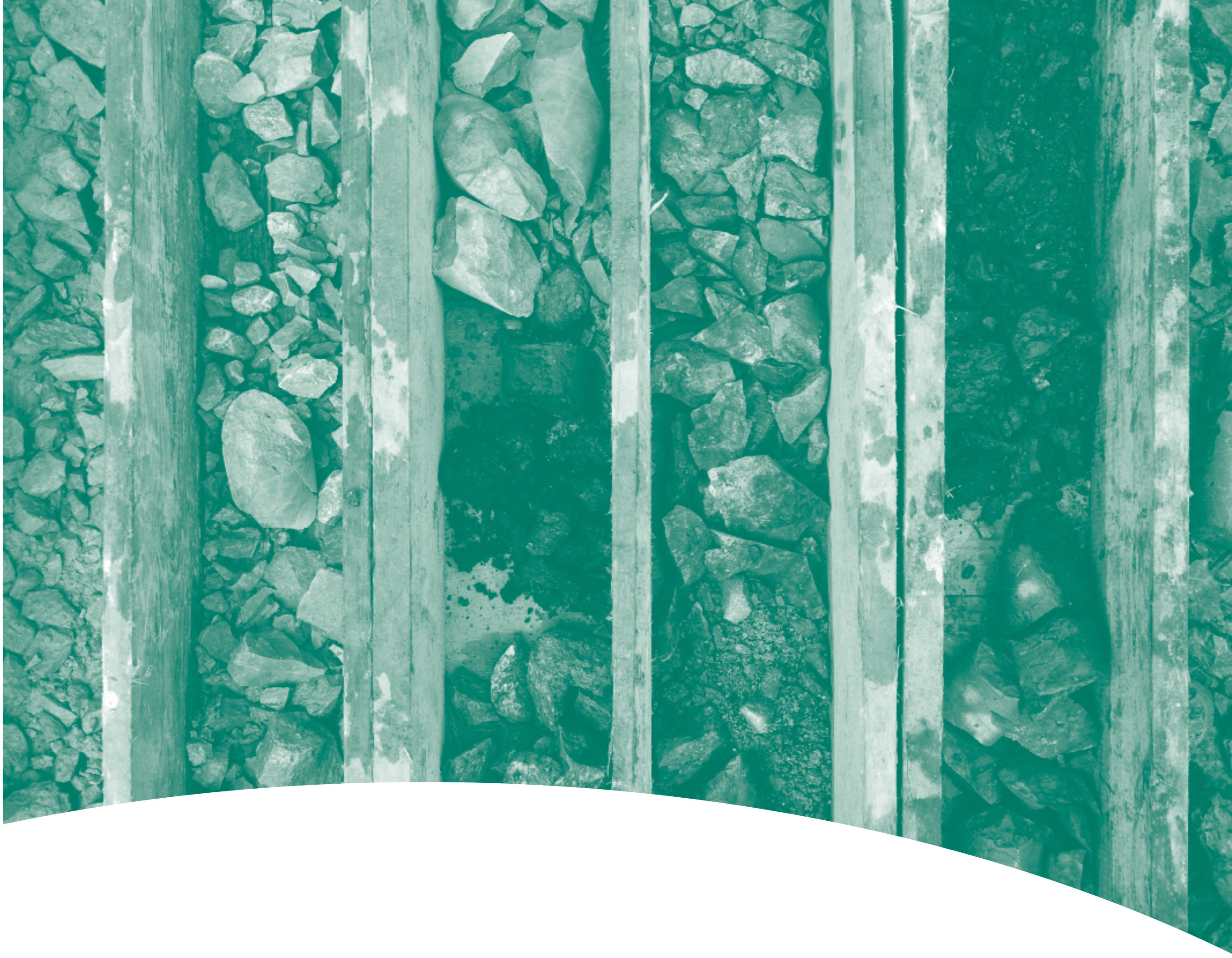
Some people have raised the question "Why extract shale gas? Why not spend the money on cleaner renewable energy?" But that is not a question that was in the terms of reference of this Review. It has also been suggested that a "business as usual" energy mix should not be assumed for the future. This may be so, but it was not possible (or appropriate) for the Expert Working Group to consider this question given the terms of reference. Additionally it should be recognised that we already have a nascent shale gas industry in Australia and that the signs are that its momentum will increase. The Review did not gain the impression that shale gas in Australia will be a great bonanza that will be easily won. Rather it became evident that whilst shale gas has enormous potential, it will require great skill, persistence, capital and careful management of any impacts on ecosystems and related natural resources, to realise that potential. It will also need an informed and supportive community, and transparent and effective regulations and companion codes of practice. Provided we have all these in place (and the right rocks), shale gas could be an important new energy option for Australia.

# Key findings

## Supply and demand economics of natural gas

1. The discovery of very large shale gas resources and the exploitation of shale gas (and shale oil) reserves have transformed the energy market in North America and have the potential to have a major impact on global gas supplies. The Expert Working Group considers that there is a clear need for Australia to quickly move to better assess its shale gas resources and reserves and to consider their potential social, economic and environmental impact, whilst exploration in Australia is still at an early stage.

2. There are currently three independent domestic gas markets in Australia – the western and northern markets already linked to export markets for gas through LNG production and exports and the eastern market, which has a significant domestic customer base but will also soon be linked to LNG export via facilities at Gladstone, Queensland. Shale gas resources (and more modest tight gas resources in some basins) have the potential to contribute to all three of these markets.



## Reserves and resources

3. The Expert Working Group recognises that not all coal seam gas (CSG) reserves have been announced, but current Proven and Probable (2P) CSG reserves for Eastern Australia are almost fully committed to Liquefied Natural Gas (CSG-LNG) export requirements over the next twenty years. This tightness in the market could be compounded by movement from coal-fired to gas fired power generation and by declining conventional gas production. At the same time gas prices will rise, with significant flow-on effects to domestic retail electricity and gas prices. There will be an opportunity for cost competitive shale gas to contribute to this need for additional east coast gas.

4. The projected cost of producing at least some of Australia's shale gas reserves is at or below some future gas price projections for Eastern Australia, and shale gas will contribute to Australian gas supplies in the coming decades. Shale gas could be available to both Western Australia and the Northern Territory as a potential new domestic energy source, particularly for some of the more remote energy users.

5. Australia has a number of sedimentary basins, particularly in northern, central and western Australia, which are prospective for shale gas, based on the abundance of shales, their likely maturity and their total organic carbon content. Because of its established infrastructure (such as the gas processing facility at Moomba and pipelines), shale gas (along with tight gas) in the Cooper Basin could be the first to be developed at a large scale.

6. Although the most prospective Australian shale gas basins are located inland, in arid sparsely populated areas, it is likely that some shale gas resources will also be found in more densely populated parts of Queensland, New South Wales, Victoria and SW Western Australia and the presence of existing gas infrastructure there, could mean that it may be economic to develop shale gas in these areas as long as social and environmental issues are appropriately addressed.

7. Estimates of Australian shale gas resources are considerable, but have a high degree of uncertainty attached to them. The commonly cited undiscovered resource value of 396 tcf(trillion cubic feet) of gas is based on only four basins, but if all prospective basins are considered, the undiscovered resource could be in excess of 1000 tcf. Reliable economic reserve figures for shale gas are not available, largely because there has been little or no exploration or drilling in most basins. The Expert Working Group considers that there is an urgent need to encourage shale gas exploration in Australia to provide a clearer picture of the extent of the resources and to safeguard Australia's position as a major world gas exporter and to improve resource and reserve estimates.

## Technology and Engineering

8. The Expert Working Group considers it unlikely there will be technology barriers related to gas production that will inhibit the development of a shale gas industry in Australia. The central technology components developed by industry for shale gas extraction, namely well drilling, well completion, hydraulic fracture stimulation and production, including real-time sensing technology to monitor and minimise risks, will be applicable in Australia. However, some of these existing technologies and exploration models will need to be tailored to suit particular Australian geological, environmental and economic conditions.

9. A key breakthrough in the United States has been to reduce the time and cost of shale gas extraction by drilling a number of deep horizontal wells from a single pad. Horizontal shale gas wells require an *in-situ* stress regime that sustains vertical fracture planes at the many fracture stages along the lateral length. Local stress regimes in parts of some Australian basins may lead to fractures developing significant horizontal components; this results in less efficient extraction of gas. Whilst this will not necessarily be the case throughout a particular basin, or in all Australian basins, knowledge gained from Australian shale gas wells in the near future will considerably clarify the situation.

10. In addition to shale targets, overlying and underlying rock formations, in some basins such as the Cooper Basin, contain tight gas in deep low permeability sandstones, which similarly require hydraulic fracturing for extraction. This vertical column of deep gas-bearing strata, with higher permeability than shale, can be accessed by hydraulic fracturing at several depths in the same well bore; this is compatible with drilling a number of near-vertical wells from a single pad.

## Infrastructure considerations

11. Access to appropriate drilling rigs may delay the early development of the shale gas industry.

12. Pipe line and road networks are much less developed in Australia than in the United States and this will have a significant impact on the rate of development of shale gas in remote regions where much of the shale gas opportunities are likely to be found and on access to potential gas consumers. However, there are opportunities to utilise the road, rail, human resources and water infrastructure that will be required to also develop and assist other local industries and community amenity.

13. Although many skills will be transferable from the CSG industry, access to a skilled workforce is likely to be an issue for the shale gas industry in specialist areas such as hydraulic fracturing and will need consideration by the education and training sector and governments. The industry should be encouraged to provide on-the-job experience to graduates and tradespeople.
14. An Australian shale gas industry could provide direct employment to thousands of people. However, Australia currently lacks some of the essential skills and the domestic capacity to cost-competitively manufacture much of the drilling, production and transport infrastructure that would be required by a major expansion into shale gas production.

## Financial analysis of shale gas

15. An important parameter dictating the threshold gas price that would make shale gas economic is capital intensity, that is, the ratio of drilling and completion costs to initial gas production. At present, based on limited recent production data and forecast drilling costs, the capital intensity for shale gas extraction in Australia is significantly higher than in the United States.
16. Shale gas production differs from conventional gas and CSG in that the shale gas well production decline rate is rapid, meaning that capital expenditure needs to be approximately maintained each year because of the need to drill and complete new wells to maintain production from a field.
17. Natural gas liquid (NGL) content in shale gas is important, since the market for shale oil, condensate and liquefied petroleum gas (propane and butane) can be a driver of overall shale gas economics. The market for ethane from shale gas is less certain and the potential to value-add through production of chemicals would depend upon the price of ethane versus the price of natural gas and the competitiveness of a domestic chemicals industry.
18. Sustainable shale gas development in Australia requires that suppliers receive a price for the gas they produce that at least covers their marginal cost of production. Best estimates of the current wellhead costs of production of Australian shale gas, range from around $6/Gigajoule (GJ) to about $9/GJ. By comparison, the wholesale gas price for long-term contracts of gas for the domestic market in eastern Australia is around $4/GJ while current eastern Australia domestic wholesale prices are about $6/GJ and the current netback price for Australian gas exported to Japan is around $10/GJ. Based on these estimates, development of Australian shale gas marketed on the east coast is unlikely to occur until domestic and international netback prices are equalised (assuming international netback prices remain above about $10/GJ in real terms).
19. It has been suggested that reserving a proportion of Australia's shale gas could be a way of providing Australia with cheaper and more secure energy but the Expert Working Group was not persuaded that this was a practical mechanism, given that modelling suggests that for eastern Australia at least, shale gas prices would need to be approximately double the existing gas price to provide an economic return. Government and industry cooperation in the development of shale gas infrastructure warrants consideration.

## Landscape and biodiversity

20. Strategic Environmental Assessment prior to development, including the use of cumulative risk analysis tools applied at the catchment and appropriate regional scales, are now technically feasible. Provided they are supported by an enabling regulatory environment and spatially adequate and explicit ecological, hydrological and geological data, these tools and the social consideration involved, have the potential to contribute to the management and minimisation of regional environmental impacts arising from shale gas developments.

21. Shale gas developments can extend over large land areas and have aggregated and cumulative environmental impacts through surface disturbance and clearing of native vegetation for drilling pads, roads, pipelines and related infrastructure. These activities need to be effectively managed to avoid impacts such as destruction and fragmentation of habitats and the overall landscape function, loss of threatened species habitats and ecological communities or an increase of invasive species. The use of cumulative risk assessment and best practice in minimal impact infrastructure will be crucial to the future of the shale gas industry.

22. The potential exists for conflicts between current land, water and infrastructure use and competition by new multiple or sequential uses (e.g. traditional land owners, conservation, agriculture, other resource projects, tourism and urban development). The shale gas industry, governments and the community needs to learn from experience of the CSG industry to avoid these conflicts. Use of best practice tools including cumulative risk assessment and strategic land use planning and policies such as the proposed Multiple Land Use Framework developed by the Land Access Working Group under the Standing Council on Energy and Resources should assist to resolve potential conflicts.

## Water

23. The volume of water required to hydraulically fracture shale gas strata can be an order of magnitude larger than that for coal seam gas depending on well depth and extent of horizontal drilling. Conversely, the total volume of produced water in shale gas operations is orders of magnitude less than the total amount produced during CSG operations. The information available to the Expert Working Group leads it to conclude that while initial extraction of water for shale gas operations will be significant, shale gas operations will not be faced with the ongoing disposal and subsequent replacement of large volumes of produced water as is the case for CSG operations.

24. During the early stages of shale gas operations, the large quantities of water (including saline water) used for hydraulic fracturing will need to be extracted from surface and/or groundwater resources. The extraction and subsequent disposal will need to be managed within regulatory processes including water entitlements (in most circumstances) and aquifer management plans in order to minimise changes to flow regimes and the potential for contamination of aquifers.

25. Contamination of freshwater aquifers can occur due to accidental leakage of brines or chemically-modified fluids during shale gas drilling or production; through well failure; via leakage along faults; or by diffusion through over-pressured seals. Contamination of terrestrial and riverine ecosystems may occur from spills associated with chemicals used during the early stages of production; from impoundment ponds and holding tanks; and because of the volume of traffic needed to service operations. The petroleum industry has experience in managing these issues and remediating them, but in a relatively new shale gas industry, unanticipated problems may arise and it is important to have best practice in place, to minimise the possibility of this risk.

26. All gas wells pass through aquifers ranging from freshwater to saline and at depths ranging from very near surface (tens of metres) to deep (hundreds to thousands of metres), and are subject to well integrity regulation. In important Australian basins such as the Cooper-Eromanga Basin, in addition to surface aquifers, shale gas wells (like conventional gas wells) pass through deep aquifers of the Great Artesian Basin. To minimise the risk to this vital groundwater

resource, best practice should be adopted in both well integrity and the use of sensing technology to accurately and closely monitor the hydraulic fracturing process, particularly the potential for extended vertical growth of fractures.

## Induced seismicity

27. Although there is ample evidence in Australia of induced seismic activity associated with large dams, mining operations and geothermal operations, there is currently no seismic risk data for gas-related activity in Australia, such as hydraulic fracturing operations. Overseas evidence suggests that induced seismicity of magnitude 3 to 4 can be generated by the reinjection of large volumes of produced water in deep wastewater wells or in geothermal operations, particularly at or near a critically-stressed fault, but hydraulic fracturing is unlikely to lead to damaging or felt seismic events. Best practice mitigation involves better knowledge of fault structures close to disposal sites, and control of volume and pressure of produced water re-injection.Such measures should, when necessary, be put in place for shale gas.

28. Overseas evidence from extensive shale gas operations documents only a few cases involving low magnitude seismic events, where the hydraulic fracturing process itself has resulted in induced seismicity. These few events have been linked to the intersection of active fault structures by hydraulic fractures. Best practice mitigation involves the identification and characterisation of local fault structures, avoidance of fracture stimulation in the vicinity of active faults, real-time monitoring and control of fracture growth through available sensing technologies and the establishment of 'cease-operation' triggers based on prescribed measured seismicity levels. Such best practice approaches will need to be utilised in Australia.

## Greenhouse gas emissions

29. Like all other natural gas activities, the production, processing, transport and distribution of shale gas results in greenhouse gas (GHG) emissions. In addition, shale gas can also generate emissions associated with the hydraulic fracturing and well completion processes, particularly during the flowback stage prior to gas production. The magnitude of the emissions is not known with great accuracy and published results normally include wide uncertainty bands. Initiatives have commenced in Australia to collect greenhouse gas data for CSG but all of the available data for shale gas is from overseas, and its applicability to Australia is not clear. Data applicable to Australian conditions will need to be collected to monitor and comprehensively report emissions and to have strategies to mitigate risks.

30. In general terms the GHG emissions associated with combustion of natural gas to generate energy are greater than emissions occurring during production processing, transport and distribution, and in turn these are greater than those emissions generated during the flowback stage and the pre-production stage. Total lifecycle analysis (LCA) of emissions has limited sensitivity to very substantial differences in emissions at well completion. Emissions, particularly during the flowback stage, can be ameliorated by the implementation of best practice strategies such as the use of so-called "green completions", including the adoption of emission capture and/ or flaring rather than venting. Some Australian shale sedimentary basins may also contain high $CO_2$levels, which will need to be removed from the gas before transmission via pipeline;$CO_2$ sequestration is a possible process strategy.

31. There are uncertainties in estimating the total lifecycle greenhouse gas (GHG) footprint of electric power generating technologies. These uncertainties are quantified for a number of technologies

in this report. The implications, based on the mean valuesof the total lifecycle GHG footprint (from distributions of uncertainty) of the use of shale gas for electricity production (with green completion schemes) are: emissions will be approximately 10% to 20% higher than that of conventional gas; higher efficiency combined-cycle gas turbines will have approximately half to three quarters the emissions of black coal, and; open-cycle gas turbines will have approximately 70% to 90% the emissions of black coal. Based on an analysis of uncertainty there is a low chance that the performance of somecombined cycle gas turbines (CCGT) using shale gas in the future will have larger emissions than higher efficiency black coal sub-critical generators.

32. Government projections indicate that gas may grow to 30% of the technology mix by 2030. Based on gas supplying either 30% or 50% of electricitygeneration in 2030, analysis indicates that this could lead to reductions of either 27% or 52% respectively in terms of the current GHG emissions for electricity production– based on gas replacing coal-fired generation. These are mean value estimates (from distributions of uncertainty) and are applicable to low values of $CO_2$ in the gas stream being vented to atmosphere during processing.The large amount of gas required for this to occur could be provided, in part, by shale gas.

## Community issues

33. Gaining and retaining a 'social licence to operate' will be crucial to all shale gas projects. It will not be possible for a shale gas development to be approached as just a 'local issue' given that there will be stakeholders at the regional and national and global levels whose views will need to be taken into account. Experience with other resource projects demonstrates that a 'one size fits all' approach to communication and engagement will not work for shale gas; different groups will have different concerns and will require different communication strategies. Respect and transparency are critical elements of effective engagement.

34. Building trust is key to securing a social licence for any major resource project, including shale gas project developments, and it is essential to have a transparent approach to collection and dissemination of reliable data. Many people are distrustful of the information provided by industry and government and also from research and academic bodies where there is a perceived close financial relationship with industry. Communities are more likely to accept information as credible if it comes from a source such as CSIRO or universities, but only if they are perceived to be truly independent. Opportunities should also be explored to involve local people and landowners in the collection and understanding of environmental monitoring data, as this has also been shown to increase trust.

35. There is an opportunity to initiate a dialogue at both the national and regional level to develop one or more linked narratives around shale gas that go beyond economic contribution or energy security. The dialogue could focus on how shale gas development might be used to address other societal priorities, such as enhancing productivity of agricultural regions, enabling development in remote regions of Australia or facilitating the transition to a low carbon economy.

36. If shale gas development is to occur on a large scale in Australia, it is likely that much of this will occur on lands over which Native Title has either been recognised or is subject to a claim pursuant to the Native Title Act 1993, or which are designated Aboriginal Lands under the Aboriginal Land Rights (Northern Territory) Act 1976.Understanding Indigenous parties' aspirations, and ensuring that the parties have an informed understanding of the scale of the proposed

project and the expected impacts, should be the starting point for any developer seeking to enter into an agreement with traditional owners. There is potential to use shale gas developments to help address the aspirations of Aboriginal people to build greater economic self-sufficiency. In addition to direct employment in the sector, there may be significant opportunities for Aboriginal people to be engaged in land protection and rehabilitation activities associated with shale gas projects.

37. The issue of compensation for landowners directly affected by resource projects such as shale gas, is complex and controversial. There is a need to consider whether current compensation schemes are appropriate and whether there could be a system that would provide more direct returns to communities most impacted by shale gas projects.

## Monitoring, governance and regulation

38. Emissions of hydrocarbons and other atmospheric pollutants can arise from shale gas extraction and production as they can arise from other forms of production. The possible impact of shale gas production on human health has received some attention overseas. There are limited overseas data suggesting some increased health risk. There are no Australian data to suggest that major health risks are likely to arise from shale gas operations (a recent Australian CSG study did not indicate any significant health risk), but there will need to be health risk assessments (particularly where shale gas production takes place in populated areas), together with baseline monitoring including local and regional atmospheric monitoring regimes and transparent reporting of pollutants.

39. A number of the activities associated with shale gas exploration development and production have the potential to have an adverse impact on the natural and the human environment and therefore it is essential that shale gas activities are carefully and comprehensively monitored and transparently regulated to best practice. These include monitoring of surface and subsurface water, air quality, greenhouse gas emissions, and seismicity.The current lack of baseline data in many areas and lack of information on natural variability in particular need to be addressed. Many existing Australian regulations for onshore conventional and unconventional gas production will be applicable to shale gas. Nonetheless the overlapping and regional aspects of shale gas impacts will confront Australian regulators with new challenges.

40. The likelihood of shale gas operations producing damaging induced seismicity is low; but there is a need to better understand and mitigate the risk of induced seismicity and this will require site, local and regional monitoring of earthquakes at a far greater resolution in key areas than is currently the case in Australia. It is also important to address uncertainty, including through the use of remote sensing technology, and close monitoring of the hydraulic fracturing process.

41. At the present time there is a lack of reliable dataon the release of methane and related hydrocarbons to the atmosphere along with other gaseous constituents. There will be a need to implement baseline and ongoing atmospheric monitoring of shale gas because of the nature of the production process, together with a code of practice for the management of GHG emissions.

42. The concept of risk-based and play-based regulation proposed by Alberta could be applicable to the Australian regulatory framework for shale gas and warrants further consideration. The related issue of orphan wells also requires further consideration and the trust fund approach adopted by Alberta may be appropriate for Australia.

43. There are effective regulations in place covering abandonment for conventional gas wells, but shale gas regulations will need to take account of the fact that there could be hundreds of abandoned wells, many of them penetrating major aquifers; long term monitoring will be needed.

44. There are opportunities to learn from the CSG experience in Queensland, including what appear to be some of the more significant initiatives such as the Gasfields Commission, the establishment of regional and local consultative committees, the Royalties for Regions Program and the use of Social Impact Management Plans to proactively address anticipated impacts. A more direct financial return to communities most affected by shale gas developments may facilitate ongoing access and maintain the social licence to operate.

45. Shale gas developments will need to work within a robust legislative and regulatory framework to ensure sensible and equitable multiple land use, based around well-resourced regional strategic biophysical and geological resource planning and cumulative risk assessment.

46. Exploring for and producing shale gas will provide an unprecedented opportunity to acquire subsurface information on some of Australia's most important sedimentary basins, that will be of great value to the future assessment and management of major resources, such as ground water. To capture and curate this information will require new measures by government, including new requirements on industry to ensure that this information is not lost and that it can be made publicly available.

47. Most governments have only limited experience in regulating shale gas (or tight gas) production. Government and industry need to jointly address this issue, particularly to ensure that new companies with only limited experience of shale gas are effectively regulated as these companies gain experience.

## Knowledge Needs

48. While techniques and practices used in other countries will need to be adapted in some cases to Australian conditions, there are no major technology gaps relating to shale gas production which would constitute grounds for delaying the development of a shale gas industry in Australia. However, there are knowledge gaps in the environmental and social areas that will require the collection of more data and additional research to ensure that the impact of the industry is minimal and that any potential difficulties can be adequately remediated, or stopped if a significant threat were to arise, so that the industry and the community can move forward confident in the knowledge that resilient systems are in place.

49. It is important to start collecting baseline information and undertake researchnow on groundwater chemistry, ecological systems, landscape changes, methane emissions and seismic activity, at a level of resolution and accuracy that would enable any future impacts to be clearly identified at an early stage.

50. This report catalogues potential hazards that might arise from shale gas activities, but other than for operational risk (where industry has extensive data and well established risk management strategies in place) there is little or no information available to quantify the likelihood of an environmental or health event occurring or the impact of that event. Industry, regulators, environmental authorities, scientists and the community need to collect data to quantify the risk of an event occurring, so that a full and transparent risk management approach can be developed for shale gas projects.

51. Well abandonment is not just a regulatory issue but is also an issue that requires more research and development in areas such as the very long-term behaviour of cements and extended monitoring under hostile subsurface conditions.

# About Securing Australia's Future

In June 2012 the Australian Government announced Securing Australia's Future, a $10 million investment funded by the Australia Research Council in a series of strategic research projects for the Prime Ministers Science, Engineering and Innovation Council (PMSEIC), delivered through the Australian Council of Learned Academies (ACOLA) via the Office of the Chief Scientist and the Chief Scientist.

Securing Australia's Future is a response to global and national changes and the opportunities and challenges of an economy in transition. Productivity and economic growth will result from: an increased understanding in how to best stimulate and support creativity, innovation and adaptability; an education system that values the pursuit of knowledge across all domains, including science, technology, engineering and mathematics; and an increased willingness to support change through effective risk management.

PMSEIC identified six initial research topics:

i. Australia's comparative advantage

ii. STEM: Country comparisons

iii. Asia literacy – language and beyond

iv. The role of science, research and technology in lifting Australian productivity

v. New technologies and their role in our security, cultural, democratic, social and economic systems

vi. Engineering energy: unconventional gas production

The Program Steering Committee responsible for the overall quality of the program, including selection of the Expert Working Groups and the peer review process, is comprised of three Fellows from each of the four Learned Academies:

Professor Michael Barber FAA FTSE (Chair)

Mr Dennis Trewin AO FASSA (Deputy Chair – Research)

Professor Ruth Fincher FASSA

Professor Mark Finnane FAHA

Professor Paul Greenfield AO FTSE

Professor Iain McCalman AO FAHA FASSA FRHS

Professor Peter McPhee AM FAHA FASSA

Dr Graham Mitchell AO FAA FTSE

Dr Jim Peacock AC FAA FTSE FRS

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